Steph

DEPARTMENT OF THE AIR FORCE

HEADQUARTERS 27th FIGHTER WING (ACC)
CANNON AIR FORCE BASE, NEW MEXICO

16 JUL 1992

JUL 1992
RECEIVED
HAZARDOUS WASTE
PROGRAM

27 SG/CC
100 S DL Ingram Blvd Suite 200
Cannon AFB NM 88103-5217

Mr Edward L Horst
Program Manager RCRA
Hazardous and Radioactive Materials Bureau
New Mexico Environment Department
1190 St Francis Drive
P O Box 26110
Santa Fe NM 87502

RE: Review of Landfill 5 Cell 3 Cap Design

Dear Mr Horst

During a meeting in Albuquerque on 26 Jun 92, Ms Stephanie Stoddard of your office was given a copy of the 100% design drawings for the landfill 5 cell 3 cap. We will send you a copy of the specifications after we receive your comments for incorporation into the final design. We request that you review and approve the documents as quickly as possible in order for us to be able to advertise the project by 15 Aug 92. We will not proceed without your comments and approval of the design.

The design and specifications are being submitted as an amendment to the initial closure plan approved by NMED in 1989. This facility is being closed under interim status and will not operate as a TSD unit.

If you have any questions, please contact Mr Jim Richards or Mr Bruce Hale at (505) 784-4639.

Sincerely

David E Benson

DAVID E. BENSON, Colonel, USAF
Commander, 27th Support Group

cc: COE Tulsa
COE Albuquerque

Global Power for America

SOLICITATION NO. F CA47-92-B-0045
DATE: JULY 1992

LIBRARY COPY

Bill's Copy

LIBRARY COPY

SMC

US Army Corps
of Engineers
Albuquerque District

SPECIFICATIONS

FOR

LANDFILL #5 CELL #3 SOIL CAP

CANNON AIR FORCE BASE
CURRY COUNTY, CLOVIS, NEW MEXICO

"INCREASE PROFIT - SUBMIT VECP'S"

Solicitation No. DACA47-92-B-0045

BIDDING SCHEDULE
(To be attached to SF 1442)

Item No.	Description	Estimated Quantity	Unit	Unit Price	Estimated Amount
1.	Landfill Cover, Complete	Job	Sum	***	$_____
2.	All Other Work Not Separately Listed	Job	Sum	***	$_____
3.	Final As-Built Drawings	Job	Sum	***	$ 1000.00
	TOTAL AMOUNT				$_____

NOTES:

1. Bidders must bid on all items.

2. ARITHMETIC DISCREPANCIES: (APR 1984)

(a) For the purpose of initial evaluation of bids, the following will be utilized in resolving arithmetic discrepancies found on the face of the bidding schedule as submitted by bidders:

(1) Obviously misplaced decimal points will be corrected;

(2) Apparent errors in addition of lump sum and extended prices will be corrected.

(b) For the purposes of bid evaluation, the Government will proceed on the assumption that the bidder intends his bid to be evaluated on the basis of the unit prices, extensions, and totals arrived at by resolution of arithmetic discrepancies as provided above and the bid will be so reflected on the abstract of bids. (EFAR 14.201/90)

3. If a modification to a bid based on unit prices is submitted, which provides for a lump sum adjustment to the total estimated cost, the application of the lump sum adjustment to each unit price in the bid schedule must be stated. If it is not stated, the bidder agrees that the lump sum adjustment shall be applied on a pro rata basis to every unit price in the bid schedule.

4. PROGRESS PAYMENT REQUESTS made by the Contractor pursuant to the provisions of Contract Clause, PAYMENTS UNDER FIXED-PRICE CONSTRUCTION CONTRACTS, shall be submitted on ENG FORM 93 to the billing office as designated on Block 26, Standard Form 1442, Solicitation, Offer and Award, back. ENG FORM 93 shall be submitted to that office on the 1st of each month in appropriate form and certified. A copy of ENG FORM 93 and Certification (SWA 739-R) are attached at the end of the Contract Clauses. Xeroxed copies of the form shall be furnished on that same date to the Corps of Engineers offices designated at the Pre-Construction Conference.

SECTION 00800

SPECIAL CLAUSES

1. COMMENCEMENT, PROSECUTION AND COMPLETION OF WORK (FAR 52.212-3) (APR 1984).

(a) The Contractor shall be required to (a) commence work under this contract within ten (10) calendar days after the date the Contractor receives notice to proceed, (b) prosecute the work diligently, and (c) complete the entire work ready for use not later than the dates or number of calendar days after the date of receipt by him of notice to proceed set forth in the schedule below, except as specified in the turfing sections and final as-built drawings, which will be accomplished as specified below:

SCHEDULE

Item of Work	Commencement Time in Calendar Days After Receipt of Notice To Proceed	Liquidated Damages Per Calendar Day
(1) All work	120	197.00
(2) Final As-Built Drawings	*	*

*The Contractor shall commence work on final as-built drawings upon his receipt of the approved preliminary as-built drawings and the reproducible original contract drawings. The Contractor shall have 60 calendar days after such receipt to complete and return to the Contracting Officer all specified final as-built drawing work. Upon satisfactory completion of this work the Contractor shall have earned the amount shown for Final As-Built Drawings in the Bid Schedule.

(b) The time stated for completion shall include final cleanup of the premises.

2. LIQUIDATED DAMAGES - CONSTRUCTION (FAR 52.212-5) (APR 1984).

(a) If the Contractor fails to complete the work within the time specified in the contract, or any extension, the Contractor shall pay to the Government as liquidated damages, the sum stated in Clause 1(a) above for each day of delay. for completing the work on this contract, exclusive of the work in the Section, ESTABLISHMENT OF TURF.

(b) If the Government terminates the Contractor's right to proceed, the resulting damage will consist of liquidated damages until such reasonable time as may be required for final completion of the work together with any increased costs occasioned the Government in completing the work.

(c) If the Government does not terminate the Contractor's right to proceed, the resulting damage will consist of liquidated damages until the work is completed or accepted.

3. CONTRACT DRAWINGS, MAPS, AND SPECIFICATIONS (DFAR 252.236-7001) (DEC 1991):

(a) The Government

(1) Will provide the Contractor, without charge, one (1) set of reduced scale and one (1) set of large scale reproducible contract drawings and five (5) sets of specifications except publications incorporated into the technical provisions by reference;

(b) The Contractor shall

(1) Check all drawings furnished immediately upon receipt;

(2) Compare all drawings and verify the figures before laying out the work;

(3) Promptly notify the Contracting Officer of any discrepancies; and

(4) Be responsible for any errors which might have been avoided by complying with this paragraph (b).

(c) Large scale drawings shall, in general, govern small scale drawings. Figures marked on drawings shall, in general, be followed in preference to scale measurements.

(d) Omissions from the drawings or specifications or the misdescription of details of work which are manifestly necessary to carry out the intent of the drawings and specifications, or which are customarily performed, shall not relieve the Contractor from performing such omitted or misdescribed details of the work, but shall be performed as if fully and correctly set forth and described in the drawings and specifications.

(e) The work shall conform to the specifications and the contract drawings identified on the following index of drawings:

CONTRACT DRAWINGS LANDFILL 5, CELL 3 SOIL CAP, CAFB	
Sequence No.	Title
1 thru 5	The list of drawings and maps set out in the index on the drawings is hereby incorporated by reference into these specifications. Schedules included in the drawings are for the purpose of defining requirements other than quantities.

4. TIME EXTENSIONS FOR UNUSUALLY SEVERE WEATHER (ER 415-1-15) (OCT 1989).

(a) This provision specifies the procedure for the determination of time extensions for unusually severe weather in accordance with the Contract Clause entitled "DEFAULT (FIXED PRICE CONSTRUCTION)". In order for the Contracting Officer to award a time extension under this clause, the following conditions must be satisfied:

1. The weather experienced at the project site during the contract period must be found to be unusually severe, that is, more severe than the adverse weather anticipated for the project location during any given month.

2. The unusually severe weather must actually cause a delay to the completion of the project. The delay must be beyond the control and without the fault or negligence of the Contractor.

(b) The following schedule of monthly anticipated adverse weather delays is based on National Oceanic and Atmospheric Administration (NOAA) or similar data for the project location and will constitute the base line for monthly weather time evaluations. The Contractor's progress schedule must reflect these anticipated adverse weather delays in all weather dependent activities.

Monthly Anticipated Adverse Weather Delay
Work Days Based on (5) Day Work Week

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
7	6	5	5	5	7	5	7	4	4	5	8

(c) Upon acknowledgement of the Notice to Proceed (NTP) and continuing throughout the contract, the Contractor will record on the daily CQC report, the occurrence of adverse weather and resultant impact to normally scheduled work. Actual adverse weather delay days must prevent work on critical activities for 50 percent or more of the Contractor's scheduled work day.

(d) The number of actual adverse weather delay days shall include days impacted by actual adverse weather (even if adverse weather occurred in previous month), be calculated chronologically from the first to the last day of each month, and be recorded as full days. If the number of actual adverse weather delay days exceeds the number of days anticipated in paragraph B, above, the Contracting Officer will convert any qualifying delays to calendar days, giving full consideration for equivalent fair weather work days, and issue a modification in accordance with the contract clause entitled "Default (Fixed Price Construction)."

5. PERFORMANCE OF WORK BY CONTRACTOR (FAR 52.236-1) (APR 1984). The Contractor shall perform on the site, and with its own organization, work equivalent to at least twenty-five percent (25%) of the total amount of work to be performed under the contract. This percentage may be reduced by a supplemental agreement to this contract if, during performing the work, the Contractor requests a reduction and the Contracting Officer determines that the reduction would be to the advantage of the Government.

6. PHYSICAL DATA (FAR 52.236-4) (APR 1984). Data and information furnished or referred to below is for the Contractor's information. The Government shall not be responsible for any interpretation of or conclusion drawn from the data or information by the Contractor.

(a) The indications of physical conditions on the drawings and in the specifications are the result of site investigations by surveys and as shown on the drawings.

(b) Weather Conditions:

(1) Climate: The climate is continental and is characterized by abundant sunshine, low relative humidities and considerable ranges of annual and diurnal temperatures.

(2) Precipitation: The average annual precipitation is 13.42 inches. The maximum annual rainfall of 29.56 inches occurred in 1941. The maximum monthly rainfall os 8.66 inches occurred in September 1941. The maximum 24-hour rainfall of 4.35 inches also occurred in September 1941. The average annual snowfall is 13.6 inches. The highest average monthly snowfall is 3.5 inches and is in December.

(3) Temperature: Average monthly maximum temperatures range from 51.6 degrees F in January to 92.5 degrees in July. Average monthly minimum temperature range from 24.5 degrees in January to 66.9 degrees in July. Temperature extremes are minus 20.0 degrees and 110.0 degrees.

(4) Relative Humidity: Monthly average relative humidities at 4:00 p.m. range from 54 percent in January to 32 percent in June.

(5) Wind: Wind speeds are normally moderate although relatively strong winds often accompany frontal activity during late winter and spring months. Wind speeds that may exceed 30 m.p.h. are not uncommon.

(6) Frost Data: Frost free periods vary from 177 days to 229 days per year and average 205 days per year. The average date of the last killing frost in the spring is 11 April. The average date of the first killing frost in the autumn is 2 November.

7. LAYOUT OF WORK (1965 APR OCE):

(a) The Government has laid out the work on the drawings from existing physical features. The Contractor shall lay out the work under this contract using the same features.

8. INSURANCE - WORK ON A GOVERNMENT INSTALLATION (FAR 52.228-5) (APR 1984). See Contract Clause with above title.

Schedule of Insurance

Type	Amount
Employers' Liability Insurance	$100,000.00
Comprehensive General Liability Insurance:	
Bodily Injury	$500,000.00 per occurrence
Comprehensive Automobile Liability Insurance:	
Bodily Injury	$200,000.00 per person
Bodily Injury	$500,000.00 per occurrence
Property Damage	$ 20,000.00 per occurrence

Workmen's Compensation in accordance with the laws of the State of New Mexico.

9. EQUIPMENT OWNERSHIP AND OPERATING EXPENSE SCHEDULE (EFARS 31.105(d)(2)(i)(A)):

(a) Allowable cost for construction and marine plant and equipment in sound workable condition owned or controlled and furnished by a contractor or subcontractor at any tier shall be based on actual cost data when the Government can determine both ownership and operating costs for each piece of equipment or equipment groups of similar serial and series from the Contractor's accounting records. When both ownership and operating costs cannot be determined from the Contractor's accounting records, equipment costs shall be based upon the applicable provisions of EP 1110-1-8, "CONSTRUCTION EQUIPMENT OWNERSHIP AND OPERATING EXPENSE SCHEDULE", Region VI. Working conditions shall be considered to be average for determining equipment rates using the schedule unless specified otherwise by the Contracting Officer. For equipment not included in the schedule, rates for comparable pieces of equipment may be used or a rate may be developed using the formula provided in the schedule. For forward pricing, the schedule in effect at the time of negotiations shall apply. For retrospective pricing, the schedule in effect at the time the work was performed shall apply.

(b) Equipment rental costs are allowable, subject to the provisions of FAR

31.105(d)(ii) and FAR 31.205-36 substantiated by certified copies of paid invoices. Rates for equipment rented from an organization under common control, lease-purchase or sale-leaseback arrangements will be determined using the schedule except that rental costs leased from an organization under common control that has an established practice of leasing the same or similar equipment to unaffiliated lessees are allowable. Costs for major repairs and overhaul are unallowable.

(c) When actual equipment costs are proposed and the total amount of the pricing action is over $25,000, cost or pricing data shall be submitted on Standard Form 1411, "Contract Pricing Proposal Cover Sheet". By submitting cost or pricing data, the Contractor grants to the Contracting Officer or an authorized representative the right to examine those books, records, documents and other supporting data that will permit evaluation of the proposed equipment costs. After price agreement, the Contractor shall certify that the equipment costs or pricing data submitted are accurate, complete and current.

10. INCLUSION OF LABOR PROVISIONS IN SUBCONTRACTS (SWDOC, Ltr No. 86-3, 3 Sep 86). To show compliance with Contract Clause, "SUBCONTRACTS", the Contractor shall, within seven days after award of any subcontract either by himself or a subcontractor of any tier, deliver to the Contracting Officer a completed Standard Form 1413. Nothing contained in this clause or any other provision of this contract shall create any contractual relation between any subcontractor and the Government.

- END OF SPECIAL CLAUSES -

TABLE OF CONTENTS

DIVISION 1 - GENERAL REQUIREMENTS

SECTION 01000 - GENERAL REQUIREMENTS

SECTION 01100 - ENVIRONMENTAL PROTECTION

SECTION 01110 - ENVIRONMENTAL PROTECTION SPECIAL PROVISIONS

SECTION 01300 - SUBMITTALS

SECTION 01310 - PROGRESS SCHEDULE

SECTION 01400 - CONTRACTOR QUALITY CONTROL SYSTEM

SECTION 01420 - SAFETY

SECTION 01430 - EMERGENCY RESPONSE AND WORK SAFETY PROCEDURES

SECTION 01580 - BULLETIN BOARD, PROJECT SIGN AND PROJECT SAFETY SIGN

SECTION 01720 - AS-BUILT DRAWINGS

SECTION 01740 - WARRANTY OF CONSTRUCTION

DIVISION 2 - SITE WORK

SECTION 02050 - DEMOLITION

SECTION 02110 - CLEARING AND GRUBBING

SECTION 02210 - GRADING

SECTION 02215 - PLASTIC FILTER FABRIC

SECTION 02224 - IMPERVIOUS SOIL CAP

SECTION 02245 - GEOCOMPOSITE MEMBRANE

SECTION 02935 - TURF

SECTION 01000

GENERAL REQUIREMENTS

1. SUPERVISION BY THE CONTRACTOR. The following requirements, in addition to those contained in the Contract Clause entitled: SUPERINTENDENCE BY CONTRACTOR, shall be met by the Contractor:

1.1 Authority of Contractor Representative. The site representative appointed by the Contractor and approved by the Contracting Officer shall, as a minimum, have the following authority:

1.1.1 To negotiate and execute Supplemental Agreements having a value up to $100,000.

2. AGE AND VALUE OF EQUIPMENT. If requested by the Contracting Officer, the Contractor shall provide documentation to establish the age and value of any equipment being utilized to perform work under this contract.

3. WORK SCHEDULE. If the Contractor intends to work outside the normal 40 hour Monday through Friday work week, he shall notify the Contracting Officer one full workday (Monday - Friday) in advance.

- - o 0 o - -

SECTION 01100

ENVIRONMENTAL PROTECTION

1. SCOPE: The work covered by this section consists of furnishing all labor, materials and equipment and performing all work required for the prevention of environmental pollution during and as the result of construction operations under this contract except for those measures set forth in other Technical Provisions of these specifications. For the purpose of this specification environmental pollution is defined as the presence of chemical, physical, or biological elements or agents which adversely affect human health or welfare; unfavorably alter ecological balances of importance to human life; affect other species of importance to man; or degrade the utility of the environment for aesthetic and recreational purposes. The control of environmental pollution requires consideration of air, water, and land, and involves noise, solid waste-management and management of radiant energy and radioactive materials, as well as other pollutants.

2. APPLICABLE REGULATIONS: In order to prevent, and to provide for abatement and control of, any environmental pollution arising from the construction activities of the Contractor and his subcontractors in the performance of this contract, they shall comply with all applicable Federal, State, and local laws, and regulations concerning environmental pollution control and abatement, and all applicable provisions of the Corps of Engineers EM 385-1-1, entitled "Safety and Health Requirements Manual" as well as the specific requirements stated in this section and elsewhere in the contract specifications.

3. NOTIFICATION: The Contracting Officer will notify the Contractor in writing of any observed non-compliance with the foregoing provisions. The Contractor shall, after receipt of such notice, immediately take corrective action. Such notice, when delivered to the Contractor or his authorized representative at the site of the work, shall be deemed sufficient for the purpose. If the Contractor fails or refuses to promptly take corrective action, the Contracting Officer may issue an order stopping all or part of the work until satisfactory corrective action has been taken. No part of the time lost due to any such stop orders shall be made the subject of a claim for extension of time or for excess costs or damages by the Contractor unless it was later determined that the Contractor was in compliance.

4. SUBCONTRACTORS: Compliance with the provisions of this section by subcontractors will be the responsibility of the Contractor.

5. IMPLEMENTATION: Prior to commencement of the work the Contractor will:

(1) submit in writing his proposals for implementing the provisions of this section and other sections of these specifications for environmental pollution control;

(2) meet with representatives of the Contracting Officer to develop mutual understandings relative to compliance with these provisions and administration of the environmental pollution control program.

6. PROTECTION OF LAND RESOURCES:

6.1 General: The land resources within the property of the Government but outside the limits of permanent work performed under this contract shall be preserved in their present condition or be restored to a condition after completion of construction that will appear to be natural and not detract from the appearance of the project. Insofar as possible, the Contractor shall confine his construction activities to areas defined by the plans or specifications, to areas to be cleared for other operations, or to quarry, borrow or waste areas indicated on the plans. At the onset of borrow excavation, topsoil shall be saved for use in restoring the borrow area. Waste and borrow areas shall be leveled or trimmed to regular lines and shaped to provide a neat appearance. In all instances the restored area shall be well drained, so as to prevent the accumulation of stagnant water. The following additional requirements are intended to supplement and clarify the requirements of Contract Clauses entitled PROTECTION OF EXISTING VEGETATION, STRUCTURES, EQUIPMENT, UTILITIES, AND IMPROVEMENTS; OPERATIONS AND STORAGE AREAS; and CLEANING UP.

6.2 Prevention of Landscape Defacement: Except in areas shown on the plans or specified to be cleared, the Contractor shall not deface, injure, or destroy trees or shrubs, nor remove or cut them without special authority from the Contracting Officer. Trees designated to be saved shall be protected from either excavation or filling within the root zone closer than the normal drip line of the tree. No ropes, cables, or guys shall be fastened to or attached to any existing trees for anchorages unless specifically authorized by the Contracting Officer. Where such special emergency use is permitted, the Contractor shall first adequately wrap the trunk with a sufficient thickness of burlap or rags over which softwood cleats shall be tied before any rope, cable, or wire is placed. The Contractor shall in any event be responsible for any damage resulting from such use. Where, in the opinion of the Contracting Officer, trees may possibly be defaced, bruised, injured, or otherwise damaged by the Contractor's equipment or by his blasting, dumping, or other operations, he may direct the Contractor to protect adequately such trees by placing boards, planks, or poles around them. When earthwork operations are liable, in the opinion of the Contracting Officer, to cause rock to roll or otherwise be displaced into uncleared areas, the Contractor shall construct barriers to protect the trees. Rocks that are displaced into uncleared areas shall be removed. Monuments, markers, and works of art shall be protected similarly before beginning operations near them.

6.3 Restoration of Landscape Damage: Any trees or other landscape feature scarred or damaged by the Contractor's equipment or operations shall be restored as nearly as possible to original condition at the Contractor's expense. The Contracting Officer will decide what method of restoration shall be used, and whether damaged trees shall be treated or removed and disposed of under requirements for clearing and grubbing. All scars made on trees (not designated on the plans to be removed) by equipment, construction operations, or by the removal of limbs larger than 1-inch in diameter shall be coated as soon as possible with an approved tree wound dressing. All trimming or pruning shall be performed in an approved manner by experienced workmen with saws or pruning shears. Tree trimming with axes will not be permitted. Where tree climbing is necessary, the use of climbing spurs will not be permitted. The use of climbing

ropes will be required by the Contracting Officer where deemed necessary for safety. Trees that are to remain, either within or outside established clearing limits, that are subsequently damaged by the Contractor and are beyond saving in the opinion of the Contracting Officer, shall be immediately removed and replaced with nursery-grown trees of the same species and size approved by the Contracting Officer.

6.4 Location of Temporary Field Offices, Storage, and Other Construction Buildings: The location on Government property of the Contractor's temporary field office, storage, and other construction buildings, required temporarily in the performance of the work, shall be upon cleared portions of the job site or areas to be cleared, and shall require written approval of the Contracting Officer. The preservation of the landscape shall be an imperative consideration in the selection of all sites and in the construction of buildings. Plans showing temporary field office, storage, and other construction buildings shall be submitted for approval of the Contracting Officer. Where buildings or tent platforms are constructed on sidehills, the Contracting Officer may require cribbing to be used to obtain level foundations. Benching or leveling of earth may not be allowed, depending on the location of the proposed facility.

6.5 Temporary Excavation and Embankments: If the Contractor proposes to construct temporary roads or embankments and excavations for plant and/or work areas, he shall submit the following for approval at least thirty (30) days prior to scheduled start of such temporary work.

6.5.1 A layout of all temporary roads, excavations, and embankments to be constructed within the work area.

6.5.2 Details of road construction.

6.5.3 Details of the completed quarry or borrow excavation.

6.5.4 Plans and cross sections of proposed embankments and their foundations, including a description of proposed materials.

6.5.5 A landscaping plan prepared by a competent landscape architect showing the proposed restoration of the area. Removal of any necessary trees and shrubs outside the limits of required clearing or quarry, borrow, or waste areas shall be indicated. The plan shall also indicate location of required guard posts or barriers required to control vehicular traffic passing close to trees and shrubs to be maintained undamaged. The plan shall provide for the obliteration of construction scars as such and shall provide for a reasonably natural appearing final condition of the area. Modification of the Contractor's plans shall be made only with the written approval of the Contracting Officer. No unauthorized road construction, excavation or embankment construction (including disposal areas) will be permitted.

6.6 Post-Construction Cleanup or Obliteration: The Contractor shall obliterate all signs of temporary construction facilities such as haul roads, work areas, structures, foundations of temporary structures, stockpiles of excess or waste materials, or any other vestiges of construction, as directed by the Contracting Officer. It is anticipated that excavation, filling, and plowing of

roadways will be required to restore the area to near natural conditions which will permit the growth of vegetation thereon. The disturbed areas shall be graded and filled as required, sufficient topsoil shall be spread to provide a minimum depth of 4 inches of suitable soil for the growth of grass, and the entire area seeded. Restoration to original contours is not required.

7. PROTECTION OF HISTORICAL AND ARCHEOLOGICAL RESOURCES:

7.1 Preservation of Existing Historical, Archeological, and Cultural Resources: Any known existing historical, archeological and cultural resources within the Contractor's work area are designated on the contract drawings. The Contractor shall take precautions during this contract to preserve all resources as they existed at the time of contract award. The Contractor shall install all protective devices such as off limits markings, fencing, barricades or other devices as designated on the contract drawings and shall be responsible for preservation of the sites during this contract.

7.2 Recording and Preserving Historical and Archeological Finds: All items having any apparent historical or archeological interest outside of designated areas which are discovered in the course of any construction activities shall be carefully preserved. The Contractor shall leave the archeological find undisturbed and shall flag an area of 50 feet radius around the find, and shall immediately report the find to the Contracting Officer so that the proper authorities may be notified. Any work required to preserve or protect these finds will be accomplished by change order under the clause entitled CHANGES of the CONTRACT CLAUSES.

8. PROTECTION OF WATER RESOURCES:

8.1 General: The Contractor shall not pollute streams, lakes, or reservoirs with fuels, oils, bitumens, calcium chloride, acids, construction wastes, or other harmful materials. It is the responsibility of the Contractor to investigate and comply with all applicable Federal, State, County, and Municipal laws concerning pollution of rivers and streams. All work under the contract shall be performed in such a manner that objectionable conditions will not be created in lakes, reservoirs, or streams through or adjacent to the project areas.

8.2 Erosion Control: Prior to start of construction the Contractor shall submit a plan for approval of the Contracting Officer showing his scheme for controlling erosion and disposing of wastes. Surface drainage from cuts and fills within the construction limits, whether or not completed, and from borrow and waste disposal areas, shall, if turbidity producing materials are present, be held in suitable sedimentation ponds, or the areas shall be graded to control erosion within acceptable limits. Temporary erosion and sediment control measures such as berms, dikes, drains, or sedimentation basins, if required to meet the above standards, shall be provided and maintained until permanent drainage and erosion control facilities are completed and operative. The area of bare soil exposed at any one time by construction operations shall be held to a minimum. Unless otherwise approved by the Contracting Officer, the Contractor shall apply as soon as practicable an approved temporary mulch on denuded ground. This shall apply to all areas not subject to appreciable traffic during

construction, including areas that are to receive some form of construction later, if ground is to be exposed 60 days or more. Stream crossings by fording with equipment shall be limited to control turbidity and in areas of frequent crossings temporary culverts or bridge structures shall be installed. Any temporary culverts or bridge structures shall be removed upon completion of the project. Fills and waste areas shall be constructed by selective placement to eliminate to the extent practicable silts or clays on the surface that will erode and contaminate adjacent streams or lakes.

8.3 Spillages: Special measures shall be taken to prevent chemicals, fuels, oils, greases, bituminous materials, waste washings, herbicides and insecticides, and cement from entering streams, rivers, or lakes.

8.4 Disposal: Disposal of any materials, wastes, effluents, trash, garbage, oil, grease, chemicals, etc., in areas adjacent to streams shall be subject to the approval of the Contracting Officer. If any waste material is dumped in unauthorized areas the Contractor shall remove the material and restore the area to the condition of the adjacent undisturbed area. If necessary, contaminated ground shall be excavated, disposed of as directed by the Contracting Officer, and replaced with suitable fill material, compacted and finished with topsoil all at the expense of the Contractor.

9. PROTECTION OF FISH AND WILDLIFE: The Contractor shall at all times perform all work and take such steps required to prevent any interference or disturbance to fish and wildlife. The Contractor will not be permitted to alter water flows or otherwise disturb native habitat adjacent to the project area which, in the opinion of the Contracting Officer, are critical to fish or wildlife. Fouling or polluting of water will not be permitted. Wash waters and wastes shall be processed, filtered, ponded, or otherwise treated prior to their release into a river or other body of water.

10. CLEAN-UP: The Contractor shall furnish daily janitorial services for the temporary field office, storage, and other construction buildings on the project site and perform any required maintenance of facilities and grounds as deemed necessary by the Contracting Officer during the entire life of the contract. Toilet facilities shall be kept clean and sanitary at all times. Services shall be performed at such a time and in such a manner to least interfere with the operations but will be accomplished only when the buildings are occupied. Services shall be accomplished to the satisfaction of the Contracting Officer. The Contractor shall also provide daily trash collection and cleanup of the buildings and adjacent outside areas and snow removal in season, and shall dispose of all discarded debris, aggregate samples and concrete test samples in a manner approved by the Contracting Officer.

11. BURNING: No material shall be burned at the project site unless otherwise specified in other sections of these specifications or authorized by the Contracting Officer.

12. DUST CONTROL: The Contractor will be required to maintain all excavations, embankments, stockpiles, haul roads, permanent access roads, plant sites, waste areas, borrow areas, and all other work areas within or without the project boundaries free from dust which would cause a hazard or nuisance to

others. Approved temporary methods of stabilization consisting of sprinkling, chemical treatment, light bituminous treatment or similar methods will be permitted to control dust. Sprinkling, to be approved, shall be repeated at such intervals as to keep all parts of the disturbed area at least damp at all times, and the Contractor shall have sufficient competent equipment on the job to accomplish this if sprinkling is used. Dust control shall be performed as the work proceeds and whenever a dust nuisance or hazard occurs.

13. MAINTENANCE OF POLLUTION CONTROL FACILITIES DURING CONSTRUCTION: During the life of this contract the Contractor shall maintain all facilities constructed for pollution control under this contract as long as the operations creating the particular pollutant are being carried out or until the material concerned has become stabilized to the extent that pollution is no longer being created. During the construction period the Contractor shall conduct frequent training courses for his maintenance personnel. The curricula shall include methods of detection of pollution, familiarity with pollution standards, and installation and care of vegetation covers, plants, and other facilities to prevent and correct environmental pollution.

14. PESTICIDES (INSECTICIDES, FUNGICIDES, HERBICIDES, ETC.): Application of all pesticides shall be accomplished by certified pest control personnel or under the supervision of a certified pest control operator. Delivery and storage of pesticides will be monitored by certified personnel to insure the adequacy of containers and the safe storage of toxic materials. Disposal of containers and chemicals will be monitored to prevent pollution of natural drainage systems.

- - o 0 o - -

SECTION 01110

ENVIRONMENTAL PROTECTION SPECIAL PROVISIONS

1. INTRODUCTION

1.1 This section describes the Contractor's responsibilities and obligations to provide for protection from hazardous waste and chemical accidents and spills. The potential for accumulated long-term effects even from seemingly small incidents can be considerably grave, and all spills shall be regarded as critical regardless of size. No matter where a spill incident occurs, some "local" jurisdiction (municipal, State, and Federal land management) has an obligation to protect the public and the environment. The Contractor must be familiar with the local regulations regarding spills. Environmental Protection shall include maintaining the integrity of air, water land, and natural resources and ensuring protection against toxic and conventional contaminants, noise and other pollutants.

1.2 The Contractor shall have on his staff a trained team capable of dealing with a spill. Free training for personnel is usually available from the U.S. EPA, State environmental agencies, or a fire marshal or fire academy.

1.3 All spills occurring during the construction of this project must be reported to the respective authorities, and the Contractor shall bear all costs and liabilities that may arise due to an accident or a spill outside the construction site. If hazardous waste or hazardous waste constituents are discharged, the Contractor shall take appropriate, immediate action (including notifications) to protect human health and the environment.

1.4 DISPOSAL. In compliance with Federal, State, and local regulations that require protection of the environment from mishandling and mismanagement of waste disposal practices, any waste material dumped by the Contractor in an authorized and/or unauthorized area and/or causing any form of contamination shall be removed and the area(s) restored to its (their) original condition(s) at the time specified by the Contracting Officer and at the Contractor's expense. Open burning shall not be permitted. All costs and liabilities due to illegal or mishandled activities must be borne by the Contractor.

1.5 HAZARDOUS WASTE. Disposal practices used must avoid any potential for ground or surface water contamination and shall follow the requirements for loading, hauling, transportation, and disposal specified by Federal, State, and local regulatory authorities. If a spill occurs and contaminates the ground, all contaminated soil shall be excavated, disposed of, and replaced with suitable, fill material, and the area shall be compacted, all at the expense of the Contractor. All contaminated debris shall be disposed of off site in an EPA approved disposal area. Transport vehicles shall be designed to prevent spills and contamination of the environment. Any liabilities that might occur during transportation are the responsibility of the Contractor.

- - o O o - -

SECTION 01300

SUBMITTALS

PART 1 - GENERAL

1.1 GENERAL: Within 10 days after receipt of notice to proceed, the Contractor shall complete and submit to the Contracting Officer, for approval, two computer printouts and one floppy disc of the submittal register listing all submittals and dates, if available. In addition to those items listed in the register, the Contractor will furnish submittals for any deviation from the plans or specifications. Scheduling shall be coordinated with the approved progress schedule. The Contractor's Quality Control representative shall review the listing with the Project Engineer at least every 30 days and take appropriate action to maintain an effective system.

1.2 The Government will make available to the Contractor a disc containing an IBM compatible data base management system for submittal of the original submittal register and 30 day updates. This system requires DBase III+ for operation. DBase III+ will not be made available by the Government. (Refer to DBase software for hardware requirements.) The documentation for the Government system will also be made available. The Contractor may propose an alternate computerized system for Government approval. This system must be menu driven, including a menu screen that guides the user through the options, an input screen that prompts the user for information and all screens should display instructions to assist the user. This system must be able to produce the following reports: 1. All disapproved submittals; 2. All submittals due within two weeks after any reference date; 3. All submittals currently due and not received; 4. All submittals that have been under review for less than 22 days; 5. All submittals that have been under review more than 21 days. In addition the system must be capable of displaying to the screen or printer specified criteria, i.e. a transmittal by specification section, by transmittal number and disapproved transmittals. A user's guide/instruction must be provided along with any required software. Printing the report from the Government data base management system requires a printer capable of printing a 14-inch wide report. Normally, technical specifications are organized into three parts:

PART 1 - GENERAL
PART 2 - PRODUCTS
PART 3 - EXECUTION

1.2.1 A "Project Specific List of Submittals" listing equipment, material, and procedures for which submittals are required by the specifications, is attached at the end of this section. This listing is not considered to be all inclusive and shall not alleviate the Contractor from his responsibility to provide all submittals required in the technical sections. The Contracting Officer may also request submittals that are in addition to those covered in the technical sections.

1.3 PART 1 normally relates to the overall general requirements for the products listed in PART 2. The submittal register should be organized on the basis of products used for the construction process. Sometimes the GENERAL part

has items that are not product oriented. These include: instruction manuals, special skilled worker certification, coordination studies, special system drawings, and the listed shop drawing (SD) requirements. These should be separately submitted items. Products may be listed separately or as a group of products with one transmittal number. If a group of products are listed on an ENG Form 4025, each product should be given an item number. Then each product data sheet should be stamped with the same item number.

1.4 Columns entitled "SCHEDULED SUBMITTAL TO COE" of the register shall be fully completed for each submittal item to show the data called for thereon. Need dates are not required until the schedule is approved. Columns entitled "REVIEWER'S NAME" and "DATE APPROVED/SIGNED" shall be left blank, see Paragraph 1.6.

1.5 Submittals on component items forming a system or that are interrelated shall be scheduled to be correlated and submitted concurrently. A minimum of 30 calendar days, exclusive of mailing time, will be allowed on the register for review and approval of any items requiring Government approval. No delay damages or time extensions will be allowed for time lost due to late submission by the Contractor.

1.6 The Government will review the Submittal Register for approval action. The column designated "Reviewer's Name" will also be completed by the Government. The Government will designate those to be submitted "For Information Only". These will be identified by an "I" in the column entitled "Reviewer's Name". A copy of the Submittal Register (printout), so marked in the "Reviewer's Name" column, will be returned to the Contractor. Those items marked "For Information Only" submittal shall be subject to review action by the Contracting Officer. Any such "For Information Only" submittals found to contain errors or omissions shall be resubmitted. No adjustment for time or money will be allowed for corrective action required as a result of noncompliance with plans and specifications.

1.7 The approved register will become part of the contract and the Contractor will be subject to requirements therein. The Contractor shall revise and/or update the register every 30 days to take into account all changes in the contract and the current construction schedule. Copies of updated or corrected registers shall be submitted to the Contracting Officer at least every 60 days in the same format and copies required for the original register.

1.8 It is essential that submittals and current construction progress be thoroughly coordinated. The dates in columns under the heading "SCHEDULED SUBMITTAL TO COE" shall be realistic, and shall provide sufficient lead time for the respective construction activity (as indicated on the approved progress schedule). Failure to comply with this requirement will be cause for rejection of the Submittal Register.

1.9 The Contractor shall submit all items listed on the contract drawings and listed or specified in Section 02000 and beyond of these specifications. The Contracting Officer may request submittals in addition to those listed when deemed necessary to adequately describe the work covered in the respective sections. Units of weight and measurements used on all submittals shall be the

same used in the contract drawings. Each submittal shall be complete and in sufficient detail for ready determination of compliance with the contract requirements. Prior to submittal, all items shall be checked and approved by the Contractor's Quality Control (C.Q.C.) Manager who shall certify by signature on the ENG Form 4025 that he has reviewed the submittal in detail and that it is correct and in strict conformance with the contract drawings and specifications except as may be otherwise explicitly stated. Submittals shall include such items as: Contractor's, manufacturer's or fabricator's drawings; HVAC control descriptions; descriptive literature including (but not limited to) catalogue cuts, diagrams, operation charts or curves; samples, O&M manuals including parts lists; certifications; warranties and other such required submittals. Submittals pertinent to materials and equipment which are specified to receive advance approval shall be scheduled and made prior to the acquisition or the delivery thereof. Each required submittal which is in the form of a drawing shall be submitted as one (1) reproducible and four (4) prints of the drawing for Division 15 and 16 submittals, and one (1) reproducible and three (3) prints for all others. Drawing prints shall be either blue or black line permanent-type prints on a white background. Reproducibles shall be brownline diazo or sepia and shall be of such quality that prints made therefrom are sufficiently clear for microfilm copying. A shop drawing submitted without a reproducible drawing will not be reviewed and will be automatically returned. All catalog and descriptive data shall be submitted in 4 copies. Catalog cuts and other descriptive data which have more than one model, size, or type or which shows optional equipment shall be clearly marked to show the model, size, or type and all optional equipment which is proposed for approval. Submittals on component items forming a system or that are interrelated shall be submitted at one time as a single submittal in order to demonstrate that the items have been properly coordinated and will function as a unit. All submittals shall be mailed or delivered directly to the address shown below.

Resident Engineer
U.S. Army, Corps of Engineers
Cannon Resident Office
Cannon Air Force Base, NM 88103

1.9.1 All samples, except for those required to be submitted to the Division Lab, shall be submitted to the Resident Engineer. In addition to the copies specified above, one courtesy copy of each submittal sent to the Albuquerque District Office should be forwarded to the Resident Engineer.

1.10 The Transmittal Form (ENG 4025) attached to this Section shall be used for all submittals and shall be completed in strict accordance with the instructions on the reverse side thereof. This form shall be reproduced by the Contractor. (The instructions on the back need not be reproduced on the copies used by the Contractor in forwarding the submittals.) This form shall be properly completed by filling out all the heading blank spaces and identifying each item submitted. Special care should be exercised to insure proper listing of the specification paragraph and sheet number of the contract drawings pertinent to the data submitted for each item. A separate submittal form (ENG 4025) shall be attached to each copy of the data being submitted. Only one specification section shall be addressed on a transmittal form except where required for system submittals. In addition, a Submittal Review Verification

Sheet will accompany each copy of the submittal. The Submittal Review Verification Sheet is attached to this section and will be reproduced by the Contractor.

1.11 All proposed variations requested by the Contractor shall be checked in Column "g", and noted in the "Remarks" column of the ENG Form 4025. The Contractor shall set forth in writing the reason for any variation and annotate such variation on the shop drawing. The Government reserves the right to rescind inadvertent approval of shop drawings containing unnoted variations.

1.11.1 Approval by the Contractor shall be accomplished by stamping each shop drawing sheet and by inserting the required information with a stamp similar to the following:

CONTRACTOR
(Firm Name)

☐ Approved.

☐ Approved with corrections as noted on shop drawings and/or attached sheets.

SIGNATURE: _____
TITLE: _____
DATE: _____

1.12 The approval of the submittals by the Contracting Officer or his authorized representative shall not be construed as a complete check, but will indicate only that the general method of construction and detailing is satisfactory. Approval will not relieve the Contractor of the responsibility for any undiscovered error because the Contractor, under the Contractor Quality Control requirements of this contract, is responsible for the dimensions and design of adequate connections, details and satisfactory construction of all work. After submittals have been approved by the Contracting Officer or his authorized representative, no resubmittal for the purpose of substituting materials or equipment will be given consideration unless accompanied by an acceptable explanation as to why a substitution is necessary.

1.13 The Contractor shall make all corrections required by the Contracting Officer or his authorized representative and promptly furnish a corrected submittal in the form and number of copies as specified for initial submittals. (If a submittal requires extensive revisions, it will be returned to the Contractor with comments by serial letter for correction prior to approval.) If the Contractor considers any correction indicated on the submittals to constitute a change to the contract, notice as required under the Contract Clause entitled "CHANGES" should promptly be given to the Contracting Officer.

1.14 Payment for materials incorporated into the work will not be made if required approvals have not been obtained.

1.15 Any certificates required for demonstrating proof of compliance of materials with specification requirements shall be executed in 4 copies. Each certificate shall be signed by an official authorized to certify in behalf of the manufacturing company and shall contain the specific item trade name, and model number, if applicable. The certification shall contain the specification/test identification to which compliance is being certified. A general statement that item complies with all requirements is not acceptable. Copies of laboratory test reports submitted with certificates shall contain the name and address of the testing laboratory and the date or dates of the tests to which the report applies. Certification shall not be construed as relieving the Contractor from furnishing satisfactory material, if, after tests are performed on selected samples, the material is found not to meet the specific requirements.

1.16 Each purchase order issued by the Contractor or his subcontractors for materials and equipment to be incorporated into the project shall (1) be clearly identified with the applicable DA contract number, (2) carry an identifying number, (3) be in sufficient detail to identify the material being purchased, (4) indicate a definite delivery date, and (5) display the DMS priority rating. Copies of purchase orders shall be furnished to the Contracting Officer when the Contractor requests assistance for expediting deliveries of equipment or materials, or when requested by the Contracting Officer for the purpose of quality assurance review.

1.17 If the Contractor elects to install mechanical and/or electrical equipment of size, shape, or arrangement differing from those shown and specified in mechanical rooms with limited available space, he shall prepare and submit room plans for such mechanical rooms or similar areas.

1.17.1 Submittals describing the various mechanical and electrical equipment items which are to be installed in the above described area(s) shall be assembled and submitted concurrently and accompanied by the room plans. If some items have already been submitted, their transmittal number shall be identified.

1.17.2 Plans, consolidated for all trades, shall be to scale and shall show all pertinent structural features and other items such as doors, windows, and cabinets required for installation and which will affect the available space. All mechanical and electrical equipment and accessories shall be shown to scale in plan and elevation and/or section in their installed positions. All duct work and piping shall be shown. All clear spaces required for equipment maintenance shall also be shown.

1.18 Performance Evaluation of Contractor. Since the Contractor's Quality Control personnel are required to review all submittals for contract compliance before forwarding to the Government, the Quality of Work and Effectiveness of Management performance elements of the final Performance Evaluation will be based in part on the number of submittals disapproved by the Government. An unsatisfactory rating in any element may adversely effect future awards of Department of Defense contracts to the Contractor.

PART 2 - PRODUCTS (NOT USED)

PART 3 - EXECUTION (NOT USED)

- - o 0 o - -

SECTION 01310

PROGRESS SCHEDULE

1. CONTRACTOR-PREPARED CONSTRUCTION SCHEDULE. Pursuant to the Contract Clause entitled "SCHEDULE FOR CONSTRUCTION CONTRACTS" the Contractor shall prepare a schedule of construction utilizing a construction progress chart as described herein.

1.1 Construction Progress Chart. Construction progress charts shall be prepared on ENG Form 2454. The Contractor shall submit three copies of the Construction Progress Chart for approval. No progress payments will be made without an approved progress chart.

1.1.1 The Contractor shall prepare the chart with the following considerations. The contract work shall be divided into definable contract features. The WT. column should indicate the percentage of the contract for which each principal contract feature accounts. The vertical lines shall be identified by specific time frames, (i.e., weekly, bi-weekly, monthly) with one space accounting for no more than one month. The Contractor shall identify the date which Notice to Proceed is acknowledged on the chart. The Contractor shall also identify the contract completion date on the chart.

1.1.2 The Contractor shall place bars on the chart to indicate scheduled progress for each feature of work. The Contractor shall note the anticipated percentage complete for each item at the end of each month and at the end of each scheduled block.

SECTION 01400

CONTRACTOR QUALITY CONTROL SYSTEM

1. CONTRACTOR QUALITY CONTROL (ER 1180-1-6) (JUL 1986).

1.1 General. The Contractor shall establish and maintain an effective quality control system in compliance with the Contract Clause entitled "INSPECTION OF CONSTRUCTION". The quality control system shall consist of plans, procedures, and organization necessary to provide materials, equipment, workmanship, fabrication, construction and operations.

1.2 Coordination Meeting. Before start of construction, the Contractor shall meet with the Contracting Officer (CO) or his authorized representative (ACO) and discuss the Contractor's quality control system.

1.3 Quality Control Plan:

1.3.1 General. The Government will consider an interim plan for the first 15 days of operation. However, the Contractor shall furnish for acceptance by the Government, not later than 10 days after receipt of Notice to Proceed, the final Contractor Quality Control (CQC) Plan with which he proposes to implement the requirements of Contract Clause entitled "Inspection of Construction". If the Contractor fails to submit an acceptable QC plan within the time herein prescribed, the CO or ACO may withhold funds from progress payments in accordance with the Contract Clause entitled "PAYMENTS UNDER FIXED-PRICE CONSTRUCTION CONTRACTS" until such time as the Contractor submits an acceptable final plan.

1.3.2 The Quality Control Plan. This plan shall include as a minimum, the following:

a. A description of the quality control organization, including a chart showing lines of authority and acknowledgement that the CQC staff shall implement the three phase control systems for all aspects of the work specified and shall report to the project manager or someone higher in the Contractor's organization.

b. The name, qualifications, duties, responsibilities and authorities of each person assigned a QC function.

1.3.3 Acceptance of Plan. Acceptance of the Contractor's plan is required prior to the start of construction. Acceptance is conditional and will be predicated on satisfactory performance during the construction. The Government reserves the right to require the Contractor to make changes in his CQC plan, staffing and operations as necessary to obtain the quality specified.

1.3.4 Notification of Changes. After acceptance of the QC plan, the Contractor shall notify the CO in writing of any proposed change. Proposed changes require approval by the CO or ACO.

1.4 Quality Control Organization.

1.4.1 CQC System Manager. The Contractor shall identify an individual within his organization at the site of the work, who shall be responsible for overall management of CQC and have the authority to act in all CQC matters for the Contractor. This individual shall provide inspection of the work to ensure compliance with the contract plans and specifications. This person shall be on the job site at all times that work is in progress. This person shall have as a minimum: three (3) years verifiable experience at the construction skilled-craft foreman level or above; at least three (3) years verifiable experience as a construction Contractor Quality Control Representative.

1.5 Submittals. Submittals shall be as specified in the Section 01300 entitled "SUBMITTALS".

1.6 Control. Contractor Quality Control is how the Contractor assures himself that his construction complies with the requirements of the contract plans and specifications. The controls shall be adequate to cover all construction operations, including both onsite and offsite fabrication, and will be keyed to the proposed construction sequence. The controls shall include at least three phases of control for all definitive features of work as follows:

1.6.1 Preparatory Phase. This shall be performed prior to beginning any work on any definable feature of work. It shall include a review of contract requirements; a check to assure that all materials and/or equipment have been tested, submitted and approved; a check to assure that provisions have been made to provide required control testing; examination of the work area to ascertain that all preliminary work has been completed; and a physical examination of materials and equipment. The Contractor shall attach copies of codes appropriately referenced in the Technical Provisions. The Contracting Officer's Authorized Representative (ACO) shall be notified at least 48 hours in advance of beginning of any of the required actions of the preparatory phase. The results of the preparatory phase
actions shall be made a matter of record in the Contractor's Quality Control documentation as required below. Subsequent to the preparatory phase and prior to commencement of work, the Contractor shall instruct applicable workers as to the acceptable level of workmanship required in his CQC plan in order to meet contract specifications.

1.6.2 Initial Phase. This phase starts as soon as a representative portion of the particular feature of work has been accomplished. This phase shall include examination of the quality of workmanship and a review of control testing for compliance with contract requirements. The work shall be inspected for use of defective or damaged materials, omissions, and dimensional requirements. The Contracting Officer's Representative shall be notified at least 24 hours in advance of the inspection of the initial phase. The inspection results shall be made a matter of record in the CQC documentation as required below. The initial phase should be repeated for each new crew to work on site, or if acceptable standards of workmanship are not being met.

1.6.3 Follow-Up-Phase. Daily inspections shall be performed to assure continuing compliance with contract requirements. The inspections shall be made a matter of record in the CQC documentation as required below. Final follow-up inspections shall be conducted and all deficiencies corrected prior to the start of additional features of work.

2. DOCUMENTATION.

2.1 The Contractor shall maintain current records of quality control operations, activities, and tests performed including the work of the subcontractors. These records shall be on an acceptable form and indicate a description of trades working on the project, the numbers of personnel working, the weather conditions encountered, any delays encountered, and acknowledgement of deficiencies noted along with the corrective actions taken on current and previous deficiencies. In addition, these records shall include factual evidence that required activities or tests have been performed, including but not limited to the following:

a. Type and number of control activities and tests involved.

b. Results of control activities or tests.

c. Nature of defects, causes for rejection, etc.

d. Proposed remedial action.

e. Corrective actions taken.

2.2 These records shall cover both conforming and defective or deficient features and shall include a statement that supplies and materials incorporated in the work comply with the contract. Legible copies of these records shall be furnished to the CO daily. Preparatory and initial inspections will be documented on an approved form and submitted in duplicate with the quality control report for the day of inspection.

2.3 Deficiency Log. The Contractor shall maintain at the site a deficiency log which includes entries of all deficiencies or departures from contract requirements in the work which the CQC and/or the Government Quality Assurance personnel have noted. The deficiency log shall include the following:

a. Date deficiency noted.

b. Name of person noting deficiency.

c. CQC report number deficiency noted on.

d. Brief description of deficiency.

e. Date deficiency correction noted.

f. The Contractor shall submit for review the deficiency log to the Government at each monthly progress payment request and shall surrender permanently the deficiency log to the Government at completion of the work but prior to final inspection. The deficiency log shall be made available to the Government for review at all times during the life of the contract.

2.4 The Contractor shall establish and implement a serialized numbering system for letters sent to the Government. The numbering system shall identify the contract number and shall progress sequentially starting with the number one (1) and continuing thereafter without break in numbering. All letters sent to the Government shall include a subject heading, which identifies the Contract Clause Number, Special Clause Number, or Technical Provision Number, and the particular subject item addressed by the letter.

2.5 Notification of Noncompliance. The Contracting Officer will notify the Contractor of any noncompliance with the foregoing requirements. The Contractor shall, after receipt of such notice, immediately take corrective action. Such notice, when delivered to the Contractor or his representative at the site of the work, shall be deemed sufficient for the purpose of notification. If the Contractor fails or refuses to comply promptly, the Contracting Officer may issue an order stopping all or part of the work until satisfactory corrective action has been taken. No part of the time lost due to any such stop orders shall be made the subject of claim for extension of time or for excess costs or damages by the Contractor.

- - o 0 o - -

SECTION 01420

SAFETY

1. SAFETY. The Contractor shall comply with all applicable Federal laws and with such additional measures as the Contracting Officer may find necessary in accordance with the Contract Clause titled: ACCIDENT PREVENTION. Applicable provisions of the Corps of Engineers manual entitled Safety and Health Requirements Manual EM 385-1-1, dated April 1981, revised October 1987, will be applied to all work under this contract. The reference manual may be obtained from the Contracting Officer's Representative, at the job site. EM 385-1-1 is hereby changed in accordance with the paragraphs attached after this Section entitled "INTERIM CHANGE TO EM 385-1-1 - SAFETY AND HEALTH REQUIREMENTS MANUAL.

1.1 Accident Prevention Program. Within fifteen (15) calendar days after receipt of Notice to Proceed, and at least ten (10) calendar days prior to the Safety Prework Conference, four (4) copies of the Accident Prevention Program required by the Contract Clause titled: ACCIDENT PREVENTION shall be submitted for review by the Contracting Officer. The program shall be prepared in the following format:

1.1.1 SWA Form 705 "Accident Prevention Program" fully completed and signed by an officer of the company in Block No. 28.

1.1.2 SWA Form 704 "Job Hazard Analysis" fully completed and signed by an officer of the company. The job hazard analysis is a method in which those hazards most likely to cause a fatality or significant disability are analyzed. Corrective action is then planned in advance which will eliminate the hazards. A written analysis is required for each phase of work and shall be presented at the preparatory inspection (P/I) meeting. On large or complex jobs the first phases may be presented in detail with the submittal of the Accident Prevention Program rather than presenting the complete analysis initially. If the plan is to be presented in phases, a proposed outline for future phases must be submitted as a part of the initial Accident Prevention Program submittal. The Accident Prevention Program will be reviewed for timeliness and adequacy at least monthly by the Contractor and noted as such on the Contractor's Quality Control Report at that time.

1.1.3 Copy of company policy statement on accident prevention and any other guidance or indoctrination provided to new employees. In addition, a description of the employee and supervisor safety responsibilities and authorities from the working level up through each supervisory level of the Contractor's organization shall be provided.

1.1.4 In addition to those contained in EM 385-1-1, Appendix "Y", include the following items in the Accident Prevention Program:

1.1.4.1 Hard Hat Area. A statement that the job site is classified a "hard hat" area from start to finish.

1.1.4.2 Sanitation and Medical Requirements. Estimate of the greatest number of employees, supervisors, etc., to be working at peak construction period, including sub-contractor personnel. Include sanitation and medical facilities planned for the job site.

1.1.4.3 Equipment Inspection. What type of inspection program on cranes, trucks, and other types of construction equipment does the Contractor plan to implement. Who will be responsible for the inspection and how does the Contractor plan to control equipment of sub-contractors and equipment brought to the job site by rental companies. Types of records to be kept.

2. WORK SAFETY INCENTIVE AND OTHER ITEMS. The Contractor shall provide a plan to encourage all employees to work safely. This plan shall be directed at the individual employee and shall be so designed such that it motivates all employees toward a safe work attitude. The plan shall be designed to be a positive incentive plan and must include a tangible reward and benefit to the individual employee. The reward frequency shall be at least once a month. The "Work Safety Incentive Plan" must be integrated into the overall "Accident Prevention Plan" which must be approved prior to the start of construction.

3. ACCIDENT REPORTS. The Contractor shall immediately report all accidents by telephone to the Contracting Officer. The Contractor Initial Report of Accident form shall be submitted by the following day to the Contracting Officer (See Contractor Initial Report of Accident form, attached.) The Contractor shall complete and submit ENG Form 3394 for all lost time accidents within 3 days of the accident.

3.1 Monthly Exposure Report. The Contractor shall submit SWD Form 743-J, Monthly Exposure Report, to the Contracting Officer no later than the 5th of each month. This report is a compilation of manhours worked each month by the prime contractor and each subcontractor.

4. CLEANUP. The Contractor's accident prevention program shall identify the individuals responsible for cleanup and shall establish a regular cleanup procedure and schedule. If the Contracting Officer determines that cleanup is not being performed satisfactorily, the Contractor shall establish a work crew to perform the continuous cleanup required by the Contract Clause titled: CLEANING UP. The individual(s) appointed to the work crew to perform daily cleanup shall not perform any other duties under this contract, unless approved by the Contracting Officer. The number of individuals appointed to perform cleanup shall be increased as directed by the Contracting Officer until adequate cleanup is maintained.

5. SPECIAL REQUIREMENTS. The following requirements shall be met by the Contractor if applicable:

5.1 Electrical Work: Electrical work will not be performed on or near energized lines or equipment unless specified in the plans and specifications.

5.1.1 Upon request by the Contractor, arrangements will be made for deenergizing lines and equipment so that work may be performed. All outages shall be requested through the authorized representative of the Contracting

Officer a minimum of 14 days, unless otherwise specified, prior to the beginning of the requested outages. Dates and duration will be specified.

5.1.2 Upon approval of the Contracting Officer's representative, the following work may be performed with the lines energized using certified hot line equipment on lines above 700 volts, when the following conditions have been met.

5.1.2.1 Work below the conductors no closer than the clearance required in EM 385-1-1 from the energized conductors.

5.1.2.2 Setting and connection of new pretrimmed poles in energized lines which do not replace an existing pole.

5.1.2.3 Setting and removing transformers or other equipment on poles.

5.1.2.4 Installation or removal of hot line connectors, jumpers, dead-end insulators for temporary isolation, etc., which are accomplished with hot line equipment from an insulated bucket truck.

5.1.3 The Contractor shall submit a plan, in writing, describing his method of operation and the equipment to be used on energized lines. Proper certification from an approved source of the safe condition of all tools and equipment will be provided with the plan. The work will be planned and scheduled so that proper supervision is maintained. The Contractor will review his plan with the Contracting Officer's representative prior to being granted permission to perform the work.

5.1.4 No work on lines greater than 600 volts will be performed from the pole or without the use of an insulated bucket truck.

5.1.5 No work will be done on overbuilt lines while underbuilt lines are energized, except for temporary isolation and switching in accordance with 5.1.2.4 hereinbefore.

5.2 Electrical Tools: Hand held electric tools shall be used only on circuits protected by ground fault circuit interrupters for protection of personnel.

5.3 Grounding Generators and Arc Welders: Non-current carrying metal parts of all generators and arc welders shall be grounded.

5.4 Rollover Protective Structures:

5.4.1 R.O.P.S. for rollers and compactors will be certified to meet SAE requirement J1040C.

5.4.2 R.O.P.S., as required by paragraph 18.B.20, EM 385-1-1, includes self-propelled pulverizers.

5.5 Radiation Permits or Authorizations:

5.5.1 Contractors contemplating the use of radioactive materials or radiation producing equipment while performing work on this contract must obtain written

authorization from the Department of the Army or Department of the Air Force, as applicable.

5.5.2 A 45-day lead time should be programmed for obtaining this written authorization.

5.5.3 When requested, the Contracting Officer's Authorized Representative will assist Contractor in obtaining the required permit or authorization.

5.6 Self-Propelled Elevating Work Platforms: All self-propelled elevating work platforms will be designed, constructed, maintained, used, and operated in accordance with the guidance provided in American National Standard for Self-Propelled Elevating Work Platforms (ANSI A92.6-1990) together with any amendments which may be in force at time contract is awarded.

5.7 Language: For each work group that has employees that do not speak English the Contractor will provide a bilingual foreman that is fluent in the language of the workers. The Contractor will implement the requirements of EM 385-1-1, Para. 01.B.01, 01.B.02, and 01.C.02 through these foremen.

5.8 Guarding of Roofs and Open-Sided Floors: To supplement and emphasize the requirements of Contract Clause "Accident Prevention" and the safety manual, EM 385-1-1, the following is provided:

5.8.1 Perimeter guard rails will be installed on all open-sided floors on multistoried buildings, and on all roof perimeters. Guard rails will be installed as the decking crew completes an area and before any other work starts and will remain intact as long as construction work is in progress in the area.

5.8.2 The Contractor will submit his proposed method of fall protection to the Contracting Officer's Representative as part of his Job Hazard Analysis for approval before beginning roof operations.

6. The Contracting Officer will notify the Contractor of any noncompliance with the foregoing provisions and the action to be taken. The Contractor shall, after receipt of such notice, immediately take corrective action. Such notice, when delivered to the Contractor or his representative at the site of the work, shall be deemed sufficient for the purpose. If the Contractor fails or refuses to comply promptly, the Contracting Officer may issue an order stopping all or part of the work until satisfactory corrective action has been taken. No part of the time lost due to any such stop orders shall be made the subject of a claim for extension of time or for excess costs or damages by the Contractor. The Contractor shall be responsible for subcontractor compliance with this provision. The Contractor shall include the provisions of this clause in all subcontracts involving performance of work at the site. However such provision in the subcontractor's contract shall not relieve the Contractor of his obligation to assure compliance with the provisions of this clause for all aspects of the work.

INTERIM CHANGE TO EM 385-1-1 - SAFETY AND HEALTH REQUIREMENTS MANUAL

1. Page 21, Section 07.A.03, replace with the following:

"07.A.03 - Protective footwear, such as rubber boots, protective covers, ice clamp-ons, steel-toed safety boots, shall be worn by all persons exposed to hazards to the feet (including, but not limited to impact, puncture, slipping, electrical, or chemical hazards).

a. For all activities in which Corps or contractor personnel or official visitors are potentially exposed to foot hazards, the applicable job/activity hazard analysis, accident prevention plan, or project safety plan shall include an analysis of, and prescribe specific protective measures to be enforced for, foot hazards.

b. Footwear providing protection against impact and compressive forces, conduction hazards, electrical hazards,and sole puncture shall meet the applicable requirements of ANSI Z41."

2. Page 143, Section 18.C.05, replace with the following:

"18.C.05 - All load drums on loading-hoisting equipment shall be equipped with at least one positive holding device. This device should be applied directly to the motor shaft or some part of the gear train. It is not necessary that the positive holding device utilize shearing of metal to meet this requirement. Friction surfaces are acceptable."

3. Page 145, add Section 18.C.24 and 18.C.25 which will read:

"18.C.24 - During personnel handling operations load and boom hoist drum brakes, swing brakes, <u>and</u> locking devices such as pawls or dogs shall be engaged when the occupied platform is in a stationary working position."

"18.C.25 - During personnel handling operations the load hoist drum shall have a system or device on the power train other than the load hoist brake, which regulates the lowering rate of speed of the hoist mechanism (controlled load lowering). Free fall is prohibited."

4. Page 146, Section 18.D.09, replace with the following:

"18.D.09 - All telescopic boom cranes engaged in standard lift operations (including concrete bucket) should be equipped with a two-block warning feature(s), a two-block damage prevention feature, or an anti-two block device for all points of two-blocking (i.e., jibs, extension, etc.). In addition, all new telescopic boom cranes shall be equipped with a anti-two block device or a two-block damage prevention feature for all points of two-blocking. Cranes that are used exclusively as duty cycle machines (clamshell, dragline, grapple, pile driving operations) are exempt from this requirement but will meet the requirements of ANSI/ASME-B30.5-1989 (as revised). In all cases where cranes are utilized without these safeguards equivalent protection shall be established, documented and approved by the designated authority."

INTERIM CHANGE TO EM 385-1-1 (CONTINUED):

5. Page 146, add Sections 18.D.10 and 18.D.11, which will read:

"18.D.10 - All lattice boom cranes engaged in standard lift crane operations (including concrete bucket) should be equipped with a two-block warning feature which functions ford all points of two-blocking. Cranes that are used exclusively as duty cycle machines (clamshell, dragline, grapple, pile driving operations) are exempt from this requirement but will meet the requirements of ANSI/ASME-B30.5-1989 (as revised). In all cases where cranes are utilized without these safeguards equivalent protection shall be established and documented and then approved by the designated authority."

"18.D.11 - During personnel handling operations all telescopic and lattice boom cranes shall be equipped with a device which when activated disengages all functions whose movement can cause contact between the load block or overhaul ball and the boom tip (anti-two block device), or a system shall be used which deactivates the hoisting action before damage occurs in the event of a two-blocking situation (two-block damage prevention feature). The device or systems must be installed for all points of two-blocking (i.e., job or boom points) and in the case of the anti-two block device the crane must be equipped with automatic brakes on each hoist line; hoist lines not so equipped must be taken out of service while personnel lifts are being made."

- - o 0 o - -

Names of first aid attendants having certificates	Types of certificate and expiration date	Names of U.S.C.G. licensed boat operators, type license & expiration date
19	19a	20

21 Fire Fighting Equipment				22 First Aid Kits		23 Wash Facilities		
No.	Rating	Type	Location	No.	Type	No.	Type	

24 Toilets				
No.	Type			

What flammable or combustible liquids or gases will be on job site?

25

Where and how will flammables and combustibles be stored?

26

Who will be responsible for inspection and maintenance of fire fighting equipment?

27

If the Company has a published statement of safety policy, please transmit a copy with the return of your Accident Prevention Program.

On a separate sheet submit your proposed layout of temporary buildings and facilities (including subcontractors) and traffic patterns including access roads, haul roads, R.R.s, utilities, etc.

The _____ will pursue a positive program of training,
(Company)
inspections and hazard control throughout the term of this contract. Mr./Ms. _____

Has the responsibility and authority for enforcing them.

_____ _____

Contractor's Signature Date

28

CONTRACTORS ACCIDENT PREVENTION PROGRAM

Willingness to correct safety hazards detected by the Corps is commendable, but a poor substitute for a positive program that prevents or detects and corrects hazards.

Contractor 1	Contract Name & No. 2		Date 3
Project Superintendent 4	Shifts/day 5	Hour/shift 5a	Maximum employees/shift 5b
Superintendent's training in Corps' safety requirements 6			
Major Units of Equipment 7			
Who will inspect equipment? 8	Inspector's qualifications 8a		Inspection frequency? 8b
Who is responsible for operators' physicals? 9	Location of all records 10		Day and hour weekly safety meeting 11
Who is responsible for employee training? 12	Who will orient new employees? 13		
Who is responsible for clean-up? 14	Where will drinking water be obtained? 15		
Who will investigate accidents? 16	Who is responsible for providing personal protective equipment? 17		

Name Doctors, Hospitals & Ambulance services with whom arrangements have been made for this contract.

Doctor	Hospital	Ambulance
18	18a	18b

What form of communication will be used to summon ambulance?

18c

(over)

SWA 705
FEB 83

CONTRACTOR INITIAL REPORT OF ACCIDENT

Date
and Time of Accident _____ Lost Time _____ Property _____
Injury _____ Damage _____

Contract No. _____ Prime _____ Sub _____

Name of Injured or Equipment Operator _____ Occupation _____

Social Security No. _____ Age _____

Extent of Injury _____

Equipment or tools involved (Include type, brand, model, age, damage if any)

Description of Accident _____

Corrective Action _____

Namees of Witnesses _____

Signature _____ Date _____

Title _____

JOB HAZARD ANALYSIS

CONTRACT NO.	PROJECT:	FACILITY:
DATE:	MAJOR PORTION OF WORK:	ESTIMATED START DATE:

ITEM	PHASES OF WORK	SAFETY HAZARD	PRECAUTIONARY ACTION TAKEN
	Break the job down into its basic steps, e.g., what is done first, what is done next, and so on. You can do this by 1) observing the job, 2) discussing it with the operator, 3) drawing on your knowledge of the job, or 4) a combination of the three. Record the job steps in their normal order of occurrence. Describe what is done, not the details of how it is done. Usually 3 or 4 words are sufficient to describe each basic job step.	For each job step, ask yourself what accidents could happen to the man doing the job step. You can get the answers by 1) observing the job, 2) discussing it with the operator, 3) recalling past accidents or 4) a combination of 3. Ask yourself: Can he be struck by or contacted by anything; can he strike against or come in contact with anything; can he fall, can he be caught in, or between something; can he overexert; is he exposed to gas, radiation, welding rays, etc; for example, acid burns or fumes.	For each potential accident or hazard ask yourself how should the man do the job step to avoid the potential accident, or what should he do or not do to avoid the accident. You can get your answers by 1) observing the job for leads, 2) discussing precautions with th experienced job operators 3) drawing on your experience or 4) a combination of the three. Be sure to describe specifically the precaution a man must take. Don't leave out important details. Number each separate recommended precaution with the same number you gave the potential accident (See center column) that the precaution seeks to avoid. Use simple do or don't statements to explain recommended precautions as if you were talking to the man. For example, "Lift with your legs, not your back," Avoid such generalities as "Be Careful", "Be alert", "Take caution", etc.

CONTRACTOR (SIGNATURE & DATE)	
REPORT DISCUSSED WITH CONTRACTOR/SUPERINTENDENT ON:	RESIDENT ENGINEER (SIGNATURE)
PROJECT ENGINEER (SIGNATURE):	

SWA 704
FEB 83

Cont'd from other side

								Total Manhours
Sub-Contractor	_____	MH	_____	_____	_____	_____	_____	_____
		Date	( )	( )	( )	( )	( )	
" "	_____	MH	_____	_____	_____	_____	_____	_____
		Date	( )	( )	( )	( )	( )	
" "	_____	MH	_____	_____	_____	_____	_____	_____
		Date	( )	( )	( )	( )	( )	
" "	_____	MH	_____	_____	_____	_____	_____	_____
		Date	( )	( )	( )	( )	( )	
" "	_____	MH	_____	_____	_____	_____	_____	_____
		Date	( )	( )	( )	( )	( )	
" "	_____	MH	_____	_____	_____	_____	_____	_____
		Date	( )	( )	( )	( )	( )	
" "	_____	MH	_____	_____	_____	_____	_____	_____
		Date	( )	( )	( )	( )	( )	
" "	_____	MH	_____	_____	_____	_____	_____	_____
		Date	( )	( )	( )	( )	( )	
" "	_____	MH	_____	_____	_____	_____	_____	_____
		Date	( )	( )	( )	( )	( )	
" "	_____	MH	_____	_____	_____	_____	_____	_____
		Date	( )	( )	( )	( )	( )	

ARMY MOTOR VEHICLE MILEAGE

	Passenger Cars	Truck Mileage	Total
Vehicles on civil works inventory	_____	_____	_____
Vehicles on military works inventory	_____	_____	_____
GSA vehicles	_____	_____	_____
All Other (Loaned, rented, leased and privately owned)	_____	_____	_____

Submitted by: _____
(COE Engineer in Charge)

SWD Form 743-J
Rev 10 Nov 80

MONTHLY EXPOSURE REPORT OF OPERATIONS AND ACTIVITIES	Reports Control Symbol DAEN-30-1 (RI)	Date:

Read instructions below.

Monthly report of accident and exposure data as required by the Accident Prevention Article of contract shown below.

THRU: _____ ENGINEER	TO: District Engineer	Contractor:
		Contract Number:

								Total Manhours
Prime-Contractor	Administrative, Professional & Supervisors	MH						
		Date	( )	( )	( )	( )	( )	
	Skilled & Common Labor	MH						
		Date	( )	( )	( )	( )	( )	
Sub-Contractor		MH						
		Date	( )	( )	( )	( )	( )	
" "		MH						
		Date	( )	( )	( )	( )	( )	
" "		MH						
		Date	( )	( )	( )	( )	( )	
" "		MH						
		Date	( )	( )	( )	( )	( )	
" "		MH						
		Date	( )	( )	( )	( )	( )	

(Add additional names on reverse side)

Sub-total this page _____

Sub-total reverse side _____

Grand Total _____

ENG Form 3394, MISHAP REPORT, submitted this period:
Disabling Injuries _____

Amount Property Damage (in excess of $300) _____

Submitted by:

_____
(Contractor)

Instructions:
1. This report to be submitted in duplicate by each prime contractor as directed by Contracting Officer, or Authorized Representative.
2. The above figures include all operations directly supporting the contract. They do not include offsite operations not on government property or under government supervision which supply projects other than this contract. Neither do they include materials supplied F.O.B. the job site.
3. Above figures include overtime, etc.
4. Figures will cover regular pay periods without allowing for calendar month. This method automatically corrects the log every three months as eight months will have four pay periods and four months will have five pay periods.

Section 01430

~~SECTION 10~~

EMERGENCY RESPONSE AND WORK SAFETY PROCEDURES

~~INDEX~~

1. General
2. Staff and Qualifications
3. Work Stages
4. Work Zones
5. Personal Protective Equipment Program
6. Employee Training
7. Emergency Response Plan
8. Prohibitions
9. Logs and Reports
10. Identification and Control
11. Signs
12. Submittals

1. GENERAL.

1.1 PURPOSE AND BACKGROUND. This section describes the minimum health, safety, and emergency response requirements for this project. Using this section as a guideline, the Contractor shall develop a detailed Health, Emergency Response, Safety, Fire Protection, Decontamination, and Environmental Protection Plan (HESFDEP). The program must establish in detail the procedures necessary for protecting the worker and others from the hazards associated with the closure of Cell No. 3 of Landfill Area 5 at Cannon Air Force Base (CAFB) New Mexico.

1.2 PRECONSTRUCTION PLANNING MEETING. The Contracting Officer will review and discuss the safety and emergency response requirements, as well as the planning and administrative requirements of the overall HESFDEP, at the preconstruction planning meeting. See Section 1A - Special Clauses, paragraph 7.2, for further details.

1.3 HEALTH AND SAFETY PROGRAM. The Health and Safety Program for this project shall be based on the requirements of the OSHA Standards for General Industry, 29 CFR 1910 (including the interim final rule, Hazardous Waste Opera-

tions and Emergency Response), the Construction Industry, 29 CFR 1926, and/or the EPA Standard Operating Safety Guides, November 1984, whichever provides the greatest degree of protection.

1.4 ACCIDENT PREVENTION PROGRAM. As part of the HESFDEP, the Contractor shall submit a proposed Accident Prevention Program (Emergency Response, Fire Protection, Decontamination, etc.) that will be followed by Contractor and subcontractor personnel, including supervisory staff, during performance of the work.

1.4.1 Requirements. The program shall be developed only after a careful analysis of the work involved and shall be tailored specifically to the conditions of the project. The Contractor's proposed Accident Prevention Program shall conform to the requirements of subparagraph 1.3 of this section.

1.4.2 Accident Prevention Outline. The Contractor's Accident Prevention Program shall address, as a minimum, the following items:

- Responsibility;
- Accountability;
- Subcontractor supervision;
- Employee orientation and training;
- Safety meetings;
- Fire prevention, suppression, and protection;
- Air monitoring;
- Accident investigation and reporting;
- Mechanical equipment inspection;
- Housekeeping and sanitation;
- First aid and medical facilities; and
- Phase safety planning.

1.4.3 Phase Safety Planning. As a supplement to the required basic Accident Prevention Program, the Contractor shall prepare a safety plan for each phase of the work. A phase is defined as an operation involving work that

represents hazards not experienced in previous operations or work to be performed by a new subcontractor. Each phase safety plan shall include, but not be limited to, a description of the work, probable hazards related to that work, and precautionary measures to be taken to reduce or eliminate each particular hazard. The actual work on each phase will not be permitted to proceed until the phase safety plan is found to be acceptable by the Contracting Officer.

2. STAFF AND QUALIFICATIONS.

2.1 STAFF.

2.1.1 Certified Safety Professional. The Contractor must provide the services of a Certified Safety Professional (CSP) who shall be on site and shall be responsible for the implementation and enforcement of the Health and Safety Program. The qualifications and experience of the Contractor's health and safety personnel shall be subject to review by the Contracting Officer. If the Contracting Officer determines that personnel assigned are not providing adequate health and safety controls, the Contractor shall obtain the services of additional health and safety personnel at no additional cost to the Government.

2.1.2 Certified Industrial Hygienist. The Contractor must provide the services of a Certified Industrial Hygienist (CIH) who shall work in coordination and consultation with the CSP and be responsible for the initial content and implementation of the personal protective equipment program, employee training program, and air monitoring plan.

2.2 QUALIFICATIONS.

2.2.1 Certified Safety Professional. The CSP shall have worked in health and safety for a minimum of 5 years in an industry with hazards similar to those anticipated on this project (e.g., excavation, potential exposure to hazardous substances). The CSP shall have a sound working knowledge of State (i.e., New Mexico) and Federal occupational health and safety regulations, and

formal training in occupational health and safety. The individual's name and work experience shall be submitted to the Contracting Officer for approval prior to commencement of work at the site.

2.2.2 Certified Industrial Hygienist. The Industrial Hygienist shall be certified by the American Board of Industrial Hygiene (ABIH) and have a minimum of 5 years' working experience in safety and health in an industry with hazards similar to those anticipated on this project (e.g., excavation, potential exposure to hazardous substances, and hazardous waste disposal). He/she shall have demonstrable expertise in air monitoring techniques and in the development and implementation of respiratory protective programs suitable for working in atmospheres that are either chronically or acutely dangerous to health. In addition, the CIH shall have a sound working knowledge of State (i.e., New Mexico) and Federal occupational health and safety regulations, and formal training in occupational health and safety. The individual's name and work experience shall be submitted to the Contracting Officer for approval prior to commencement of work at the site.

2.3 AUTHORITY. The CSP shall have the right to correct, command, and determine courses of action on all health and safety measures.

2.4 RESPONSIBILITY. The CSP shall answer for all activities and results with regard to health and safety. In addition to responsibilities in paragraph 2.1.2, the CIH shall be responsible for developing procedures for heat-stress monitoring of employees working in protective clothing or respiratory protection when ambient temperatures reach or exceed 75°F. Work-rest schedules shall be adjusted accordingly. Cold stress, although not generally considered a problem above 10°F for properly dressed workers, should also be addressed by the CIH. The Contractor's proposed work-rest schedule shall be submitted to the Contracting Officer for approval.

3. WORK STAGES.

Work stages shall be established to ensure that each employee is properly equipped with the personal protective equipment needed to safely complete his/

her task (see paragraph 5 - Personal Protective Equipment Program). The stages are defined as follows:

3.1 STAGE I. Preparation of subgrade, root picking, smooth finishing, and compaction of existing cap of Cell No. 3 of Landfill Area 5.

3.2 STAGE II. Excavation, loading, transportation, placement, compaction, and grading of various soil layers in the final cover, including installation of polymeric membrane, geotextile fabric, and PVC venting system.

3.3 STAGE III. Construction of ~~ditches~~, ~~dikes~~, ~~and~~ fences.

4. WORK ZONES. Work zones shall be established to contain contamination within the smallest area possible. The Contractor shall ensure that each employee is trained in the use of the proper personal protective equipment for the area or zone in which he/she is to work. Zone requirements shall conform to the EPA Standard Operating Safety Guides, November 1984.

4.1 EXCLUSION ZONE. The Exclusion Zone will require different levels of protective equipment depending on the exposure potentials. The required protective equipment for use by personnel working or entering the Exclusion Zone is specified in paragraph 5 - Personal Protective Equipment Program.

4.2 CONTAMINATION REDUCTION ZONE. This area shall be established as a buffer between the Exclusion Zone and the Support Zone. The decontamination facilities for all equipment, including personal protective equipment, shall be located within the Contamination Reduction Zone for this site. Containers shall be provided for proper disposal of used clothing. Emergency equipment, such as self-contained breathing apparatus, emergency showers, and eyewash facilities, must be located in this zone. The personal protective equipment required for use by personnel working in this area is specified in paragraph 5 - Personal Protective Equipment Program.

4.3 SUPPORT ZONE. The Support Zone shall include the remaining "clean" areas of the job site. Change rooms, lunch and break supplies, and equipment storage and maintenance areas shall be located in this area. Eating, smoking,

and drinking will be allowed only in this area.

5. PERSONAL PROTECTIVE EQUIPMENT PROGRAM. Construction operations under this contract will require work in hazardous environments. The Contractor shall ensure adequate protection for all onsite employees. The Contractor shall establish and maintain a complete program as part of the HESFDEP for all personnel visiting or working at the site, including support for five Government employees at any time they may be required to monitor the Contractor's work. The Contractor must have evidence of medical review for ability to wear respirators and must provide for selection, fit, and testing as required in 29 CFR 1910.134 and ANSI 288.2 (1980). The Contractor shall submit the details of the program for acceptance as part of the HESFDEP.

5.1 PROGRAM ELEMENTS. The Contractor's Personal Protective Equipment Program shall provide protection against exposure to hazardous substances identified at the site. See Appendix C for chemicals detected at this site. The program shall include the following elements as a minimum and shall be approved by the Contracting Officer before work commences:

- Medical surveillance;
- Industrial hygiene support;
- Employee training;
- Complete respiratory program;
- Eye protection;
- Skin protection;
- Emergency provisions;
- Record keeping and reporting;
- Personnel and equipment decontamination; and
- Fire protection.

5.2 PROGRAM REQUIREMENTS. The Contractor shall provide all personal protective equipment. This equipment must provide protection against any hazardous substance identified on site. The intent of the program is to provide a level of worker protection appropriate to the exposure.

5.3 EQUIPMENT TYPES. The personal protective equipment shall provide hearing, respiratory, skin, and eye protection for personnel during each phase of work.

5.3.1 Respiratory Protection. The Contractor shall prepare a written respiratory protection program in accordance with OSHA 29 CFR 1910.134. Respiratory protection devices shall be provided, inspected, and maintained by the Contractor. Individuals shall be properly fitted with their own breathing devices. The cartridge and filter shall be changed at the beginning of each 8-hour work shift or more frequently as necessary. A procedure shall be established for ensuring daily cleaning, maintenance, and change of filters.

5.3.2 Personal Protective Equipment. All required protective equipment shall be provided and maintained by the Contractor. This equipment includes, but is not limited to, eyewash/shower equipment, emergency showers, respirators, explosionproof equipment, first-aid kits, fire blankets, fire extinguishers, protective clothing, hardhats, and signs. All equipment shall conform to requirements of the American Industrial Hygiene Association (AIHA), NIOSH, National Safety Council, and OSHA.

5.4 EQUIPMENT REQUIREMENTS. Levels of protection for personnel involved in site work will be based on U.S. EPA-specified levels of protection, levels A, B, C, and D. The Contractor's CSP, in coordination with the CIH, shall evaluate the various work activities and air monitoring results and shall determine what protection is warranted.

5.4.1 The Contractor shall provide the Contracting Officer with a detailed personal air monitoring plan for the additional protection of workers. This plan shall be prepared by the Contractor's CIH as part of the Health and Safety Program Submittal (see Section 1A, paragraph 7.2), and shall comply with applicable State of New Mexico regulations, OSHA Instruction CPL 2-2.208 (March 30, 1984), and NIOSH Manual of Analytical Methods (2nd Ed., 1981, and/or 3rd Ed., 1984 and 1985, Supplement No. 84-100). The Contractor shall submit the Air Monitoring Plan prior to any excavation operations. The Contractor shall report any need for change and any unexpected events to the Contracting Officer

and obtain his approval for proposed actions. It is important to ensure that personnel are protected against exposure to any of the potentially dangerous and toxic chemicals present.

5.4.2 Personal and area samples for benzene, toluene, and other chemicals present shall be taken during work operations near the hazardous landfill. In addition, air sampling must be performed to identify other components to which workers may be exposed.

5.4.3 Monitoring for air contaminants must be performed during construction of the final cover. Since the contaminants have not been fully identified, sampling shall be conducted to (1) determine the workplace concentration of the known or suspected materials, particularly benzene and toluene; and (2) identify the unknown materials in the workplace air. The latter type of sampling must be performed at the start of construction operations, and a variety of sample media shall be used to identify the classes of airborne contaminants and their concentrations. Level C protection must be worn during the initial sampling. Levels of protection for subsequent sampling shall be based on initial analytical results and on the Certified Industrial Hygienists's Assessment of potential for exposure.

5.4.4 At least one personal sample and one area sample shall be taken in the immediate work area. In addition, an area sample shall be taken in the Exclusion Zone surrounding the work area, and an area sample shall be taken in the Contamination Reduction Zone. When area samples are collected, the sample collection device shall be placed 60 to 66 inches above ground level. The CIH shall determine the best location for sampling. Short-Term Exposure Limit (STEL) samples shall be taken at appropriate intervals, as determined by the CIH, to ensure that set STELs are not exceeded.

5.4.5 The level of respiratory protection required shall be adjusted based on the analytical results obtained from the samples.

5.4.6 Direct reading instruments shall be used daily during the final cover construction. These instruments shall be operated by individuals ex-

perienced in the use, calibration, operating principles, and limitations of such instruments.

5.4.7 The Contractor shall employ a CIH, who shall establish the protocol for all air monitoring. The Contractor shall ensure that experienced personnel perform the monitoring, and that appropriate equipment and methods are utilized. The Contractor shall provide monitoring equipment and the necessary engineering controls and/or personal protective equipment for the employees' protection. All sampling shall be done in accordance with OSHA and EPA regulations.

5.4.8 Samples shall be collected and analyzed as prescribed in the NIOSH Manual of Analytical Methods. All chemical analyses shall be performed by a laboratory accredited by the AIHA.

5.4.9 All monitoring results, with the exception of direct reading instrument results, shall be reported to the Contracting Officer in a timely fashion, within 48 hours. The results shall be reported on specific forms developed by the Contractor. The air monitoring report forms must include the following information:

- Date of sample;
- Name of person conducting sampling;
- Calibration record of equipment used;
- Sampling method (NIOSH);
- Description of process/operation;
- Type of sample (personal/area);
- Time and duration of sample;
- Location and height of sample;
- Distance from source;
- Weather conditions;
- Name and job of person sampled;
- Personal protective equipment worn;
- Name of laboratory performing analysis;
- Date of analysis;

- Name of person performing analysis;
- Method of analysis;
- Result of analysis;
- Type of filter used;
- Air temperature; and
- Barometric pressure.

5.4.10 A daily log shall be maintained for recording of direct reading instrument measurements. The log must contain the following information:

- Name of person(s) operating the direct reading monitors;
- Type of calibration method used before and after every use;
- Field observations, such as weather conditions during sampling periods;
- Activity taking place during monitoring;
- Results of monitoring; and
- Duration of test.

Direct reading results shall be reported to the Contracting Officer on a daily basis.

5.5 HANDLING PRECAUTIONS. The CIH, together with other responsible personnel of the Contractor's organization, shall personally examine and evaluate the prevailing onsite conditions and determine the handling precautions needed for construction of a final cover on top of the hazardous waste landfill. The determined handling precautions must include safety and occupational health aspects promulgated by OSHA under 29 CFR 1910.1000. Disposal operations must meet requirements of U.S. EPA Regulations under 40 CFR, Part 165. Storage, handling, and disposal of any other wastes determined to be hazardous must meet the applicable sections of the Resource Conservation and Recovery Act (RCRA), 40 CFR, Parts 260-265.

5.5.1 The Contractor shall provide detailed specifications and precautions for the safe operation of work in his HESFDEP. Protection shall be provided in accordance with OSHA 29 CFR 1926, Subpart E, or 29 CFR 1910, Subpart I.

5.6 MEDICAL SURVEILLANCE. The OSHA Hazardous Waste Operations and Emergency Response Rule requires a Medical Surveillance Program for employees engaged in hazardous waste operations where it is medically prudent. The medical examinations must be made available to employees who may be required to wear respirators or who may be exposed to substances in excess of OSHA limits. The Contractor shall utilize the services of a licensed occupational health physician to provide the medical examinations and surveillance specified herein. The name and qualifications of this physician shall be provided to the Contracting Officer prior to commencement of work at the site.

5.6.1 Medical Examinations. The Contractor shall provide to employees selected for the Medical Surveillance Program, or make available at his cost, medical examinations relative to exposure to identified hazardous chemicals before employees participate in onsite operations and at the conclusion of the work. The Contractor's physician shall also provide a medical certification that each employee is fit for employment on the job and can wear the necessary respiratory protection. Medical examinations shall include a medical history and work history, physical examination that includes vital signs and an evaluation of all major organ systems, audiogram and vision screening, chest x-ray to be performed no more frequently than every 4 years (except when otherwise indicated), electrocardiogram (EKG) for individuals over 35 years of age, complete blood count (CBC), blood chemistry screen (SMAC 23-test survey), urinalysis, and pulmonary function test, which includes forced expiratory volume (capacity) at 1 second (FEV_1) and forced vital capacity (FVC). All medical examination results shall be forwarded to the Contracting Officer for record keeping. If a detrimental condition is determined, the Contractor must immediately inform the affected employee, the CSP, and the Contracting Officer.

5.6.2 This evaluation shall be repeated as indicated by substandard performance or evidence of particular stress or chemical exposure that is demonstrated by injury or time-loss illness on the part of the worker.

5.6.3 If employment is terminated for an individual prior to completion of the contract, an examination shall be given.

6. EMPLOYEE TRAINING.

6.1 INITIAL TRAINING. The CSP, with support from the CIH, shall be responsible for providing occupational hazard training to all employees prior to the commencement of work. This training shall include the following as a minimum: This shall include successfully completing The 40-Hour course "Health & Safety For Hazardous Waste Operations" as required by OSHA 29 CFR 1910.120

6.1.1 Basic construction safety emphasizing the hazards on this site.

6.1.2 Acute and chronic effects of substances identified at the site. See Section 1B - Summary of Work and Appendix "C", for more details about the waste.

6.1.3 Requirements for personal protection and their effectiveness and limitations.

6.1.4 Selection, fitting, use, and limitations of respirators, including as a minimum the following:

- o Criteria for respirator selection;
- o Donning techniques for respirators;
- o Use of emergency respirators; and
- o Eyeglasses and contact lenses and limitations.

6.2 FOLLOWUP TRAINING. Followup training shall be provided by the Health and Safety Specialist at least weekly and prior to each change in phase of work. The CSP shall also provide initial training for replacement employees.

6.3 RECORDS. The Contractor shall keep a record of all training periods, documenting date and acceptance. The Contractor shall also maintain a record of each employee's performance evaluation pertinent to use of personal protective equipment.

7. EMERGENCY RESPONSE PLAN.

7.1 The Contractor shall develop a site Emergency Response Plan. This plan shall include, as a minimum, the following:

- o Fire explosion provisions;
- o Emergency spill control;
- o First aid and emergency medical treatment;
- o Communications; and
- o Site evacuation.

7.2 The Contractor shall be responsible for notifying the physician, ambulance service, and fire department of any site hazards before the start of work. The following information from the Emergency Response Plan shall be summarized and posted in the Contractor's trailers:

- o Contractor physician name, address, and telephone number;
- o Ambulance service and fire department telephone number;
- o Detailed, written instructions, including a map that describe the location and route to the cleanup site and route to the nearest hospital;
- o Location of emergency shower/eyewash stations;
- o Location of self-contained breathing devices;
- o Location of fire stations or fire extinguishers and procedures in case of potential or actual fire or explosion;
- o Specific procedure for handling personnel with excessive exposure to chemicals or contaminated soil; and
- o Procedure for prompt notification of Contracting Officer and appropriate Federal and State regulatory agencies.

7.3 EMERGENCY EYEWASH. Portable eyewash units shall be provided for activities involving the handling of acidic supernatant, sludge, or other materials that may be hazardous to the eyes. These units must be able to flush both eyes simultaneously for a minimum of 15 minutes and be of the variety that maintains suitably temperate water. These units shall be provided close to the work area and protected from possible contamination.

7.4 EMERGENCY MEDICAL CARE. The Contractor shall prearrange for emergency medical care services at a nearby medical facility. The staff at the facility shall be advised of emergency routes to the site, potential medical emergencies that might occur, and possible contamination of the patient's clothing or skin with specific chemicals.

7.5 COMMUNICATION SYSTEM. The Contractor shall provide a communication system as a part of the health and emergency services.

8. PROHIBITIONS. The following are expressly forbidden while working with suspected toxic and flammable chemicals:

- Eating, smoking, chewing tobacco, chewing gum, drinking;
- Working when ill;
- Entering areas or spaces in which toxic or explosive conditions may exist without performing required testing and/or using proper personal protective equipment;
- Conducting onsite operations without offsite backup personnel immediately available; and
- Wearing beards and long sideburns that inhibit the use of personal protective equipment. Facial hair, facial features, and/or eyeglasses shall not interfere with the sealing surface or function of respirators.

9. LOGS AND REPORTS. The Contractor shall maintain logs and reports covering the implementation of the Personal Protective Equipment Program. The format shall be developed by the Contractor to include training logs, daily logs, weekly reports, and a closeout report to the satisfaction of the Contracting Officer, and these must be accessible to him as requested.

9.1 TRAINING LOGS. The training logs shall include data on both initial training and refresher training such as the following:

- Employee's name (attendance check);
- Time allocation in training session:
  - Topics covered,

- Materials used,
- Equipment demonstrated,
- Equipment practice for each employee,
- Respirator performance evaluation,
- Prohibitions covered,
- Buddy system explanation; and,

o Date and place of training.

9.2 DAILY LOGS. Daily logs shall include the following as a minimum:

o Date, time, and weather;

o Area (site-specific) checked;

o Employees in a particular area;

o Equipment used by employees;

o Protective clothing worn by employees;

o Protective devices used by employees and area assignment of employees; and

o CSP signature.

9.3 WEEKLY REPORTS. Weekly reports shall include the following as a minimum:

o A summary sheet covering the types of work being done;

o Reports of any of the following incidents:

- Nonuse of protective devices in an area where required,
- Nonuse of protective clothing,
- Disregard of buddy system,
- Disregard of eating, smoking, and chewing regulations in prohibited areas,
- Instances of job-related injuries or illnesses and corrective measures taken to avoid repetition of accidents;

- o CSP signature;
- o Copies of daily logs; and
- o Copies of injury-related medical certificates.

9.4 CLOSEOUT REPORT. At the completion of work, the Contractor shall submit a closeout report. The report shall include:

- o Final physical/medical and decontamination certification;
- o Procedures and techniques used to decontaminate;
  - Equipment and vehicles,
  - Shower facility,
  - Portable chemical toilets, etc.; and
- o Signature of the Project Superintendent and the CSP, and the date of each signature.

The report shall be submitted to the Contracting Officer prior to final acceptance of the work.

9.5 EMPLOYER OBLIGATION. The Contractor shall be aware that Federal laws, such as OSHA 29 CFR 1910, Subpart C, require that chemical exposure records and/or medical records be maintained by the employer for a specified length of time after termination of the exposure.

9.6 TIME-LOSS ILLNESS. Any employee who develops a time-loss illness or injury during the period of the contract must be evaluated by the Contractor's physician. The supervisor must be provided with a written statement, signed by the physician, indicating the employee's fitness before the employee is allowed to reenter the work site. A copy of the written statement shall be submitted to the Contracting Officer.

10. IDENTIFICATION AND CONTROL.

10.1 GENERAL. A check-in and check-out system shall be used to assure personnel control, and a record of each employee and piece of equipment is to

be maintained for each specific work area. The format shall be submitted as part of the Health and Safety Program.

10.2 BUDDY SYSTEM. The work conducted during any phase shall be scheduled to ensure that no employee works alone.

11. SIGNS. The Contractor shall post the following signs in locations approved by the Contracting Officer:

11.1 Signs shall be posted as required by OSHA regulations on the fence surrounding the area or zone where contamination does or could occur, indicating that it is a hazardous area and that unauthorized entry is prohibited.

11.2 Signs shall be posted directing all visitors to the authorized entrance or security point.

11.3 Signs stating "No Smoking or Open Flames" shall be posted in the area immediately adjacent to any area or zone where contamination with flammable materials does or could occur.

11.4 Temporary fences or barricades shall be used to prevent any person not equipped with the prescribed safety equipment from entering the exclusion zone and also to protect any person or animal from falling into the excavation. The location of the fence shall be decided by the CSP and approved by the Contracting Officer.

12. SUBMITTALS. The following items form a list of the submittals that represent a prerequisite for work to be performed in the hazardous waste area. They shall be presented at the specified times to the Contracting Officer for approval. See paragraph 7.2 of Section 1A - Special Clauses.

12.1 HEALTH AND SAFETY PLAN.

- o Accident Prevention Program - submitted prior to commencement of any work;
- o Safety Plan for each phase of work performed - submitted prior to commencement of work on that phase;

- Detailed Specifications and Precautions for the safe handling of wastes - submitted prior to commencement of work;

- Personal Protective Equipment Program - submitted prior to commencement of work; program includes details of employee training, emergency response, decontamination, medical surveillance, etc.; see paragraph 5.1 for list of elements;

- Reports covering the implementation of the Personal Protective Equipment Program - submitted weekly;

- Identification and Control - submitted prior to commencement of work;

- Work-Rest Schedules - submitted prior to commencement of work and adjusted as required thereafter; and

- Time Loss-Illness-Physician Report - submitted before allowing an employee to return to the site after a time-loss illness or injury during the period of the contract.

12.2 EMERGENCY RESPONSE PLAN. This plan must be submitted to the Contracting Officer prior to commencement of work on site. See Section 1D, paragraph 7.1 for elements.

12.3 CLOSEOUT REPORT. This report shall be submitted at the completion of work. See Section 1D, paragraph 9.4 for elements.

SECTION 01580

BULLETIN BOARD, PROJECT SIGN AND PROJECT SAFETY SIGN

1. SCOPE: This section covers a project bulletin board, a project sign, and a project safety sign, complete.

2. GENERAL: Immediately upon beginning of work under this contract, the Contractor shall accomplish the work covered under this section of the specifications. Locations of the bulletin board, the project sign, and the project safety sign shall be as determined by the Contracting Officer.

3. BULLETIN BOARD: Immediately upon beginning of work under this contract, the Contractor shall provide a weatherproof glass-covered bulletin board not less than 36 x 48 inches in size, for displaying the Equal Employment Opportunity Poster, a copy of the wage decision contained in the contract, Wage Rate Information Poster, and other information approved by the Contracting Officer. The bulletin board shall be located at the site of work in a conspicuous place easily accessible to all employees as approved by the Contracting Officer. Legible copies of the aforementioned data shall be displayed until work under the contract is complete. Upon completion of work under this contract the bulletin board shall be removed by and remain the property of the Contractor.

4. PROJECT SIGN: The Contractor shall furnish and erect a project sign in the location as hereinbefore specified. Details of construction shall be as shown on the drawings attached at the end of this section. The sign shall be constructed of 1/2-inch-thick, grade A-C, exterior type plywood. The sign shall receive 2 coats of dark blue, semigloss, exterior type enamel, color number 25053, as shown in Federal Standard 595a and Change Notice No. 1. Lettering shall be as shown on the drawings and shall be an approved white, semigloss, exterior type enamel. Upon completion of work under this contract, the project sign shall be removed from the job site and shall remain the property of the Contractor.

5. PROJECT SAFETY SIGN: The Contractor shall furnish and erect a project safety sign at the Contractor's field office. The safety sign shall be located in a conspicuous place easily within view of all employees and visitors as approved by the Contracting Officer. Details of construction shall be as shown on the drawings attached at the end of this section. The sign shall be constructed of 3/4-inch-thick, grade A-C, exterior-type plywood. The sign shall receive two coats of an approved white, semigloss, exterior type enamel. Lettering shall be as shown on the drawings and shall be semigloss, exterior type enamel of the colors noted on the drawings. The Contractor shall furnish and apply a red decal of the Corps of Engineers' Castle, or may use a stencil in lieu of a decal provided the dimensions are the same. The decal, if used, shall receive a thin coat of clear spar varnish after application. If a stencil is used, the castle shall be painted with an approved red, semigloss, exterior type, enamel. The Contractor shall furnish a sufficient number of sign numbers to cover the length of the contract period and to keep both numbered spaces up to date. The Contractor shall keep the safety sign current by posting the numbers daily in both slots (lines 5 and 6 of sign). Numbers shall be red and the size

size, and material of utility lines.

2.2.2 The location and dimensions or any changes within the building or structure.

2.2.3 Correct grade or alinement of roads, structures or utilities if any changes were made from contract plans.

2.2.4 Correct elevations if changes were made in site grading.

2.2.5 Changes in details of design or additional information obtained from working drawings specified to be prepared and/or furnished by the Contractor including but not limited to fabrication, erection, installation plans and placing details, pipe sizes, insulation material, dimensions of equipment foundations, etc.

2.2.6 The topography and grades of all drainage installed or affected as a part of the project construction.

2.2.7 Options: Where contract drawings or specifications allow options, only the option selected for construction shall be shown on the as-built drawings.

2.2.8 As part of the prefinal inspection, the preliminary as-built drawings will be reviewed. They must comply with this specification prior to scheduling the final inspection, and/or prior to substantial completion of the project.

2.2.9 Submittal to Contracting Officer for Review and Approval: One copy of the preliminary as-built marked prints and one copy of the preliminary as-built reproducibles shall be delivered to the Contracting Officer before the time of final inspection for his review and approval. Final inspection will not be scheduled by the Contracting Officer until preliminary as-built drawings have been approved. The review by Government personnel will be expedited to the maximum extent possible. Upon approval, one copy of the as-built marked prints will be returned to the Contractor for use in preparation of final as-built drawings. If upon review, the drawings are found to contain errors and/or omissions, they shall be returned to the Contractor for corrections. The Contractor shall complete the corrections and return the drawings to the Contracting Officer within ten (10) calendar days.

2.2.9.1 Withholding for Preliminary As-Builts: Failure by the Contractor to maintain current and satisfactory as-built drawings in accordance with these requirements will result in withholding from progress payments an amount equal to the value of the subject as-built drawings. The Contracting Officer will indicate an unearned balance on monthly payment estimates in accordance with the above, until the Contractor has fulfilled the contract requirements.

2.3 Final As-Built Drawings: The contract drawings were produced using Computer-Aided Drafting (CAD). The CAD software to be used by the Contractor for preparing the as-built drawings shall be AutoCAD, Release 10 by Autodesk Inc. The Contractor will be furnished 5-1/4 inch floppy diskettes containing the AutoCAD drawing files to be revised with the as-built drawings.

SECTION 01720

AS-BUILT DRAWINGS

1. SCOPE: This section covers as-built drawings, complete.

2. AS-BUILT DRAWINGS:

2.1 General: The Contractor shall furnish one full-size set of blueline prints and one full-size set of reproducible drawings for use in preparation of as-built drawings. The as-built drawings shall be a record of the construction as installed and completed by the Contractor. They shall include all the information shown on the contract set of drawings and a record of all deviations, modifications, or changes from those drawings, however minor, which were incorporated in the work, all additional work not appearing on the contract drawings, and all changes which are made after final inspection of the contract work. In event the Contractor accomplishes additional work which changes the as-built conditions of the facility after submission of the as-built drawings, the Contractor shall furnish revised and/or additional drawings as required to depict as-built conditions. The requirements for these additional drawings will be the same as for the as-built drawings included in the original submission.

2.2 Preliminary As-Built Drawings: The Contractor shall mark up one set of paper prints and an identical markup on the reproducible to show the as-built conditions. These as-built marked prints shall be kept current and available on the jobsite at all times. Subject to the approval of the Contracting Officer, a member of the Contractor's Quality Control Organization shall be assigned sole responsibility for the maintenance and currency of preliminary as-built drawings. Any reassignment of duties concerning the maintenance of the as-built drawings shall be promptly reported to the Contracting Officer. All changes from the contract plans which are made in the work or additional information which might be uncovered in the course of construction shall be accurately and neatly recorded as they occur by means of details and notes. All changes and/or required additions to the paper prints shall be clearly identified in a color contrasting to blue, preferably red. The as-built marked prints will be jointly inspected for accuracy and completeness by the Contracting Officer's representative and the assigned representative of the Contractor's Quality Control Organization prior to submission of each monthly pay estimate. (See paragraph: Withholding for Preliminary As-Builts.) The as-built drawings shall show the following information, but not be limited thereto.

2.2.1 The location and description of any utility lines or other installations of any kind or description known to exist within the construction area. The location of exterior utilities includes actual measured horizontal distances from utilities to permanent facilities/features. These measurements shall be within an accuracy range of six inches and shall be shown at sufficient points to permit easy location of utilities for future maintenance purposes. Measurements shall be shown for all change of direction points and all surface or underground components such as valves, manholes, drop inlets, clean outs, meter, etc. The general depth range of each underground utility line shall be shown (i.e., 3' to 4' depth). The description of exterior utilities includes the actual quantity,

2.3.1 The Government will scan the diskettes for virus infections, and examine the drawing files for integrity before delivery to the Contractor. Upon receipt of the drawing files, the Contractor shall verify that the drawing files can be brought up using AutoCAD, and shall certify this to the Contracting Officer. Any drawing files that appear to be corrupt or otherwise unusable shall be identified immediately and returned to the Contracting Officer for replacement.

2.3.2 The Contractor shall revise the CAD drawings to reflect the as-built changes to match the approved marked set of blueline prints. Some of the drawing changes, amendments prior to bid opening, and changes resulting from contract modification may have been added to the original mylars by hand drafting. The Contractor shall revise the CAD drawing to reflect the amendment/contract changes, in addition to all other as-built changes.

2.3.3 The Contractor shall certify that the media (floppy diskettes) containing the as-built drawing files have been scanned for known computer viruses before delivery to the Government. The name(s) and release date(s) of the virus scanning software used to analyze the delivered floppies shall be furnished to the Contracting Officer at the time of delivery. The release or revision date of the virus scanning software used shall be no older than ninety (90) days in age at the time of delivery of the media. If analysis of the delivered media by the Government finds evidence of virus infection, the media will be returned to the Contractor. The Contractor shall re-submit virus-free media at no cost to the Government.

2.3.4 Plotting: Each changed diskette shall be plotted on mylar and the diskette and the plot shall be returned to the Contracting Officer.

2.3.5 Drafting: Only personnel proficient in the preparation of engineering drawings shall be employed to modify the original contract drawings or prepare additional new drawings. All additions and corrections to the contract drawings shall match the adjacent existing linework and/or lettering being annotated in type, density, size, and style. All modifications and new drawings shall, in addition to the above, conform to applicable requirements of the Architect-Engineer Instruction Manual (AEIM), Chapter I - Drafting, and available from the Area or Resident Engineer's Office. The Contracting Officer will review all as-built drawings for accuracy and conformance to the above specified drafting standards. The Contractor will make all corrections, changes, additions, and deletions to meet these standards.

2.3.5.1 When final revisions have been completed, each drawing shall be lettered with the words "DRAWING OF WORK AS BUILT" in letters at least 3/16" high placed below the title block between the border and the trim line. The date of completion and the words "REVISED AS-BUILT" shall be placed in the revision block above the latest existing revision notation.

2.3.5.2 Title Blocks: The title block to be used for any new as-built drawings shall be similar to that used on the original drawings.

2.4 Submittal Requirements: After receipt of the approved as-built preliminary drawings, the Contractor shall submit to the Contracting Officer the following:

a. The 5-1/4 inch revised diskette.

b. One set of reproducible mylars produced from the revised diskette.

c. The approved marked set of blueline prints.

All of the above shall become the property of the Government upon final approval and shall be complete in all details.

2.5 Final As-Built Drawings, Bid Item.

a. A special bid item entitled "Final As-Built Drawings" has been placed in the Bid Schedule for work on "As-Built Drawings". The amount of this item has been established by the Contracting Officer and entered in the Bid Schedule. This bid item becomes a part of the overall Contractor's bid, but payment of the amount shown in the bid schedule shall be withheld until the "Final As-Built Drawings" have been approved and accepted by the Contracting Officer.

b. The Contractor shall commence work on final as-built drawings upon his receipt of the approved preliminary as-built drawings. The Contractor shall have the number of calendar days specified in the Special Clause, COMMENCEMENT, PROSECUTION AND COMPLETION OF WORK, to complete and return to the Contracting Officer all specified final as-built drawing work. In the event that the Contractor fails to complete as-built drawing work within the specified time, the Contracting Officer shall withhold payment due the Contractor for final as-built drawings under this contract.

****
NOTE: Use [Proposal] for 8(a) projects only.
****

2.6 Payment for Final As-Built Drawings: Payment for the performance of the work outlined above will be made after its approval and acceptance by the Contracting Officer. This work is a subsidiary portion of the contract work; therefore an amount as specified in the [Bid] [Proposal] Schedule will be withheld from the Contractor's bid price until acceptable performance of the work.

- - o 0 o - -

SECTION 01740

WARRANTY OF CONSTRUCTION

1. WARRANTY OF CONSTRUCTION (FAR 52.246-21) (APR 1984).

1.2 In addition to any other warranties in this contract, the Contractor warrants, except as provided in paragraph 1.11 of this clause, that work performed under this contract conforms to the contract requirements and is free of any defect in equipment, material, or design furnished, or workmanship performed by the Contractor or any subcontractor or supplier at any tier.

1.3 This warranty shall continue for a period of 1 year from the date of final acceptance of the work. If the Government takes possession of any part of the work before final acceptance, this warranty shall continue for a period of 1 year from the date the Government takes possession.

1.4 The Contractor shall remedy at the Contractor's expense any failure to conform, or any defect. In addition, the Contractor shall remedy at the Contractor's expense any damage to Government-owned or controlled real or personal property, when that damage is the result of-

1.4.1 The Contractor's failure to conform to contract requirements; or

1.4.2 Any defect of equipment, material, workmanship, or design furnished.

1.5 The Contractor shall restore any work damaged in fulfilling the terms and conditions of this clause. The Contractor's warranty with respect to work repaired or replaced will run for 1 year from the date of repair or replacement.

1.6 The Contracting Officer shall notify the Contractor, in writing, within a reasonable time after the discovery of any failure, defect, or damage.

1.7 If the Contractor fails to remedy any failure, defect, or damage within a reasonable time after receipt of notice, the Government shall have the right to replace, repair, or otherwise remedy the failure, defect, or damage at the Contractor's expense.

1.8 With respect to all warranties, express or implied, from subcontractors, manufacturers, or suppliers for work performed and materials furnished under this contract, the Contractor shall-

1.8.1 Obtain all warranties that would be given in normal commercial practice;

1.8.2 Require all warranties to be executed, in writing, for the benefit of the Government, if directed by the Contracting Officer; and

1.8.3 Enforce all warranties for the benefit of the Government, if directed by the Contracting Officer.

1.9 In the event the Contractor's warranty under paragraph (b) of this clause

has expired, the Government may bring suit at its expense to enforce a subcontractor's, manufacturer's, or supplier's warranty.

1.10 Unless a defect is caused by the negligence of the Contractor or subcontractor or supplier at any tier, the Contractor shall not be liable for the repair of any defects of material or design furnished by the Government nor for the repair of any damage that results from any defect in Government-furnished material or design.

1.11 This warranty shall not limit the Government's rights under the Inspection and Acceptance clause of this contract with respect to latent defects, gross mistakes, or fraud.

1.12 Defects in design or manufacture of equipment specified by the Government on a "brand name and model" basis, shall not be included in this warranty. In this event, the Contractor shall require any subcontractors, manufacturers, or suppliers thereof to execute their warranties, in writing, directly to the Government.

2. PRE-WARRANTY CONFERENCE. Prior to contract completion and at a time designated by the Contracting Officer or his representative, the Contractor shall meet with the Contracting Officer to develop a mutual understanding with respect to the requirements specified herein. The Contracting Officer shall establish communication procedures for oral notification to the Contractor of warranty defects; establish reasonable time for Contractor responses; and other details deemed necessary by the Contracting Officer for the execution of the construction warranty. In connection with these requirements the Contractor will furnish the name, telephone number and address of representatives authorized to perform warranty repairs. If the Contractor is located outside the local service area, the name, telephone number and address of a licensed and bonded company which is authorized to initiate and maintain warranty work action on behalf of the Contractor shall be furnished. This point of contact will be located within the local service area of the warranty work and shall be an established company capable of performing the type of work under the warranty item. At this conference, the Contracting Officer shall furnish names and telephone numbers of the personnel authorized to notify the Contractor or his designated representative of any failure, defect or damage, and to request warranty repair work.

3. WARRANTY REPAIRS. Warranty repair work which threatens the health, safety, or well-being of personnel or the safety of property and/or equipment will be handled by the Contractor on an immediate basis as orally directed by the Contracting Officer or authorized representative, as established in subparagraph, Pre-Warranty Conference, above. Such items requiring immediate attention shall include but not be limited to: air conditioning, heating, and ventilating systems; sewage disposal facilities or components thereto; fire protection systems; water supply system or components thereto; and electrical power systems. Other warranty repair which does not threaten the health, safety, or well-being of personnel and/or safety of property or equipment will be handled by the Contractor within seventy two hours or the time frame established during the pre-warranty conference. Failure of the Contractor to respond as requested will be cause for the Contracting Officer to have the warranty repair work performed by

others and proceed against the Contractor as outlined in subparagraphs, Bid Item and Performance Bond, above. Any work required to correct a warranty item, accomplished by the Government under these paragraphs shall not void the warranty of the item. (SWD letter, dated 18 July 1988).

- - o 0 o - -

SECTION 02050 - DEMOLITION

PART 1 - GENERAL

1.1 SUMMARY (Not Applicable)

1.2 REFERENCES (Not Applicable)

1.3 GENERAL REQUIREMENTS

The work includes demolition, salvage of identified items and materials, and removal of resulting rubbish and debris. Rubbish and debris shall be removed from Government property daily, unless otherwise directed, to avoid accumulation at the demolition site. Materials that cannot be removed daily shall be stored in areas specified by the Contracting Officer. In the interest of conservation salvage shall be pursued to the maximum extent possible; salvaged items and materials shall be disposed of as specified.

1.4 SUBMITTALS

Government approval is required for submittals with a "GA" designation; submittals having an "FIO" designation are for information only. The following shall be submitted in accordance with SECTION 01300 SUBMITTALS:

SD-18, Records

Work Plan; "FIO".

The procedures proposed for the accomplishment of the work. The procedures shall provide for safe conduct of the work, careful removal and disposition of materials specified to be salvaged, protection of property which is to remain undisturbed, coordination with other work in progress, and timely disconnection of utility services. The procedures shall include a detailed description of the methods and equipment to be used for each operation, and the sequence of operations.

1.5 DUST CONTROL

The amount of dust resulting from demolition shall be controlled to prevent the spread of dust to occupied portions of the construction site and to avoid creation of a nuisance in the surrounding area. Use of water will not be permitted when it will result in, or create, hazardous or objectionable conditions such as ice, flooding and pollution.

1.6 PROTECTION

1.6.1 Protection of Existing Property

Before beginning any demolition work, the Contractor shall carefully survey the site and examine the drawings and specifications to determine the extent of the work. The Contractor shall take all necessary precautions to avoid

damage to existing items to remain in place, to be reused, or to remain the property of the Government, and any damaged items shall be repaired or replaced as approved by the Contracting Officer at no additional cost to the Government. The Contractor shall carefully coordinate the work of this section with all other work and construct and maintain shoring, bracing and supports, as required. The Contractor shall ensure that structural elements are not overloaded and be responsible for increasing structural supports or adding new supports as may be required as a result of any cutting, removal, or demolition work performed under this contract.

1.6.2 Environmental Protection

The work shall comply with the requirements of SECTION 1100.

1.7 BURNING

The use of burning at the project site for the disposal of refuse and debris will not be permitted.

1.8 USE OF EXPLOSIVES

Use of explosives will not be permitted.

PART 2 - PRODUCTS (Not Applicable)

PART 3 - EXECUTION

3.1 FILLING

Holes and other hazardous openings shall be filled in accordance with SECTION: 02210 GRADING.

3.2 DISPOSITION OF MATERIAL

Title to all materials and equipment to be demolished, excepting Government salvage and historical items, is vested in the Contractor upon receipt of notice to proceed. The Government will not be responsible for the condition, loss or damage to such property after notice to proceed.

3.2.1 Salvageable Items and Materials

Contractor shall salvage items and materials to the maximum extent possible.

3.2.1.1 Material Salvaged for the Contractor

Material salvaged for the Contractor shall be stored as approved by the Contracting Officer and shall be removed from Government property before completion of the contract. Material salvaged for the Contractor shall not be sold on the site.

3.2.1.2 Historical Items

Historical items shall be removed in a manner to prevent damage. The following historical items shall be delivered to the Government for disposition: Corner stones, contents of corner stones, and document boxes wherever located on the site.

3.2.2 Unsalvageable Materials

Concrete, masonry, and other noncombustible materials, except concrete permitted to remain in place, shall be disposed of out side the limits of government controled land. Combustible materials shall be disposed of out side the limits of government controled land .

3.3 CLEAN-UP

Debris and rubbish shall be removed and transported in a manner as to prevent spillage on streets or adjacent areas. Local regulations regarding hauling and disposal apply.

- - o 0 o - -

SECTION 02110 - CLEARING AND GRUBBING

PART 1 - GENERAL

1.1 SUMMARY (Not Applicable)

1.2 REFERENCES (Not Applicable)

1.3 DEFINITIONS

1.3.1 Clearing

Clearing shall consist of the felling, trimming, and cutting of trees into sections and the satisfactory disposal of the trees and other vegetation designated for removal, including down timber, snags, brush, and rubbish occurring in the areas to be cleared.

1.3.2 Grubbing

Grubbing shall consist of the removal and disposal of stumps, roots larger than 3 inches in diameter, and matted roots from the designated grubbing areas.

1.4 SUBMITTALS

The following shall be submitted in accordance with SECTION: 01300 - SUBMITTALS:

SD-91, Records

Permission to dispose of cleared and grubbed materials on private property shall be in writing, and a copy of this permit shall be filed with the Contracting Officer.

PART 2 - PRODUCTS (Not Applicable)

PART 3 - EXECUTION

3.1 CLEARING

Trees, stumps, roots, brush, and other vegetation in areas to be cleared shall be cut off flush with or below the original ground surface, except such trees and vegetation as may be indicated or directed to be left standing. Trees designated to be left standing within the cleared areas shall be trimmed of dead branches 1-1/2 inches or more in diameter and shall be trimmed of all branches the heights indicated or directed. Limbs and branches to be trimmed shall be neatly cut close to the bole of the tree or main branches. Cuts more than 1-1/2 inches in diameter shall be painted with an approved tree-wound paint. Trees and vegetation to be left standing shall be protected from damage incident to clearing, grubbing, and construction operations by the erection of barriers or by such other means as the circumstances require.

Clearing shall also include the removal and disposal of structures that obtrude, encroach upon, or otherwise obstruct the work.

3.2 GRUBBING

Material to be grubbed, together with logs and other organic or metallic debris not suitable for foundation purposes, shall be removed to a depth of not less than 18 inches below the original surface level of the ground in areas indicated to be grubbed and in areas indicated as construction areas under this contract. Depressions made by grubbing shall be filled with suitable material and compacted to make the surface conform with the original adjacent surface of the ground.

3.3 TREE REMOVAL

Where indicated or directed, trees and stumps that are designated as trees shall be removed from areas outside those areas designated for clearing and grubbing. This work shall include the felling of such trees and the removal of their stumps and roots as specified in paragraph "GRUBBING." Trees shall be disposed of as specified in paragraph "DISPOSAL OF MATERIALS."

3.4 DISPOSAL OF MATERIALS

3.4.1 Materials

Logs, stumps, roots, brush, rotten wood, and other refuse from the clearing and grubbing operations, shall be disposed of outside the limits of Government-controlled land at the Contractor's responsibility

- - o O o - -

SECTION 02210 - GRADING

PART 1 - GENERAL

1.1 SUMMARY (Not Applicable)

1.2 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D 75	(1987) Sampling Aggregates.
ASTM C 136	(1984; Rev. a) Sieve Analysis of Fine and Coarse Aggregates.
ASTM D 422-63	Particle size Analysis of Soils
ASTM D 1556	(1982) Density of Soil In-Place by the Sand-Cone Method.
ASTM D 1557	(1978) Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb. (4.54-kg) Rammer and 18-in. (457-mm) Drop.
ASTM D 2216	(1987) Determination of Water (moisture) Content of Soil, Rock, & Soil-Aggregate Mixtures.
ASTM D 2487	(1985) Classification of Soils for Engineering Purposes.
ASTM D 4643	(1980) Laboratory determination of Water (Moisture) Content of Soil by the Microwave Oven Method.

1.3 DEFINITIONS

1.3.1 Satisfactory Bedding Materials

Materials classified in ASTM D 2487 as GW, GP, GM, GC, SW, SP, SC, SM, and CL and free from roots and other organic matter, trash, debris, and frozen materials and stones larger than 3 inches in any dimension are satisfactory.

1.3.2 Unsatisfactory bedding Materials

Materials which do not comply with the requirements for satisfactory materials are unsatisfactory. Materials classified in ASTM D 2487 as CH, Pt, OH, OL, ML, and MH are unsatisfactory. Unsatisfactory materials also include refuse.

1.3.3 Satisfactory Cover Materials

Materials classified in ASTM D 2487 as SC and CL and free from roots and other organic matter, trash, debris, and frozen materials and stones larger than 1 inch in any dimension are satisfactory. Satisfactory Cover Materials shall have the following properties:

1. Fines content $\geq$ 30% passing the #200 sieve
2. Plasticity 15% $\leq$ PI $\leq$ 40%
3. Course Aggregates retained on the #4 sieve < 10%
4. No particles $\geq$ 1-inch

1.3.4 Unsatisfactory Cover Materials

Materials which do not comply with the requirements for satisfactory materials are unsatisfactory. Materials classified in ASTM D 2487 as GW, GP, GM, GC, SW, SP, SM, MH, ML, CH, Pt, OH, and OL, are unsatisfactory. Materials classified in ASTM D 2487 as CH Pt, OH, OL, ML, and MH are unsatisfactory. Unsatisfactory materials also include refuse.

1.3.5 Cohesionless and Cohesive Materials

Cohesive materials include materials classified as GC, SC, ML, CL, MH, and CH. Cohesionless materials include materials classified in ASTM D 2487 as GW, GP, SW, and SP. Materials classified as GM and SM will be identified as cohesionless only when the fines have a plasticity index of zero.

1.3.6 Degree of Compaction

Degree of compaction is a percentage of the maximum density obtained by the test procedure presented in ASTM D 1557, Method D and abbreviated below as a percent of laboratory maximum density.

1.3.7 Topsoil

Material obtained from off-site areas suitable for topsoils, is defined as natural, friable surface soil possessing the characteristics of representative soils in the vicinity that produce heavy growth of crops, grass, or other vegetation.

1.4 SUBMITTALS

The following shall be submitted in accordance with SECTION: 01300 - SUBMITTALS:

SD-39, Qualifications

The Contractor shall furnish the qualifications of the commercial testing laboratory who will be performing all testing in accordance with the paragraph, FIELD TESTING CONTROL.

SD-70, Test Reports

The Contractor shall furnish certified test reports and analysis certifying that the satisfactory materials proposed for use at the project site conform to the specified requirements, and for all tests conducted in accordance with the paragraph, FIELD TESTING CONTROL.

SD-91, Records

The Contractor shall notify the Contracting Officer of the opening of excavation or borrow areas in accordance with paragraph, BORROW MATERIAL.

PART 2 - PRODUCTS

2.1 BORROW MATERIAL

Borrow material shall be selected to meet requirements and conditions of the particular fill for which it is to be used. Necessary clearing, grubbing, disposal of debris, and satisfactory drainage of borrow pits shall be performed by the Contractor as incidental operations to the borrow excavation.

2.1.1 Selection

Borrow materials shall be obtained from sources outside the limits of Government-controlled land or sources within the limits of Government-controlled land, subject to approval. Borrow materials shall be subject to approval. The source of borrow material shall be the Contractor's responsibility. Unless otherwise provided in the contract, the Contractor shall obtain from the owners the right to procure material, shall pay all royalties and other charges involved, and shall bear all the expense of developing the sources, including rights-of-way for hauling.

2.1.2 Borrow Pits

Except as otherwise permitted, borrow pits shall be excavated to afford adequate drainage. Overburden and other spoil material shall be disposed of or used for special purposes. Borrow pits shall be neatly trimmed after the excavation is completed.

PART 3 - EXECUTION

3.1 PREPARATION OF GROUND SURFACE FOR FILL

All vegetation, such as trees, stumps, roots, brush, and other vegetation in the area to be cleared shall be cut off flush with or below the original ground surface. Clearing shall also include the removal and disposal of structures that obtrude, encroach upon, or otherwise obstruct the work. In no case will unsatisfactory material remain in or under the fill area. Sloped ground surfaces steeper than one vertical to four horizontal on which fill is to be placed shall be plowed, stepped, or broken up, as directed, in such manner that the fill material will bond with the existing surface. Prepared surfaces on which compacted fill is to be placed shall be wetted or dried as may be required to obtain the specified moisture content and density.

3.2 BACKFILL ADJACENT TO STRUCTURES

Backfill adjacent to structures shall be placed and compacted uniformly in such manner as to prevent wedging action or eccentric loading upon or against the structures. Slopes bounding or within areas to be backfilled shall be stepped or serrated to prevent sliding of the fill. During backfilling operations and in the formation of embankments, equipment that will overload the structure in passing over and compacting these fills shall not be used.

3.3 FILLS AND EMBANKMENTS

Fills and embankments shall be constructed at the locations and to lines and grades indicated. The completed fill shall conform to the shape of the typical sections indicated or shall meet the requirements of the particular case. Satisfactory material obtained during excavation may be used in forming required fill. Fill shall be satisfactory material and shall be reasonably free from roots, other organic material, and trash and from stones having a maximum diameters as specified in paragraphs "Satisfactory Bedding Materials" and "Satisfactory Cover Materials". No frozen material will be permitted in the fill. The material shall be placed in successive maximum horizontal layers of 8 inches in loose depth for the full width of the cross section and shall be compacted as specified. Each layer shall be compacted before the overlaying lift is placed. Moisture content of the fill or backfill material shall be adjusted by wetting or aerating, as required, to at least one (1) percent above optimum moisture content as determined from laboratory tests specified in paragraph "DEFINITIONS."

3.4 COMPACTION

Each layer of the landfill cap shall be compacted to at least 95 percent of laboratory maximum density .

3.5 FINISHED EXCAVATION, FILLS, AND EMBANKMENTS

All areas covered by the project, including excavated and filled sections and adjacent transition areas, shall be uniformly smooth-graded. The finished surface shall be smooth, compacted, and free from irregular surface changes.

The degree of finish shall be that ordinarily obtainable from finish roller operations, except as otherwise specified. The surface of areas to be turfed shall be finished to a smoothness suitable for the application of turfing materials. Surfaces shall be finished not more than 0.15 foot above or below the established grade or approved cross section.

3.6 PLACING TOPSOIL

On areas to receive topsoil, the compacted subgrade soil shall be scarified to a 2-inch depth for bonding of topsoil with subsoil. Topsoil then shall be spread evenly to a thickness of 8 inches and graded to the elevations and slopes shown. Topsoil shall not be spread when frozen or excessively wet or dry. Material required for topsoil in excess of that produced by excavation within the grading limits shall be obtained from off-site areas.

3.7 FIELD TESTING CONTROL

Testing shall be the responsibility of the Contractor and shall be performed by an approved commercial testing laboratory or by the Contractor subject to approval. Field density and moisture content tests shall be performed once or fraction there of on every lift placed. Field in-place density shall be determined in accordance with ASTM D 1556 or ASTM D 2167 . When test results indicate, as determined by the Contracting Officer, that compaction is not as specified, the material shall be removed, replaced and recompacted to meet specification requirements, at no additional expense to the Government. Tests on recompacted areas shall be performed to determine conformance with specification requirements. Inspections and test results shall be certified by a registered professional civil engineer. These certifications shall state that the tests and observations were performed by or under the direct supervision of the engineer and that the results are representative of the materials or conditions being certified by the tests. The following number of tests, if performed at the appropriate time, will be the minimum acceptable for each type operation.

3.7.1 Test Results

A coordinate system (x,y,z) shall be established to report sample locations. All tests including failures shall be reported and submitted to the Contracting Officer within 24 hours of the time of sampling. Only passing tests are acceptable. In the event of a failing moisture or density test a minimum of two passing tests of the suspect area of the fill shall be run. Results shall verify that materials comply with this specification. When a material source is changed, the new material will be tested for compliance. When deficiencies are found, the initial analysis shall be repeated and the material already placed shall be retested to determine the extent of unacceptable material. All in-place unacceptable material shall be replaced or modified as directed by the Contracting Officer.

3.7.2 Sampling

Aggregate samples for laboratory tests shall be taken in accordance with ASTM D 75.

3.7.3 Sieve Analysis

Before starting work, at least one sample of material to be placed shall be tested in accordance with ASTM C 136 and ASTM D 422 on sieves conforming to ASTM E 11. After the initial test, a minimum of one analysis shall be performed for each 1000 CY of material placed, with a minimum of three analyses for each day's run until the layer is completed.

3.7.4 Liquid Limit and Plasticity Index

One liquid limit and plasticity index shall be performed for each sieve analysis. Liquid limit and plasticity index shall be in accordance with ASTM D 4318.

3.7.5 Density Control

The Contractor shall adequately control his compaction operations by tests made in accordance with ASTM D 1556 or ASTM D 2167 . One in-place density and one in-place moisture test shall be performed per 12,000 square feet, or fraction thereof, of each lift. Moisture content shall be in accordance with ASTM D 2216 or ASTM D 4643 for determining density. When ASTM D 4643 is utilized, the moisture content should be checked a minimum of once per day using ASTM D 2216. The density test hole shall be backfilled and compacted to the required moisture and density of the adjacent fill. Additional tests shall be made as necessary. All test results shall be made available to the Contracting Officer. Acceptance tests may be made by the Government for verification of compliance; however, the Contractor shall not depend on such test for his control of operations. Deficiencies in construction shall be corrected by the contractor at no additional cost to the Government.

3.7.6 Density-Moisture Determinations

Test for determination of maximum density and optimum moisture content shall be performed by the contractor in accordance with the requirements of ASTM D 1557. Density-Moisture Tests shall be run on the same sample on which the in-place density test is run. The percent compaction of the fill sample is then calculated from the results of the field and laboratory density tests. The above testing shall include Atterberg limits and grain size determinations and shall be made on the same material as the in-place density and moisture test.

3.9.1 Moisture-Density and Classification of Soil Tests

3.8 PROTECTION

Newly graded areas shall be protected from traffic and from erosion, and any settlement or washing away that may occur from any cause, prior to acceptance, shall be repaired and grades reestablished to the required elevations and slopes. All work shall be conducted in accordance with the environmental protection requirements of the contract.

- - o 0 o - -

SECTION 02215 - PLASTIC FILTER FABRIC

1. GENERAL

1.1 SCOPE

The work provided for herein consists of furnishing all plant, labor, material, and equipment and performing all operations required for furnishing, hauling, and placing the geotextile, complete, as specified herein and shown on the contract drawings, and maintaining the geotextile until placement of the geocomposite liner is completed and accepted.

1.2 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by basic designation only.

American Society for Testing and Materials (ASTM).

ASTM-D 123 REV A-90	Standard Terminology Relating to Textiles.
ASTM-D 1683-90	Failure in Sewn Seams of Woven Fabrics.
ASTM-D 3787-89	Bursting Strength of Knitted Goods: Constant-Rate-of-Traverse (CRT), Ball Burst Test.
ASTM-D 4491-89	Test Methods for Water Permeability of Geotextiles by Permittivity.
ASTM-D 4533-85	Trapezoid Tearing Strength of Geotextiles.
ASTM-D 4632-86	Breaking Load and Elongation of Geotextiles (Grab Method).

U.S. Army Corps of Engineers.

EM 1110-2-1906	Laboratory Soils Testing.

2. MATERIALS.

2.1 Geotextile (Plastic Filter Fabric)

The geotextile shall be a non-woven pervious sheet of plastic yarn as defined by ASTM D-123. The geotextile shall meet the physical requirements listed in Table No. 1 of the specifications. The geotextile fiber shall consist of a long chain synthetic polymer composed of at least 85 percent by weight of propylene, ethylene, ester, amide, or vinylidene-chloride, and shall contain stabilizers and/or inhibitors added to the base plastic if necessary to make the filaments resistant to deterioration due to ultra-violet and heat

exposure. The edges of the geotextile shall be finished to prevent the outer fiber from pulling away from the geotextile.

2.2 Seams

The seams of the geotextile shall be sewn with thread of a material meeting the chemical requirements given above for geotextile yarn or shall be bonded by cementing or by heat. The sheets of geotextile shall be attached at the factory or another approved location, if necessary, to form sections not less that 6 feet wide. Seams shall be tested in accordance with method ASTM D 1683, using 1-inch square jaws and 12 inches per minute constant rate of traverse. The strengths shall be not less than 90% of the required tensile strength (Table 1) of the unaged geotextile in any principal direction.

2.3 Acceptance Requirements

All brands of geotextile and all seams to be used shall be accepted on the following basis. The Contractor shall furnish the Contracting Officer, in duplicate, a mill certificate or affidavit signed by a legally authorized official from the company manufacturing the geotextile. The mill certificate or affidavit shall attest that the geotextile meets the chemical, physical and manufacturing requirements stated in this specification. If requested by the Contracting Officer, the Contractor shall provide to the Government geotextile samples for testing to determine compliance with any or all of the requirements in this specification. When samples are to be provided, they shall be submitted a minimum of 30 days prior to the beginning of installation of the same geotextile. All samples provided shall be from the same production lot as will be supplied for the contract, and shall be the full manufactured width of the geotextile by at least 10 ft. long, except that samples for seam strength may be a full width sample folded over and the edges stitched for a length of at least 5 ft. Samples submitted for testing shall be identified by manufacturers lot designation.

2.4 Securing Pins

Securing pins shall be 3/16 inch in diameter, of steel, pointed at one end and fabricated with a head to retain a steel washer having an outside diameter of no less than 1.5 inches. The lengths of the pins shall be no less than 18 inches.

Table No. 1 - Physical Requirements

Physical Property	Test Procedure	Acceptable Values++
Tensile Strength +(unaged geotextile)	ASTM D 4632 Grab Test using 1 inch square jaws and a 12 inches per minute constant rate of traverse.	100 pound minimum in any principal direction.
Breaking Elongation (unaged geotextile)	ASTM D 4632 Determine Apparent Breaking Elongation.	15 percent minimum in any principal direction.
Puncture Strength +(unaged geotextile)	ASTM D 3787 except polished steel ball replaced with a 5/16-inch diameter solid steel cylinder with a hemispherical tip centered within the ring clamp.	40 pound minimum.
Geotextile Permeability	ASTM D 4491 Test Methods for Water Permeability of Geotextiles by Permittivity.	The permeability of the geotextile shall be greater than 0.1 cm/sec.
Equivalent Opening Size (EOS)	Specification Paragraph titled "Determination of Equivalent Opening Size (EOS)".	No coarser than the U.S. Standard Sieve No. 70.
Tear Strength	ASTM D 4533 Trapezoidal Tear Strength.	40 lbs. minimum in any principal direction.

+Unaged geotextile is defined as geotextile in the condition received from the manufacturer or distributor.

++All numerical values represent minimum average roll values (i.e., any roll in a lot should meet or exceed the minimum in the table).

2.5 SHIPMENT AND STORAGE

During all periods of shipment and storage, the geotextile shall be protected from direct sunlight, ultra-violet rays, temperatures greater than 140 degrees fahrenheit, mud, dirt, dust and debris. To the extent possible, the fabric shall be maintained wrapped in a heavy duty protective covering.

3. INSTALLATION OF THE GEOTEXTILE

The geotextile shall be placed in the manner and at the locations shown on the drawings. At the time of installation, the geotextile shall be rejected if it has defects, rips, holes, flaws, deterioration or damage incurred during manufacture, transportation or storage. The surface to receive the geotextile shall be prepared to a relatively smooth condition free of obstructions, depressions, debris and soft or low density pockets of material. The geotextile shall be laid smooth and free of tension, stress, folds, wrinkles, or creases. The strips shall be placed to provide a minimum width of 12 inches of overlap for each joint. Temporary pinning of the textile to help hold it in place until the geocomposite lineris installed shall be allowed. The geotextile shall be protected at all times during construction from contamination by surface runoff and any geotextile so contaminated shall be removed and replaced with uncontaminated geotextile. Any damage to the geotextile during its installation or during placement of the geocomposite liner shall be replaced by the Contractor at no cost to the Government. The work shall be scheduled so that the covering of the geotextile with a layer of the specified material is accomplished within 7 calendar days after placement of the geotextile. Failure to comply shall require replacement of geotextile. The geotextile shall be protected from damage prior to and during the placement of the geocomposite liner or other materials. Before placement of the geocomposite liner or other materials, the Contractor shall demonstrate that the placement technique will prevent damage to the geotextile. In no case shall any type of equipment be allowed on the unprotected geotextile.

4. QUALITY CONTROL.

4.1 General

The Contractor shall establish and maintain quality control for the work covered in this section of the Technical Provisions to assure compliance with contract requirements and maintain quality control records for all construction operations including but not limited to the following:

(1) Field inspection of materials.

(2) Placing of fabric and securing pins.

(3) Protection of fabric.

Two (2) legible copies of these records, as well as the records of corrective action taken, shall be furnished the Government as directed by the Contracting Officer.

- - o O o - -

SECTION 02224 - GAS VENT SYSTEM

PART 1 - GENERAL

1.1 SUMMARY

This section covers the source and placement of compacted sand filter and PVC pipe to construct a gas vent system for the landfill.

1.2 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by basic designation only.

AMERICAN SOCIETY OF TESTING AND MATERIALS (ASTM)

ASTM D 75	(1987) Sampling Aggregates.
ASTM C 136	(1984; Rev. a) Sieve Analysis of Fine and Coarse Aggregates.
ASTM D 422-63	Particle size Analysis of Soils
ASTM D 1556	(1982) Density of Soil in Place by the Sand-Cone Method.
ASTM D 2167	(1984) Density and Unit Weight of Soil In-Place by the Rubber Balloon Method.
ASTM D 2216	(1980) Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures
ASTM D 2487	(1985) Classification of Soils for Engineering Purposes.
ASTM D 3034	Standard Specification for Type PSM Poly(Vinyl Chloride) (PVC) Sewer Pipe and Fittings
ASTM D 4253-83	Maximum Index Density of Soils Using a Vibratory Table.
ASTM D 4318-87	Liquid Limit, Plastic Limit, and Plasticity Index of Soils.
ASTM D 4643-87	Determination of Water (Moisture) Content of Soil by the Microwave Oven Method.

ASTM F 758	Standard Specification for Smooth-Wall Poly (Vinyl Chloride) (PVC) Plastic Underdrain Systems for Highway, Airport, and Similar Drainage
ASTM F 949 REV A	Standard Specification for Poly(Vinyl Chloride) (PVC) Corrugated Sewer Pipe with a Smooth Interior and Fittings

1.3 DEFINITIONS

1.3.1 Sand Filter Material

1.3.1.1 Satisfactory Materials

Materials shall be classified in accordance with ASTM D 2487 and free from roots and other organic matter, trash, debris and frozen materials. Sand material shall be compromise of tough, durable particles, shall be reasonably free from thin , flat and elongated pieces, and shall contain no organic materials. The sand materials shall consist of well graded sand between the limits specified below:

Sieve Designation	Percentage by Weight Passing Square-mesh Sieve
3/8-inch	100
No. 4	95-100
No. 16	45-80
No. 50	10-30
No. 100.	2-10

1.3.2 Degree of Compaction

Degree of compaction is a percentage of the relative density obtained by the test procedure presented in ASTM D 4253, abbreviated below as a percent of laboratory maximum density.

1.3.3 PVC Pipe Material

1.3.3.1 Satisfactory Materials

PVC pipe shall contain ultriviolate inhibitor to provide protection from exposure to direct sunlight. Polyvinyl Chloride (PVC) Pipe and Fittings shall conform to ASTM D 3034 (SDR 35), F 949, or F 758, Type PS 46.

1.4 SUBMITTALS

The following shall be submitted in accordance with SECTION: 01300 - SUBMITTALS:

SD-39 Qualifications

The Contractor shall furnish the qualifications of the commercial testing laboratory who will be performing testing in accordance with PART 3 paragraph, SAMPLING AND TESTING.

SD-70 Test Reports

The Contractor shall furnish certified test reports and analysis certifying that the satisfactory materials proposed for the use at the project site conform to the specified requirements, and for all tests conducted in accordance with PART 3 paragraph, SAMPLING AND TESTING.

SD-91 Records

The Contractor shall notify the Contracting Officer of the opening of excavation or borrow areas in accordance with Paragraph 2.

1.5 PLANT, EQUIPMENT, MACHINES, AND TOOLS

1.5.1 General Requirements

Plant, equipment, machines, and tools used in the work shall be subject to approval and shall be maintained in satisfactory working condition at all times. Other compacting equipment may be used in lieu of that specified, where it can be demonstrated that the results are equivalent. The equipment shall be adequate and have the capability of producing the results specified.

1.5.2 Steel-Wheeled Rollers

Steel-wheeled rollers shall be the self-propelled type weighing not less than 10 tons, with a minimum weight of 300 pounds per inch width of rear wheel. Wheels of the rollers shall be equipped with adjustable scrapers. The use of vibratory rollers is optional.

1.5.3 Sprinkling Equipment

Sprinkling equipment shall consist of tank trucks, pressure distributors, or other approved equipment designed to apply controlled quantities of water uniformly over variable widths of surface.

1.5.7 Straightedge

The Contractor shall furnish and maintain at the site, in good condition, one 12-foot straightedge, for use in the testing of the finished surface. Straightedge shall be made available for Government use. Straightedges shall be constructed of aluminum or other lightweight metal and shall have blades of box or box-girder cross section with flat bottom reinforced to insure rigidity and accuracy. Straightedges shall have handles to facilitate movement.

1.6 STOCKPILING MATERIALS

Materials, including approved material available from excavation and grading, shall be stockpiled in the manner and at locations designated. Before stockpiling of material, storage sites shall be cleared, and sloped to drain. Materials obtained from different sources shall be stockpiled separately.

PART 2 -PRODUCTS

2.1 SAND MATERIAL

Sand material shall be selected to meet requirements and conditions of fill for the vent layer. Necessary clearing, grubbing, disposal of debris, and satisfactory drainage of borrow pits shall be performed by the Contractor as incidental operations to the borrow excavation.

2.2 PVC VENT PIPES

Four, 4-inch diameter, perforated PVC pipes and fitting shall be used for the base of the venting system. Nonperforated PVC 4-inch diameter pipe shall be used for the vertical portion of the vent. Each vertical vent pipe shall be fitted with an inverted "U" or a "J" bent at the end, and the end opening shall be protected with a perforated cap. The contractor shall submit details of his method and procedure of providing a watertight joint of the vertical vent pipe with the geocomposite membrane for approval by the Contracting Officer befor the venting system is installed.

2.3 PERFORATIONS IN PVC PIPE

2.3.1 Sloted Perforations in PVC Pipe

Circumferential slots shall be cleanly cut along the length of the horizontal pipe. Width of slots shall not exceed 1\8 inch nor be less than 1\32 inch. Length of the individial slots shall not exceed 1-1/2 ± 1\4 for the 4-inch diameter pipe. slots shall be approximatly 3 inches center-to-center along the pipe. Rows of slots shall be symmetrically spaced so that they are fully contained in 2 quadrans of the pipe. Slots shall be centerd in the valleys of the corrigations of profile wall pipe.

2.3.2 Circular Perforations in PVC Pipe

Circular holes shall be cleanly cut along the length of the horizontal pipe. Diameters of holes shall not exceed 3\8 inch nor be less than 3\16 inch and arranged in rows parallel to the longitudinal axis of the pipe. Perforations shall be approximatly 3 inches center-to-center along the pipe. The rows shall be appraximatly 1-1\2 inches apart and arranged in a stagered pattern do that all perforations lie at the midpoint between perforations in adjacent rows.

PART 3 - EXECUTION

3.1 GENERAL

3.2 PREPARATION OF GROUND SURFACE FOR FILL

All vegetation, trees and brush, rubbish, and other unsatisfactory material within the area upon which fill is to be placed, shall be stripped or otherwise removed before the fill is started. Sloped ground surfaces steeper than one vertical to four horizontal on which fill is to be placed shall be plowed, stepped, or broken up, as directed, in such manner that the fill material will bond with the existing surface. Prepared surfaces on which compacted fill is to be placed shall be wetted or dried as may be required to obtain the specified moisture content and density.

3.3 SAND VENT MATERIAL

The vent material fill shall be constructed at the locations and to lines and grades indicated. The completed fill shall conform to the shape of the typical sections indicated or shall meet the requirements of the particular case. Satisfactory material shall be used in forming required fill. Compacted fill shall be satisfactory material and shall be reasonably free of debris, roots, organic material, frozen materials and trash, and shall not contain clods, rock or fractured stones. The material shall be placed in successive horizontal layers of 8 inches in loose depth for the full width of the cross section. Each layer shall be compacted before the overlaying lift is placed. Moisture content of the fill or backfill material shall be at a moisture content of optimum or greater. Moisture content adjustments shall be assisted by using a disk that will penetrate the full loose layer thickness and will scarify the upper two inches of the underlying lift. Disking shall continue until the specified moisture is obtained throughout the layer to be compacted.

Don't want to scarify underlying lift below sand vent layer

3.3.1 Speading

After dumping , the materials shall be spead by bulldozer or other approved means in approximately horizontal layers over the fill area. Unless otherwise directed, the thickness of these layers befor compaction shall be as specified hereinafter in part 3. The entire surface of any section of the vent layer under construction shall be maintained in such condition theat construction equipment coan travel to any part of one section. Ruts in the surface of any layer shall be filled satisfactorily beforw compacting.

3.3.2 Compaction

Each layer of sand material shall be compacted. Water content shall be maintained at optimum. Density of compacted mixture shall be at least 90 percent of laboratory maximum density in accordance with ASTM D 1557, Method D. Rolling shall begin at the outside edge of the surface and proceed to the center, overlapping on successive trips at least one-half the width of the roller. Alternate trips of the roller shall be slightly different lengths. Speed of the roller shall be such that displacement of the aggregate does not

occur. Areas inaccessible to the rollers shall be compacted with mechanical vibrotory plates, and shall be shaped and finished by hand methods.

Design is 6" Might with to narrow spec

3.3.3 Layer Thickness

Compacted thickness of the bedding material shall be as indicated. No layer shall be in excess of 8 inches nor less than 3 inches in compacted thickness.

3.3.4 Finishing

The surface of the top layer shall be finished to grade and cross section shown. Finished surface shall be smooth and of uniform texture. Light blading during compaction may be necessary (or the finished surface to conform to the lines, grades, and cross sections. Should the surface for any reason become rough, corrugated, uneven in texture, or traffic marked prior to completion, such unsatisfactory portion shall be scarified, reworked, recompacted, or replaced as directed.

3.3.5 Smoothness

Surface of the layer shall show no deviations in excess of 3/8-inch when tested with the 12-foot straightedge. Deviations exceeding this amount shall be corrected by removing material and replacing with new material, or by reworking existing material and compacting, as directed.

3.3.6 Thickness Control

Compacted thickness of the layer shall be within 1/2-inch of the thickness indicated. Where the measured thickness is more than 1/2-inch deficient, such areas shall be corrected by scarifying, adding new material of proper gradation, reblading, and recompacting as directed. Where the measured thickness is more than 1/2-inch thicker than indicated, the course shall be considered as conforming to the specified thickness requirements. Average job thickness shall be the average of all thickness measurements taken for the job, but shall be within 1/4-inch of the thickness indicated.

3.4 PVC VENTS

3.4.1 Instalation of Filter Fabric

One layer of filter fabric shall be rapped around perforated of slotted collector pipes in such a manner that longitudinal overlaps of fabric are in unperforated or unslotted quadrants of the pipes. The overlap shall be at least 2 inches. Thje fabric shall be secured to the pipe in such a manner that the backfill materials will nit infiltrate through any fabric overlaps.

3.4.2 Jointing

PVC joints shall be in accordance with the requirements of ASTM D 3034, D 3212, of F 949.

3.4.3 Instalation of PVC Vents

Each vent shall be carfully inspected before it is to be installed. Any defects if canaged oipe shall be rejected. No vents shall be laid when the weather is unsutible for such work. The pipe shall be laid to the grades and aliement as indicated. All vents in place shall be inspected prior to backfilling.

3.5 SAMPLING AND TESTING

Sampling and testing shall be performed by an government approved commercial testing laboratory or may be tested by the Contractor subject to approval, with the exception that all laboratory permeability testing shall be performed by the US Army Corps of Engineers, Southwestern Division Laboratory. No work requiring testing shall be permitted until the facilities have been inspected and approved. If the Contractor elects to establish testing facilities, no work requiring testing will be permitted until the Contractor's facilities have been inspected and approved by the Contracting Officer. The first inspection shall be at the expense of the Government. Cost incurred for any subsequent inspections required because of failure of the first inspection will be charged to the Contractor. Testing shall be the responsibility of the Contractor and shall be performed at no additional cost to the Government. Field in-place density shall be determined in accordance with ASTM D 1556 or ASTM D 2167. When test results indicate, as determined by the Contracting Officer, that compaction is not as specified, the material shall be removed, replaced and recompacted to meet specification requirements, at no additional expense to the Government. Tests on recompacted areas shall be performed to determine conformance with specification requirements. Inspections and test results shall be certified by a registered professional civil engineer. These certifications shall state that the tests and observations were performed by or under the direct supervision of the engineer and that the results are representative of the materials or conditions being certified by the tests. The following number of tests, if performed at the appropriate time, will be the minimum acceptable for each type operation.

? why include this

3.5.1 Test Results

A coordinate system (x,y,z) shall be established to report sample locations. All tests including failures shall be reported and submitted to the Contracting Officer within 24 hours of the time of sampling. Only passing tests are acceptable. In the event of a failing moisture or density test a minimum of two passing tests of the suspect area of the fill shall be run. Results shall verify that materials comply with this specification. When a material source is changed, the new material will be tested for compliance. When deficiencies are found, the initial analysis shall be repeated and the material already placed shall be retested to determine the extent of unacceptable material. All in-place unacceptable material shall be replaced or modified as directed by the Contracting Officer.

3.5.2 Sampling

Aggregate samples for laboratory tests shall be taken in accordance with ASTM D 75.

3.5.3 Sieve Analysis

Before starting work, at least one sample of material to be placed shall be tested in accordance with ASTM C 136 and ASTM D 422 on sieves conforming to ASTM E 11. After the initial test, a minimum of one analysis shall be performed for each 1000 CY of material placed, with a minimum of three analyses for each day's run until the layer is completed.

PI ? why bother for clean sands

3.5.4 Liquid Limit and Plasticity Index

One liquid limit and plasticity index shall be performed for each sieve analysis. Liquid limit and plasticity index shall be in accordance with ASTM D 4318.

3.5.5 Density Control

The Contractor shall adequately control his compaction operations by tests made in accordance with ASTM D 1556 or ASTM D 2167 . One in-place density and one in-place moisture test shall be performed per 12,000 square feet, or fraction thereof, of each lift. Moisture content shall be in accordance with ASTM D 2216 or ASTM D 4643 for determining density. When ASTM D 4643 is utilized, the moisture content should be checked a minimum of once per day using ASTM D 2216. The density test hole shall be backfilled and compacted to the required moisture and density of the adjacent fill. Additional tests shall be made as necessary. All test results shall be made available to the Contracting Officer. Acceptance tests may be made by the Government for verification of compliance; however, the Contractor shall not depend on such test for his control of operations. Deficiencies in construction shall be corrected by the contractor at no additional cost to the Government.

3.5.6 Density-Moisture Determinations for Vent Materials

Test for determination of maximum density and optimum moisture content shall be performed by the contractor in accordance with the requirements of ASTM D 4253 . Density-Moisture Tests shall be run on the same sample on which the in-place density test is run. The percent compaction of the fill sample is then calculated from the results of the field and laboratory density tests. The above testing shall include Atterberg limits and grain size determinations and shall be made on the same material as the in-place density and moisture test.

3.6 PROTECTION

Newly graded areas shall be protected from traffic and from erosion, and any settlement or washing away that may occur from any cause, prior to acceptance, shall be repaired and grades reestablished to the required elevations and

slopes. All work shall be conducted in accordance with the environmental protection requirements or the contract.

- - o O o - -

SECTION 02245

GEOCOMPOSITE MEMBRANE LINER

PART 1 - GENERAL

1.1 SCOPE

This section covers the furnishing and installation of a geocomposite membrane liner(s). All work shall be performed in strict accordance with the liner manufacturer's recommendations, as shown on the drawings, and as described in the specifications. The term "geocomposite membrane liner" shall be defined as a 40 mil, High Density Polyethylene (HDPE), liner with either a sodium bentonite glued to the HDPE liner or combination of the 40 mil HDPE Liner and a separate sodium bentonite liner, glued or sewn to a fabric, and placed under the HDPE liner. The term "geocomposite membrane liner" will be abbreviated "GML" in the remainder of this section.

1.2 APPLICABLE PUBLICATIONS

The publications listed below form a part of the specification to the extent referenced. The publications are referenced to in the text by basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D 638	(1989) Tensile Properties of Plastics.
ASTM D 696	(1991) Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between -30 Degrees C and 30 Degrees C
ASTM D 1004	(1990) Initial Tear Resistance of Plastic Film and Sheeting.
ASTM D 1204	(1984) Linear Dimensional changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperature.
ASTM D 1238; REV B	(1988) Flow Rates of Thermoplastics by Extrusion Plastometer.
ASTM D 1505	(1985; R 1990) Density of Plastics by the Density-Gradient Technique.
ASTM D 1593	(1981; R 1988) Nonrigid Vinyl Chloride Plastic Sheeting.
ASTM D 1693	(1979; R 1988) Environmental Stress - Cracking of Ethylene Plastics.

ASTM D 2216	(1980) Laboratory determination of Water (Moisture) Content of Soil by the Microwave Oven Method.
ASTM D 2434	(R 1974) Test Method for Permeability of Granular Soils (Constant Head)
ASTM D 3083	(1976; R 1983) Specification for Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal, and Reservoir Lining.
ASTM D 3895	(1980; R 1986) Copper - Induced Oxidative Induction Time of Polyolefins by Thermal Analysis.

FEDERAL TEST METHOD STANDARDS (FTMS)

101 C 2065.1	Puncture Resistance and Elongation Test.

1.3 SUBMITTALS

Submit shop drawings for GML installation, including anchorage details, penetration details, and layout plan.

Submit copies of laboratory and field test reports presenting data on GML materials and seams.

The following shall be submitted in accordance with Section 01300 SUBMITTALS:

SD-70, Test Reports

Certified copies of laboratory test reports, including all test data, shall be submitted for the sodium bentonite. These tests shall be made by an approved commercial laboratory or by a laboratory maintained by the manufacturers of the materials.

SD-76, Certificates of Compliance

The HDPE liner and Sodium Bentonite will be accepted on the basis of manufacturer's certification of compliance, accompanied by mill test reports attesting that the materials meet the requirements of the specification under which it is furnished. No GML shall be used until notice of acceptance has been given by the Contracting Officer. The GML materials may be subjected to check testing by the Government. Samples may be obtained at the mill, at transfer points, or at the project site.

1.4 GENERAL REQUIREMENTS

1.4.1 HDPE Liner Material

The material shall be unsupported high-density polyethlene (HDPE) 40 mil in thickness and shall be extruded to produce a uniform sheet free of defects

such as holes, tears, nodules, blisters, or other manufacturing defects that may effect the serviceability. The HDPE liner shall conform to the following criteria listed below:

ITEM	40 MIL	SPECIFICATION
Thickness, mils (nominal)	40	ASTM D 1593 Par 8.1.3
Density g/cc (Min)	0.94	ASTM D 1505
Melt Flow Index g/10 (Max)	0.3	ASTM D 1238 Condition E (190°C, 2.16 kg)
Tensile Properties (Typical)		ASTM D 638 Type IV Dumb-bell at 2 ipm
1. Tensile Strength at Break (lbs/inch width)	160	
2. Tensile Strength at Yield (lbs/inch width)	95	
3. Elongation at Break (Percent)	700	
4. Elongation at Yield (Percent)	13	
Tear Resistance Initiation lbs (Typical)	30	ASTM D 1004 Die C Condition E (190°C, 2.16 kg)

ITEM	40 MIL	SPECIFICATION
Dimensional Stability % Change each direction (Max)	±2	ASTM D 1204 Condition E (190°C, 2.16 kg)
Resistance to Soil Burial Percent Change in Original Value (Typ)		ASTM D 3083 using ASTM D 638 Type IV Dumb-bell at 2 ipm
1. Tensile Strength at Break	±10	
2. Tensile Strength at Yield	±10	
3. Elongation at Break	±10	
4. Elongation at Yield	±10	
Environmental Stress Crack Hours (Min)	1500	ASTM D 1693 (10% Igepal, 50°C)
Puncture Resistance Pounds (Typ)	52	FTMS Method 2065
Coefficient of Liner Thermal Expansion x 10^{-4} cm\(cm °C) (Typical)	1.2	ASTM D 696
Thermal Stability	2000	ASTM D 3895

hydraulic conductivity of HDPE?

Oxidation Induction Time Minutes (Min)	130°C, 800 psi O_2

1.4.2 Sodium Bentonite

The Sodium Bentonite material and/or liner shall be a uniform sheet free of defects such as holes, tears, nodules, blisters, or other manufacturing defects that may effect the serviceability. The Sodium Bentonite shall conform to the following criteria listed below:

ITEM	BENTONITE	SPECIFICATION
Bentonite Loading lbs\ft^2 (Min)	1.0	Will this bentonite loading achieve min thk of 1/8"? OK
Hydraulic Conductivity cm/sec (Max)	$1x10^{-9}$	
Percent Montmorillonite	80-90%	
Silicon Dioxide (SiO_2)	55-64%	
Aluminum Oxide (Al_2O_3)	16-22%	
Ferric Oxide (Fe_2O_3)	3-6%	
Sodium Oxide (Na_2O)	0-3%	
Magnesia (MgO)	2-4%	
Lime (CaO)	0-3%	

ITEM	BENTONITE	SPECIFICATION
Water Content	5-20%	ASTM D 2216
Bulk Density lbs\ft^3 (Typ)	77	

1.5 STORAGE OF GML

Until installed, factory-fabricated panels shall be stored in their original unopened crates; if outdoors, they shall be stored on pallets and shall be protected from the direct rays of the sun under a light-colored, heat-reflective, opaque cover in a manner that provides a free-flowing air space between the crate and cover. The Contractor shall be responsible for providing all required care and see that the GML is kept in good condition prior to its installation. Any GML materials found to be damaged shall be replaced with new at the Contractor's expense.

'PART 2 - PRODUCTS

2.1 GENERAL

The manufacturer(s) shall have produced, and have in service in similar applications for a period of not less than one (1) year and at least five (5) million square feet of GML meeting these specifications. The GML manufacturer(s) shall furnish to the Government, evidence of this prior to the

start of work. This evidence shall include names of contacts and phone numbers.

The Contractor shall provide GML products, or there equal, meeting the following specifications:

40 mil HDPE with glued Sodium Bentonite to liner; Gundseal from

Gundle Lining Systems, Inc.
19103 Gundle Road
Houston, Texas 77073;
1-800-435-2008.

40 mil HDPE Liner with a separate sodium bentonite liner, glued or sewn to a fabric, and placed under the HDPE liner:

BENTOMAT from
CETCO
1500 West Shure Dr.
Arlington Heights, IL 60004-1434
(708) 392-5800

CLAYMAX from
James Clem Corporation
444 N. Michigan Ave
Suite 1610
Chicago, Illinois 60611
(312) 321-6255
or
(505) 989-7029 - Southwest Office

If the Contractor proposed to provide other type materials, complete laboratory and descriptive information shall be submitted for evaluation by the Contracting Officer.

PART 3 - EXECUTION

GML manufacturer will need to be present prior to installing fabric

3.1 PREPARATION OF SUBGRADE FOR GML

The subgrade for the GML shall be prepared as specified in SECTION 02215 - PLASTIC FILTER FABRIC. An authorized representative of the GML manufacturer(s) shall certify in writing that the surface on which the GML is to be placed is acceptable, prior to start of GML placement.

3.2 PLACEMENT OF GML

3.2.1 General

The Contractor shall require the GML manufacturer(s) to furnish the services of a competent, factory trained, field technical representative to supervise installation of the GML. The GML shall be placed over the prepared surfaces

to be lined in such a manner as to assure minimum handling. Any portion of GML damaged during installation shall be removed or repaired by using an additional piece of GML, as specified hereinafter.

All equipment, tools, and machines used in performance of the work shall be subject to approval prior to commencement of work by the Contracting Officer. This equipment shall be maintained in satisfactory working conditions at all times.

3.2.2 Weather Limitations

GML shall be placed only when the temperature is above 45 degrees F. GML shall <u>not</u> be placed during rain, snow, or bad weather.

3.2.3 Field Procedures

Field procedures shall be specifically suitable for the type of GML selected by the Contractor. The GML shall be installed with the bentonite face or layer down. The GML joints shall be overlapped a minimum of 1-foot, or as specified in the plans, with a layer of bentonite between the over lapping HDPE liners. The overlap edges shall be tapped to prevent the intrusion of soil between the overlap during placement of the overlaying soil. The GML shall be free of wrinkles, bulges and folds. Procedures for alternative material shall be submitted for evaluation by the Contracting Officer.

3.2.4 Quality of Workmanship

All joints, on completion of the work, shall be properly overlaid. Any lining surface showing improper installation, injury due to scuffing, penetration by foreign objects, or distress from rough subgrade shall, as directed by the Contracting Officer, be replaced or repaired at no additional cost to the Government.

3.3 SAMPLING AND TESTING

3.3.1 Sampling and Testing at Jobsite

3.3.1.1 Inspection of Sheet Installation

The Contractor shall conduct a visual inspection of each panel or sheet as it is unrolled. The Contracting Officer shall be notified of any damage. All faulty areas shall be repaired as specified in paragraph, PLACEMENT OF GML.

3.3.2 Approval of Materials

Source of all materials shall be selected well in advance of the time that materials will be required in the work. Manufactures certification and test results for the HDPE liner and sodium bentonite shall be submitted for approval not less than 30 days before the material is required for the work.

3.3.3 Friction Testing

Where GML is to be placed on slopes greater than 4:Horizontal on 1:Vertical, the Contractor shall perform laboratory friction tests using a direct shear test method as approved by the Contracting Officer to assure a minimum friction angle of 17° can be obtained between all cover system components. Friction testing shall be performed with a direct shear box with minimum dimensions of 12 inches by 12 inches and applied normal stresses of 1.0, 2.0, and 4.0 psi for each cover system interface. A displacement rate of 0.005 inches per minute shall be used. All cover system soil components shall be compacted to the density and moisture content required for full scale placement and then tested in a saturated condition. All geotextile shall be oriented such that the shear force is parallel to the downslope orientation of the geotextiles in the field. These tests shall be performed and the results approved by the Contracting Officer prior to delivery of the cover system components.

- - o 0 o - -

SECTION 02935 - TURF

PART 1 GENERAL

1.1 SUMMARY (Not Applicable)

1.2 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by basic designation only.

AGRICULTURAL MARKETING SERVICE (AMS)

AMS-01	(Sep 1977; Amended Oct 29, 1986) Federal Seed Act Regulations (Part 20): Certified Seed Regulations

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D 977	(1986) Emulsified Asphalt
ASTM D 2028	(1976; R 1986) Cutback Asphalt (Rapid-Curing Type)
ASTM D 2607	(1969) Peats, Mosses, Humus, and Related Products

FEDERAL SPECIFICATIONS (FS)

FS O-F-241	(Rev D) Fertilizers, Mixed, Commercial
FS JJJ-S-181	(Rev B) Seeds, Agricultural

1.3 SUBMITTALS

The following shall be submitted in accordance with Section 01300 SUBMITTALS:

SD-17, Manufacturer's Catalog Data

Manufacturer's literature discussing physical characteristics, application and installation instructions for erosion control material, and for chemical treatment material shall be submitted.

SD-43, Construction Equipment List

A list of proposed seeding and mulching equipment to be used in performance of turfing operation, including descriptive data and calibration tests.

SD-62, Work Plan

a. Delivery Schedule. Submittal of the delivery schedule shall be at least 10 days prior to the intended date of the first delivery.

b. Maintenance Report. Written record of maintenance work performed shall be furnished.

c. Turf Establishment Period. Written calendar time period for the turf establishment period shall be furnished. When there is more than one turf establishment period, describe the boundaries of the turfed area covered for each period.

SD-76, Certificates of Compliance

Prior to the delivery of materials, certificates of compliance shall be submitted certifying that materials meet the requirements specified. Certified copies of the reports for the following materials shall be submitted.

a. Seed: For mixture, percent pure live seed, minimum percent germination and hard seed, maximum percent weed seed content, date tested and state certification.

b. Fertilizer: For chemical analysis, composition percent.

c. Agricultural Limestone: For calcium carbonate equivalent and sieve analysis.

d. Peat: For compliance with ASTM D 2607.

e. Topsoil: For pH, particle size, chemical analysis and mechanical analysis.

517 Gold Ave S.W. 1.4 DELIVERY, INSPECTION, STORAGE, AND HANDLING

1.4.1 Delivery

1.4.1.1 Topsoil

A soil test shall be provided for topsoil delivered to the site.

1.4.1.2 Soil Amendments

Soil amendments shall be delivered to the site in the original, unopened containers bearing the manufacturer's chemical analysis. In lieu of containers, soil amendments may be furnished in bulk. A chemical analysis shall be provided for bulk deliveries.

1.4.2 Inspection

Seeds shall be inspected upon arrival at the job site by the Contracting Officer for conformity to type and quality in accordance with paragraph MATERIALS. Other materials shall be inspected for meeting specified requirements and unacceptable materials shall be removed from the job site.

1.4.3 Storage

Materials shall be stored in areas designated by the Contracting Officer. Seed, lime and fertilizer shall be stored in cool, dry locations away from contaminations.

PART 2 PRODUCTS

2.1 MATERIALS

2.1.1 Seed

2.1.1.1 Seed Classification

State-certified seed of the latest season's crop shall be provided in original sealed packages bearing the producer's guaranteed analysis for percentages of mixture, purity, germination, hard seed, weed seed content, and inert material. Labels shall be in conformance with AMS-01 and applicable state seed laws.

2.1.1.2 Seed Mixtures

Seed mixtures shall be proportioned by weight as follows:

Botanical Name	Common Name	Mixture Percent by Weight	Percent Pure Live Seed
Bouteloua gracilis 'Lovington' or 'Hachita'	BLUE GRAMA	17	98
Bouteloua curtipendula 'El Reno'	SIDE-OATS GRAMA	35	98
Buchloe dactyloides 'Texoka'	BUFFALO GRASS	35	98
Agropyron smithii	WESTERN WHEAT GRASS	9	98
Sprobolus airoides	ALKALI SACATON	4	98

2.1.1.3 Quality

Seed shall conform to FS JJJ-S-181. Weed seed shall not exceed 1 percent by weight of the total mixture. Wet, moldy, or otherwise damaged seed shall be rejected.

2.1.1.4 Seed Mixing

The field mixing of seed shall be performed on site in the presence of the Contracting Officer.

2.1.2 Soil Amendments

Soil amendments shall consist of lime, fertilizer, organic soil amendments and soil conditioners meeting the following requirements.

2.1.2.1 Lime

Lime shall be agricultural limestone and shall have a minimum calcium carbonate equivalent of 90 percent and shall be ground to such a fineness that at least 90 percent will pass a 10-mesh sieve and at least 50 percent will pass a 60-mesh sieve.

2.1.2.2 Fertilizer

Fertilizer shall be commercial grade, free flowing, uniform in composition and conforming to FS O-F-241. Granular Fertilizer: As recommended by the soil test.

2.1.2.3 Organic Soil Amendments

a. Topsoil: The existing surface soil shall be stripped and stockpiled on the site in accordance with Section 02210 GRADING. When required beyond that available from stripping, the topsoil shall be delivered. Delivered topsoil shall conform to topsoil requirements specified in Section 02210 GRADING, and shall be amended as recommended by soil test.

b. Peat: Peat moss derived from a bog, swampland or marsh shall conform to ASTM D 2607.

c. Sand: Clean, free of toxic materials; 95 percent by weight shall pass a 10-mesh sieve and 10 percent by weight shall pass a 16-mesh sieve.

d. Rotted Manure: Well rotted, horse or cattle manure containing a maximum 25 percent by volume of straw, sawdust, or other bedding materials, free of stones, sticks, soil and containing no chemicals or ingredients harmful to plants.

e. Decomposed Wood Derivatives: Ground bark, sawdust, or other wood waste material free of stones, sticks, soil, and toxic substances harmful to plants, stabilized with nitrogen and having the following properties:

Particle Size: Minimum percent by weight passing:

Screen Size	Percent
No. 4 mesh Screen	95
No. 8 mesh screen	80

Nitrogen Content: Minimum percent based on dry weight:

Material	Percent
Redwood Sawdust	0.5
Fir Sawdust	0.7
Fir or Pine Bark	1.0

f. Calcined Clay: Granular particles produced from montmorillonite clay calcined to minimum temperature of 1200 degrees F to the following gradation: minimum 90 percent passing 8-mesh screen, 99 percent retained on 60-mesh screen and maximum 2 percent passing 100-mesh screen. Bulk density: maximum 40 pounds per cubic foot.

2.1.2.4 Soil Conditioner

Soil conditioner shall be for single use or in combination to meet requirements for topsoil. Gypsum shall be commercially packaged, free flowing, minimum 95 percent calcium sulfate by volume.

2.1.3 Mulch

Mulch shall be free from weeds, mold, and other deleterious materials.

2.1.3.1 Straw

Straw shall be stalks from oats, wheat, rye, barley, or rice furnished in air-dry condition and with a consistency for placing with commercial mulch-blowing equipment.

2.1.3.2 Hay

Hay shall be native hay, sudan-grass hay, broomsedge hay, or other herbaceous mowings furnished in an air-dry condition suitable for placing with commercial mulch-blowing equipment.

2.1.3.3 Wood Cellulose Fiber

Wood cellulose fiber shall not contain any growth or germination-inhibiting factors and shall be dyed an appropriate color to facilitate visual metering during application. Composition on air-dry weight basis: 9 to 15 percent moisture, pH range from 4.5 to 6.0.

2.1.3.4 Wood Chips

Wood chips shall be chips or shredded bark with maximum particle size of 3/16 inch.

2.1.3.5 Paper Fiber Mulch

Paper fiber mulch shall be recycled news print that is shredded for the purpose of mulching seed.

2.1.4 Water

Water shall not contain elements toxic to plant life.

2.1.5 Erosion Control Material

Soil erosion control shall conform to the following:

2.1.5.1 Soil Erosion Control Blanket

Machine produced mat of wood excelsior formed from a web of interlocking wood fibers, covered on one side with either knitted straw blanket-like mat construction, covered with biodegradable plastic mesh, or interwoven biodegradable thread, plastic netting or twisted kraft paper cord netting.

2.1.5.2 Soil Erosion Control Fabric

Knitted construction of polypropylene yarn with uniform mesh openings 3/4 to 1 inch square with strips of biodegradable paper. Filler paper strips shall last 6 to 8 months.

2.1.5.3 Soil Erosion Control Net

Heavy, twisted jute mesh weighing approximately 1.22 pounds per linear yard and 4 feet wide with mesh openings of approximately 1 inch square.

2.1.5.4 Soil Erosion Control Chemicals

High-polymer synthetic resin or cold-water emulsion of selected petroleum resins.

2.1.5.5 Hydrophilic Colloids

Hydrophilic colloids shall be physiologically harmless to plant and animal life, without phytotoxic agents. Colloids shall be naturally occurring, silicate powder based, and shall form a water insoluble membrane after curing. Colloids must resist mold growth.

2.1.5.6 Anchors

Erosion control anchor material shall be as recommended by the manufacturer.

PART 3 EXECUTION

3.1 SEEDING TIMES AND CONDITIONS

3.1.1 Seeding Time

Seed shall be sown from March to May for spring planting and from June to August for fall planting.

3.1.2 Turfing Conditions

Turf operations shall be performed only during periods when beneficial results can be obtained. When drought, excessive moisture or other unsatisfactory conditions prevail, the work shall be stopped when directed. When special conditions warrant a variance to the turf operations, proposed times shall be submitted to and approved by the Contracting Officer.

3.2 SITE PREPARATION

3.2.1 Grading

The Contracting Officer shall verify that finished grades are as indicated on drawings, and the placing of topsoil and the smooth grading has been completed in accordance with Section 02210 GRADING.

3.2.2 Application of Soil Amendments

3.2.2.1 Soil Test

A soil test shall be performed for pH, chemical analysis and mechanical analysis to establish the quantities and type of soil amendments required to meet local growing conditions for the type and variety of turf specified.

3.2.2.2 Lime

Lime shall be applied at the rate recommended by the soil test. Lime shall be incorporated into the soil to a minimum depth of 4 inches or may be incorporated as part of the tillage operation.

3.2.2.3 Fertilizer

Fertilizer shall be applied at the rate recommended by the soil test. Fertilizer shall be incorporated into the soil to a minimum depth of 4 inches or may be incorporated as part of the tillage or hydroseeding operation.

3.2.2.4 Soil Conditioner

Soil Conditioner shall be spread uniformly over the soil to a minimum depth of 1/2 inches and thoroughly incorporated by tillage into the soil to a minimum depth of 4 inches.

3.2.3 Tillage

3.2.3.1 Minimum Depth

Soil on slopes gentler than 3-horizontal-to-1-vertical shall be tilled to a minimum depth of 4 inches. On slopes between 3-horizontal-to-1-vertical and 1-horizontal-to-1 vertical, the soil shall be tilled to a minimum depth of 2 inches by scarifying with heavy rakes, or other method. Rototillers shall be used where soil conditions and length of slope permit. On slopes 1-horizontal-to-1 vertical and steeper, no tillage is required.

3.2.4 Finished Grading

3.2.4.1 Preparation

Turf areas shall be filled as needed or have surplus soil removed to attain the finished grade. Drainage patterns shall be maintained as indicated on drawings. Turf areas compacted by construction operations shall be completely pulverized by tillage. Soil used for repair of erosion or grade deficiencies shall conform to topsoil requirements specified in Section 02210 GRADING. Finished grade shall be 1 inch below the adjoining grade of any surfaced area. New surfaces shall be blended to existing areas.

3.2.4.2 Field Area Debris

Field areas shall have debris and stones larger than 3 inches in any dimension removed from the surface.

3.2.4.3 Protection

Finished graded areas shall be protected from damage by vehicular or pedestrian traffic and erosion.

3.3 SEEDING

3.3.1 General

Prior to seeding, any previously prepared seedbed areas compacted or damaged by interim rain, traffic or other cause, shall be reworked to restore the ground condition previously specified. Seeding operations shall not take place when the wind velocity will prevent uniform seed distribution.

3.3.2 Equipment Calibration

The equipment to be used and the methods of turfing shall be subject to the inspection and approval of the Contracting Officer prior to commencement of turfing operations. Immediately prior to the commencement of turfing operations, the Contractor shall conduct turfing equipment calibration tests in the presence of the Contracting Officer.

3.3.3 Applying Seed

3.3.3.1 Drill Seeding

Seed shall be uniformly drilled to an average depth of 1/2 inch and at the rate of 9 pounds per 1000 square feet using equipment having drills not more than 6-1/2 inches apart. Row markers shall be used with the drill seeder.

3.3.3.2 Rolling

Immediately after seeding, except for slopes 3-horizontal-to-1 vertical and greater, the entire area shall be firmed with a roller not exceeding 90 pounds

for each foot of roller width. Areas seeded with seed drills equipped with rollers shall not be rolled.

3.3.4 Hydroseeding

Seed and fertilizer shall be added to water and thoroughly mixed at the rates specified. Wood cellulose fiber mulch shall be added at the rates recommended by the manufacturer after the seed, fertilizer and water have been thoroughly mixed, to produce a homogeneous slurry. Slurry shall be uniformly applied under pressure over the entire area. The hydroseeded area shall not be rolled.

3.3.5 Mulch

3.3.5.1 Straw or Hay Mulch

Straw or hay mulch shall be spread uniformly at the rate of 2 tons per acre. Mulch shall be spread by hand, blower-type mulch spreader or other approved method. Mulching shall be started on the windward side of relatively flat areas or on the upper part of a steep slope and continued uniformly until the area is covered. The mulch shall not be bunched. All seeded areas shall be mulched on the same day as the seeding.

3.3.5.2 Mechanically Anchoring

Immediately following spreading, the mulch shall be anchored to the soil by a V-type-wheel land packer, a scalloped-disk land packer designed to force mulch into the soil surface, or other suitable equipment.

3.3.5.3 Non-Asphaltic Tackifier

Hydrophilic colloid shall be applied at rate recommended by manufacturer. Apply with hydraulic equipment suitable for mixing and applying uniform mixture of tackifier.

3.3.5.4 Wood Cellulose Fiber

Wood cellulose fiber mulch for use with the hydraulic application of seed and fertilizer shall be applied as part of the hydroseeding operation.

3.3.6 Water

Watering shall be started within 7 days after completing the seeded area. Water shall be applied at a rate sufficient to ensure moist soil conditions to a minimum depth of 1 inch. Run-off and puddling shall be prevented.

3.4 EROSION CONTROL

3.4.1 Erosion Control Material

Erosion control material, where indicated or required, shall be installed in accordance with manufacturer's instructions. Placement of the erosion control

material shall be accomplished without damage to installed material or without deviation to finished grade.

3.4.2 Temporary Turf Cover

3.4.2.1 General

When there are contract delays in the turfing operation or a quick cover is required to prevent erosion, the areas designated for turf shall be seeded with a temporary seed as directed by the Contracting Officer.

3.4.2.2 Application

When no other turfing materials have been applied, the quantity of one half of the required soil amendments shall be applied and the area tilled in accordance with paragraph SITE PREPARATION. Seed shall be uniformly broadcast and applied at the rate of 9 pounds per 1000 square feet. The area shall be watered as required.

3.5 RESTORATION AND CLEAN UP

3.5.1 Restoration

Existing turf areas, pavements and facilities that have been damaged from the turfing operation shall be restored to original condition at Contractor's expense.

3.5.2 Clean Up

Excess and waste material shall be removed from the planting operation and shall be disposed of off the site. Adjacent paved areas shall be cleaned.

3.6 PROTECTION OF TURFED AREAS

Immediately after turfing, the area shall be protected against traffic or other use by erecting barricades and providing signage as required, or as directed by the Contracting Officer.

3.7 TURF ESTABLISHMENT PERIOD

3.7.1 Commencement

The Turf Establishment Period for establishing a healthy stand of turf shall begin on the first day of work under this contract and shall end three (3) months after the last day of turfing operations required by this contract. Written calendar time period shall be furnished to the Contracting Officer for the Turf Establishment Period. When there is more than one turf establishment period, describe the boundaries of the turfed area covered for each period.

3.7.2 Satisfactory Stand of Turf

3.7.2.1 Seeded Area

a. Field Area: A satisfactory stand of turf from the seeding operation for a field area is defined as a minimum of 10 grass plants per square foot. The total bare spots shall not exceed 2 percent of the total seeded area.

3.7.3 Maintenance During Establishment Period

3.7.3.1 General

Maintenance of the turfed areas shall include eradicating weeds, eradicating insects and diseases, protecting embankments and ditches from erosion, maintaining erosion control materials and mulch, protecting turfed areas from traffic, watering, and post-fertilization.

3.7.3.2 Watering

Watering shall be at intervals to obtain a moist soil condition to a minimum depth of 1 inch. Frequency of watering and quantity of water shall be adjusted in accordance with the growth of the turf. Run-off, puddling and wilting shall be prevented.

3.7.3.3 Post-Fertilization

Nitrogen carrier fertilizer shall be applied at the rate of 1 pound per 1000 square feet after the first month and again in 3 months. The application shall be timed prior to the advent of winter dormancy and shall avoid excessively high nitrogen levels.

3.7.3.4 Repair

The Contractor shall re-establish as specified herein, eroded, damaged or barren areas. Mulch shall also be repaired or replaced as required.

3.7.3.5 Maintenance Report

A written record shall be furnished to the Contracting Officer of the maintenance work performed.

3.8 FINAL ACCEPTANCE

3.8.1 Preliminary Inspection

Prior to the completion of the Turf Establishment Period, a preliminary inspection shall be held by the Contracting Officer. Time for the inspection shall be established in writing. The acceptability of the turf in accordance with the Turf Establishment Period shall be determined. An unacceptable stand of turf shall be repaired as soon as turfing conditions permit.

3.8.2 Final Inspection

A final inspection shall be held by the Contracting Officer to determine that deficiencies noted in the preliminary inspection have been corrected. Time for the inspection shall be established in writing.

- - o O o - -

LIBRARY COPY

LANDFILL #5
CELL #3
Cannon AFB, NM

FINAL DESIGN ANALYSIS

July 21, 1992

CAFB 031

US Army Corps
of Engineers
Albuquerque District

FINAL COVER
LANDFILL #5, CELL #3
GEOCOMPOSITE-SOIL CAP
Cannon AFB, New Mexico
FY 92

100% DESIGN

TABLE OF CONTENTS

I. INTRODUCTION AND DESIGN ANALYSIS I-1

II. CIVIL II-1

III. ARCHITECTURAL . . . . . N/A

IV. STRUCTURAL . . . . . N/A

V. MECHANICAL . . . . . N/A

VI. ELECTRICAL . . . . . N/A

VII. ENVIRONMENTAL . . . . . N/A

VIII. COST ESTIMATE VIII-1

IX. ENERGY CONSERVATION . . . . . N/A

X. FIRE SAFETY . . . . . N/A

XI O & M PROVISIONS . . . . . N/A

DRAWING LIST

	Drawing No.	Seq. No.
Cover Sheet		0
Project Location, Vicinity Maps and Index	C1	1
Site Plan	C2	2
Grading Plan	C3	3
Site Details	C4	4
Site Details	C5	5

APPENDICES		Page
Appendix A	Landfill Cap Analysis	A-1
Appendix B	Related Correspondence	B-1
Appendix C	Summary of Field Activities	C-1
Appendix D	Closure and Post Closure Plan For Landfill Area #5	D-1
Appendix E	Product Technical Articles & Literature	E-1
Appendix F	Soils and Field Test Results	F-1

PART I INTRODUCTION AND DESIGN ANALYSIS

PART I INTRODUCTION AND DESIGN ANALYSIS

1. DIRECTIVE AUTHORIZATION AND PROJECT DESCRIPTION.

a. Directive Authorization.

b. Project Description. The project consists of providing a geocomposite-soil cap and tieing into the existing cap for Sanitary Landfill #5, Cell #3 at Cannon Air Force Base (CAFB), New Mexico. Cell #3 was in operation during the "RCRA INTERIM STATUS" time period and the cell was documented as having received contaminates for disposal. These contaminates consisted of solvents, paints, paint removers, and thinners.

Closure and Post Closure Plan, Plans, and Specifications for Landfill Cell #3 were developed by Hazard Materials Technical Center, 11140 Rockville Pike, Rockville, Maryland 208552, in October 1988. This Cap was constructed as per plans and specifications. The Cannon AFB, Base Environmental Section, later determined that the location of this cap did not cover the entire area of cell #3. The Cannon AFB, Base Environmental Section, requested the US Army Corps of Engineers, Tulsa District, to develop a set of plans and specifications for a soil cap for cell #3. Subsequently, the Tulsa District brokered this work to the Albuquerque District.

2. A-E CONTRACT DATA. Project engineering and design for this facility is being accomplished by hired labor personnel at the Albuquerque District. The basic plans, specifications, design analysis and cost estimate are being prepared by the Albuquerque District.

3. APPLICABLE CRITERIA. This project will be a site adapt to an existing landfill cap. Criteria for the design includes the following:

The Cap shall be designed to satisfy all state and federal closure regulations.

a. State requirements include the following:

-Provide long-term minimization of migration of liquids through the closed landfill cell.

-Function with minimum maintenance.

-Promote drainage and minimize erosion and abrasion of the cover.

-Accommodate settling and subsidence so that the cover's integrity is maintained.

-Have a permeability less than or equal to the permeability of any bottom liner system of natural subsoils present.

b. Federal requirements are identical to the state of New Mexico as per Code of Federal Regulations, Protection of Environment, 40 (CFR 40), Revised as of July 1, 1991, Section 265.310.

c. CAFB requirements:

-Meet all Federal and State requirements

-The cap shall be designed for ease of integration and tie-in to future landfill cell cap(s).

4. PURPOSE AND FUNCTION. This cover is to be installed to seal cell #3 to preclude and restrict any escape of hazardous waste material, waste constituents from the cell below and prevent passage of surface and subsurface fluids and gasses, including surface runoff, through its substance.

5. DESIGN SCOPE. The project scope is to provide a landfill cover for cell #3 , which measures 800 feet by 50 feet.

6. SITE VISIT AND CONFERENCE NOTES. A copy of all conference minutes is provided in Appendix B.

7. GOVERNMENT EQUIPMENT. N/A

8. CONSTRUCTION.

a. Instructions. All Government and contractor personnel will be required, as a minimum, to have current training for "HEALTH & SAFETY FOR HAZARDOUS WASTE OPERATION" as required by OSHA 29 CFR 1919.120.

b. Phasing. N\A

c. Duration. Construction time for this project will be approximately 120 days from the date of notice to proceed.

9. AIR AND WATER POLLUTION CONTROL. Special features will be provided for dust control, hazardous waste, and air monitoring during construction.

10. DESIGN PROBLEMS. Specific design problems are addressed separately for each discipline in the following parts of this design analysis.

11. WAIVERS. N\A.

12. ECONOMIC SUMMARY. Economic measures taken for this design are addressed separately for each discipline in the following parts of this design analysis.

13. USER INFORMATION. N\A.

14. REFERENCES TO PREVIOUS STUDIES OF RECORD. Previous studies of record are listed below and are provided in Appendix C and D:

a. Closure and Post Closure Plan, Plans, and Specifications for Landfill Cell #3 were developed by Hazard Materials Technical Center, 11140 Rockville Pike, Rockville, Maryland 208552, in October 1988.

b. Summary of Field Activities, Cannon AFB, Clovis New Mexico, Prepared by: Jo Brady, US Army Corps of Engineers, Tulsa District, Geology Section, Dated Monday, January 27, 1992.

15. GUIDE SPECIFICATIONS. The following is a list of applicable guide

specifications:

SECTION 01000 - General Requirements

SECTION 01100 - Environmental Protection

SECTION 01300 - Submittals

SECTION 01310 - Progress Schedule

SECTION 01440 - Contractor Quality Control System

SECTION 01420 - Safety

SECTION 01510 - Utilities

SECTION 01580 - Bulletin Board, Project Sign and Project Safety Sign

SECTION 01720 - As-Built Drawings

SECTION 01740 - Warranty Of Construction

SECTION 002050 - Demolition

SECTION 002110 - Clearing and Grubbing

SECTION 002210 - Grading

SECTION 002215 - Plastic Filter Fabric

SECTION 002224 - Gas Vent System

SECTION 002245 - Geocomposite Membrane Liner

SECTION 002935 - Turf

PART II CIVIL

PART II CIVIL

1. SITE ANALYSIS. The project consists of providing a geocomposite-soil cap for part of cell #3, landfill area #5, Cannon AFB, NM. The new cap ties into the existing cap on the remainder of cell #3.

a. Existing Conditions. This project is located on the southeast corner of CAFB, within landfill area #5. An existing landfill cap exists presently for Cell #3. This cap is approximately 350 feet by 70 feet and is surrounded by a 7-foot high chain link fence. Approximately one-half of the existing fence and cap will be removed and the remainder ties into the new geocomposite-soil cap.

b. Site Analysis. In January 1992, cell #3 was trenched to determine the extent of the cell (See Appendix B for trenching report). The trenching showed that cell #3 was approximately 800-feet long and 50-feet wide, with 10-foot barriers between adjacent cells. The new cap shall incorporate a gas vent system and a geocomposite-soil membrane liner. The geocomposite-soil membrane liner is composed of a High Density Polyethlene (HDPE) liner and a Sodium Bentonite Clay material. Twenty-four (24) inches minimum cover soil and native vegetation will be provided for evapotranspiration of rainfall infiltration into the cover soil. A four strand barb wire fence, with a 16-foot gate for access to the cell, will be constructed around the cell for safety.

2. GRADING. The new cell is constructed with a top slope ranging from 3%-4% and side slopes at 4:1 (Horizontal:Vertical).

3. PAVEMENT. None.

4. STORM DRAINAGE.

a. Hydrology. Cannon Air Force Base, approximately 7 miles west of the City of Clovis, lies at the headwaters of the Brazos River. Landfill #5, encompassing 40 acres, is located near the southeast corner of the base. The Rational Method for computation of runoff from small watersheds provided the 100-year and 25-year discharges for the landfill #5 site. The Rational Method is expressed as:

$$Q = CIA$$

where:
- Q = Maximum runoff from a given area in cubic feet per second
- C = Coefficient representing the ratio of runoff to rainfall
- I = Intensity of rainfall in inches per hour for the estimated time of concentration
- A = Drainage area in acres

The derivation of this equation assumes that the maximum rate of runoff from a given rainfall intensity occurs when all parts of the basin are contributing. The time of concentration describes the period of time it takes a particle of water to travel from the most distant point in the watershed to the basin outlet. For this study, the time of concentration was calculated from the formula developed by Kirpich describing the relationship between the time of

concentration (Tc) and a watershed factor (K) based on the length and slope of the basin:

$$Tc = 0.0078K^{0.770} \qquad \text{and} \qquad K = L/S^{0.5}$$

where:
- L = Maximum length of travel in feet
- S = Slope H/L
- H = Difference in elevation between the most remote point and the basin outlet in feet

Surface drainage in the vicinity of the landfill flows generally to the south. The maximum length of travel for the 40-acre site is 1600 feet, and the slope measures 3%. The formula computes a time of concentration for the site of approximately 10 minutes.

With the time of concentration established at 10 minutes and set equal to the critical storm duration, the rainfall intensity for a 10-minute duration must be determined. NOAA Atlas 2, "Precipitation-Frequency Atlas of the Western United States, Volume IV, New Mexico", provided the 100-year and 25-year 1-hour duration rainfall of 3.1 inches and 2.3 inches, respectively, for the Clovis area. Technical Paper No. 25, "Rainfall Intensity-Duration-Frequency Curves for Selected Stations in the United States, Alaska, Hawaiian Islands, and Puerto Rico", provided rainfall intensity-duration-frequency curves for two nearby stations at Roswell, New Mexico, and Amarillo, Texas. Whereas the respective 100-year and 25-year frequency-intensity-duration curves for Roswell and Amarillo are parallel, similar curves for Clovis were drawn, also parallel to the Roswell and Amarillo curves, but with the 100-year and 25-year 1-hour intensities plotted at 3.1 inches and 2.3 inches, respectively. The plotted curves for Clovis produced a rainfall intensity of 7.0 inches for a 100-year frequency, 10-minute duration storm and a rainfall intensity of 5.7 inches for a 25-year frequency, 10-minute duration storm.

The "C" value used in the rational method expresses as a ratio the percentage of rainfall that is expected to run off. The basic value of "C" is taken from Table 1.

TABLE 1
SURFACE RUNOFF COEFFICIENTS

TYPE OF SURFACE	FACTOR (C)
Asphalt pavements	0.80 to 0.95
Concrete pavements	0.70 to 0.90
Gravel or macadam pavements	0.35 to 0.70
Impervious soils*	0.40 to 0.65
Impervious soils with turf*	0.30 to 0.55
Slightly pervious soils*	0.15 to 0.40
Slightly pervious soils with turf*	0.10 to 0.30
Pervious soils*	0.01 to 0.10
Wooded areas	0.01 to 0.20

* For slopes from 1% to 2%

For slopes greater than 2%, those values marked with an asterisk (*) must be corrected using the following formula:

$$(\text{Average Slope} - 2)\ 0.01 + C_{assumed} = C_{corrected}$$

The 40-acre landfill site contains soils defined as SM and ML based on the Unified Soil Classification System (USCS). According to the USCS, soils of type SM and ML have drainage characteristics which range from fair to poor; soils with fair to poor drainage correspond to slightly pervious soils in Table 1. Based on soil types and drainage characteristics, a conservative "C" value of 0.40 is assumed for landfill site #5; however, this value adjusts to 0.41 based on the 3% slope correction.

Based on the rational method and the coefficients determined above, the 100-year and 25-year discharges for the 40-acre landfill site compute as follows:

$$Q_{100} = CIA = (0.41)(7.00 \text{ inches/hour})(40 \text{ acres}) = 115 \text{ cfs}$$

$$Q_{25} = CIA = (0.41)(5.70 \text{ inches/hour})(40 \text{ acres}) = 90 \text{ cfs}$$

In summary, the 100-year discharge is 115 cfs and the 25-year discharge is 90 cfs for the 40-acre landfill #5 site at Cannon Air Force Base.

b. Drainage. It was determined that the most economical means of controlling runoff and erosion is to utilize sheet flow for the runoff and reseed the area with native grasses to minimize the erosion and maximize evapotranspiration. The 40-acre Landfill #5 area is presently 1 to 3 feet above the surrounding topography, therefore no runoff will be induced onto Landfill #5 from the surrounding area. Only the rainfall runoff from the 40 acre site shall be addressed. The existing topography shows that Cell #3 is located on a crown within Landfill #5. The natural drainage patterns are to the west and east of Cell #3. Therefor no additional grading outside the boundaries of Cell #3 is required.

5. UTILITIES. A review of CAB utility maps show no utilities in the area.

6. FENCING. A four strand barb wire fence will be provided to secure the area. A 16-foot gate will be provided at the north end of Cell #3 for maintenance purposes. Approximately one-half of the existing 7-foot chain link fence will be removed. The warning signs on the existing chain link will be removed and reinstalled on the new barb wire fence.

7. TURFING AND LANDSCAPING. Native grasses will be provided for evapotranspiration of rainfall infiltration on the cap.

8. RAILROADS. N\A

9. ECONOMICAL JUSTIFICATION. N\A

10. ADDITIONAL INFORMATION TO COMPLETE DESIGN.

a. Sediment Analysis. A sediment analysis was performed for Cell #3, using The USDA Universal Soil Loss equation. For a 3% slope, with the edges at 4:1 (Horizontal:Vertical), total anticipated soil erosion per year is 5.2 cubic feet. The use of native grasses will act as a net to collect and deposit wind blown soils onto the cap, thus offsetting the soil erosion due to rain fall.

b. Equivalent Thickness of Clay Layers. An analysis was performed to determine the equivalent thickness of a sodium bentonite clays, minimum hydraulic conductivity of $1x10^{-9}$ cm/sec, with a 24-inch clay layer with a hydraulic conductivity of $1x10^{-7}$ cm/sec. The results indicate that a 0.1-inch thickness of sodium bentonite clay has an equivalent level of protection as the 24-inch clay layer with a hydraulic conductivity (K, also known as permeability) of $1x10^{-9}$ cm/sec. Calculations for the equivalent thickness are provided in the calculation section following this part of the Design Analysis.

c. Product Selection. Three sodium bentonite products have been researched and are recommended for usage on this project; Gundseal, which incorporates a 40 mil HDPE liner with sodium bentonite glued to the liner; Claymax, a sodium bentonite clued to a filter fabric; and Bentomat, a sodium bentonite sewn between filter fabric. Various technical articles and technical literature for these products are provided in Appendix E.

CALCULATIONS

CANNON AIR FORCE BASE, CELL #3 OF LANDFILL #5, SOIL CAP
HYDROLOGY
14 JULY 1992

Cannon Air Force Base, approximately 7 miles west of the city of Clovis, lies at the headwaters of the Brazos River. Landfill #5, encompassing 40 acres, is located near the southeast corner of the base. The Rational Method for computation of runoff from small watersheds provided the 100-year and 25-year discharges for the landfill #5 site. The Rational Method is expressed as:

$$Q = CIA$$

where:
- Q = Maximum runoff from a given area in cubic feet per second
- C = Coefficient representing the ratio of runoff to rainfall
- I = Intensity of rainfall in inches per hour for the estimated time of concentration
- A = Drainage area in acres

The derivation of this equation assumes that the maximum rate of runoff from a given rainfall intensity occurs when all parts of the basin are contributing. The time of concentration describes the period of time it takes a particle of water to travel from the most distant point in the watershed to the basin outlet. For this study, the time of concentration was calculated from the formula developed by Kirpich describing the relationship between the time of concentration Tc and a watershed factor K based on the length and slope of the basin:

$$Tc = 0.0078K^{0.770} \qquad \text{and} \qquad K = L/S^{0.5}$$

where:
- L = Maximum length of travel in feet
- S = Slope H/L
- H = Difference in elevation between the most remote point and the basin outlet in feet

Surface drainage in the vicinity of the landfill flows generally to the south. The maximum length of travel for the 40-acre site is 1600 feet, and the slope measures 3%. The formula computes a time of concentration for the site of approximately 10 minutes.

With the time of concentration established at 10 minutes and set equal to the critical storm duration, the rainfall intensity for a 10-minute duration must be determined. NOAA Atlas 2, "Precipitation-Frequency Atlas of the Western United States, Volume IV, New Mexico", provided the 100-year and 25-year 1-hour duration rainfall of 3.1 inches and 2.3 inches, respectively, for the Clovis area. Technical Paper No. 25, "Rainfall Intensity-Duration-Frequency Curves for Selected Stations in the United States, Alaska, Hawaiian Islands, and Puerto Rico", provided rainfall intensity-duration-frequency curves for two nearby stations at Roswell, New Mexico, and Amarillo, Texas. Whereas the respective 100-year and 25-year frequency-intensity-duration curves for Roswell and Amarillo are parallel, similar curves for Clovis were drawn, also parallel to the Roswell and Amarillo curves, but with the 100-year and 25-year 1-hour intensities plotted at 3.1 inches and 2.3 inches, respectively. The plotted curves for Clovis produced a rainfall intensity of 7.0 inches for a 100-year frequency, 10-minute duration storm and a rainfall intensity of 5.7 inches for a 25-year frequency, 10-minute duration storm.

The "C" value used in the rational method expresses as a ratio the percentage of rainfall that is expected to run off. The basic value of "C" is taken from Table 1.

TABLE 1
SURFACE RUNOFF COEFFICIENTS

TYPE OF SURFACE	FACTOR (C)
Asphalt pavements	0.80 to 0.95
Concrete pavements	0.70 to 0.90
Gravel or macadam pavements	0.35 to 0.70
Impervious soils*	0.40 to 0.65
Impervious soils with turf*	0.30 to 0.55
Slightly pervious soils*	0.15 to 0.40
Slightly pervious soils with turf*	0.10 to 0.30
Pervious soils*	0.01 to 0.10
Wooded areas	0.01 to 0.20

* For slopes from 1% to 2%

For slopes greater than 2%, those values marked with an asterisk (*) must be corrected using the following formula:

$$(\text{Average Slope} - 2)\ 0.01 + C_{assumed} = C_{corrected}$$

The 40-acre landfill site contains soils defined as SM and ML based on the Unified Soil Classification System (USCS). According to the USCS, soils of type SM and ML have drainage characteristics which range from fair to poor; soils with fair to poor drainage correspond to slightly pervious soils in Table 1. Based on soil types and drainage characteristics, a conservative "C" value of 0.40 is assumed for landfill site #5; however, this value adjusts to 0.41 based on the 3% slope correction.

Based on the rational method and the coefficients determined above, the 100-year and 25-year discharges for the 40-acre landfill site compute as follows:

$$Q_{100} = CIA = (0.41)(7.00 \text{ inches/hour})(40 \text{ acres}) = 115 \text{ cfs}$$

$$Q_{25} = CIA = (0.41)(5.70 \text{ inches/hour})(40 \text{ acres}) = 90 \text{ cfs}$$

In summary, the 100-year discharge is 115 cfs and the 25-year discharge is 90 cfs for the 40-acre landfill #5 site at Cannon Air Force Base.

100-year P

COMPUTATION SHEET

Project Canon AFB - [illegible] Industry File _____

Project Curry Hill Computed by [illegible] Date [illegible] Checked By _____ Date _____ Book No. _____

Rational Method: $Q = CIA$

A = Area = 40 acres

I = Rainfall Intensity (100-yr) = 7.00" / hour
for Curry Hill
10 minute storm (3% slope)

C = Runoff Coefficient = 0.41

$Q = CIA$

$Q = (0.41)(7.00"/\text{hour})(40 \text{ acres})$

$Q = 115$ cfs

100-year runoff from 40 acre area ≈ 115 cfs

Determination of 100-yr Q with 3% slope

COMPUTATION SHEET

Project Q=CIA from "Engineering Hydraulics" (by Rouse) File _____

Project Canon AFB HQ (Cross) Computed by PK Date July 92 Checked By _____ Date _____ Book No. _____

Q = CIA

A = area = 40 acres

L = Maximum length of travel in feet = 1600 feet

H = Elevation between most remote point & outlet = 5 feet

S = Slope = 3% (determined by Mark Wilhoch)

K = L/√S = 9238

T_c = 0.0078 $K^{0.770}$ = 882 minutes ≈ 10 minutes

I = Intensity = 7.00" / hour

Intensity determined from TP-40 and NOAA Atlas for NM. Clovis is approximately half way between Roswell, NM & Amarillo, Tx. When the Amarillo intensity curve is superimposed on the Roswell ref intensity curve, the midpoint value between the two for the 100-yr 1-Hr value is ≈ 3.00" / hour. NOAA Atlas provides a 3.10" / hour 100-yr 1-Hr value for Clovis; because these values are similar I interpolated between the two curves to determine the 10 minute ref intensity value.

C = Runoff Coefficient = 0.41

from Corps of Engineers "Runoff Coefficients" for Clovis (assumed soil type SM & ML)

Slope adjustment = (S − 2)(0.01) + (assumed) = (Corrected)

(3 − 2)(0.01) + 0.40 = 0.41

Q = CIA

Q = (0.41)(7.00"/hr)(40 acres)

Q = 115 cfs

25-year C

COMPUTATION SHEET

Project Corrin AFB - Hill Site - Addition File _____

Project Clovis, NM Computed by PK Date 9 July 92 Checked By _____ Date _____ Book No. _____

Rational Method: Q = CIA

A = Area = 40 acres

I = Rainfall Intensity (25-year) = 5.50"/hour
for Clovis, NM
10 minute storm (3% slope)

C = Runoff Coefficient = 0.41

Q = CIA
Q = (0.41)(5.70"/hour)(40 acres)

Q = 93 cfs

25-year runoff from 40 acre area = 90 cfs

Determination of 25-yr Q on 3% Slope

COMPUTATION SHEET

Project Q = CIA from "Engineering Hydraulics" (by Rouse) File _____

Project Cannon AFB HWD (Clovis) Computed by RA Date 9 July 92 Checked By _____ Date _____ Book No. _____

Q = CIA

A = Area = 40 acres

L = Maximum length of travel in feet = 1600 feet

H = Δ Elevation between most remote point & outlet = 5 feet

S = Slope = 3% (Determined by Mark Wittrock)

K = L/√S = 9238

Tc = 0.0078 K^0.77 = 8.82 minutes ≈ 10 minutes

I = Intensity = 5.70"/Hour

Intensity determined from TP-40 and NOAA Atlas for New Clovis is approximately half way between Roswell, NM & Amarillo, TX. When the Amarillo 25 intensity curve is superimposed on the Roswell 25 intensity curve, the midway value between the two curves for the 25-yr 1-Hr value ≈ 2.30"/hour. NOAA Atlas provides a 2.30"/hour 25-yr 1-Hr value for Clovis. Because these two values are similar I assumed the Clovis intensity curve to be equidistant between the Roswell & Amarillo curves.

C = Runoff Coefficient = 0.41

from Corps of Engineers "Surface Runoff Coefficient" for slightly pervious soils (soil types SM & ML)
slope adjustment = (S-2)(0.01) + C assumed = C corrected

Q = CIA

Q = (0.41)(5.70"/hour)(40 acres)

Q = 93 cfs

Rainfall Intensity - Duration

COMPUTATION SHEET

ject Determination of 100-yr Rainfall from NOAA Atlas II File _____

Project Cannon AFB HTW Computed by [illegible] Date 24 July 90 Checked By _____ Date _____ Book No. _____

Determination for Clovis, NM (Region I)

2-yr 6-Hour precipitation = 2.00"
2-yr 24-Hour precipitation = 2.40"

100-yr 6-Hour precipitation = 4.60"
100-yr 24-Hour precipitation = 6.00"

Elevation = 4261' = 43 hundred feet

2-yr 1-Hour precipitation = $0.218 + 0.709\left[(2.00)\left(\frac{2.00}{2.40}\right)\right]$

2-yr 1-Hour precipitation = 1.40"

100-yr 1-Hour precipitation = $1.897 + 0.439\left[(4.60)\left(\frac{4.60}{6.00}\right)\right] - 0.008(43)$

100-yr 1-Hour precipitation = 3.10"

From graph 25-yr, 1-Hour Rainfall = 2.30"

Determination of time of concentration

In an attempt to apply the results of Ramser's research to other areas, Kirpich found a relation between the time of concentration (as defined by Ramser) and a watershed factor based on the length and slope of the basin and reproduced in Fig. 37 [52]. An extension of this relation has been developed by the California Department of Public Works on the basis of studies by the U. S. Soil Conservation Service

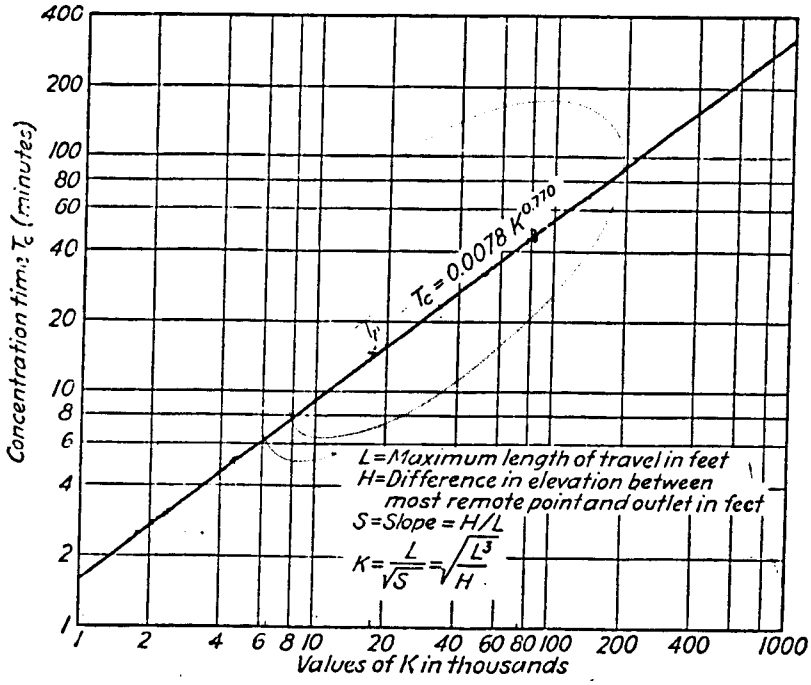


FIG. 37. Time of concentration of small agricultural drainage basins.

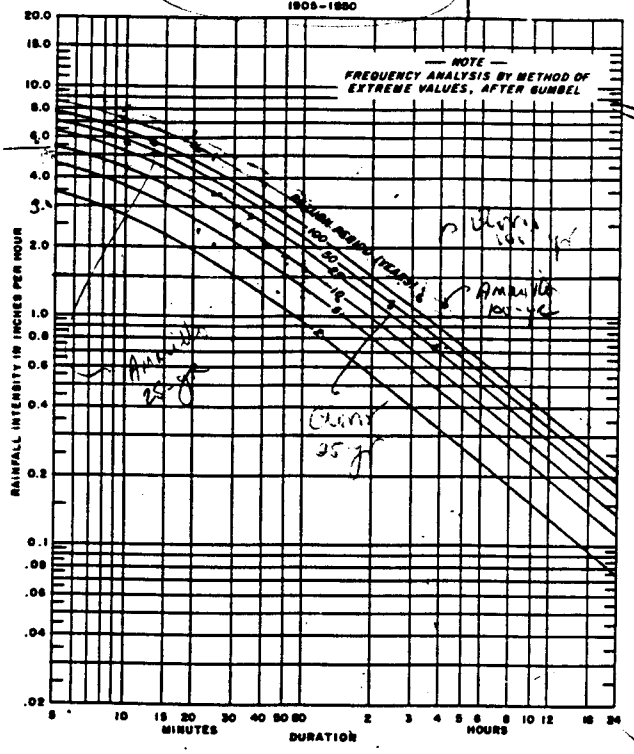
in California [53]. The upper end of the curve in Fig. 37 is defined by these studies. Published data obtained by the U. S. Soil Conservation Service at other locations unfortunately do not give the necessary watershed factors [54]. It is important to bear in mind that the time of concentration as given by Fig. 37 is the time of peak T_p observed (on the average) on natural areas from intense non-uniform rainfalls.

43. Coefficient of Runoff. Extensive studies of the runoff coefficient made by W. W. Horner and F. L. Flynt [55] were based on 20 years of records of rainfall and storm-sewer discharges from three urban areas varying in size from 2.3 acres to 4.3 acres and having different degrees of development. In brief, conclusions based on these studies are:

P.E.
ing Branch

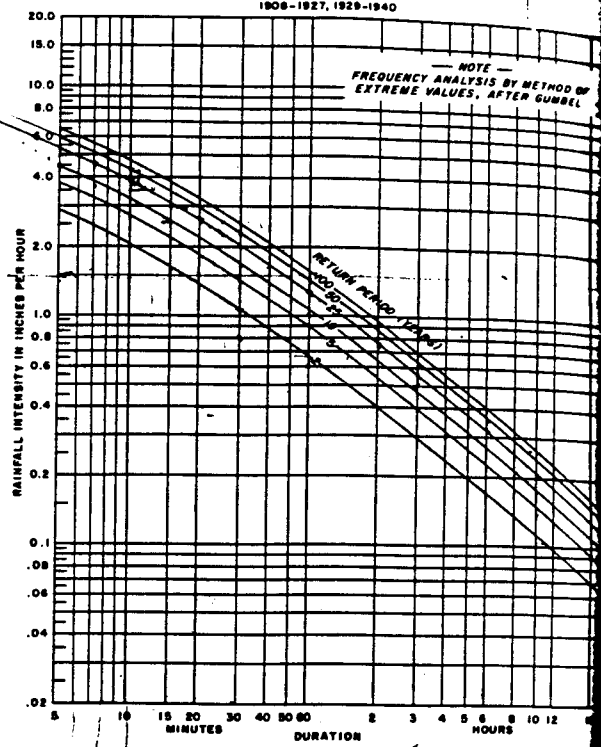
RAINFALL INTENSITY– DURATION–FREQUENCY CURVES

ROSWELL, NEW MEXICO
1905–1950

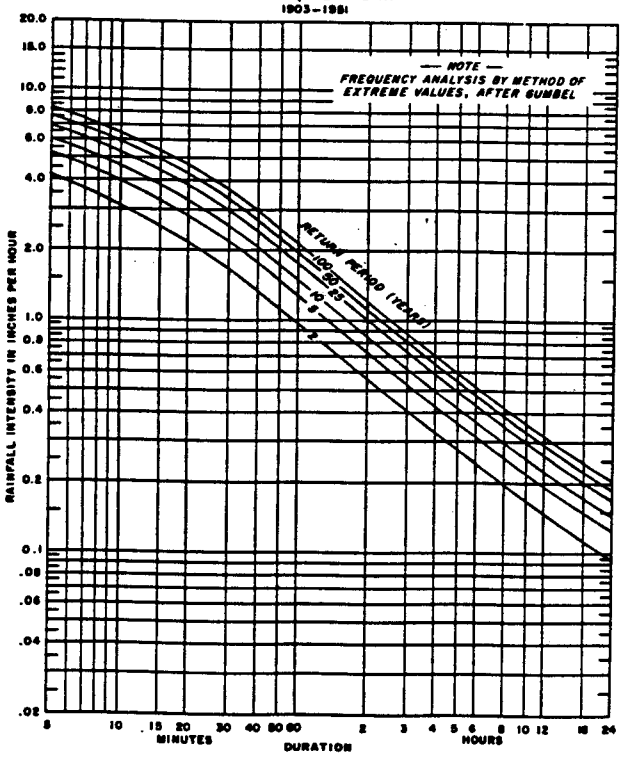


5.40" @ 20 min

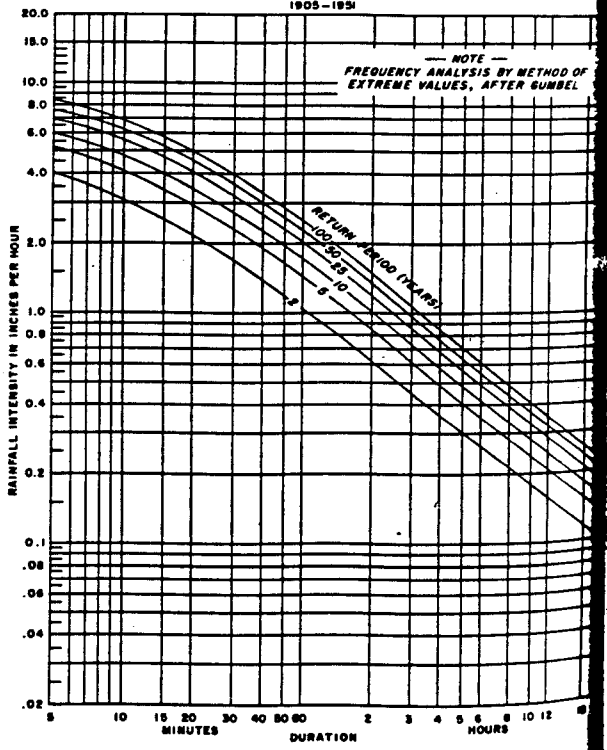
SANTA FE, NEW MEXICO
1908–1927, 1929–1940



ALBANY, NEW YORK
1903–1951

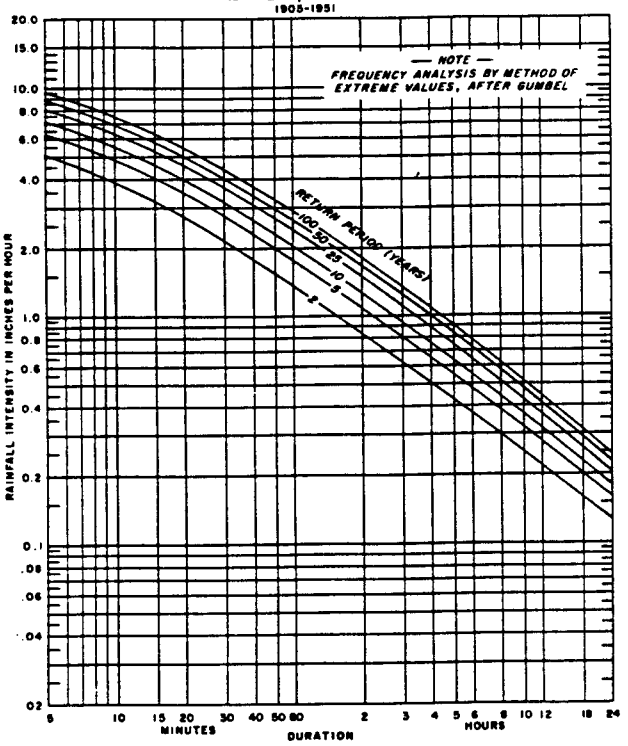


BINGHAMTON, NEW YORK
1905–1951

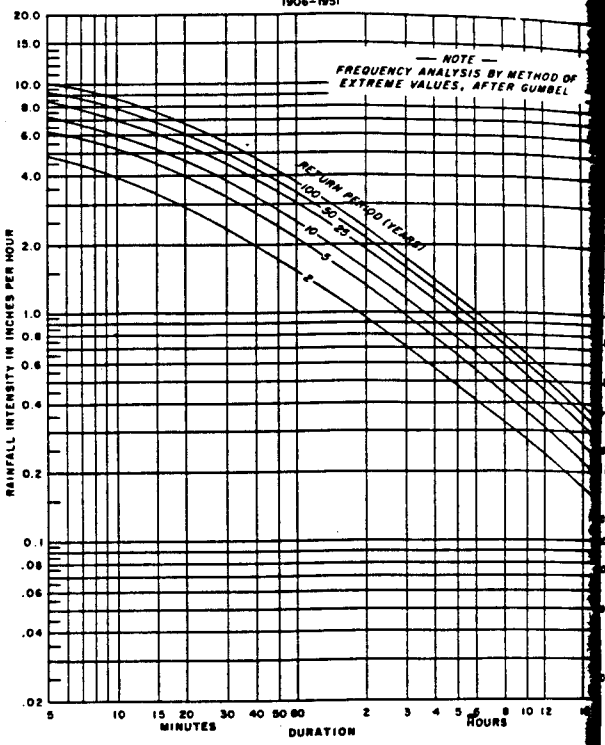


RAINFALL INTENSITY-DURATION-FREQUENCY CURVES

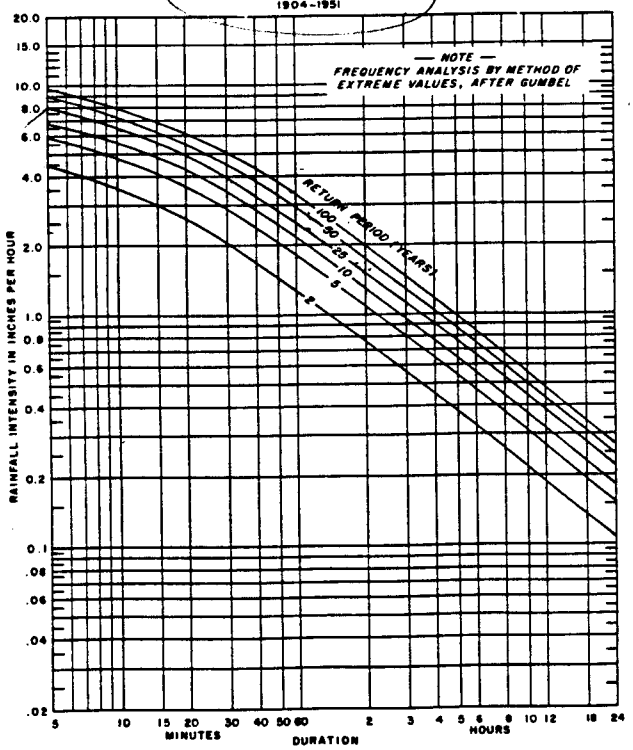
NASHVILLE, TENNESSEE
1905-1951



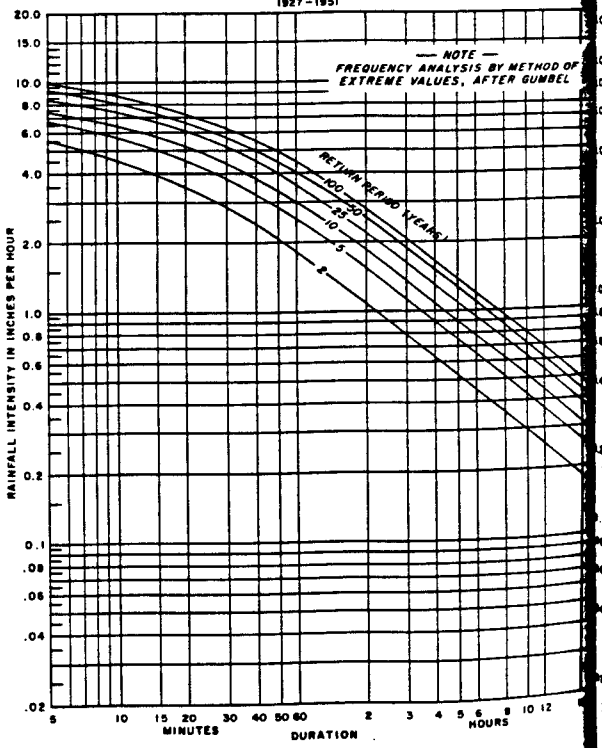
ABILENE, TEXAS
1906-1951



AMARILLO, TEXAS
1904-1951



AUSTIN, TEXAS
1927-1951



r (oil and
ol d from

essary charts,
gn of the vari-
t construction

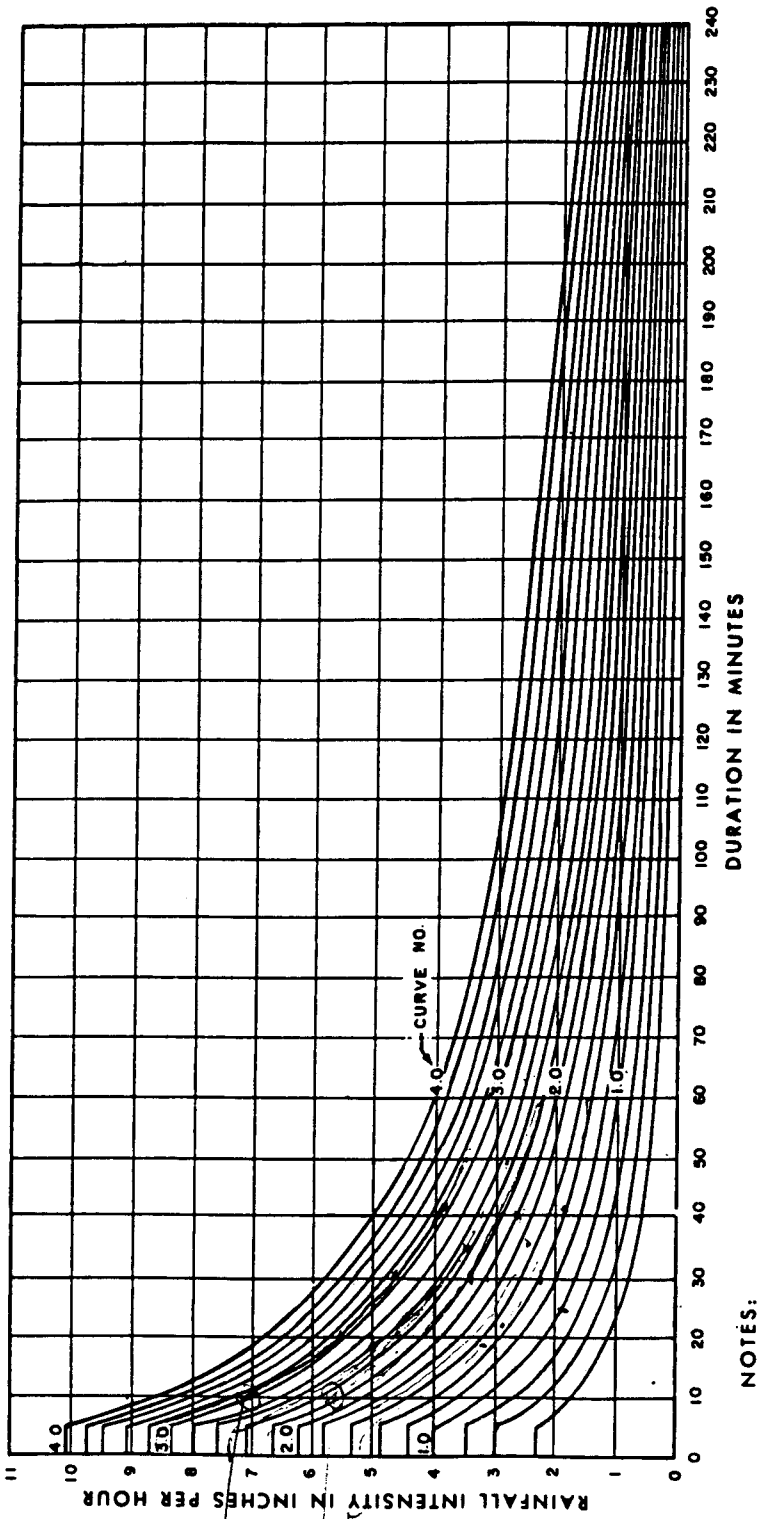
ANCE

hould provide
n beyond that
ragraph. Such
because many
ge can be ob-
ite. In many
age paths in-
rainfall. Pud-
-plant growth
portion of the
nadequate for
cracked earth
h evaporation
s subsoil and
ge jacent
lev e the
letermine the
Similarly, in
of high tide
the drainage
ble overflow.
e from steep
high ground-
or. The type,
cover should
r absence of
unoff charac-

DRAINAGE

the type of
er resources
reliability of
e degree of
steps are es-

tor aphic
eas may



100-yr, 10 minute = 7.00"

25-yr, 10 minute = 5.70"

close as check for rainfall intensities

NOTES:
1. Curve numbers correspond to one-hour values of rainfall or supply indicated by respective curves.
2. All points on the same curve are assumed to have the same average frequency of occurrence

Figure 1-5. Standard rainfall intensity-duration curves.

TABLE 2-2. *Surface Runoff Coefficients*

TYPES OF SURFACE	FACTOR (C)
Asphalt pavements	0.80 to 0.95
Concrete pavements	0.70 to 0.90
Gravel or macadam pavements	0.35 to 0.70
Impervious soils*	0.40 to 0.65
Impervious soils with turf*	0.30 to 0.55
Slightly pervious soils*	0.15 to 0.40
Slightly pervious soils with turf*	0.10 to 0.30
Pervious soils*	0.01 to 0.10
Wooded areas (depending on surface slope and soil cover)	0.01 to 0.20

*For slopes from 1 to 2 percent.

NOTE: The figures given are for comparatively level ground. For slopes greater than 2%, the factor should be increased by 0.01 for every 1 percent of slope, up to a maximum C of 1.0.

Use of "C" Value Table

1. Determine drainage characteristics of soil type(s).
2. Correlate terminology with terms used in "C" value table (Terms correlated in paragraph 2-7a(2)).
3. Locate the soil and/or cover type in the left column of table 2-2. Read the highest value of the range listed in the column at the right for that type of soil and/or cover.
4. This is the "C" assumed value. For slopes greater than 2%, those values marked with an asterisk (*) must be corrected using the following formula:

$$(S_{average} - 2)\ 0.01 + C_{assumed} = C_{corrected}$$

Excellent → Pervious
Fair to Poor → Slightly Pervious
Poor to Practically Impervious → Impervious

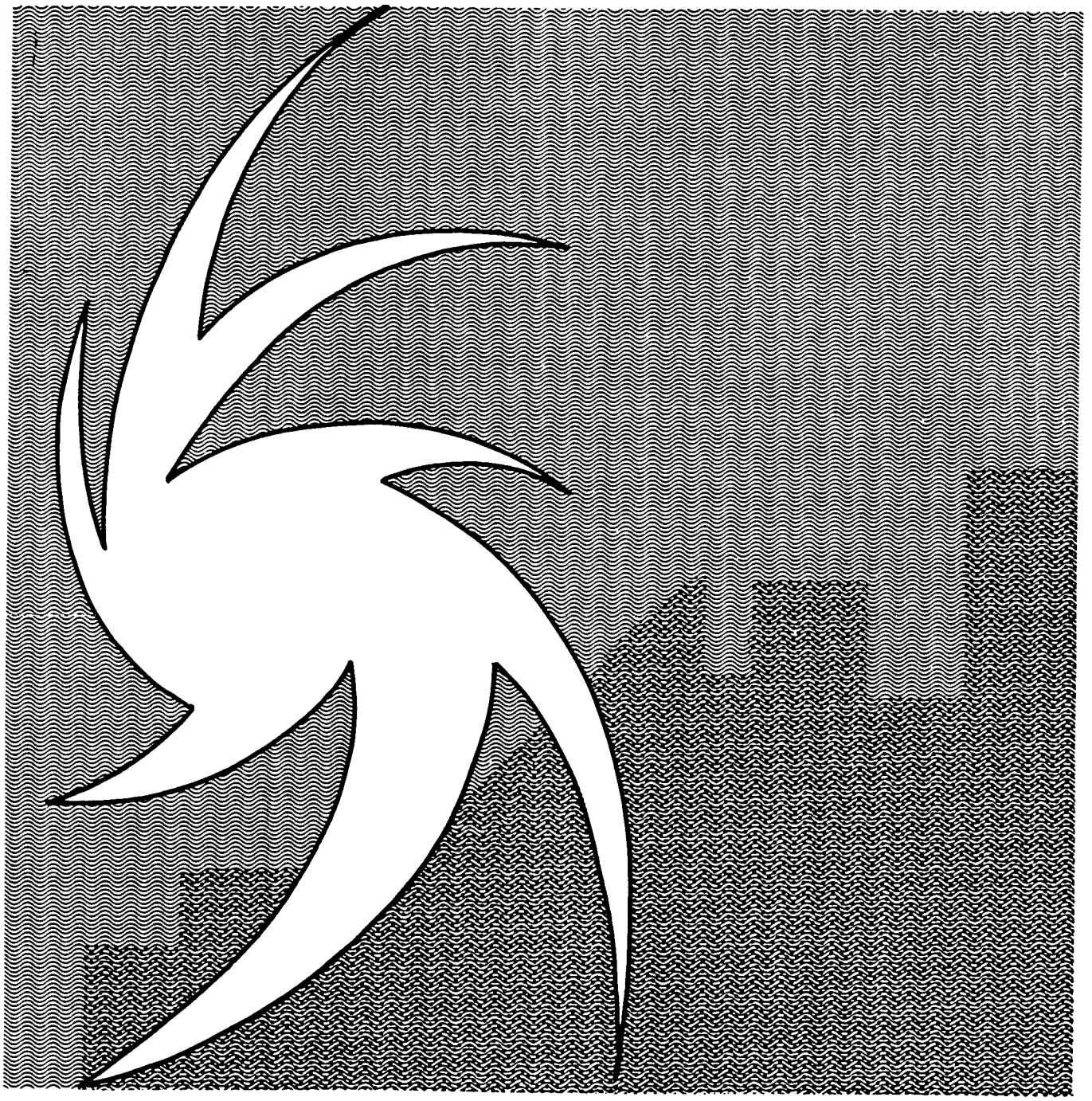
for table 2.2

TABLE 2-3. *USCS Soil Characteristics (Extract)*

MAJOR DIVISIONS (1)	(2)	LETTER (3)	DRAINAGE CHARACTERISTICS (11)
Coarse Grained Soils	Gravel and Gravelly Soils	GW	Excellent
		GP	Excellent
		GM d	Fair to Poor
		GM u	Poor to Practically Impervious
		GC	Poor to Practically Impervious
	Sand and Sandy Soils	SW	Excellent
		SP	Excellent
		SM d	Fair to Poor
		SM u	Poor to Practically Impervious
		SC	Poor to Practically Impervious
Fine Grained Soils	Silts and Clays LL < 50	ML	Fair to Poor
		CL	Practically Impervious
		OL	Poor
	Silts and Clays LL > 50	MH	Fair to Poor
		CH	Practically Impervious
		OH	Practically Impervious
Highly Organic Soils		Pt	Fair to Poor

CLIMATOGRAPHY OF THE UNITED STATES NO. 20

Climate of Clovis, New Mexico



noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / ENVIRONMENTAL DATA SERVICE / NATIONAL CLIMATIC CENTER ASHEVILLE, N.C. AUGUST 1976

LATITUDE N34 26

LONGITUDE W103 12

CLIMATOLOGICAL SUMMARY

MEANS AND EXTREMES FOR PERIOD 1951-1974

CLOVIS, NM

ELEVATION 4280

MONTH	TEMPERATURE (°F) MEANS: DAILY MAXIMUM	DAILY MINIMUM	MONTHLY	EXTREMES: RECORD HIGHEST	YEAR	DAY	RECORD LOWEST	YEAR	DAY	MEAN NUMBER OF DAYS: MAX. 90° AND ABOVE	MAX. 32° AND BELOW	MIN. 32° AND BELOW	MIN. 0° AND BELOW	PRECIPITATION TOTALS (INCHES): MEAN	GREATEST MONTHLY	YEAR	GREATEST DAILY	YEAR	DAY	SNOW, SLEET: MEAN	MAXIMUM MONTHLY	YEAR	GREATEST DEPTH	YEAR	DAY	MEAN NUMBER OF DAYS: .10 or MORE	.50 or MORE	1.00 or MORE
JAN	52.3	22.9	37.6	79	74	18	-12	63	13	0	3	27	1	.45	1.76	68	1.02	68	21	2.2	10.9	58	9.0	58	5	1	0	0
FEB	55.5	25.8	40.7	83	62	13	-17	51	1	0	2	22	0	.46	1.32	56	.70	51	25	2.9	13.0	64	10.0	64	5	2	0	0
MAR	62.3	31.4	46.9	88	63	29	7	60	3	0	1	17	0	.65	2.21	61	1.39	73	10	1.6	8.8	69	6.0	61	19	2	0	0
APR	72.2	40.3	56.3	95+	65	23	15	73	8	0	0	5	0	.70	3.06	52	1.25	71	16	.1	3.1	66	3.0	66	5	2	0	0
MAY	80.9	49.6	65.3	100	53	27	27	54	3	5	0	0	0	1.68	5.57	69	2.90	69	6	.0						3	1	0
JUN	89.1	58.5	73.8	108	68	28	41+	64	1	16	0	0	0	2.54	6.16	63	3.00	63	2	.0						4	2	1
JULY	91.2	63.0	77.1	105+	58	15	50	64	13	21	0	0	0	3.03	13.44	60	3.46	60	9	.0						5	2	1
AUG	89.3	61.0	75.2	103	69	18	48	56	21	18	0	0	0	2.49	6.13	54	3.32	54	22	.0						5	1	1
SEPT	82.8	53.6	68.3	100	51	3	34	70	26	7	0	0	0	1.89	6.72	58	5.26	57	7	.0						3	1	1
OCT	73.4	43.0	58.2	98	51	2	23	69	13	1	0	2	0	1.71	6.76	60	2.42	74	23	.0						3	1	0
NOV	60.9	31.7	46.3	84	67	16	0	52	26	0	1	16	0	.54	2.32	61	.95	71	17	1.3	8.0	52	7.0	52	25	2	0	0
DEC	53.2	25.0	39.1	77	58	5	-4	61	12	0	2	27	0	.53	2.18	59	.96	59	17	3.8	14.0	60	9.0	67	16	2	0	0
YEAR	71.9	42.2	57.1	108	JUN 68	28	-17	FEB 51	1	68	9	116	1	16.67	13.44	JUL 60	5.26	SEP 57	7	11.9	14.0	DEC 60	10.0	FEB 64	5	34	8	4

+ ALSO ON EARLIER DATES

FREEZE PROBABILITIES

PROBABILITY OF LATER DATE IN SPRING (MO/DA) THAN INDICATED

TEMP	.10	.20	.30	.40	.50	.60	.70	.80	.90
32	5/ 4	4/29	4/25	4/22	4/18	4/15	4/12	4/ 8	4/ 3
28	4/22	4/17	4/13	4/10	4/ 7	4/ 4	4/ 1	3/28	3/23
24	4/10	4/ 5	4/ 1	3/29	3/26	3/23	3/20	3/16	3/11
20	4/ 2	3/27	3/22	3/18	3/15	3/11	3/ 7	3/ 2	2/24
16	3/30	3/20	3/13	3/ 6	3/ 1	2/23	2/16	2/ 9	1/30

0/ 0 PROBABILITY OF OCCURRENCE OF THRESHOLD TEMP IS LESS THAN INDICATED PROBABILITY

PROBABILITY OF EARLIER DATE IN FALL (MO/DA) THAN INDICATED

TEMP	.10	.20	.30	.40	.50	.60	.70	.80	.90
32	10/12	10/16	10/19	10/22	10/24	10/27	10/29	11/ 1	11/ 6
28	10/16	10/22	10/26	10/29	11/ 2	11/ 5	11/ 8	11/12	11/18
24	10/31	11/ 4	11/ 7	11/ 9	11/12	11/14	11/17	11/20	11/24
20	11/ 8	11/13	11/16	11/19	11/22	11/25	11/28	12/ 1	12/ 6
16	11/12	11/21	11/26	12/ 1	12/ 6	12/11	12/16	12/22	12/30

0/ 0 PROBABILITY OF OCCURRENCE OF THRESHOLD TEMP IS LESS THAN INDICATED PROBABILITY

PROBABILITY OF LONGER THAN INDICATED FREEZE FREE PERIOD (DAYS)

TEMP	.10	.20	.30	.40	.50	.60	.70	.80	.90
32	206	200	195	192	188	184	181	176	170
28	230	223	217	212	208	203	199	193	185
24	248	242	238	234	230	227	223	218	212
20	273	265	260	256	252	248	243	238	231
16	314	303	294	287	280	273	266	257	245

PRECIPITATION WITH PROBABILITY EQUAL OR LESS THAN

LVL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0.05	0.00	0.02	0.00	0.00	0.23	0.26	0.36	0.39	0.07	0.01	0.00	0.00
0.10	0.00	0.08	0.00	0.00	0.37	0.45	0.60	0.60	0.27	0.09	0.00	0.02
0.20	0.03	0.15	0.06	0.10	0.61	0.80	1.02	0.96	0.57	0.29	0.03	0.10
0.30	0.10	0.22	0.16	0.22	0.84	1.15	1.44	1.30	0.86	0.52	0.10	0.19
0.40	0.19	0.30	0.28	0.34	1.08	1.53	1.89	1.65	1.15	0.79	0.19	0.28
0.50	0.29	0.37	0.41	0.49	1.35	1.96	2.38	2.04	1.47	1.12	0.31	0.38
0.60	0.41	0.46	0.58	0.66	1.66	2.46	2.97	2.49	1.86	1.52	0.45	0.50
0.70	0.56	0.57	0.80	0.88	2.04	3.08	3.68	3.01	2.32	2.06	0.64	0.65
0.80	0.78	0.71	1.10	1.18	2.54	3.92	4.64	3.72	2.94	2.81	0.92	0.86
0.90	1.14	0.96	1.62	1.67	3.40	5.37	6.28	4.93	4.00	4.12	1.41	1.21
0.95	1.52	1.18	2.15	2.17	4.16	6.69	7.76	5.99	4.96	5.43	1.91	1.56

MEDIAN PRECIPITATION AMOUNTS (0.50 PROBABILITY LEVEL) IN THIS TABLE DIFFER FROM THE MEANS SHOWN IN THE ABOVE TABLE BECAUSE OF THE METHOD USED IN MAKING THE COMPUTATIONS. THESE VALUES WERE DETERMINED FROM THE INCOMPLETE GAMMA DISTRIBUTION WHOSE CURVE HAS BEEN FOUND TO GIVE BEST FITS TO PRECIPITATION CLIMATOLOGICAL SERIES.

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

In Cooperation with the UNM Bureau of Business Research

LATITUDE: 34° 24' N
LONGITUDE: 103° 12' W
ELEV. (GROUND): 4280 Ft.

CLIMATOLOGICAL SUMMARY

STATION: CLOVIS
NEW MEXICO

MEANS AND EXTREMES FOR PERIOD OF RECORD: 1931 - 1960

Month	Temperature (°F) Means: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	** Mean degree days	Precipitation Totals (Inches): Mean	Greatest daily	Year	Snow, Sleet: Mean	Maximum monthly	Year	Greatest daily	Year	Mean number of days: Precip. .10 inch or more	Temperatures: Max. 90° and above	Max. 32° and below	Min. 32° and below	Min. 0° and below	Month
(a)	30	30	30	30	--	30	--	30	30	30	--	30	30	--	30	--	30	30	30	30	30	(a)
Jan.	51.0	23.8	37.4	77	1950+	- 4	1959+	860	0.55	1.60	1939	2.4	8.0	1946+	8.0	1946	2	0	2	28	*	Jan.
Feb.	55.8	26.8	41.3	81	1940+	-17	1951	660	0.41	0.69	1956	1.0	4.7	1933	4.0	1940	1	0	1	21	*	Feb.
Mar.	62.4	31.8	47.2	90	1943	- 4	1958	550	0.49	1.45	1941	0.7	5.2	1934	5.0	1934	1	*	1	15	*	Mar.
Apr.	72.1	41.3	56.7	99	1936	14	1945	270	0.92	1.77	1941	0.3	2.8	1949	2.8	1949	2	1	*	4	0	Apr.
May	80.6	50.7	65.6	101	1938	27	1954	80	2.51	3.45	1936	0.2	4.5	1935	2.4	1935	4	5	0	*	0	May
June	90.8	60.1	75.4	106	1942+	41	1955	0	2.29	2.80	1941	0	0	--	0	--	4	19	0	0	0	June
July	93.3	63.7	78.5	109	1940	51	1954	0	2.64	3.46	1960	0	0	--	0	--	5	23	0	0	0	July
Aug.	92.2	62.7	77.4	110	1944	48	1956	0	2.62	4.36	1932	0	0	--	0	--	4	22	0	0	0	Aug.
Sept.	85.3	55.0	70.2	105	1939+	31	1945	40	2.10	5.26	1957	0	0	--	0	--	3	10	0	*	0	Sept.
Oct.	74.3	44.3	59.3	98	1951	24	1949+	220	1.89	3.65	1942	0.2	5.0	1936	5.0	1936	3	1	0	2	0	Oct.
Nov.	60.9	31.4	46.3	85	1932+	0	1952	560	0.46	1.46	1935	0.6	5.6	1931	5.6	1931	1	0	1	17	*	Nov.
Dec.	53.0	25.8	39.4	78	1948+	- 4	1950	790	0.59	1.88	1943	2.4	11.3	1931	7.4	1931	2	0	2	26	*	Dec.
Year	72.6	43.1	57.9	110	Aug. 1944	-17	Feb. 1951	4030	17.47	5.26	Sept. 1957	7.8	11.3	Dec. 1931	8.0	Jan. 1946	32	81	7	113	1	Year

* Less than one half.

** Base 65° F (estimated).

(a) Average length of record, years.

T Trace, an amount too small to measure.

+ Also on earlier dates, months, or years.

ϕ Partial year's record considered.

CLIMATE OF CLOVIS, NEW MEXICO

The city of Clovis is located in the extreme southeastern portion of Curry County in east-central New Mexico near the State's east border. Founded by the Santa Fe Railway engineers in 1906 and incorporated in 1909, it is the county seat. Clovis is surrounded by the Eastern New Mexico High Plains, gently rolling and generally level except for breaks along various watercourses. The area is one of extensive farming and stock raising; and cotton, truck, and feed crops are grown under irrigation pumped from abundant underground water supplies, while winter grains and summer feed crops are raised in dry-land farming areas. Stock raising plays an important part in the area economy, and Clovis is one of the largest livestock markets and commercial feeding centers in the Southwest. Clovis Air Force Base, a permanent installation, is located adjacent to the city.

Situated near the southwestern edge of the Great Plains, Clovis has a semiarid continental climate, little influenced by the topography except for an occasional upslope movement of air in the winter, which may produce low cloudiness, rain, and possible icing for several hours. Otherwise, winters are dry and sunny with mild daytime temperatures but night minima usually well below freezing. Few of the cold arctic outbreaks which sweep across the northern plains in winter penetrate so far south and west, so that there are on an average only seven days a year when shade temperatures remain below freezing. In the 30 years of record summarized here, only 23 days had minimum readings of zero or below. Winter precipitation totals average about one-half inch per month, with less than 20 per cent of the year's moisture falling in the November-April period. Some of this precipitation falls as snow; yet the average in December and January, the snowiest months, is only 2.4 inches, and snow seldom lies on the ground more than a few hours.

Summer is the rainy season, with 80 per cent of the year's moisture falling during the May-September months. Much of this precipitation comes during brief but sometimes heavy thundershowers, accompanied by considerable lightning, some hail, and briefly strong winds. Throughout 40 years of tornado records for New Mexico only two small tornadoes have been recorded in the Clovis area: the first on June 10, 1932, caused property damage estimated at $15,000; the other on September 17, 1944, caused damage estimated at $25,000. No deaths or injuries resulted. Although July and August are the rainiest months, only four or five days each month bring as much as one-tenth inch of rain. Daytime temperatures in June, July, and August average above 90°, but only 12 days a year on an average have temperatures of 100° or higher. Daily readings range from quite high levels to ones averaging 30° lower than the highs.

Clovis has an average growing season of 195 days, beginning with April 15, the average date of the last freeze, and ending on October 28, the average date of the first freeze. Sunshine, relative humidity, and wind records are not available for Clovis. The following information is taken from records at stations in that general area and are considered applicable to Clovis: the sun normally shines between 70 per cent and 80 per cent of the possible hours, with winter months usually clear and sunny; relative humidities range from about 70 per cent in early morning to about 40 per cent in late afternoon and are usually much lower during periods of high or low temperatures, thereby making such extremes less uncomfortable; wind velocities average about 12 miles per hour, with the prevailing direction being southerly and southwesterly. Late winter and spring are the windiest seasons, with occasional gusts ranging from 30 to 40 miles per hour, bringing considerable dust for several hours.

Although weather records began in Clovis in June 1911, only the years 1931 through 1960 are included in this summary. (See Station History at left.) The roof exposures in effect from September 1944 to February 1951 probably resulted in minimum temperature readings slightly higher than a ground exposure would have given. Extreme values are published for the 30-year period, but the following extremes were noted in earlier records:

(Continued Under Precipitation Table)

STATION: 29 1939 — MAX TEMP — CLOVIS, NM

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
51	50.8	55.1	60.4	71.1	78.8	87.8	93.9	93.2	85.9	76.0	57.9	52.2	71.9
52	56.0	57.7M	60.0M	69.3	79.6M	92.3	89.4	94.0	82.7M	75.3	54.8M	51.3	71.9M
53	60.6	54.9	67.7M	71.9	78.5	96.0	93.0	89.4	88.3	74.2	62.5	49.2	73.9M
54	55.1	63.8	61.4	76.8	76.9	91.2	95.6	90.1	86.4	73.2	65.6	57.1	74.4
55	50.1	54.2	63.3	72.0	78.1M	86.9	87.6	90.0	85.2	74.5	62.5	57.2	71.8M
56	55.4	49.3	66.5	71.7	84.5	91.5	91.8	89.8	89.8	77.5	60.0	57.1	73.7
57	52.4	61.4	61.1	66.9	74.9	86.4	93.7	89.7	81.6	67.2	52.4	58.7	70.5
58	47.8	55.6	51.1	66.0	80.8M	90.2	92.7	91.8	81.5	68.4	64.7	56.0	70.6M
59	53.0	52.7	62.0	69.5	80.0	88.5	88.4	90.4	87.4	70.9	57.7	52.7	71.1
60	46.2	48.3	60.1	75.6	81.0	90.0	87.0	89.4	84.5	72.7	64.4	44.6	70.3
61	49.7	56.6	62.0	71.2	82.1	88.6	88.0	87.8	81.1M	76.1	51.3	51.3	70.5M
62	47.9M	63.8	59.7	73.2	86.4	88.1M	89.7	93.2	82.2	75.2	63.6	54.2	73.1M
63	48.9	57.4	65.4	77.5	82.4	85.7M	94.1E	89.1M	84.6	80.5	64.9	49.7	73.4M
64	52.7	46.6	61.1	73.5	82.7	90.6E	94.8	91.6	80.7	76.2M	60.6	52.2	71.9M
65	57.1	52.3	54.7	73.6	81.6E	86.8M	92.2	88.4	83.1	75.6	68.3	56.4	72.5M
66	46.7	51.4	66.9	71.7	80.1	86.7M	95.3M	84.9	81.6	71.2M	66.4	53.0	71.3M
67	54.9	57.2	70.0M	79.7	84.0	87.0	90.9	87.5	83.0	77.8	64.1	48.5	73.7M
68	54.0	55.2	63.2	72.1	82.2	93.4	88.7	88.1	82.8	75.4	57.6	54.4	72.3
69	58.7	54.9	52.3	72.5	79.7	85.9	94.7	92.8	81.0	65.9	61.0	56.1	71.3
70	50.0	57.7	57.0	69.9	82.2	86.5	89.2	90.6	80.8	68.3	62.4M	59.1	71.1M
71	54.8	55.0	65.5	72.2	81.6	90.4	90.5	82.5	78.7	71.6	62.2	51.5	71.4
72	55.3	59.9	72.4	76.7	78.6	88.7	87.1	84.7	82.0	71.3	50.8	49.8	71.4
73	45.3	51.6	59.8	63.9	77.4	87.6	84.0	89.7	80.3	75.6	67.4	56.2	70.2
74	52.2	58.3	70.7	73.9	87.2	90.5	91.7	84.7	72.5	70.1	58.4	49.1	71.6
SUM	1255.6	1330.9	1494.3	1732.4	1941.3	2137.3	2188.0	2143.4	1987.7	1760.7	1461.5	1277.6	1725.8

STATION: 29 1939 — MIN TEMP — CLOVIS, NM

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
51	21.2	25.2	30.2	38.5	49.1	57.1	63.3	62.1	53.0	42.6	29.1	25.0	41.4
52	25.8	27.5M	30.4M	41.4	50.5M	63.4	63.0	64.7	52.3M	40.3	27.7M	25.2	42.7M
53	30.1	25.5	36.6	39.1	48.4	64.0	65.4	62.1	53.0	45.6	33.1	22.9	43.8
54	25.9	33.0	31.5	45.7	49.9	59.8	65.3	63.7	57.4	46.4	33.2	26.6	44.9
55	24.5	21.4	30.9	41.2	47.6M	55.4	63.4	61.4	56.1	43.7	30.6	27.0	41.9M
56	25.4	21.9	32.5	38.0	52.7	61.9	62.5	60.2	53.2	45.2	28.3	26.2	42.3
57	23.5	34.4	33.1	37.6	48.2	57.4	63.9	61.9	50.5	43.8	31.0	28.6	42.8
58	24.2	27.6	29.0	39.2	53.1M	60.7	63.6	62.8	56.6	43.9	31.6	22.5	42.9M
59	20.2	25.3	30.5	40.6	51.1	60.2	60.8	61.8	53.6	39.3	26.4	27.1	41.4
60	21.0	20.9	28.5	40.7	46.2	59.2	60.9	61.0	53.5	42.2	32.2	22.9	40.8
61	19.7	25.4	32.1	38.0	48.2	57.1	60.5	59.6	51.2	41.7	30.1	24.2	40.7
62	18.9M	28.8	28.1	40.6	51.6	56.7M	62.6	59.9	55.8	45.1	33.2	26.3	42.3M
63	13.5	26.9	33.0	43.3	51.3	57.5M	64.3E	61.4M	55.4	46.8	32.7	20.4	42.2M
64	21.2	19.7	28.1	38.8	50.3	55.7E	63.6	61.4	54.8	42.6M	31.6	23.7	41.0M
65	25.2	22.4	23.9	42.3	49.1E	57.1M	62.3	58.4	51.3	40.3	36.2	28.0	41.4M
66	18.4	22.1	34.0	40.9	48.9	58.0M	66.2E	60.6	55.3	41.0M	35.1	21.9	41.9M
67	24.1	26.7	37.7M	44.1	46.7	58.1	61.8	58.6	53.3	41.6	33.4	22.7	42.4M
68	25.6	26.9	32.8	38.5	48.4	57.7	62.9	61.5	52.1	44.3	33.3	23.7	42.3
69	25.3	28.7	27.1	44.2	51.1	57.5	65.5	63.5	56.9	41.1	31.0	28.2	43.3
70	21.9	29.4	28.4	38.5	49.8	56.7	63.7	60.8	52.8	38.3	32.2	28.0	41.7
71	25.5	25.1	30.9	40.0	48.3	59.4	62.3	59.0	52.3	43.5	33.7	27.8	42.3
72	23.0	25.7	36.5	41.7	49.3	58.9	60.9	58.7	54.5	43.3	26.4	21.0	41.7
73	21.6	24.9	33.0	34.5	47.0	56.0	61.8	60.2	52.4	43.7	33.8	24.6	41.1
74	22.8	24.4	35.9	40.6	53.0	58.1	62.2	59.6	50.1	45.0	34.2	24.8	42.6
SUM	548.5	619.8	754.7	968.0	1189.8	1403.6	1512.7	1464.9	1287.4	1031.3	760.1	599.3	1011.6

STATION: 29 1939 — AVERAGE TEMPERATURE — CLOVIS, NM

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
51	36.0	40.2	45.3	54.8	64.0	72.5	78.6	77.7	69.5	59.3	43.5	38.6	56.7
52	40.9	42.6M	45.2M	55.4	65.1M	77.9	76.2	79.4	67.5M	57.8	41.3M	38.3	57.3M
53	45.4	40.2	52.2M	55.5	63.5	80.0	79.2	75.8	70.7	59.9	47.8	36.1	58.9M
54	40.5	48.4	46.5	61.3	63.4	75.5	80.5	76.9	71.9	59.8	49.4	41.9	59.7
55	37.3	37.8	47.1	56.6	62.9M	71.2	75.5	75.7	70.7	59.1	46.6	42.1	56.9M
56	40.4	35.6	49.5	54.9	68.6	76.7	77.2	75.0	71.5	61.4	44.2	41.7	58.1
57	38.0	47.9	47.1	52.3	61.6	71.9	78.8	75.8	66.1	55.5	41.7	43.7	56.7
58	36.0	41.6	40.1	52.6	67.0M	75.5	78.2	77.3	69.1	56.2	48.2	39.3	56.8M
59	36.6	39.0	46.3	55.1	65.6	74.4	74.6	76.1	70.5	55.1	42.1	39.9	56.3
60	33.6	34.6	44.3	58.2	63.6	74.6	74.0	75.2	69.0	57.5	48.3	33.8	55.6
61	34.7	41.0	47.1	54.6	65.2	72.9	74.3	73.7	66.2M	58.9	40.7	37.8	55.6M
62	33.4M	46.3	43.9	56.9	69.0	72.4M	76.2	76.6	69.0	60.2	48.4	40.3	57.7M
63	31.2	42.2	49.2	60.4	66.9	71.6M	79.1E	75.3M	70.0	63.7	48.8	35.1	57.8M
64	37.0	33.2	44.6	56.2	66.5	73.2E	79.2	76.5	67.8	59.4M	46.1	38.0	56.5M
65	41.2	37.4	39.3	58.0	65.4E	72.0M	77.3	73.4	67.2	58.0	52.3	42.2	57.0M
66	32.6	36.8	50.5	56.3	64.5	72.4M	80.8E	72.8	68.5	56.1M	50.8	37.5	56.6M
67	39.5	42.0	53.9M	61.9	65.4	72.6	76.4	73.1	68.2	59.7	48.8	35.6	58.1M
68	39.8	41.1	48.0	55.3	65.3	75.6	75.8	74.8	67.5	59.9	45.5	39.1	57.3
69	42.0	41.8	39.7	58.4	65.4	71.7	80.1	78.2	69.0	53.5	46.0	42.2	57.3
70	36.0	43.6	42.7	54.2	66.0	71.6	76.5	75.7	66.8	53.3	47.3M	43.6	56.4M
71	40.2	40.1	48.2	56.1	65.0	74.9	76.4	70.8	65.5	57.6	48.0	39.7	56.9
72	39.2	42.8	54.5	59.2	64.0	73.8	74.0	71.7	68.3	57.3	38.6	35.4	56.6
73	33.5	38.3	46.4	49.2	62.2	71.8	74.9	75.0	66.4	59.7	50.6	40.4	55.7
74	37.5	41.4	53.3	57.3	70.1	74.3	77.0	72.2	61.3	57.6	46.3	37.0	57.1
SUM	902.5	975.9	1124.9	1350.7	1566.2	1771.0	1850.8	1804.7	1638.2	1396.5	1111.3	939.3	1369.6

MONTHLY NORMALS OF TEMPERATURE, PRECIPITATION AND HEATING AND COOLING DEGREE DAYS (1941-70)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
TEMPERATURE	37.2	41.1	46.5	56.8	65.4	74.2	77.6	76.3	69.1	58.6	46.4	39.3	57.4
PRECIPITATION	0.45	0.46	0.55	0.80	2.08	2.60	2.89	2.50	1.89	1.81	0.44	0.60	17.07
HEATING DEGREE DAY	862	669	574	263	55	6	0	0	11	214	558	797	4009
COOLING DEGREE DAY	0	0	0	17	67	282	391	354	134	16	0	0	1261

STATION: 29 1939 — TOTAL PRECIPITATION — CLOVIS, NM

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
51	.70	.74	.19	.12	3.52	2.31	1.86	1.09	.20	1.86	.38	.57	13.54
52	.54	.29	.26	3.06	.37	2.13	2.18	1.00	.85	.00	1.25	.40	12.33
53	.68	.29	.71	1.09	1.09	.03	2.82	3.23	.00	1.61	.37	.30	12.22
54	.22	.62	.10	.86	1.34	1.06	.50	6.13	.14	3.65	.02	.22	14.86
55	.30	T	.01	.80	2.10	2.66	4.37	.58	1.49	.43	.02	.03	12.79
56	.08	1.32	T	.26	2.87	2.10	1.29	.55	.41	1.21	T	T	10.09
57	.15	.49	1.66	1.08	5.05	.06	.36	3.51	5.26	3.00	.74	T	21.36
58	1.39	.12	1.88	1.36	1.50	2.60	2.68	1.83	6.72	1.01	.51	.27	21.87
59	.05	.12	.23	.37	1.53	6.09	3.86	2.64	.25	2.48	.07	2.18	19.87
60	1.58	1.07	.32	.26	1.25	2.88	13.44	1.18	1.85	6.76	.00	1.70	32.29
61	.56	.47	2.21	.10	1.32	2.31	2.83	3.46	1.56	.94	2.32	.80	18.88
62	.84	.45	.49	.38	.29	.82	6.08	.39	2.93	1.08	.43	.39	14.57
63	.05	.86	.04	.14	2.47	6.16	3.44	2.76	1.38	.32	.41	.20	18.23
64	.08	1.08	.43	T	.77	4.35	.13	.45	2.56	.06	1.70	.45	12.06
65	.06	.53	.59	.56	1.72	3.03	1.46	2.27	1.36	.43	T	.59	12.60
66	.55	.08	T	.63	.72	2.63	.77	5.84	.84	.09	.47	.09	12.71
67	.00	.10	.48	.07	.29	5.63	3.92	2.50	1.30	.12	.09	.83	15.33
68	1.76	.42	1.23	.12	1.58	.75	1.54	3.25	1.06	.19	.62	.20	12.72
69	T	.84	.92	1.43	5.57	1.09	2.65	1.67	3.38	5.40	.33	1.02	24.30
70	T	.12	.81	.60	.53	3.74	4.08	1.74	2.90	.71	.01	.03	15.27
71	T	.20	.10D	1.25	1.12	2.17	1.53	4.16	2.04	1.19	1.71	1.02	16.49D
72	.09	.17	T	.00	1.97	2.38	2.54	2.98	2.51	2.00	1.09	.73	16.46
73	.56	.64	2.09	2.32	1.16	2.01	5.69	.43	1.86	.92	.08	.15	17.91
74	.66	.11	.92	T	.18	1.92	2.69	6.09	2.40	5.64	.43	.47	21.51
SUM	10.90	11.13	15.67	16.86	40.31	60.91	72.71	59.73	45.25	41.10	13.05	12.64	400.26

STATION: 29 1939 — TOTAL SNOWFALL — CLOVIS, NM

SEASON	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	SEASON
50-51							2.1E	T	.0	T	.0	.0	
51-52	.0	.0	.0	.0	1.5	7.0	T E	.0	.0	.0	.0	.0	8.5
52-53	.0	.0	.0	.0	8.0E	5.0	T E	3.0E	T	T	T	.0	16.0E
53-54	.0	.0	.0	.0	.0	T	2.5	T E	T	.0	T	.0	2.5
54-55	.0	.0	.0	.0	.0	1.0	1.0	T	T E	T	.0	.0	2.0
55-56	.0	.0	.0	.0	1.5	T	.3	11.5E	T	.0	.0	.0	13.3E
56-57	.0	.0	.0	.0	T	T	T E	.0	T E	T	.0	.0	.0
57-58	.0	.0	.0	.0	5.0E	T	10.9E	2.0E	2.0E	.0	.0	.0	19.9E
58-59	.0	.0	.0	.0	.5	4.1E	T E	1.2E	T E	T E	.0	.0	5.8E
59-60	.0	.0	.0	.0	T	8.0E	10.0E	5.0E	T	.0	.0	.0	23.0E
60-61	.0	.0	.0	.0	.0	14.0E	5.8E	2.7E	8.6E	T	.0	.0	31.1E
61-62	.0	.0	.0	.0	5.6E	6.0E	3.0E	T	T	.0	.0	.0	14.6E
62-63	.0	.0	.0	.0	.0	1.5	1.5	6.0E	.0	.0	.0	.0	9.0E
63-64	.0	.0	.0	.0	.0	3.0E	T	13.0	3.3	T	.0	.0	19.3E
64-65	.0	.0	.0	.0	T	T E	.0	5.0E	2.3	.0	.0	.0	7.3E
65-66	.0	.0	.0	.0	.0	2.0E	4.7E	T	T	3.1E	.0	.0	9.8E
66-67	.0	.0	.0	.0	T	.8E	.0	T E	T	.0	.0	.0	.8E
67-68	.0	.0	.0	.0	1.0	11.0	1.0	4.6	8.0	.0	.0	.0	25.6
68-69	.0	.0	.0	T	3.0	T	.5	1.0	8.8	.0	.0	.0	13.3
69-70	.0	.0	.0	.0	.0	7.0	.0	1.0	4.5	.0	.0	.0	12.5
70-71	.0	.0	.0	T	.1	T	T	2.5	1.0	.0	.0	.0	3.6
71-72	.0	.0	.0	.0	.4	10.3	1.0	1.0E	T	.0	.0	.0	12.7E
72-73	.0	.0	.0	T	4.5	6.5	8.0	8.0	T E	T E	.0	.0	27.0
73-74	.0	.0	.0	T	1.0	1.0	T	2.5	T	.0	.0	.0	4.5
74-75	.0	.0	.0	.0	.0	2.5							
SUM	.0	.0	.0	.0	32.1	90.7	52.3	70.0	38.5	3.1	.0	.0	282.1

E AMOUNT IS WHOLLY OR PARTLY ESTIMATED.

T TRACE, AN AMOUNT TOO SMALL TO MEASURE.

M ONE OR MORE DAYS OF RECORD MISSING; IF AVERAGE VALUE IS ENTERED, LESS THAN 10 DAYS RECORD IS MISSING.

D WATER EQUIVALENT OF SNOWFALL WHOLLY OR PARTLY ESTIMATED.

Sale Price: 15 cents per copy. Checks and money orders should be made payable to Department of Commerce, NOAA. Remittances and correspondence regarding this publication should be sent to: National Climatic Center, Federal Building, Asheville, N. C. 28801.

USCOMM–NOAA–ASHEVILLE 400

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

Average Temperature (°F)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann'l
1931	40.1	44.0	45.9	55.4	63.8	77.9	78.6	75.0	75.1	61.3	47.9	39.3	58.7
1932	34.6	48.0	42.7	58.2	66.7	74.1	79.6	76.9	67.6	56.6	46.3	27.0	56.5
1933	38.3	31.4	44.9	50.0	61.7	73.6	79.3	77.0	74.4	62.4	48.8	46.3	57.4
1934	40.7	44.8	48.6	61.0	70.7	79.8	83.6	81.0	69.7	64.2	50.5	41.6	61.4
1935	43.0	43.0	51.6	57.8	62.0	74.5	79.0	78.0	67.2	60.0	46.2	38.0	58.4
1936	34.0	40.8	53.5	59.6	68.7	78.7	80.0	80.6	69.0	56.8	44.4	40.6	58.9
1937	32.8	40.2	42.7	57.9	68.4	75.4	80.9	81.5	72.1	60.0	46.8	38.2	58.1
1938	39.4	42.3	49.2	57.6	67.4	75.2	78.0	80.0	71.4	60.6	46.8	40.4	59.0
1939	37.2	35.2	50.7	56.7	67.6	78.2	79.8	76.4	72.6	58.9	45.0	41.4	58.3
1940	32.7	41.5	51.1	57.0	68.7	75.3	83.1	76.4	73.4	63.0	43.0	42.9	59.0
1941	38.6	43.6	44.4	56.8	66.0	72.6	78.0	77.6	70.3	59.9	48.4	40.5	58.0
1942	37.5	39.3	49.0	59.1	67.9	77.8	80.8	77.8	69.8	58.6	52.8	43.0	59.2
1943	41.6	49.0	51.2	65.3	67.8	79.4	81.8	85.4	72.3	60.8	46.5	38.9	61.7
1944	38.4	45.4	50.4	57.8	68.4	78.4	80.6	81.2	71.0	58.0	46.3	35.4	59.3
1945	38.2	42.6	49.0	51.3	66.2	72.2	76.1	77.4	69.5	57.5	48.2	37.2	57.2
1946	34.9	41.6	50.2	61.6	62.2	75.0	78.6	77.4	69.9	60.8	46.0	42.3	58.4
1947	34.8	36.9	42.8	52.2	65.3	74.0	77.6	75.7	70.8	61.8	40.1	37.7	54.9
1948	31.0	36.2	39.5	58.7	65.2	74.2	77.4	75.7	69.0	56.7	41.9	41.4	55.6
1949	26.4	39.9	48.5	54.7	65.3	72.5	76.8	73.7	67.9	56.4	52.5	35.7	55.9
1950	41.9	44.7	46.8	56.3	64.3	74.3	73.7	73.3	66.0	63.3	47.3	40.0	57.6
1951	36.0	40.2	45.3	54.8	64.0	72.5	78.6	77.7	69.5	59.3	43.5	38.6	56.7
1952	40.9	42.6	45.2	55.4	65.1	77.9	76.2	79.4	67.5	57.8	41.3	38.3	57.3
1953	45.4	40.2	52.2	55.5	63.5	80.0	79.2	75.8	70.7	59.9	47.8	36.1	58.9
1954	40.5	48.4	46.5	61.3	63.4	75.5	80.5	76.9	71.9	59.8	49.4	41.9	59.7
1955	37.3	37.8	47.1	56.6	62.9	71.2	75.5	75.7	70.7	59.1	46.6	42.1	56.9
1956	40.4	35.6	49.5	54.9	68.6	76.7	77.2	75.0	71.5	61.4	44.2	41.7	58.0
1957	38.0	47.9	47.1	52.3	61.6	71.9	78.8	75.8	66.1	55.5	41.7	43.7	56.7
1958	36.0	41.6	40.1	52.6	67.0	75.5	78.2	77.3	69.1	56.2	48.2	39.3	56.8
1959	36.6	39.0	46.3	55.1	65.6	74.4	74.6	76.1	70.5	55.1	42.1	39.9	56.3
1960	33.6	34.6	44.3	58.2	63.6	74.6	74.0	75.2	69.0	57.5	48.3	33.8	55.6

Total Precipitation (Inches)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann'l
1931	1.46	0.52	0.62	3.09	1.06	0.60	3.06	4.87	3.41	0.70	1.68	1.15	22.22
1932	0.57	0.49	0.32	1.17	2.45	4.00	1.27	7.38	3.38	0.46	0.00	0.86	22.80
1933	1.04	0.54	0.21	T	2.03	0.29	2.81	3.30	1.85	0.08	0.11	0.00	12.26
1934	T	0.32	0.97	1.73	0.93	1.53	2.19	1.30	0.67	0.69	1.36	0.08	11.77
1935	0.16	0.03	0.27	0.03	4.02	3.82	2.56	2.05	0.45	T	1.87	0.22	15.48
1936	0.80	0.10	0.00	T	7.00	1.98	0.69	0.61	6.88	0.99	0.00	0.30	19.35
1937	0.11	0.24	1.40	0.20	5.05	3.76	2.04	1.03	4.17	1.69	T	0.58	20.27
1938	0.52	0.95	0.96	T	0.98	3.45	3.66	1.23	3.46	5.00	0.00	0.11	20.32
1939	1.94	0.10	0.54	0.50	2.11	1.16	0.90	4.62	0.28	1.23	0.33	0.94	14.65
1940	0.26	0.31	T	0.95	2.62	1.01	0.45	1.51	0.48	0.86	1.76	0.11	10.32
1941	0.35	0.25	2.48	3.43	11.87	8.57	4.60	2.02	6.79	5.96	0.16	0.43	46.91
1942	T	0.59	0.03	2.64	0.79	1.30	1.87	7.01	0.64	6.27	0.00	1.19	22.33
1943	0.00	0.00	0.00	0.10	1.01	0.48	0.91	0.89	0.87	0.10	0.60	2.62	7.58
1944	0.20	0.52	0.00	1.12	1.48	2.51	0.86	3.11	2.03	0.61	0.69	1.06	14.19
1945	0.59	0.26	0.17	0.16	0.33	T	2.79	1.48	3.02	0.69	T	0.04	9.53
1946	0.64	0.09	0.16	0.66	0.31	1.16	1.77	2.39	2.88	5.16	0.53	0.41	16.16
1947	0.65	0.09	0.56	1.32	3.23	0.06	1.15	2.36	0.24	0.42	0.76	1.06	11.90
1948	0.37	1.25	0.28	0.25	1.04	2.59	1.32	3.47	0.48	0.27	0.58	0.21	12.11
1949	1.23	0.65	0.29	0.52	5.58	5.29	2.07	3.82	1.53	2.44	0.13	0.57	24.12
1950	T	0.02	T	0.41	0.83	3.46	8.96	2.31	1.80	0.97	T	0.05	18.81
1951	0.70	0.74	0.19	0.12	3.52	2.31	1.86	1.09	0.20	1.86	0.38	0.57	13.54
1952	0.54	0.29	0.26	3.06	0.37	2.13	2.18	1.00	0.85	0.00	1.25	0.40	12.33
1953	0.68	0.29	0.71	1.09	1.09	0.03	2.82	3.23	0.00	1.61	0.37	0.30	12.22
1954	0.22	0.62	0.10	0.86	1.34	1.06	0.50	6.13	0.14	3.65	0.02	0.22	14.86
1955	0.30	T	0.01	0.80	2.10	2.66	4.37	0.58	1.49	0.43	0.02	0.03	12.79
1956	0.08	1.32	T	0.26	2.87	2.10	1.29	0.55	0.41	1.21	T	T	10.09
1957	0.15	0.49	1.66	1.08	5.05	0.06	0.36	3.51	5.26	3.00	0.74	T	21.36
1958	1.39	0.12	1.88	1.36	1.50	2.60	2.68	1.83	6.72	1.01	0.51	0.27	21.87
1959	0.05	0.12	0.23	0.37	1.53	6.09	3.86	2.64	0.25	2.48	0.07	2.18	19.87
1960	1.58	1.07	0.32	0.26	1.25	2.88	13.44	1.18	1.85	6.76	0	1.70	32.29

STATION HISTORY

A Clovis climatological substation was established three blocks east-northeast of the Post Office on June 14, 1911. The instruments were sheltered on the roof of a small shed with the floor about 10 feet aboveground. Mr. J. H. Barry was the first observer, continuing the records without a break through September 1944. On May 12, 1942, the equipment was moved to a ground exposure at the same site. On October 1, 1942, the Soil Conservation Service began monthly reports from its own standard equipment exposed on the roof of the SCS office about one-quarter mile north-northeast of the Post Office. This exposure was about 20 feet aboveground. This station was made the official Clovis station on October 1, 1944, and was used until February 20, 1951, when the equipment was again moved to a ground installation at 1312 Prince Street some nine tenths of a mile northeast of the Post Office. Mr. Karl Kramer of the Soil Conservation Service has continued the records at this site.

Climate (continued)

Record highest temperature:	June	109°	1918
Record lowest temperature:	January	- 8°	1919
	April	12°	1913
	June	36°	1919
	August	46°	1920
	October	13°	1917
	December	- 9°	1918+
Greatest daily precipitation:	February	1.30	1912
	March	1.47	1919
	April	2.87	1915
	June	3.93	1923
	July	4.69	1921
Greatest monthly snowfall:	February	11.50	1913
	March	14.20	1915
	April	4.00	1919
	November	11.00	1923
	December	11.80	1923

G. F. VON ESCHEN
State Climatologist
Weather Bureau Airport Station
Albuquerque, New Mexico

TABLE I -- MEAN MONTHLY, SEASONAL, AND ANNUAL CLASS A PAN EVAPORATION (INCHES) FOR STATIONS WITH 10 YEARS OR MORE OF RECORD FOR BEST MONTH*

	State No.	Station Index No.**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	May-Oct ***	Nov-Apr ***	Other Season ***	Annual ***	Record Began Mo/Yr	Latest Data Mo/Yr
NEW MEXICO (continued)																				
Alamogordo Dam	29	0205	3.82	4.66	8.51	11.12	13.18	14.95	14.25	12.38	10.14	7.35	4.87	3.79	72.25	36.77	-	109.02	1/39	11/73
34° 36', 104° 23'			24	31	31	35	36	36	36	36	36	36	31	26						
			****	23	19	13	11	10	11	12	19	19	17	****	8	****		****		
Animas	29	0417				10.98	14.38	14.40	12.87	11.19	8.62	6.77			68.23	-	-	-	1/67	11/79
31° 57', 108° 49'						12	10	11	12	13	10	10								
						****	****	****	****	****	****	****			****					
Bitter Lakes Wild Rfg.	29	0992	2.92	4.34	7.28	10.14	11.73	12.94	12.37	10.83	8.46	6.20	3.63	2.72	62.53	31.03	-	93.56	1/51	10/79
33° 29', 104° 24'			17	23	24	24	24	21	25	24	22	22	20	18						
			35	20	18	8	10	10	15	8	14	19	17	26	6	****		****		
Bosque del Apache	29	1138	3.57	3.52	7.79	10.38	11.38	13.41	11.48	10.52	8.12	6.56	3.31	2.84	61.47	31.65	-	93.39	1/49	10/73
33° 46', 106° 54'			12	16	16	14	16	17	18	17	17	17	12	14						
			****	****	****	5	6	3	6	12	17	13	13	****	5	****		****		
Caballo Dam	29	1886	4.45	5.41	9.05	12.20	14.23	16.19	13.66	12.00	9.75	7.28	4.92	3.51	73.11	39.54	-	112.65	3/42	10/79
32° 54', 107° 18'			32	34	37	36	36	36	37	37	37	37	33	33						
			24	15	16	7	8	7	8	10	16	16	16	24	6	7		6		
Capulin Nat'l Mon	29	1454					9.73	10.90	10.24	9.41	8.22				-	-	48.50	-	5/63	9/79
36° 47', 103° 58'							12	14	13	12	12									
							****	****	****	****	****									
Clovis 13 N	29	1963		4.07	6.94	9.10	10.56	11.83	11.56	9.87	8.09	6.19	4.43	3.73	56.39	-	-	-	4/51	11/79
34° 36', 103° 13'				14	24	28	28	28	28	28	29	29	27	12						
				23	26	12	16	14	17	15	22	15	23	24	12					
Eagle Nest	29	2700					7.55	8.25	7.62	6.74	5.76				-	-	35.92	-	8/34	9/79
36° 33', 105° 16'							25	32	35	36	33									
							****	****	12	17	19									
El Vado Dam	29	2837					8.06	9.36	8.89	7.38	6.29	4.68	4.38		44.66	-	-	-	7/36	10/75
36° 36', 106° 44'							32	38	39	39	39	22	13							
							15	10	12	18	25	****	****		****					
Elephant Butte Dam	29	2848	3.28	4.85	8.53	11.75	14.45	16.17	13.64	11.63	9.72	7.70	4.75	3.21	73.31	36.37		109.68	4/16	12/79
33° 09', 107° 11'			63	63	63	63	64	64	63	64	64	64	63	62						
			25	16	17	8	9	6	8	10	18	14	18	17	6	8		6		
Estancia	29	3060					9.00	8.97	8.29	7.40	5.90				-	-	39.56	-	5/66	9/79
34° 45', 106° 04'							10	12	12	11	12									
							****	****	****	****	****									

* First line of data in the table for each station is mean evaporation in inches; second line is the number of years of record per month; and third line is the coefficient of variation in percent (computed only where there are 10 years or more of record during 1956-1970).

** Climatological Data (NOAA-EDIS)

*** Sum of monthly means.

**** Insufficient data between 1956-70 to compute the coefficient of variation.

SWD FORM 521 (R)
8 Jan 65

SUBJECT CELL #3, LANDFILL #5, GEOCOMPOSITE - MEMBRANE FINAL COVER
COMPUTATION EROSION POTENTIAL FILE NO.
COMPUTED BY M. WITTROCK DATE CHECKED BY DATE

EVALUATION OF EROSION POTENTIAL

THE USDA UNIVERSAL SOIL LOSS EQUATION (USLE):

$A = R \cdot K \cdot LS \cdot C \cdot P$

Where
A = average annual soil loss, tons/acre
R = rainfall and runoff erosivity index
K = soil erodibility factor, tons/acre
LS = combination of slop-length factor and slope-steepness factor
C = cover/management factor
P = practice factor

For a 3 % Grade

for Eastern NM, R = 100 (See figure 1.1)

for 4% organic mater and Sandy Clay loam, K = .21 (see table 1.1)

for 3% slope and 800-ft Slope length (worst case), LS = 0.54 (see table 1.2)

for moderately Productive grass C = 0.01 (see table 1.3)

for spring-seeded grain P = 0.60 (see table 1.4)

thus $A = 100 \cdot (0.21 \frac{tons}{acre}) \cdot 0.54 \cdot 0.01 \cdot 0.60 \Rightarrow A = 0.068$ tons/acre

$A = 136$ lb/acre

Assume density of soil = 90 lb/ft³

Surface area of Final Cover = $\frac{60 ft \times 810 ft}{43,600 ft/acre} \Rightarrow = 1,115$ acres

SWD FORM 521 (R)
8 Jan 65

SUBJECT _____
COMPUTATION _____ FILE NO. _____
COMPUTED BY _____ DATE _____ CHECKED BY _____ DATE _____

Erosion per year

$$= \frac{136\ lb/acre * 1.115\ acres}{90\ lb/ft^3} \Rightarrow 1.69\ ft^3$$

25% Side Slopes

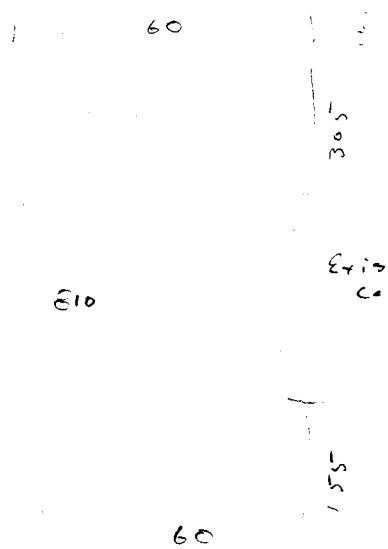
R = 100
K = 0.21
LS = 3 for 25% slope and 12.5 ft length (use 25 ft)
C = 0.01
P = 0.60

So $A = 100 \cdot 0.21\ tons/acre \cdot 3 \cdot 0.01 \cdot 0.6 \Rightarrow A = 0.378\ tons/acre$
$A = 756\ lbs/acre$

Surface Area = [835 ft + 2(60 ft) + 317.5 ft + 167.5 ft] * 12.5 ft

Area = 18,000 ft^2

Area = 0.413 acres



Erosion per year

$$= \frac{756\ lb/acre * 0.413\ acre}{90\ lb/ft^3}$$

$= 3.47\ ft^3$

TOTAL Erosion per Year

$= 1.69\ ft^3 + 3.47\ ft^3$

$= 5.16\ ft^3$ ⟸

SWD FORM 521 (R)
8 Jan 65

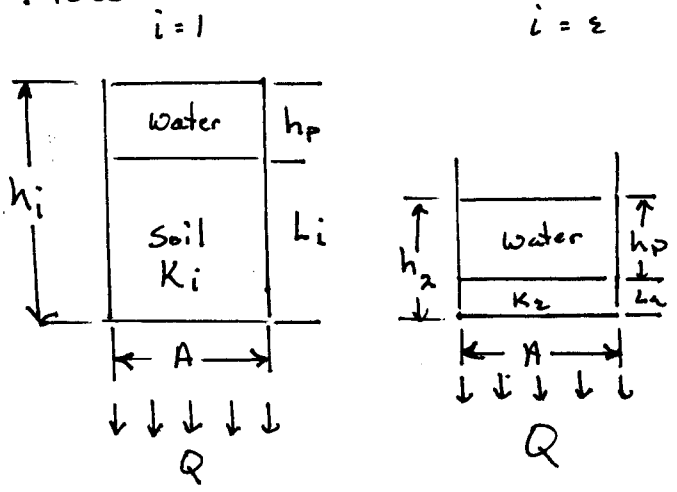
SUBJECT CELL #3, LANDFILL #4
COMPUTATION EQUIVALENT THICKNESS FILE NO.
COMPUTED BY M. WITTROCK DATE CHECKED BY DATE

Darcy's Law $v = ki$ where $i = \frac{h}{l}$ h = head loss, l = length

Conservation of mass $q = v_1 A_1 = v_2 A_2 = \text{constant}$

Assumptions

- incompessibly steady flow
- Constant head



$\therefore \quad q = K_i i_i A_i$

$q = \frac{Q}{t} = K \frac{h}{L} A$

$q_1 = q_2$

let $Q_1 = Q_2$; $t_1 = t_2$; $A_1 = A_2$

$$\therefore \quad \frac{K_1 h_1}{L_1} = \frac{K_2 h_2}{L_2}$$

$$L_2 = \frac{K_2}{K_1} \frac{h_2}{h_1} L_1 \qquad h_1 = h_p + L_1 \qquad h_2 = h_p + L_2$$

$$L_2 = \frac{K_2 \cdot L_1 \cdot (L_2 + h_p)}{K_1 (L_1 + h_p)} =$$

$$L_2 \left[1 + \frac{K_2 \cdot L_1}{K_1 (L_1 + h_p)} \right] = \frac{K_2 \cdot L_1 \cdot h_p}{K_1 (L_1 + h_p)}$$

$$L_2 = \frac{K_2 \cdot L_1 \cdot h_p}{K_1 (L_1 + h_p)} \Big/ \left[1 + \frac{K_2 \cdot L_1}{K_1 \cdot (L_1 + h_p)} \right]$$

let

$K_1 = 1 \times 10^{-7}$ cm/sec
$K_2 = 1 \times 10^{-9}$ cm/sec
$L_1 = 24$ in
$h_p = 12$ in (Assumed)

Solve for L_2

$L_2 = 0.08$ inches $\Leftarrow$ $\boxed{\text{Use } 0.125 \text{ inches } 1/8 \text{ in}}$

PART III - ARCHITECTURAL N\A

PART III - ARCHITECTURAL N\A

PART IIIA - INTERIOR DESIGN N\A

PART IV - STRUCTURAL N\A

PART V - MECHANICAL N\A

PART VI - ELECTRICAL N\A

PART VII - ENVIRONMENTAL N\A

APPENDIX A

LANDFILL CAP ANALYSIS

LANDFILL CAP ANALYSIS

1. GENERAL. The project consists of providing a geocomposite-soil cap and tieing into the existing cap for Sanitary Landfill #5, Cell #3 at Cannon Air Force Base (CAFB), New Mexico. Cell #3 was in operation during the "RCRA INTERIM STATUS" time period and the cell was documented as having received contaminates for disposal. These contaminates consisted of solvents, paints, paint removers, and thinners. Closure and Post Closure Plan, Plans, and Specifications for Landfill Cell #3 were developed by Hazard Materials Technical Center, 11140 Rockville Pike, Rockville, Maryland 208552, in October 1988. This Cap was constructed as per plans and specifications. The Cannon AFB, Base Environmental Section, later determined that the location of this cap did not cover the entire area of cell #3. The Cannon AFB, Base Environmental Section, requested the US Army Corps of Engineers, Tulsa District, to develop a set of plans and specifications for a soil cap for cell #3. Subsequently, the Tulsa District brokered this work to the Albuquerque District. (See Appendix A)

2. Subsurface Conditions.

a. Geology. Cannon Air Force Base is in the Great Plains Physiographic Province on the Llano Estacado. The Quaternary surficial deposits are commonly eolian sand, loess and colluvium which have been deposited on the Ogallala Formation, of late Tertiary age. The Ogallala Formation is a complex sequence of alluvial strata deposited during Miocene and Pliocene time. These strata are well exposed at many localities along the escarpments that characteristically define the physiographic limits of the Llano Estacado. In the vicinity of Cannon AFB, the Ogallala Formation included lenticular beds of clay, silt, sand and mixtures of sand and gravel. Caliche is normally present in the uppermost part of the formation. The Ogallala Formation is 350 feet to 400 feet thick in the vicinity of Cannon AFB. Unconformably underlying the Ogallala Formation are a series of "red beds" assigned to the Dockum Group of Triassic age. The Dockum Group is composed of siltstone, mudstone and interbedded silty to clayey, very fine to fine grained sandstone.

3. Subsurface Investigations. Site investigations for the proposed cell #3 cap were performed during 22 January 1985, 14 thru 16 January 1992, and 28 February 1992 to present.

In January 1985, two 9-inch diameter cores, 40-feet deep, were taken from the landfill cell. Six samples from the core (depths of 10, 15, 20, 25, 30 and 40 feet) were analyzed for chromium, lead, arsenic, tin, mercury, and volatile organics. The results of the tests detected <0.001 ppm of volatile organics and no organic solvents present in the core samples. (See appendix C)

In January 1992, cell #3 was trenched to determine the extent of the cell. (See appendix B for trenching report). The trenching showed that cell #3 was approximately 800-feet long and 50-feet wide, with 10-foot barriers between adjacent cells.

In February 1992, two 4-inch field permeameters were installed at depths of 20-feet below existing ground level and 6-inch undisturbed Denison can samples were taken at each hole at depths between 18 to 20 feet below existing ground

level. Permeameter #1 is located on the east side of landfill #5, approximately 750-feet north of the SE corner of the landfill. Permeameter #2 is located on the south side of landfill #5, approximately 600-feet west of the SE corner of the landfill. The undisturbed samples were delivered to the Southwest Division Laboratory for the following tests: soil classification, moisture content, Atterberg limits, specific gravity, and hydraulic conductivity (K). The tests results from the undisturbed samples show an average hydraulic conductivity (K) of $5.7*10^{-5}$ cm/sec. The field hydraulic conductivity (K) tests were inconclusive. The holes were maintained with water for 3 weeks, yet the hydraulic conductivity (K) did not stabilize during this time period. The hydraulic conductivity (K) was still declining when the testing was halted at the end of three weeks. After 3 weeks, hole #1 had a average hydraulic conductivity (K) of $5.0*10^{-4}$ cm/sec. and hole #2 had a average hydraulic conductivity (K) of $7.0*10^{-3}$ cm/sec.

4. DESIGNS: Two design alternatives were analyzed for the cell #3 cap based on the laboratory undisturbed hydraulic conductivity (K) test results, K = $5.7X10^{-5}$ cm\sec (See Drawings Sheet 4 & 5 for Details):

Alternative #1 - based on the undisturbed sample average hydraulic conductivity (K) of $5.7*10^{-5}$ cm/sec, it is recommended that the following cap system be utilized.

6-inches	Bedding Material consisting of crusher fines.
24-inches	soil cap material consisting of a Clayey Sand (SC) or Low to Medium Plasticity Clay (CL) soil with a maximum hydraulic conductivity (K) of $1*10^{-6}$ cm/sec
12-inches	Biobarrier material consisting of gravel, sands, and fines (approx. 30% passing the #200 sieve). This is used to hinder burrowing animals.
12-inches	Minimum of cover soil consisting of Silty Sand (SM), Clayey Sand (SC), Low Plasticity Silt (ML), or Low to Medium Plasticity Clay (CL). If cost effective this could be the same material as the soils cap material.

Alternative #2 - A geocomposite system may be cost effective based on preliminary cost estimates. This cap system was analyzed and the following cap system is recommended if is more cost effective than the soil cap system:

3-inches	Bedding Material consisting of crusher fines.
6-inches	Sand vent layer, with 4-inch PVC pipe vent system.
	Non-woven filter fabric
40-mil	Geocomposite liner with bentonite (Gunseal or equivalent) hydraulic conductivity (K) of $3*10^{-10}$ cm/sec

24-inches Minimum of cover soil consisting of SC or CL.

Total settlements of 5-15% of the cell depth can be expected for Cell #3. Approximately 80% or more of this settlement should have occurred over the last 10-years since the cell was last utilized. This leaves approximately 7-inches of additional settlement which may occur. It can be anticipated that 3-4 inches of settlement will be induced during construction. The remaining 3-4 inches of settlement should occur uniformly over the next 30+ years. Both options should be able to withstand up to 1-inch of differential settlement with out damage to the cap systems.

5. RECOMMENDATIONS: Based on the meeting held with the NMED on June 26, 1992 and their subsequent comments and recommendation, alternative #1 is no longer economical due to the increase in hydraulic conductivity (K). Therefor it is recommended that alternative #2 be used as it is more economical, provides a higher level of protection, meets or exceeds the intentions of a full RCRA cap, and will be easier to construct.

ALBUQUERQUE DISTRICT - JULY 1992

APPENDIX B

RELATED CORRESPONDENCE

DEPARTMENT OF THE ARMY
TULSA DISTRICT, CORPS OF ENGINEERS
POST OFFICE BOX 61
TULSA, OKLAHOMA 74121-0061

REPLY TO
ATTENTION OF

6 FEB '92

CESWT-DE (200)

MEMORANDUM FOR Commander, Albuquerque District

SUBJECT: Landfill 5/Cell 3 Cap Design for Cannon Air Force Base (AFB), NM

1. Corps support has been requested to provide design and construction specifications for the placement of a final cover on Cell 3 in Landfill 5 at Cannon AFB. Cannon AFB requires that the design and construction specifications be completed in time to allow a construction award for the cap during FY92. Your office has faxed a schedule and cost estimate that meets this requirement.

2. Mr. Mark Wittrock, Albuquerque District, met in Tulsa District on 21 and 22 January to discuss landfill cap design requirements and to develop a schedule for completion of both design and specifications. A kickoff meeting for the design was scheduled for 12 February at Cannon Air Force Base. Your personnel stated that it was within their capability to accomplish this work with technical support from the Tulsa District.

3. I request that the Albuquerque District formally accept this mission and the required work for the design of the landfill cap project at Cannon AFB. The design shall meet the requirements stipulated in the enclosed scope of work (encl 1). Tulsa District will provide technical support and will perform technical review on all deliverables.

4. A Military Interdepartmental Purchase Request for $39,200 will be forwarded for your design requirements. Formal acceptance of this mission is requested by 7 February 1992. A 1st Endorsement to accomplish this is at enclosure 2.

5. Point of contact is Mr. Robert Wilson at FTS 745-6148.

2 Encls

for F. L. SMITH, JR.
Colonel, EN
Commanding

[illegible]
Lieutenant [illegible]
Deputy Commander

CANNON AFB
LANDFILL 5 - CELL 3 CAP DESIGN

Scope of Work

1. **Introduction.** Cannon Air Force Base is a U.S. Department of Defense facility located in Curry County west of Clovis, New Mexico. Landfill 5 - Cell 3 is located on the southeast corner of the base. Cell 3 was in operation during the 1981-1982 timeframe and was known to have received waste oil and solvents. In 1989, the cell was covered with a clay and flexible membrane cover. It was later determined that the cover was incorrectly located. The Tulsa District conducted an investigation during January 1992, which determined the actual boundaries of Cell 3 (the results of this investigation has been forwarded to Cannon AFB and Albuquerque District). Cannon Air Force Base has set aside FY92 funds for the construction of the new landfill cap for Cell 3. To award a construction contract by the end of FY92, the schedule for completion of design and specifications should include sufficient lead time to allow procurement of the contract.

2. **Design and Specification Work.** Cannon Air Force Base is studying options for the closure of Landfill 5 (ie. construct one contiguous cap covering all cells in the landfill or construct separate caps over each cell). According to Cannon, a decision on this should be available by 15 March 1992. If a contiguous cap is chosen, the cap for Cell 3 must be designed to allow its future integration into the landfill cap. The cap shall be designed to satisfy all state and federal closure regulations. The state's requirements include the following:

-Provide long-term minimization of migration of liquids through the closed landfill cell.

-Function with minimum maintenance.

-Promote drainage and minimize erosion and abrasion of the cover.

-Accommodate settling and subsidence so that the cover's integrity is maintained.

-Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

The Albuquerque District will perform the design and write the specifications for this project with technical support from the Tulsa District. The Albuquerque District will submit a schedule for 30%, 95% (Advance Final), 100% (Final) Design completion.

CESWA-DE (CESWT-DE/Jan 92) (200-1c) 1st End
SUBJECT: Landfill 5/Cell 3 Cap Design For Cannon Air Force Base, New Mexico

Commander, Albuquerque District

For Commander, Tulsa District

Mission assignment is accepted.

MICHAEL J. DEBOW
LTC, EN
Commanding

RET TO GEOTECH BR

(LANDCAP.MEM)

SD&DS Sec DEF

Geotech Br DEF 13 FEB 9

Engrg/Plng Div Gamel

DDE PM WP/13

DDE 2/19

DE

CESWA-DE (200)

14 FEB 1992

MEMORANDUM FOR Commander, Tulsa District

SUBJECT: Landfill 5/Cell 3 Cap Design for Cannon Air Force Base (AFB), NM

1. As requested in Memorandum CESWT-DE, SAB, dated 6 FEB 92, the Albuquerque District accepts the mission to provide design and construction specifications for the placement of a final cover on Cell 3 in Landfill 5 at Cannon AFB, NM. As noted in the above memorandum, a schedule and a cost estimate in the amount of $39,200 was faxed to CESWT-EC-GP on 25 Jan 92. The schedule and cost estimate were based on discussions, during the 21-22 Jan 92 meeting, regarding the design of a geosynthetic composite liner (GCL) system. Based on discussions at the kickoff meeting at Cannon AFB, NM on 12 Feb 92, Base Environmental personnel indicated that the New Mexico Environment Department may accept a more permeable landfill cap design using natural soils in lieu of a GCL system. The Albuquerque District will evaluate the possible design alternatives for the subject design. However, additional costs in the amount of approximately $10,000 may be required for field and laboratory investigations and evaluation.

2. If there are any questions, please call me or Mr. Wittrock, of my staff, at FTS 474-1722 or (505)766-1722.

SIGNED

MICHAEL J. DEBOW
LTC, EN
Commanding

1 9 DEC 1991
9 b 10a

State of New Mexico
ENVIRONMENT DEPARTMENT
HAZARDOUS AND RADIOACTIVE MATERIALS BUREAU
RADIATION LICENSING AND REGISTRATION SECTION
525 Camino De Los Marquez
Post Office Box 26110
Santa Fe, New Mexico 87502
(505)827-4300

BRUCE KING
GOVERNOR

JUDITH M. ESPINOSA
SECRETARY

RON CURRY
DEPUTY SECRETARY

December 16, 1991

Mr. Jim Richards
27 CSG-DEV
Cannon Air Force Base
Cannon Air Force Base, New Mexico 88103

Due 19 Feb 91

RE: Post-Closure Care Permit Application

Dear Mr. Richards:

As we discussed in our meeting on November 19, 1991 held in Santa Fe, New Mexico the Hazardous and Radioactive Materials Bureau (HRMB) has completed an administrative review of your post-closure care permit application dated December 20, 1988. Based on the review we have determined the application to be incomplete. The enclosed deficiencies are provided to assist you in developing a complete application in view of the current status of Landfill 5. Your post-closure care permit application should be submitted as a stand-alone document which addresses all of the enclosed deficiencies. Your response to the enclosure must be submitted within 60 days of receipt of this letter.

After we have received your complete post-closure permit application a technical review of the information will be conducted. Additional information may be requested to clarify, modify, or supplement previously submitted material. Failure to supply the requested information in a timely manner may be grounds for permit denial or enforcement action.

Please contact Herb Grover at (505) 827-4300 if you have any questions or if you need further assistance.

Sincerely yours,

Edward L. Horst
Program Manager

Enclosure

cc: William K. Honker, (6H-P), U.S. EPA, Region 6
Guanita Reiter, (6H-H), U.S. EPA, Region 6

closure activities which have not been completed. At a minimum this includes providing a description of the plans for locating the boundaries of cell No. 3 (i.e. a description of geophysical and geotechnical techniques), and include provisions for placing a final cover on Cell No. 3. Design and construction specifications for the final cover should be as complete as possible for Cell No. 3.

The final cover design and construction proposal should be able to provide a cover which will:

F. Provide long-term minimization of migration of liquids through the closed landfill cell;

G. Function with minimum maintenance;

H. Promote drainage and minimize erosion and abrasion of the cover;

I. Accommodate settling and subsidence so that the cover's integrity is maintained; and

J. Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

4. Documentation of the Notice in Deed
HWMR-6, Part IX, Sec. 270.14(b)(14)

The post-closure permit application must include provisions for recording on the deed to the facility a notification that the land has been used to manage hazardous waste, and that its use is restricted under 40 CFR 264 Subpart G regulations. The survey plat and record of the type, location, and quantity of hazardous waste disposed of within Cell No. 3 must be filed with the local zoning authority and a certified copy provided to the Secretary of the NMED.

5. Ground Water Monitoring System
HWMR-6, Part IX, Sec. 270.14(c)

The post-closure applications must address all information requirements for a detection monitoring program according to Sec. 264.98. Design and construction details for proposed monitoring wells L and M must be included in this program. Point of Compliance wells surrounding the Landfill 5 waste management area may be considered appropriate for purposes of detection monitoring of Cell No. 3 in view of ongoing investigations at Landfill 5 through the HSWA permit requirements.

The detection monitoring program portion of the application shall at a minimum include the following information:

A. A proposed list of indicator parameters to be measured

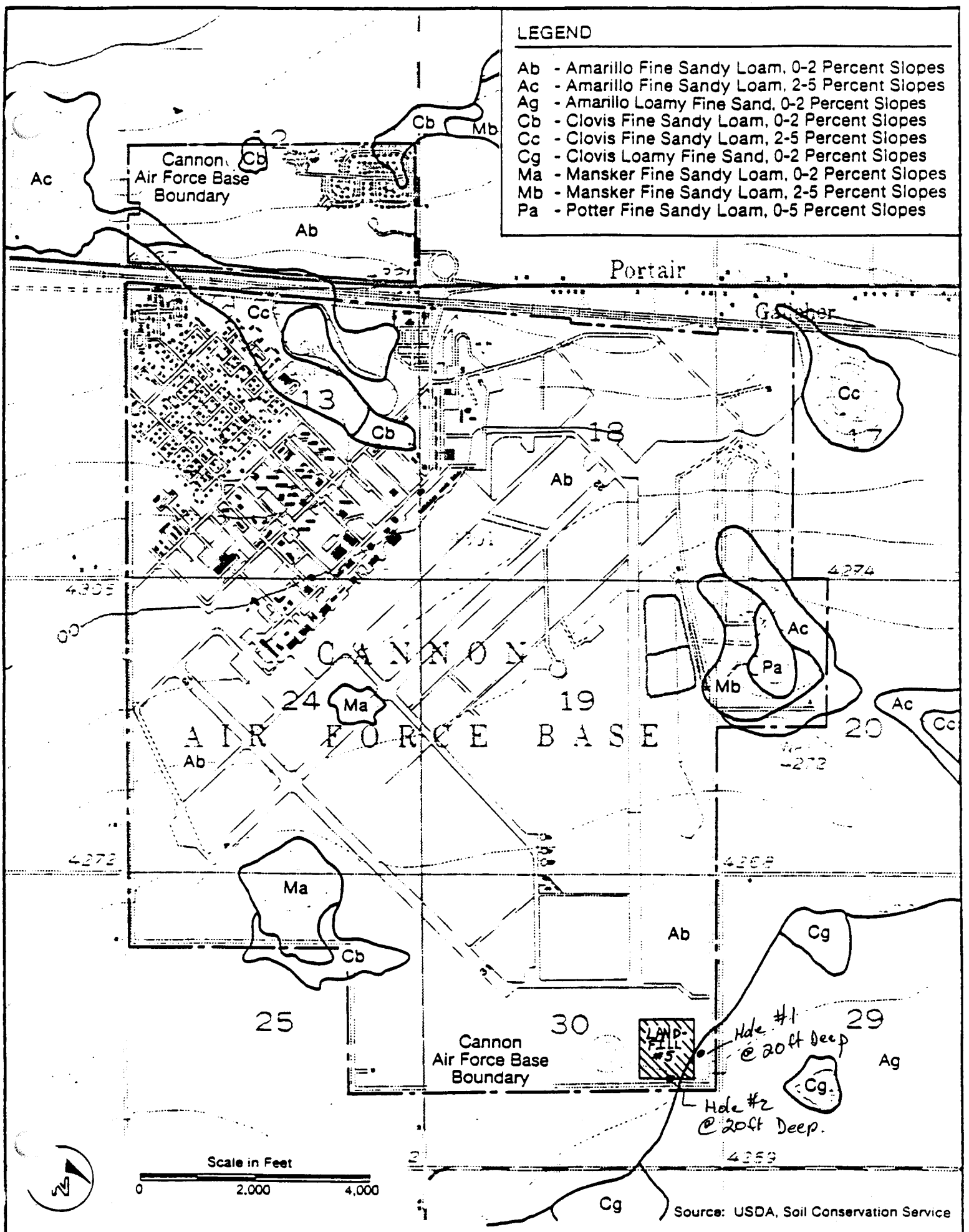


FIGURE 4
Soils Map.

CESWT-EC-GE 21 February 1992

MEMORANDUM FOR RECORD

SUBJECT: Landfill 5/Cell 3 Cap Pre-design Meeting at Cannon Air Force Base

1. This memorandum summarizes the subject meeting held at Cannon Air Force Base (AFB) on 12 February 1992.

2. Meeting attendees:

Name	Office
Jim Richards	Cannon AFB, Env. Office
Bruce Hale	" "
Pete Zamie	" , Civ.Engr.Off.
Bob Wilson	Tulsa District
Dennis Thomas	" "
Mark Wittrock	Albuquerque District

3. A pre-design meeting was held at Cannon to review the design schedule and go over suggested cap design alternatives. A summary of this meeting is as follows:

a. Cell 3 Cap Design Schedule.

Prior to this meeting, Cannon was mailed a copy of the design schedule. Cannon was asked if sufficient review time was allotted for the 30% and 95% submittals. Per an agreement with the Tulsa District, the Albuquerque District will forward these submittals directly to Cannon to save time. Cannon was satisfied that sufficient time was available for each review period. Cannon will provide copies of each submittal to the New Mexico Environmental Department (NMED) and will work with NMED to maintain the design schedule.

It was decided to also schedule a 60% design meeting, to be held at the Albuquerque District offices. It was felt that at 60%, a more detailed design could be presented to NMED and would allow sufficient time for any changes should NMED disapprove the proposed design. Also, by the 60% timeframe, a decision will have been reached on the design of the Landfill 5 cap (which effects the Cell 3 cap design). In addition, a survey will have been completed to provide an accurate surface topography at the site.

b. Cap Design Alternatives.

Albuquerque District proposed using a geocomposite liner for capping Cell 3. Cannon objected to this option stating costs as their main reason. Cannon was also concerned that this type of

liner could not be effectively integrated into a future landfill cap. In past discussions with NMED, Cannon believes that NMED would accept a simple 3' clay cap as long as it was slightly more impermeable than the native soil beneath the cell. Tulsa District brought up concerns that a clay cap would desiccate and fissure in this semi-arid region unless some sort of moisture barrier was placed above it (ie. a high density polyethylene liner). Cannon, again concerned with costs, felt that a clay cap would be sufficient stating that fissuring was not a problem in this area.

Albuquerque District was requested to schedule and prepare an estimate to determine the permeability of the native soil beneath the cell. Instead of sampling directly beneath cell 3, it was agreed that obtaining a permeability sample immediately adjacent to Landfill 5 would be sufficient, thus avoiding the added costs of sampling through contaminated materials. Well logs, for monitoring wells surrounding the landfill, indicated that the subsurface soils were relatively homogeneous.

To control rainwater runoff, Albuquerque proposed designing the cell's drainage system as if the entire landfill would be capped at the same time. The drainage pattern for Cell 3 would be generated from the drainage system developed for Landfill 5. Cannon concurred with this stating that this would help tie the cell cap into the future landfill cap.

The potential of rodents burrowing into the cap was discussed. Albuquerque District stated that it was discovered that rodents would not burrow through one brand of geocomposite cover. Another option raised for rodent control would be the use of a gravel layer between the top soil and clay layers. It was agreed that burrowing rodents are a problem at Cannon and that the Albuquerque District would address this in the cap design.

3. In summary, the Albuquerque District will design a cap for Cell 3 to be slightly more impermeable than the native soil beneath the cell. The cap's drainage pattern will be designed for future tie-in to a landfill drainage system. The cap design shall include a means to prevent rodents from burrowing thru it. To determine permeabilities, Albuquerque will have tests performed on native subsurface soils immediately adjacent to Landfill 5. A 60% design meeting will be scheduled at the Albuquerque District, Cannon will invite NMED to attend.

ROBERT C. WILSON
Environmental Engineer

LANDFILL 5, CELL 3 CAP, CANNON AFB, NM

A/E FIRM: IN-HOUSE HIRED LABOR — DATE: 18-Feb-92

COMMENTS: TULSA DISTRICT BROKER — LAST REV 18-Feb-92

RECEIVE DESIGN INSTRUCTION	Mon	27-Jan-92		CALENDAR DAYS
ESTIMATE/REQUEST FUNDS	Fri	24-Jan-92	-3	
RECEIVE FUNDS	Fri	24-Jan-92		
PREDESIGN CONFERENCE	Wed	12-Feb-92	19	At CAFB
TOPO AVAILABLE	Fri	28-Feb-92	16	
NOTICE TO PROCEED (NTP)	Thu	13-Feb-92		
COMPLETE 30% DESIGN/SEND TO REPRO	Fri	13-Mar-92	29	
REPRODUCTION COMPLETE	Tue	17-Mar-92	4	
MAIL 30% DESIGN	Wed	18-Mar-92	1	
TULSA REVIEW COMPLETE/CMTS REC'D	Fri	27-Mar-92	9	
START FINAL DESIGN	Fri	27-Mar-92		
ON-BOARD 60% REVIEW CONFERENCE	Fri	17-Apr-92	21	At Albuquerque Dist
SUBMIT ADV FNL DESIGN FOR I-H REVIEW	Fri	08-May-92	21	
I-H REVIEW COMPLETE	Tue	12-May-92	4	
COMMENTS INCORPORATED/SEND TO REPRO	Fri	15-May-92	3	
REPRODUCTION COMPLETE	Mon	18-May-92	3	
MAIL ADVANCE FINAL DESIGN	Mon	18-May-92		
TULSA REVIEW COMPLETE/CMTS REC'D	Mon	01-Jun-92	14	
COMMENTS INCORPORATED	Mon	22-Jun-92	21	
100% DESIGN COMPLETE	Mon	22-Jun-92		
REPRODUCTION COMPLETE/MAIL	Fri	26-Jun-92	4	
COMPLIANCE CHECK COMPLETED	Fri	03-Jul-92	7	
COMPLIANCE COMMENTS INCORPORATED	Tue	07-Jul-92	4	
MAIL FINAL DESIGN DOCUMENTS	Wed	08-Jul-92	1	By Tulsa Dist
BCO CERTIFICATE ISSUED	Wed	15-Jul-92	7	
DRAWING & SPECS READY FOR REPRO	Wed	15-Jul-92		
REPRO FOR ADVERTISING COMPLETE	Wed	22-Jul-92	7	
PROJECT ADVERTISES	Wed	05-Aug-92	14	
BID OPENING	Fri	04-Sep-92	30	
AWARD CONSTRUCTION CONTRACT	Fri	18-Sep-92	14	
NOTICE TO PROCEED (NTP)	Fri	02-Oct-92	14	Unconfirmed duration
CONSTRUCTION COMPLETE	Fri	19-Feb-93	140	
BENEFICIAL OCCUPANCY DATE (BOD)	Fri	19-Feb-93		

CESWT-EC-GE 24 April 1992

MEMORANDUM FOR RECORD

SUBJECT: Landfill 5/Cell 3 Cap 60% Design Meeting at Cannon Air Force Base

1. This memorandum summarizes the subject meeting held on 16 April 1992.

2. Meeting attendees:

Name	Office
Herb Grover	New Mexico Environmental Dept.
Stephanie Stoddard	" "
Bruce Eale	Cannon AFB Environmental Off.
Lt. Crawford	" "
Pete Zamie	" , Civ.Engr.Off.
Bob Wilson	Tulsa District
Bill Erdner	" "
Mark Wittrock	Albuquerque District

3. A 60% interim-design meeting was held at Cannon to provide NMED and Cannon information on the proposed cap design alternatives. A summary of this meeting is as follows:

a. Cell 3 Cap 60 % Design Review.

Albuquerque District went over the procedures used to develop the landfill cap design alternatives. One of the cap design requirements was that the cap have a permeability less than or equal to the natural subsoils present. To determine this, Albuquerque performed in-place permeability tests (completed in March 92) and found that the in-situ soils had a permeability of 5.7×10^{-5} cm/sec.

Due to the semi-arid region in which Cannon is located, there was concern that a clay cap would be subject to desiccation cracking. One of the design alternatives proposed using a two foot thick "soil" cap meeting 10^{-6} cm/sec maximum permeability. The soil cap would consist of a mixture of clay and sand to help reduce shrink-swell potential due to a lower placement water content. The second alternative would use a geocomposite liner (consisting of a bentonite material attached to a flexible membrane liner (FML)). Should the bentonite material be subject to dissication, the FML would provide secondary protection against vertical migration of surface water.

Both alternatives were designed to meet both EPA and NMED requirements and both allow future integration into a Landfill 5 cap (assuming the landfill cap only has to meet current Cell 3

cap requirements). However, it was brought up in the meeting that if a RCRA cap (which requires a maximum permeability of 10^{-7} cm/sec) is eventually required for Landfill 5, the current Cell 3 soil cap alternative would not meet RCRA standards. Thus, to fully integrate it into Landfill 5's cap, the Cell 3 cap would have to be partially or totally reconstructed.

NMED commented that they thought Albuquerque's design was well thought out. Before accepting either alternative, however, they want to have their technical section review the design. No matter what alternative is selected, a test cell cap will be constructed adjacent to or on Landfill 5 near the Cell 3 site. This will be used to determine the adequacy of the materials used before any construction commences and will be a "learning experience" for the contractor constructing the cap. NMED proposed that both alternatives be used in the test cell to both help insure the adequacy of the selected cap alternative and also to help develop the future design of Landfill 5's cap **(this will be Cannon's decision on whether or not they want this suggestion implemented)**. NMED also suggested that Albuquerque look into records for the original Cell 3 cap to provide information on how it was actually constructed and also on what problems they ran into.

b. 30% Design comment review. Albuquerque went over Tulsa District comments and responses to the 30% Design. The Tulsa District concurred with the comment responses. Cannon and NMED had not submitted comments, however both NMED and Cannon felt that this meeting answered all questions they had on the design to date.

4. The 95% "Advance Final" Design is scheduled to be submitted by 18 May 92. According to the design schedule, advance final comments are needed by 1 June 92.

ROBERT C. WILSON
Environmental Engineer

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS 27TH SUPPORT GROUP (TAC)
CANNON AIR FORCE BASE, NM 88103

REPLY TO:
ATTN. OF: 27 CSG/CEV

30 APR 1992

SUBJECT: 60% Design Review Comments, Soil Cap, Landfill 5, Cell 3

TO: Albuquerque District Corps of Engineers
Attn: Mark Wittrock
CESWA-RE
P.O. Box 1580
Albuquerque, NM 87103-1580

1. 60% design submittal for Soil Cap, Landfill 5, Cell 3, Cannon Air Force Base (CAFB) has been reviewed by this office, and the following comment(s) are returned for your info/action.

2. A question concerning the requirements for signage encompassing the aforementioned area was raised at the 60% design review conference conducted at CAFB 16 APR 92. The applicable Code of Federal Regulations states, "A sign with the legend, DANGER - UNAUTHORIZED PERSONNEL KEEP OUT, must be posted at each entrance to the active portion of a facility, and at other locations, in sufficient numbers to be seen from any approach to this active portion. The legend must be written in English and Spanish, and must be legible from a distance of at least 25 feet".

3. Our POC is Mr. Hale or 1Lt Crawford at DSN 681-4348.

FOR THE COMMANDER

Timothy G. Wise

Timothy G. Wise, Major, USAF
Base Civil Engineer

cc: HQ TAC/CEV
Tulsa District
Corps of Engineers

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS 27TH SUPPORT GROUP (TAC)
CANNON AIR FORCE BASE, NM 88103

6 MAY 1992

REPLY TO:
ATTN OF: 27 SG/CEV

SUBJECT: Landfill 5/Cell 3 Cap 60% Design Meeting

TO: Tulsa District Corps of Engineers
Attn: Robert C. Wilson
CESWT-EC-GE
P.O. Box 61
Tulsa, OK 74102

1. Reference your 24 April 1992 Memorandum for Record, same subject.

2. In the above mentioned Memorandum for Record, you state:

> "However, it was brought up in the meeting that if a RCRA Cap (which requires a maximum permeability of 1 x 10(-7) cm/sec) is eventually required for Landfill 5, the current Cell 3 soil cap alternative would not meet RCRA standards".

This is not the case. All cells in Landfill 5 operate without any bottom liner, therefore IAW 40 CFR, 265.310(a)(5), permeability of the cap must be less than or equal to the permeability of the natural subsoils present, (ie., less than or equal to 5.7 x 10(-5) cm/sec).

3. Please direct any questions to 1Lt Crawford at (505) 784-4639.

FOR THE COMMANDER

Timothy G. Wise, Major, USAF
Base Civil Engineer

cc: HQ TAC/CEV
Albuquerque District
Corps of Engineers

July 20, 1992
CAFB Cell 3 Landfill 5 ~~des~~ cap design meeting

Name	Representing	Phone #
William F. Moats	NMED	827-5824
Jimmie N Richards	Cannon AFB 27CES/CEV	784-4639
Stephanie Feldacil	NMED	827-4308
MARK WITTROCK	COE	766-1722
John Pfeil	NMED	827-2776

State of New Mexico
ENVIRONMENT DEPARTMENT
Harold Runnels Building
1190 St. Francis Drive, P.O. Box 26110
Santa Fe, New Mexico 87502
(505) 827-2850

BRUCE KING
GOVERNOR

JUDITH M. ESPINOSA
SECRETARY

RON CURRY
DEPUTY SECRETARY

July 15, 1992

Mr. Jim Richards
27 CSG-DEV
Cannon Air Force Base
Cannon Air Force Base, New Mexico 88103

Dear Mr. Richards:

It has come to our attention that a miscommunication may have occurred at the June 26 meeting with reference to the Hazardous and Radioactive Materials Bureau's (HRMB) position regarding design requirements for the cover of Cell 3, Landfill 5. Attached are HRMB's requirements for the cap design based on our technical review, which is also our recollection of the principal points covered at the meeting. Recall that HRMB agreed in principle with the geocomposite design, which is reflected in only a portion of the meeting record.

RCRA guidance documents are written to assist facilities in demonstrating compliance with design and operating or closure and post-closure requirements. It is HRMB's position that EPA guidance must be followed. However, a departure from guidance may be accepted if the facility can establish and adequately document that any change will provide at a minimum an equivalent level of performance/protection as can be obtained by the guidance design.

Once satisfied that the cap design meets the fundamental technical requirements per EPA guidance, HRMB is prepared to issue a letter to CAFB stating such. This letter will not, however, constitute final approval of the cap design. Final approval is subject to public comment as an amendment to the approved closure plan per 40 CFR 265.112 (d)(4).

We look forward to meeting with you on July 21. In addition to our discussions, please have any justifications for changes to the cap design in writing for our review. With respect to the post closure care permit application, HRMB hopes at that time to clarify the regulatory procedures that need to be followed and any further requirements that need to be met prior to its approval.

If you have any questions regarding this matter, please call Stephanie Stoddard at (505)827-4308 or 827-4313.

July 15, 1992
CAFB Pg 2.

Sincerely,

Edward L. Borsa
RCRA Program Manager

xc: Mark Wittrock, P.E.
Army Corps of Engineers

Thomas Manning, AICP
Air Force Center For Environmental Excellence

REVIEW COMMENTS TO 100% REVIEW OF LANDFILL 5 CELL 3 SOIL CAP.

1. Bedding material needs a separate spec. This material will be under the clay cap or the GML, whichever system is chosen. The requirements for each may vary. The largest size material for the bedding under the GML should be one inch. The largest size material under the clay cap can remain at three inches. A

2. Section 01420. Workers should be required to have the 40 hour health and safety training. An on-site safety briefing should be given to each worker before the start of work. Work should be in modified level D or level D protection. A

3. There needs to be an air monitoring program for identification of vapors and combustible gases. The air monitoring program will determine at what levels workers will upgrade to a higher level of protection. There is a layer of soil shown on the drawings however this is not uniform and there is some trash mixed in with the soil cover. A

4. A provision needs to be included in the specs to provide for reburial of trash that has been uncovered during construction. This material needs to be reburied under the constructed cap. A

5. Consideration should be given to anchoring the GML at the edges. Also the seam between the new GML and the old GML may be very difficult (the HDPE liner may be puckered or folded). Consideration should be given to welding this seam rather than just having an overlap. TAPE SEAMS

6. Section 02245. This section should include description of installation which includes free of wrinkles, puckers, or folds. If the edges of the GML are not flat the integrety of the seam will be in question. A

DEPARTMENT OF THE AIR FORCE

HEADQUARTERS 27th FIGHTER WING (ACC)
CANNON AIR FORCE BASE, NEW MEXICO

6/22/92

FROM: 27 SG/CE
111 Engineers Way
Cannon AFB NM 88103-5136

10 JUN 1992

SUBJ: 95% Design Review Comments, Soil Cap, Landfill 5, Cell 3

TO: Albuquerque District Corps of Engineers
Attn: Mark Wittrock
CESWA-RE
P.O. Box 1580
Albuquerque, NM 87103-1580

1. Your 95% design submittal for Soil Cap, Landfill 5, Cell 3, Cannon Air Force Base (CAFB) has been reviewed by this office, and is satisfactory. We forward no other comments at this time.

2. Our POC is Mr. Bruce Hale or Capt Crawford at DSN 681-4348.

Lawrence Nygren
LAWRENCE NYGREN, GM-14
Deputy Base Civil Engineer

cc: HQ TAC/CEV
Tulsa District
Corps of Engineers

Global Power for America

File: D:\ARMS\CANNON.CMT
Printed: Friday May 15, 1992 at 2:28:41 p.m.

Project Info: Cannon Air Force Base Landfill # 5 Cell # 3 Soil Cap

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
1	ERDNER	CESWT-EC-G	02210-1	GEO	1.2

Delete reference ASTM D 3017. Studies at the University of Texas have shown the nuclear method of determining moisture is not very accurate in the field. Moisture contents are commonly three to four percent different than the values determined by the ASTM D 2216 procedure. The microwave procedure (ASTM D 4643) has been shown to be a much more accurate method of determining moisture content. A

2	ERDNER	CESWT-EC-G	02210-1	GEO	1.2

Reverse ASTM D 2216 and ASTM D 4643. ASTM D 4643 is the microwave procedure. A

3	ERDNER	CESWT-EC-G	02210-1	GEO	1.2

Add the following references:

ASTM D 422 (1963) Particle-Size Analysis of Soils

ASTM D 4318 (1984) Liquid Limit, Plastic Limit, and Plasticity Index of Soils A

ASTM D 4253 (1983) Maximum Index Density of Soils Using a Vibratory Table

ASTM D 2167 (1984) Density and Unit Weight of Soil in Place by the Rubber Balloon Method

4	ERDNER	CESWT-EC-G	02210-1	GEO	1.3.1

If gravels and sands are acceptable for this project, include SW, SP, GC, and GP. A

5	ERDNER	CESWT-EC-G	02210-2	GEO	1.3.4

Mark, let's decide if ASTM D 698 or ASTM D 1557 is the procedure we want to use. Since this is a landfill cap with no loads (pavement, etc.) I am leaning to the Standard Compactive effort. ASTM D 698 or 1557 is not applicable to free draining, cohesionless soils which have been included as satisfactory materials. The "Degree of Compaction" paragraph has been revised to agree with the ASTM Standards as follows: A

Degree of compaction is a percentage of the maximum laboratory dry density obtained by the test procedure presented in ASTM D 698 or ASTM D 4253. ASTM D 698 shall be used for soils containing 15 percent or more fines. ASTM D 4253 shall be used for soils containing 5 percent or less fines. The maximum laboratory dry denity of soils containing between 5 and 15 percent fines shall be determined by the above procedure achieving the highest dry density. Degree of compaction shall be expressed as a percentage of the maximum laboratory dry density obtained by the appropriate procedure as defined above. Percentage of

File: D:\ARMS\CANNON.CMT
Printed: Friday May 15, 1992 at 2:29:47 p.m.

Project Info: Cannon Air Force Base Landfill # 5 Cell # 3 Soil Cap

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail

maximum laboratory dry density has been abbreviated hereinafter as percent laboratory maximum density or percent maximum density.

6 ERDNER CESWT-EC-G 02210-3 GEO 2.1.1
2nd line. Insert spacing between words in "landorsources".

7 ERDNER CESWT-EC-G 02210-3 GEO 3.1
Last line. Typing error! "beremoved" Insert space.

8 ERDNER CESWT-EC-G 02210-4 GEO 3.5
Revise to state the maximum stone diameter to be 4 inches rather than 6 inches.

9 ERDNER CESWT-EC-G 02210-4 GEO 3.5
Next to last sentence: The moisture content requirement is not applicable to the cohesionless satisfactory materials specified. Let's discuss whether to delete cohesionless materials or specify the moisture requirements for both cohesive and cohesionless soils. Include using a disk to aid in adjusting the moisture content.

10 ERDNER CESWT-EC-G 02210-5 GEO 3.6
Specify 95 percent of maximum laboratory dry density. 95 percent is applicable to both the ASTM D 698 and ASTM D 4253 procedures.

11 ERDNER CESWT-EC-G 02210-5 GEO 3.8
3rd line: Insert "loose" before the word "thickness".

12 ERDNER CESWT-EC-G 02210-5 GEO 3.8
Include compaction and moisture requirements. Compaction shall be achieved by one complete coverage of a dozer track. Moisture content shall be adjusted as required to facilitate compaction.

13 ERDNER CESWT-EC-G 02210-5 GEO 3.9
Revise this paragraph as required to delete moisture determination by the nuclear method. A possible wording is as follows:

Moisture contents shall be determined in accordance with ASTM D 4643 or ASTM D 2216. If ASTM D 4643 is used, moisture contents shall be checked by ASTM D 2216 once per each ten microwave test procedures. If ASTM D 2922 is used, in-place densities shall be checked by ASTM D 1556 at a frequency of one sand cone test for each 8 nuclear tests and not less than one sand cone test per lift. The sand cone test shall be performed adjacent to the area where a

File: D:\ARMS\CANNON.CMT
Printed: Friday May 15, 1992 at 2:28:55 p.m.

Project Info: Cannon Air Force Base Landfill # 5 Cell # 3 Soil Cap

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail

nuclear test was performed to insure a proper correlation is established. Material from the sand cone location shall be tested to determine the laboratory maximum dry density as specified hereinafter.

14 ERDNER CESWT-EC-G 02210-5 GEO 3.10.1
Change to paragraph 3.10 unless something has been left out. Revise the paragraph to include the following.

A sufficient quantity of material shall be obtained from the sand cone test location to determine the maximum laboratory dry density, gradation, liquid limit, and plastic limit. A gradation test shall be run on the sample prior to determining the maximimum laboratory dry density. A portion of the sampled material shall be tested to determine the liquid limit and plastic limit of the material passing the no. 40 sieve. A mimimum of one laboratory density test, gradation, liquid limit, and plastic limit test shall be run each placement day or fraction thereof. Additional tests shall be run for each material change. A

15 ERDNER CESWT-EC-G 02224-2 GEO 1.3
Bedding and biobarrier materials should not be included in this section: Impervious Soil Cap. Move to Section 2210 - GRADING A

16 ERDNER CESWT-EC-G 02224-2 GEO 1.3.1.3
Comment Deleted.

17 ERDNER CESWT-EC-G 02224-2 GEO 1.3.2 A
Delete the second sentence.

18 ERDNER CESWT-EC-G 02224-2 GEO 1.3.3
Specify ASTM D 698 be used for the impervious ~~clay~~ soil cap. If the bedding and biobarrier materials are not moved to GRADING the degree of compaction shall be defined as specified in comment No. 5. A N/A

19 ERDNER CESWT-EC-G 02224-2 GEO 1.3.1.1
Add SW as a satisfactory material. If the bedding layer is to be used as a gas collection layer then a sand or gravel material with a soil filter will be required. Other options are a thick geotextile which serves as both drain and filter or a geonet drain with a geotextile filter. Revise as required to satisfy cap criteria for this project. Address both options proposed for this project. A

20 ERDNER CESWT-EC-G 02224-3 GEO 1.5
Include a tamping roller. The tamping roller shall meet the specifications of A

File: D:\ARMS\CANNON.CMT
Printed: Friday May 15, 1992 at 2:29:02 p.m.

Project Info: Cannon Air Force Base Landfill # 5 Cell # 3 Soil Cap

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail

a Caterpillar 815 or 825 roller or equivalent. If a tamping roller is used, a rubber tired roller may be required on the first and last lift of impervious cap. The advantage of the tamping roller is a better bond is provided between layers of the ~~clay~~ Soil cap material.

21 ERDNER CESWT-EC-G 02224-3 GEO 1.5
Specify a disk be used to blend the materials and be used to assist in achieving the specified moisture content. The disk should be capable of blending the entire loose layer thickness.

22 ERDNER CESWT-EC-G 02224-2 GEO 1.3.1.2
Add the following: SC material shall contain 30 percent or more fines.

23 ERDNER CESWT-EC-G 02224-7 GEO 3.3.1
Specify a moisture content range and/or as required to meet the compaction requirements. Method of determining maximum laboratory dry density depends on the material gradation(percent fines). Refer to paragraph on degree of compaction. Specify 95 percent compaction which refers to both the ASTM D 698 and ASTM D 4253 procedures.

24 ERDNER CESWT-EC-G 02224-7 GEO 3.4.1
Fourth line. Is "pad foot" roller the same as a tamping roller?

yes it appears so

25 ERDNER CESWT-EC-G 02224-7 GEO 3.4.2
This paragraph is for the impervious cap. Delete reference to bedding material. Delete this paragraph?

26 ERDNER CESWT-EC-G 02224-7 GEO 3.6
Revise this paragraph to delete moisture content determination by the nuclear method. See comment No. 13.

27 ERDNER CESWT-EC-G 02224-7 GEO 3.6
Clarify whether all of the tests specified (sampling, gradation, liquid limit, plasticity index, and density control) and the frequency of testing is applicable to the impervious ~~clay~~ soil, bedding, and biobarrier materials.

28 ERDNER CESWT-EC-G 02224-11 GEO 3.6.5
5th line. Delete "for determining density". Specify frequency of checking the microwave moisture content method as stated in comment no. 13.

File: D:\ARMS\CANNON.CMT
Printed: Friday May 15, 1992 at 2:29:11 p.m.

Project Info: Cannon Air Force Base Landfill # 5 Cell # 3 Soil Cap

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
29	ERDNER	CESWT-EC-G	02224-12	GEO	3.6.6

Depending on the percent fines of the material, the maximum laboratory dry density of the material shall be determined by ASTM D 698 or ASTM D 4253. Revise paragraph and refer to paragraph on degree of compaction. A

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
30	ERDNER	CESWT-EC-G	02224-13	GEO	3.8.1

Minimum size of the test fill shall be 50 x 150 feet. E

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
31	ERDNER	CESWT-EC-G	02224-13	GEO	3.8.2

1st. line. Delete the word "All". Clearly state, the contractor shall purchase the necessary sealed double ring device and be responsible for running the test. State a source where the SDRI device can be purchased. State; if the test is performed improperly due to negligence of the contractor the test shall be rerun at no cost to the government. For bidding purposes the contractor shall run one test. E

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
32	ERDNER	CESWT-EC-G	DWG-C5	GEO	TYP.X-SEC

Albuquerque District's response to the 30 percent design comments was a vent system will be required if a geocomposite design is utilized. Show the vent system in the typical section. Bedding material must be pervious enough to permit gas removal. See comment no. 19. A

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
33	ERDNER	CESWT-EC-G	DWG-C5	GEO	TYP.X-SEC

jack

File: C:\ARMS\AJA1.DBF

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
1	PAYNE	SWT-EC-DS	02050-1	CIV	PAR 1.3

The term "salvaged items" appear in this paragraph; however, this reviewer could not find any items specified to be salvaged. Coordinate.

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
2	PAYNE	SWT-EC-DS	02050-2	CIV	PAR 1.6.1

1st and 2nd line at top of page, delete "to be reused, or to remain the property of the Government" or indicate where required.

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
3	PAYNE	SWT-EC-DS	02050-2	CIV	PAR 3.2

Delete "excepting Government salvage and historical items" or indicate where required.

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
4	PAYNE	SWT-EC-DS	02050-2, -3	CIV	P 3.2.1.2

Delete this paragraph. The historical items listed would not be found at at landfill site.

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
5	PAYNE	SWT-EC-DS	02050-3	CIV	PAR 3.2.2

Change this paragraph to read, "All combustible and non-combustible materials shall be disposed of off Government controlled land at the Contractor's responsibility." A

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
6	PAYNE	SWT-EC-DS	02110-1	CIV	PAR 1.3.1

Change the last two lines of this paragraph to read "including down timber, snags, brush, and rubbish occurring within the area indicated to be capped." A

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
7	PAYNE	SWT-EC-DS	02110-1	CIV	PAR 1.3.2

Change this paragraph to read "Grubbing shall consist of the removal and disposal of stumps, roots larger than 3 inches in diameter, and matted roots from the area indicated to be capped." A

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
8	PAYNE	SWT-EC-DS	02110-1	CIV	PAR 1.5

Delete this paragraph.

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
9	PAYNE	SWT-EC-DS	02110-1, -2	CIV	PAR 3.1

Change this paragraph to read "Trees, stumps, roots, brush, and other vegetation in the area to be cleared shall be cut off flush with or below the original ground surface. Clearing shall also include the removal and disposal of structures that obtrude, encroach upon, or otherwise obstruct the work." A

jack

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
10	PAYNE	SWT-EC-DS	02110-2	CIV	PAR 3.2

In 3rd line after "surface" delete the remainder of the sentence.

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
11	PAYNE	SWT-EC-DS	02110-2	CIV	PAR 3.3

Delete this paragraph or indicate where clearing outside the cap area will be required.

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
12	PAYNE	SWT-EC-DS	02110-2	CIV	PAR 3.4.1

Delete "3.4.1 Materials"

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
13	PAYNE	SWT-EC-DS	02210-2	CIV	PAR 1.3.4

Select the appropriate laboratory density test to be performed. This should not be a decision to be made in the field. The appropriate specification should be referenced and the other deleted. (See Erdner cmt. 5)

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
14	PAYNE	SWT-EC-DS	02210-2	CIV	PAR 1.4

Delete "SD-91 Records" and the text. It appears all borrow will be from off-site sources.

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
15	PAYNE	SWT-EC-DS	02210-3	CIV	PAR 2.1

Delete last sentence of this paragraph.

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
16	PAYNE	SWT-EC-DS	02210-3	CIV	PAR 2.1.1

This paragraph is unbiddable. If a borrow source is available on Government property it must contain the appropritate material and be indicated on the drawings. If a borrow source is not available on Government property delete the references thereto and require all borrow to be furnished by the Contractor.

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
17	PAYNE	SWT-EC-DS	02210-3	CIV	PAR 2.1.2

If no borrow areas are available on Government property delete this paragraph.

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
18	PAYNE	SWT-EC-DS	02210-3	CIV	PAR 3.1

This paragraph starts with the statement "Where indicated"; however, none of the drawings or specifications indicate stripping of topsoil is required. Paragraph 1.3.5 states all topsoil shall be obtained from off-site sources. Coordinate.

jack

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
19	PAYNE	SWT-EC-DS	02210-3, -4	CIV	PAR 3.2

In the first line delete "After topsoil removal has been completed,". In the last sentence on page 4, delete "obtained from borrow areas" and substitute "provided by the Contractor"

20	PAYNE	SWT-EC-DS	02210-4	CIV	PAR 3.3

Delete this paragraph or indicate where required.

21	PAYNE	SWT-EC-DS	02210-4	CIV	PAR 3.5

In the title insert "(OTHER THAN IMPERVIOUS SOIL CAP)"

22	PAYNE	SWT-EC-DS	02210-5	CIV	PAR 3.6

Indicate percent of compaction required.

23	PAYNE	SWT-EC-DS	02210-5	CIV	PAR 3.9

The second sentence for frequency of testing is not comprehendible.

24	PAYNE	SWT-EC-DS	02215-1	CIV	PAR 1

At the end of this paragraph add "This section is applicable only for OPTION NO 2."

25	PAYNE	SWT-EC-DS	02224-1	CIV	PAR 1

At the end of this paragraph add "This section is applicable only for OPTION NO. 1."

26	PAYNE	SWT-EC-DS	02224-2	CIV	PAR 1.3.3

Select the appropriate ASTM specification to determine maximum laboratory density. This should be specified by the designer and not left to the field. Paragraph 3.3.1 of this section requires ASTM D1557. Coordinate.

27	PAYNE	SWT-EC-DS	02224-3	CIV	PAR 1.4

Delete "SD-91 Records" and the text. No borrow areas are on Government property.

28	PAYNE	SWT-EC-DS	02224-4	CIV	PAR 1.6

In the first line after "Materials" delete the remainder of the line. Delete the last sentence.

jack

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
29	PAYNE	SWT-EC-DS	02224-4	CIV	PAR 2.1

Delete the last sentence of this paragraph and substitute.
"Bedding material shall be obtained from sources outside the limits of Government property at the Contractor's responsibility."

30	PAYNE	SWT-EC-DS	02224-4, -5	CIV	PAR 2.2

Delete the last sentence of this paragraph. On page 5 delete "2.2.1 Selection of Borrow Material" and incorporate the text with paragraph 2.2 and delete the last sentence of current paragraph 2.2.1.

31	PAYNE	SWT-EC-DS	02224-6	CIV	PAR 3.2

Indicate depth of stripping and disposition of the stripped material. B N/A

32	PAYNE	SWT-EC-DS	02224-7	CIV	PAR 3.3.3

In the 3rd line change "(or" to "for" A

33	PAYNE	SWT-EC-DS	02224-8	CIV	PAR 3.4.1

No density is specified in the reference paragaraph. Coordinate. In the 10th line delete "cap is maintained" A

34	PAYNE	SWT-EC-DS	02224-10	CIV	PAR 3.5.3

This paragraph for compaction is a method specification and does not require the Contractor to perform any density test. Other portions of this section require density testing. Coordinate. A

35	PAYNE	SWT-EC-DS	02224-12	CIV	PAR 3.6.6

Choose the appropriate ASTM specification for determination of maximum laboratory density. A

36	PAYNE	SWT-EC-DS	02224-13	CIV	PAR 3.8.2

In the last sentence change "contractor officer" to "Contracting Officer" A

jack

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail
37	PAYNE	SWT-EC-DS	02224-13	CIV	PAR

General comment on SECTION 02224: This section requires the Contractor to select a borrow source that will produce material classified as SC or CL. He must then deliver 200 pounds of the material to SWD Laboratory for testing. After SWD testing of the material the Contractor must construct a test fill section and extract in-place material and submit it to the SWD Lab for testing again. By this time approximately 150 to 180 days have expired and no construction has commenced. How can the Contractor expect payment for all this preliminary work? Double testing seems excessive. If the first round of test proves the material acceptable why construct a test fill? E

38	PAYNE	SWT-EC-DS	02245-1	CIV	PAR 1.1

At the end of this paragraph add "This section applies to OPTION NO. 2 only." A

39	PAYNE	SWT-EC-DS	02245-3	CIV	PAR 3.1

Change the referenced section to "SECTION 02210 GRADING". Section 02224 is not applicable if this option is constructed. A

40	PAYNE	SWT-EC-DS	02245-3	CIV	PAR

General Comment on Section 02245: The drawing indicate the other composit material with the geomembrane is bentonite, but the specification never reflect this requirement. A

41	PAYNE	SWT-EC-DS	02935-	CIV	PAR

Section 02935 TURF needs to be edited to reflect what is required. The drawings indicate "grass". The specifications include many items that are not applicable. B

42	PAYNE	SWT-EC-DS	02830-	CIV	PAR

No fencing specifications were included in the submittal, but fencing is required. Provide a section on fencing. E

fencing on plan

43	PAYNE	SWT-EC-DS	0-BID SCH	CIV	PAR

No bid schedule was included in the submittal, but the specifications and drawings indicate a need for one. The bid schedule should indicate the two options indicated on the drawings and should direct the bidders to bid on the one of their choice. A

44	PAYNE	SWT-EC-DS	C-2 OF 5	CIV	

At coordinates C,5 identify "Permeameter # 1" A

jack

Num	Name	Office	Page/Sheet	Discipline	Rm/Detail

45 PAYNE SWT-EC-DS C-4 OF 5 CIV

"TYPICAL CROSS SECTION" and "JUNCTURE NEW SOIL CAP TO EXISTING SOIL CAP" A
The dimensions for the different layers of materials do not match. The left side of the detail "JUNCTURE NEW .....SOIL CAP" should match "TYPICAL CROSS SECTION". Coordinate.

"JUNCTURE NEW SOIL CAP TO EXISTING SOIL CAP" In the notation at coordinates D,8 change "membrain" to "membrane" A

"EXISTING LANDFILL CAP" The total dimension should be "33.5'" A

46 PAYNE SWT-EC-DS C-5 OF 5 CIV

"EXISTING LANDFILL CAP" The total dimension should be "33.5'"

"JUNCTURE NEW SOIL CAP TO EXISTING SOIL CAP" A distance from the existing vent pipe to the top of cut should be indicated. Slopes for the indicated excavation line should also be indicated. A

CESWA-CO-Q (415) 4 June 1992

MEMORANDUM THRU

Ch, Construction Branch
Ch, Con-Opns Division
DDE Project Management
Ch, Engr & Plng Division

TO CH, GEO-TECH BRANCH

SUBJECT: **B C O REVIEW**
Landfill #5, Cell #3, Soil Cap
Cannon AFB, NM

Enclosed herewith are the BCO comments on the **95%** submittal for the subject project. Duplicate comments were hand delivered separately to Mark Wittrock on 4 June 92.

DALE H. CARVER, P.E.
BCO Manager
Construction Branch

Enclosure

Copy Furnished:
DDE Project Management

REVIEW COMMENTS | CESWA-CO-NA-C | Keith Wylie | 30 May 92

- ☐ ____ Concept
- ☐ Early/____ Preliminary
- ☒ Early/~~Advance~~ Finals 95%
- ☐ Compliance Check
- ☐ Invitation to Bid
- ☐ Conference
- ☐ P. B.
- ☐ ____
- ☐ ____
- ☐ ____

- ☐ Agru
- ☐ Arch
- ☐ Civil
- ☐ Elec
- ☐ Envir
- ☐ Est
- ☐ G & M-P
- ☐ G & M-S
- ☐ Int Des
- ☐ ____
- ☐ Mech
- ☐ Stucs
- ☐ Struc
- ☒ Envir
- ☐ ____

ACTION:
A - CONCUR
D - DO NOT CONCUR
E - EXCEPTION
X - DELETION
(EXPLAIN & XI)

CMT NO	DWG NO OR REF	PROJECT/NUMBER: LandFill #5, Cell #3, Soil Cap	LOCATION: Cannon AFB, NM	ACTION
1	Seq 4	Suggest that wood posts & braces be changed to steel pipe. Steel posts should be embedded in concrete. Steel will last longer		A
2	Seq 4	Could the test cap be part of the new cell cap? If this is possible, it would save the government a good deal of money & time.		E
3	TP 02224 para 3.8	The detail of existing landfill cap as shown on Seq #4, C/C2/C4 is incorrect. The 15" rectangular concrete gutter drain shown is not what is installed. A precast conc. "cattle trough" or "hog trough" has been installed instead.		A

SWD Form 732 (R)
Rev 20 Apr 82

State of New Mexico
ENVIRONMENT DEPARTMENT
Harold Runnels Building
1190 St. Francis Drive, P.O. Box 26110
Santa Fe, New Mexico 87502
(505) 827-2850

BRUCE KING
GOVERNOR

JUDITH M. ESPINOSA
SECRETARY

RON CURRY
DEPUTY SECRETARY

July 15, 1992

Mr. Jim Richards
27 CSG-DEV
Cannon Air Force Base
Cannon Air Force Base, New Mexico 88103

Dear Mr. Richards:

It has come to our attention that a miscommunication may have occurred at the June 26 meeting with reference to the Hazardous and Radioactive Materials Bureau's (HRMB) position regarding design requirements for the cover of Cell 3, Landfill 5. Attached are HRMB's requirements for the cap design based on our technical review, which is also our recollection of the principal points covered at the meeting. Recall that HRMB agreed in principle with the geocomposite design, which is reflected in only a portion of the meeting record.

RCRA guidance documents are written to assist facilities in demonstrating compliance with design and operating or closure and post-closure requirements. It is HRMB's position that EPA guidance must be followed. However, a departure from guidance may be accepted if the facility can establish and adequately document that any change will provide at a minimum an equivalent level of performance/protection as can be obtained by the guidance design.

Once satisfied that the cap design meets the fundamental technical requirements per EPA guidance, HRMB is prepared to issue a letter to CAFB stating such. This letter will not, however, constitute final approval of the cap design. Final approval is subject to public comment as an amendment to the approved closure plan per 40 CFR 265.112 (d)(4).

We look forward to meeting with you on July 21. In addition to our discussions, please have any justifications for changes to the cap design in writing for our review. With respect to the post closure care permit application, HRMB hopes at that time to clarify the regulatory procedures that need to be followed and any further requirements that need to be met prior to its approval.

If you have any questions regarding this matter, please call Stephanie Stoddard at (505)827-4308 or 827-4313.

Sincerely,

Edward L. Borsa
RCRA Program Manager

xc: Mark Wittrock, P.E.
Army Corps of Engineers

Thomas Manning, AICP
Air Force Center For Environmental Excellence

June 26, 1992

CAFB Cap Design Landfill 5, Cell 3

Design Requirements per HRMB Technical Review

Because both design options are somewhat less rigorous than those required by EPA in the Technical Enforcement Guidance Document "Final Covers on Hazardous Waste Landfills and Surface Impoundments", HRMB recommended, but did not require, that CAFB consider combining both options (1 and 2) into a single composite cover system.

Requirements Concerning Both Options

1. The 2:1 (H:V) side slopes are too steep. HRMB views the cap as a stand-alone RCRA unit and required that the side slopes be reduced to no greater than 4:1. A

2. A top slope of 1% is insufficient to prevent ponding on and to ensure adequate drainage off the top of the landfill. HRMB required that CAFB increase the top slope to meet EPA guidance requirements (3-5%). A

3. The Contractor Quality Control Plan must be approved by HRMB prior to construction of the landfill cap. Noted

4. All quality control data must be to HRMB for its review and acceptance following construction of the cap. Noted

5. As-built drawings must be provided to HRMB prior to certification of closure. Noted

6. CAFB must provide HRMB with calculations/documentation to support the assertion that drainage ditches or berms to divert surface flow are not necessary. A

7. In consideration of potential pathways for landfill gas migration, HRMB was informed at the that no underground utilities were located close to the landfill. HRMB recommends that CAFB test for landfill gas prior to finalizing either design option. A

Soil Cap Option 1, Impervious Layer

8. The hydraulic conductivity for the impervious layer cannot exceed 1 X 10E-7. N/A

9. HRMB recommended the following material specifications be incorporated for the impervious layer: N/A

Fines (passing the #200 screen) > 30%
Coarse (retained on the #4 screen) < 10%
Liquid Limit >35%
Plasticity Index >15%

10. The construction quality assurance plan must be revised to reflect any changes necessary to achieve acceptable hydraulic conductivity. Detailed information concerning construction methodology should be provided in the plan. All quality control data resulting from tests conducted on the test pad must be provided to HRMB for review and approval prior to commencing construction of the actual soil cap. N/A

11. The method by which sampling points are selected must be stated in the specifications. N/A

12. If a test result indicates a failure, the method by which the extent of the deficient area is delineated must be clarified. N/A

13. Additional quality control testing must be done at the borrow source for the impervious layer. HRMB recommends that at a minimum the following additional tests be performed (see below). CAFB may adopt these changes to the specifications or propose an alternative. N/A

Grain Size	at least 1 test per 1000 CY
Moisture Content	at least 1 test per 1000 CY
PI and LL	at least 1 test per 5000 CY

At least one test per day of excavation and at least one test per visual or suspected changes in fill material should be performed for each or these test parameters.

14. Additional quality control sampling must be performed on the constructed soil cap (impervious layer). HRMB recommends that the following additional tests be performed . CAFB may adopt these changes to the specifications or propose an alternative. N/A

Undisturbed Hydraulic Conductivity:	at least 1 test per 1500 CY
Moisture Density Curve:	at least 1 test per 5000 CY

N/A

At least one test per day for density and moisture content, and at least one test per visual or suspected change in fill material should be performed on each day of soil cap construction.

15. All voids or holes in the soil cap resulting from testing efforts or survey stakes must be carefully filled with suitable compacted material. N/A

<u>Geocomposite Membrane Option #2</u>

1. The construction specifications should state that the geocomposite membrane cannot be placed during periods of significant rainfall. A

2. CAFB may wish to add a biobarrier layer to the design. Noted

APPENDIX C

SUMMARY OF FIELD ACTIVATES

SUMMARY OF FIELD ACTIVITIES
CANNON AFB, CLOVIS, NEW MEXICO

Prepared By: Jo Brady
Geology Section
Monday, January 27, 1992

PURPOSE: To determine the areal extent of Cell 3 by excavating trenches in both east-west and north-south directions. The State of New Mexico and the EPA are requiring Cannon AFB to place an impermeable soil cover over Cell 3 as it was in operation when the "land ban" regulations went into effect and the cell has been documented to have received solvents for disposal.

The site, Cell 3, is located in Sanitary Landfill Number 5, which in the southeastern corner of the base.

Tuesday, January 14, 1992

Arrived onbase at 1400 local time (New Mexico is on mountain time). Located project geologist Jim Martell and operator Jerry Camp onsite. Jerry was operating a rented John Deere 690D-LC trac-hoe from Yellowhouse Machinery, Amarillo, Texas. Excavation of a north-south trench had commenced from the south and was progressing upwind to the north. Excavated soil/trash was stockpiled adjacent to the trench so that it could be replaced upon completion of the trenching activities.

On the previous day (Monday), Jim Martell had located, measured, and staked the line for excavation a total length of 1000 feet. The centerline of the trench was approximately 15 feet west of the fenced area (refer to enclosed figure). To determine the length of time the cell was in operation, old newspapers were collected from the excavated piles of soil/trash and stored individually in plastic ziploc bags. Typically the layers of trash were 1-2 feet thick and separated by 6-12 inches of soil. Cover soil was placed over the trash 2-3 feet thick, however there was a veneer of trash spread over the cell which appeared erratically about 2 feet below the surface. Average depth of the excavation was 8-10 feet, although select areas were excavated to depth of 18 feet to locate the bottom of the cell.

Approximately 150 feet of the trench was excavated by the end of Tuesday.

Jim Martell returned to Tulsa Wednesday morning and Jo Brady directed the work.

Wednesday, January 15, 1992

Temperature with wind chill was -20 degrees F, winds from the north.

Work commenced at 0730. Continued excavating the north-south trench, obtaining dated material (newspapers) when available. At random intervals, the trench was excavated to depths of 18 to 19 feet (as the trench would allow) to determine the depth of the cell; but the total depth of the cell could not be determined. Historic reports indicate the depth could be as great as 25 feet, but no trac-hoe was available to dig to this depth. Native, undisturbed soil was encountered 650 feet north from the southwest corner of the fenced area. The soil/trash layers were observed to be spread to the sloped interface of native, undisturbed soil - refer to figure 2. Following confirmation of the cell's north limit, activities commenced to fill in the trench.

While soil/debris was being dozed into the trench, Mark Wittrock, Civil Engineer from the Albuquerque District, arrived to review the work. Mark is scheduled to design the soil cover for the cell. Jo Brady familiarized Mark with the scope of work and presented her observations of the cell. Each drove to the base Corps of Engineers office to inform Jim Richards, the base point-of-contact, that the work had been completed. Jim Richards was concerned that he did not have enough information available from the work just completed to define the areal extent of Cell 3. Jo Brady agreed to return Thursday to excavate more of the cell until its boundaries could be defined.

Thursday, January 16, 1992

Temperature with wind chill was -3 degrees F, winds from the north gradually changing in the afternoon to southerly winds and a high in the 30's.

Jo Brady met Mark Wittrock at the base COE office at 0730 to confirm the day's activities with Jim Richards. Jo Brady drove to the site at 0800 and drove Jerry Camp to town for a transfer pump to switch fuel from the tractor-trailer to the trac-hoe. Trenching activities recommenced at 0900 extending the north-south trench to define the southern boundary of the landfill. Jo Brady was joined by Mark Wittrock and Glenn Woodson (Jim Richard's representative) to observe the work. The southern boundary of the

trench was defined to be 150 feet south from the SW fencepost of the fenced area. Mark Wittrock and Jo Brady measured the vertical change in relation to the horizontal difference to calculate the slope of the trench. The slope was conservatively determined to be no steeper than 3H:1V (see figure 2) and the overall cell length was determined to be 800 feet.

East-west trenches were excavated until undisturbed native soil was encountered both north and south of the fenced area to further define the cell boundaries. Cell 3 was measured to be 50 feet wide; 35 feet from the western fence line of the fenced area and 15 feet to the east of the western fence line. A second north-south trench was excavated between the 250 and 300 foot mark as Jo Brady had observed an area of apparently clean fill and this was approximately one-half the length of the entire trench. Jim Martell had speculated that there may be two cells with a native soil barrier or berm between rather than one long cell. No barrier or berm was observed in the second north-south trench. Refer to figure 1 for location of various excavations.

Typically the trash consisted of household refuse and office waste. Tires and other automotive items were occasionally observed as was medical waste in the form of syringes and intravenous bags. A "solvent" smell was noticed in two trenches (see figure 1 for locations). At one of these locations, Mark Wittrock observed free liquid draining into the soil from a container disturbed by the excavation activities.

Jim Richards stopped by towards the end of the day to briefly observe the work and was pleased with the progress and results. Excavation was halted at 1700 due to impending darkness; excavation would continue Friday morning at 0800.

Friday, January 16, 1992

Weather was overcast and cold throughout the day, with winds from the north.

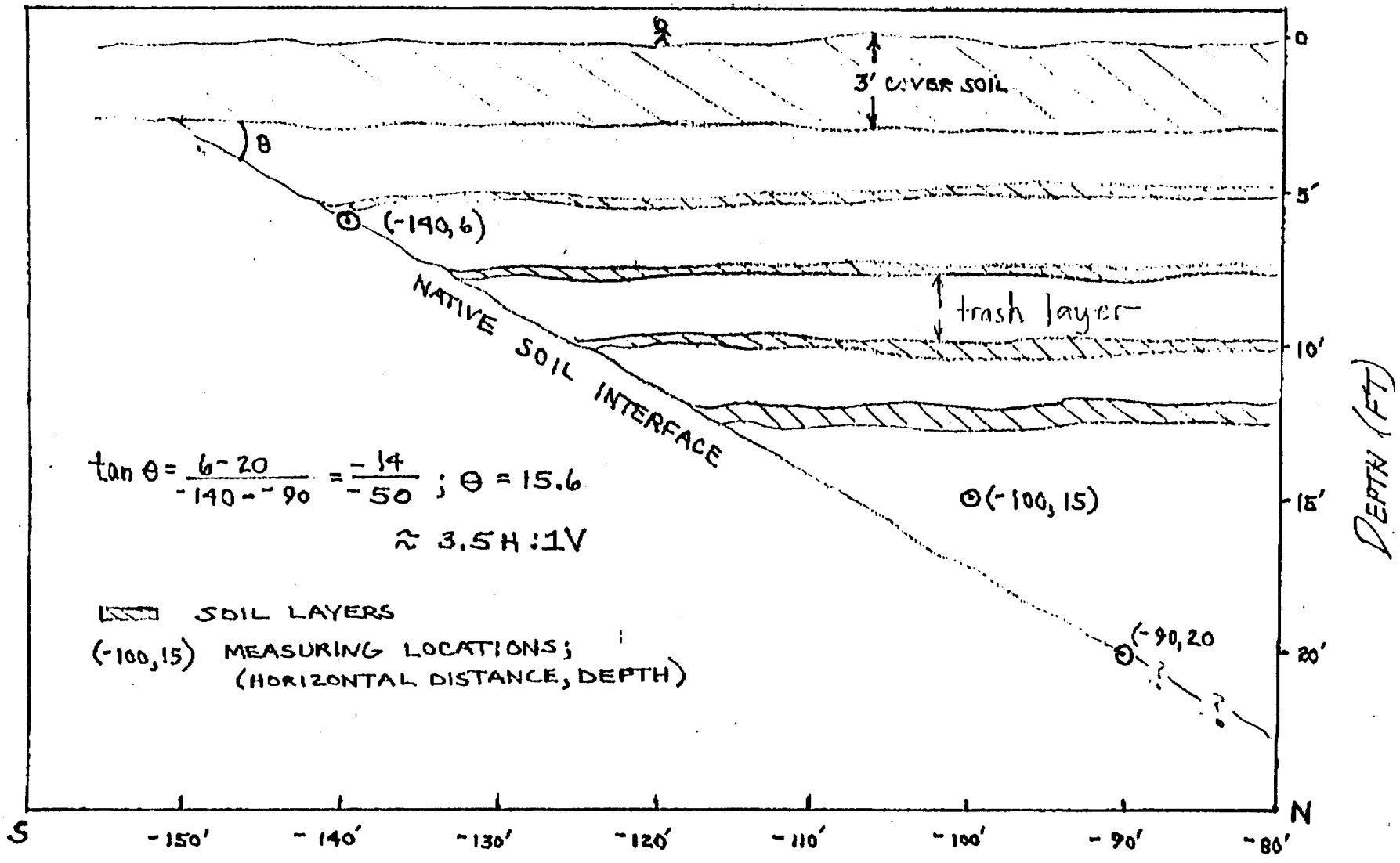
Jo Brady stopped at the base COE office at 0730 to outline the day's activities with Jim Richards. Jim requested that the extent of the native soil barriers separating Cell 3 from surrounding cells be determined by extending the east-west trenches into the adjacent cell and obtaining dated material from them. Jo Brady expressed her concern of potential cross-contamination to Jim Richards when he visited the site after the eastern cell had been

encountered. Jim was aware of Jo Brady's concern; however he said the State had specifically requested the width of the soil barrier be determined. It was agreed that an attempt to reduce the potential for cross-contamination would be made by minimizing the amount of soil barrier excavated until the adjacent cell was encountered. An average of 10 feet separated Cell 3 from the adjacent cells on each side. The newspaper obtained from the cell to the east of Cell 3 yielded a date of 1978, while the date from the cell to the west was 1979. Only Glenn Woodson observed the day's activities as Mark Wittrock was returning to Albuquerque.

Excavation activities concluded approximately 1100. The trenches were filled in the afternoon.

The site was inspected after all the trenches had been refilled and compacted by the equipment driving over it. Although the debris visible at the surface was unavoidable, further work may be necessary to cover the debris to prevent a safety hazard to the flightline of blowing trash.

Jo Brady stopped by the base COE office to inform Jim Richards that the work had been completed and the trenches filled. Jo Brady indicated there was debris at the surface which may require further attention and informed Jim to expect a report of the field activities sometime next week. Jo Brady left the base at 1730; Jerry Camp drove the equipment to the hotel for an early departure Saturday morning. The rental company was contacted to pick up the trac-hoe. It was arranged to leave the trac-hoe at the site outside the locked gate where it would be picked up on Tuesday.



CANNON AFB
SANITARY LANDFILL 5
PARTIAL CROSS-SECTION OF CELL 3

FIGURE 2

CANNON AFB
SANITARY LANDFILL 5
CELL 3

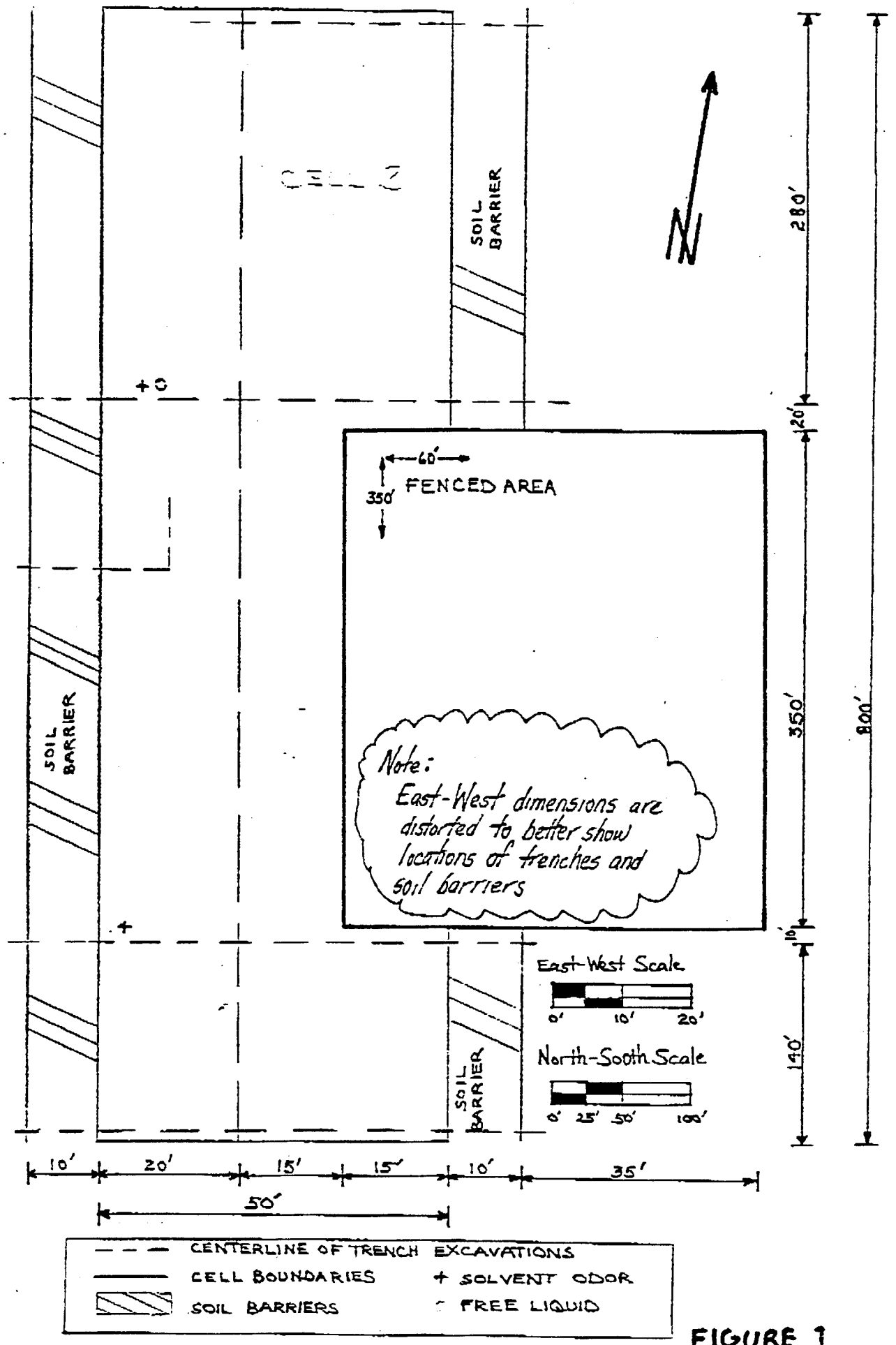
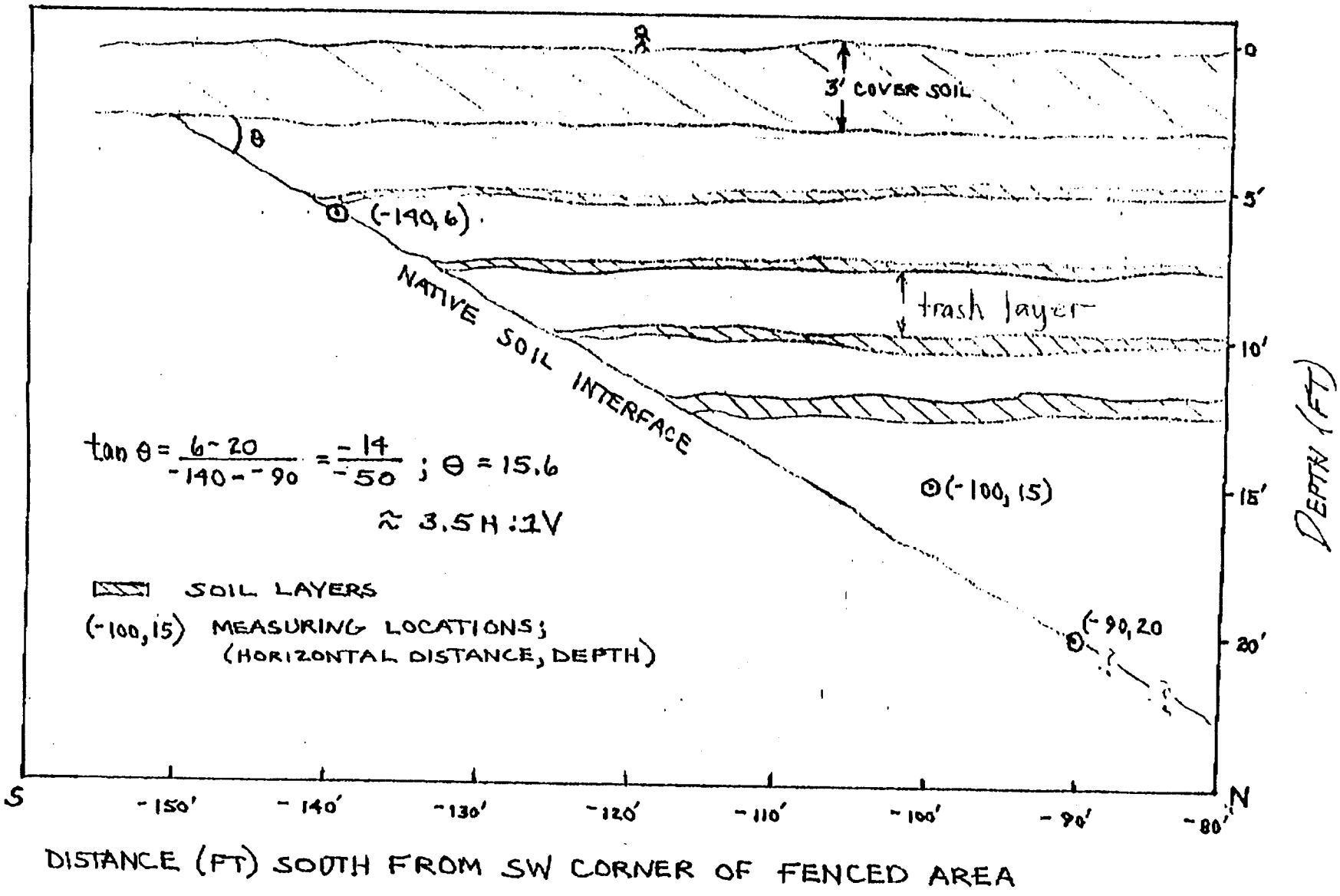


FIGURE 1



CANNON AFB
SANITARY LANDFILL 5
PARTIAL CROSS-SECTION OF CELL 3

FIGURE 2

APPENDIX D

CLOSURE AND POST CLOSURE PLAN
FOR LANDFILL AREA #5, CELL #3
CANNON AFB, NM
DATED: OCTOBER 1988

CLOSURE AND POST CLOSURE PLAN FOR LANDFILL CELL NO. 3 AT CANNON AIR FORCE BASE

REVISED

FINAL

October 1988

Submitted to:

Headquarters Tactical Air Command/DEEV
Langley Air Force Base, Virginia 23665

Submitted by:

Hazardous Materials Technical Center
The Dynamac Building
11140 Rockville Pike
Rockville, Maryland 20852

TABLE OF CONTENTS

	Page
INTRODUCTION	1
INSTALLATION DESCRIPTION AND HISTORY	1
SITE PHYSICAL DESCRIPTION	3
Meteorology	3
Hydrology	6
Soils	8
Clovis Soils	10
Mansker Soils	10
Potter Soils	10
WASTE DISPOSAL AND MIGRATION	14
Maximum Inventory of Waste	14
Core Sample Results	15
Groundwater Monitoring Results	15
FINAL CLOSURE	16
General Design of the Final Cover	16
Gas Venting	22
Surface Drainage Control	24
Security of the Closed Cell	24
ESTIMATED CONSTRUCTION SCHEDULE	25
TEST CAP	25

TABLE OF CONTENTS (Continued)

	Page
COMPLETION REPORT	25
Quality Assurance/Quality Control	27
Soil Cover Stabilization	32
Equipment Decontamination	34
Certification of Closure	34
Deed Recording	35
Survey Plat	35
POST CLOSURE MONITORING PLAN	35
Post Closure Groundwater Monitoring	36
Exhibit 1	41
Post Closure Cover Maintenance	43
Vent Monitoring	45
Inspection Schedule	45
REFERENCES	46
APPENDIX I	47
APPENDIX II	56

LIST OF FIGURES

		Page
1.	Location Map of Cannon AFB, Melrose Bombing Range, and Conchas Lake Recreation Annex	2
2.	Site Map of Cannon AFB	4
3.	Topography and Surface Drainage Map	7
4.	Soils Map	9
5.	Half Cross Section of Final Cover	17
6.	Plan View of Final Cover System for Cell No. 3	23
7.	Monitoring Well Locations for Landfill No. 5	37
8.	Typical Monitoring Well Installation	38

LIST OF TABLES

		Page
1.	Meteorological Data Summary for Cannon AFB, New Mexico . . .	5
2.	Permeability Coefficients	12
3.	Hazardous Waste Inventory	14
4.	Core Analyses	15
5.	Estimated Construction Schedule	26
6.	Earth Work Construction Inspection Methods	28
7.	Quality Assurance/Quality Control Testing Procedures	29
8.	Seed Mix	33
9.	EPA Interim Primary Drinking Water Standards	44

DEFINITIONS

The acronyms used in this report and their corresponding definitions are:

AFB	Air Force Base
EID	Environmental Improvement Division of New Mexico Health and Environment Department
ppb	parts per billion
ppm	parts per million
SCS	Soil Conservation Service
TOC	Total Organic Carbon
TOX	Total Organic Halogen
USAF	United States Air Force
USCS	Unified Soil Classification System

INTRODUCTION

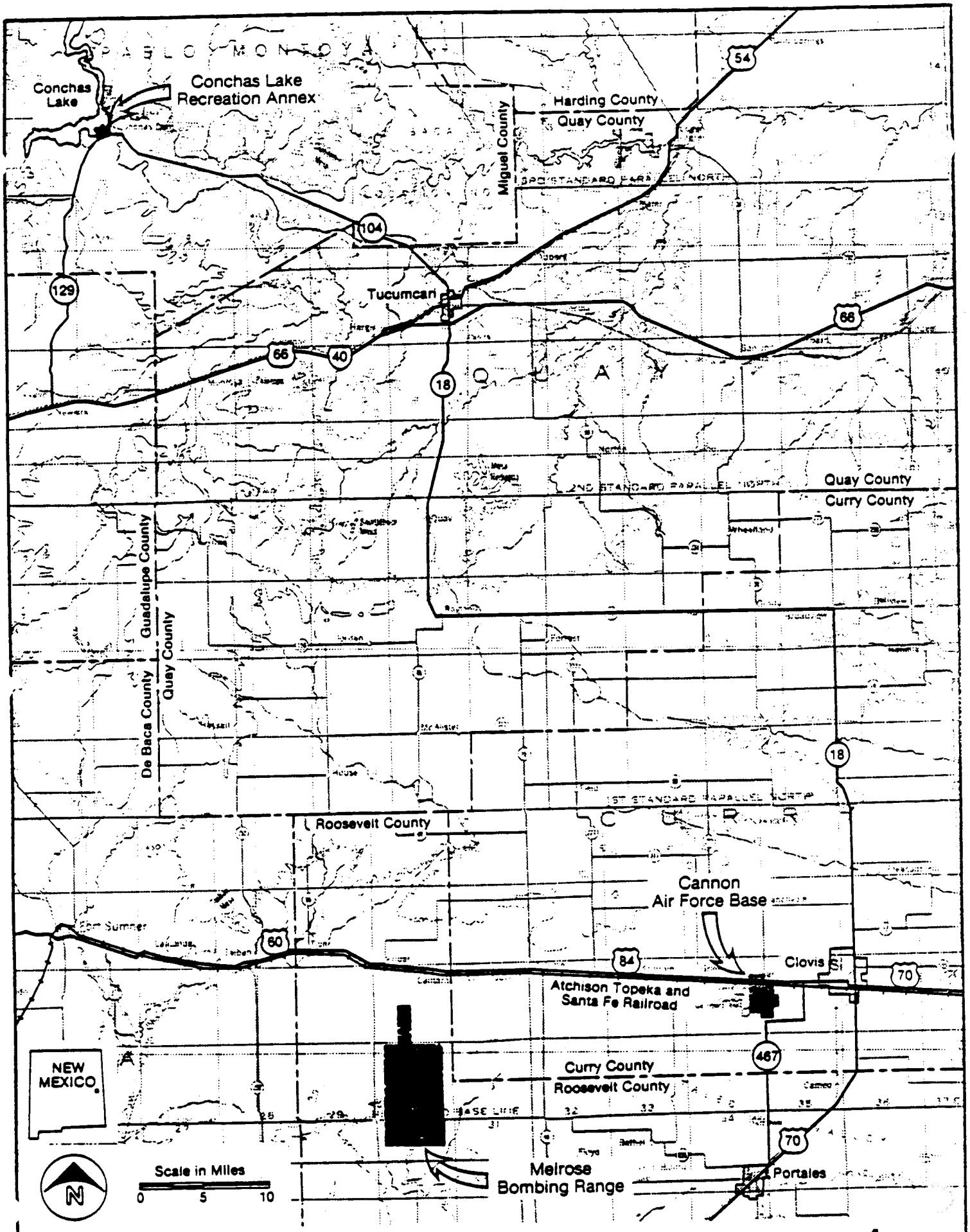
This closure plan is submitted in accordance with the requirements promulgated by the Federal Government and the State of New Mexico. Any facility that stores hazardous wastes for 90 days or longer, treats hazardous wastes, or disposes of such wastes must plan for eventual closure. This closure plan identifies all the steps that will be necessary to completely close cell No. 3 at landfill No. 5 at Cannon Air Force Base (AFB). The owner or operator must complete closure activities in accordance with the submitted closure plan.

The closure plan is designed to conform to the closure performance standards (Section 206C, New Mexico Hazardous Waste Regulations). Specifically, the plan ensures that cell No. 3 will require minimum further maintenance and controls; minimizes threats to human health and the environment; and eliminates post closure escape of hazardous waste, hazardous waste constituents, or waste decomposition products to the ground, surface waters, or atmosphere. The completed sanitary landfill site will be retained as grassland. All citations to the New Mexico Hazardous Waste Regulations are in reference to the New Mexico Hazardous Waste Management Regulation-4 (NMHWMR-4).

INSTALLATION DESCRIPTION AND HISTORY

Cannon AFB is located in Curry County, New Mexico, and is approximately 7 miles west of the city of Clovis (Figure 1). The base is situated on approximately 4,320 acres of land. Off-base facilities include the Melrose Bombing Range and the Conchas Lake Recreation Annex.

The history of Cannon AFB dates back to 1929, when Portair Field was established on the site. Portair Field was a civilian passenger terminal for early commercial transcontinental flights. In 1942, the Army Air Corps took control of the civilian airfield and it became known as the Clovis Army Air Base. In early 1945, the base was renamed Clovis Army Air Field. The installation was deactivated in May 1947. In July 1951, the base was assigned to the Tactical Air Command. The first units arrived in October of that year, but the airfield was formally reactivated in November 1951 as Clovis Air Force Base. In June 1957, the base became a permanent installation and was renamed Cannon Air Force



Source: USGS

FIGURE 1

Location Map of Cannon AFB, Melrose Bombing Range, and Conchas Lake Recreation Annex.

Base in honor of the late General John K. Cannon, a former commander of the Tactical Air Command.

The primary mission of Cannon AFB has remained unchanged since 1965; that being to develop and maintain an F-111 tactical fighter wing capable of day, night, and all-weather combat operations and to provide replacement training of combat aircrews for tactical organizations worldwide. Aircraft stationed at Cannon AFB since 1965 include the F-100 "Super Sabre" fighter jet, the F-111A, the F-111D, and the F-111E. The total work force at Cannon AFB is approximately 4,780, which includes 4,090 military, 425 civil service, and 265 nonappropriated-fund employees. The major organizations at Cannon AFB are the 27th Combat Support Group, the 27th Tactical Fighter Wing, and the 27th Medical Group.

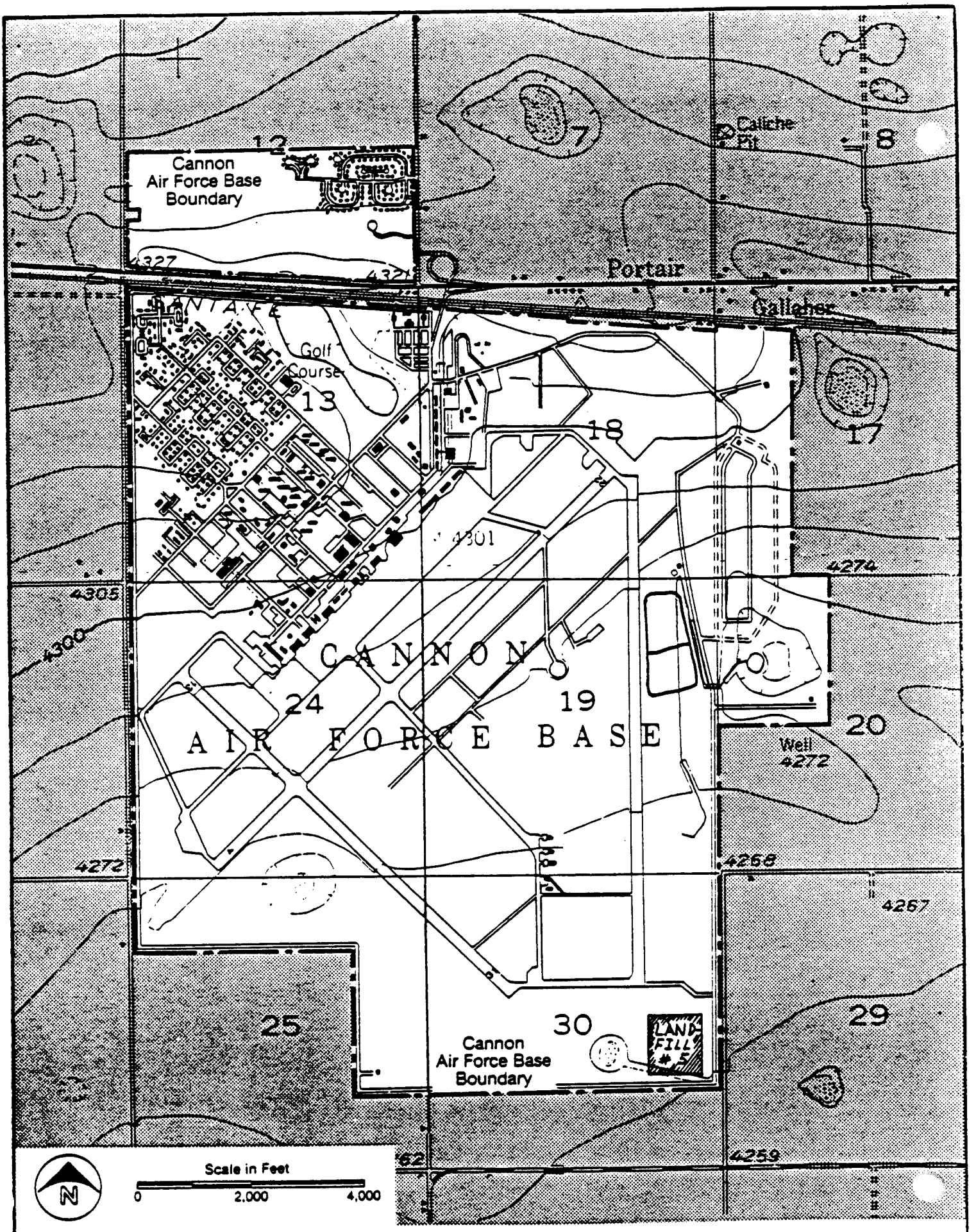
SITE PHYSICAL DESCRIPTION

Cannon AFB is located in the Southern High Plains section of the Great Plains physiographic region. The Southern High Plains includes parts of eastern New Mexico and western Texas and covers approximately 32,000 square miles. The section is a plateau, bounded on the north and west by cliffs as much as 300 feet above the surrounding area. The southern and eastern boundaries are less well-defined.

Cannon AFB is situated near the center of this plateau and is typified by flat, featureless terrain with almost no relief. Elevations at the base range from 4,327 feet above sea level at the northwest corner to approximately 4,260 feet above sea level at the southeast corner where landfill No. 5 is located (Figure 2). The base slopes very gently downward toward the southeast corner. The only features of relief occurring on the base are playas, sand dunes, and small stream valleys.

METEOROLOGY

The area around Cannon AFB is semiarid. (See Table 1 for meteorological data.) The annual precipitation is approximately 14 inches; at Clovis, 7 miles east of the base, it is approximately 16 inches. The annual lake evaporation,



Source: Cannon AFB

FIGURE 2
Site Map of Cannon AFB.

TABLE 1. Meteorological Data Summary for Cannon AFB, New Mexico

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Temperature (°F)													
Record High	76	80	89	94	97	106	105	105	100	90	84	77	106
Record Low	-11	2	8	14	32	43	55	53	29	28	-4	-11	-11
Normal Maximum	51	55	61	71	80	89	90	89	82	72	60	51	71
Normal Minimum	25	28	32	42	52	61	65	64	57	46	33	27	45
Precipitation (inches)													
Record Maximum (in 24 hours)	0.9	0.6	0.7	1.6	2.0	2.5	3.7	2.5	2.9	2.8	0.5	0.6	3.7
Normal Mean	0.5	0.4	0.4	0.6	1.3	2.0	2.8	1.9	1.4	1.5	0.4	0.5	13.7
Mean Snowfall	3	3	1	Trace	Trace	0	0	0	0	Trace	2	3	12
Wind													
Mean Velocity (mph)	10	10	12	12	11	11	9	8	8	8	9	10	10
Prevailing Direction	W	W	W	W	S	S	S	S	S	W	W	W	W

Period: 1943-1967, extremes updated 12/75

Source: Brotzman and Hughes, 1976

used to estimate the annual evapotranspiration rate, is about 69 inches per year. Therefore, the annual net precipitation, which is the annual precipitation minus annual evapotranspiration, is approximately minus 55 inches per year. The wettest months are during the summer, and virtually all of the precipitation is due to thunderstorms. Winters in the Cannon AFB area are relatively dry, with about 12 inches of snow occurring. Due to the warm temperature (average daily maximum of 51 ^{o}F), snow usually melts within a 24-hour period.

During the summer, temperatures are cooler than in the lower elevations to the east, and the air is drier. The dryness is due to the "Marfa" or "dew-point" front, which usually lies to the east. Whenever this front moves to the west of Cannon AFB, the relative humidity rises dramatically. Frontal passages throughout the year are normally dry and only contribute to gusty winds. The wind usually blows from the west during the winter and shifts to the south as the temperatures rise in the spring and summer. In the spring, the winds gust to approximately 25 knots.

HYDROLOGY

Due to the low precipitation, the high evapotranspiration, and low relief, the area around Cannon AFB has poorly developed surface drainage systems (Figure 3). Cannon AFB lies at the headwaters of the Brazos River. Little, if any, water that falls as rain or snow at Cannon AFB ever reaches the river. Most of the rain or snow is lost to evapotranspiration and shallow infiltration. Most of the surface drainage from Cannon AFB is directed through a series of ditches to a large playa near the intersection of the primary NE-SW runway and the NW-SE runway. However, surface drainage in the vicinity of the landfill flows to the south during episodes of heavy rainfall. The Phase I IRP report states that a low potential for contaminant migration exists at Cannon AFB, due primarily to: (1) depth to groundwater, (2) low precipitation, (3) high evapotranspiration rate, and (4) the occurrence of a very low permeability caliche layer under most of the base. In other words, very little precipitation is available for infiltration, and what little does infiltrate is impeded first by the cap and then by the caliche before it begins a descent of over 200 feet to the aquifer system.

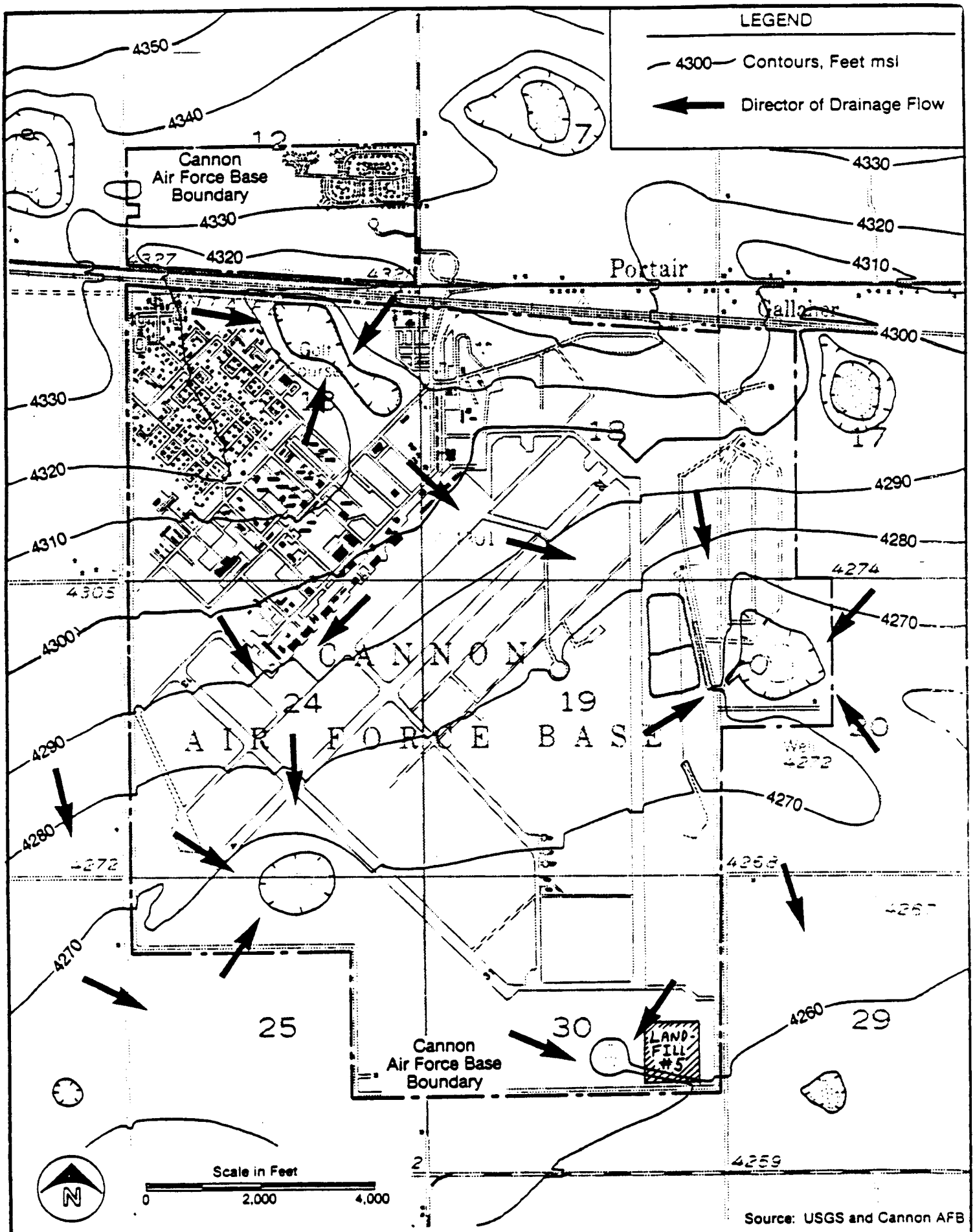


FIGURE 3
Topography and Surface Drainage Map.

Groundwater occurs under unconfined conditions at Cannon AFB. The base is underlaid by a portion of the High Plains Aquifer developed in the unconsolidated sediments of the Ogallala Formation. The High Plains Aquifer is the major and in some places the only source of water. The Ogallala Formation consists of clay, silt, fine- to coarse-grained sand, gravel, and caliche (calcium carbonate crusted soil). Groundwater quality within the Ogallala is acceptable for most uses. Water is typically hard and high in silica and fluoride. The potential for contamination of the High Plains Aquifer at Cannon AFB is low, because of the low rainfall, depth to water table, and the occurrence of a caliche layer of low permeability.

SOILS

The following is a general description of soils at Cannon AFB. (See Figure 4 for soils map.) The soils in question are Ab-Amarillo Fine Sandy Loam and Ag-Amarillo Loamy Fine Sand. The Amarillo loams resemble the Pullman loams with which they merge, but the structure of their B horizon is not so strongly developed, and their profile is sandier throughout. Except that they are less sandy and their surface layers are thinner, the Amarillo loamy fine sands are like the Brownfield fine sands with which they merge. The Amarillo loamy fine sands are less sandy and are better developed structurally than the Springer loamy fine sands.

The Amarillo soils overlie a white chalky zone that begins at depths of 3 to 6 or more feet (but generally about 4 feet). From 40 to 70 percent of this zone is lime. The amount of lime in the profile above the chalky zone varies. The Amarillo fine sandy loams and loamy fine sands are deeper over calcareous material than the Amarillo loams. In places, the Amarillo loamy fine sands are noncalcareous to within 1 or 2 inches of the chalky zone. Some areas of the Amarillo loams are calcareous at a depth of about 18 inches.

The color of the surface soil ranges from brown to reddish brown in the Amarillo loams, through yellowish red in the loamy fine sands. The color of the subsoil ranges from dark reddish brown in some areas of Amarillo loam to yellowish red in the loamy fine sands.

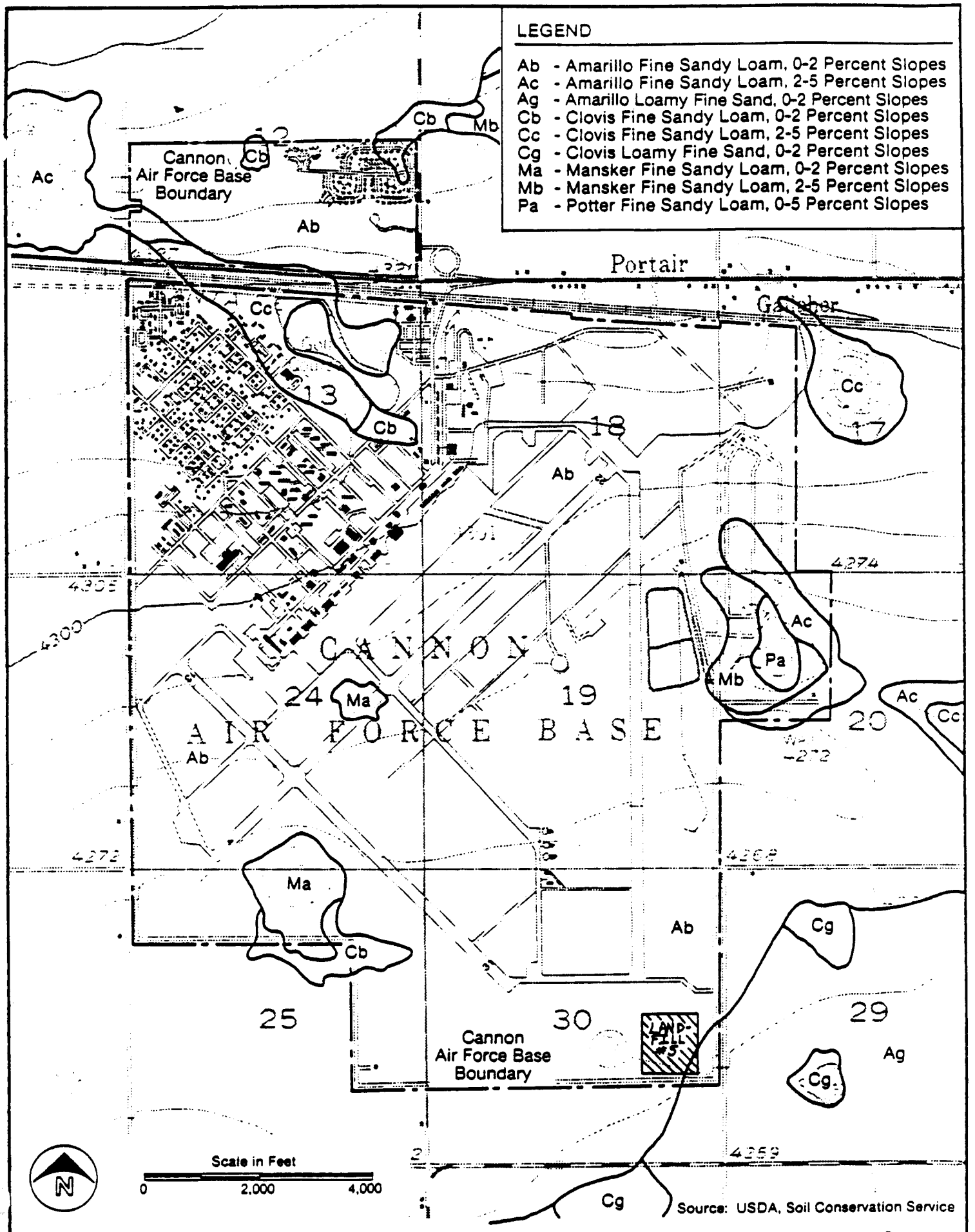


FIGURE 4
Soils Map.

Amarillo soils cover over 90 percent of Cannon AFB. Typical permeabilities are moderate and range from 1×10^{-3} to 4×10^{-4} cm/sec.

Other soil associations occurring at Cannon AFB, primarily in the vicinity of playa "lakes," include Clovis soils, Mansker soils, and Potter soils. Together, these soil types account for less than 10 percent of the area at Cannon AFB. The Soil Conservation Service (SCS) describes these soils as follows.

Clovis Soils. These soils generally occur in small areas within broader areas of Amarillo soils. They occupy the upper margins of many of the draws and playas. The Clovis soils are similar to the Amarillo, but the chalky zone occurs at shallower depths (16 to 36 inches), and in many places the profile is not so well-developed. In Curry County, the Clovis series is represented by three soil types; they are Clovis loam, Clovis fine sandy loam, and Clovis loamy fine sand. The Clovis loams resemble the thin solum phases of the Pullman loams, except for weaker structural development in the B horizon.

Mansker Soils. Mansker soils are strongly calcareous. They normally occupy the slopes of draws and playas. However, small, nearly level to gently sloping areas occur within larger areas of Pullman, Amarillo, and Clovis soils. The Mansker soils are extensive throughout Curry County. They have formed where the upper part of some other soil has been lost through erosion, and the strongly calcareous substratum has been exposed. These soils show very little profile development.

Potter Soils. The Potter soils are shallow and strongly calcareous. They overlie hard, consolidated caliche. The degree of cementation in the caliche varies. In some places, the caliche resembles limestone; in others, it consists of lime-cemented pebbles and nodules. The material from which these soils developed was mainly weathered caliche, but it was intermixed with wind-deposited materials. The Potter soils occur throughout the county, normally in areas of less than 100 acres. In many places, they are closely associated with the Mansker soils.

Permeability of all three soil types is toward the lower end of the range typical for the Amarillo soils.

At Cannon AFB, the soil layer is underlaid by a fairly thick (approximately 25 feet) caliche layer, which is part of the Ogallala Formation. This caliche varies in depth and thickness across the base. Geologic logs indicate that caliche occurs as shallow as 2 feet below the surface and is up to 54 feet in thickness. Observations made at the current landfill operation (not the cell addressed in this report) indicate that the top of the caliche layer is approximately 5 feet below the surface and becomes harder with depth. In fact, at a depth of approximately 15 feet, heavy-duty earth-moving equipment could not penetrate the caliche.

Although there are no specific boring data for the landfill area, boring data do exist for much of the base, especially the northwest region of the base. Some inferences about boring data at the landfill are made by the Department of the Air Force Tactical Air Command, Cannon AFB, New Mexico, in their publication entitled, "Sanitary Landfill--Design, Construction and Operation," 15 December 1976:

> "Site Soils. No soils tests have been made at the landfill site; however, the uniformity of soil conditions in the area and on the base allow for fairly accurate prediction of site soil conditions from other soil borings. Inspection of the existing 16-foot deep trench verifies the textural classification expected--loamy fine sand or fine sandy loam underlain by sandy clay loam and light sandy clay loam with caliche pockets. Under the Unified Soil Classification System (USCS), the predominate soils are SC, CL, or combinations of them with some areas of SM or ML and a few pockets of GP, GL, GC, and caliche."

Of particular interest is the frequent occurrence of clay in the boring profiles (uses Type CL). Examination of the profiles reveals that approximately 70 percent of the 191 borings taken show clay in the top 10 feet of the borings. The profile chart describes the clay as inorganic clay of low to medium plasticity. Table 2 shows that clays, especially colloidal clay, has the lowest permeability coefficient.

In the case of this particular landfill, the underlying material is caliche. While it is generally understood that caliche is very impermeable, a question arises as to the complete occlusive properties of large expanses of

Table 2. Permeability Coefficients

Typical Values of Permeability Coefficients

		PARTICLE SIZE RANGE				"EFFECTIVE" SIZE		PERMEABILITY COEFFICIENT—k		
		Inches		Millimeters						
		D_{max}	D_{min}	D_{max}	D_{min}	D_{20} in.	D_{10} mm.	Ft./yr.	Ft./mo.	Cm./sec.
TURBULENT FLOW	Derrick STONE	120	36	—	—	48	—	100×10^6	100×10^5	100
	One-man STONE	12	4	—	—	6	—	30×10^6	30×10^5	30
	Clean, fine to coarse GRAVEL	3	1/4	80	10	1/2	—	10×10^6	10×10^5	10
	Fine, uniform GRAVEL	3/8	1/16	8	1.5	1/8	—	5×10^6	5×10^5	5
	Very coarse, clean, uniform SAND	1/8	1/32	3	0.8	1/16	—	3×10^6	3×10^5	3
LAMINAR FLOW	Uniform, coarse SAND	1/8	1/64	2	0.5	—	0.6	0.4×10^6	0.4×10^5	0.4
	Uniform, medium SAND	—	—	0.5	0.25	—	0.3	0.1×10^6	0.1×10^5	0.1
	Clean, well-graded SAND & GRAVEL	—	—	10	0.05	—	0.1	0.01×10^6	0.01×10^5	0.01
	Uniform, fine SAND	—	—	0.25	0.05	—	0.06	4000	400	40×10^{-4}
	Well-graded, silty SAND & GRAVEL	—	—	5	0.01	—	0.02	400	40	4×10^{-4}
	Silty SAND	—	—	2	0.005	—	0.01	100	10	10^{-4}
	Uniform SILT	—	—	0.05	0.005	—	0.006	50	5	0.5×10^{-4}
	Sandy CLAY	—	—	1.0	0.001	—	0.002	5	0.5	0.05×10^{-4}
	Silty CLAY	—	—	0.05	0.001	—	0.0015	1	0.1	0.01×10^{-4}
	CLAY (30 to 50% clay sizes)	—	—	0.05	0.0005	—	0.0008	0.1	0.01	0.001×10^{-4}
	Colloidal CLAY ($-2\mu \leq 50\%$)	—	—	0.01	10Å	—	40Å	0.001	10^{-4}	10^{-9}

caliche. On the basis of available data and field experience, the caliche occurring at the landfill site is probably young in nature and not entirely cemented. This would lead to the belief that the caliche formations here would exhibit some permeability, albeit low. While caliche in and of itself can be very impermeable, one would expect that a large expanse of the material would exhibit many fractures due to its relative hardness and brittle characteristics if mature, and incomplete cementation if young. Hence, while the material itself is very impermeable, these fractures would afford avenues for some percolation to occur.

The following is a description of caliche that is characteristic of the Central High Plains region of New Mexico where Cannon AFB is located, which supports these conclusions (New Mexico State Highway Department, "Geology and Aggregate Resources, District 11," 1972).

> "Many geologists believe that the Central High Plains and the Llano Estacado are universally underlaid by caliche deposits, but anyone who has had an occasion to explore this hypothesis on the working end of a jack-hammer will disagree, at least about the top 25 to 50 feet. Nevertheless, exposures along the escarpment indicate that some form of caliche does exist below a large part of these surfaces. The stages of development of these caliche profiles will vary from very youthful to late in maturity. As previously mentioned, some of the profiles may be over one million years old. Some of the older profiles have undergone attacks from solution and weathering and, therefore, can be expected to be extremely discontinuous across the plain. Although these surfaces have remained quite stable for hundreds of thousands of years, aggradation and degradation have continued at a slow, steady pace. The result, considering the climatic fluctuations of the past one million years, has been degradation and recementation of the profiles on the windward and uphill side of the plains and aggradation on the lee side of the plains, the rock-house type structure being more common in older profiles, and lamination more common in younger profiles. Perhaps this helps explain the variations in soundness, loss, and Los Angeles abrasion test values from different locations across the plains or even within a local pit area."

WASTE DISPOSAL AND MIGRATION

MAXIMUM INVENTORY OF WASTE

Landfill No. 5 began operation in 1968 and is in current use. The site is located in the southeast corner of the base and covers approximately 30 acres. Cell No. 3, the specific cell for which this closure plan is applicable, was closed in 1981. The cell covers an area of approximate dimensions 330 feet long by 39 feet wide.

Materials received at this landfill in 1981 are similar to those received at the former base landfills and include waste oils and solvents, paints, paint removers and thinners, pesticide containers, empty cans, and general construction debris. Materials from drums were generally deposited on absorbent materials placed in the cell. The drums were then reclaimed for reuse.

From 1968 to about 1972, wastes were burned and then buried in cells. Since 1972, the standard procedure has been direct burial of the wastes in cells. There are 11 covered cells at the site. No volatile organics were found in cell No. 3. The estimated maximum inventory of hazardous waste in cell No. 3 is shown in Table 3.

Table 3. Hazardous Waste Inventory

Haz. Waste Haz. Substance	Hazardous Waste	Percent	Amount in Pounds
U-W S	Methyl ethyl ketone	39.6	3,564
U-W S	Toluene	43.4	3,906
U-W S	Methyl isobutyl ketone	10.4	936
U-W S	Cyclohexanone	2.4	216
U-W S	Xylene	1.6	144
U-W S	Ethylene glycol monobutyl ether	1.6	144
D-W	Lead	0.6	54
D-W	Chromate	0.4	36

CORE SAMPLE RESULTS

Two 9-inch diameter cores of 40-foot depth were removed from the landfill cell on January 22, 1985. Six samples from each core (depths of 10, 15, 20, 25 30, and 40 feet) were analyzed for chromium, lead, arsenic, tin, mercury, and volatile organics. The metals analyses were accomplished by nitric acid digestion/atomic adsorption spectroscopy and the volatile organics were analyzed using gas chromatograph mass spectrometry. Table 4 summarizes the composite results of these analyses.

TABLE 4. Core Analyses

Constituent	Concentration (ppm)	Detection Limit (ppm)
Chromium	14 - 36	0.005
Lead	0.2 - 10.5	0.001
Arsenic	3.70 - 9.61	0.002
Tin	0.5 - 2.0	0.002
Mercury	0.04 - 0.68	0.002
Volatile Organics	< 0.01	0.01

The metal levels appear to be high in these analytical results, but this is not significant because the lowest level of the value ranges are reached at the 40-foot depth. Very little would be available to groundwater which is 200 feet deeper still.

GROUNDWATER MONITORING RESULTS

Four groundwater monitoring wells were installed near the landfill cell during December 1984 and January 1985. Monitoring of the wells began with first-quarter samples taken on January 25, 1985. For indicator parameters (pH, specific conductance, TOC, and TOX), heavy metals, pesticides, endrin, lindane, methoxychlor, toxaphene, 2, 4-D and 2, 4, 5-TP-Silvex, radioactivity, coliform bacteria, chloride, iron, manganese, phenols, sodium, and sulfate the sample

analyses show that there are no significant increases over background levels of groundwater constituents evidenced in the three downgradient wells compared to the upgradient well. Preliminary examination of data from analyses of second quarter groundwater samples received by the laboratory on April 30, 1985, indicates that there continues to be no significant increase over background levels of groundwater constituents in the vicinity of landfill cell No. 3. (See post closure groundwater monitoring section for details about monitoring well locations.)

FINAL CLOSURE

Final closure of the landfill cell will involve covering it with a combination polymeric membrane liner and soil protective cover. The combination cover will keep liquids from reaching the cell contents, thus minimizing leachate generation and also will prevent any wastes present in the cell from coming in contact with the above-ground environment. A post closure maintenance inspection program will guarantee the integrity of the protective cover.

A discussion of the general design of the final protective cover follows. Figure 5 illustrates the proposed components of the cover structure for cell No. 3 in a cross-sectional view. The cross-section ranges from the centerline of cell No. 3, to the centerline between the adjacent cell and cell No. 3, a distance of 35 feet, 6 inches.

GENERAL DESIGN OF THE FINAL COVER

The final cover was chosen with the following considerations:

(1) Long-term minimization of liquid migration through the closed landfill;

(2) Minimum maintenance requirements;

(3) Promotion of drainage and minimization of cover erosion;

(4) Accommodation of settling and subsidence; and

(5) Obtaining a cover that will act as seal against passage of fluids.

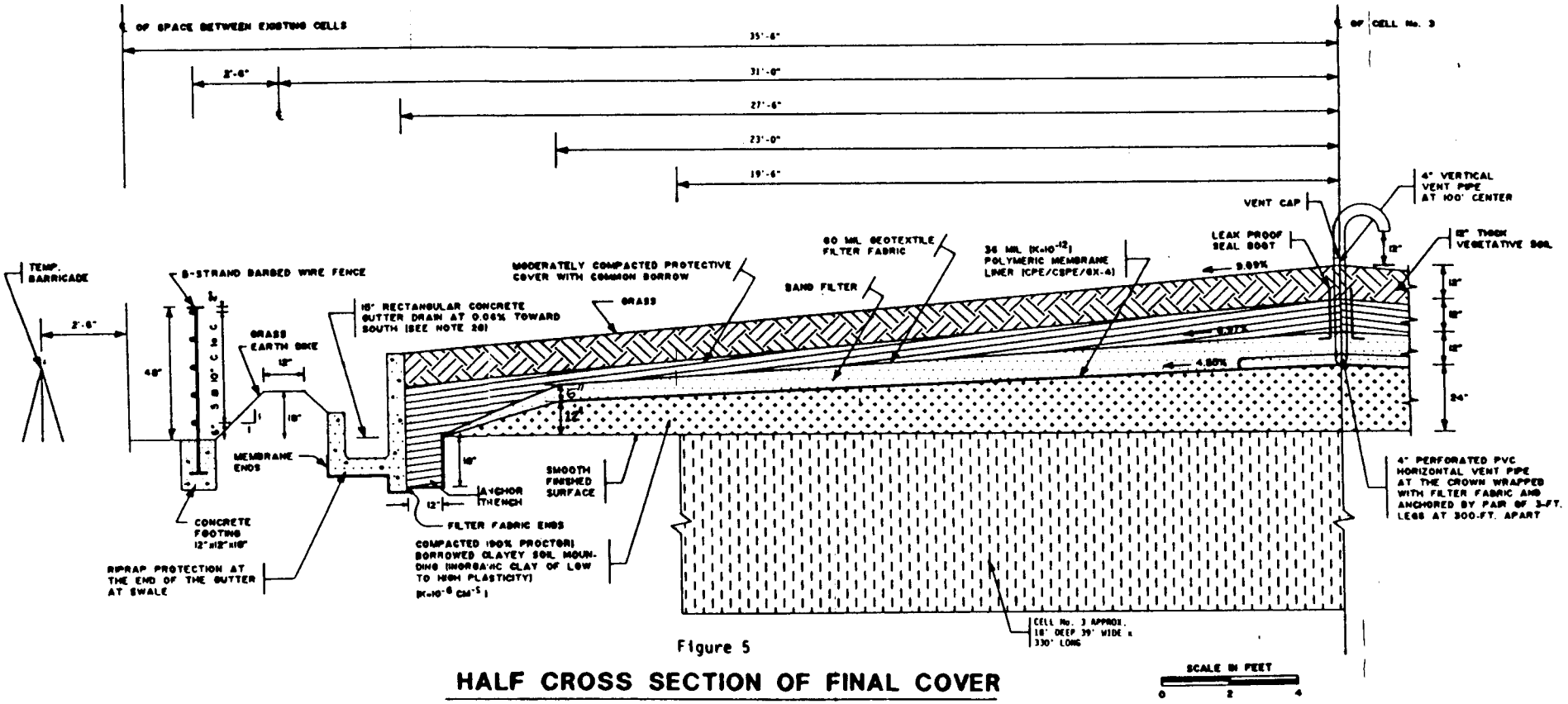


Figure 5

HALF CROSS SECTION OF FINAL COVER

The following components will constitute the cover system planned for landfill cell No. 3:

- o Buffer layer
- o Mounding layer
- o Geotextile filter
- o Filter sand layer
- o Polymeric membrane liner
- o Moderately compacted protective layer with vegetative cover
- o Horizontal vent pipe
- o Vertical vent pipes
- o Perimeter anchor trench
- o Gutter drain and tail-end ditch
- o Dike
- o Barbed wire fence

A general description of each of the aforementioned components and the function of each component is presented here. Specific design plans and detailed specifications are presented in the document, "Cannon Air Force Base Closure of Cell No. 3 of Landfill Area 5 - Designs and Specifications, 1987."

Presently, a buffer layer (existing 2-feet-thick cap) exists immediately above the actual waste and serves to protect the mounding layer (to be installed above the buffer layer) from penetration by protruding objects in the landfill by minimizing the effects of settling on the mounding layer. In addition, the buffer layer is usually more porous, so that gases can migrate through it and so that siltation from the mounding layer will be contained in the upper part of the buffer. In the case of this landfill, where the climate is semi-arid and the net precipitation is quite low (minus 55 in/yr) and a polymeric membrane liner will be present, no appreciable siltation from the mounding layer is anticipated to occur.

The construction of the buffer has been completed for about 6 years. The document by the Department of the Air Force, Tactical Air Command, Cannon AFB, New Mexico, entitled "Sanitary Landfill -- Design, Construction, and Operation," 15 December 1976, indicates that this buffer layer is constructed of

soils from the cell excavation. The document specifies a minimum thickness of 2 feet for this layer and calls for it to be compacted in four 6-inch lifts. During a site visit in March 1985, it was observed that the site was "criss-crossed" with bulldozer tracks, implying that this cover was "tracked in" for compaction, as per the regulation.

Settling and subsidence typically occur immediately following the final cover of a landfill. The rate of this settling is fastest in the first few years following final cover and slows to a minimal rate after 5 years or so. Total settling might amount from 5 to 50 percent of a landfill's height, depending on such factors as the depth of the fill, composition of the waste, and the climate and groundwater characteristics. At this site, the depth of the fill is estimated at 15 feet. The waste consists of construction/demolition debris and hazardous wastes consisting mainly of paints and solvents (noncontainerized). The semiarid climate and very deep aquifer system would suggest that decomposition of organics would occur rather slowly after the first several years.

The relatively small volume of compacted waste in the landfill, placed in a shallow configuration of maximum depth of 20 feet, would also suggest a low total settling of the fill. In support of this contention is the fact that no cracks, craters, or depressions were observed during the site visit. Therefore, it is anticipated that little additional settling will occur in the future and that the existing buffer layer is adequate.

The planned final cover will consist of the following components to be installed above the buffer layer:

- A compacted inorganic clay mounding layer of low to medium plasticity on top of and in direct contact with the smooth finished surface of the cell No. 3 buffer layer. The compacted clayey soil mounding layer will extend a distance of 3 feet, 6 inches from the edge of the cell in all directions to a perimeter anchor trench. The depth of mounding layer will be 24 inches at the cell centerline, with a 4.55% slope toward the anchor trench as depicted in Figure 5. The minimum thickness of the clay cover at the inside edge of the anchor trench will be 12 inches. The maximum permeability of the clay layer will be 10^{-6} cm per sec.

- A 60 mil thick geotextile filter fabric to cover the compacted inorganic clay mounding layer to prevent mixing with a layer of filter sand above the clay mounding layer. The geotextile filter has the capacity to vent any gases that may be generated in cell No. 3. The filter fabric will have 5% slack for any subsidence and will be anchored in the anchor trench. Documentation in the form of a manufacturer's warranty on the geotextile filter fabric, indicating that it has 30 years of excellent aging and weathering characteristics will be provided to the Contracting Officer by the Contractor.

- A layer of filter sand on top of the geotextile filter and in contact with the overlying 36 mil polymeric membrane liner. The filter sand serves to drain any liquids away from underneath the membrane liner and serves to allow gases to properly vent. The filter sand will be of 12 inches depth at the cell No. 3 centerline and slope 6.97% toward the perimeter anchor trench reinforced cross-sectionally as shown in Figure 5. The minimum thickness of the sand layer at the inside edge of the anchor trench will be 6 inches. The minimum saturated hydraulic conductivity of the emplaced sand layer will be 10^{-2} cm per sec.

- A 36 mil reinforced polymeric membrane liner (either CPE/CSPE/GX-4) of low permeability (10^{-12} cm/sec) installed on top of the filter sand layer, and extending a distance of approximately 8 feet, 6 inches from the edge of the cell in all directions, extending beyond the perimeter anchor trench, underlying perimeter precast concrete gutter drain, and terminating at the foot of an earth dike. Any percolation that reaches the membrane liner surface from above will be shed to beyond the perimeter of the cell.

  Documentation in the form of a manufacturing warranty on the polymeric membrane liner, indicating that it has 30 years of excellent aging and weathering characteristic will be provided to the Contracting Officer by the Contractor.

  The Installation Contractor will certify that the final cover system was constructed according to the designs and specifications and industrial standards, and is free of any damages, leaks, and other defects to provide a leak proof cover system and the quality of construction and workmanship is guaranteed.

- A moderately compacted protective cover of common borrow, installed on top of the membrane liner, and extending a distance of 8 feet from the edge of the cell in all directions, and terminating at the perimeter precast concrete gutter drain. The protective cover will be of 24 inches depth at cell No. 3 centerline and slope 9.09% (crosssectionally) to the perimeter concrete gutter drain. The slope of the compacted protective cover surface is of a suitable gradient to allow diversion of rainwater and surface runoff away from cell No. 3 in a reasonable manner toward the perimeter concrete gutter drain. The designed shallow slopes to the cover system also will reduce the surface area exposed to high winds. The minimum thickness of the protective cover at the inside edge of the perimeter gutter drain will be 12 inches.

The protective cover material will be screened through a two-inch or smaller screen to remove foreign objects and large rocks which may puncture or abrade the membrane liner. A visual check of the screening and emplacement will be made to assure effective removal. The upper 12 inches of the protective cover will be a silty clay loam capable of supporting vegetation.

The protective cover will preserve the integrity of the membrane liner by preventing direct exposure of the liner to ultraviolet solar radiation and will deter liner wear due to weather and direct physical contact. The protective cover will be graded so that a constant level is maintained along the north-south axis of the cell. The protective cover will extend 8 feet beyond the edges of cell No. 3.

To avoid damage to the geotextile filter fabric and to the polymeric liner, the common borrow soil used on the final cover will be hand compacted using a vibrating plate.

A supply of common borrow, identical in characteristics to the common borrow installed on top of the membrane liner, will be kept in reserve in the event of future cover repair activities. The common borrow supply should be maintained in a protected pile, in a convenient location outside of the cell No. 3 perimeter fence.

- A 4-inch diameter perforated PVC horizontal vent pipe installed at the bottom of the filter sand layer and residing upon the geotextile filter, approximately 20 inches above the surface of cell No. 3. The PVC vent pipe will be wrapped with geotextile fabric and will be oriented along the length of the centerline of cell No. 3. The horizontal vent pipe will collect any gases permeating through the layer of filter sand from beneath the geotextile filter.

- Three 4-inch diameter PVC vertical vent pipes (with vent caps) 100 feet apart from each other, will extend up from the horizontal vent pipe through the filter sand, penetrating the membrane liner and through the protective cover, finally venting to the ambient atmosphere at a height of 12 inches above cover crown. A leakproof seal boot between the vent pipes and the membrane liner will ensure continuity in liner protection integrity.

- Two anchor leg supports will be provided to the horizontal vent pipe at 300 feet apart to prevent any rotation of the vent pipe system.

- A 12 inch by 18 inch deep perimeter anchor trench to anchor the geotextile filter and membrane liner under a protective common borrow cover. The inside edge of the anchor trench will be a mininum of 3 feet from the edge of the cell.

- A 15 inch concrete rectangular gutter drain along the perimeter of the moderately compacted protective cover of cell No. 3. The gutter drain

is designed to accommodate the volume of rain and peak surface runoff from the protective cover of cell No. 3 which could result from a 100-year storm event (6.67 inches/hour). The total drop in elevation from the northwest corner to the southeast corner of the gutter drain will be 3 inches. Runoff from the cover will experience a 1/2 inch drop when draining from west to east (a 0.07% gradient), and a 2 1/2 inch drop when draining from north to south (a 0.06% gradient). The south end of the gutter drain will be connected to an existing swale by a 60 foot tail-end ditch. The beginning of the tail-end ditch will be provided with a rip rap protection.

- A 15 inch earth dike along the outside perimeter of the concrete rectangular gutter drain. The dike will serve to prevent rain and surface runoff from the protective cover of cell No. 3 from overshooting the gutter drain and possibly draining to the adjacent landfill cells. The dike will also serve to prevent surface run-on from the neighboring landfill cells from infringing upon cell No. 3.

- A 5-strand barbed wire fence with a metal panel gate will protect the perimeter of cell No. 3 from nearby activities on adjacent cells. The fence will be located 11 feet, 6 inches from the edge of cell No. 3. The fence will withstand the stress of high winds, tumbleweeds, and blowing sand, and will require no maintenance.

- A temporary barricade will be established 2 feet and 6 inches away from the centerline of space between cell No. 3 and adjoining cells No. 2 and No. 4. The temporary barricade will prevent damage to adjoining cells by delineating a work zone for equipment used in capping cell No. 3. The temporary barricade will be removed once the 5-strand barbed wire is constructed.

- To prevent any impact on the adjacent cells, all designs have been kept within 2 feet of the mid-point of the distance between cell No. 3 and the adjacent cells.

Figure 6 shows a plan view of the proposed landfill closure final cover and associated structures.

GAS VENTING

Cell No. 3 has received solvents, paints, paint removers, and thinners which, after closure, could volatilize and release gases. Core analyses (Table 4) detected <0.01 ppm of volatile organics and no organic solvents in cell No. 3 core samples. Complete volatilization may have occurred in the 6 years since 1981; however, the general design of the final protective cover allows for venting of any potential gases.

SURFACE DRAINAGE CONTROL

Drainage of surface rainwater runoff shall be accomplished so that infiltration is minimized between cell Nos. 3 and 2 and between cell Nos. 3 and 4. To effect positive drainage in these areas without causing soil erosion and subsequent undermining/failure of the seal created by the protective soil cover, a 15 inch precast concrete rectangular gutter drain will drop a total of 3 inches toward an existing drainage swale to the south, with rip rap protection at the beginning of the tail-end ditch to accommodate surface runoff. An earth dike will follow the perimeter of the gutter drain to prevent excessive runoff from cell No. 3 and run-on from adjoining cells.

SECURITY OF THE CLOSED CELL

Security for the closed cell will follow the rules governing security for the working portion of the landfill. Access to the site shall be controlled by a lockable entry gate attached to a permanently anchored 5-strand barbed wire fence surrounding the perimeter of the landfill cell, a distance of 11 feet, 6 inches from the edge of cell No. 3. A placard that identifies the landfill cell shall be permanently attached to the fence. The gate shall be closed and locked when an operator is not on duty. The following access categories shall be utilized:

1. Unlimited Entry--unlimited entry to the landfill site shall be authorized for landfill operators.

2. Limited Entry--personnel with authorized limited entry shall make their presence known to the landfill operator before conducting business on the site.

3. Restricted Entry--personnel with authorized restricted entry shall make their presence known to and be accompanied by the landfill operator while on the site.

4. Unauthorized Entry--access to the site by persons other than those listed above is not authorized and shall be prohibited.

The fence, gate, and placard shall be durable enough to last the duration of the post closure period and shall remain in place throughout this time. No

future use is planned or allowed. The base master plan will restrict subject to Civil Engineering and Base Commander approval.

The placard with the legend, "Danger-Unauthorized Personnel Keep Out" will be posted at each entrance to the facility. These warning signs will also be posted at intervals no greater than 50 feet apart on the fence around the closed unit. The legend will be written in English and Spanish and will be legible from a distance of at least 25 feet.

ESTIMATED CONSTRUCTION SCHEDULE

Table 5 presents an estimated construction schedule for the closure of cell No. 3 of landfill area 5. A detailed description of each of the activities listed in Table 5 is presented in the document, "Cannon Air Force Base Closure of Cell No. 3 of Landfill Area 5 - Designs and Specifications."

TEST CAP

A test cap will be constructed on the site near the final cover using the same methods, equipment and materials as those used to construct the final cover. The test cap will be constructed so that, as each construction step on the final cover proceeds, the same step will be performed on the test cap. The test cap can then be cored and tested for uniformity and effective permeability. See QUALITY ASSURANCE/QUALITY CONTROL Section.

COMPLETION REPORT

Upon completion of the closure, the Commander will submit, in support of the Certification of Closure, the following information:

1. An annotated map showing the location of the test cap.

2. A copy of the QA/QC report.

TABLE 5. Estimated Construction Schedule

Cannon Air Force Base
Closure of
Cell No. 3 of Landfill Area 5

Activity	Completion Date (Weeks)
o Contract Award	A
o Preconstruction Conference	A + 2
o Submit QA/QC Plan to EID	A + 3
o Review and Approve Contractor's Submittals	A + 4
o Onsite Operations Begin	A + 4
o Complete Mobilization and Construction of Contractor's Facilities	A + 6
o Subgrade Preparation	A + 8
o Mounding	A + 10
o Review and Approve Layout Pattern for Liner and Fabric and the Materials for Final Cover System	A + 12
o Filter Fabric, Sand Filter, and Venting System	A + 15
o Polymeric Membrane and Protective Layer	A + 22
o Drainage System and Dike	A + 23
o Fence and Caution Sign	A + 24
o Demobilization and Project Closeout	A + 25

NOTE: A = date of plan approval, October 3, 1988

QUALITY ASSURANCE/QUALITY CONTOL

The Commander will appoint an individual to oversee the quality control effort and report directly to the Commander upon closure completion.

Before actual construction commences, a test cap will be constructed to evaluate actual construction procedures. This test cap will be constructed according to the procedures outlined in EPA/530-SW-86-031, the Technical Guidance Document: Construction Quality Assurance for Hazardous Waste Land Disposal Facilities. This document will verify the adequacy of materials, design, equipment, and construction procedures. This will minimize the potential dangers and expense of constructing an unacceptable cover.

The primary function of the test cap will be to verify that the specified soil density/moisture content/permeability values are achieved consistently with the actual construction equipment and procedures.

During construction of the test cap, the inspection procedures listed in Table 6 will be conducted to document the acceptability of installation procedures. Field tests are usually more accurate rate predictors of the water that will drain through a soil layer than laboratory tests. When used in conjunction with these field tests and the QA/QC construction plan outlined in Table 7, the test cap section will allow the performance of the final cover to be predicted.

In order to ensure that the final cover is constructed per design specifications, the same methodologies and equipment will be used in all phases of final construction. During construction, the following parameters will be closely observed and followed:

- Construction of the final cover will use the same soil material, design specifications, equipment, and procedures used in constructing the test cap.
- All applicable parts of the QA/QC test requirements will be followed precisely to monitor and document cap construction and testing.

Table 6. Earth Work Construction Inspection Methods

Factor To Be Inspected	Inspection Methods	Test Method Reference
Coverage	Observation	NA
Thickness	Surveying: Measurement	NA
Clod size	Observation	NA
Tying together of lifts	Observation	NA
Slope	Surveying	
Installation of protectt-ive cover	Observation	NA
Soil type (index properties)	Particle size analysis Atterberg limits	ASTM D422-63 ASTM D4318-84
Moisture-density relation	Modified proctor	ASTM D1557-78

TABLE 7. Quality Assurance/Quality Control Testing Procedures

	Moisture/Density Test Frequency
Mass Earthworks (embankments, dikes)	1 per 1,000 yd^3
Earth Linings	1 per 500 yd^3
Hand-tamped Backfill	1 per 100 to 200 yd^3
Minimum per Shift (mass earthwork)	1
Doubtful Areas (inspector's discretion)	1

Inspection personnel will monitor and thoroughly document construction of the cap. Test cap documentation will be extremely important because it will verify all data involved in facility construction and provide a complete description of the construction equipment and procedures used during the construction of the final cover.

As construction of the final cover proceeds, all procedures used in constructing the test cap will be closely adhered to and documented in a dedicated construction/inspection record book. This will ensure that the final cover meets or exceeds the design criteria, including the use of the optimal materials, equipment and construction methodologies. During construction of the final cover, the following inspection procedures will be used to ensure that it is constructed according to specifications:

- Removal of roots, rocks, rubbish, or off-spec soil from the cover materials
- Identification of changes in soil characteristics necessitating a change in construction specifications
- Adequate spreading of materials to obtain complete coverage and the specified loose lift thickness
- Adequate clod size reduction of cover material
- Adequate spreading and incorporation of any certified amendments to obtain the specified amount uniformly in the amended cover material
- Adequate spreading and incorporation of water to obtain full penetration through clods and uniform distribution of the specified water content
- Procedures to be followed to adjust the soil moisture content in the event of a significant prolonged rain during construction
- Prevention of significant water loss before and after compaction
- Use of compaction equipment of the same type, configuration, and weight
- Use of the same equipment speed and number of equipment passes for compaction
- Uniformity of coverage by compaction equipment, especially at fill edges, in equipment turn-around areas, and at the tops and bottoms of slopes

- Consistent achievement of the specified soil density/water content/compactive effort throughout each completed lift
- Use of methods sufficient to tie the soil lifts together
- Achievement of sufficient soil strength to maintain stable sidewalls and to supply a stable base for supporting overlying materials
- Application of water to prevent desiccation of soil material between the installation of lifts or after completion of the cover (where necessary)
- Prevention of accidental damage of installed portions of the cover by equipment traffic

Climatic conditions will also be monitored to be sure that they do not adversely affect the compaction process and cause variabilities in the permeation rate of the final cover.

As detailed in this section, a rigorous construction QA/QC program will be conducted to ensure that the following non-specification conditions are prevented or, if they should inadvertently occur, are detected and corrected:

- Regions of higher-than-specified permeability caused by the use of unspecified materials, inadequate moisture control, insufficient compactive effort, failure to fill test holes properly or construction during periods of freezing temperature
- Less-than-specified thickness or coverage from failure to observe, monitor, and control soil placement and compaction operations
- Partings between lifts from failure to scarify and control moisture in adjacent lifts
- Leaks around designed cover penetrations resulting from improper sealing and compaction
- Erosion or desiccation from failure to provide protective cover when construction is interrupted or after cap completion

The low permeability layer will be inspected for cracks, holes, defects, or any other features that may increase its field permeability. All defective areas will be removed and repaired. If the underlying foundation is defective (soft or wet), then this material will also be removed and recompacted. Excavated areasd will be repaired by the method verified during test cap construction. Special attention will be paid to the final inspections of the

sidewall and bottom slopes, cap coverage, and cap thickness. The completed cap will be protected from desiccation, erosion, and freezing immediately following completion of the uppermost lift.

All seams made in the synthetic liner will be constructed in accordance with the manufacturer's specifications. Similar seams will be made in the test cap and subject to testing to determine adequacy of the seal.

Upon completion of the closure, a written report will be prepared and submitted to the Commander and the EID. This report will summarize the QA/QC plan and report fully all observations and accumulated data.

SOIL COVER STABILIZATION

The final phase of closure consists of placing a soil blanket over the compacted surface of the cap and seeding the blanket with a native grass seed mixture (see Table 8). The soil mantle will average 12 inches in thickness to allow for some erosional loss during the establishment of the vegetation. The mantle's composition will be that of the local loam described in the soil characterization.

The soil mantle will be applied uniformly with minimal compaction and will be graded to approximately 9% (See Appendix I) from the site's central axis to all sides. A drag harrow will be used to pulverize the clods and smooth the surface to a moderately fluffed composition.

Soil pH, nitrogen, organic matter, phosphorus and potassium will be tested to determine the type and quantity of fertilizer necessary for the soil to sustain the vegetative cover.

The vegetation shall consist of a mixture of perennial grasses that readily thrive in this climate and need little maintenance.

If closure commences within the first six months of 1989, then seeding can occur during the proper season. The seeds will be planted by drilling them at the proper density to ensure a thick vegetative cover from the first growth.

TABLE 8. Seed Mix

	Lbs. Pure Live Seed/acre
BLUE GRAMA, Bouteloua gracilis 'Lovington' or 'Hachita'	2
SIDEOATS GRAMA, Bouteloua curtipendula 'El Reno'	4
BUFFALOGRASS, Buchloe dactyloides 'Texoka'	4
BERMUDAGRASS, Cynodon dactylon	1
ALKALI SACATON, Sporbolus airoides	0.5
TOTAL	11.5

A straw mulch will be evenly applied at the rate of 2.5 tons per acre to help retain moisture, prevent erosion, and protect the vegetation until it matures.

Establishment of the vegetative cover will be monitored to ensure adequate cover to prevent erosion and stabilize the soil. If inadequate rainfall occurs to establish adequate cover, a temporary watering system will be installed.

EQUIPMENT DECONTAMINATION

The construction of the final cover over the landfill has been planned such that there may be some limited contact between construction equipment and the waste mass. The following steps will be taken to decontaminate equipment:

1. As much as possible of the waste and/or contaminated soil clinging to the equipment after contact will be removed and redeposited within the landfill, such that it can be covered by the cap.

2. Tools and/or equipment contacting the waste or contaminated soil will be taken to an onbase area where they will be steam cleaned on an impervious catchment apron with the wash waters collected, tested, and properly disposed of.

CERTIFICATION OF CLOSURE

According to Part II, Section 206.C.2.f of the New Mexico Hazardous Waste Management Regulations, which addresses certification of closure at disposal facilities with interim status, the Combat Support Group Commander will submit a certificate of closure to the director. Such certificate will be made by both himself and an independent registered professional engineer that the facility has been closed in accordance with the specifications in the approved closure plan.

Closure is not complete until the closure performance standard is met (Part II, Section 206.C.2.b). This standard requires that the facility is closed so that further maintenance is minimized and that human health and the environment are protected from post closure escape of hazardous wastes.

The appropriate time to submit the Certification of Closure for cell No. 3 at landfill No. 5 will be at the time that the protective cover and all ancillary structures have been constructed.

DEED RECORDING

The exact location of the closed landfill cell as well as a general description of the waste that it contains will be annotated in the Air Force Base Master Plan with a statement that this information is to be transferred to any new documents should the parcel of land be sold. The landfill boundaries and description will also be recorded in the facility folder and by facility number at the base.

The Combat Support Group Commander will ensure proper recording in accordance with New Mexico law, of a notation on the deed to the facility property or on some other instrument which is normally examined during title source - that will, in perpetuity, notify any potential purchaser of the property that the land has been used to manage hazardous wastes, and its use is restricted under the New Mexico Hazardous Waste Management Regulations, specifically Section 206.C.2.g(3).

SURVEY PLAT

Within 90 days after closure is completed, notice to local land authorities and to the Director will be submitted in the form of a survey plat in accordance with HWMR-4, Section 206.C.2.i.

POST CLOSURE MONITORING PLAN

The post closure monitoring program includes three concurrent activities. The first is a groundwater monitoring program designed to detect containment

migration from the landfill through the existing aquifer system. The second is an inspection and maintenance program designed to ensure the integrity of the cap. The third is a vent monitoring program designed to detect releases of volatile organic gases to the atmosphere.

POST CLOSURE GROUNDWATER MONITORING

The post closure groundwater monitoring program will utilize the four existing wells installed in December 1984 and January 1985 and identified as wells A, B, C, and D in the base records (see Figure 7). These four wells, one upgradient and three downgradient, as determined by the actual well water elevations measured after installation, are appropriate to monitor for contaminant migration from the landfill, since no contamination was detected from the first analytical samples taken in January 1985. They are screened into the uppermost aquifer (a depth of approximately 300 feet) and installed as shown in Figure 8.

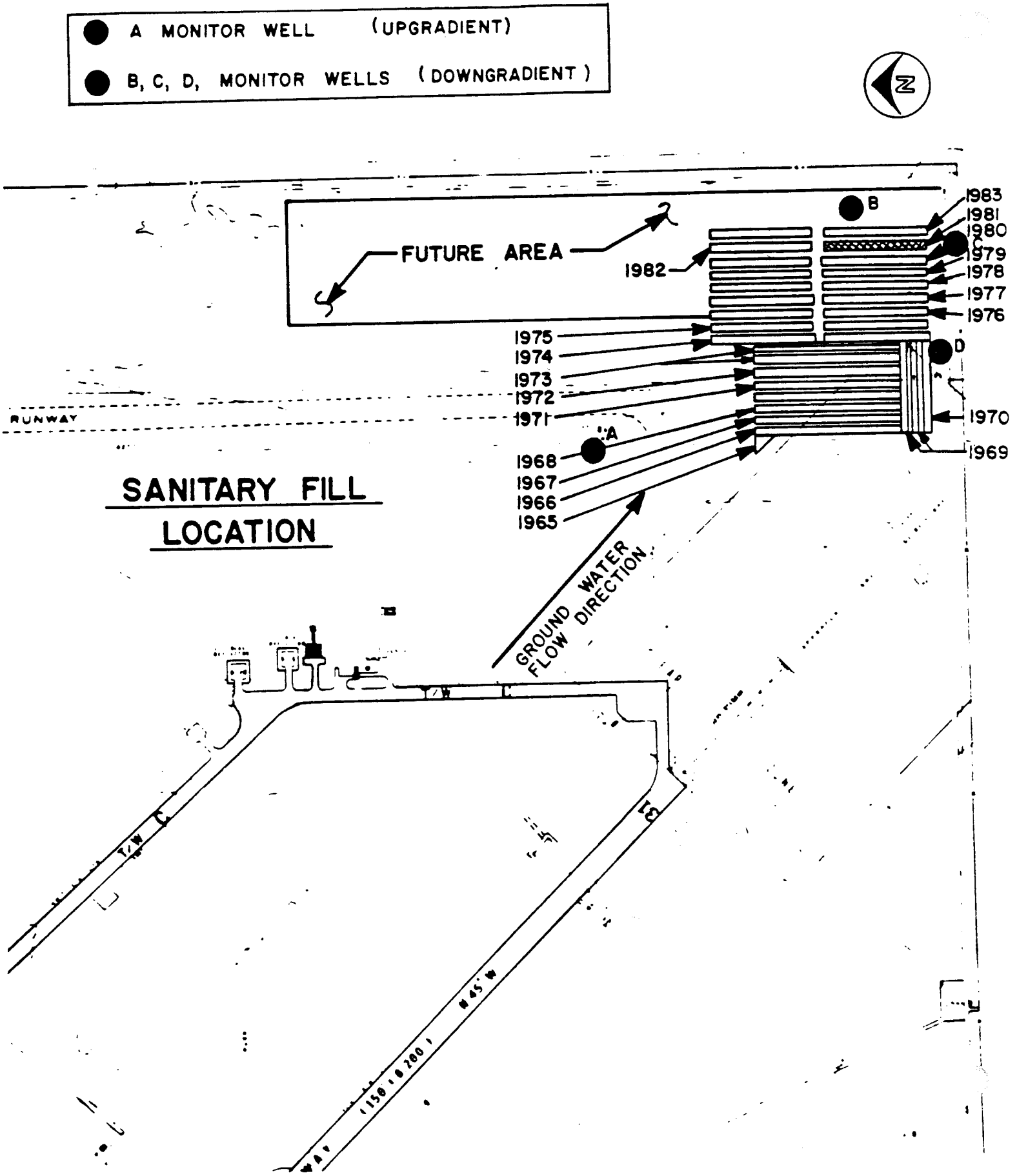
The sampling and analysis of each well will occur on the schedule discussed below. Parameter selection includes those analyses identified by Cannon AFB personnel in the base groundwater monitoring plan, those recommended by New Mexico State officials, and those suggested by a review of the wastes known to be present in the landfill (i.e., chromium, lead, toluene, xylene, cyclohexanone, MEK, and MIBK).

The procedures and techniques for sample collection, preservation, and shipment, as well as specified analytical procedures and chain of custody, are described in the Cannon AFB Groundwater Sampling and Analysis Plan. The plan appears as Appendix II of this report. In addition to obtaining samples for the laboratory analyses, the elevation, pH, and conductivity of the water in the wells will be measured and recorded.

Samples were collected and analyzed quarterly for the first year of monitoring. The sampling and analysis did cover all parameters required by NMHWMR-4. Sampling and analysis will be performed annually for chloride, iron, manganese, phenols, sodium and sulfate. Sampling and analysis will be performed semiannually for pH, conductivity, total organic carbon (TOC) and total organic

FIGURE 7

MONITORING WELL LOCATIONS FOR LANDFILL No. 5



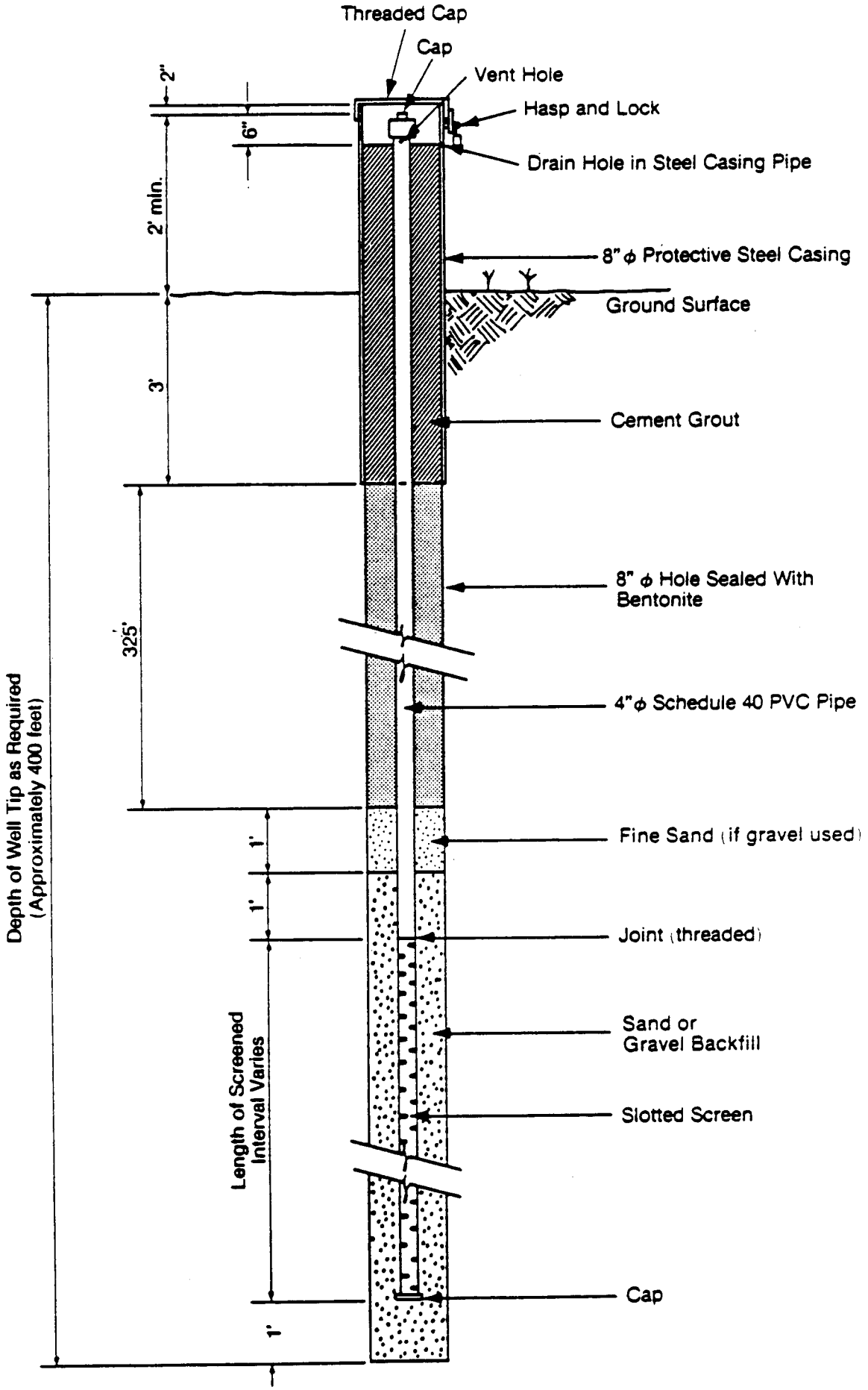


FIGURE 8
Typical Monitoring Well Installation.

halogen (TOX). Groundwater elevations will be measured before the collection of any sample and the locations of the monitoring wells and well performance will be evaluated. Additional wells will be installed if problems develop.

The analytical data obtained during the first year's quarterly monitoring will be used to establish initial background concentrations against which subsequent results will be assessed. Arithmetic means and variances based on four replicate measurements on each sample will be calculated for each of the indicator parameters, pH, conductivity, TOC, and TOX over the four quarters of the first year's sampling. Subsequently, each well's sample analysis for an indicator parameter will be compared to the initial background concentrations by calculating the arithmetic mean and variance for the parameter based on four replicate measurements and using the Student's t-test at the 0.01 level of significance to determine statistically significant increases (or decreases) over the initial background concentration. The GC/MS scans for priority pollutants will be evaluated on a present/nonpresent basis at the limit of detectability in all cases.

If the comparisons of the indicator parameters in the upgradient well show a significant deviation from initial background concentrations after a sampling effort, or if the GC/MS scan in the upgradient well shows positive results, the Director of the Environmental Improvement Division of the State of New Mexico will be notified no later than March 1 following each calendar year (New Mexico Hazardous Waste Regulations - 206.C.1.e.(1).(b).(ii)). If the comparisons of the indicator parameters in any of the downgradient wells show a significant deviation from initial background concentrations after a sampling effort, or if the GC/MS scan shows positive, the well or wells will be immediately resampled and the samples split in two and reanalyzed. If neither of the split samples confirms the deviation, it will be attributed to laboratory error, documented, and reported as such on the regular reporting schedule described below. If either of the reanalyses confirms the significant deviation from the initial background concentrations, the Director will be notified within 7 days [206.C.1.d.(5)].

Within 15 days of that confirmation of significant deviation, a specific plan for a groundwater quality assessment program will be developed and submitted to the Director [206.C.1.d.(6)]. The outline of the groundwater quality assessment program is shown in Exhibit 1. It will provide mechanisms to confirm or refute the presence of contaminants in the groundwater, determine the concentration of confirmed contaminants in the groundwater, and determine the rate and extent of migration of confirmed contaminants through the groundwater system. The first determination of the groundwater quality assessment program will be made as soon as it is technically feasible, and a written report of the determination will be submitted to the Director within 15 days [206.C.1.d.(8)]. If the results of the determination indicate that no landfill contamination has entered the groundwater, the groundwater monitoring program described herein will be reinstated and the Director so notified [206.C.1.d.(9)]. If the results indicate that contaminants have entered the groundwater, the Director will be so notified, and planning will be undertaken to develop remediation measures [206.C.1.d(10)].

The groundwater elevations in all wells (those already installed for the groundwater monitoring program and any that may have been installed as part of a groundwater quality assessment program) will be measured during every sampling effort. There will be an annual review to ensure that monitoring wells are placed correctly with respect to groundwater flow directions.

Exhibit 1

GROUNDWATER QUALITY ASSESSMENT PROGRAM OUTLINE

NOTE: The initiation of this program is triggered by the confirmation of a significant deviation from quality standards as discussed. It is not triggered by a deviation from quality standards in a normal monitoring sample but by the confirmation of that deviation in a subsequent split sample reanalysis.

I. Quantification

A. A predictive model will be developed to project the extent of the contaminant plume based on the existing well data.

B. Additional monitoring wells will be installed at the locations and depths suggested by the predictive model.

C. Samples from all wells will be quantitatively analyzed for the standard semiannual analyses, for use in the predictive model to calculate the extent of the contaminant plume and the rate of migration.

D. Samples from all wells will be analyzed to quantify those parameters appearing in Appendix VIII of 40 CFR Part 261. The list of those parameters and the appropriate test methods (as per SW-846, Test Methods for Evaluating Solid Waste) are as follows:

Parameter	Method(s)
Chromium	7190,7191
Lead	7420,7421
Arsenic	7060,7061
Mercury	7470,7471
Total organic halogens	9020
Methyl ethyl ketone	8015,8240
Methyl isobutyl ketone	8015,8240
Toluene	8020,8024
Xylene	8020,8024

Exhibit 1 (Continued)

E. A determination will be made whether the landfill is affecting the water quality.

II. Remediation

A. A decision will be made whether emergency remedial action is necessary and technically possible (i.e., pumping the existing wells to minimize migration).

B. A feasibility study will be undertaken to provide a permanent solution to the contamination problem and the cleanup of affected areas. Possible remedial alternatives include groundwater pumping and/or removal of landfill contents.

C. Upon approval, the design specifications for the selected remedial alternative will be prepared and the work performed.

Records of all analytical and water elevation data will be kept at the base throughout the post closure care period of 15 years (through 2000). Additionally, the following reports will be made to the Director (206.C.1.e):

- The results of the quarterly sampling and analysis efforts during the first year of monitoring will be submitted with 15 days after receipt of such information by the base. In this report, any well exhibiting a parameter or parameters that exceed the maximum contaminant level listed in Appendix II of the New Mexico State regulations (reproduced as Table 9 in this report) will be separately identified.

- Annually, no later than March 1 following each calendar year, the results of the semiannual and annual monitoring will be submitted, including deviations from the background concentrations in the upgradient well, as previously discussed.

- If a groundwater quality assessment program is initiated, reports containing calculated concentrations and migration rates will be submitted annually, no later than March 1, following each calendar year.

POST CLOSURE COVER MAINTENANCE

The second activity of the post closure monitoring plan is the inspection and maintenance program to ensure the integrity of the cover. On a quarterly basis and after a heavy precipitation, a prolonged drought, and/or a high wind, the cover will be inspected. Any rill erosion, damage to the vegetative cover or minor settling will be corrected with common borrow patching or seeding of the problem area. Weeding will be conducted at every inspection to control undesirable weeds which may take root. If rills are deeper than 10 inches, then it will be necessary to regrade the problem area in accordance with the specifications of this report.

Equipment to be used during post closure maintenance is essentially the same as that used to construct the final cover system. If inadequate rainfall occurs to establish adequate cover, a temporary watering system will be installed. If regrading and/or removal becomes necessary, then a backhoe will secure necessary common borrow for the cover from an existing pile outside of the fence. Heavy machinery will not be allowed to travel on the cover. All repair work on the cover will be done by hand compaction, using a vibrating plate.

TABLE 9. EPA Interim Primary Drinking Water Standards

PARAMETER	MAXIMUM LEVEL (mg/l)
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Fluoride	1.4-2.4
Lead	0.05
Mercury	0.002
Nitrate (as N)	10
Selenium	0.01
Silver	0.05
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
2,4,5-TP Silvex	0.01
Radium	5 pCi/l
Gross alpha	15 pCi/l
Gross beta	4 millirem/yr
Turbidity*	1/TU
Coliform bacteria	1/100 ml

*Turbidity is applicable only to surface water supplies.

VENT MONITORING

On a periodic basis, the three vents along the centerline of cell No. 3 will be monitored for evidence of gaseous emission to the ambient atmosphere. Monitoring results will be maintained at Cannon AFB.

INSPECTION SCHEDULE

These inspections and maintenance activities will be maintained for 15 years following the receipt of certification of final closure for landfill cell No. 3.

Should any difficulties arise during the post closure period, the base environmental coordinator should be contacted. The office is located at Cannon AFB, New Mexico, and the phone number is (505) 784-4639.

REFERENCES

1. CH2M Hill, "Installation Restoration Program Records Search for Cannon Air Force Base", New Mexico, August 1983.

2. Cannon Air Force Base, "Sanitary Landfill - Design Construction and Operation," 1976.

3. Bennett, Warren, Design Division, New Mexico State Highway Administration, personal communication, 1985.

4. Daugherty, Ph.D., Professor of Agronomy, New Mexico State University, personal communication, 1985.

5. New Mexico State Highway Department, "Geology and Aggregate Resources, District 11," 1972.

6. USEPA, "Handbook for Evaluating Remedial Action Technology Waste," EPA 600/2-83-076, 1983.

7. Lutton, R. J., "Evaluating Cover Systems for Solid and Hazardous Waste," EPA SW - 867, 1980.

8. Lutton, R. J., et al, "Design and Construction of Covers for Solid Waste Landfills," EPA 600/2-79-165, 1979.

9. Lutton, R. J., U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, personal communication, 1985.

10. Geoscience Consultants, Ltd., "Cannon AFB, New Mexico Landfill Core Drilling Project (CAN 84-0082)," 1985.

APPENDIX I

EVALUATION OF EROSION POTENTIAL

The USDA universal soil loss equation (USLE):

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

Where
- A = average annual soil loss, tons/acres
- R = rainfall and runoff erosivity index
- K = soil erodibility factor, tons/acre
- LS = combination of slope-length factor and slope-steepness factor
- C = cover/management factor
- P = practice factor

For a 9.09% Grade:

for Eastern NM,	R = 100	(See Figure 1.1)
for 4% organic matter and silty clay loam,	K = 0.26	(See Table 1.1)
for 9.09% slope and 27.5-foot slope length,	LS = 0.62	(See Table 1.2)
for moderately productive grass,	C = 0.01	(See Table 1.3)
for spring-seeded grain,	P = 0.60	(See Table 1.4)

Thus, A = 100 (0.26 tons/acre) (0.62) (0.01) (0.60)
= 0.10 tons/acre
= 200 lbs/acre

Assume density of topsoil = 90 lbs/cu. ft.

Surface area of final cover $= \frac{55 \times 346}{43{,}650}$ acres

Total erosion per year $= \frac{200 \times 0.44}{90}$ cu. ft.

= 0.98 cu. ft.

Similarly, for a 3% Grade:

R = 100
K = 0.26 tons/acre
LS = 0.19
C = 0.01
P = 0.50

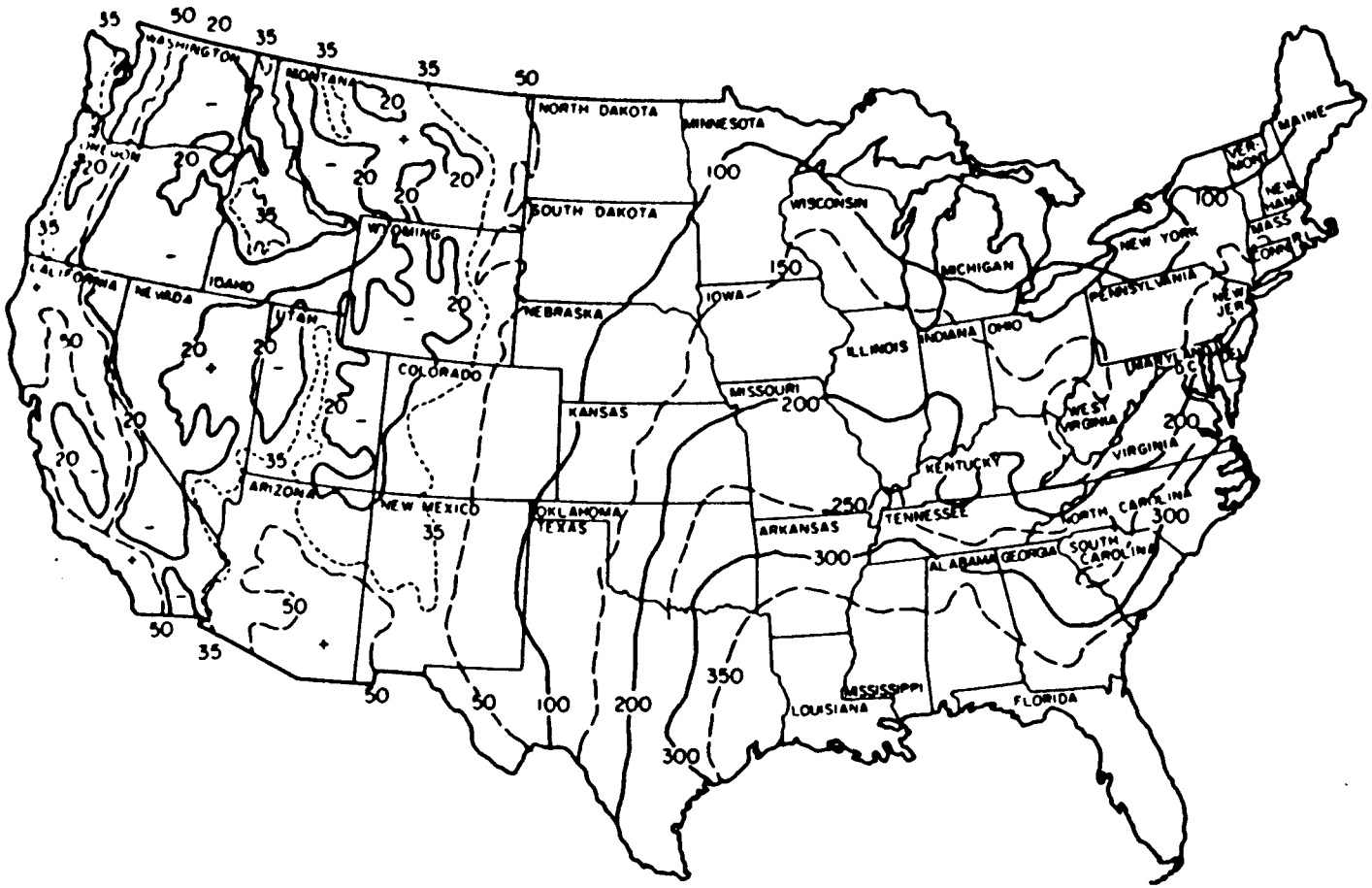
Thus, A = 100 (0.26 tons/acre) (0.19) (0.01) (0.50)
= 0.02 tons/acre
= 40 lbs/acre

Total erosion per year $= \frac{40 \times 0.44}{90}$

$= 0.20$ cu. ft.

The calculations for a 9.09% grade versus the state recommended 3% grade show only a slight difference in the total erosion per year. However, a 3% grade requires a retaining wall of approximately 6 feet high, whereas a 9.09% grade only requires a 2 1/2-foot-high wall at the toe-end of the cover. Due to the existence of surrounding cells, the construction space for the final cover is limited; therefore, a 9.09% gradient for the soil mantle is chosen.

Figure 1.1. Average annual values of rainfall-erosivity factor R.*



*See Ref. 7, p. 46.

TABLE 1.1 Approximate Values of Factor K for USDA Textural Classes*

Texture Class	Organic matter content <0.5% K	2% K	4% K
Sand	0.05	0.03	0.02
Fine sand	.16	.14	.10
Very fine sand	.42	.36	.28
Loamy sand	.12	.10	.08
Loamy fine sand	.24	.20	.16
Loamy very fine sand	.44	.38	.30
Sandy loam	.27	.24	.19
Fine sand loam	.35	.30	.24
Very fine sandy loam	.47	.41	.33
Loam	.38	.34	.29
Silt loam	.48	.42	.33
Silt	.60	.52	.42
Sandy clay loam	.27	.25	.21
Clay loam	.28	.25	.21
Silty clay loam	.37	.32	.26
Sandy clay	.14	.13	.12
Silty clay	.25	.23	.19
Clay		0.13-0.29	

The values shown are estimated averages of broad ranges of specific-soil values. When a texture is near the borderline of two texture classes, use the average of the two K values.

*See Ref. 7, p. 46.

TABLE 1.2 Values of the Factor LS for Specific Combinations of Slope Length and Steepness*

	Slope length (feet)											
% Slope	25	50	75	100	150	200	300	400	500	600	800	1000
0.5	0.07	0.08	0.09	0.10	0.11	0.12	0.14	0.15	0.16	0.17	0.19	0.20
1	0.09	0.10	0.12	0.13	0.15	0.16	0.18	0.20	0.21	0.22	0.24	0.26
2	0.13	0.16	0.19	0.20	0.23	0.25	0.28	0.31	0.33	0.34	0.38	0.40
3	0.19	0.23	0.26	0.29	0.33	0.35	0.40	0.44	0.47	0.49	0.54	0.57
4	0.23	0.30	0.36	0.40	0.47	0.53	0.62	0.70	0.76	0.82	0.92	1.0
5	0.27	0.38	0.46	0.54	0.66	0.76	0.93	1.1	1.2	1.3	1.5	1.7
6	0.34	0.48	0.58	0.67	0.82	0.95	1.2	1.4	1.5	1.7	1.9	2.1
8	0.50	0.70	0.86	0.99	1.2	1.4	1.7	2.0	2.2	2.4	2.8	3.1
10	0.69	0.97	1.2	1.4	1.7	1.9	2.4	2.7	3.1	3.4	3.9	4.3
12	0.90	1.3	1.6	1.8	2.2	2.6	3.1	3.6	4.0	4.4	5.1	5.7
14	1.2	1.6	2.0	2.3	2.8	3.3	4.0	4.6	5.1	5.6	6.5	7.3
16	1.4	2.0	2.5	2.8	3.5	4.0	4.9	5.7	6.4	7.0	8.0	9.0
18	1.7	2.4	3.0	3.4	4.2	4.9	6.0	6.9	7.7	8.4	9.7	11.0
20	2.0	2.9	3.5	4.1	5.0	5.8	7.1	8.2	9.1	10.0	12.0	13.0
25	3.0	4.2	5.1	5.9	7.2	8.3	10.0	12.0	13.0	14.0	17.0	19.0
30	4.0	5.6	6.9	8.0	9.7	11.0	14.0	16.0	18.0	20.0	23.0	25.0
40	6.3	9.0	11.0	13.0	16.0	18.0	22.0	25.0	28.0	31.0	--	--
50	8.9	13.0	15.0	18.0	22.0	25.0	31.0	--	--	--	--	--
60	12.0	16.0	20.0	23.0	28.0	--	--	--	--	--	--	--

Values given for slopes longer than 300 feet or steeper than 18% are extrapolations beyond the range of the research data and, therefore, less certain than the others.

*See Ref. 7, p. 46.

TABLE 1.3 Generalized Values of Factor C for States East of the Rocky Mountains*

Crop, rotation, and management	Productivity level High	Productivity level Mod.
	C value	
Base value: continuous fallow, tilled up and down slope	1.00	1.00
CORN		
C, RdR, fall TP, conv	0.54	0.62
C, RdR, spring TP, conv	.50	.59
C, RdL, fall TP, conv	.42	.52
C, RdR, wc seeding, spring TP, conv	.40	.49
C, RdL, standing, spring TP, conv	.38	.48
C-W-M-M, RdL, TP for C, disk for W	.039	.074
C-W-M-M-M, RdL, TP for C, disk for W	.032	.061
C, no-till pl in c-k sod, 95-80% rc	.017	.053
COTTON		
Cot, conv (Western Plains)	0.42	0.49
Cot, conv (South)	.34	.40
MEADOW		
Grass & Legume mix	0.004	0.01
Alfalfa, lespedeza or Sericia	.020	
Sweet clover	.025	

Abbreviations defined:

B - soybeans
C - corn
c-k - chemically killed
conv - conventional
cot - cotton
F - fallow
M - grass & legume hay
pl - plant
W - wheat
wc - winter cover

lbs rc - pounds of crop residue per acre remaining on surface after new crop seeding
% rc - percentage of soil surface covered by residue mulch after new crop seeding
70-50% rc - 70% cover for C values in first column; 50% for second column
RdR - residues (corn stover, straw, etc.) removed or burned
RdL - all residues left on field (on surface or incorporated)
TP - turn plowed (upper 5 or more inches of soil inverted, covering residues)

*See Ref. 7, p. 46.

TABLE 1.3 Generalized Values of Factor C for States East of the Rocky Mountains* (continued)

Crop, rotation, and management	Productivity level High	Productivity level Mod.
	C value	
Base value: continuous fallow, tilled up and down slope	1.00	1.00
SORGHUM, GRAIN (Western Plains)		
RdL, spring TP, conv	0.43	0.53
No-till pl in shredded 70-50% rc	.11	.18
SOYBEANS		
B, RdL, spring TP, conv	0.48	0.54
C-B, TP annually, conv	.43	.51
B, no-till pl	.22	.28
C-B, no-till pl, fall shred C stalks	.18	.22
WHEAT		
W-F, fall TP after W	0.38	
W-F, stubble mulch, 500 lbs rc	.32	
W-F, stubble mulch, 1000 lbs rc	.21	

Abbreviations defined:

B - soybeans
C - corn
c-k - chemically killed
conv - conventional
cot - cotton
F - fallow
M - grass & legume hay
pl - plant
W - wheat
wc - winter cover

lbs rc - pounds of crop residue per acre remaining on surface after new crop seeding
% rc - percentage of soil surface covered by residue mulch after new crop seeding
70-50% rc - 70% cover for C values in first column; 50% for second column
RdR - residues (corn stover, straw, etc.) removed or burned
RdL - all residues left on field (on surface or incorporated)
TP - turn plowed (upper 5 or more inches of soil inverted, covering residues)

*See Ref. 7, p. 46.

TABLE 1.4 Values of Factor P*

Practice	Land slope (percent) 1.1-2	2.1-7	7.1-12 (Factor P)	12.1-18	18.1-24
Contouring (P_c)	0.60	0.50	0.60	0.80	0.90
Contour strip cropping (P_{sc})					
R-R-M-M[1]	0.30	0.25	0.30	0.40	0.45
R-W-M-M	0.30	0.25	0.30	0.40	0.45
R-R-W-M	0.45	0.38	0.45	0.60	0.68
R-W	0.52	0.44	0.52	0.70	0.90
R-O	0.60	0.50	0.60	0.80	0.90
Contour listing or ridge planting (P_{cl})	0.30	0.25	0.30	0.40	0.45
Contour terracing (P_t)[2]	[3]$0.6/n^{1/2}$	$0.5/n^{1/2}$	$0.6/n^{1/2}$	$0.8/n^{1/2}$	$0.9/n^{1/2}$
No support practice	1.0	1.0	1.0	1.0	1.0

[1]R = rowcrop, W = fall-seeded grain, O = spring-seeded grain, M = meadow. The crops are grown in rotation and so arranged on the field that rowcrop strips are always separated by a meadow or winter-grain strip.

[2]These P_t values estimate the amount of soil eroded to the terrace channels and are used for conservation planning. For prediction of off-field sediment, the P_t values are multiplied by 0.2.

[3]n = number of approximately equal-length intervals into which the field slope is divided by the terraces. Tillage operations must be parallel to the terraces.

*See Ref. 7, p. 46.

APPENDIX II

GROUNDWATER SAMPLING AND ANALYSIS PLAN

A. SAMPLE COLLECTION

1. Determine the static water elevation to the nearest 0.01 inch using an electronic well probe.

2. Calculate the wetted well volume.

3. Pump out 5 wetted well volumes or until pH, conductivity and temperature stabilize (whichever is greater).

4. For total organic carbon (TOC) and total organic halogen (TOX), fill the sample container until overfilled, place the cap on it, and tighten. Turn the container upside down and check for air bubbles. If any air is present retake the sample (see Table 2.3, Note E).

5. For all other samples, fill the sample container full enough to ensure a sufficient volume for the analytical test to be performed.

B. SAMPLE PRESERVATION AND SHIPMENT

1. Sampling Parameters Used to Indicate Suitability of the Groundwater as a Drinking Water Supply (see Table 2.1).

2. Sampling Parameters Used to Establish Groundwater Quality (see Table 2.2).

3. Sampling Parameters Used as Indicators of Groundwater Contamination (see Table 2.3).

C. CHAIN OF CUSTODY. Samples will be sent to USAF OEHL in a sealed shipping container. A Chain-Of-Custody record (see Figure C-4) will be filled out, signed and placed in a plastic bag along with the usual sample submission form (see Figure C-5) and sealed in the shipping container. A duplicate will be kept by SGPB with the duplicates of the sample submission forms. OEHL personnel will acknowledge receipt of the samples in good condition by signing the Chain-Of-Custody form and returning it to Cannon AFB. If the container is damaged in any way or not sealed when the lab receives the package, the technician will so annotate on the form.

TABLE 2.2

ANALYSIS	PRESERVATIVE GROUP	STORET#	PRESERVATIVE/ WORK CENTER	NOTES	REF
ARSENIC	F	01002	F1XX-10510	B	E206
BARIUM	F	01007	F1XX-10510	B	E208
CADMIUM	F	01027	F1XX-10510	B	E213
CHROMIUM	F	01034	F1XX-10510	B	E218
FLUORIDE	G	00951	G1XX-10630	C	E340
LEAD	F	01051	F1XX-10510	B	E239
MERCURY	F	71900	F1XX-10510	B	E245
NITRATE	A	00620	A1XX-10110	B,X	E353
SELENIUM	F	01147	F1XX-10510	B	E270
SILVER	F	01077	F1XX-10510	B	E272
ENDRIN	H	39390	H1XX-10700	D	E608
LINDANE	H	39782	H1XX-10700	D	E608
METHOXYCHLOR	H	39480	H1XX-10700	D	E608
TOXAPHENE	H	39400	H1XX-10700	D	E608
2,4-D	H	39730	H1XX-10700	D	A509
2,4,5-TP-SILVEX	H	39760	H1XX-10700	D	A509
RADIUM	R1				E600
GROSS ALPHA	R1				E600
GROSS BETA	R1				E600
COLIFORM BACT.	G	31501	G1XX-10000	G	A908A

TABLE 2.2

ANALYSIS	PRESERVATIVE GROUP	STORET#	PRESERVATIVE/ WORK CENTER	NOTES	REF
CHLORIDE	G	00940	G1XX-10630	B	E325
IRON	F	01045	F1XX-10510	B	E236
MANGANESE	F	01055	F1XX-10510	B	E243
PHENOLS	E	32730	E1XX-10400	B	E420
SODIUM	F	00929	F1XX-10510	B	E273
SULFATE	G	00945	G1XX-10630	B	E375

TABLE 2.3

ANALYSIS	PRESERVATIVE GROUP	STORET#	PRESERVATIVE/ WORK CENTER	NOTES	REF
SPECIFIC COND.	G	00095	G1XX-10620	B	E120
ORGANIC CARBON	A	00680	A1XX-10130	B	E415
TOT ORG HALOGENS	T			E	E9020
PH	G	00400	G1XX-10000	F	A423

NOTES

NOTE A. STORET# is a number assigned by EPA to a specific environmental parameter such as a physical characteristic or a chemical.

REF is the source for the analytical method.

E = EPA Manual for Chemical Analysis of Water and Wastes, EPA Manual of Methods, Pesticide Residues in Human and Environmental Samples, or Prescribed Procedures for Measurement of Radioactivity in Drinking Water

A = APHA Standard Methods for the Examination of Water and Waste Water.

NOTE B. Sample containers for environmental samples may be either polyethylene (plastic) or glass except where a specific container and/or special sampling techniques are called for in the notes.

NOTE C. Samples must be submitted in polyethylene (plastic) containers for this analysis.

NOTE D. Samples must be submitted in glass containers for this test.

NOTE E. Volatile Halocarbon Compounds; Sample Collection and Handling.

1. Sample containers are 40 ml glass screw cap bottles with TFE fluorocarbon faced silicon septa liners. These containers will be supplied by the USAF OEHL.

2. Sample Collection

a. Collect samples from each sampling site in triplicate. Mark the bottles A, B, and C.

b. Fill the sample bottles in such a manner that no air bubbles pass through the sample as the bottle is filled to overflowing.

c. Place bottle on a level surface and position the TFE side of the septum liner upon the convex meniscus of the sample. Seal the bottle by screwing the cap on tightly.

NOTE: If the septum liner is inverted (i.e., the silicon side against the sample), then significant losses of volatile compounds will occur in shipment and storage.

d. Invert the sample bottle and slightly tap the cap on a solid surface. The absence of entrapped air (bubble) indicates a successful seal. If bubbles are present, open the bottle, pour out the sample, and collect a fresh sample again.

NOTE F. In the field we will calibrate a digital pH meter using two standardized pH solutions. The solutions will be made using deionized water and two standard pH capsules. The pH sample will be collected in a 50 ml plastic beaker and analyzed before any further sampling is accomplished.

NOTE G. A sample for total coliform bacteria will be collected from each of the monitor wells in a 120 ml thio-bag or an autoclaved, sodium thiosulfate treated 100 ml glass jar. After collection, the sample will be taken to the Clovis Branch of the Scientific Laboratory Division of the State of New Mexico Environmental Improvement Division where they will run a total coliform analysis using the Most Probable Number (MPN) method.

NOTE X. Holding time for the chemical/compound is 7 days. Consult the chemist at USAF OEHL/SA or the Water Quality Function at USAF OEHL/ECQ and alert them that we are sending nitrates to be analyzed. This way we can be assured that the recommended maximum holding time will not be exceeded.

PRESERVATION

A1XX. Cool to 4 degrees C. Add sulfuric acid to pH <2. Submit 1 liter in a polyethylene or glass container.

E1XX. Cool to 4 degrees C. Add sulfuric acid to pH <2. Submit 1 liter in a polyethylene or glass container.

F1XX. Add nitric acid to pH <2. Submit 1 liter in a polyethylene or glass container.

G1XX. Cool to 4 degrees C. Add no other preservative. Submit 1 liter in a glass or polyethylene container.

H1XX. Cool to 4 degrees C. Submit 1 liter in glass container with Teflon (R) lined cap for the OCL screen. Submit 1 liter in glass container with Teflon (R) lined cap for 2,4-D and 2,4,5-TP-Silvex.

R1. Add Nitric acid to pH <2. Submit 1 liter in a polyethylene container.

T1XX. Submit only in special containers obtained from USAF OEHL/SAN [AUTOVON 240-3626 or (512) 536-3626/Mr. Rodriguez].

Figure C-4 Chain-of-Custody Record

Survey

Samplers: *Signature*

Station Number	Station Location	Date	Time	Sample Type Water Comp.	Sample Type Water Grab	Sample Type Air	Seq. No.	No. of Containers	Analysis Required

Relinquished by: *Signature*	Received by: *Signature*	Date/Time
Relinquished by: *Signature*	Received by: *Signature*	Date/Time
Relinquished by: *Signature*	Received by: *Signature*	Date/Time
Relinquished by: *Signature*	Received by Mobile Laboratory for Field analysis: *Signature*	Date/Time

Dispatched by: *Signature*	Date/Time	Received for Laboratory by:	Date/Time

Method of Shipment:

Distribution: Orig.—Accompany Shipment
1 Copy—Survey Coordinator Field Files

ENVIRONMENTAL SAMPLING DATA

OEHL USE ONLY

(Use this space for mechanical imprint)

SAMPLING SITE IDENTIFIER (AFR 19-7)

BASE WHERE SAMPLE COLLECTED

SAMPLING SITE DESCRIPTION

DATE COLLECTION BEGAN (YYMMDD)

TIME COLLECTION BEGAN (24 hour clock)

COLLECTION METHOD [ ] GRAB [ ] COMPOSITE _____ HOURS

MAIL REPORTS TO (circle if changed): ORIGINAL / COPY 1 / COPY 2

SAMPLE COLLECTED BY (Name, Grade, AFSC)

SIGNATURE

AUTOVON

REASON FOR SUBMISSION: A-ACCIDENT/INCIDENT, R-ROUTINE/PERIODIC, C-COMPLAINT, N-NPDES, F-FOLLOWUP/CLEANUP, O-OTHER (specify)

BASE SAMPLE NUMBER

OEHL PID

ANALYSES REQUESTED (check appropriate blocks)

	GROUP A		Hardness	00900		Residue, Settleable	50086		GROUP T
	Ammonia	00610	Iron	01045		Residue, Volatile	00505		Bromoform 32104
	Chemical Oxygen Demand	00340	X Lead	01051		Silica	00955		Bromodichloromethane 32101
	Kjeldahl Nitrogen	00625	Magnesium	00927		Specific Conductance	00095		Carbon Tetrachloride 32102
X	Nitrate	00620	Manganese	01055		Sulfate	00945		Chloroform 32106
	Nitrite	00615	X Mercury	71900		Sulfite	00740		Chloromethane 34418
	Oil & Grease	00560	Nickel	01067		Surfactants -MBAS	38260		Dibromochloromethane 32105
	Organic Carbon	00680	Potassium	00937		Turbidity	00076		Methylene Chloride 34423
	Orthophosphate	00671	X Selenium	01147					Tetrachloroethylene 34475
	Phosphorus, Total	00665	X Silver	01077					1,1,1-Trichloroethane 34506
			Sodium	00929		GROUP H			Trichloroethylene 39180
	GROUP D		Thallium	01059		BHC Isomers	39340		Trihalomethanes 82080
	Cyanide, Total	00720	Zinc	01092		Chlordane	39350		PCBs 39516
	Cyanide, Free	00722				DDT Isomers	39370		
						Dieldrin	39380		
	GROUP E		GROUP G		X	Endrin	39390		
	Phenols	32730	Acidity, Total	70508		Heptachlor	39410		
			Alkalinity, Total	00410		Heptachlor Epoxide	39420		
	GROUP F		Alkalinity, Bicarbonate	00425	X	Lindane	39782		
	Antimony	01097	Bromide	71870	X	Methoxychlor	39480		
X	Arsenic	01002	Carbon Dioxide	00405	X	Toxaphene	39400		
X	Barium	01007	Chloride	00940	X	2,4-D	39730		ON SITE ANALYSES
	Beryllium	01012	Color	00080	X	2,4,5-TP-Silvex	39760		Parameter / Value
	Boron	01022	X Fluoride	00951		2,4,5-T	39740		Flow 50050 mgd
X	Cadmium	01027	Iodide	71865					Chlorine, Total 50060 mg/l
	Calcium	00916	Odor	00086					Dissolved Oxygen 00300 mg/l
X	Chromium, Total	01034	Residue, Total	00500					pH 00400 units
	Chromium VI	01032	Residue, Filterable (TDS)	70300		GROUP J			Temperature 00010 °C
	Copper	01042	Residue, Nonfilterable	00530		Sulfides	00745		

COMMENTS ~~Used Racine Laboratories, Inc. Form~~ 2753

California

AF FORM JAN 81 2752

figure C-5

D. SAMPLING FREQUENCY

1. Sampling for all parameters will be performed on a quarterly basis for the first year in order to establish initial concentrations for all groundwater parameters.

2. For the first year, samples collected for the parameters used as indicators of groundwater contamination (pH, specific conductance, TOC, and TOX) from the upgradient well (well A) must be taken in replicates of four. The initial background arithmetic mean and variance must be determined by pooling the replicate measurements for the respective parameter concentrations or values.

3. After the first year, samples collected to establish groundwater quality, i.e., chloride, iron, manganese, phenols, sodium, and sulfate, will be collected annually. Whereas, samples collected to indicate groundwater contamination, i.e., pH, specific conductance, TOC, and TOX, will be collected semi-annually and will be collected from each well in replicates of four. The arithmetic mean and variance will be calculated based on the four replicate samples and the results from each will be compared to its respective initial background arithmetic mean.

4. The comparison will consider each of the wells in the monitoring system individually and will use the student's t-test (see 206.C -Appendix III of the New Mexico Hazardous Waste Management Regulation [NMHWMR]) at the 0.01 level of significance to determine statistically significant increases (and decreases, in the case of pH) over initial background.

5. If the comparison for the upgradient well shows a significant increase (or pH decrease), in accordance with the NMHWMR section 206.C.1.d. (3) the owner or operator will submit this information to the director of the State of New Mexico Environmental Improvement Division (NMEID) no later than March 1 following the calendar year in which the reportable incident occurred.

6. If the comparisons for the downgradient wells show a significant increase (or pH decrease), the owner or operator will immediately obtain additional groundwater samples from those downgradient wells where a significant difference was detected. These samples will be split in two, and analyses obtained for all additional samples to determine whether the significant difference was a result of laboratory error. If the analyses performed confirm the significant increase (or pH decrease), the owner or operator will provide written notice to the director of the State of New Mexico Environmental Improvement Division (NMEID) within seven calendar days of the date of such confirmation that the facility may be affecting groundwater quality.

7. Within fifteen days after the notification, the owner or operator will develop and submit to the director of the State NMEID a specific plan, based on the groundwater assessment outline and certified by a qualified geologist or geotechnical engineer, for a groundwater quality assessment program.

E. RECORDKEEPING AND REPORTING

1. In accordance with the NMHWMR section 206.C.1.e(1)(a) records of the required analyses will be maintained in both the Bioenvironmental Engineering Section and the Environmental Coordinator's office at Cannon AFB, NM throughout the post-closure care period.

2. The following groundwater monitoring information will be reported to the director of the State NMEID in Santa Fe.

a. During the first year when initial background concentrations are being established, concentrations or values of the parameters characterizing the suitability of the groundwater as a drinking water supply for each groundwater monitoring well must be received within fifteen days after completing each quarterly analysis. The owner or operator must separately identify for each monitoring well any parameter whose concentration or value has been found to exceed EPA's maximum contaminant levels.

b. Annually: Concentrations or values of the parameters used as indicators of groundwater contamination for each groundwater monitoring well along with the required evaluations for these parameters in accordance with NMHWMR section 206.C.1.d. (2).

c. Not later than March 1 following each calendar year, results of the evaluation of groundwater surface elevations and a description of the response to that evaluation, if applicable, will be reported to the director of the NMEID.

3. There is no requirement after the first year for periodic sampling for parameters indicating suitability as potable water (EPA Interim Primary Drinking Water Standards).

F. POST-CLOSURE SAMPLING. Sampling of the groundwater monitoring wells for the required parameters will continue for 30 years after the date of completing closure in accordance with the NMHWMR section 206.C.2.g. (1) unless the director of the NMEID reduces this requirement due to a lack of significant findings.

Chapter 7

CLAY LINERS

by David E. Daniel

7.1 INTRODUCTION

Low-hydraulic-conductivity soil liners are given various names, including *soil liner* and *clay liner*. In this chapter, the term *clay liner* is used even though other minerals in the liner material (e.g., sand) may be present in larger quantities than clay. The term *clay* is emphasized because clay is largely responsible for the low hydraulic conductivity of earthen liners. Attention in this chapter is focused on three types of clay liners: (1) naturally-occurring clay liners; (2) compacted clay liners; and (3) geosynthetic clay liners.

A clay liner serves as a hydraulic barrier to flow of fluids. Clay liners are used to minimize infiltration of water into buried waste (cover systems) or to control release of leachate from the waste (liner systems). To meet these objectives, clay liners must have low hydraulic conductivity over long periods of time. Further, one must be able to verify that the hydraulic conductivity will be suitably low, which is often the most difficult problem to be resolved. In addition, clay liners are expected to attenuate the movement of leachate, to prolong release of chemicals in leachate, and to serve other site-specific functions.

7.2 NATURAL CLAY LINERS

Natural clay liners are naturally-occurring formations of low-hydraulic-conductivity, clay-rich soil. Waste can be buried above or within a natural liner. Natural liners normally contain significant amounts of clay minerals and have hydraulic conductivities less than or equal to 1×10^{-6} to 1×10^{-7} cm/s. Natural liners more typically serve as a back-up to engineered liners, but occasionally (for old landfills or, where regulations allow, for new landfills), a natural liner may represent the only liner at a waste disposal facility.

The continuity and hydraulic conductivity of natural liner materials are critical issues. To function effectively, the natural liner must be continuous and be free from major hydraulic imperfections such as fractures, joints, and holes.

An evaluation of a liner's continuity begins with a geologic evaluation and includes a careful study of local and regional hydrogeology (see Chapter 4). Exploratory borings are an essential investigatory tool; surface and borehold geophysics often provide a wealth of valuable information. Analysis of radioisotopic concentrations of certain constituents in ground water can lead to the determination of the age of ground water; knowledge of the age of ground water can help to establish that a soil liner hydrogeologically isolates one aquifer from another. Another useful way to investigate the ability of a natural liner to isolate one stratum from another is to pump from a well in an underlying aquifer and to observe changes in water levels in wells installed in an overlying aquifer, or vice versa.

Hydraulic conductivity of a natural liner should be studied with a combination of laboratory and in situ hydraulic conductivity tests. Laboratory test are usually performed with flexible-wall cells used to permeate samples obtained by pushing a thin-walled tube into soil that underlies a borehole (Daniel et al., 1984). The results of such tests should be viewed with suspicion because if the liner contains hydraulic defects (e.g., cracks, fissures, slickensides, or root holes), the defects will probably be missed and the measured hydraulic conductivity will be too low (Olson and Daniel, 1981; and Daniel, Trautwein, and McMurtry, 1985; Keller, van der Kamp, and Cherry, 1986; and Bradbury and Muldoon, 1990).

In situ hydraulic conductivity tests are an essential part of a credible effort to characterize the hydraulic conductivity of natural soil liners. The normal type of test involves a single cased borehole and either a constant or a falling head. Several equations may be used to compute hydraulic conductivity (see Olson and Daniel, 1981, and Chapuis, 1989, for details). The number of tests that are needed to characterize the hydraulic conductivity of a natural deposit of soil or rock varies from site to site and depends upon hydrogeologic complexity, the required accuracy to which the hydraulic conductivity needs to be determined, available

funding, and other factors. Typically, of the order of 10-20 in situ hydraulic conductivity tests are appropriate. Great care must be taken to seal the boreholes so that the hydraulic integrity of the liner is not compromised. Sealing techniques are discussed in Part IV of this book.

It is extremely difficult and expensive to prove that a naturally-occurring stratum of soil or rock uniformly possesses low hydraulic conductivity. For this reason, use of a natural soil liner as the sole means for protecting ground water from contamination is not normally recommended. An exception might be the case of an extraordinarily uniform, massive, and well-characterized stratum of material, but such strata are rare. Another exception might be site remediation cases in which ground water flow and contamination patterns are monitored and contingencies are made in case strata are more permeable than expected.

The interested reader is encouraged to consult Keller, van der Kamp, and Cherry (1986) and Bradbury and Muldoon (1990) for examples of well-conceived evaluations of natural soil liners.

7.3 COMPACTED CLAY LINERS

7.3.1 Introduction

Compacted clay liners are constructed primarily from natural soil materials, although the liner may contain processed materials such a bentonite or even synthetic materials such as polymers. Clay liners are constructed in layers called *lifts*. On side slopes, the lifts can be horizontal or parallel to the slope, although parallel lifts are not recommended for side slopes steeper than 2.5 to 3 on 1 (horizontal to vertical). As suggested by Fig. 7.1, lifts parallel to the side slopes are preferred because the effect of a zone of poor material, or imperfect bonding of lifts, is less with parallel lifts. If horizontal lifts are used, it may help to place a slight inward inclination on the lift interfaces (Fig. 7.1) to minimize the tendency for leachate to flow along lift interfaces.

7.3.2 Compaction Requirements

The objective of compaction is to remold chunks ("clods") of soil into a homogeneous mass that is free of large, continuous interclod voids. If this objective is accomplished with suitable soil materials, low hydraulic conductivity ($\leq 1 \times 10^{-7}$ cm/s) will result.

Experience has shown that the water content of the soil, method of compaction, and compactive effort have a major influence on the hydraulic conductivity of compacted soil liners. Laboratory studies have demonstrated that low hydraulic conductivity is easiest to achieve when the soil is compacted wet of optimum water content with a high level of kneading-type compactive energy (Mitchell, Hooper, and Campanella, 1965). Figure 7.2 illustrates the influence of molding water content and compactive energy upon hydraulic conductivity. The soil must be sufficiently wet so that, upon compaction, clods of clayey soil will mold together, eliminating large inter-clod pores. Kneading the soil during compaction with a high level of compactive energy helps to remold clods and to eliminate large pore spaces.

Studies have also demonstrated lifts of soil must be bonded together to eliminate, to the extent possible, highly permeable zones at lift interfaces. The idea is illustrated in Fig. 7.3; if permeable inter-lift zones are eliminated, hydraulic connection between "defects" in each lift is destroyed and a low overall hydraulic conductivity is achieved.

7.3.4 Materials

The minimum requirements recommended to achieve a hydraulic conductivity $\leq 1 \times 10^{-7}$ cm/s for most soil liners materials are as follows:

Percentage Fines:	$\geq$ 20 to 30%
Plasticity Index:	$\geq$ 7 to 10%
Percentage Gravel:	$\leq$ 30%
Maximum Particle Size:	25 to 50 mm

Percentage fines is defined as the percent by dry weight passing the U.S. No. 200 sieve, which has openings of 75 μm. Plasticity index may be determined by ASTM D4318. Percentage gravel is defined as the percent by dry weight retained on a No. 4 sieve (4.76 mm openings). Local experience may dictate more stringent requirements, and, for some soils, more restrictive criteria may be appropriate. However, if the criteria tabulated above are not met, it is unlikely that a natural soil liner material will be suitable without additives such as bentonite.

Recent work conducted to evaluate gravel content bears mentioning. Shelley (1991) mixed kaolinite and mine spoil with varying percentages of gravel (maximum particle size = 20 mm), moistened the soil to a few percent wet of optimum, compacted the soil/gravel mixtures using standard Proctor compaction procedures (ASTM D698), and then permeated the compacted specimens. Results are summarized in Fig. 7.4. Shelley found that the soil could contain up to 50% to 60% gravel without a detrimental impact upon hydraulic conductivity. Shelley reported that at gravel percentages ≤ 50% to 60%, clay particles plugged the voids between the gravel particles. Shakoor and Cook (1990) report similar results. However, in both investigations, the soil and gravel were carefully and uniformly mixed in the laboratory; in the field, the mixing will be less perfect. The main issue is not necessarily how much gravel is present (assuming the gravel content is ≤ 50% to 60%) but, rather, with the liklihood that pockets of gravel (segregation of gravel) can occur during construction. The potential for gravel segregation to occur depends on the soil material and construction procedures. The author recommends that the gravel content not exceed about 30%, but notes that this value should be increased or decreased as appropriate for a given material and construction process.

If suitable materials are unavailable locally, local soils can be blended with commercial clays, e.g., bentonite, to achieve low hydraulic conductivity. A relatively small amount of bentonite can lower hydraulic conductivity as much as several orders of magnitude (Fig. 7.5).

One should be cautious about using highly plastic soils (soils with plasticity indices > 30 to 40%) because these materials form hard clods when the soil is dry and are very sticky when the soil is wet. Highly plastic soils, for these reasons, are difficult to work with in the field.

7.3.5 Construction

7.3.5.1 Processing. Some liner materials need to be processed to break down clods of soil (Benson and Daniel, 1990; and Shackelford and Javed, 1991), to sieve out stones and rocks, to moisten the soil, or to incorporate additives. Clods of soil can be broken down with tilling equipment. Stones can be sieved out of the soil with large vibratory sieves or mechanized "rock pickers" passed over a loose lift of soil. Road reclaimers can process soil in a loose lift and crush stones or large clods.

If the soil must be wetted or dried more than 2-3 percentage points in water content, the soil should be processed by spreading it in a loose lift about 300 mm thick. Water can be added and mixed into the soil with a tiller, or the soil can be disced or tilled to allow it to dry uniformly. It is essential that time be allowed for the soil to wet or dry uniformly. At least 1-3 days is usually needed for adequate hydration or dehydration. Frozen soil should never be used to construct a soil liner.

Additives such as bentonite can be introduced in two ways. One technique is to mix soil and additive in a pugmill. Water can also be added in a pugmilleither concurrently with bentonite or in a separate processing step. Alternatively, the soil can be spread in a loose lift 200-300 mm thick, the additive spread over the surface, and rototillers used to mix the materials. Several passes of the tiller over a given spot are usually needed. Water can be added in the tiller during mixing or later, after mixing is complete. The pugmill is more reliable in providing thorough, controlled mixing, but, done carefully, the other method can provide adequate mixing. For more information on bentonite and soil/bentonite testing, the reader is referred to Alther (1983), Alther (1987), Chapuis (1990).

7.3.5.2 Surface Preparation. It is crucial that each lift of a soil liner be effectively bonded to the overlying and underlying lifts (Fig. 7.3). The surface of a previously-compacted lift must be rough rather than smooth. If the surface has been smoothed, e.g., with a smooth steel-drummed roller, the surface should be excavated to a depth of 20-30mm with a disc or other suitable device.

7.3.5.3 Soil Placement. Soil is placed in a loose lift that is no thicker than about 230 mm (9 inches). If grade stakes are used to gauge thickness, the stakes must be removed and the hole left by the stakes sealed. Other techniques, e.g., use of lasers, are preferable for control of elevations. After the soil is placed, a small amount of water may be added to offset evaporative losses, and the soil may be tilled one last time prior to compaction.

7.3.5.4 Compaction. Heavy, footed compactors with large feet that fully penetrate a loose lift of soil (Fig. 7.6) are ideal. Recommended specifications include: minimum weight: 18,000 kg (40,000 pounds); minimum foot length: 180 to 200 mm; and minimum number of passes: 5. (More passes may sometimes be needed. A "pass" is defined as one pass of the compactor, not just an axle, over a given area, and the recommended minimum of 5 passes is for a vechncle with front and rear drums). In the U.S., the Caterpillar 815B and 825C are examples of equipment in widespread use that have led to satisfactory results in most cases.

Statically operated compactors are preferred over vibratory compactors for soil liners. The weight of the compactor must be compatible with the soil: relatively dry soils with firm clods require a very heavy compactor whereas relatively wet soils with soft clods require a roller that is not so heavy that it becomes bogged down in the soil.

7.3.5.5 Protection. After compaction of a lift, the soil must be protected from desiccation and freezing. Desiccation can cause cracking of the clay (Boynton and Daniel, 1985, and Kleppe and Olson, 1985). Freeze-thaw changes the structure and fabric of compacted clay in as way that increases hydraulic conductivity (Fig. 7.7) (Chamberlain and Gow, 1979; Zimmie and LaPlante, 1990), and Kim and Daniel (1992). Desiccation can be minimized in several ways: the lift can be temporarily covered with a sheet of plastic (but one must be

careful that the plastic does not heat excessively and itself dry the clay), the surface can be smooth-rolled to form a relatively impermeable layer at the surface, or the soil can be periodically moistened. The compacted lift can be protected from damage by frost by avoiding construction in freezing weather or by temporarily covering the lift with an insulating layer of material. The protective measures discussed in this section apply to each lift as well as to the completed liner or cover barrier.

7.3.5.6 Quality Control Tests. A critical component in construction quality assurance are quality control (QC) tests. For soil liners, the tests fall into two categories: (1) tests to verify that the materials of construction are adequate, and (2) tests and observation to verify that the compaction process is adequate. Recommended tests and minimum testing frequencies are summarized by Daniel (1990).

7.3.6 Water Content and Dry Unit Weight.

A critical step in design of a compacted soil liner is determination of the range of acceptable water content and dry unit weight of the soil. If the soil is too dry at the time of compaction, suitably low hydraulic conductivity may be unachievable. If the soil is too wet, a variety of problems may ensue, e.g., problems with construction equipment operating on soft, weak soils and potential slope instability caused by low strength of the soil.

Once an acceptable water content range has been selected, the soil must be compacted with adequate compactive energy to compress large voids and to remold clods of soil into a homogeneous, relatively impermeable mass. The dry unit weight of the soil can be a useful indicator of the effectiveness of compaction.

One problem confronting the designer is that both the water content of the soil and the compactive energy delivered to soil during construction of a soil liner vary. Further, precise duplication of field compaction in the laboratory is impossible. Accordingly, the recommended approach (Daniel and Benson, 1990) for establishing water content and dry unit weight requirements during the design stage is to utilize a range in water content that more than spans

the range anticipated in the field and to compact the soil with three compactive energies that represent estimates of the lowest compactive energy anticipated, average energy, and highest compactive energy. The author recommends standard and modified Proctor (ASTM D698 and D1557) for the average and high compactive energies, respectively, and "reduced Proctor" for the lowest energy. "Reduced Proctor" is the same as standard Proctor but with only 15 drops of the compactive ram per lift rather than the usual 25 drops.

The recommended procedure is illustrated in Fig. 7.8. One compacts 5-6 samples of soil with 3 different compactive efforts and plots 3 compaction curves (Fig. 7.8a). Next, the compacted soils are permeated and hydraulic conductivity is measured (Fig. 7.8b). The compaction points are replotted (Fig. 7.8c) with solid symbols used for test specimens that had adequately low hydraulic conductivity and open symbols used for test specimens that were too permeable. An "Acceptable Zone" is drawn (usually with some judgement applied) that encompasses the solid points. Finally, the Acceptable Zone is modified to account for any other relevant factors, e.g., shear strength considerations or local construction practices (Fig. 7.8d). Figure 7.9 illustrates how an Acceptable Zone can be defined from hydraulic conductivity, shear strength, and desiccation shrinkage criteria.

7.3.7 Test Pads

The construction of a test pad prior to building a full-sized liner has many advantages. By constructing a test pad, one can experiment with compaction water content, construction equipment, number of passes of the equipment, lift thickness, etc. Most importantly, though, one can conduct extensive testing, including quality control testing and in-situ hydraulic conductivity testing, on the test pad.

It is usually recommended that the test pad have a width of at least 3 construction vehicles (>10m), and an equal or greater length. The pad should ideally be the same thickness as the full-sized liner, but the trial pad may be thinner than the full-sized liner. (The full-thickness liner should perform at least as well as, and probably better than, a thinner test section because defects in any one lift become less important as the number of lifts increases).

The in-situ hydraulic conductivity may be determined in many ways. The large sealed double-ring infiltrometer is usually the best large-scale test (Daniel, 1989; and Sai and Anderson, 1990), although the Boutwell test (Daniel, 1989, and references therein) is enjoying increased popularity due to its ease of operation and relatively short testing times.

One problem with in situ tests on test pads is that the test ped is subjected to essentially zero overburden stress. Hydraulic conductivity decreases with increasing compressive stress. The author recommends that the hydraulic conductivity measured on a test pad with in situ methods be corrected for the effects of overburden stress based on results of laboratory hydraulic conductivity tests performed over a range in compressive stress (Fig. 7.10).

7.3.8 Chemical Attack by Waste

Waste liquids may attack and effectively destroy earthen liners. It is convenient to consider acids and bases, neutral inorganic liquids, neutral organic liquids, and leachates separately. Testing protocols have been described by Bowders et al. (1986).

7.3.8.1 Acids and Bases. Strong acids and bases can dissolve solid material in the soil, form channels, and increase hydraulic conductivity. Some acids, e.g., hydroflouric and phosphoric acid, are particularly aggressive and dissolve soil readily. Concentration of acid, duration of reaction, liquid-solid ratio, type of clay, and temperature are also important variables (Grim, 1953). Leachates with pH < 3 or >11 are usually of the most concern.

When concentrated acid is passed through clayey soil, hydraulic conductivity often declines initially but later increases. Soils have a high capacity to buffer acid; many pore volumes of flow are usually needed before the full effect of the acid is observed. Examples include Nasiatka et al. (1981), Peterson and Gee (1986), and Bowders and Daniel (1987). Soils that are composed primarily of sand, with a small amount of bentonite, are particularly susceptible to attack by acids because the small mass of bentonite is readily dissolved (Nasiatka et al. (1981).

7.3.8.2 Neutral, Inorganic Liquids. The effects of neutral, inorganic liquids may be evaluated with the Gouy-Chapman theory (Mitchell, 1976), which states that the thickness (T)

of the diffuse double layer varies with the dielectric constant of the pore fluid (D), the electrolyte concentration (n_o), and the cation valence (v) as follows:

$$T \; a \; [\, D/(n_o \, v^2) \,]^{1/2} \qquad 7.1$$

For solutions containing mainly water, the dielectric constant of the liquid is relatively constant, and thus the main parameters are n_o and v. As the diffuse double layer of adsorbed water and cations expands, hydraulic conductivity decreases because flow channels become constricted. Attempts to validate quantitatively the effect of D, n_o, and v on conductivity have generally failed. Qualitatively, however, the Gouy-Chapman theory explains the observed patterns. Aqueous solutions with few electrolytes, e.g., distilled water, tend to expand the double layer and to produce low hydraulic conductivity. Solutions with monovalent cations, e.g., Na^+, Ca^{++}. A strong (high n_o) solution containing polyvalent cations tends to produce the largest conductivity. Further details and supporting data are reported by Fireman (1944) andMcNeal and Coleman (1966).

7.3.8.3 Neutral, Organic Liquids. Most organic chemicals have lower dielectric constants than water. Low D tends to cause low T (Eq. 7.1) and thus high hydraulic conductivity. In addition, low-dielectric-constant liquids cause clay particles to flocculate and cause the soil to shrink and to crack (Anderson, 1983; and Quigley and Fernandez, 1985 and 1988). This phenomenon is called "syneresis" and the cracks "syneresis cracks". Numerous studies have shown that organic chemicals can cause large increases in hydraulic conductivity (Anderson, 1982; Acar et al., 1985; Fernandez and Quigley, 1985; Foreman and Daniel, 1986; and others).

High compressive stress causes the soil to compact when an organic solvent passes through the soil rather than to crack (Broderick and Daniel, 1990; and Fernandez and Quigley, 1991). Thus, soil liners perform much better at high compressive stress than low stress when they are permeated with organic liquids.

Dilute organic liquids do not tend to alter hydraulic conductivity significantly (Bowders and Daniel, 1987, and references therein). If a small amount of low-dielectric-constant

liquid, e.g., trichlorethylene (D=3), is mixed with water, the dielectric constant of the mixture is only slightly less than that of water (80). Tests have indicated that the dielectric constant must be less than 30 to 50 for hydraulic conductivity to increase. Experience indicates that soil liners are not attacked by an organic liquid if (1) the solution consists of at least 50% water, and (2) there is no separation of phases, i.e., all of the organic liquid is dissolved in the water and none exists as a separate phase. A recent, comprehensive review is provided by Budhu et al. (1991).

7.3.9 Reliability of Compacted Clay Liners

Many examples can be cited of soil liners that failed to function effectively as hydraulic barriers. Soil liners are not the problem; inadequate investigations (natural soil liners) or inadequate construction or quality control (compacted soil liners) are the main causes of problems. Gordon et al. (1989), Cartwright and Krapac (1990), Johnson et al. (1990), and Reades et al. (1990) provide examples of well-built, full-scale compacted soil liners that have in situ hydraulic conductivities $\leq 1 \times 10^{-7}$ m/s. Good-quality soil liners that will perform effectively can beconstructed.

7.4 GEOSYNTHETIC CLAY LINERS

A relatively new type of manufactured clay liner is receiving widespread attention as a potential hydraulic barrier in liner and cover systems at waste disposal facilities. The liner consists of a thin layer of clay sandwiched between two geotextiles or glued to a geomembrane. Four companies currently manufacture these types of materials, and new products of a similar design are expected to appear on the market in the next year or two.

Various terms have been used to describe these materials, e.g., clay mat, bentonite matting, bentonitic clay liner, prefabricated clay blanket, prefabricated clay liner, etc. Recently, the term *geosynthetic clay liner* (GCL) has received widespread use for these materials and is used in the remainder of this chapter.

7.4.1 Types of Geosynthetic Clay Liners

Four GCL's are currently manufactured: Bentofix®, Bentomat®, Claymax®, and Gundseal. The configurations, summarized in Fig. 7.11, fall into 2 categories: (1) bentonite sandwiched between two geotextiles (Bentofix®, Bentomat®, and Claymax®), and (2) bentonite mixed with an adhesive and glued to a geomembrane (Gundseal). All the GCL's contain approximately 5 kg/m^2 (1 lb/ft^2) of bentonite. The materials are manufactured in panels with widths of approximately 4 to 5 m and lengths of 25 to 60 m.

The panels are placed on rolls at the factory, stored, shipped to the construction site, and unrolled in their final location. All four GCL's are said to be self sealing at overlaps between panels (see Fig. 7.12): when water hydrates the clay in the GCL, the clay swells and automatically seals the overlap. Because no mechanical seaming of joints between panels is needed, GCL's can be installed very rapidly.

After the GCL is placed, it must be covered immediately. If the GCL becomes wet, e.g., from a rainstorm, the clay swells in an uneven manner and the material does not properly self-seam. Thus, the GCL cannot be installed when precipitation is threatening, and the GCL cannot be left exposed.

Bentofix® is manufactured in Germany by Naue-Fasertechnik. Sodium-activated bentonite is placed between two thick, nonwoven, high density polyethylene (HDPE) geotextiles and then the geotextiles are needlepunched together. The lower and upper geotextiles weigh 800 g/m^2 and 400 g/m^2, respectively. The purpose of needlepunching the geotextiles together is twofold: (1) to hold the GCL together during handling and deployment, and (2) to provide increased in-plane shear strength after deployment.

In the field, the Bentofix® sheets are unrolled and overlapped. Additional granular bentonite is placed between overlapped panels to make the material self-sealing at overlaps. Further information is available from Scheu et al. (1990).

Bentomat® is manufactured by American Colloid Company in Villa Rica, Georgia. Several geotextiles and grades of bentonite can be used in making Bentomat®. The usual configuration

consists of regular or contaminant-resistant sodium bentonite sandwiched between two geotextiles (each 170 g/m^2) that are needlepunched together. Conceptually, the product is similar to Bentofix®, but Bentomat® is made with thinner geotextiles and a natural, sodium bentonite.

At overlapped sections of Bentomat®, 0.4 kg/m of additional bentonite is placed between the GCL panels to assist in self sealing upon hydration.

Claymax® is manufactured by the James Clem Corporation in Fairmont, Georgia. With this GCL, bentonite is mixed with a water-soluble adhesive and sandwiched between two geotextiles. The upper geotextile usually consists of a 119 g/m^2 woven polypropylene needlepunched with a 17 g/m^2 nylon fabric to form a 136 g/m^2 (4 oz/yd^2) primary geotextile for the GCL. The other geotextile is a 25 g/m^2 open-weave, spun-lace polyester backing. The adhesive mixed with the bentonite serves to hold the GCL together during manufacture and installation. After Claymax® has been installed, the adhesive no longer serves a purpose; hence, the solubility of the adhesive is insignificant in terms of long-term performance.

Claymax® panels are overlapped in the field, but no extra bentonite is required; the bentonite is said to ooze through the openings in the geotextiles (especially the open-weave polyester backing)to self-seal the overlapped panels when the bentonite is hydrated.

Further information about Claymax® may be obtained from Schubert (1987), Shan (1990), and Shan and Daniel (1991).

Gundseal is manufactured by Gundle Lining Systems in Spearfish, South Dakota. The material consists of sodium bentonite that is mixed with an adhesive and attached to a high density polyethylene (HDPE) geomembrane through a calendaring process. The geomembrane is usually a 0.5 mm smooth HDPE sheet, but textured geomembranes and very low density polyethylene (VLDPE) geomembranes can be used.

Gundseal is unrolled in the field with the HDPE facing either up or down. Overlapped areas are said to be self sealing at the bentonite/polyethylene contact; no mechanical seaming is necessary, although the polyethylene sheets could be welded together, if desired.

If the bentonite is facing downward, Gundseal serves as a composite geomembrane/clay liner with the geomembrane on the top. If one wished to place a conventional geomembrane on top of Gundseal to form a composite liner, the bentonite in the Gundseal would face upward as shown in Fig. 1; the composite liner would consist of a separate geomembrane underlain by the bentonite component of Gundseal underlain by the polyethylene geomembrane component of Gundseal.

7.4.2 Engineering Properties

7.4.2.1 Hydraulic Conductivity

Various organizations have measured the hydraulic conductivity of GCL's. The tests have been performed with flexible-wall permeameters over a range in effective stress. The tests on Gundseal were performed by punching holes in the geomembrane (otherwise the geomembrane would restrict cross-plane flow). Figure 7.13 summarizes the available hydraulic conductivity data. Information about the tests and sources of data may be found in Daniel and Estornell (1990), Scheu et al. (1990), and Estornell (1991).

The hydraulic conductivity to water varies between approximately 1×10^{-10} and 1×10^{-8} cm/s, depending on compressive stress. There are some differences in hydraulic conductivity between the various GCL's, but those differences are difficult to sort out given the very limited data base for some of the materials and differences in testing procedures employed to measure hydraulic conductivity. The engineer who compares the hydraulic conductivity of one GCL to that of another GCL should be careful to compare hydraulic conductivities determined at the same compressive stress and similar test conditions.

Estornell (1991) built several tanks to evaluate the hydraulic integrity of overlapped seams. The tanks measured 1.2 m in width by 2.4 m in length. Samples of three GCL's (Bentomat®, Claymax®, and Gundseal) were placed on a drainage layer on the bottom of the tank and then covered with 300 to 600 mm of gravel. The GCL's were flooded with water to a depth of 300 to 600 mm, and the flow rate in the drainage layer located beneath the GCL was monitored. Tests were performed with control samples containing no overlapped seam and with

overlapped samples. Estornell found that the fluxes through the control samples and the overlapped samples were consistently low and were about the same. The overlapped sections did in fact self-seal under in these large-scale, controlled tests.

Shan and Daniel (1991) describe tests in which one geosynthetic clay liner was permeated with a variety of chemicals. Shan and Daniel found that the liner maintained low hydraulic conductivity to a broad range of chemicals when the bentonite was fully hydrated with fresh water prior to introduction of the chemical. However, when the dry GCL was permeated directly with an organic chemical, the bentonite did not hydrate, did not swell, and did not attain a low hydraulic conductivity. The designer should be careful to utilize the results of hydraulic conductivity tests performed under the most critical conditions of hydration that can be expected in the field.

Shan and Daniel (1991) also describe tests aimed at documenting the ability of one GCL to self heal when damaged by puncture, desiccation, or freeze/thaw. Shan and Daniel found that if the dry material is punctured, the bentonite will swell when hydrated and fill small punctures. If the GCL is hydrated and dried, severe desiccation cracks can form. However, Shan and Daniel found that when the GCL was rewetted, the bentonite swelled, and the hydraulic conductivity returned to the original, low value for the undamaged material. Several cycles of wet/dry did not cause a permanent change in the hydraulic conductivity of the hydrated material under controlled laboratory test conditions. Similarly, freeze/thaw cycles did not cause an increase in hydraulic conductivity of one GCL investigated. The very high swelling capacity of bentonite was presumably responsible for the self healing capability that was observed.

One topic of interest concerning geosynthetic clay liners is the behavior of composite geomembrane/geosynthetic clay liner. The question is the following: if a geomembrane is placed on a geosynthetic clay liner with a geotextile separating the geomembrane from the bentonite (see upper half of Fig. 7.14), will the highly transmissive geotextile transmit water laterally (in which case the composite action is less than ideal), or will bentonite seal the geotextile (lower half of Fig. 7.14) such that lateral flow is minimal? Estornell (1991) used the large

tanks mentioned earlier to study this issue for two GCL's that had geotextiles on both the upper and lower surface and one GCL that had no geotextile on one surface. Estornell placed a geomembrane that contained several punctures directly on the GCL's and found that lateral wicking of water through the geotextile in two of the GCL's was significant. For the GCL that did not contain a geotextile on one surface of the material, no lateral flow at the geomembrane/bentonite interface was noted (in fact, the bentonite was only wetted to a distance of 50 to 75 mm from the puncture in the geomembrane after about 3 months of wetting). These tests illustrate that composite action with a geomembrane may be affected by a geotextile that separates the geomembrane from the clay. Further study of this phenomenon is in progress, and at least one manufacturer is attempting to added agents to the geotextile in contact with a geomembrane that will reduce the in-plane transmissivity of the geotextile. Also, the reader should realize the the effectiveness of the composite action between a geomembrane and a GCL depends on overburden stress; the higher the overburden stress, the less the lateral flow along the interface.

7.4.2.2 Shear Strength

Fully-drained direct shear tests have been performed on Bentomat®, Claymax®, and Gundseal. The tests were performed on 60-mm-diameter samples that were subjected to a normal stress, hydrated, and then sheared very slowly. Separate consolidation tests were performed to obtain the parameters needed to determine the time to failure required to ensure fully drained conditions. Times to failure were typically 4 to 8 days, although the tests were continued to residual conditions over a shearing period of about 4 weeks.

Results of the tests are plotted in Fig. 7.15. The straight lines shown in the figure were determined from linear regression; regression coefficients are as follows:

Geosynthetic Clay Liner	Effective Cohesion (kPa)	Effective Angle of Internal Friction (degrees)
Bentomat®	30	26
Claymax®	4	9
Gundseal	8	8

7.4.3 Current Applications

To date, there have been two primary applications of GCL's for waste containment applications: (1) as the clay component of a primary composite liner for double liner systems, and (2) as the clay component of a composite liner in final cover systems for landfills or site remediation projects. Geosynthetic clay liners have also been used by themselves as a barrier layer in liners and covers, although to a lesser extent. Secondary containment structures have also been lined with GCL's (Bruton, 1991).

7.4.4 Advantages and Disadvantages of GCL's

Geosynthetic clay liners are usually viewed as an alternative to a compacted clay liner (Grube, 1991; and Grube and Daniel, 1991). Hence, the following discussion is addressed at the relative advantages of GCL's compared to CCL's.

Table 7.1 contrasts the differences between geosynthetic clay liners and compacted clay liners. The main advantages of GCL's are that GCL's can be installed much more quickly, lightweight construction equipment can be used (which is especially important when the clay liner is placed on top of other components of a liner system that might be punctured or damaged by heavy equipment), GCL's are installed dry and are therefore not as vulnerable to damage from desiccation during construction, and dry GCL's do not produce water upon loading (wet,

compacted clay liners consolidate when loaded and the consolidation water can be misinterpreted as leakage if the liner is placed on top of a leak detection layer). The main disadvantages of GCL's are a general lack of experience, the vulnerability of a thin GCL to puncture, questionable composite behavior of some GCL's with an adjacent geomembrane, less leachate attenuation capacity than a thick liner, and questions about stability of hydrated bentonite.

GCL's and CCL's both enjoy advantages and disadvantages. The engineer should weigh the pluses and minuses for each project and make a decision about which type of clay liner is most appropriate based on such an evaluation.

Table 1. Comparison of Geosynthetic Clay Liners with Conventional Compacted Clay Liners

Compacted Clay Liner (CCL)	Geosynthetic Clay Liner (GCL)
Thick (0.6 - 1.5 m)	Thin (≤ 10 mm)
Field Constructed	Manufactured
Hard to Build Correctly	Easy to Build (Unroll & Place)
Impossible to Puncture	Possible to Damage and Puncture
Constructed with Heavy Equipment	Light Construction Equipment Can Be Used
Often Requires Test Pad at Each Site	Repeated Field Testing Not Needed
Site-Specific Data on Soils Needed	Manufactured Product; Data Available
Large Leachate-Attenuation Capacity	Small Leachate-Attenuation Capacity
Relatively Long Containment Time	Shorter Containment Time
Large Thickness Takes Up Space	Little Space Is Taken
Cost Is Highly Variable	More Predictable Cost
Soil Has Low Tensile Strength	Higher Tensile Strength
Can Desiccate and Crack	Can't Crack Until Wetted
Difficult to Repair	Not Difficult to Repair
Vulnerable to Freeze/Thaw Damage	Less Vulnerable to Freeze/Thaw Damage
Performance Is Highly Dependent Upon Quality of Construction	Hydraulic Properties Are Less Sensitive to Construction Variabilities
Slow Construction	Much Faster Construction

REFERENCES

Acar, Y.B., Hamidon, A., Field, S.D., and L. Scott (1986), "The Effect of Organic Fluids on Hydraulic Conductivity of Compacted Kaolinite," *Hydraulic Barriers in Soil and Rock, ASTM STP 874*, Johnson et al. (Eds.), American Society for Testing and Materials, Philadelphia, pp. 171-187.

Alther, G. R., (1983), "The Methylene Blue Test for Bentonite Liner Quality Control," *Geotechnical Testing Journal*, Vol. 6, No. 3, pp. 128-132.

Alther, G.R. (1987), "The Qualifications of Bentonite as a Soil Sealant," *Engineering Geology*, Vol. 23, pp. 177-191.

Anderson, D.C. (1982), "Does Landfill Leachate Make Clay Liners More Permeable?", *Civil Engineering*, Vol. 52, No. 9, pp. 66-69.

Benson, C.B., and D.E. Daniel (1990), "The Influence of Clods on the Hydraulic Conductivity of a Compacted Clay," *Journal of Geotechnical Engineering*, Vol. 116, No. 8, p. 1231-1248.

Bowders, J.J., Daniel, D.E., Broderick, G.P., and H.M. Liljestrand (1986), "Methods for Testing the Compatibility of Clay Liners with Landfill Leachate," *Hazardous and Industrial Solid Waste Testing, Fourth Symposium, ASTM STP 886*, J.K. Petros et al. (Eds.), American Society for Testing and Materials, Philadelphia, pp. 233-250.

Bowders, J.J., and D.E. Daniel (1987), "Hydraulic Conductivity of Compacted Clays to Dilute Organic Chemicals, *Journal of Geotechnical Engineering*, Vol. 113, No. 12., pp. 1432-1448.

Boynton, S.S., and D.E. Daniel (1985), "Hydraulic Conductivity Tests on Compacted Clay," *Journal of Geotechnical Engineering*, Vol. 111, No. 4, pp. 465-478.

Bradbury, K.R., and M.A. Muldoon (1990), "Hydraulic Conductivity Determinations in Unlithified Glacial and Fluvial Materials," *Ground Water and Vadose Zone Monitoring, STP 1053*, D.M. Nielsen and A.I. Johnson (Eds.), American Society for Testing and Materials, Philadelphia, pp. 138-151.

Broderick, G.P., and D.E. Daniel (1990), "Stabilizing Compacted Clay Against Chemical Attack," *Journal of Geotechnical Engineering*, Vol. 116, No. 10, pp. 1549-1567.

Bruton, D. (1991), "Bentonite Mats Meet Secondary Containment Standards," *Geotechnical Fabrics Report*, Vol. 9, No. 4, pp. 26-27.

Budhu, M., et al. (1991), "The Permeability of Soils with Organic Fluids," *Canadian Geotechnical Journal*, Vol. 28, No. 1, pp. 140-147.

Cartwright, K., and I.G. Krapac (1990), "Construction and Performance of a Long-Term Earthen Liner Experiment," *Waste Containment Systems: Construction, Regulation, and Performance*, R. Bonaparte (ed.), American Society of Civil Engineers, New York, pp. 135-155.

Chamberlain, E.J., and A.J. Gow (1979), "Effects of Freezing and Thawing on the Permeability and Structure of Soil," *Engineering Geology*, Vol. 13, pp. 73-92.

Chamberlain, E.J., Iskander, I., and S.E. Hunsicker (1990), "Effect of Freeze-Thaw Cycles on the Permeability and Macrostructure of Soils," *Proceedings*, International Symposium on Frozen Soil Impacts on Agricultural, Range, and Forest Lands, CRREL Special Report 90-1, U.S. Army Corps of Engineers Cold Regions Research & Engineering Laboratory, Hanover, Ne Hampshire, pp. 145-155.

Chapuis, R.P. (1989), "Shape Factors for Permeability Tests in Boreholes and Piezometers," *Ground Water*, Vol. 27, No. 5, pp. 647-654.

Chapuis, R.P. (1990), "Soil-Bentonite Liners: Predicting Permeability from Laboratory Tests," *Canadian Geotechnical Journal*, Vol. 27, No. 1, pp. 47-57.

Daniel, D.E. (1984), "Predicting Hydraulic Conductivity of Clay Liners," *Journal of Geotechnical Engineering*, Vol. 110, No. 2, pp. 285-300.

Daniel, D.E., Trautwein, S.J., Boynton, S.S, and D.E. Foreman (1984), "Permeability Testing with Flexible-Wall Permeameters, *Geotechnical Testing Journal*, Vol. 7, No. 3, pp. 113-122.

Daniel, D.E., Trautwein, S.J., and D. McMurtry (1985), "A Case History of Leakage from a Surface Impoundment," *Seepage and Leakage from Dams and Impoundments*, R.L. Volpe and W.E. Kelly (Eds.), American Society of Civil Engineers, New York, pp. 220-235.

Daniel, D.E. (1989), "In Situ Hydraulic Conductivity Tests for Compacted Clay," *Journal of Geotechnical Engineering*, Vol. 115, No. 9, pp. 1205-1226.

Daniel, D.E. (1990), "Summary Review of Construction Quality Control for Compacted Soil Liners," *Waste Containment Systems: Construction, Regulation, and Performance*, R. Bonaparte (ed.), American Society of Civil Engineers, New York, pp.175-189.

Daniel, D.E., and C.H. Benson (1990), "Water Content-Density Criteria for Compacted Soil Liners," *Journal of Geotechnical Engineering*, Vol. 116, No. 12, pp. 1811-1830.

Daniel, D. E., and P. M. Estornell (1990), "Compilation of Information on Alternative Barriers for Liner and Cover Systems," U. S. Environmental Protection Agency, EPA 600/2-91/002, Cincinnati, Ohio, 81 p.

Estornell, P. M. (1991), "Bench-Scale Hydraulic Conductivity Tests of Bentonitic Blanket Materials for Liner and Cover Systems," M. S. Thesis, Univ. of Texas, Austin, TX, 153 p.

Fernandez, F., and R.M. Quigley (1985), "Hydraulic Conductivity of Natural Clays Permeated with Simple Liquid Hydrocarbons,," *Canadian Geotechnical Journal*, Vol. 22, No. 2, pp. 205-214.

Fernandez, F., and R.M. Quigley (1988), "Viscosity and Dielectric Constant Controls on teh Hydraulic Conductivity of Clayey Soils Permeated with Water-Soluble Organics," *Canadian Geotechnical Journal*, Vol. 25, No. 4, pp. 582-589.

Fernandez, F., and R.M. Quigley (1991), "Controlling the Destructive Effects of Clay - Organic Liquid Interactions by Application of Effective Stress," *Canadian Geotechnical Journal*, Vol. 28, No. 3, pp. 388-398.

Fireman, M. (1944), "Permeability Measurements on Disturbed Soil Sample," *Soil Science*, Vol. 58, pp. 337-355.

Foreman, D.E., and D.E. Daniel (1986), "Permeation of Compacted Clay with Organic Chemicals," *Journal of Geotechnical Engineering*, Vol. 112, No. 7, pp. 669-681.

Gordon, M.E., Huebner, P.M., and T.J. Miazga (1989), "Hydraulic Conductivity of Three Landfill Clay Liners," *Journal of Geotechnical Engineering*, Vol. 15, No. 8, pp. 1148-1160.

Grim, R.E. (1953), *Clay Mineralogy*, McGraw-Hill, New York, 384 p

Grube, W. E. Jr. (1991), "Soil Barrier Alternatives," Remedial Action, Treatment, and Disposal of Hazardous Waste, U. S. Environmental Protection Agency, Cincinnati, Ohio, EPA/600/9-91/002, pp. 436-444.

Grube, W. E., Jr., and D. E. Daniel (1991), "Alternative Barrier Technology for Landfill Liner and Cover Systems," Presented at the 84th Annual Meeting & Exhibition of the Air & Waste Management Association, Vancouver, British Columbia, Paper 91-5.9, 11 p.

Johnson, G.M., Crumbley, W.S., and G.P. Boutwell (1990), "Field Verification of Clay Liner Hydraulic Conductivity," *Waste Containment Systems: Construction, Regulation, and Performance*, R. Bonaparte (ed.), American Society of Civil Engineers, New York, pp. 226-245.

Keller, C.K., van der Kamp, G., and J.A. Cherry (1986), "Fracture Permeability and Groundwater Flow in Clayey Till near Saskatoon, Saskatchewan," *Canadian Geotechnical Journal*, Vol. 23, pp. 229-240.

Kim, W.H., and D. E. Daniel (1992), "Effects of Freezing on the Hydraulic Conductivity of a Compacted Clay," *Journal of Geotechnical Engineering*, Vol. 118, (in press).

Kleppe, J.H., and R.E. Olson (1985), "Desiccation Cracking of Soil Barriers," *Hydraulic Barriers in Soil and Rock, ASTM STP 874*, American Society for Testing and Materials, Philadelphia, pp. 263-275.

McNeal, B.L., and N.T. Coleman (1966), "The Effect of Solution on Soil Hydraulic Conductivity," *Soil Science Society of America Proceedings*, Vol. 30, No. 3, pp. 308-312.

Mitchell, J.K. (1976), *Fundamentals of Soil Behavior*, John Wiley & Sons, New York, 422 p.

Mitchell, J.K., Hooper, D.R., and R.G. Campanella (1965), "Permeability of Compacted Clay," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 91, No. SM4, pp. 41-65.

Nasiatka, D.M., Shepherd, T.A., and J.D. Nelson (1981), "Clay Liner Permeability in Low pH Environments," *Proceedings*, Symposium on Uranium Mill Tailings Management, Colorado State University, Fort Collins, Colorado, pp. 627-645.

Olson, R.E., and D.E. Daniel (1981), "Measurement of the Hydraulic Conductivity of Fine-Grained Soils," *Permeability and Ground Water Contaminant Transport, ASTM STP 746*, T.F. Zimmie and C.O. Riggs (Eds.), American Society for Testing and Materials, Philadelphia, pp. 18-64.

Peterson, S.R., and G.W. Gee (1986), "Interactions between Acidic Solutions and Clay Liners: Permeability and Neutralization," *Hydraulic Barriers in Soil and Rock, ASTM STP 874*, American Society for Testing and Materials, Philadelphia, pp. 229-245.

Reades, D.W., Lahti, L.R., Quigley, R.M., and A. Bacopoulos (1990), "Detailed Case History of Clay Liner Performance," *Waste Containment Systems: Construction, Regulation, and Performance*, R. Bonaparte (ed.), American Society of Civil Engineers, New York, pp. 156-174.

Sai, J.O., and D.C. Anderson (1990), "Field Hydraulic Conductivity Tess for Compacted Soil Liners," *Geotechnical Testing Journal*, Vol. 13, No. 3, pp. 215-225.

Scheu, C., Johannben, K., and F. Saathoff (1990), "Non-Woven Bentonite Fabrics - A New Fibre Reinforced Mineral Liner System," *Geotextiles, Geomembranes and Related Products*, D. Hoet (Ed.), Balkema Publishing, Rotterdam, pp. 467-472.

Shackelford, C.D., and F. Javed (1991), "Large-Scale Laboratory Permeability Testing of a Compacted Clay Soil," *Geotechnical Testing Journal*, Vol. 14, No. 2, pp. 171-191.

Schubert, W. R. (1987), "Bentonite Matting in Composite Lining Systems," *Geotechnical Practice for Waste Disposal '87*, R. D. Woods (Ed.), American Society of Civil Engineers, New York, pp. 784-796.

Shakoor, A., and B.D. Cook 91990), "The Effect of Stone Content, Size, and Shape on the Engineering Properties of a Compacted Silty Clay," *Bulletin of the Association of Engineering Geologists*, Vol. XXVII, No. 2, pp. 245-253.

Shan, H. Y. (1990), "Laboratory Tests on Bentonitic Blanket," M. S. Thesis, Univ. of Texas, Austin, TX, 84 p.

Shan, H. Y., and D. E. Daniel (1991), "Results of Laboratory Tests on a Geotextile/Bentonite Liner Material," *Geosynthetics 91*, Industrial Fabrics Association International, St. Paul, Minnesota, Vol. 2, pp. 517-535.

Shelley, T.L. (1991), "Effect of Gravel on Hydraulic Conductivity of Compacted Soil Liners," M.S. Thesis, Univ. of Texas, Austin, Texas.

Zimmie, T.F., and C. La Plante (1990), "The Effects of Freeze/Thaw Cycles on the Permeability of a Fine-Grained Soil," *Proceedings*, 22nd Mid-Atlantic Industrial Waste Conference, Drexel University, Philadelphia.

Titles of Figures

Figure 7.1 Side Slopes Constructed with Parallel and Horizontal Lifts

Figure 7.2 Effect of Molding Water Content and Compactive Energy on Hydraulic Conductivity (from Mitchel et al., 1965).

Figure 7.3 Effect of Bonding of Lifts on the Performance of a Compacted Clay Liner

Figure 7.4 Effect of Percent of Gravel in Clay on Hydraulic Conductivity (after Shelley, 1991)

Figure 7.5 Effect of Percent of Bentonite on Hydraulic Conductivity

Figure 7.6 Fully and Partly Penetrating Feet on a Footed Roller

Figure 7.7 Effect of Freeze-Thaw on Hydraulic Conductivity of Compacted Clay (after Chamberlain et al., 1990)

Figure 7.8 Procedure for Establishing Acceptable Zone for Water Content and Dry Unit Weight (after Daniel and Benson, 1990)

Figure 7.9 Overall Acceptable Zone Based on Hydraulic Conductivity, Shear Strength, and Shrinkage upon Desiccation

Figure 7.10 Recommended Procedure for Adjusting the Hydraulic Conductivity Measured in the Field on a Test Pad for the Influence of Compressive Stress

Figure 7.11 Geosynthetic Clay Liners

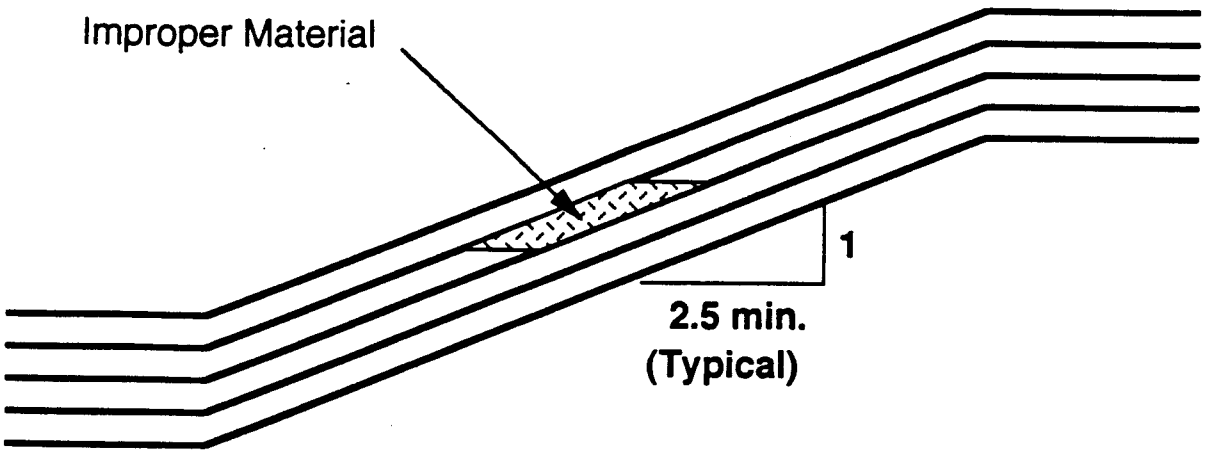
Figure 7.12 Overlapped Geosynthetic Clay Liners

Figure 7.13 Data on Hydraulic Conductivity of Geosynthetic Clay Liners

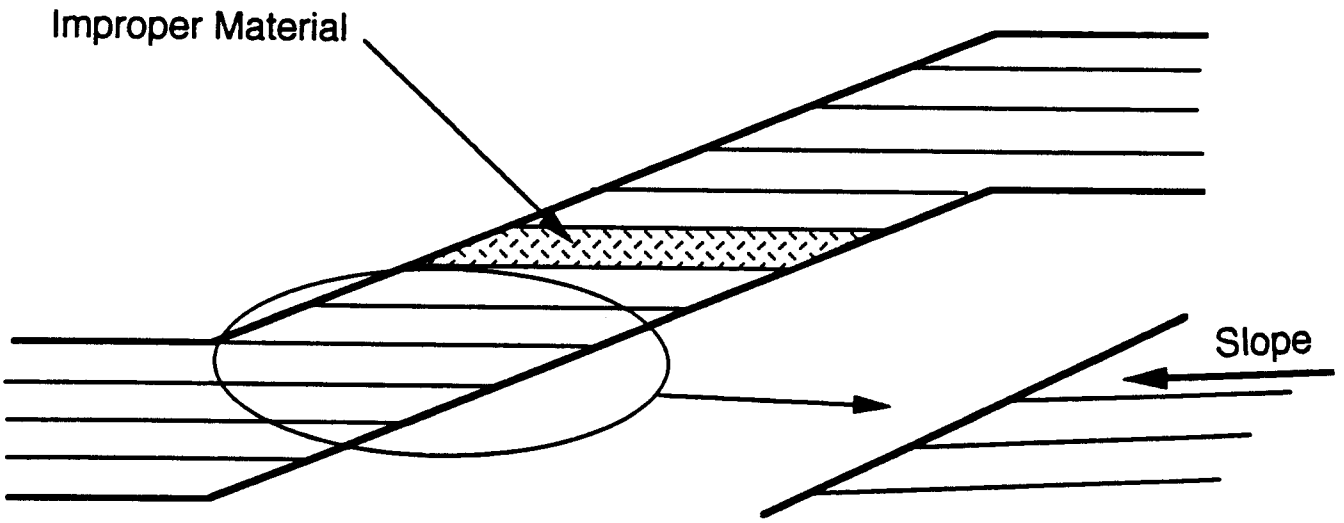
Figure 7.14 Composite Action Between Geomembrane and Geosynthetic Clay Liner

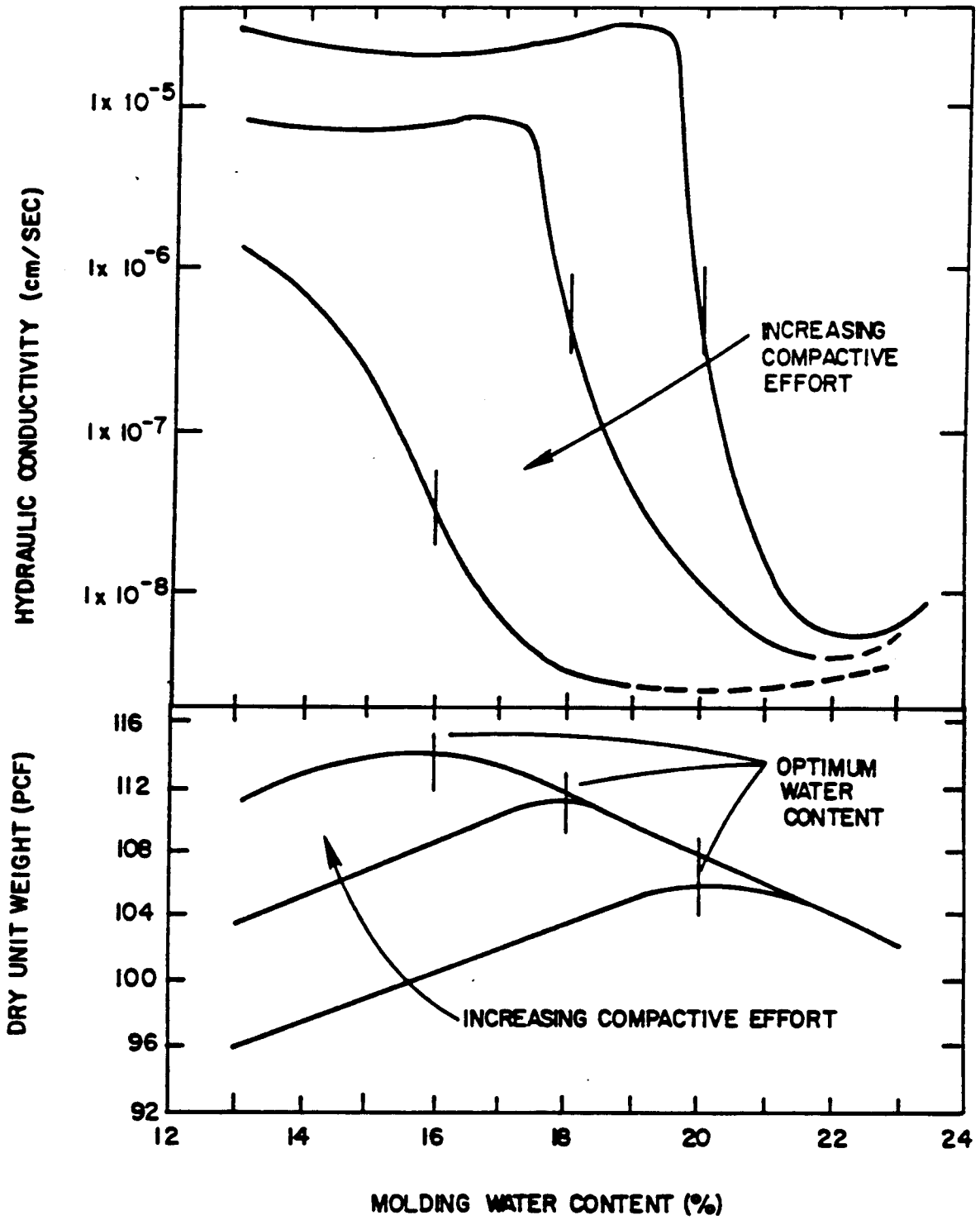
Figure 7.15 Drained Direct Shear Data on Fully Hydrated Geosynthetic Clay Liners

Parallel Lifts

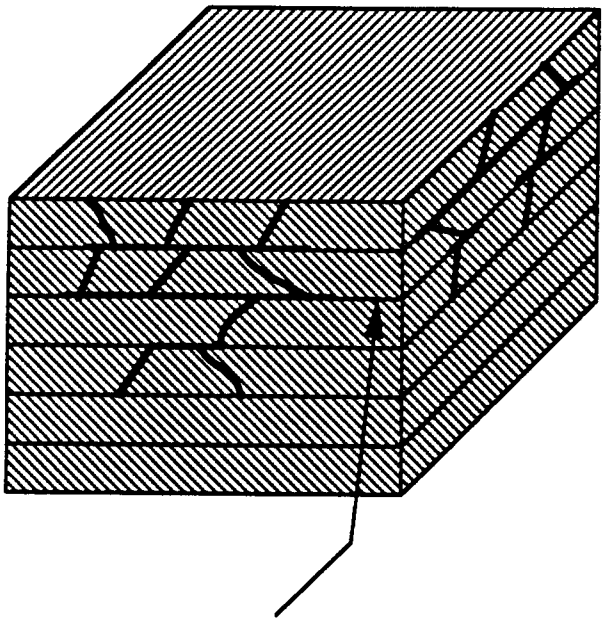


Horizontal Lifts



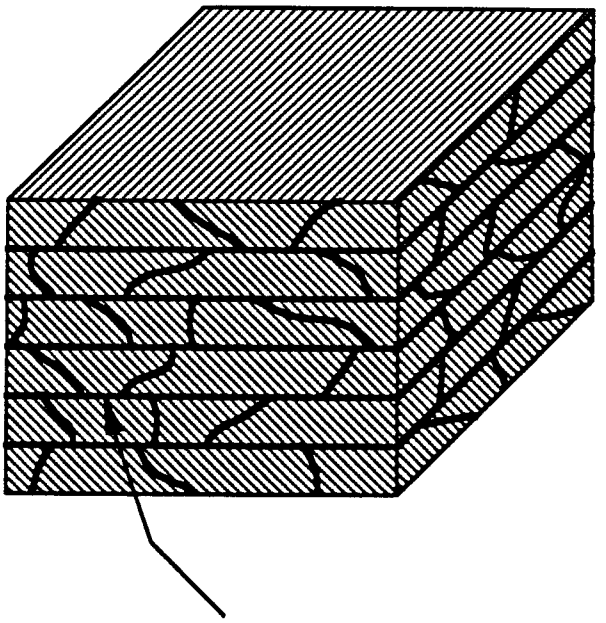

HYDRAULIC CONDUCTIVITY (cm/SEC)
1x 10^-5
1x 10^-6
1x 10^-7
1x 10^-8
INCREASING COMPACTIVE EFFORT
DRY UNIT WEIGHT (PCF)
116
112
108
104
100
96
92
OPTIMUM WATER CONTENT
INCREASING COMPACTIVE EFFORT
12
14
16
18
20
22
24
MOLDING WATER CONTENT (%)

Good Bonding of Lifts

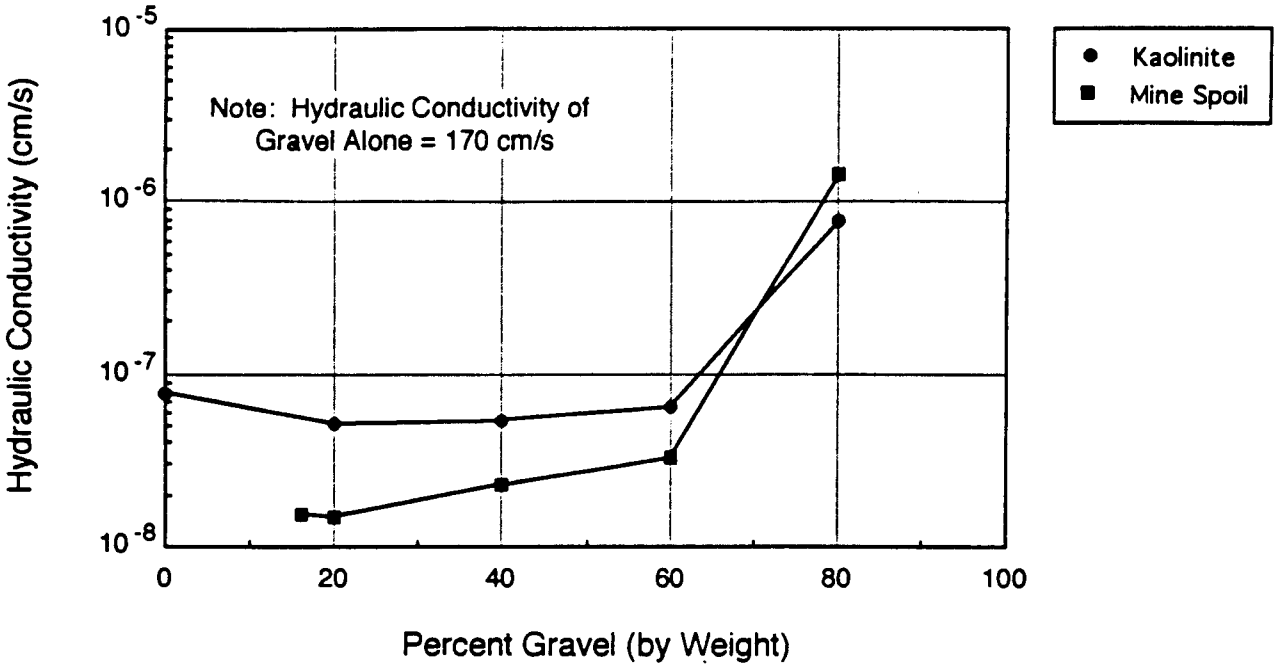


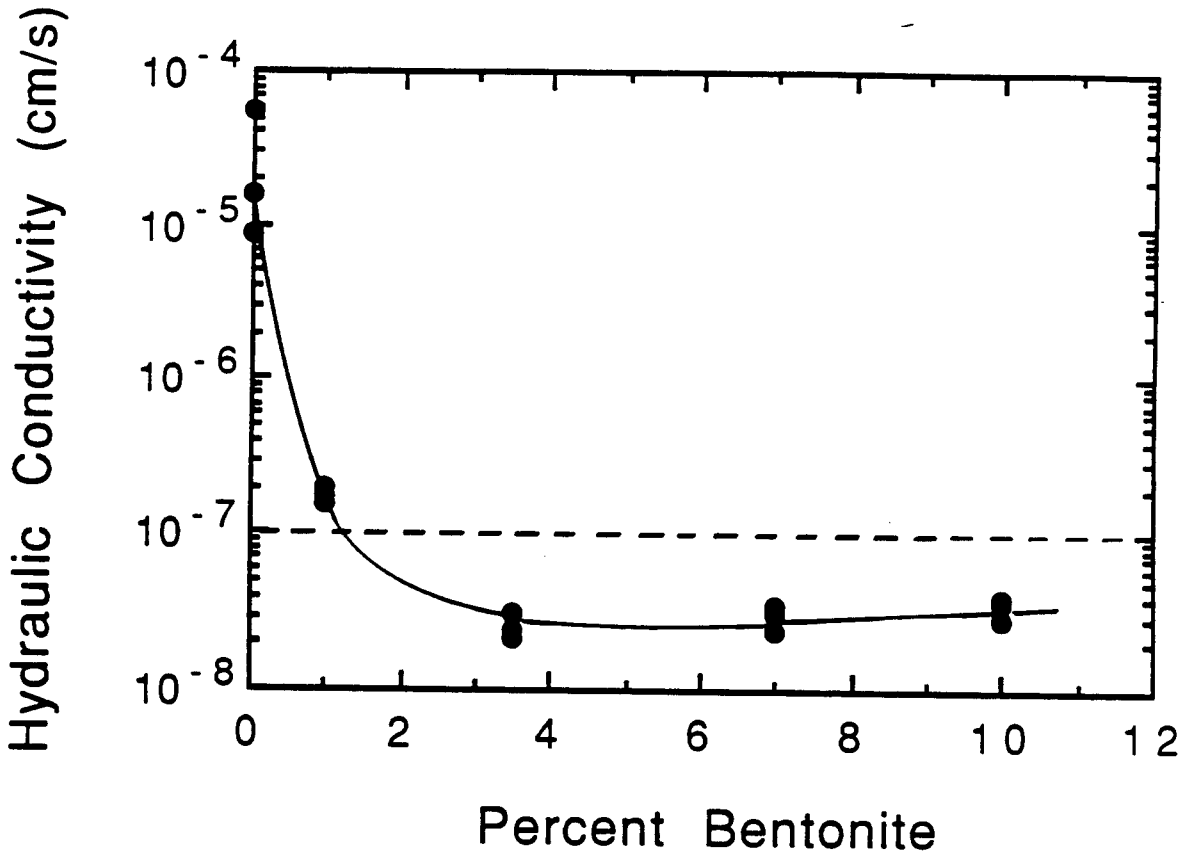
Good Bonding of Lifts Causes Hydraulic Defects in Adjacent Lifts To Be Hydraulically Unconnected

Poor Bonding of Lifts

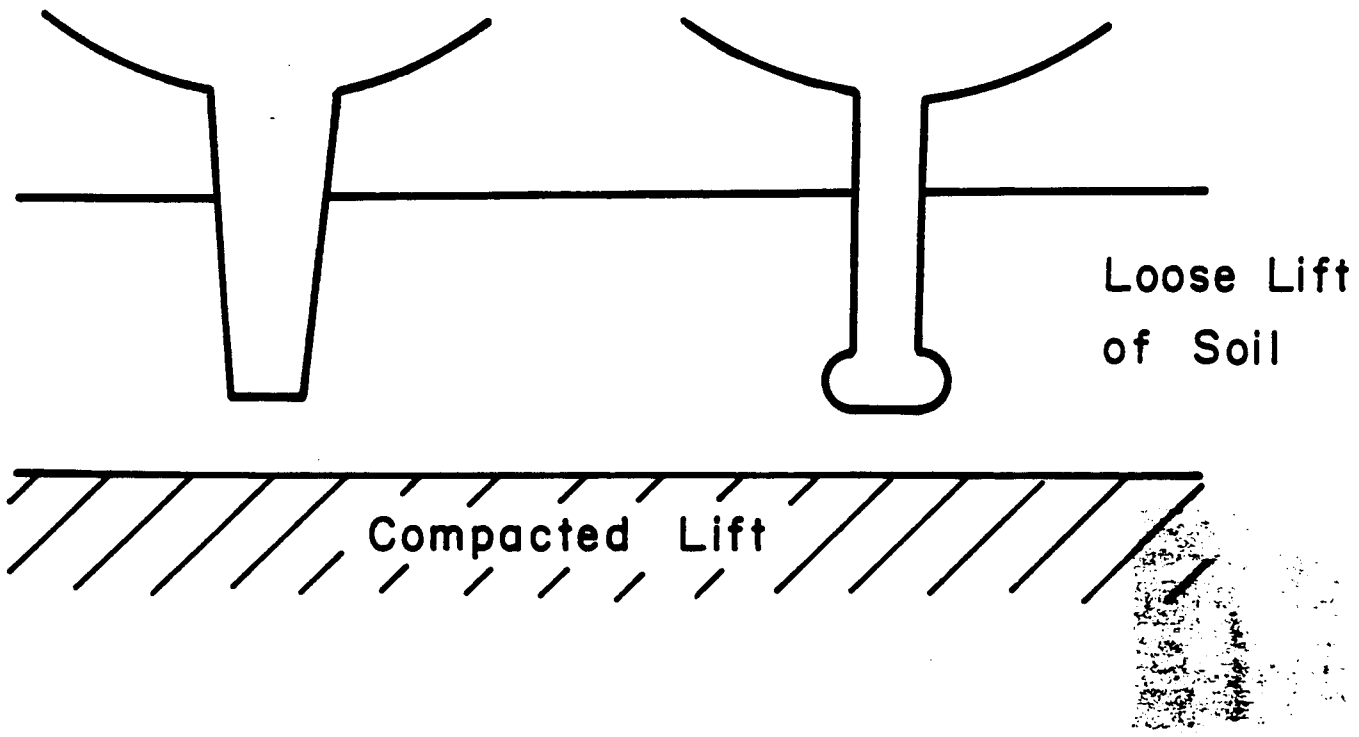


Poor Bonding of Lifts Causes Hydraulic Defects in Adjacent Lifts To Be Hydraulically Connected To Each Other

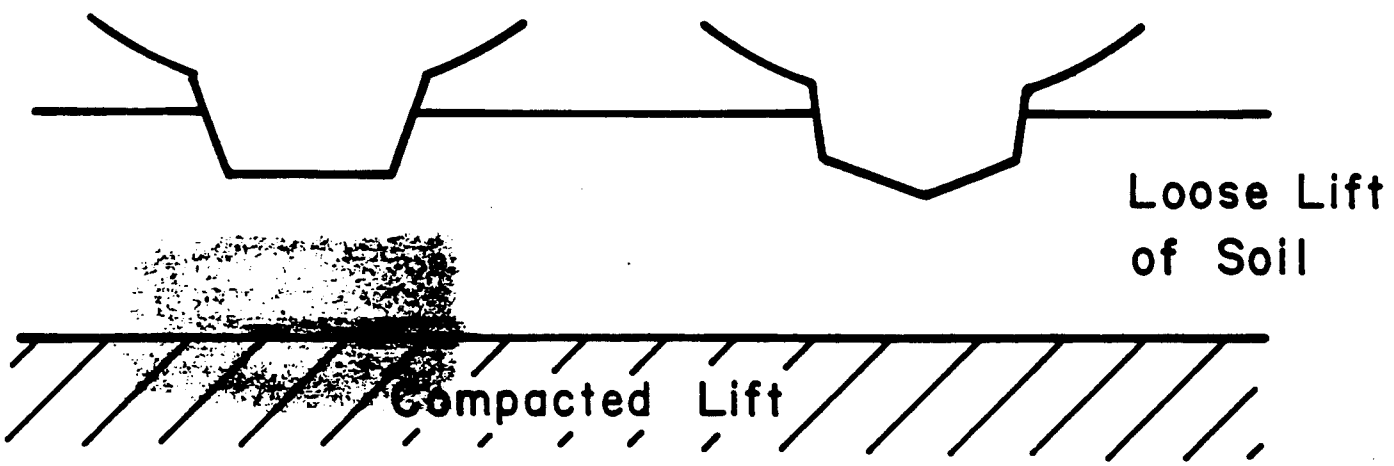

Hydraulic Conductivity (cm/s)
10^-5
10^-6
10^-7
10^-8
Note: Hydraulic Conductivity of
Gravel Alone = 170 cm/s
0
20
40
60
80
100
Percent Gravel (by Weight)
Kaolinite
Mine Spoil

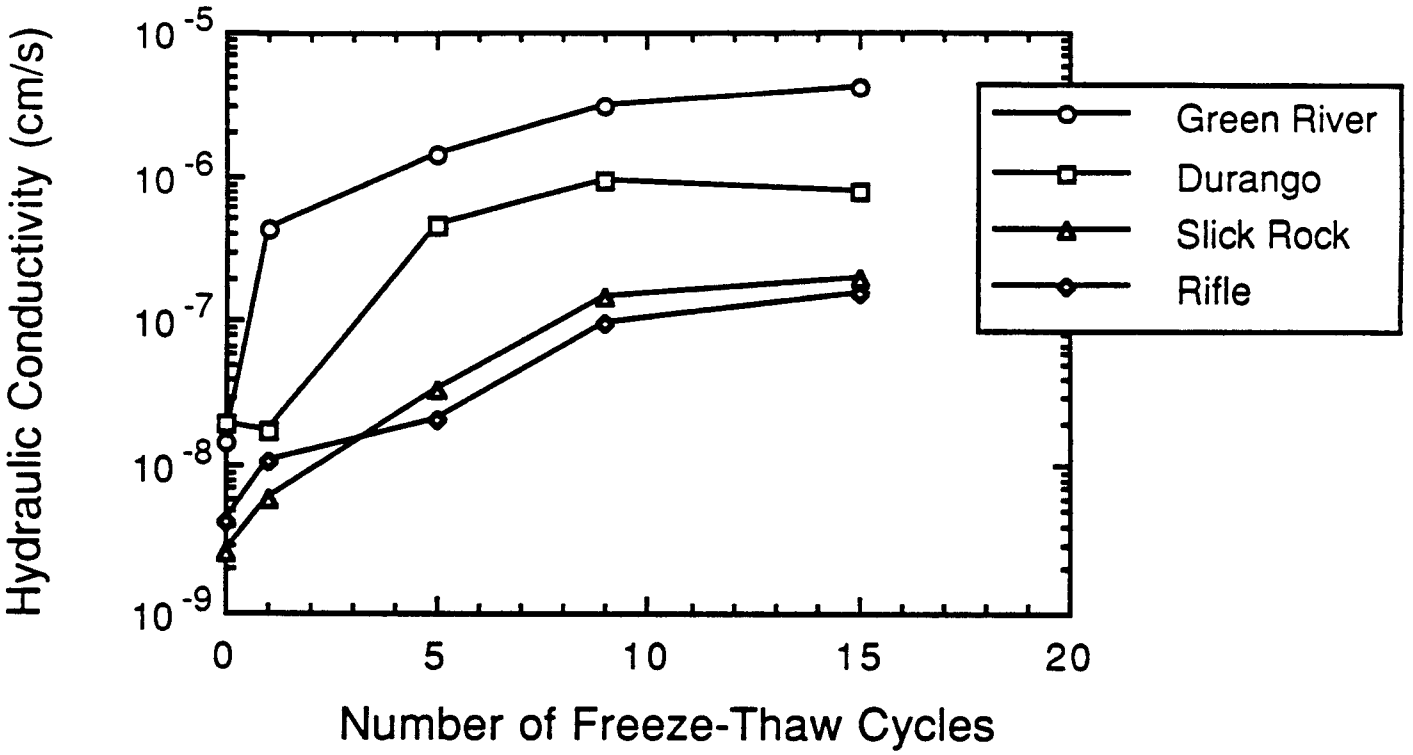

Hydraulic Conductivity (cm/s)
10 - 4
10 - 5
10 - 6
10 - 7
10 - 8
0
2
4
6
8
10
12
Percent Bentonite

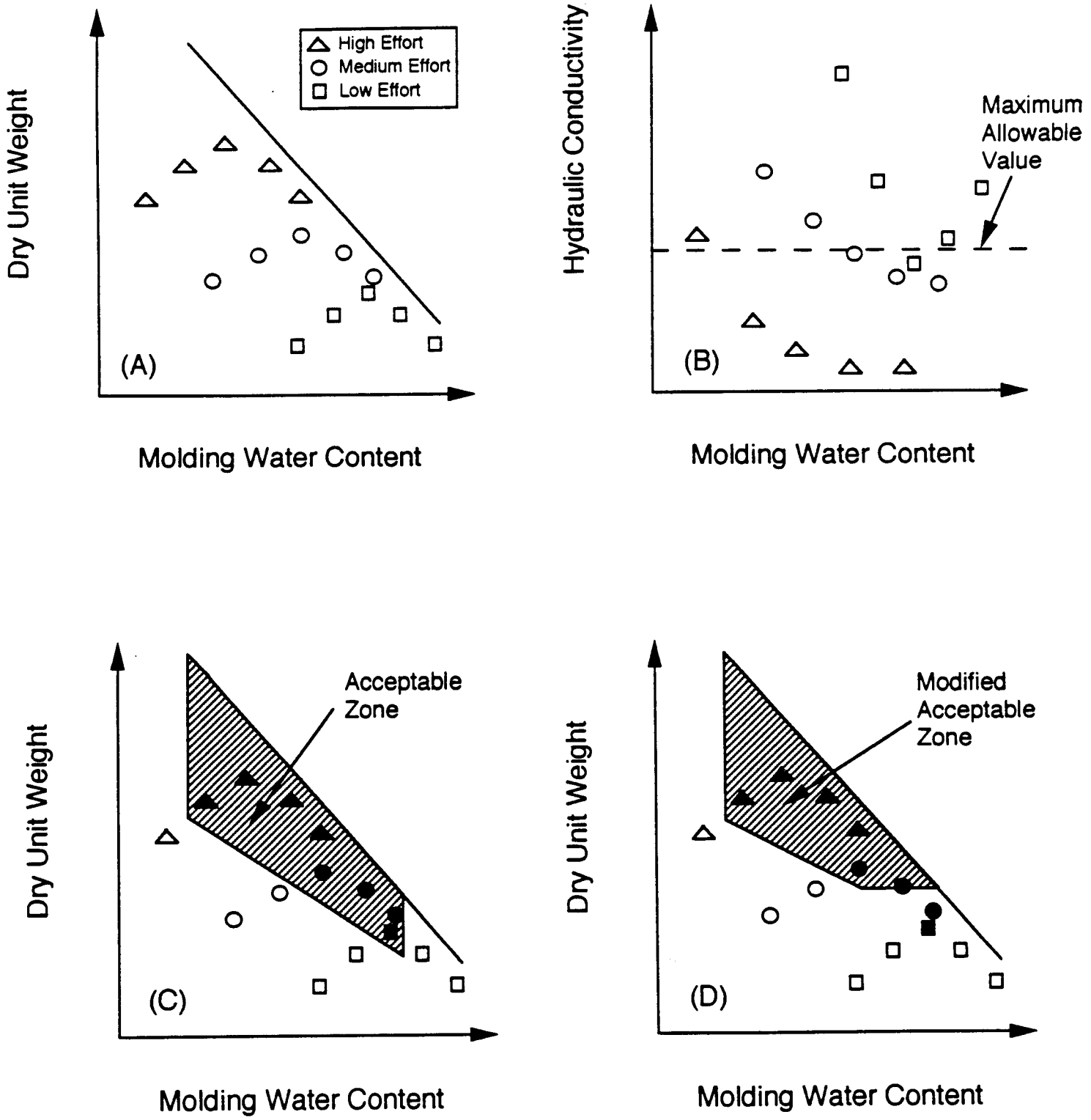
Fully-Penetrating Feet:

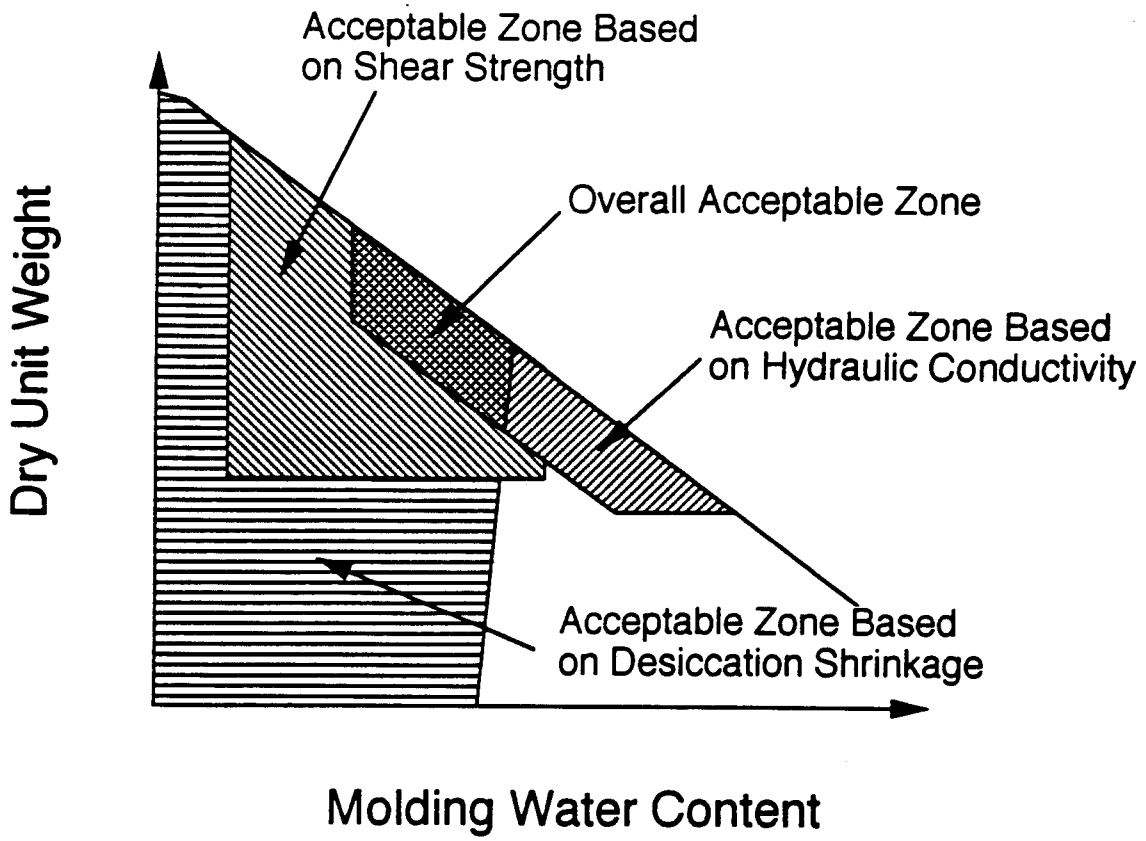


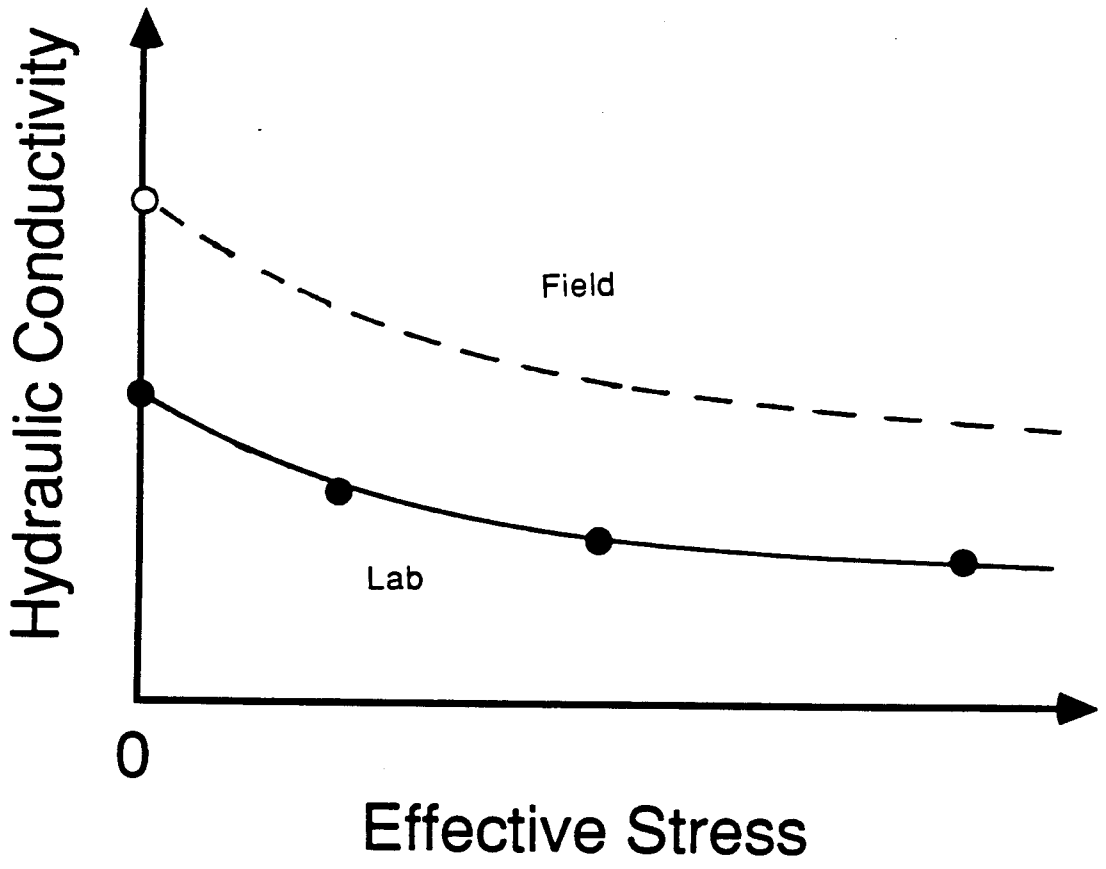
Partly-Penetrating Feet:



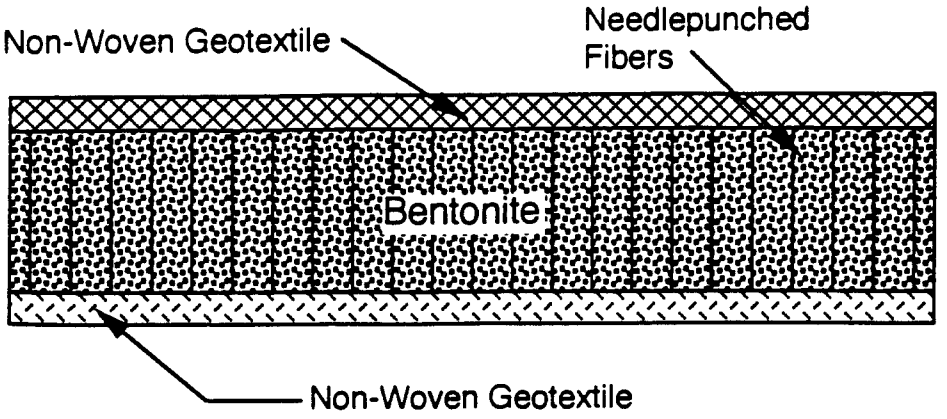

Hydraulic Conductivity (cm/s)
10 -5
10 -6
10 -7
10 -8
10 -9
0
5
10
15
20
Number of Freeze-Thaw Cycles
Green River
Durango
Slick Rock
Rifle


High Effort
Medium Effort
Low Effort
Dry Unit Weight
(A)
Molding Water Content
Hydraulic Conductivity
Maximum
Allowable
Value
(B)
Molding Water Content
Acceptable
Zone
Dry Unit Weight
(C)
Molding Water Content
Modified
Acceptable
Zone
Dry Unit Weight
(D)
Molding Water Content

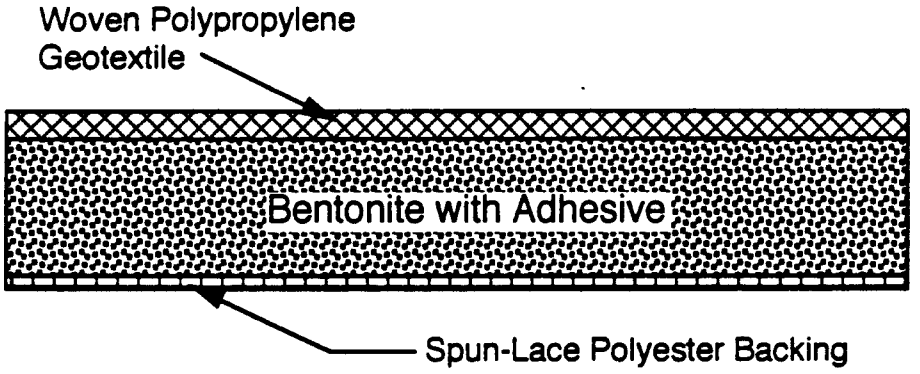

Acceptable Zone Based
on Shear Strength
Overall Acceptable Zone
Acceptable Zone Based
on Hydraulic Conductivity
Acceptable Zone Based
on Desiccation Shrinkage
Dry Unit Weight
Molding Water Content


Hydraulic Conductivity
Field
Lab
0
Effective Stress

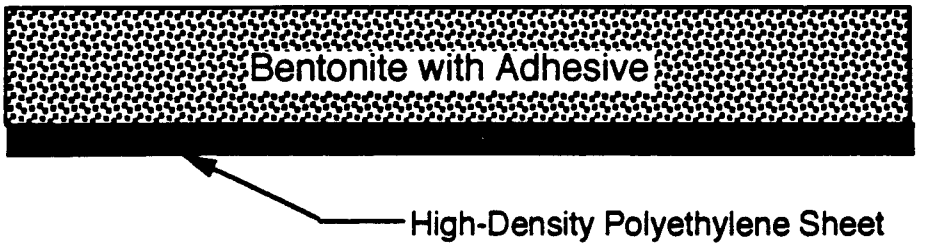
Bentofix® and Bentomat®



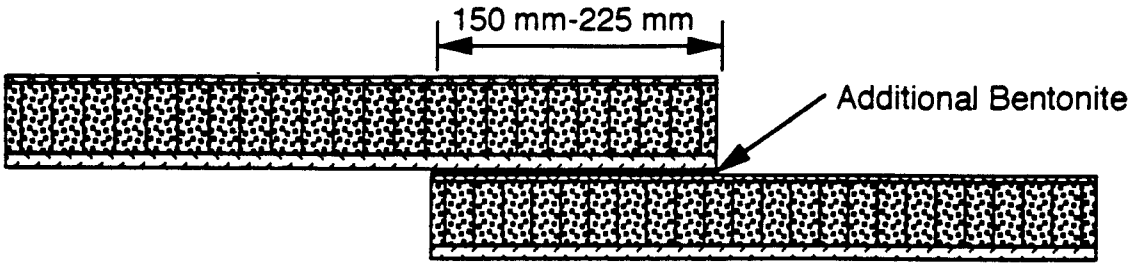
Claymax®



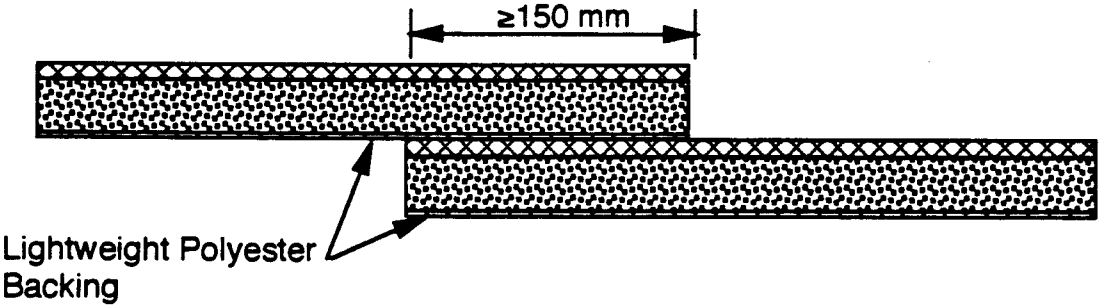
Gundseal



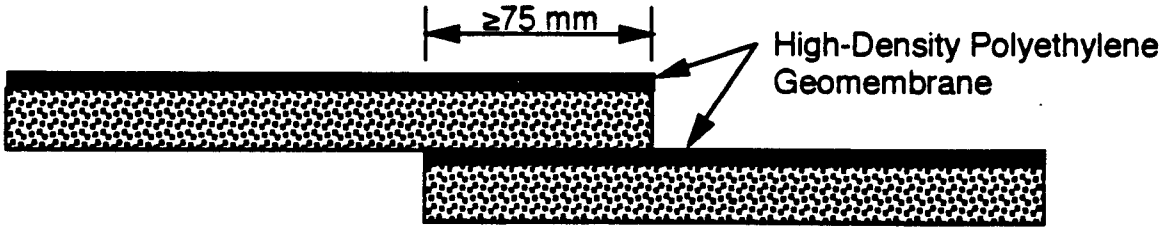
Bentofix® and Bentomat® Seam

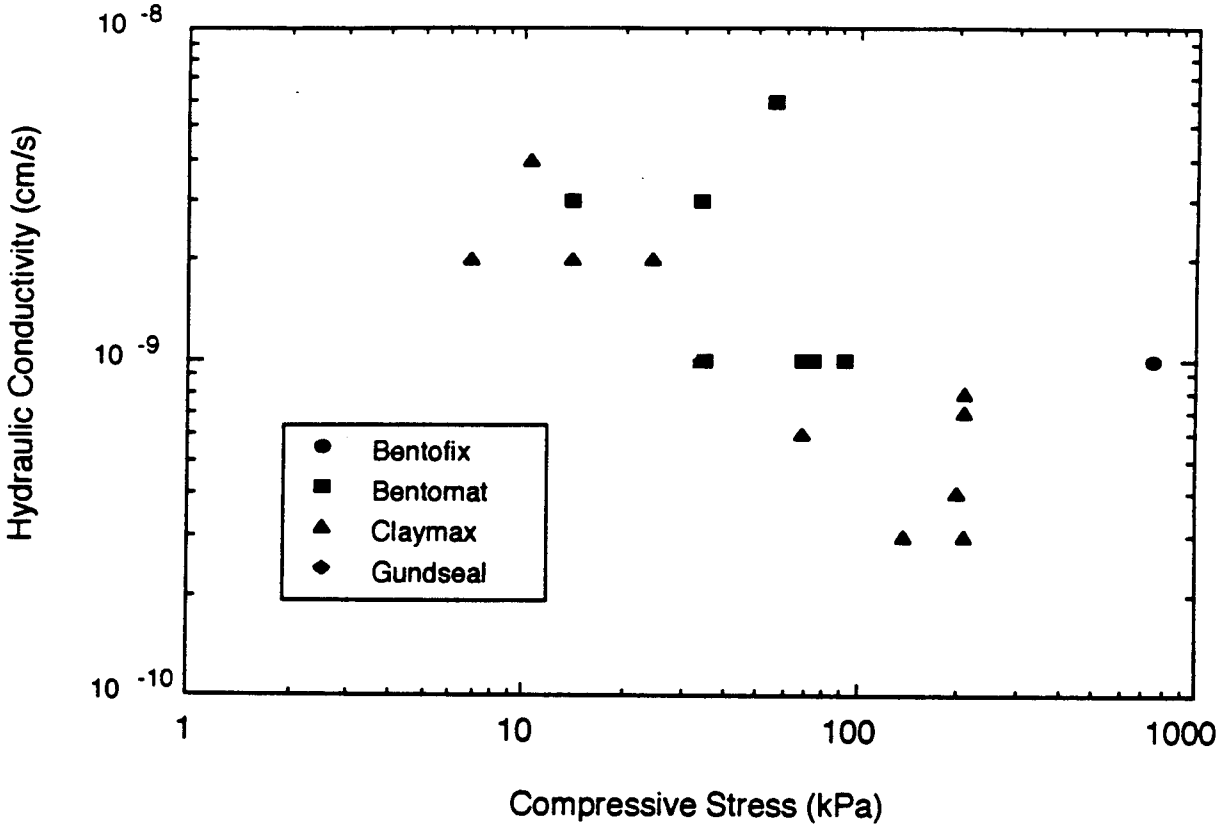


Claymax® Seam

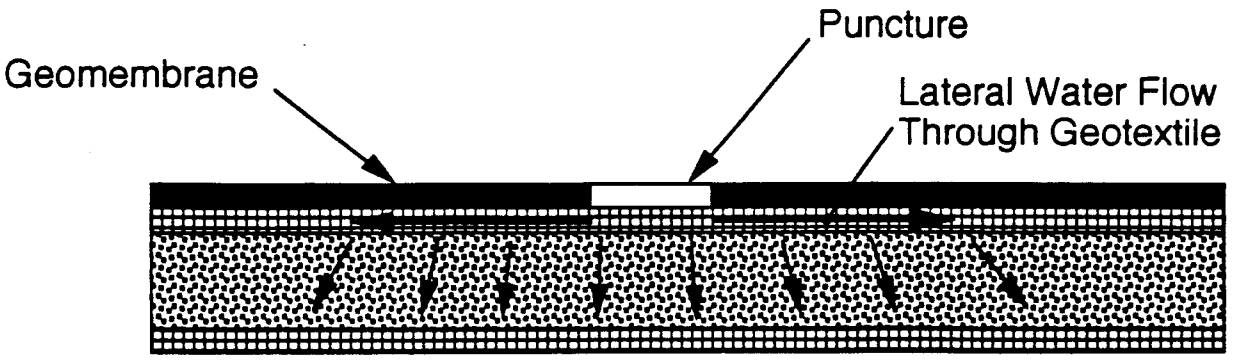


Gundseal Seam

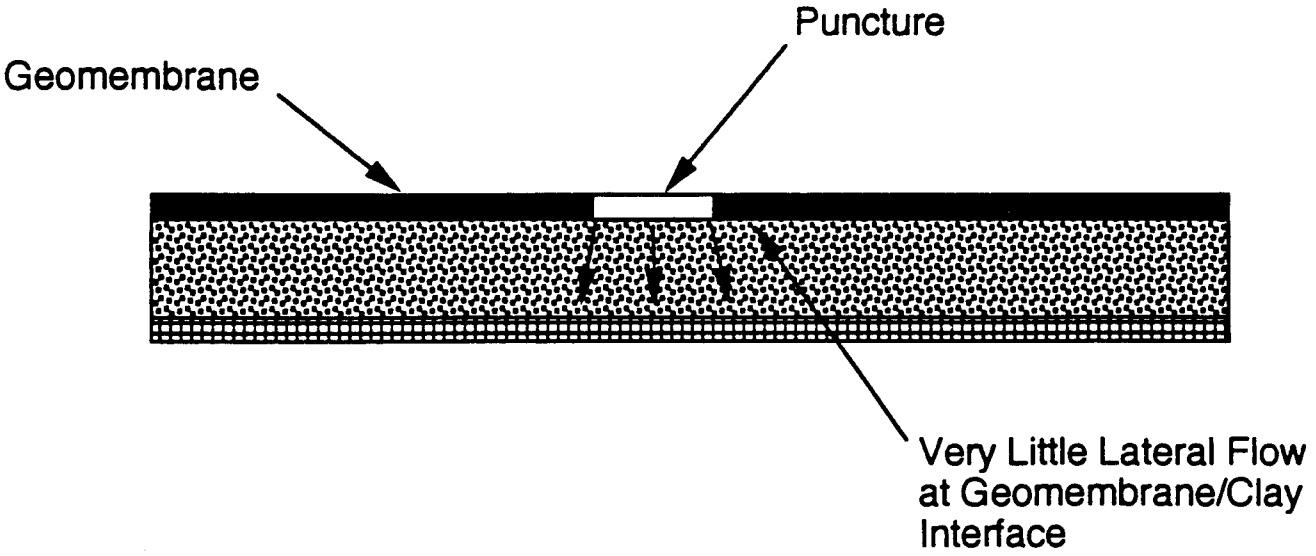


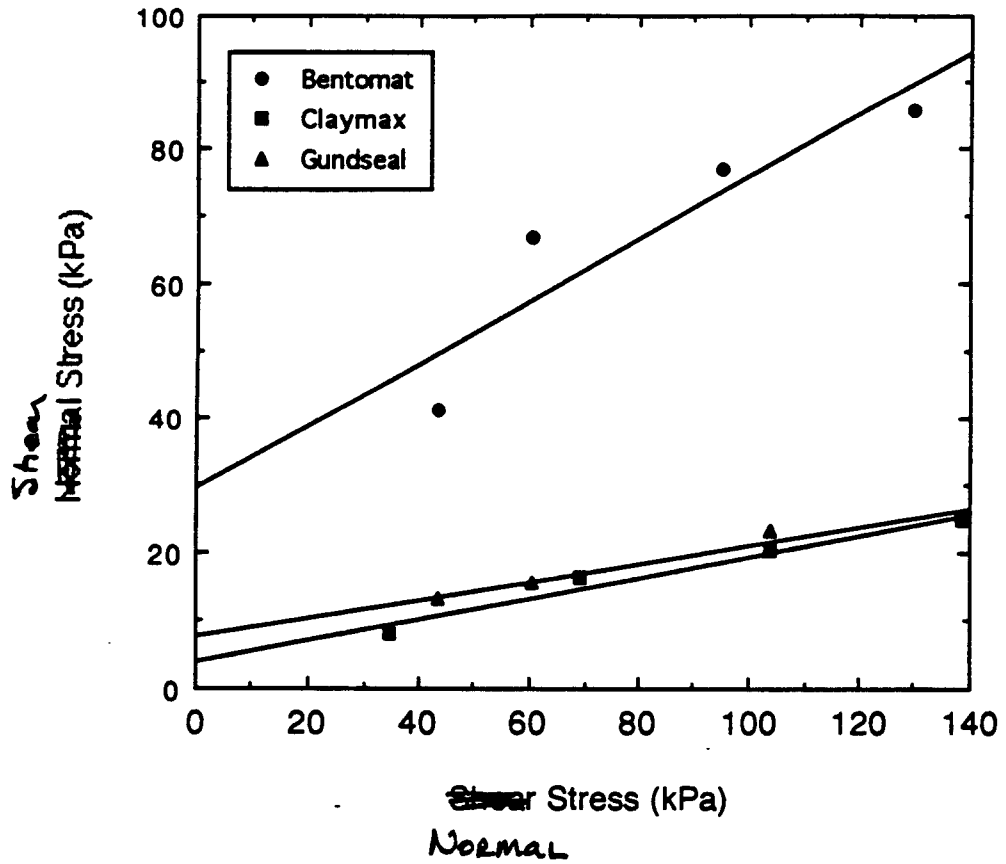

10 -8
10 -9
10 -10
Hydraulic Conductivity (cm/s)
1
10
100
1000
Compressive Stress (kPa)
Bentofix
Bentomat
Claymax
Gundseal

Poor Composite Action:



Good Composite Action:




Bentomat
Claymax
Gundseal
100
80
60
40
20
0
0
20
40
60
80
100
120
140
Shear
Normal Stress (kPa)
Stress (kPa)
Normal

HYDRAULIC CONDUCTIVITY OF THREE GEOSYNTHETIC CLAY LINERS

by Paula Estornell[1] and David E. Daniel[2]

ABSTRACT

The hydraulic conductivity of three 2.9 m^2 (32 ft^2) geosynthetic clay liners (GCL's) was measured. Tests were performed on individual sheets of the GCL's, on overlapped pieces of GCL's, and on composite liners consisting of a punctured geomembrane overlying a GCL. Hydraulic conductivities of two of the GCL's were in the range of 10^{-10} to 10^{-8} cm/s. No flow was measured through the third GCL, but the conductivity was obviously very low ($<<10^{-7}$ cm/s). The hydraulic conductivities of overlapped GCL's were about the same as those of the control samples with no overlap; an effective hydraulic seal developed along the overlaps in all of the materials tested. Performance of the punctured geomembrane/GCL composites varied – performance was best when the punctured geomembrane was placed directly against bentonite and no geotextile separated the punctured geomembrane from the bentonite. For those GCL's with geotextiles on both sides, problems with migration of bentonite into the underlying drainage layer were encountered when inadequate filtration was provided. However, with a suitable filtration layer separating the drainage layer from the GCL, problems with migration of bentonite were eliminated.

INTRODUCTION

A layer of low-hydraulic-conductivity, compacted soil is a required component of most liner and cover systems at waste containment facilities. In the past few years, several thin, prefabricated, clay blankets called *geosynthetic clay liners* (*GCL*'s) have been developed and proposed as an alternative to compacted clay in liner and cover systems. Geosynthetic clay

[1] Geotechnical Engineer, Hart-Crowser Associates, 1910 Fairview Avenue East, Seattle, WA 98102

[2] Professor of Civil Engineering, University of Texas, Austin, TX 78712

liners may supplement required components in waste containment units or, as proposed by some, replace part or all of the low-hydraulic-conductivity, compacted soil liner (Daniel and Koerner, 1991). Daniel and Estornell (1990), Eith et al. (1990), Grube (1991), and Grube and Daniel (1991) review advantages and disadvantages of GCL's for various waste-containment applications.

The research described in this article was performed to develop technical information on the engineering properties of GCL's. Work described in this paper was specifically performed to determine the hydraulic properties of GCL's and their overlapped seams, and to evaluate the composite behavior of geomembrane/GCL composite liners.

GEOSYNTHETIC CLAY LINERS

Three geosynthetic clay liners (GCL's) were investigated: Bentomat®, Claymax®, and Paraseal/Gundseal. A fourth GCL, Bentofix® (Scheu et al., 1990), is manufactured in Germany but was not included in this study. The three GCL's investigated are sketched in Fig. 1.

Bentomat® is manufactured by the Colloid Environmental Technologies Co. (CETCO) at its factory in Villa Rica, Georgia (see Appendix I for suppliers of GCL manufacturers). The material that was tested consisted of 4.9 kg/m^2 (1 lb/ft^2) of untreated, Volclay® sodium bentonite ("CS" grade) sandwiched between woven and nonwoven geotextiles that are needlepunched together (Fig. 1) to contain the bentonite and to enhance in-plane shear strength.

Claymax® is manufactured by the James Clem Corporation (see Appendix I) in Fairmont, Georgia. The material that was tested consisted of 4.9 kg/m^2 (1 lb/ft^2) of sodium bentonite sandwiched between two woven geotextiles (Fig. 1). The lower geotextile is a lightweight, open weave, spun-lace polyester with large openings. A water-soluble glue is mixed with the bentonite to hold the components together until the GCL has been installed.

Paraseal/Gundseal is manufactured by Gundle Lining Systems, Inc., and Paramount Technical Products, Inc. (see Appendix I) in Spearfish, South Dakota. The material that was tested consisted of 4.9 kg/m^2 (1 lb/ft^2) of sodium bentonite mixed with an adhesive and

attached to a 0.5 mm (20 mil) thick high density polyethylene (HDPE) geomembrane (Fig. 1). Material tested in this study was Paraseal, but Paraseal and Gundseal are functionally identical.

Geosynthetic clay liners are manufactured in panels with widths of 4 to 5 m (13 to 17 ft) and lengths of 25 to 60 m (80 to 200 ft). The panels are placed on rolls at the factory and are unrolled at the time of installation. The panels are overlapped 75 to 225 mm (3 to 9 in.) during installation and are said to be "self sealing" at the overlap. A sketch of the overlap zones is shown in Fig. 2. In the case of Bentomat®, additional sodium bentonite is placed along the overlap at a rate of 0.4 kg/m (0.25 lb/ft). The bentonite penetrates the pores of the geotextiles and is said by the manufacturer to cause the material to self seam when the bentonite hydrates.

Claymax® panels are normally placed with the open-weave, polyester backing facing downward (Fig. 2). When the bentonite hydrates, the manufacturer states that the bentonite oozes out through the openings in the geotextiles and causes the material to self seal.

With Gundseal, the GCL can be placed with the bentonite facing upward or, as shown in Fig. 2, downward. The material is said to be self sealing at the overlap. Although no mechanical joining of overlapped seams is necessary for any of the GCL's, the HDPE sheets in Gundseal can be welded together along the overlaps, if desired, but a thicker HDPE sheet than the usual 0.5 mm (20 mil) sheet would be required. Gundseal would be placed with the bentonite facing upward if a separate, conventional geomembrane lining is to be placed on top of the GCL.

More information about GCL's is available from the manufacturers and from Schubert (1987), Daniel and Estornell (1990), Shan (1990), Eith et al. (1990), Bruton (1991), Estornell (1991), Grube (1991), Grube and Daniel (1991), Shan and Daniel (1991), and Trauger (1991).

EXPERIMENTAL METHODS

Steel tanks, shown schematically in Fig. 3, were fabricated for bench-scale hydraulic conductivity tests. The tanks measured 2.4 m (8 ft) in length, 1.2 m (4 ft) in width, and 0.9 m (3 ft) in height. A 13 mm (0.5 in.) diameter drainage hole was drilled in the center of the

base (Fig. 3) of each tank. The inside walls of the tanks were coated with epoxy. The tanks were raised about 150 mm (6 in.) off the floor with wooden supports.

Acrylic fittings with PVC elbows and flexible plastic tubes were attached to the drainage holes at the bottom of each tank as shown in Fig. 4. This outlet system provided a closed channel for effluent drainage. In addition, 6.4 mm by 6.4 mm (1/4 in. by 1/4 in.) acrylic strips were glued to the bottoms of the tanks in a rectangular pattern as shown in Fig. 3. The acrylic strips provided a 75 mm (3 in.) wide space around the edges of the tanks to retain bentonite that was placed to seal the GCL's against the edges of the tanks.

To conduct a test, a 2.3 m (7.5 ft) long by 1.1 m (3.5 ft) wide sheet of geotextile/geonet/geotextile composite (Gundnet) was centered and placed on the bottom surface of the tank. The Gundnet was cut smaller than the area of the tank to create a 75 mm (3 in.) wide space between the drainage material and edge of the tank to accommodate a bentonite seal (Fig. 4). The geotextile that separated the geonet from the GCL's was a 200 g/cm^2 (6 oz/yd^2), nonwoven geotextile with an apparent opening size of 0.15 to 0.25 mm.

Next, dry bentonite was placed in the space between the drainage material and the walls of the tank. A photograph of the seal and the drainage material is shown in Fig. 5. The GCL being tested was then placed over the drainage composite and bentonite edge seal, with the edges of the GCL either going to the edges of the steel tank (first test set) or within 25 mm (1 in.) of the edge of the tank (subsequent test sets). The space between the edges of the GCL's and the walls of the tank was filled with dry bentonite.

Next, a 300 or 600 mm (1 or 2 ft) thick layer of gravel was placed over the GCL with a front-end loader. The gravel had dry and saturated unit weights of 15.4 and 19.3 kN/m^3 (98 and 123 pcf), respectively, and a hydraulic conductivity of 5 cm/s (Estornell, 1991). The tank was then slowly filled with water over a period of several days. The depth of water was then kept constant. The first set of tests was performed with a 300 mm (1 ft) thick gravel layer and 600 mm (2 ft) of water ponded on the GCL's. These conditions produced a calculated vertical effective stress of 3 kPa (0.4 psi) at the top of the GCL and 9 kPa (1.3 psi) at the

bottom. The vertical effective stress was increased in the second and subsequent series of tests by increasing the thickness of gravel to 600 mm (2 ft) and decreasing the water depth to 300 mm (1 ft); the calculated effective stress acting on the top and bottom surface of the GCL's was 8 kPa (1.1 psi) and 10 kPa (1.5 psi), respectively.

Effluent water passing through the drainage hole was collected and weighed to determine the flux of water. Corrections were made to account for evaporation of water from collection pans. Tests were continued until the flux was steady. Except for Gundseal, steady flow was achieved after 1 to 2.5 months, at which point outflow readings varied by no more than ±10%. For Gundseal, no outflow from any of the tanks occurred over 5+ months of testing.

Hydraulic conductivity was calculated from Darcy's law for those GCL's that produced flow. It was assumed that the head loss was constant and that the pressure head was zero on the base of the GCL. The hydrated thicknesses of the GCL's (9.4 mm for Bentomat® and 16-18 mm for Claymax®), which were used to calculate hydraulic conductivity, were determined from laboratory swelling tests. Hydraulic gradient was typically in the range of 30 to 60.

Three types of tests were performed (Fig. 6). One type of test was a control test on individual sheets of GCL material that had no overlap. The second type of test was on overlapped sheets of GCL material. For Bentomat®, sodium bentonite was placed along the overlap at the manufacturers' recommended rate as shown in Fig. 7. Placement of Claymax® overlaps is shown in Fig. 8. Placement of a Gundseal overlap is shown in Fig. 9 for the test with the HDPE facing upward.

At least one test was performed using the minimum overlap width recommended by the manufacturer (150 mm (6 in.) for Bentomat® and Claymax® and 75 mm (3 in.) for Paraseal/Gundseal), and at least one test was conducted using one half the minimum recommended overlap width.

The third type of test (Fig. 6) involved a composite with the GCL overlain by a 1.5 mm (60 mil) HDPE geomembrane. Punctures that were made in the geomembrane included two 75

mm (3 in.) diameter holes, three 25 mm (1 in.) diameter holes, and three 600 mm (2 ft) long slits that were about 1 mm wide (Fig. 6).

Small-scale hydraulic conductivity tests were conducted on 100 mm (4 in.) diameter specimens. Flexible-wall permeameters were used, and procedures outlined in ASTM Method D5084 were generally followed. Only Bentomat® was tested during this study. Tests on Claymax® were performed by Shan (1990) and were not repeated. Hydraulic conductivity data for all the materials were obtained from sources cited in the next section.

RESULTS OF LABORATORY HYDRAULIC CONDUCTIVITY TESTS

The results of flexible-wall hydraulic conductivity tests on the three geosynthetic clay liners are shown in Table 1 and Fig. 10. Hydraulic conductivities of all three GCL's were in the range of 3×10^{-10} to 6×10^{-9} cm/s. Hydraulic conductivity has a tendency to decrease with increasing effective stress. Individuals who compare hydraulic conductivities of different materials should be careful to compare values measured at the same maximum effective stress.

RESULTS OF BENCH-SCALE TESTS

Bentomat® and Claymax®: Tests on Control and Overlapped Samples

Two control tests (no overlapped seam) were performed on 1.2 m by 2.4 m (4 ft by 8 ft) samples. Hydraulic conductivities are summarized in Table 2. The hydraulic conductivity of Claymax® measured in the bench-scale tanks compared reasonably well with results of flexible-wall hydraulic conductivity tests performed on small test specimens at similar effective stress. However, with Bentomat®, the hydraulic conductivity in the bench-scale tanks was about 10 times lower than values measured in flexible-wall permeameters.

Possible sources of error in the tests on Bentomat® were considered. In flexible-wall permeability tests, problems were initially encountered with loss of bentonite near the edges during preparation of test specimens, which led to high flow rates near edges. The problem was minimized by hydrating an oversized test specimen, trimming the moist specimen, and

smearing the edge of the test specimen with additional bentonite paste. Despite these procedures, the edge seal may still have been imperfect.

In the tank tests on Bentomat®, migration of bentonite out of the GCL and into the underlying materials may have reduced the flux of water through the GCL. When the first set of tests was dismantled, grey bentonite was visible in the geotextile/geonet/geotextile composite drainage material beneath both the Bentomat® and the Claymax® specimens. In the final series of tests, a thick, nonwoven geotextile was placed between the Bentomat® and Claymax® and the underlying Gundnet drainage composite. The geotextile was a Trevira® 1135 fabric with a weight of 356 g/m^2 (10.5 oz/yd^2) and an apparent opening size of 0.13 to 0.21 mm. The thick geotextile filter stopped downward movement of bentonite from Bentomat® and Claymax® during the 3-month testing period: bentonite could be seen on the upper surface of the geotextile filter but not in the bulk of the geotextile nor in the underlying drainage layer. However, with respect to the hydraulic conductivity anomalies, problems with bentonite migration were about the same for Bentomat® and Claymax®, and yet the comparison of results from tank tests and flexible-wall-permeameter tests was much different (Table 2). The authors were unable to isolate the cause for the discrepancy in hydraulic conductivity of Bentomat® measured in flexible-wall permeameters and bench-scale tanks. Further investigation is recommended.

The results of tests on overlapped sheets of Bentomat® and Claymax® are summarized in Table 3. When the manufacturers' recommended minimum overlap width of 150 mm (6 in.) was maintained, the overall hydraulic conductivity of the overlapped panels was about the same as the hydraulic conductivity of non-overlapped, control panels. The GCL's self-sealed along the overlaps in these bench-scale tests.

When the overlap width for Claymax® panels was reduced to one half the minimum recommended value, the overall hydraulic conductivity of the overlapped panels was 1.2 to 9 times higher than the hydraulic conductivity of the control specimens, depending on the vertical stress applied to the specimens. For tests with effective stress greater than 7 kPa (1 psi), the performance of a narrow overlay of Claymax® was better than for tests in which a lower

effective stress was used. The differences between control and overlapped specimens may simply have been due to variations in the materials themselves; multiple tests for statistical purposes were infeasible due to the great time, effort, and expense associated with each one of the tank tests. Intuitively, though, one would expect that the hydraulic integrity of the overlap might be more sensitive to the width of the overlap when the vertical stress is small. Overburden stress is probably needed for the Claymax® seams to work because it appears that with little or no overburden, the bentonite simply expands unevenly when wetted and does not ooze through the openings of the geotextile and form a seal.

When the overlap width of Bentomat® was reduced to one-half the minimum recommended value of 150 mm (6 in.), the hydraulic conductivity was 2.5 times greater than the value measured on the control sample with no overlap or the value measured on panels with the minimum 150 mm (6 in.) overlap (Table 3). Again, the difference may simply be the result of material variability. No tests were performed on Bentomat® at the lower range of effective stress used for the first test series on Claymax®.

Gundseal: Tests on Control and Overlapped Samples

Five tests were performed on Gundseal. In the first series, the HDPE geomembrane faced upward, the calculated effective stress was between 3 and 9 kPa (0.4 and 1.3 psi), and the overlap widths were 75 mm (3 in.) and 38 mm (1.5 in.). A test on a control sample with no overlap was also performed. After 5 months of testing, no outflow was observed from any of the tanks. The tanks were dismantled, and it was found that the bentonite was wetted approximately 100 to 125 mm (4 to 5 in.) around the edges and 50 to 75 mm (2 to 3 in.) along the overlap (Fig. 11). Otherwise, the bentonite was not wetted. The tests on overlapped seams indicate that the minimum recommended overlap width contains a factor of safety under these test conditions.

In the second series, two tests were performed with the bentonite facing upward. The calculated effective stress was between 8 and 10 kPa (1.1 and 1.5 psi) and the overlap width

was 0 (control test) or 75 mm (3 in.). After 5 months, no outflow was detected. There was still some unhydrated bentonite in the overlapped areas at the end of the tests.

Composite GCL/Punctured Geomembrane

The puncture pattern in the geomembranes that were placed on top of the GCL's is shown in Fig. 2. Vertical effective stress varied from 8 to 10 kPa (1.1 to 1.4 psi), and a pressure head of 300 mm (1 ft) of water was maintained on the materials tested.

With Gundseal, water penetrated the bentonite at the defects, but water migrated < 75 mm (3 in.) from the defects over the 5-month testing period (Fig. 12). Effective composite action was obvious: the bentonite sealed off defects in the geomembrane and the GCL prevented outflow of water from the punctured geomembrane/GCL composite.

With tests involving Bentomat® and Claymax®, outflow did occur. An apparent hydraulic conductivity was calculated assuming one-dimensional flow through the entire cross sectional area of the GCL; results are shown in Table 4. Hydraulic conductivities of the punctured geomembrane/GCL composites were about the same as those of the GCL's alone. When the tests were dismantled after about 3 months of permeation, it was found that the bentonite was fully hydrated over the entire area of the Bentomat® and Claymax® sheets. It is assumed that water flowed through the punctures in the geomembranes, spread laterally through the geotextile that separated the bentonite from the geomembrane, and soaked the GCL. Once the bentonite was wetted, the high in-plane transmissivity of the geotextile that separated the punctured geomembrane from the bentonite provided an avenue for water to spread laterally from the punctures and permeate the GCL's. However, in-plane transmissivity of geotextiles tends to decrease with increasing vertical stress; the vertical stress used in these tests was low.

CONCLUSIONS

Bench-scale hydraulic conductivity tests were performed on three geosynthetic clay liners (GCL's). The purpose of the tests was to determine (1) whether overlapped seams self

seal when the bentonite in the GCL is hydrated, and (2) whether the bentonite forms a seal against an overlying, punctured geomembrane. Conclusions drawn from this study are as follows:

1. The GCL's that were placed in large tanks self sealed at overlaps when the bentonite was hydrated. Except for the case where low (< 7 kPa or 1 psi) vertical effective stress was employed, the hydraulic conductivities of overlapped materials were almost identical to values measured on control samples with no overlap.
2. For tests in which the minimum vertical effective stress was greater than 7 kPa (1 psi), the overlap width could be reduced up to 50% below the minimum values recommended by the manufacturers without significantly increasing the overall hydraulic conductivity of overlapped panels. For the carefully controlled test conditions employed in this investigation, there was a factor of safety built into the manufacturer's minimum recommended overlap widths.
3. Bentonite was found to migrate vertically out of the two GCL's that contained bentonite between two geotextiles and into the underlying drainage layer when adequate filtration was not provided. Bentonite consistently migrated through a 200 g/m^2 (6 oz/yd^2), nonwoven, needlepunched geotextile with an apparent opening size of 0.15 to 0.25 mm and into an underlying geonet. However, bentonite migration was stopped during the 3-month testing period by a 356 g/m^2 (10.5 oz/yd^2) nonwoven, needlepunched geotextile with an apparent opening size of 0.13 to 0.21 mm.
4. The effectiveness of composite action between a punctured geomembrane and the bentonite in the GCL's depended on whether a geotextile separated the punctured geomembrane from the bentonite. Good composite behavior was observed when the bentonite was in direct contact with the punctured geomembrane; liquid migrated laterally no more than about 75 mm (3 in.) from the punctures. Less effective composite action was observed when a geotextile separated the bentonite from the geomembrane.

ACKNOWLEDGMENTS

This research was funded by the U. S. Environmental Protection Agency's (EPA) Risk Reduction Engineering Laboratory under cooperative agreement CR-815546-01-0. The EPA's project officer was Walter E. Grube, Jr. The cooperation of Mr. Grube and Robert E. Landreth of the EPA are sincerely appreciated. This article has not been reviewed by the EPA. The contents do not necessarily reflect the views and policies of the EPA nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

Several graduate students who helped with the experiments are thanked: Hsin-yu Shan, Mark LaGatta, Jenghwa Lyang, and Gerald Eykholt. The cooperation of representatives of the GCL manufacturers was critical to the successful completion of this work. The authors particularly thank Thomas Stam and Robert Trauger of CETCO, Martin Simpson and William Simpson of the James Clem Corporation, Mark Cadwallader and James Anderson of Gundle Lining Systems, Inc., and Brian McGroarty and Patrick McGroarty of Paramount Technical Products, Inc.

APPENDIX I — SUPPLIERS OF MATERIALS

Bentomat® was supplied by Colloid Environmental Technologies Co., 1500 West Shure Drive, Arlington Heights, IL 60004. Claymax® was supplied by the James Clem Corp., 444 North Michigan, Suite 1610, Chicago, IL 60611. Gundseal and Gundnet were supplied by Gundle Lining Systems, Inc., 19103 Gundle Road, Houston, TX 77073. Paraseal was provided by Paramount Technical Products, Inc., 2600 Paramount Drive, Spearfish, SD 57783. Trevira® was supplied by Hoechst Celanese Corp., P.O. Box 5887, Spartanburg, SC 29304.

REFERENCES

Bruton, D. (1991), "Bentonite Mats Meet Secondary Containment Standards," *Geotechnical Fabrics Report*, Vol. 9, No. 4, pp. 26-27.

Chen-Northern, Inc. (1988), Untitled Letter Report with Results of Laboratory Tests on Claymax®, Denver, Colorado, December 31.

Daniel, D. E., and P. M. Estornell (1990), "Compilation of Information on Alternative Barriers for Liner and Cover Systems," U. S. Environmental Protection Agency, EPA 600/2-91/002, Cincinnati, Ohio, 81 p.

Daniel, D. E., and R. M. Koerner (1991), "Landfill Liners from Top to Bottom," *Civil Engineering*, Vol. 61, No. 12, pp. 46-49.

Estornell, P. M. (1991), "Bench-Scale Hydraulic Conductivity Tests of Bentonitic Blanket Materials for Liner and Cover Systems," M. S. Thesis, Univ. of Texas, Austin, TX, 153 p.

Eith, A.. W., Boschuk, J., and R. M. Koerner (1990), "Prefabricated Bentonite Clay Liners," *Proceedings*, Fourth GRI Seminar, Geosynthetics Research Instutute, Drexel University, Philadelphia, pp. 204-226.

Geoservices, Inc. (1988), "Interim Test Results - Claymax Liner, Freeze-Thaw Hydraulic Conductivity Tests," Report to James Clem Corporation, Norcross, Georgia, November 11, 3 p.

Geoservices, Inc. (1989), "Freeze-Thaw Effects on Claymax Liner Systems," Report to James Clem Corporation, Norcross, Georgia, March, 9 p.

Geoservices, Inc. (1990), "Claymax Hydraulic Conductivity Testing," Report to James Clem Corporation, Norcross, Georgia, October 10, 3 p.

GeoSyntec Consultants (1990), "Claymax Hydraulic Conductivity Testing, Haverhill Landfill Project," Report to James Clem Corporation, Norcross, Georgia, December 20, 3 p.

GeoSyntec Consultants (1991a), "Final Report, Laboratory Testing of Bentomat," Report to American Colloid Company, Norcross, Georgia, April 5, 59 p.

GeoSyntec Consultants (1991b), "Final Report, Laboratory Testing of Claymax," Report to James Clem Corporation, Norcross, Georgia, April 5, 14 p.

GeoSyntec Consultants (1991c), "Final Report, Laboratory Testing of Gundseal," Report to Gundle Lining Systems, Inc., Norcross, Georgia, June 15, 62 p.

Grube, W. E. Jr. (1991), "Soil Barrier Alternatives," *Remedial Action, Treatment, and Disposal of Hazardous Waste*, U. S. Environmental Protection Agency, Cincinnati, Ohio, EPA/600/9-91/002, pp. 436-444.

Grube, W. E., Jr., and D. E. Daniel (1991), "Alternative Barrier Technology for Landfill Liner and Cover Systems," Presented at the 84th Annual Meeting & Exhibition of the Air & Waste Management Association, Vancouver, British Columbia, Paper 91-5.9, 11 p.

J & L Testing Company, Inc. (1990), "Hydraulic Conductivity Tests, Bentomat NW/CS/W, Bentomat NW/SS/W," Report to American Colloid Company, Canonsburg, Pennsylvania, July 5.

Scheu, C., Johannben, K., and F. Saathoff (1990), "Non-Woven Bentonite Fabrics - A New Fibre Reinforced Mineral Liner System," *Geotextiles, Geomembranes and Related Products*, D. Hoet (Ed.), Balkema Publishing, Rotterdam, pp. 467-472.

Schubert, W. R. (1987), "Bentonite Matting in Composite Lining Systems," *Geotechnical Practice for Waste Disposal '87*, R. D. Woods (Ed.), American Society of Civil Engineers, New York, pp. 784-796.

Shan, H. Y. (1990), "Laboratory Tests on Bentonitic Blanket," M. S. Thesis, Univ. of Texas, Austin, TX, 84 p.

Shan, H. Y., and D. E. Daniel (1991), "Results of Laboratory Tests on a Geotextile/Bentonite Liner Material," *Geosynthetics 91*, Industrial Fabrics Association International, St. Paul, MN, Vol. 2, pp. 517-535.

Trauger, R. (1991), "Geosynthetic Clay Liner Installed in a New Municipal Solid Waste Landfill," *Geotechnical Fabrics Report*, Vol. 9, No. 8, pp. 6-17

Table 1. Results of Laboratory Hydraulic Conductivity Tests

Material (1)	Source of Information (2)	Maximum Effective Confining Stress kPa (psi) (3)	Hydraulic Conductivity cm/s (4)
Bentomat®	GeoSyntec (1991a)	35 (5)	1×10^{-9}
	J&L Testing Co. (1990)	56 (8.2)	6×10^{-9}
		73 (10.6)	1×10^{-9}
		91 (13.2)	1×10^{-9}
	This Study	14 (2)	3×10^{-9}
		34 (5)	3×10^{-9}
		69 (10)	1×10^{-9}
Claymax®	Chen-Northern (1988)	24 (3.5)	2×10^{-9}
	Geoservices (1988)	200 (29)	4×10^{-10}
	Geoservices (1989)	207 (30)	8×10^{-10}
		207 (30)	3×10^{-10}
		207 (30)	7×10^{-10}
	Geoservices (1990)	207 (30)	3×10^{-10}
	GeoSyntec (1990)	6.9 (1)	2×10^{-9}
	GeoSyntec (1990)	10.3 (1.5)	4×10^{-9}
	Shan (1990)	14 (2)	2×10^{-9}
		34 (5)	1×10^{-9}
		69 (10)	6×10^{-10}
		138 (20)	3×10^{-10}
	GeoSyntec (1991b)	14 (2)	2×10^{-9}
	Shan and Daniel (1991)	14 (2)	2×10^{-9}
Gundseal	GeoSyntec (1991c)	34 (5)	1×10^{-9}

Table 2. Comparison of Hydraulic Conductivities Measured on Unseamed Pieces of Bentomat® and Claymax®.

	Results from Bench-Scale Tank Tests		Hydraulic Conductivity
Material	Average Effective Confining Stress kPa (psi)	Hydraulic Conductivity (cm/s)	Measured with Flexible-Wall Permeameters (Fig. 10) (cm/s)
(1)	(2)	(3)	(4)
Bentomat®	6 (0.9)	4×10^{-10}	4×10^{-9}
Bentomat®	9 (1.3)	4×10^{-10}	4×10^{-9}
Claymax®	6 (0.9)	1×10^{-8}	3×10^{-9}
Claymax®	6 (0.9)	8×10^{-9}	3×10^{-9}

Table 4. Results of Tests on Punctured Geomembrane/GCL Composites.

Material (1)	Hydraulic Conductivity (cm/s) Control (No Geomembrane) (2)	Hydraulic Conductivity (cm/s) Composite (with Punctured Geomembrane) (3)	Conductivity Ratio: Column 3 Divided by Column 2 (4)
Bentomat®	4×10^{-10}	6×10^{-10}	1.5
Claymax®	7×10^{-9}	7×10^{-9}	1.0

KEYWORDS

Clay, Liner, Hydraulic Conductivity, Bentonite, Geosynthetic

40 WORD SUMMARY

Bench-scale tests demonstrated that overlapped sheets of geosynthetic clay liner self sealed when hydrated with water. The effectiveness of composite action with a punctured geomembrane was best when the geomembrane was in direct contact with the bentonite the geosynthetic clay liner.

Figure Captions

Figure 1 Schematic Diagrams of Geosynthetic Clay Liners.

Figure 2 Configuration of Overlapped Seams with Manufacturers' Minimum Recommended Overlap Width.

Figure 3 Orthogonal View of Tank Used for Bench-Scale Hydraulic Conductivity Tests.

Figure 4 Cross-Sectional View of Configuration of Materials in Tanks.

Figure 5 Photograph of Drainage Material (Geotextile/Geonet Composite) and 75 mm (3 in.) Wide Bentonitic Edge Seal.

Figure 6 Schematic Diagram of Types of Tests Performed in Tanks.

Figure 7 Photograph of Placement of Bentomat® with Overlapped Seam (Note Spreading of Granular Bentonite Along Overlapped Zone)

Figure 8 Photograph of Placement of Claymax® with Overlapped Seam

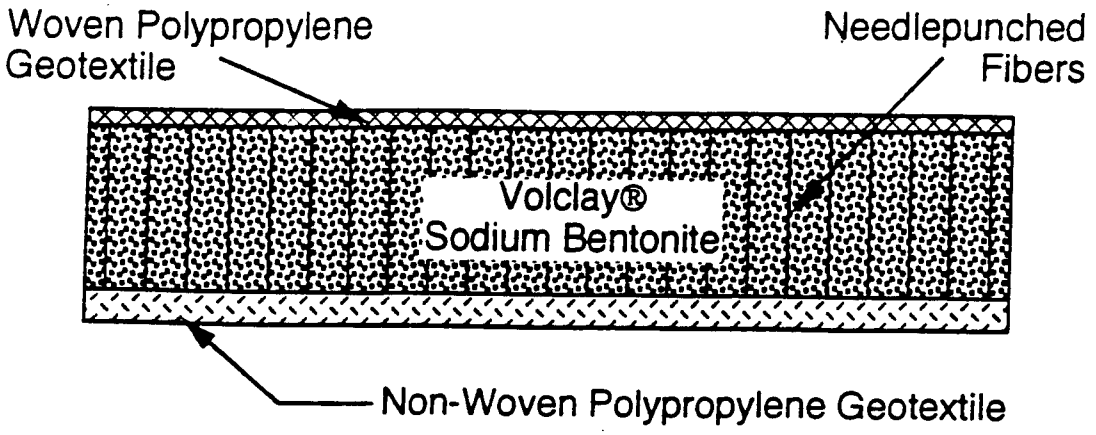
Figure 9 Photograph of Placement of Gundseal with Overlapped Seam

Figure 10 Results of Flexible-Wall Hydraulic Conductivity Tests.

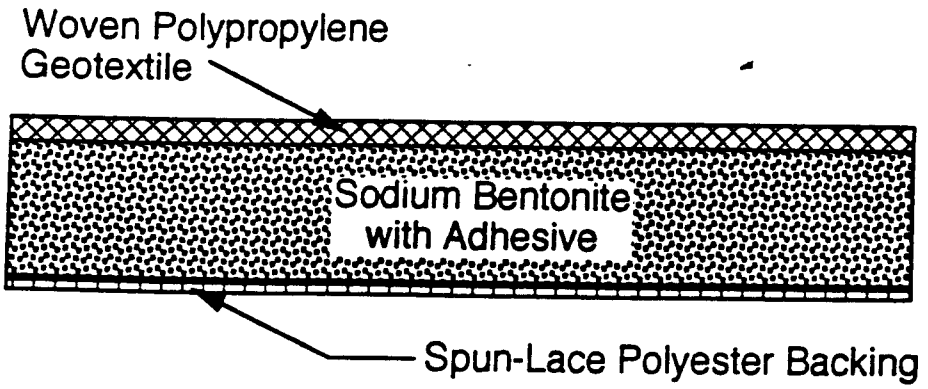
Figure 11 Pattern of Wetting of Bentonite in Overlapped Gundseal When HDPE Faced Upward.

Figure 12 Photograph of Pattern of Wetting of Bentonite in Gundseal after Overlying Gravel and Punctured Geomembrane had Been Removed from Tanks.

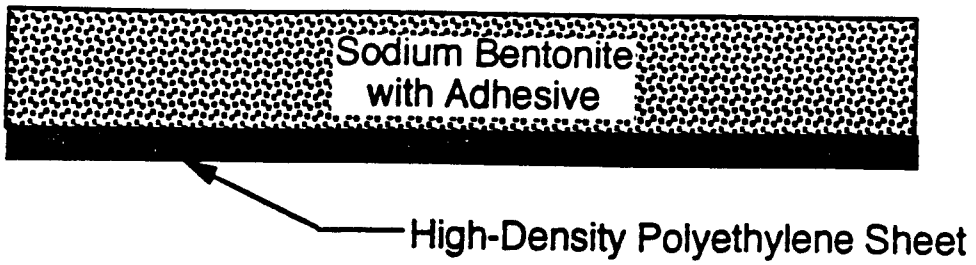
Bentomat®



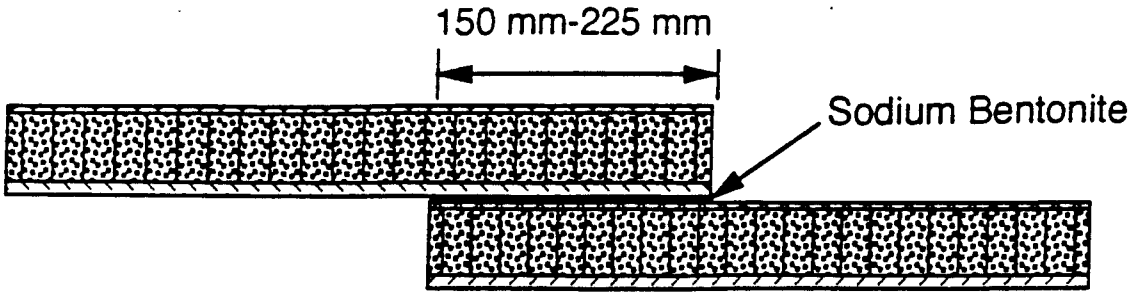
Claymax®



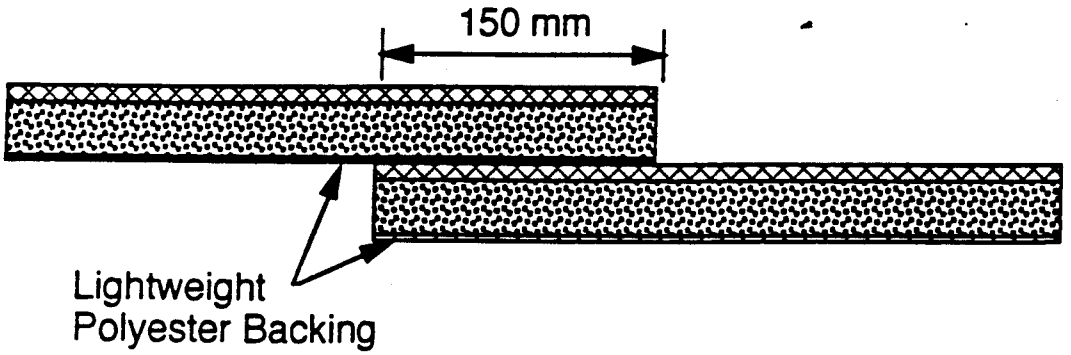
Paraseal/Gundseal



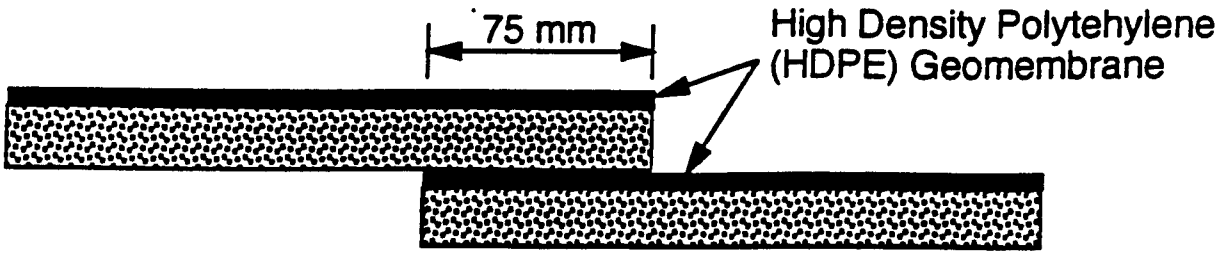
Bentomat® Seam

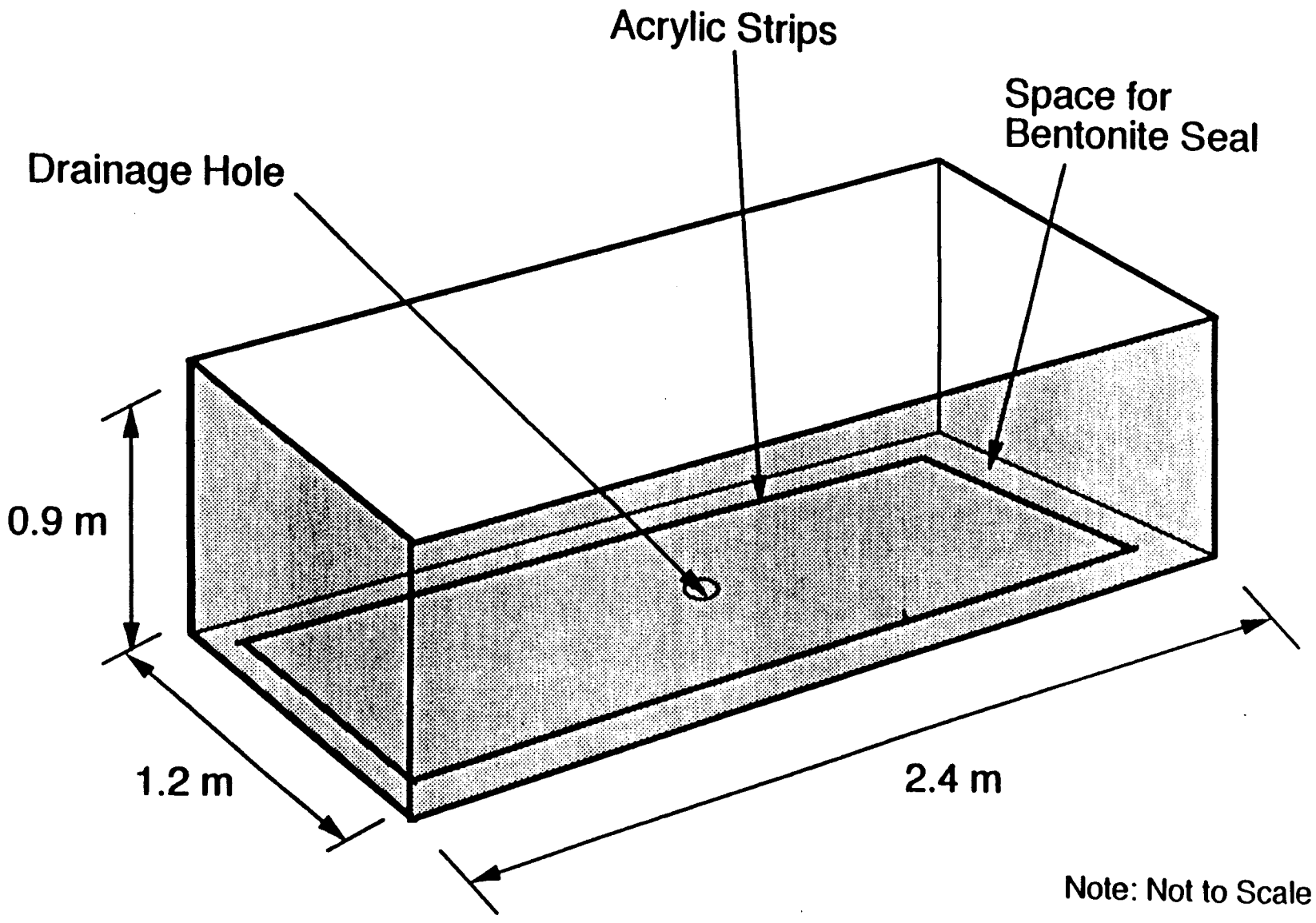


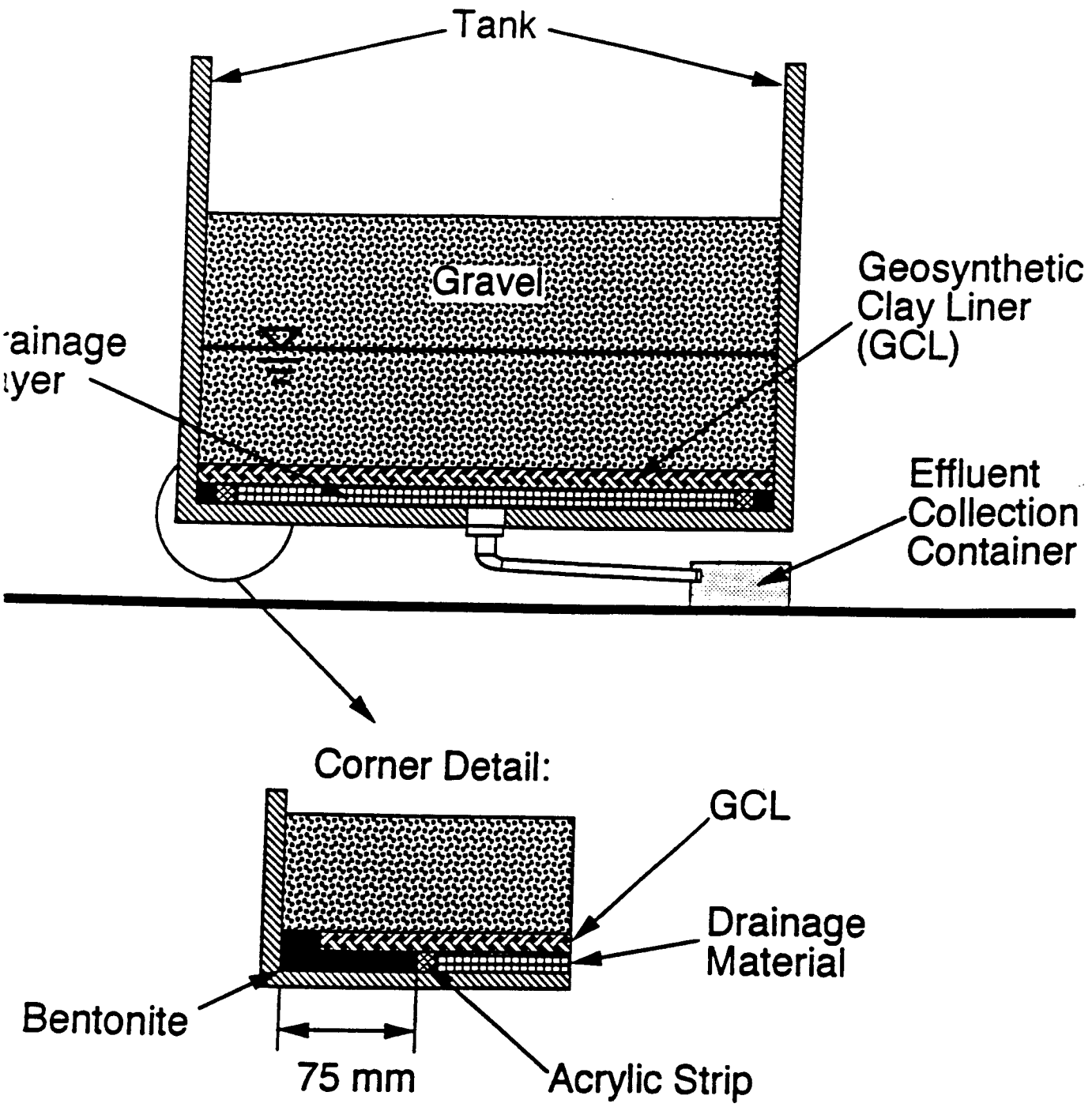
Claymax® Seam



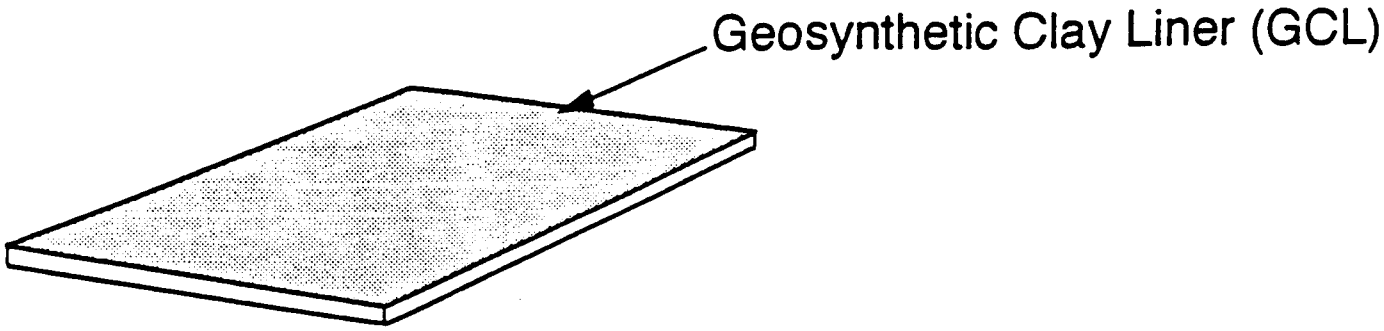
Paraseal/Gundseal Seam



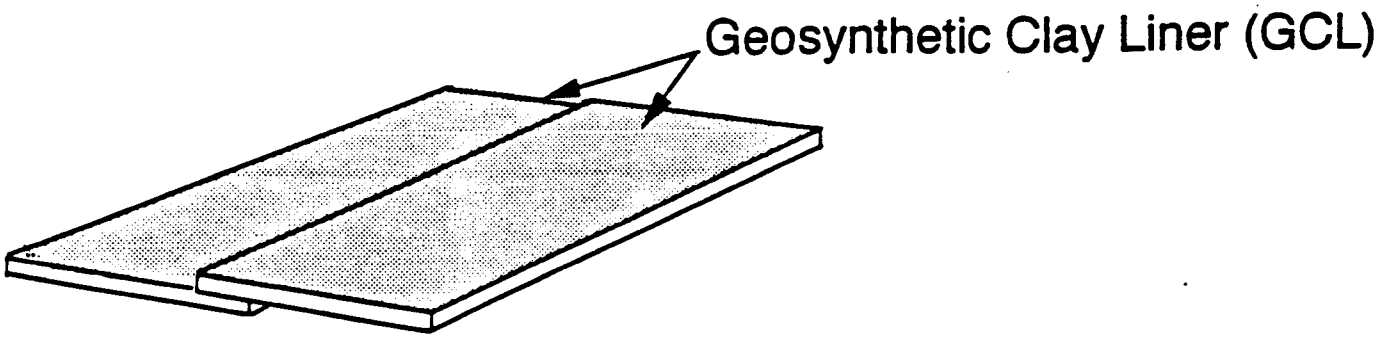

Acrylic Strips
Space for
Bentonite Seal
Drainage Hole
0.9 m
1.2 m
2.4 m
Note: Not to Scale


Tank
Gravel
Geosynthetic
Clay Liner
(GCL)
ainage
yer
Effluent
Collection
Container
Corner Detail:
GCL
Drainage
Material
Bentonite
75 mm
Acrylic Strip

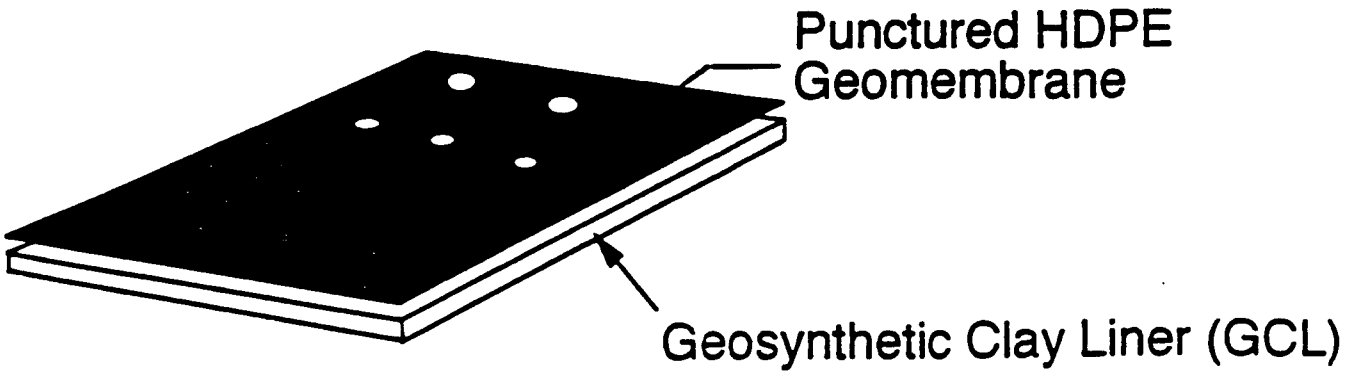
Control Test

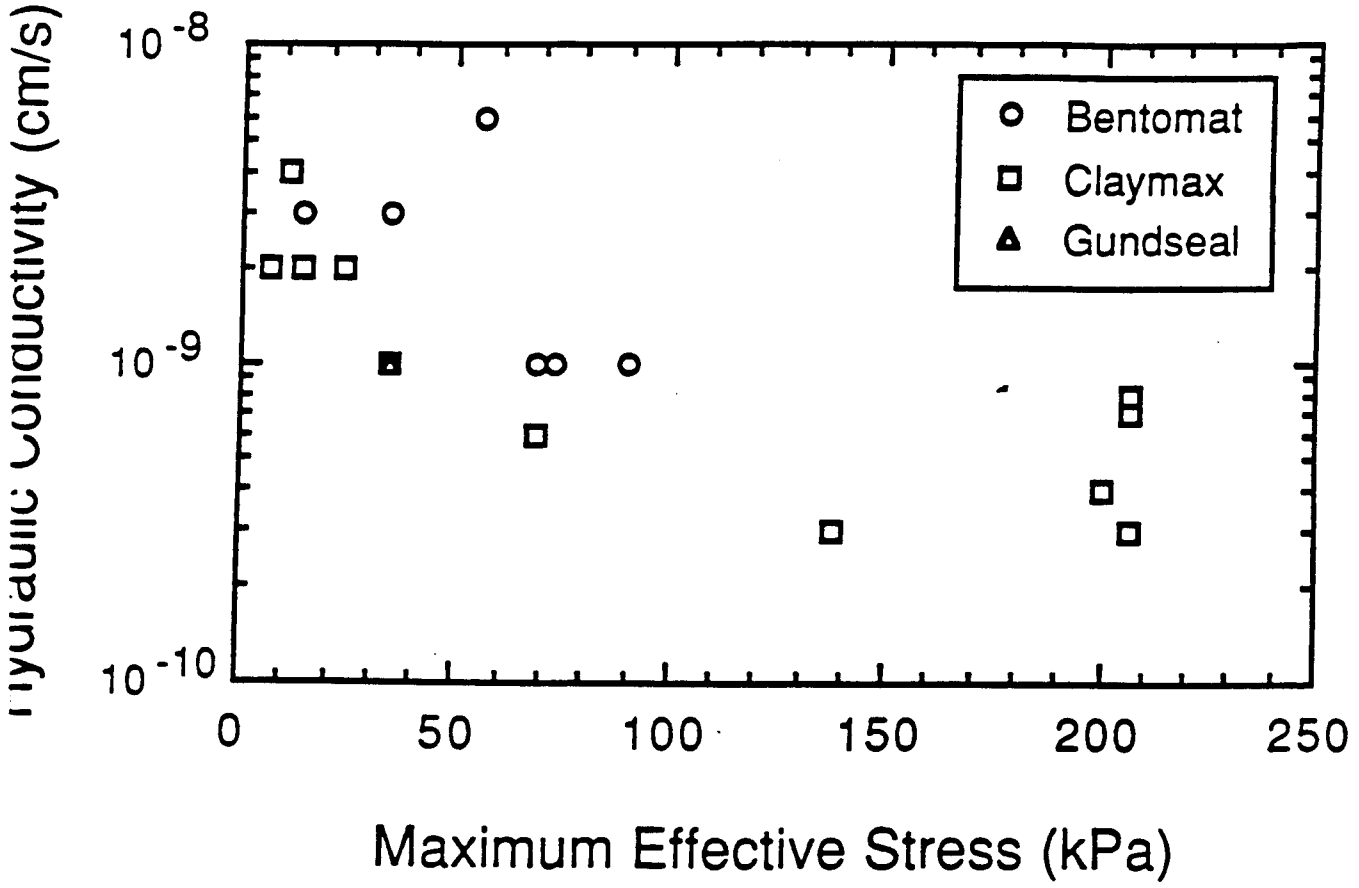


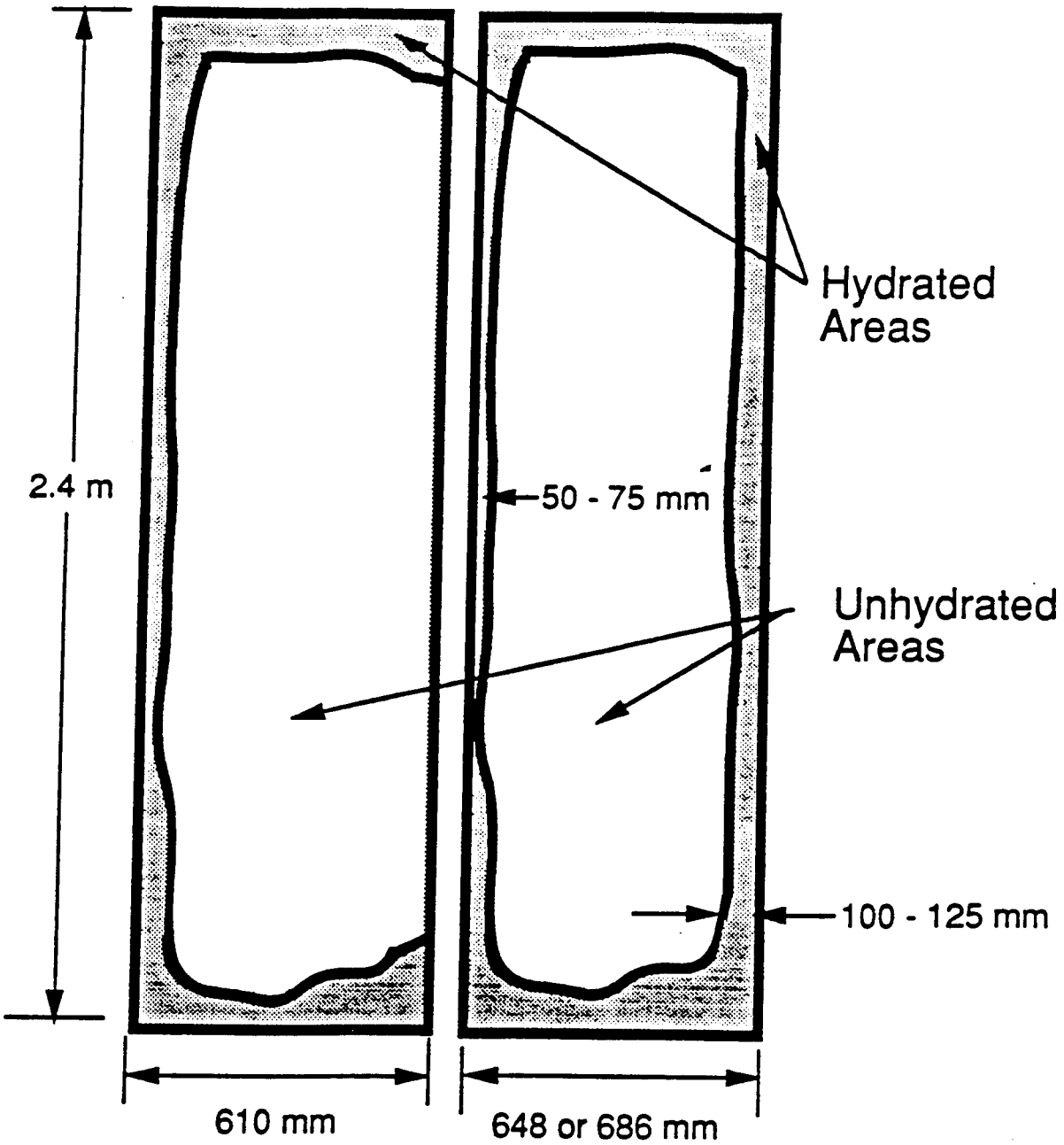
Seam Test



Punctured Geomembrane/GCL Composite Test




Hydraulic Conductivity (cm/s)
10 -8
10 -9
10 -10
0
50
100
150
200
250
Maximum Effective Stress (kPa)
Bentomat
Claymax
Gundseal


Hydrated
Areas
2.4 m
50 - 75 mm
Unhydrated
Areas
100 - 125 mm
610 mm
648 or 686 mm

APPENDIX E

PRODUCT TECHNICAL ARTICLES & LITERATURE

CLAYMAX®

CLAYMAX® IS THE STATE-OF-THE-ART GEOCOMPOSITE LINER FOR THE WATER AND WASTE CONTAINMENT INDUSTRY. CLAYMAX® . . . THE IMPERMEABLE BARRIER OF BENTONITE CLAY IN CARPET FORM.

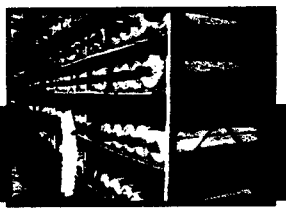
JAMES CLEM

CORPORATION

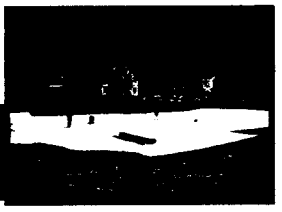
contact

James Clem Corporation
444 North Michigan Avenue, Suite 1610
Chicago, IL 60611 USA

Phone: 312-321-6255
FAX: 312-321-6258
Telex: 543408
for your local distributor.



CLAYMAX Liner Inventory



Decorative Pond

Leachate Collection Pond (Secondary Liner)

CLAYMAX® LIQUID CONTAINMENT LINER

ADVANTAGES

- Economical and easy to install
- Minimal labor required
- All seams are simple overlap seams
- Liner can be cut and trimmed with a utility knife

GENERAL CHARACTERISTICS

Self-healing/Self-sealing

Natural sealant actuated by water

Porous protection layers allowing quicker hydration

Water-soluble adhesive

Factory-uniform continuous bentonite layer

Minimum 1 lb. bentonite per sq. ft.

Totally flexible

Compatible for use with plastic liners and other multiple liner systems

Rolled goods for convenient storage

Standard sheet sizes: 13½' x 82' and custom lengths available

Relatively resistant to environmental and biological attack

INSTALLATION ADVANTAGES

Uncomplicated installation requiring:

No seam welding or sewing
No special equipment or cutting tools
No geotextile or other special protection

May be staked or nailed

Simple overlap seams

Accommodates complex configurations

No bentonite loss when cut or trimmed

Virtually no waste material

CAUTIONARY INSTRUCTIONS: CLAYMAX liner may be damaged by exposure to water turbulence or hazardous or toxic substances, hazardous or solid wastes, salt or other contaminants in water and should not be used for containment of these constituents without prior evaluation. CLAYMAX liner must be inspected for damage if exposed to any of those substances or conditions and, if damaged, must be repaired or replaced immediately. CLAYMAX liner must be installed in accordance with plan and specification requirements, prepared by a professional engineer.

All drawings are intended solely as a guide and for general information only.

All test performance data were produced under laboratory conditions and are not intended as a substitute for tests of the specific liquid or leachate that may come in contact with CLAYMAX liner. All test performance data are subject to James Clem Corporation's limitation of warranties. James Clem Corporation recommends that the purchaser perform site-specific tests of CLAYMAX liner.

LIMITATION OF WARRANTIES: James Clem Corporation warrants that CLAYMAX liner meets James Clem Corporation's specifications. James Clem Corporation disclaims any other warranties, express or implied, as to CLAYMAX liner, including all warranties of merchantibility and fitness for any particular purpose. James Clem Corporation is not liable for any incidental or consequential damages of any kind. James Clem Corporation assumes no liability for CLAYMAX liner's performance or for injuries resulting from the use of CLAYMAX liner, including any liability resulting from the purchaser's engineering, design, construction and installation.

GENERAL INSTALLATION INFORMATION: CLAYMAX liner should never be installed in standing water.

Exposure to turbulent water may also cause damage.

If exposed to any of these substances or conditions, CLAYMAX liner must be inspected and, where necessary, immediately repaired or replaced.

If rainfall commences during installation or while under construction, cover with plastic sheeting to provide interim protection.

To insure its integrity, CLAYMAX liner must be protected by and remain buried under a minimum of 6" to 8" of backfill or aggregate. Backfill must be compacted with rubber-tired or conventional rolling equipment to an 85% Modified Proctor.

All illustrations are intended solely as a guide and are for general information only. Contact James Clem Corporation for:

- ▲ Containment installation instructions on slopes greater than 3 to 1.
- ▲ Installations where CLAYMAX liner must resist extreme hydrostatic pressure that may require a double layer of CLAYMAX liner.
- ▲ Temporary containment applications.
- ▲ Suitability for secondary containment applications.

Any unusual CLAYMAX liner application procedures not covered in this brochure must be approved in writing by James Clem Corporation prior to the installation.

See James Clem Corporation's below-grade bentonite waterproofing catalog in Sweet's section 07100/CLE BuyLine 3527.

The information contained in this brochure supercedes all information printed prior to 7/89.

© Copyright 1989 James Clem Corporation, Chicago, Illinois, 60611

Printed in the USA 8-89

CLAYMAX® liner is the optimum impermeable liner for the water and waste containment industry.

CLAYMAX® PRODUCT SPECIFICATION

Sodium Bentonite Content	1.0 lbs. per square foot
Thickness	¼ inch
Liner Dimensions	13.5 feet x 82 feet
Effective Area Covered	1059.5 square feet (assume 6" overlap along one side and one end)
Roll Weight/Unit	1130 lbs. (minimum)
Permeability Coefficient	2×10^{-10} cm per second @ 35' head pressure.

LABORATORY TEST DATA

Procedure — Six inches of silica sand covering CLAYMAX liner in a triaxial cell under thirty-five feet of water head pressure.

GROUP	PERMEANT	PERMEABILITY
Water	De-Aired Water	2×10^{-10} cm/sec.
Salt	Seawater	2×10^{-10} cm/sec.
Acid	Acetic Acid Phosphoric Acid	2×10^{-10} cm/sec. 2×10^{-9} cm/sec.
Calcium	Calcium Chloride	2×10^{-9} cm/sec.
Alcohol	Ethyl Alcohol	2×10^{-9} cm/sec.
Organics	Methylene Chloride	3×10^{-10} cm/sec.
Leachate	Sewage BOD>38,000 Paper Pulp Sludge	8×10^{-10} cm/sec. 2×10^{-10} cm/sec.
Hydrocarbons	Jet Fuel Diesel Fuel Unleaded Gasoline	8×10^{-10} cm/sec. 8×10^{-10} cm/sec. 2×10^{-10} cm/sec.
Pressure	150 foot Water Head	1×10^{-9} cm/sec.

Additional tests are available upon request.

The above test performance data were produced under laboratory conditions. The actual performance characteristics may vary. No performance warranty is express or implied.

PACKAGING AND SHIPPING

Roll Content	1107.0 square feet
Roll Weight	1135 lbs. (approx.) wrapped
Roll Size	14.5 feet long (PVC wrapped) x 18" diameter (approx.)

APPLICATIONS: Fresh water ponds, waste lagoons, municipal landfills/caps, tank farm containments, irrigation canals and earthen dams.

CLAYMAX® liner is a flexible polypropylene bentonite sandwich providing a uniform layer of clay in carpet form creating a cost-effective solution for any liquid containment sealing problem.

E.P.A. regulations for waste containment specify that lagoon/landfill liners be composed of a heavy plastic membrane layer (HDPE) on top of a thick layer of **compacted clay (3 feet minimum).** Because a single sheet of **CLAYMAX liner exceeds this requirement,** it has been specified and installed as "the clay layer" in several landfills in the United States and Europe.

CLAYMAX® liner is the state-of-the-art geocomposite liner that ingeniously combines the durability of woven polypropylene fabric with the impermeability of a pound-per-square-foot of an inert mineral, sodium bentonite (montmorillonite).

Sodium bentonite, the mineral component in CLAYMAX liner, is a high-swelling clay that swells to form a monolithic seal when hydrated with fresh water. The CLAYMAX liner has **self-sealing seams** and an overall **self-healing** ability if ripped or punctured. In its hydrated (swollen) state, the clay will swell up to 15 times its dry volume providing tremendous impermeability and a great resistance to all chemicals. In a typical installation, the ¼-inch CLAYMAX liner sheet will swell ½-to-1 inch resulting in the **equivalent permeability of 30 feet of compacted clay.**

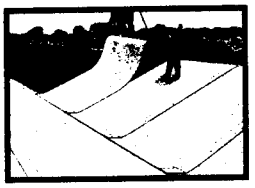
EQUIPMENT REQUIRED: The CLAYMAX liner must be installed with the **stenciled polypropylene side up (facing the operator).** The polypropylene protects and supports the system on installation. The liner can either be pulled from a roll suspended at the top of a slope, or the free end may first be secured in a locking trench and the suspended roll can be backed down the slope and across the excavation by the supporting vehicle.

Suspending and unrolling CLAYMAX liner is facilitated by inserting a heavy-duty 3-inch diameter steel pipe through the 3½-inch roll core on which CLAYMAX liner is shipped. This pipe should be 16-18 feet long to accommodate the hoisting chains from the lifting vehicle (any type of vehicle with a fork or front-end bucket). A spreader bar is required to ensure roll clearance and to prevent damage to roll edges.

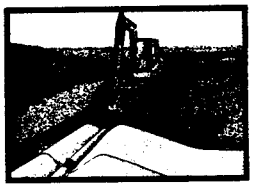
Quality control of CLAYMAX liner seams requires an on-site inspection of a uniform 6-inch overlap and supervision of backfilling to prevent aggregate from opening seams.

SITE PREPARATION: The pond, lagoon, tank farm enclosure or canal excavation depth should be determined to allow for a final addition of a minimum 6-8 inches of soil or aggregate cover material. The excavation should be well contoured with slopes that are at a maximum of three-to-one. Protrusions and rocks larger than 2 inches in diameter should be removed and the entire excavation should be compacted sufficiently to prevent ruts from installation vehicles. Compaction can be accomplished using either conventional rolling equipment or wheeled vehicles. Use of sheepsfoot rolling equipment is not recommended. A liner **locking trench (min. 18 inches deep)** must be provided at the top of all slopes.

ORIENTATION: When installing CLAYMAX liner, **all seams on slopes must be perpendicular to the excavation bottom.** This method prevents seam displacement during the backfill procedure. It is also important that the first CLAYMAX liner roll and all succeeding rolls be pulled tight to smooth out creases.



ANCHORING: All CLAYMAX liner sheets should be anchored to pressure-treated wooden 2 x 4's (or equivalent) and locked into trenches at the top of all slopes, covered with fill and compacted to prevent slippage during installation. This trench should be at least 12 inches above the final contained liquid level and should be approximately **18 inches deep** and **18 inches back from the finished waterline.**



SEAMING: CLAYMAX liner seams are non-critical and self-seaming. CLAYMAX liner seams require a **simple 6-inch overlap** with long pins or nails every yard to allow for movement of CLAYMAX liner during ground subsidence. No adhesive or thermal welding is required. The hydrated bentonite will push through the woven polypropylene forming a monolithic seal with a permeability of no greater than 1×10^{-9} cm/sec.

REPAIRING: Irregular shapes, cuts or tears are **easily repaired** by covering the area with CLAYMAX liner to provide a 6-inch overlap on all sides. These repair pieces should be stapled or nailed in position until cover material has been placed.

COVERING: Cover material (minimum 6-8 inches of aggregate or backfill) should be applied as CLAYMAX liner sheets are placed to afford maximum protection. **Correctly installed, CLAYMAX liner is capable of supporting installation personnel and equipment.** Because it is not recommended for vehicles to operate directly on CLAYMAX liner without the support of a backfill, **cover material should always be pushed forward.** Cover material (other than aggregate) should be compacted after placement.

CLAYMAX® liner, the state-of-the-art geocomposite, can be used as a primary or secondary liner.

MATERIAL SPECIFICATIONS

Primary Backing (Typical Properties) — Polypropylene is nonbiodegradable and inert to most chemicals, acids and alkalis.

Color	Natural white
Filler Fiber	Nylon
Substrate	24 x 10 Delustered woven polypropylene, non-toxic, water permeable
Weight	4 oz. per square yard
Tensile Strength	78 lbs. per inch (minimum)
Grab Strength (ASTM D-1682)	Warp 95 lbs., Fill 70 lbs.
Mullen Burst Strength (ASTM D774)	250.25 lbs. per square inch
Puncture Strength (5/16" mandril ASTM D3787 MOD.)	249 lbs.
Melting Point	329° F
Elongation (ASTM D-1682)	Warp 15%, Fill 18%
Shrinkage—Hot Water	Nil
Shrinkage—Dry (20 min. @ 270°F)	2%

Cover Fabric	100% spunlace polyester; open weave allows for expansion of bentonite
Weight	1 oz. per square yard
Grab Strength	Warp 30 lbs., Fill 13.6 lbs.
Burst Strength	35 lbs. per square inch

Bentonite Sizing (Sodium Montmorillonite)	Specially graded, 6 mesh and 30 mesh granules
Mineralogical Composition	90% Montmorillonite (min.)

Adhesive	Water soluble, non-toxic
Storage	On dry ground, under roof or other protective covering

The manufacturer reserves the right to change product specifications and instructions/limitations without notice. Information contained herein supersedes previously printed material prior to 7/89.

Golder Associates Ltd.
CONSULTING ENGINEERS

REPORT TO

ARMTEC CONSTRUCTION PRODUCTS

LABORATORY HYDRAULIC CONDUCTIVITY TESTS ON CLAYMAX MATERIAL

DISTRIBUTION:

8 copies - Armtec Construction Products
Guelph, Ontario

2 copies - Golder Associates Ltd.
Mississauga, Ontario

January 1989

881-1405

Golder Associates Ltd.
CONSULTING ENGINEERS

January 13, 1989 881-1405

Armtec
15 Campbell Road
P.O. Box 3000
Guelph, Ontario
N1H 6P2

ATTENTION: Mr. C. Mills, P.Eng.
Manager, Geosynthetics Products

RE: LABORATORY HYDRAULIC CONDUCTIVITY TESTING ON CLAYMAX MATERIAL

Dear Sirs:

This letter reports the results of two laboratory tests carried out by Golder Associates Ltd. to determine the hydraulic conductivity of samples of CLAYMAX material using de-aired tap water as the permeant. The purpose of this laboratory test program was to confirm the results of hydraulic conductivity tests performed previously on CLAYMAX material by STS Consultants Ltd., Consulting Engineers from Northbrook, Illinois, as reported in the manufacturer's literature.

Authorization to carry out the laboratory test program was given by your Mr. C. Mills, P.Eng. in Armtec's letter dated August 22, 1988. A stock roll of CLAYMAX material was subsequently provided by Armtec and delivered to our geotechnical laboratory in Mississauga, Ontario.

Test Apparatus

The test methodology used for the laboratory test program essentially followed the procedures used by STS Consultants Ltd., but with the CLAYMAX specimen located at about mid-height of the 100 mm diameter by 200 mm high composite cylindrical triaxial sample. Fine Ottawa sand was placed on both sides of the CLAYMAX specimen and de-aired tap water was used as the permeant. The procedure used by STS involved the placement of the CLAYMAX on sand followed directly by the top loading platen.

A triaxial compression chamber with a self-compensating mercury-pot pressure control system was used to carry out the constant-head hydraulic conductivity tests. This type of equipment lends itself well to the determination of hydraulic conductivity on low permeability material. The advantages of this equipment include:

- The capability of reliably maintaining a constant head differential across the test specimen for long periods of time.

- The prevention of permeant evaporation during long testing periods as the apparatus forms a closed system.

- The enhancement of the seal around the test specimen by the use of a flexible rubber membrane which tightly conforms to the specimen sides. The use of cell pressure acting on the membrane

also minimizes seepage at the membrane-specimen side interface. Vacuum grease was also applied at the specimen-membrane interface.

- The enhancement of specimen saturation through the use of back pressure into the specimen.

- The reliable measurement of permeant volumes both into and exiting the specimen to ensure that a steady-state flow condition is being achieved.

Satisfying the above conditions is essential to the accurate, proper determination of hydraulic conductivity (k), since the governing flow equation used to calculate k, under constant-head conditions, is based on steady-state flow being achieved in a fully saturated soil/material.

Specimen Preparation

The following steps were followed for specimen preparation operations:

1. A flat circular specimen approximately 100 mm in diameter and 5 mm high was carefully trimmed from the stock supply of CLAYMAX material, measured for dimensions and weighed.

2. The triaxial chamber base pedestal was flushed with de-aired tap water and a previously saturated porous stone placed on top of the base pedestal. A flexible rubber membrane was then secured to the pedestal using three tightly fitted O-rings.

3. Wet fine Ottawa sand was placed under water on the saturated porous stone and within the membrane former to form a column of sand approximately 100 mm in diameter and 100 mm high. The sand was then flushed with upward flow of de-aired water.

4. The circular CLAYMAX specimen was placed on top of the sand followed by 100 mm of wet fine Ottawa sand, the upper saturated porous stone and the top loading platen. Three tightly fitted O-rings were used to secure the membrane to the top platen. The CLAYMAX was positioned so that the geotextile side faced downwards.

5. A partial vacuum was applied to the composite sample to allow the membrane former to be removed and the outer triaxial chamber to be placed and filled with water to allow for cell pressure application.

6. De-aired tap water was flushed into the sample from the top loading platen and base pedestal, completely inundating the CLAYMAX specimen. This was followed by the application of a vacuum to remove any entrapped air bubbles from the sand.

7. The specimen of CLAYMAX was allowed to hydrate for a 48 hour period.

8. Following hydration, the cell and back pressures were simultaneously and incrementally increased to facilitate saturation of the specimen by pressure dissolving any free air into solution. Increments of 69 kPa (10 psi) were used until a differential

pressure of 7 kPa (1 psi) was obtained under a maximum cell pressure of 414 kPa (60 psi) and 407 kPa (59 psi) back pressure. Skempton's pore pressure B parameter was checked for each stage and saturation was considered complete when a value of 0.95 or greater was attained. (The B value is the ratio of the measured increase in sample pore water pressure under a simultaneous increase in cell pressure).

9. Following specimen saturation, flow of de-aired tap water was initiated through the top loading platen under a pressure of 407 kPa (59 psi) and allowed to exit through the lower sand and the base pedestal under a pressure of 392 kPa (56.9 psi), thereby inducing a head differential of 15 kPa (2.1 psi). The cell pressure was maintained at 414 kPa (60 psi) during this time to provide positive confinement against the membrane and the sample.

10. The flow of water entering and exiting the triaxial chamber were recorded by calibrated burettes to ascertain that steady-state flow conditions had been attained. The steady-state condition was then maintained for a period of 4.5 days for the first test and 10.5 days for the second test. The calculation for k was based on measurements taken during these periods of time of steady-state conditions.

11. Following completion of testing, the triaxial chamber and sample were dismantled. The dimensions of the CLAYMAX specimen were re-measured and the specimen weighed.

Laboratory Testing Results

The results of the two laboratory hydraulic conductivity tests are summarized in Table 1 and Figure 1. From the volume-time relationships shown on Figure 1, it is apparent that steady-state conditions had been reached and maintained since the rate of flow into the triaxial chamber, and hence through the CLAYMAX material, equalled the flow exiting the system.

The results from the two tests are very similar thereby demonstrating repeatability and consistency of the test data. During hydration and testing, the CLAYMAX material swelled to about double its original height. The computation for *k*, therefore, used the final height and area of the specimen and the flow rate indicated on Figure 1.

For a saturated soil under steady-state conditions, the following equation (Darcy's Law) applies:

$$Q = kiA$$

where:

- Q = steady-state flow rate (cm^3/s)
- k = hydraulic conductivity (cm/s)
- i = hydraulic gradient
- A = cross-sectional area through which flow occurs (cm^2)

Further, for constant-head conditions

$$i = h/L$$

where:

- h = head causing flow (cm)
- L = length of specimen through which the head causing flow is dissipated (cm)

The above parameters are summarized on Table 1 and Figure 1. Based on these measurements, the calculated k for the CLAYMAX material is about 8×10^{-10} cm/s.

Discussion

The results from the two tests are almost identical and indicate that the hydraulic conductivity for CLAYMAX material for de-aired tap water as the permeant is very low, being about 8×10^{-10} cm/s. The manufacturer's specifications indicate a k of 2×10^{-10} cm/s for de-aired water as the permeant as reported by STS Consultant Ltd. The results of the above laboratory test programs carried out on CLAYMAX material are, therefore, reasonably consistent and indicate that CLAYMAX material is quite impermeable. Generally, materials possessing a hydraulic conductivity of 10^{-7} cm/s or lower are considered to be practically impermeable.

Notwithstanding the above agreement in reported values for hydraulic conductivity, it should be appreciated that the determination of such low k values probably constitutes the limit of the laboratory system capability in providing reliable measurements of hydraulic conductivity. It is considered that the value of hydraulic conductivity for CLAYMAX material, as determined in the laboratory, is of the order of 10^{-9} cm/s, possibly approaching 10^{-10} cm/s.

Compacted Clay Liner Thickness Equivalency of CLAYMAX Material

The thickness equivalency of CLAYMAX material in terms of compacted clay can be assessed using Darcy's Law and the

principle of continuity of flow (viz. the flow rate through the CLAYMAX must equal the rate of flow through the clay). For a given unit area, this can be expressed mathematically as follows:

$$(k\ [h + L]\ /\ L)_1 = (k\ [h + L]\ /\ L)_2$$

where:

h = retained fluid height

(and the subscripts 1 and 2 denote the clay liner and CLAYMAX material respectively placed on free draining material (i.e. a sub-collector drainage system)

For the same retained fluid head, (h), the ratio of the thickness of clay to CLAYMAX is directly proportional to the ratio of their respective hydraulic conductivities, k_1/k_2.

For clay liners with a $k_1 = 10^{-7}$ cm/s and a CLAYMAX material with a $k_2 = 10^{-9}$ cm/s, and for the same retained height of ponded fluid, a unit thickness of CLAYMAX material would be equivalent to about 100 unit thicknesses of compacted clay liner (viz. 1 cm of CLAYMAX would be equivalent to 1.0 m of compacted clay).

It should also be appreciated that while the above is based on an equal rate of flow through the respective liners, the actual corresponding hydraulic gradient across the CLAYMAX material would be about 100 times that across the clay liner, for respective hydraulic conductivity values of 10^{-7} cm/s and 10^{-9} cm/s.

Summary and Conclusions

The results of the hydraulic conductivity tests carried out on specimens of CLAYMAX material in the laboratory, under

controlled conditions and de-aired tap water as permeant, is of the order of 10^{-9} cm/s to 10^{-10} cm/s. However, whether similar values will be operational in the field will be dependent upon the actual field installation and construction procedures. Thus, the laboratory determined value of hydraulic conductivity may not be appropriate for direct design use. The operational overall field value could be somewhat less depending on factors such as scale (size) effects, efficiency of the joints/seams and proper careful installation procedures.

Yours truly,

GOLDER ASSOCIATES LTD.

Dennis E. Becker, P.Eng.

DEB/ga

Att: Table 1 - Summary of Laboratory Hydraulic Conductivity Tests on Specimens of CLAYMAX Material

Figure 1 - Volume of Flow vs. Time Relationships Constant Head Hydraulic Conductivity Tests CLAYMAX Material

TABLE 1

SUMMARY OF LABORATORY HYDRAULIC CONDUCTIVITY TESTS ON SPECIMENS OF CLAYMAX MATERIAL

Number	1		2	
	Before Test (Dry Condition)	During/After Test (Wet Condition)	Before Test (Dry Condition)	During/After Test (Wet Condition)
Test Dates	Oct. 4, 1988 (Start)	Oct. 20, 1988 (End)	Nov. 8, 1988 (Start)	Dec. 8, 1988 (End)
Specimen Diameter (cm)	10.15	10.40	10.20	10.45
Specimen Height (cm)	0.48	1.00	0.51	1.12
Specimen Area (cm^2)	80.91	84.93	81.71	85.77
Specimen Volume (cm^3)	38.84	84.93	41.67	96.06
Specimen Weight (g)	33.82	---	34.20	116.15
Specimen Density (g/cm^3)	0.87	---	0.82	1.23
Specimen Water Content (%)	0.0	---	0.0	239.6
Specimen Void Ratio	2.16	---	2.35	6.72
Specimen Saturation (%) (1)	0.0	---	0.0	0.98
Specimen B Value	---	---	---	0.96
Steady-State Flow Rate (cm^3/s) (2)	---	1.00×10^{-5}	---	8.84×10^{-6}
Duration of Steady-State Conditions (days) (3)	---	4.5	---	10.5
Constant Head (Water) (cm)	---	147.6	---	147.6
Hydraulic Gradient	---	147.6	---	131.8
Hydraulic Conductivity (k) (cm/s) (4)	---	8.0×10^{-10}	---	7.8×10^{-10}

Notes: (1) From Fundamental Phase Relationships for Soils (eg. Se=sG; etc.) Assumed G=2.75

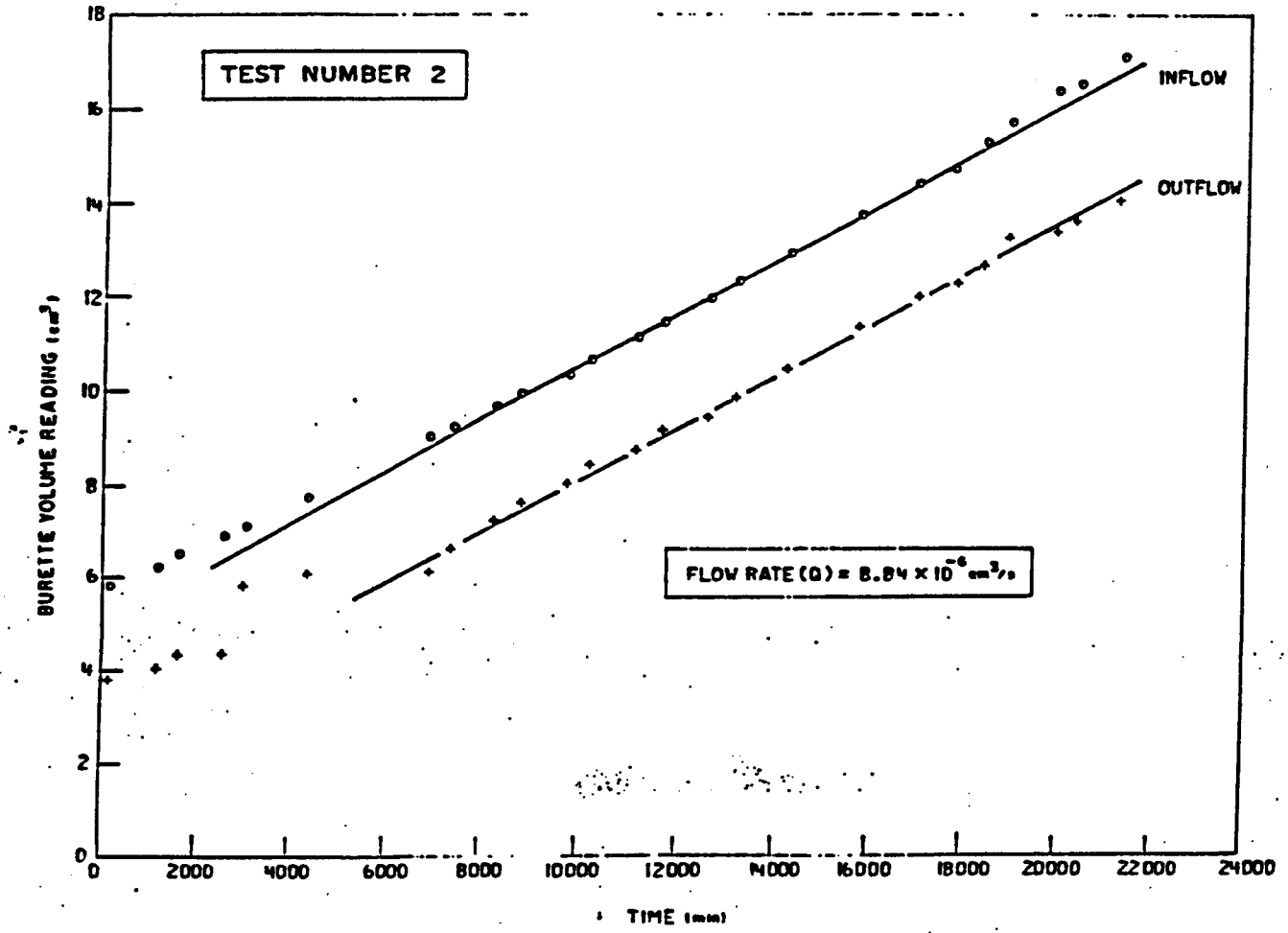
(2) During period of observed steady-state conditions. Refer to Figure 1.

(3) As determined by comparing Inflow and Outflow Rates in Specimen.

(4) De-aired tap water used as permeant.

VOLUME OF FLOW VS TIME RELATIONSHIPS
CONSTANT HEAD HYDRAULIC CONDUCTIVITY
TESTS ON CLAYMAX MATERIAL

FIG



JAN. 13, 1989

881-1409

Golder Associates

INDEPENDENT LABORATORY TEST DATA ON CLAYMAX®

1. PERMEABILITY TESTS ON CLAYMAX®

Procedure: Six inches of silica sand covering CLAYMAX® liner in a triaxial cell under thirty-five feet of water pressure.

TEST WITH CLAYMAX® HYDRATED BY PERMEANT

Group	Permeant	Permeability	Tested By*	Date
Water	De-Aired Water	2×10^{-10} cm/s	STS	9/25/83
Salt	Seawater	2×10^{-10} cm/s	GS	11/29/88
Leachates	Sewage BOD > 38,000	8×10^{-10} cm/s	STS	5/11/89
	Paper Pulp Sludge	2×10^{-10} cm/s	STS	6/03/88
	Pond Sludge	2×10^{-9} cm/s	STS	1/03/85
	Ash	1×10^{-10} cm/s	STS	4/24/89
Cyanide	Cyanide Heap Leachate	2×10^{-10} cm/s	KL	12/11/90
Pressure	150 ft Water	1×10^{-9} cm/s	STS	11/19/86

TEST WITH CLAYMAX® PREHYDRATED BY DE-AIRED WATER

Group	Permeant	Permeability	Tested By*	Date
Acid	1% Acetic Acid (pH 1)	2×10^{-10} cm/s	STS	11/28/83
	Phosphoric Acid	1×10^{-9} cm/s after 8 days	STS	11/16/87
Alkali	20% Hydrated Lime (pH 14)	6×10^{-10} cm/s	STS	10/05/81
Calcium	Calcium Chloride	2×10^{-9} cm/s	STS	4/27/83
	Calcium Lignosulfanate	2×10^{-9} cm/s after 21 days	STS	10/16/87
Alcohol	Ethyl Alcohol 10%	2×10^{-9} cm/s	STS	9/25/83
Organics	Methylene Chloride	4×10^{-10} cm/s	STS	2/12/88
Hydrocarbons	No. 1 Diesel Fuel	9×10^{-10} cm/s	STS	7/07/89
	Jet Fuel	9×10^{-10} cm/s	STS	7/07/89
	Unleaded Gasoline	2×10^{-10} cm/s	STS	7/07/89
	Gasahol	2×10^{-10} cm/s	STS	7/07/89
	MTBE	7×10^{-10} cm/s	STS	7/17/90

---

2. MECHANICAL PROPERTIES TESTING

Property	Test Details	Results	Tested By*	Date
Puncture Strength (ASTM D 3787)	Punctured with 8mm diameter solid steel rod at a strain rate of 12 in/min	39 kg, 86 lbs	STS	5/26/87
Shear Strength			GS	3/10/89
	Slip Plane Interface	Friction Angle (ø), Cohesion (C)		
	Between geotextile of CLAYMAX and dry PVC membrane	ø = 15.0° C = .239 KSC		
	Within bentonite layer of hydrated CLAYMAX	ø = 11.6° C = .500 KSC		
	Between silty sand and geotextile of CLAYMAX	ø = 17° C = .273 KSC		
	Between geotextile of CLAYMAX and dry, smooth HDPE	ø = 17° C = .300 KSC		
Wide Width Tensile Strength			GS	4/19/88
	Creep Strength	420 lbs/ft		
	Maximum Tensile Load	1440 lbs/ft		

* GS = GeoServices Inc., Atlanta, GA; STS = STS Consultants Ltd., Deerfield, IL; KL = Klohn Leonoff Inc., Kirkland, WA

3. PHYSICAL PROPERTIES TESTING

PERMEABILITY EFFECTS FOR VARIOUS CONDITIONS

Type of Test	Test Details	Permeability	Tested By*	Date
Freeze-Thaw Effects	Samples were hydrated following exposure to 0, 1, 5, 10 and 20 freeze-thaw cycles.	2×10^{-10} cm/s	GS	12/88
Puncture Effects	Punctured with 1/2" diameter rod:		STS	3/20/86
	Prior to saturation:	2×10^{-6} cm/s (initial) 4×10^{-9} cm/s (after 9 days)		
	After saturation:	9×10^{-7} cm/s (initial) 8×10^{-10} cm/s (after 5 days)		
Seam Overlap	2" overlap @ center of 4' diameter sample	7×10^{-10} cm/s	STS	7/16/84
Strain Effects	CLAYMAX stretched 15% of original length	4×10^{-10} cm/s	STS	4/18/88

PHYSICAL CHARACTERISTICS FOR VARIOUS CONDITIONS

Property	Test Details	Results	Tested By*	Date
Swell Potential	Percent of swell of original height of CLAYMAX	9% @ 1.500 KSC load 132% @ .004 KSC load	STS	7/15/87
Unsupported Slope Length			GS	4/19/88
Assuming soil/fabric friction angle of 15°; 6-9" cover material at a density of 130 P.C.F.; factor of safety = 1.5; 40 lbs/in creep strength.	Slope	Maximum Length		
	4:1	45 ft		
	3:1	27 ft		
	2.5:1	20 ft		
	2:1	15 ft		
Transmissivity of Net Under CLAYMAX	(results for a gradient of 1.0)		GS	4/19/88
	@ 1,000 PSF confining stress	4.7 gpm		
	@ 20,000 PSF confining stress	2.1 gpm		
Moisture Retention			GS	7/14/89
CLAYMAX placed in a temperature and humidity controlled chamber to simulate exposure to long term arid environments. Different overburden pressures were applied to each of the three samples to simulate various soil cover conditions.		Time (days)	Moisture Content	
	Using zero confining stress	0 (saturated)	1300%	
		4	690%	
		21	15%	
		47	6%	
		90	1%	
	8 inches of overburden soil placed on CLAYMAX	0 (saturated)	260%	
		25	280%	
		90	260%	
		154	180%	
		235	20%	
		294	1%	
	18 inches of overburden soil placed on CLAYMAX	0 (saturated)	300%	
		25	265%	
		90	248%	
		154	203%	
		235	116%	
		294	37%	

The preceeding test performance data does not represent product specifications. The tests were performed under laboratory conditions by certified independent testing labs. The actual performance characteristics may vary. No performance warranty expressed or implied.

* GS = GeoServices Inc., Atlanta, GA; STS = STS Consultants Ltd., Deerfield, IL

CLAYMAX®

PRELIMINARY CASE STUDY

YAWORSKI SUPERFUND CAP

NAME OF PROJECT:	Yaworski Superfund Site
LOCATION:	Plainfield, Connecticut
TYPE OF PROJECT:	Superfund Cap
SIZE OF PROJECT:	210,000 square feet
START DATE:	August 1990
COMPLETION DATE:	
CLIENT:	Confidential
CONTRACTOR:	Resicon Containment Sunapee, New Hampshire
ENGINEERING FIRM:	GZA Vernon, Connecticut
APPROVING AGENCY:	United States EPA Region I Boston, Massachusetts Connecticut Dept. Environmental Conservation Hartford, Connecticut
LINER CONCEPT:	40 mil HDPE over CLAYMAX Most slopes are 4° - 6°; steepest is 7°. Gabion walls around outer perimeter for drainage.

JAMES CLEM CORPORATION
444 North Michigan, Suite 1610, Chicago, IL 60611 USA
Phone: 312.321 6255 Fax: 312.321-6258

CLAYMAX®

PRELIMINARY CASE STUDY

RCRA CAP

NAME OF PROJECT:	Shelton County Landfill Cap
LOCATION:	Hartford, Connecticut
TYPE OF PROJECT:	RCRA Cap
SIZE OF PROJECT:	45,000 square feet
START DATE:	July 1988
COMPLETION DATE:	July 1988
CLIENT:	Connecticut Resource Recovery Authority
CONTRACTOR:	Sealand Environmental Bridgeport, Connecticut
ENGINEERING FIRM:	Fuss & O'Neil Manchester, Connecticut
APPROVING AGENCY:	Connecticut Dept. of Environmental Protection Hartford, Connecticut U.S. EPA, Region I Boston, Massachusettes
LINER CONCEPT:	Metal hydroxide contaminated soils were overlain with: six inch layer of 1 x 10^{-6} cm/s clay; CLAYMAX liner; 30 mil PVC; one foot sand drainage layer; filter fabric; 30 inches cover soil to protect against freeze/thaw effects; grass cover for erosion protection.

JAMES CLEM CORPORATION
444 North Michigan, Suite 1610, Chicago, IL 60611 USA
Phone: 312.321-6255 Fax: 312.321-6258

CLAYMAX®

PRELIMINARY CASE STUDY

GE SUPERFUND CAP

NAME OF PROJECT:	General Electric Cap
LOCATION:	Fort Edward, New York
TYPE OF PROJECT:	Superfund Cap
SIZE OF PROJECT:	55 Acres
START DATE:	September 1990
COMPLETION DATE:	December 1990
CLIENT:	General Electric
CONTRACTOR:	Canonie Environmental King of Prussia, Pennsylvania
ENGINEERING FIRM:	J & L Engineering Canonsburg, Pennsylvania
APPROVING AGENCY:	New York EPA
BACKROUND:	CLAYMAX replaced 2 feet of clay in a cap designed to seal off PCB contaminated soils in five areas along the Hudson River. CLAYMAX was custom made for the project with a 10 oz., non-woven material on the underside that would allow gases generated in the underlying soils to transmit laterally toward collection wells. The rolles were manufactured twice their standard length to maximize installation efficiency.

JAMES CLEM CORPORATION
444 North Michigan, Suite 1610, Chicago, IL 60611 USA
Phone: 312.321-6255 Fax: 312.321-6258

CLAYMAX®

Liquid Containment Reference List

LANDFILLS & LANDFILL CAPS

PROJECT	OWNER	CONTRACTOR	ENGINEER
Landfills			
Adams Center Hazardous Waste Landfill Fort Wayne, Indiana	Chemical Waste Management of Indiana, Inc.	National Seal Corporation Aurora, Illinois	Donahue & Associates, Inc.
Vickery Hazardous Waste Landfill Vickery, Ohio 480,000 square feet June 1988	Chemical Waste Management Vickery, Ohio Mr. Rudy Mays	Geo-Con, Inc. Pittsburgh, Pennsylvania Mr. Matthew Hart 412-244-8200	Golder Engineering Atlanta, Georgia Mr. John Hull 404-496-1893
C.I.D. Environmental Complex Calumet City, Illinois 130,680 square feet September '85 – March '86	Chemical Waste Management Palos Heights, Illinois	National Seal Corporation Aurora, Illinois	Chemical Waste Management Palos Heights, Illinois
Waste Mgt. of South Carolina Palmetto Landfill & Recycling Center Spartanburg, South Carolina 524,577 square feet April 1991	Waste Management of North America Spartanburg, SC	National Seal Corporation Southeast Regional Office	Waste Management of North America Oak Brook, Illinois 708-572-8800
B.J. Sanitary Landfill Norcross, Georgia 700,000 square feet March 1990	Waste Management of North America Atlanta, Georgia	National Seal Corporation Aurora, Illinois; I.E.L. Baton Rouge, Louisiana	Waste Management of North America Atlanta, Georgia
Turnkey Sanitary Landfill Rochester, New Hampshire 1989: 1,200,000 square feet	Waste Management of North America Manchester, MA	National Seal Corporation Aurora, Illinois	Waste Management of North America Oak Brook, Illinois
G.R.O.W.S. Sanitary Landfill Morrisville, Pennsylvania 1989: 1,840,000 square feet	Waste Management of North America Oak Brook, Illinois	National Seal Corporation Aurora, Illinois	Waste Management of North America Oak Brook, Illinois; Golder & Associates Mount Laurel, New Jersey

PROJECT	OWNER	CONTRACTOR	ENGINEER
Landfills cont.			
Tullytown Sanitary Landfill Tullytown, Pennsylvania 1988: 2,000,000 square feet 1989: 1,130,000 square feet	Waste Management of North America Oak Brook, Illinois	Gundle Lining Systems Houston, Texas	Waste Management of North America Oak Brook, Illinois; Golder Engineering Mount Laurel, New Jersey
Pottstown Sanitary Landfill Pottstown, Pennsylvania 1988: 675,000 square feet 1989: 520,000 square feet	Waste Management of North America Oak Brook, Illinois	Gundle Lining Systems Houston, Texas	Waste Management of North America Oak Brook, Illinois; Fred C. Hart Engineers Pittsburgh, Pennsylvania
Clean Fill Landfill Hauppauge, New York 48,600 square feet October 1991	Zanghi Construction	Zanghi / Zanghi	Wehran Engineering
General Motors Corp. Central Foundry Landfill Defiance, Ohio 1 acre May - June 1991	General Motors Corp. Central Foundry Defiance, Ohio	Tim Cor, Inc. Defiance, Ohio	RMT, Inc. Madison, Wisconsin
LaCrosse County Landfill LaCrosee, Wisconsin Size November 1990	LaCrosse County LaCrosse, Wisconsin	Terra Engineering & Construction Corp. Madison, Wisconsin Mr. John Karsten 608-221-3501	Terra Engineering & Construction Corporation Madison, Wisconsin Mr. John Karsten 608-221-3501
R & A Bender Sanitary Landfill Chambers, Pennsylvania 8 acres November 1990	R & A Bender Inc Chambers, PA	NSC Galesburg, Illinois	Martin & Martin Inc. Chambers, Pennsylvania Mr. Nelson Benedict 717-264-6759
Cape May Landfill Milmay, New Jersey 80,000 square feet September, 1990	Cape May Landfill Milmay, New Jersey	J.H. Water Systems Irwin, Pennsylvania	Fred C. Hart Engineers Pittsburgh, Pennsylvania
Cecil County Landfill Northeast Maryland 90,000 square feet August 1990	Cecil County, Maryland	Guardian Construction Bear, Delaware	Gannett Fleming Baltimore, Maryland
Roosevelt Regional Landfill Roosevelt, Washington 750,000 square feet July 1990	Rabanco Regional Landfill Company	Rabanco Regional Landfill Company & Nilex Corp.	Parametrix, Inc.

PROJECT	OWNER	CONTRACTOR	ENGINEER
Landfills cont.			
Peabody Ash Landfill Peabody, Massachusetts 170,000 square feet June 1990	North East Solid Waste Committee Peabody, Massachusetts	Westrack Inc. Framingham, Massachusetts; New England Liner Systems Southington, Connecticut	SAIC Engineering Lakeville, Massachusetts
Deer Island Southern Landfill Deer Island, Massachusetts 194,000 square feet June 1990	Massachusetts Water Resource Authority Boston, Massachusetts	J.M. Cashman Quincy, Massachusetts Cayer Corporation (Installer) Harvard, Massachusetts	Haley & Aldrich Boston Massachusetts; CDM Boston, Massachusetts
Anchorage Regional Landfill Municipal Solid Waste Facility Anchorage, Alaska 800,000 square feet May 1990	Solid Waste Services Municipality of Anchorage, Alaska	MB Contracting Anchorage, Alaska	Harding Lawson Assoc. Seattle, Washington Mr. Gerald Friesen 206-622-0812
Livingston Landfill Livingston, Louisiana 5,000 square feet December 1989	BFI Linthicum, MD 301-850-7444	BFI Linthicum, MD 301-850-7444	BFI Linthicum, MD 301-850-7444
Cecil County Sanitary Landfill Cecil County, Maryland 71,000 square feet September 1988	Cecil County, Maryland	T.C. Simons Fallstown, Maryland Mr. Bob Cooper 301-879-3055	Department of Public Works Elkton, Maryland Mr. Tom Delorimer 301-389-0200
Broward County Ash Landfill Broward County, Florida 870,000 square feet October '88 – January '89	Broward County Resource Recovery Broward County, Florida	Landfill Technology Fort Lauderdale, Florida Mr. Mickey Donofrio	Whellabrator Services Danvers, Massachusetts; Wehran Engineering Wexford, Pennsylvania
Haverhill Solid Waste Landfill Haverhill, Massachusetts 213,000 square feet June – December 1988	Ogden Martin Systems Haverhill, Massachusetts Mr. Ashvin Patel	Gundle Lining Systems Houston, Texas	Camp Dresser & McKee, Inc. Boston, Massachusetts Mr. Mike Magher 617-742-5151
Landfill Caps			
Dow Chemical South Landfill Closure Dalton , Georgia 200,000 square feet August 1991	Dow Chemical	Reece Trucking & Construction	Dow Chemical Eastern Division
Bossman Division RCRA Closure Bristol, Connecticut 53,000 square feet April - July 1991	Bossman Division/Copper Inds. Bristol, Connecticut	New England Liner Systems Southington, Connecticut	YWC Inc.

PROJECT	OWNER	CONTRACTOR	ENGINEER
Landfill Caps cont.			
Robert Shaw Control RCRA Cap Milford, Connecticut 33,000 square feet November 1990	Robert Shaw Control Company Milford, Connecticut	New England Liner Systems Southington, Connecticut	
General Electric Cap Fort Edward, New York 42 acres September – December 1990	General Electric Fort Edward, New York	Canonie Environmental King of Prussia, Pennsylvania	J & L Engineering Canonsburg, Pennsylvania
Contract Plating Company Stratford, Connecticut 31,000 square feet September 1990	Contract Plating Co. Stratford, Connecticut	Sealand Environmental Derby, Connecticut	Fuss & O'Neil Hartford, Connecticut
Yaworski Superfund Site Plainfield, Connecticut 210,000 square feet August 1990	Confidential	Resicon Containment Sunapee, New Hampshire	GZA Vernon, Connecticut
Department of Energy UMTRA Cap 715,000 square feet August 1990	Department of Energy	Nielsens, Inc. Cortez, Colorado	MK-Ferguson Company Albuquerque, New Mexico
Atlantic Ave Demolition Brooklyn, New York 35,000 square feet July 1990	City of New York New York, New York	Cross Bay Construction Brooklyn, New York	Envirodyne Lyndhurst, New Jersey
Pratt & Whitney Middleton, Connecticut 36,000 square feet November 1989	Pratt & Whitney Middleton, Conn	New England Liner Systems Southington, Connecticut Mr. Jim Magnolia 203-628-4423	Loreino Engineering Plainville, Connecticut Mr. Jeff Loreino 203-747-6181
Tech Systems 12,000 square feet Fall 1989		V.F.L. Technologies	Fuss & O'Neil Manchester, Connecticut 203-646-2469
Whyco Chromium Thomaston, Connecticut 41,000 square feet July 1989	Whyco Chromium Thomaston, Conn.	New England Liner Systems Southington, Connecticut Mr. Jim Magnolia 203-628-4423	Fuss & O'Neil Manchester, Connecticut Mr. Stan Alexander 203-646-2469
American Cyanamid Wellingford, Connecticut 160,000 square feet July 1989	American Cyanamid Wellingford, Conn.	Remcor Pittsburgh, Penn. Mr. Neil Lope 412-963-1106	Malcolm Pirnie Rocky Hill, Connecticut Mr. Mark Barmasse 203-257-3471

PROJECT	OWNER	CONTRACTOR	ENGINEER
Landfill Caps cont.			
Texaco Chemicals Landfill Cap Project Port Neches, Texas 1.6 acres May – June 1989	Texaco Chemical Corporation Port Neches, Texas Mr. Chris Haigler 409-724-4505	Austin Industrial Austin, Texas	In house - Texaco Staff
Shelton County Cap Shelton, Connecticut 45,000 square feet July 1988	Connecticut Resource Recovery Authority Hartford, Connecticut	Sealand Environmental Bridgeport, Connecticut	Fuss & O'Neil Manchester,Connecticut Mr. Ron Reis 203-646-2469

CLAYMAX®

PRELIMINARY CASE STUDY

UMTRA CAP

NAME OF PROJECT:	Uranium Mill Tailings Remedial Action (UMTRA) Clean-Up
LOCATION:	Durango, Colorado
TYPE OF PROJECT:	Encapsulation of Uranium Tailings
SIZE OF PROJECT:	16 acres
START DATE:	July 30, 1990
COMPLETION DATE:	1990
CLIENT:	United States Department of Energy
CONTRACTOR:	Nielsons, Inc. Cortez, Colorado
ENGINEERING FIRM:	MK-Ferguson Company Albuquerque, New Mexico
APPROVING AGENCY:	Department of Energy
LINER CONCEPT:	Two feet of clay was installed on top of the tailings piles to act as a radon barrier. CLAYMAX was placed directly above the clay to act as the sole infiltration barrier. Above CLAYMAX was a six inch drain and filter layer of sand and gravel, 1.5 feet of bio-intrusion riprap, 2.5 feet of rooting medium/frost protection followed by a 6 inch rock-soil matrix.
BACKROUND:	The UMTRA program involves the encapsulation of some 52 million tons of uranium tailings left at abandoned processing mills and those used as fill material at construction sites. The encapsulation of the tailings piles reduces exposure to gamma radiation and prevents contamination of ground water. The design is expected to last a thousand years.

JAMES CLEM CORPORATION
444 North Michigan, Suite 1610, Chicago, IL 60611 USA
Phone: 312.321-6255 Fax: 312.321-6258

CLAYMAX®

PRELIMINARY CASE STUDY

RCRA CAP

NAME OF PROJECT:	Contract Plating Company
LOCATION:	Stratford, Connecticut
TYPE OF PROJECT:	RCRA Cap
SIZE OF PROJECT:	31,000 square feet
START DATE:	September 1990
COMPLETION DATE:	
CLIENT:	Contract Plating Company Stratford, Connecticut
CONTRACTOR:	Sealand Environmental Derby, Connecticut
ENGINEERING FIRM:	Fuss & O'Neil Hartford, Connecticut
APPROVING AGENCY:	Connecticut Dept. Environmental Conservation Hartford, Connecticut
LINER CONCEPT:	60 mil HDPE over CLAYMAX

JAMES CLEM CORPORATION
444 North Michigan, Suite 1610, Chicago, IL 60611 USA
Phone: 312.321-6255 Fax: 312.321-6258

CLAYMAX®

PRELIMINARY CASE STUDY

RCRA CAP

NAME OF PROJECT:	Pratt & Whitney Cap
LOCATION:	Middletown, Connecticut
TYPE OF PROJECT:	RCRA Cap
SIZE OF PROJECT:	36,000 square feet
START DATE:	November 1989
COMPLETION DATE:	November 1989
CLIENT:	Pratt & Whitney
CONTRACTOR:	New England Liner Company Southington, Connecticut
ENGINEERING FIRM:	Louriero Engineering Plainville, Connecticut
APPROVING AGENCY:	Connecticut Dept. of Environmental Protection Hartford, Connecticut U.S. EPA, Region I Boston, Massachusettes
LINER CONCEPT:	Metal hydroxide sludge was removed from the site and taken to a hazardous waste landfill. Because of the possibility of heavy metals in the soil, the landfill needed to be capped to prevent soil contamination. *Cross section design*: subgrade; CLAYMAX liner; 60 mil HDPE; 12 inches sand; 24 inches soil; 6 inches loam.

JAMES CLEM CORPORATION
444 North Michigan, Suite 1610, Chicago, IL 60611 USA
Phone: 312.321-6255 Fax: 312.321-6258

CLAYMAX®

PRELIMINARY CASE STUDY

RCRA CAP

NAME OF PROJECT:	Whyco Chromium Company
LOCATION:	Thomaston, Connecticut
TYPE OF PROJECT:	RCRA Cap
SIZE OF PROJECT:	41,000 square feet
START DATE:	July 1989
COMPLETION DATE:	July 1989
CLIENT:	Whyco Chromium Company
CONTRACTOR:	New England Liner Systems Southington, Connecticut
ENGINEERING FIRM:	Fuss & O'Neil Manchester, Connecticut
APPROVING AGENCY:	Connecticut Dept. of Environmental Protection Hartford, Connecticut U.S. EPA, Region I Boston, Massachusettes
LINER CONCEPT:	CLAYMAX was used to replace 24 inches of 1×10^{-7} cm/sec soil layer. The slopes' ratio was 3:1 and the slope lengths were 75 feet. Geogrids were utilized to reinforce soil veneer. *Cross section design*: Metal OH; non-select fill; CLAYMAX liner; PVC; geogrid; 12" sand; 24" backfilll; 6" loam.

JAMES CLEM CORPORATION
444 North Michigan, Suite 1610, Chicago, IL 60611 USA
Phone: 312.321-6255 Fax: 312.321-6258

Gundle Lining Construction Corp

Gundle®

19103 Gundle Road
Houston, Texas 77073-3598
U.S.A.

Phone: (713) 443-8564
Toll Free: (800) 435-2008
Telex: 166657 GUNDLE HOU
FAX: (713) 875-6010

July 7, 1992

Mr. Mark Wittrock
CESWA-ED-GS
U. S. Army Corps of Engineers
Albuquerque District
517 Gold Avenue SW
Albuquerque, NM 87103-1580

Subject: Gundseal Information

Dear Mr. Wittrock:

As you requested in our telephone conversation of July 7, 1992, I am forwarding to you the following information:

1. GeoSyntec Consultants Report on Gundseal
2. Geosynthetic Research Institute Report on Gundseal Shear Behavior
3. Gundseal Project Reference List
4. Textured HDPE Versus Bentonite Friction Resistance
5. EPA Geosynthetic Clay Liner Workshop Information

If, after reviewing this information, you have any questions regarding the product, please do not hesitate to give me a call.

Sincerely,

James D. Anderson

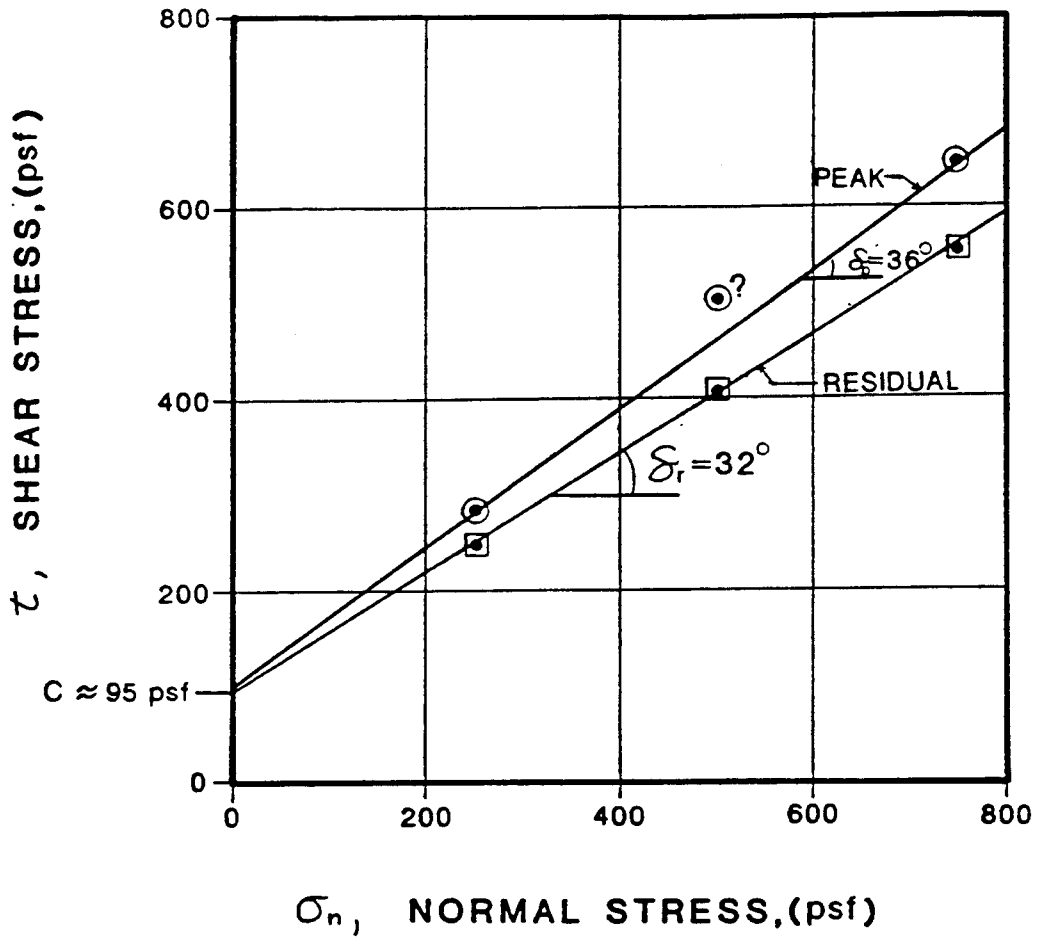
James D. Anderson, P.E.
Product Manager - Gundseal

JDA:ams

enclosure

cc: Mark Harris

TEST NO. 8 GUNDLE 40 mil HDT vs. GUNDSEAL



SUPERSTRATUM - PLATES
UPPER SPECIMEN - GUNDSEAL (BENTONITE SIDE)
LOWER SPECIMEN - GUNDLE 40 mil HDT GEOMEMBRANE
SUBSTRATUM - PLATES

Note: Test performed under dry condition.

GEOSYNTHETICS LABORATORY
DIRECT SHEAR/FRICTION TEST

GUNDLE LINING SYSTEMS, INC.

Westinghouse Environmental and Geotechnical Services, Inc.

PROJ. NO. 4147-90-580 FIG. NO.

W47-03

GUNDSEAL PROJECT REFERENCES

Product	Application	Location	Owner	Engineer	Contractor
20 mil Gundseal 1,785,000 sq.ft. Installed 1991	WWTP Liner	Grayling, MI	City of Grayling Jerry Morford (517) 348-2131	Richards & Assoc. Inc. Carl M. Lehto, P.E. (616) 946-4350	DeVere Construction Co., Inc. Thomas R. Bennett (517) 356-4411
20 mil Gundseal 900,000 sq.ft. Installed 1991	Landfill Liner	Model City, NY	Modern Landfill, Inc. John Sesera (716) 754-8226	Wehran Envirotech Jim Daigler (716) 773-1801	Nilex Corporation James Cramer (800) 537-4241
80 mil Gundseal 37,000 sq.ft. Installed 1991	Sedimentation Pond Liner	Deadwood, SD	Wharf Resources Vicki Franzen (605) 584-1441 Ext. 146	Wharf Resources	Gundle Lining Construction Larry Glowacky (800) 435-2008, Ext. 723
20 mil Gundseal 95,000 sq.ft. Installed 1991	Drainage Channel Liner	Fairfax County, VA	I-95 Landfill		Hercules Construction Co. Ms. Gunn Ulelick (703) 471-6658
20 mil Gundseal 145,000 sq.ft. Installed 1991	Tank Liner	Joliet, IL	Mobil Chemical	Mobil Chemical	Road Fabrics, Inc. Ed Fee (708) 447-0088
20 mil Gundseal 77,280 sq.ft. Installed 1991	Landfill Liner	Goshen, NY	Al Turi Landfill	Wehran Envirotech Joe Dennis (914) 343-0660	Wehran Construction Pete Haponenko (914) 294-5630

Product	Application	Location	Owner	Engineer	Contractor
20 mil Gundseal 35,000 sq.ft. Installed 1991	Landfill Liner	Newburg, NY	Central Hudson Gas & Electric	Wehran Envirotech Mark Swyka (914) 343-0660	Geo-Con, Inc. (914) 564-0405
20 mil Gundseal 70,000 sq.ft. Installed 1991	Hazardous Waste Storage Facility Liner	Deer Island, MA	MWRA Ken Chen (617) 242-6000	HMM Associates Cosmo Gallinaro (508) 371-4000	Laidlaw David Hutten (508) 238-0175
60 mil Gundseal 350,000 sq.ft. 200,000 sq.ft. Installed 1991	Landfill Liner	Broad Acre Landfill Pueblo, CO	Mid-American Waste System, Inc. Tom Flippo (719) 545-3321	In House	In House
20 mil Gundseal 24,500 sq.ft. Installed 1991	Landfill Liner	Christiansburg, VA	Mid-County Landfill	Draper Aden Associates Dean Downs Becky Clark (703) 552-0444	Alleghany Construction Co. (703) 345-0817
20 mil Gundseal 31,500 sq.ft. Installed 1992	WWTP Liner	Mclain State Park Hancock, MI	State of Michigan Parks Department	Roberts Bartow & Assoc. Gary Bartow (517) 684-8850	EPI Steve Shoemaker (812) 422-5334
20 mil Gundseal 17,600 sq.ft. Installed 1991	Drainage Ditch Liner	Kitsap County Landfill Port Orchard, WA	Kitsap County Dick Arnold	In House	In House
20 mil Gundseal 35,000 sq.ft. Awarded 1991	Leachate Collection Pond Liner	Vancouver, WA	Liechner Brothers Landfill	Sweet-Edwards/ Emcon Inc. Mike Stewart (206) 485-5000	Serrot Corp. Jerry Emerson (800) 624-2437
20 mil Gundseal 378,000 sq.ft. Installed 1991-92	WWTP Liner	Beaverton, MI	City of Beaverton	Wade-Trim/Edmands Terry Bartels (517) 686-3100	DeVere Construction Co., Inc. Tom Bennett (517) 356-4411

Product	Application	Location	Owner	Engineer	Contractor
40 mil Gundseal Textured 98,000 sq.ft. Awarded	WWTP Liner	Leland, MI	City of Leland, MI	Williams & Works Engineering & Science William Danly (616) 942-9600	C-Land Excavating Pat Frusti (616) 943-4141
20 mil Gundseal 749,000 sq.ft. Awarded	Landfill Liner	Somerset, PA	Mid American Waste Systems, Inc. Brian Gracey (814) 754-4587	Paul Rizzo Associates Ed Zullo (412) 856-9700	In-House
20 mil Gundseal 73,500 sq.ft. Awarded	WWTP Liner	Wilderness State Park Silver City, MI	State of Michigan Parks Department	Roberts Bartow & Assoc. Gary Bartow (517) 684-8850	EPI Fred Roe (616) 587-9108
20 mil Gundseal 120,000 sq.ft. Installed 1992	Landfill Liner	Wangford Suffolk County, England	Suffolk County England	Golder Associates	Taggart Contracts

Gundle®

Rev. 6-92

SWELLING BEHAVIOR AND SHEAR STRENGTH BEHAVIOR OF GUNDSEAL

T-052

Swelling Behavior of PBC Liners in Distilled Water

A set of five experimental test devices were constructed to evaluate the swelling behavior of the different products under different normal pressures. Three devices are dead weight systems which are capable of imposing pressures up to 1.0 lb/in^2. The other two devices are air activated consolidometers capable of normal pressures of up to 100 lbs/in^2. For these latter devices we used either 2.5 and 5.0 lb/in^2, or 5.0 and 10.0 lb/in^2, depending on the trends that were being developed by the different products. Note that in all cases the sample sizes are 6.0 in. by 6.0 in. Thus scale effects are hopefully minimized.

The hydrating liquid used in the first series of tests was distilled water. The test results for Gundseal follow. The trends developed are seen to be reasonably well behaved with the higher pressures allowing for less swelling than the lower pressures.

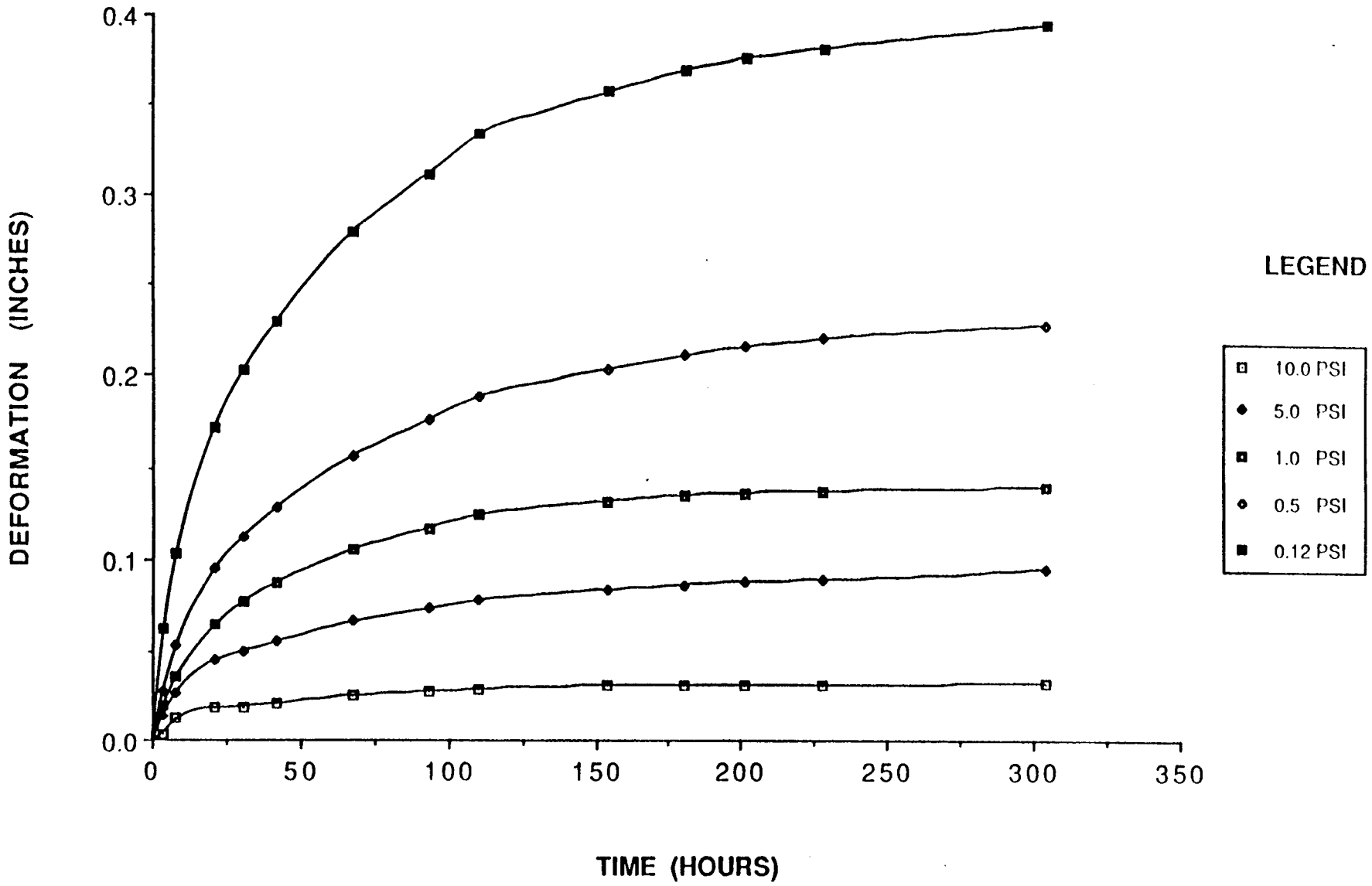


Fig. - Deformation Vs. Time for Gundseal® Hydrated in Distilled Water

Swelling Behavior of PBC Liners in Leachate #1

The same set of five experimental test devices were used as in the testing with distilled water but now for the first leachate.

The hydrating liquid used in this series of tests was leachate that was obtained from a nearby waste landfill. The approximate leachate characteristics are as shown below.

pH	COD (mg/L)	TS (mg/L)	BOD_5 (mg/L)
8.0	10,500	5000	3000

The hydration test results for Gundseal follow. The trends developed are seen to be reasonably well behaved with the higher pressures allowing for less deformation than the lower pressures. The hydration behavior of future leachates will be added to this data.

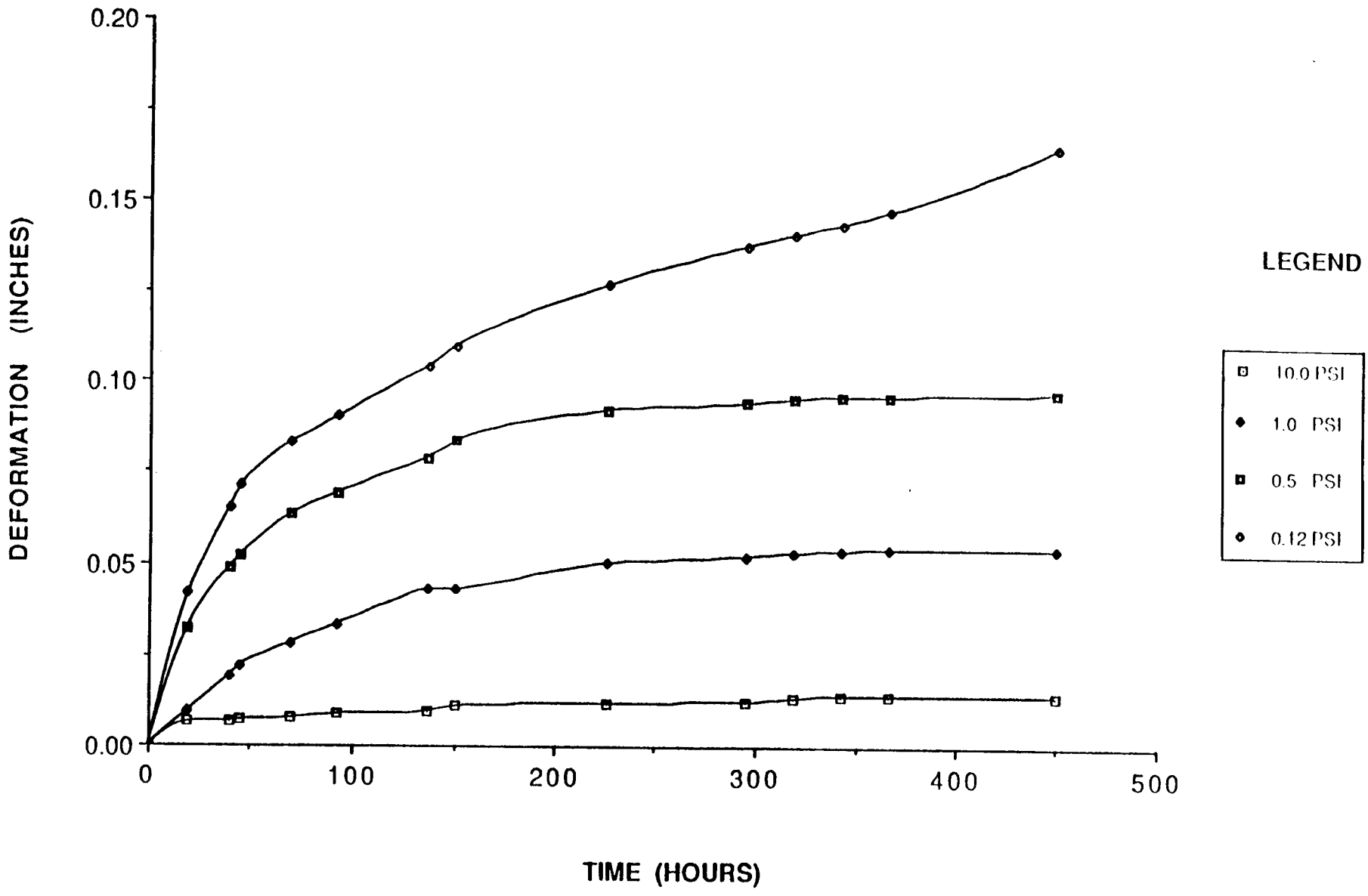


Fig. - Deformation Vs. Time for Gundseal® Hydrated in Leachate

Direct Shear Behavior of PBC Liners

Saturated bentonite clay, as a geotechnical engineering material, is notoriously low in its shear strength. In an unconsolidated, undrained state using shear testing, the angle of shear resistance (ϕ) can approach zero, while the cohesion (c) is only nominal. Thus a shear study of these products under saturated conditions is certainly of importance.

Our test set up for shear strength determinations utilized a 4.0 in. by 4.0 in. split sample box in a Wykeham Farrance direct shear device. It is loaded normally from a harness attached to a 10 to 1 mechanical advantage dead weight arrangement. The shear stress is mobilized by a geared drive which was set at 0.035 in/min for all tests. The device is set up so that the shear plane is always in the direct center of the clay component. It should be emphasized that these results do not investigate the shear strength behavior of the upper and/or lower surface of the various products to any other surface. There is a large, and growing data base for these determinations. This study assumes that the site-specific design has covered the various interfaces and now is concerned about the stability of the center of the PBC product.

In the direct shear test to following (and for subsequent shear tests as well), three separate conditions will be evaluated.

1. Testing in the as-received, or "dry" state. Note, however, that bentonite clay absorbs some moisture from the atmosphere. Table 1 shows that such a moisture content of the as-received product can be as high as 18%.
2. Testing in the normally loaded, hydrated conditions, or "constrained swell" state.

3. Testing in the hydrated condition under no normal stress, or "free-swell" state.

Testing in the as-received state (or dry state) has been conducted on Gundseal for reference purposes. Gundseal was tested dry at six normal pressures, along with the resulting Mohr Coulomb failure envelope shown in the following two figures.

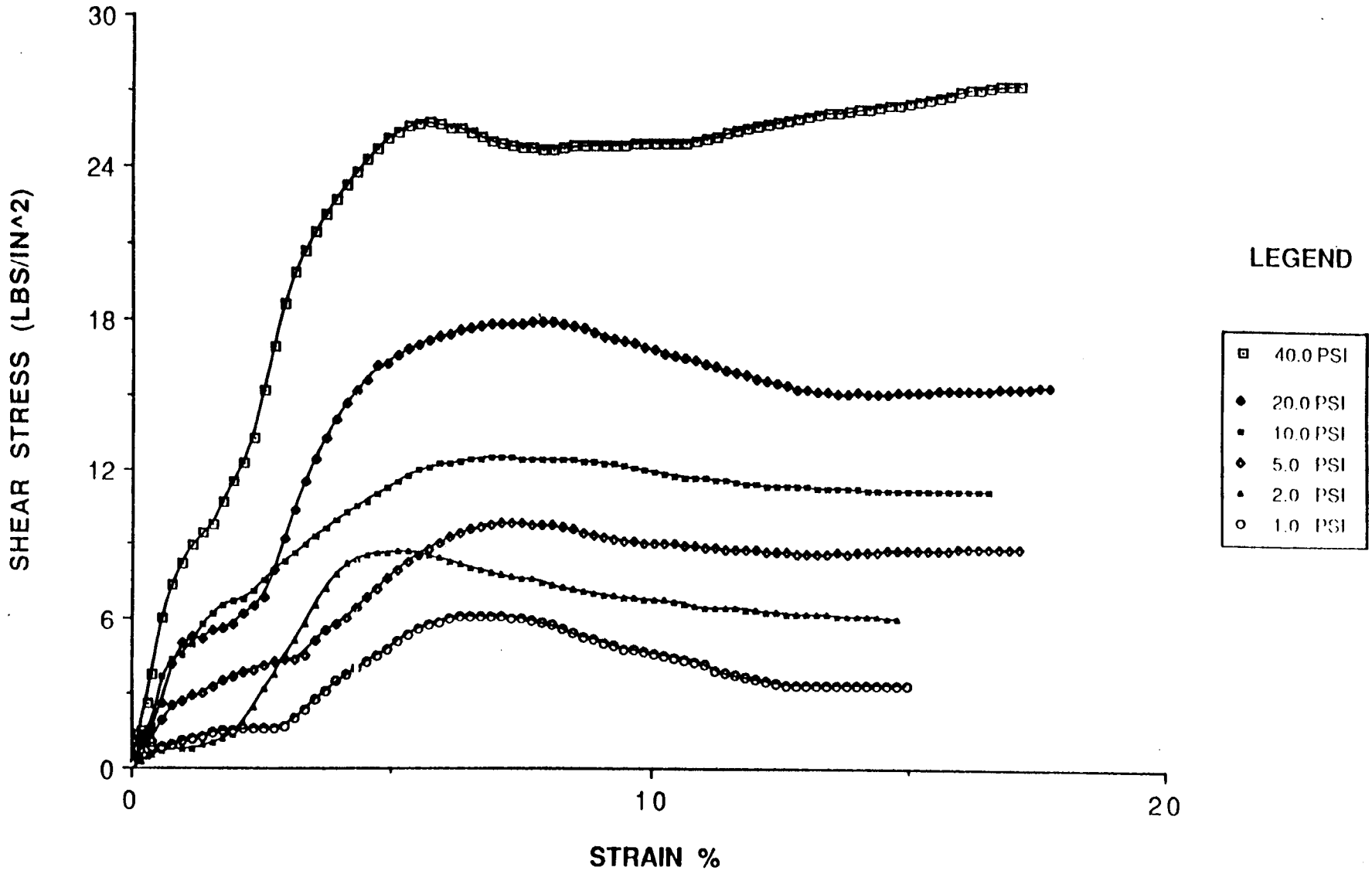


Fig. - Shear Stress Vs. Strain for Gundseal® Dry (As-Recieved-State)

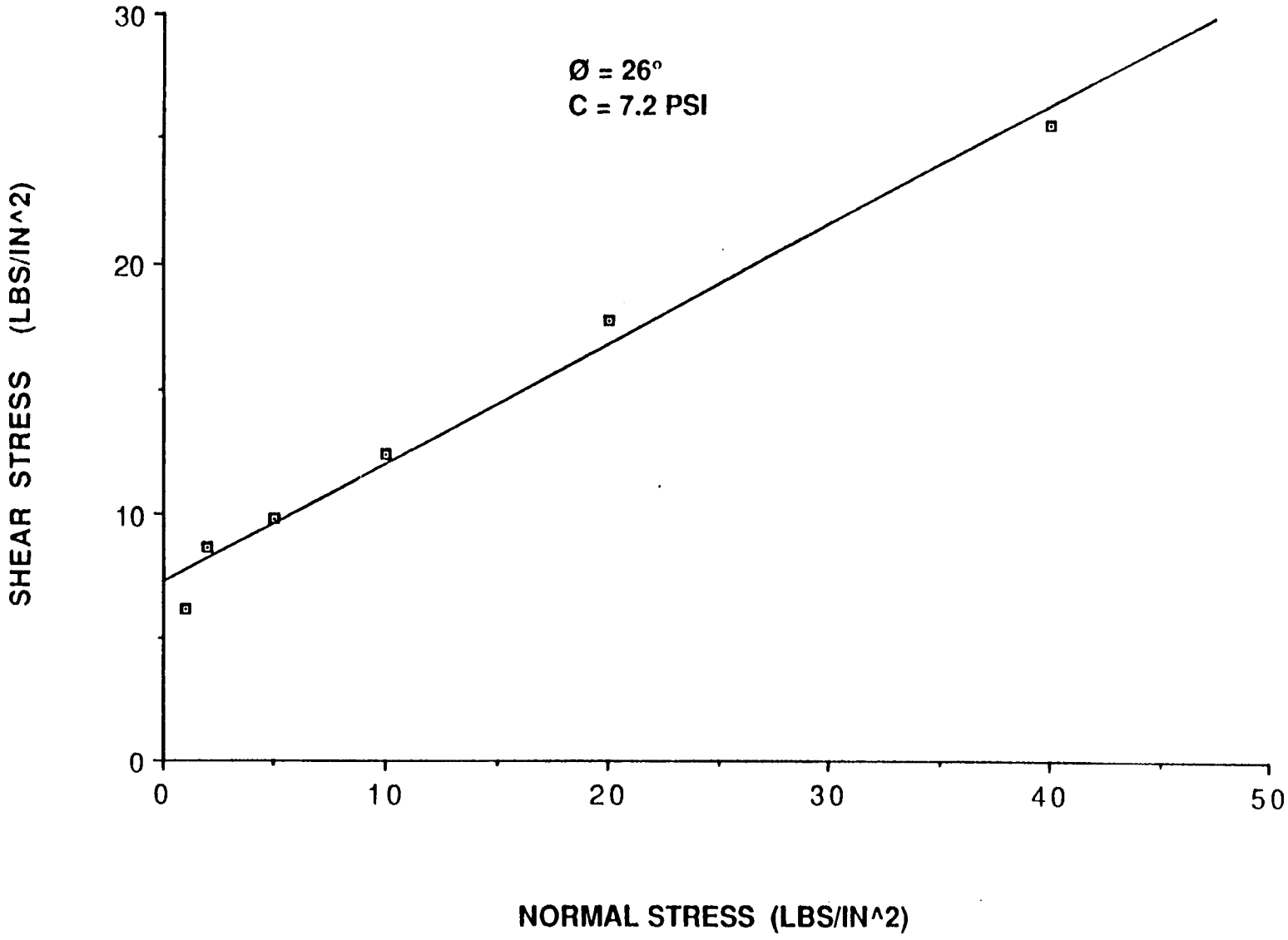


Fig. - Direct Shear Test Results for Gundseal®
in the Dry (As-Recieved-State)

Shear Strength Behavior of PBC Liners in Distilled Water

Testing in the first part of this series of shear strength tests was in the normally loaded and hydrated (i.e., "constrained swell") condition. Thus the test samples were hydrated under their desired normal pressure, and then sheared at the same normal pressure. Testing for Gundseal hydrated by distilled water has been completed, see the following two figures.

Testing in the second part of this series of shear strength tests was in the hydrated and unconsolidated (i.e., "free swell") conditions. In these tests the samples were hydrated under zero normal load, then placed in the direct shear device, loaded normally and sheared. Testing for Gundseal follows in the subsequent two figures. The shear stress versus strain test results and resulting Mohr-Coulomb failure envelopes are given. There are a limited number of data points for this condition because at higher normal pressures the clay laterally extrudes out of the stressed zone.

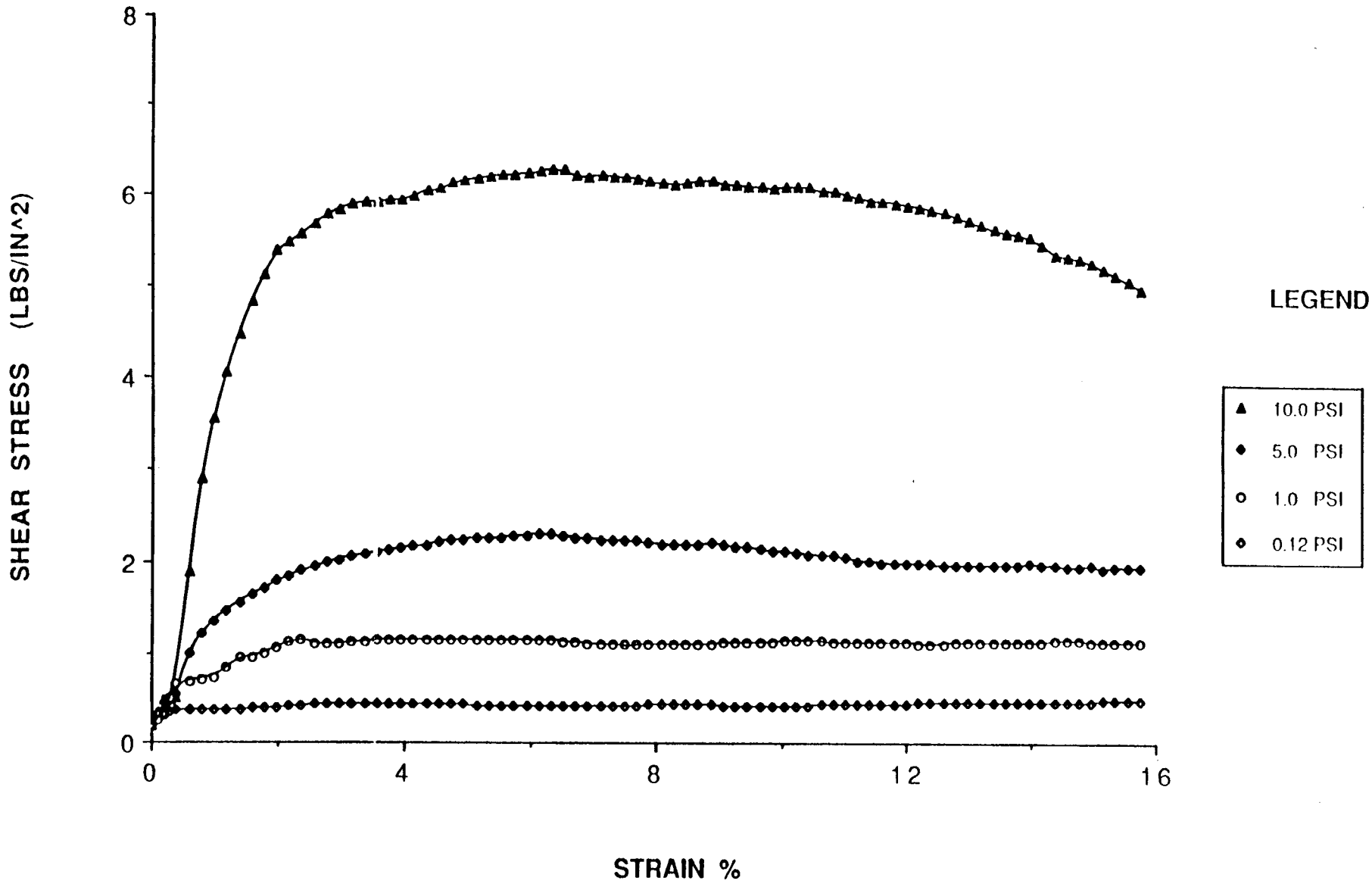


Fig. - Shear Stress Vs. Strain for Gundseal®
Hydrated in Distilled Water Under "Constrained Swell" Conditions

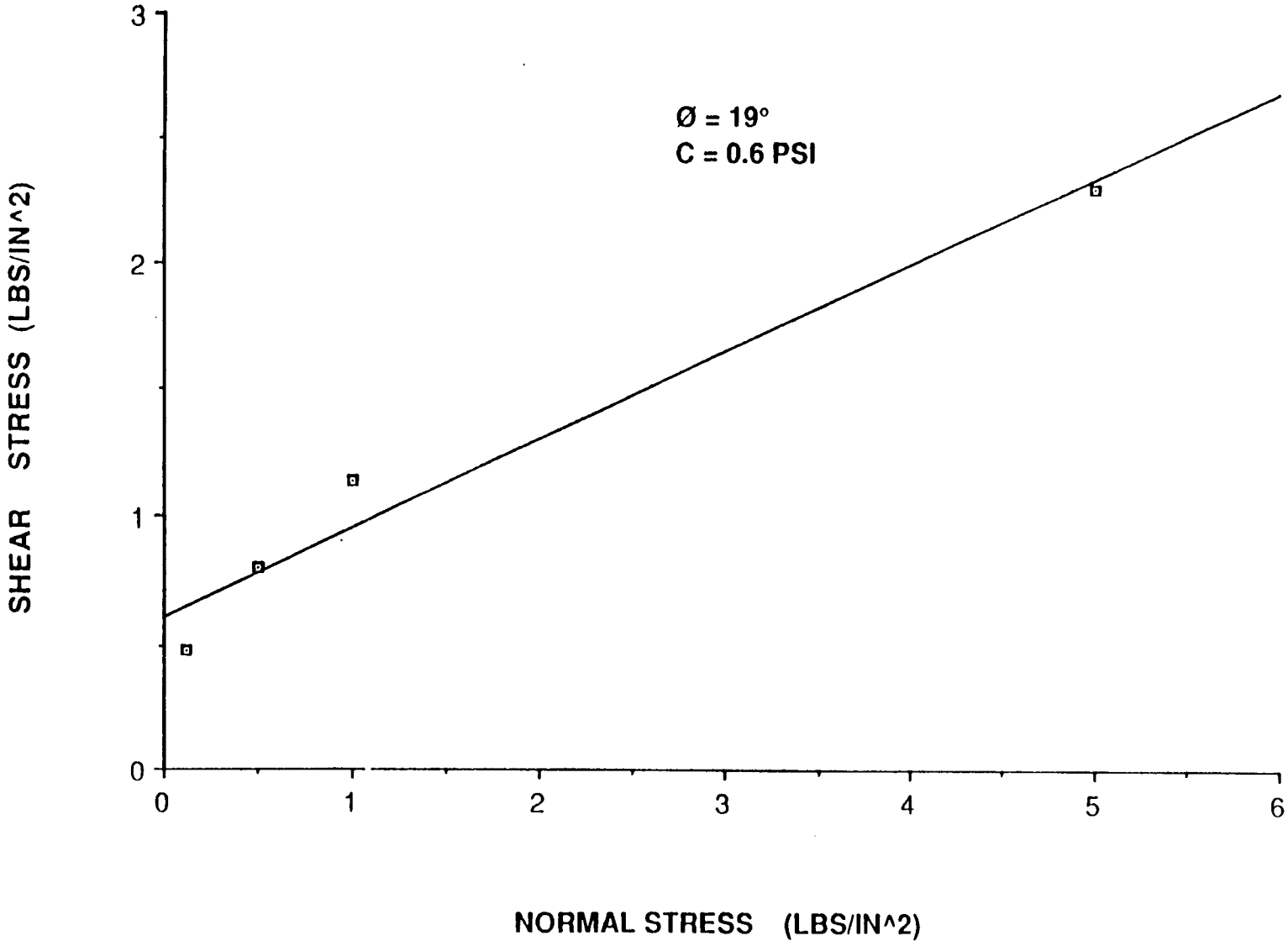


Fig. - Direct Shear Test Results for Gundseal®
Hydrated in Distilled Water Under "Constrained Swell" Conditions

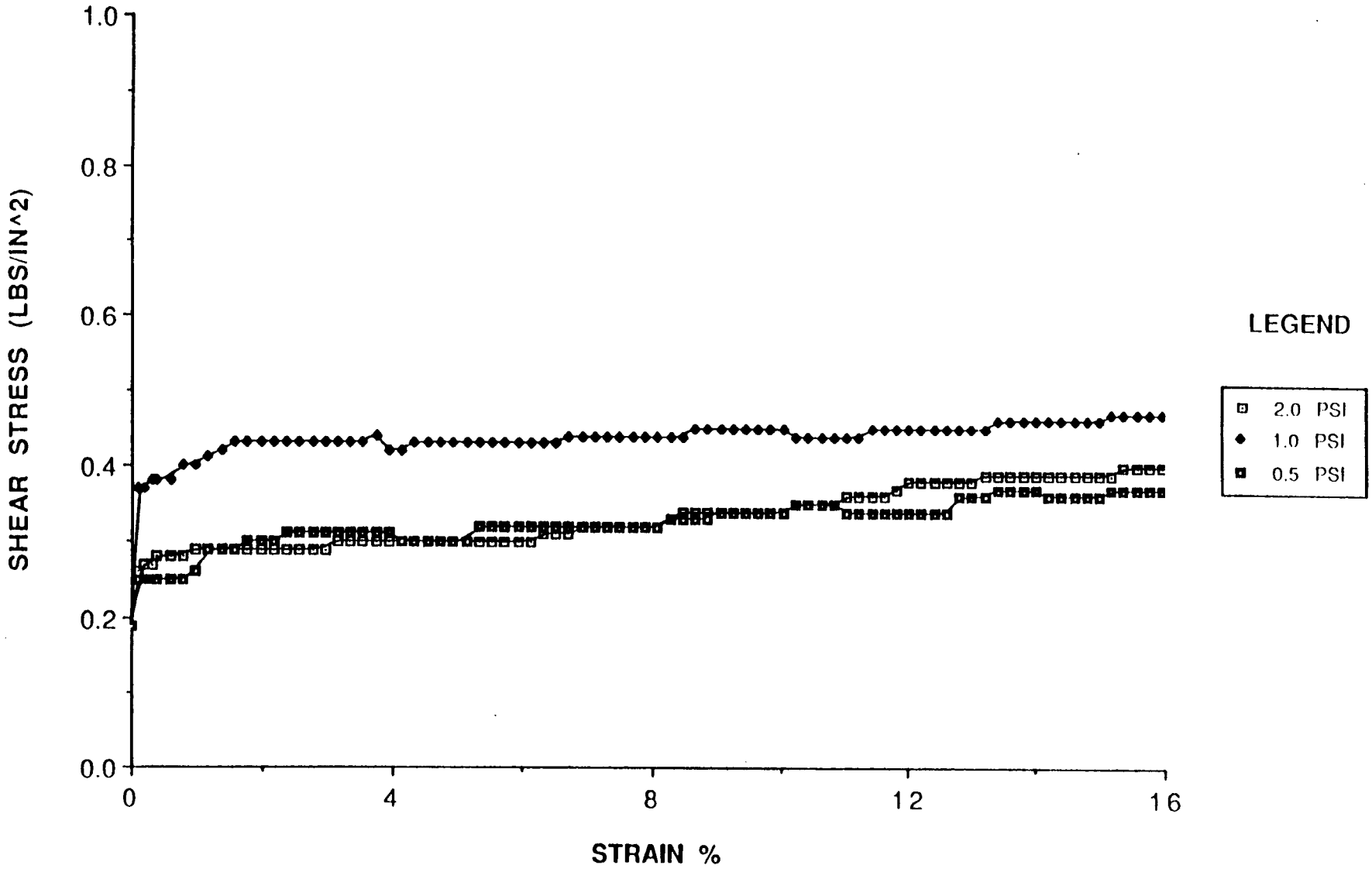


Fig. - Shear Stress Vs. Strain for Gundseal®
Hydrated In Distilled Water Under "Free Swell" Conditions

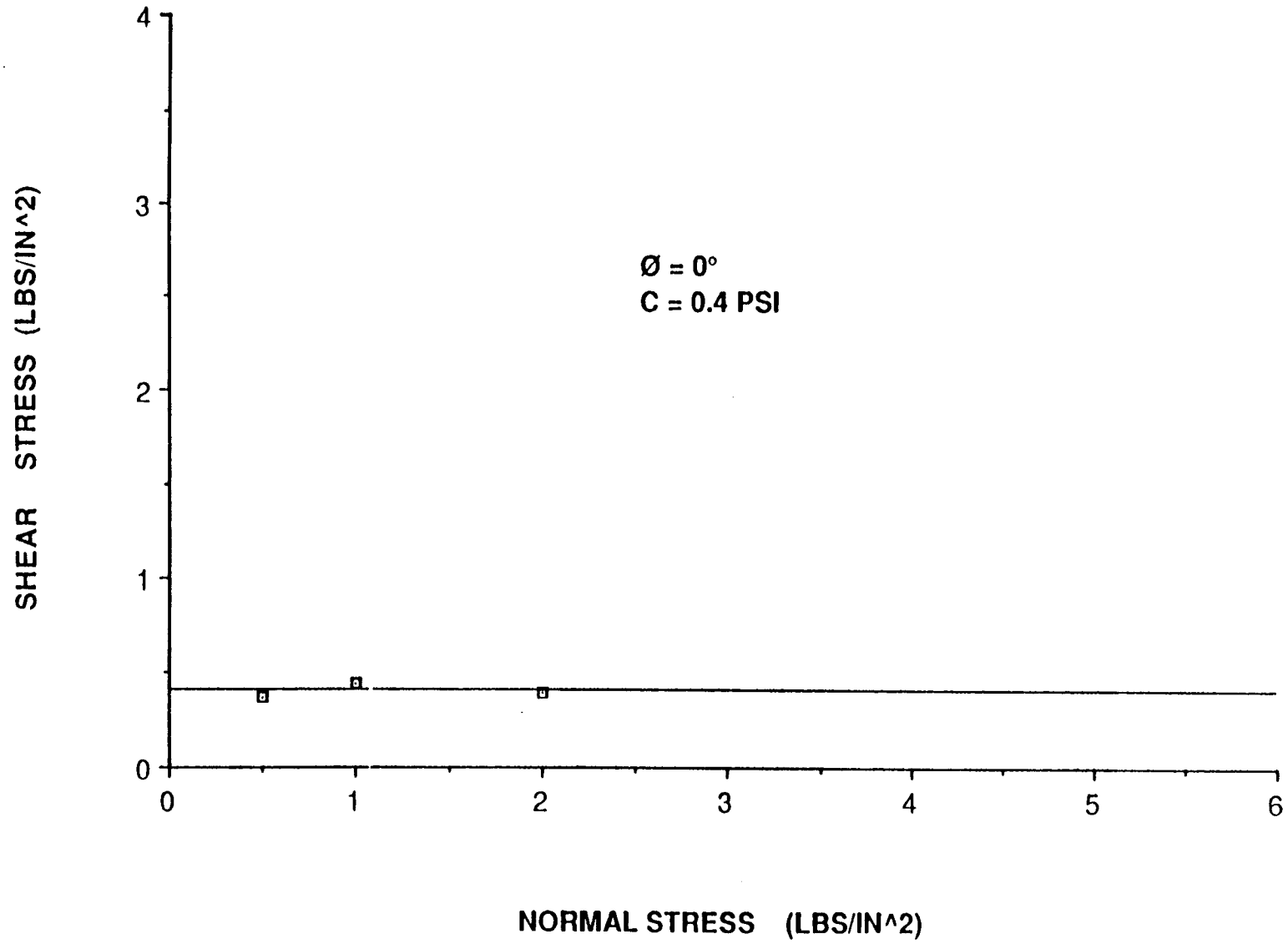


Fig. - Direct Shear Test Results for Gundseal®
Hydrated in Distilled Water Under "Free Swell" Conditions

Shear Strength Behavior of PBC Liners in Leachate #1

The same testing equipment was used in this phase of the study as in the testing with distilled water, but the testing was performed with the leachate. The shear device was again set up so that the shear plane was always in the direct center of the clay component. The leachate used in this portion of the study was obtained from a nearby domestic waste landfill. (Note it is the same leachate as was used in the swelling tests described earlier.) The approximate leachate characteristics are as shown below:

pH	COD (mg/L)	TS (mg/L)	BOD_5 (mg/L)
8.0	10,500	5000	3000

Testing in the first part of this series of shear strength tests was in the normally loaded and hydrated (i.e., "constrained swell") condition. Thus the test samples were hydrated under their desired normal pressure, and then sheared at the same normal pressure. Testing on Gundseal hydrated by domestic leachate have been completed, see the following two figures.

Testing in the second part of this series of shear strength test was in the hydrated and unconsolidated (i.e., "free swell") condition. In these tests the samples were hydrated under zero normal load, then placed in the direct shear device, loaded normally and sheared. Testing on Gundseal with domestic leachate as the hydration liquid has been completed. The shear stress versus strain test results and resulting Mohr-Coulomb failure envelopes follow in the subsequent two figures. There are a limited number of data points for this condition because at higher normal pressures the clay laterally extrudes out of the stressed zone.

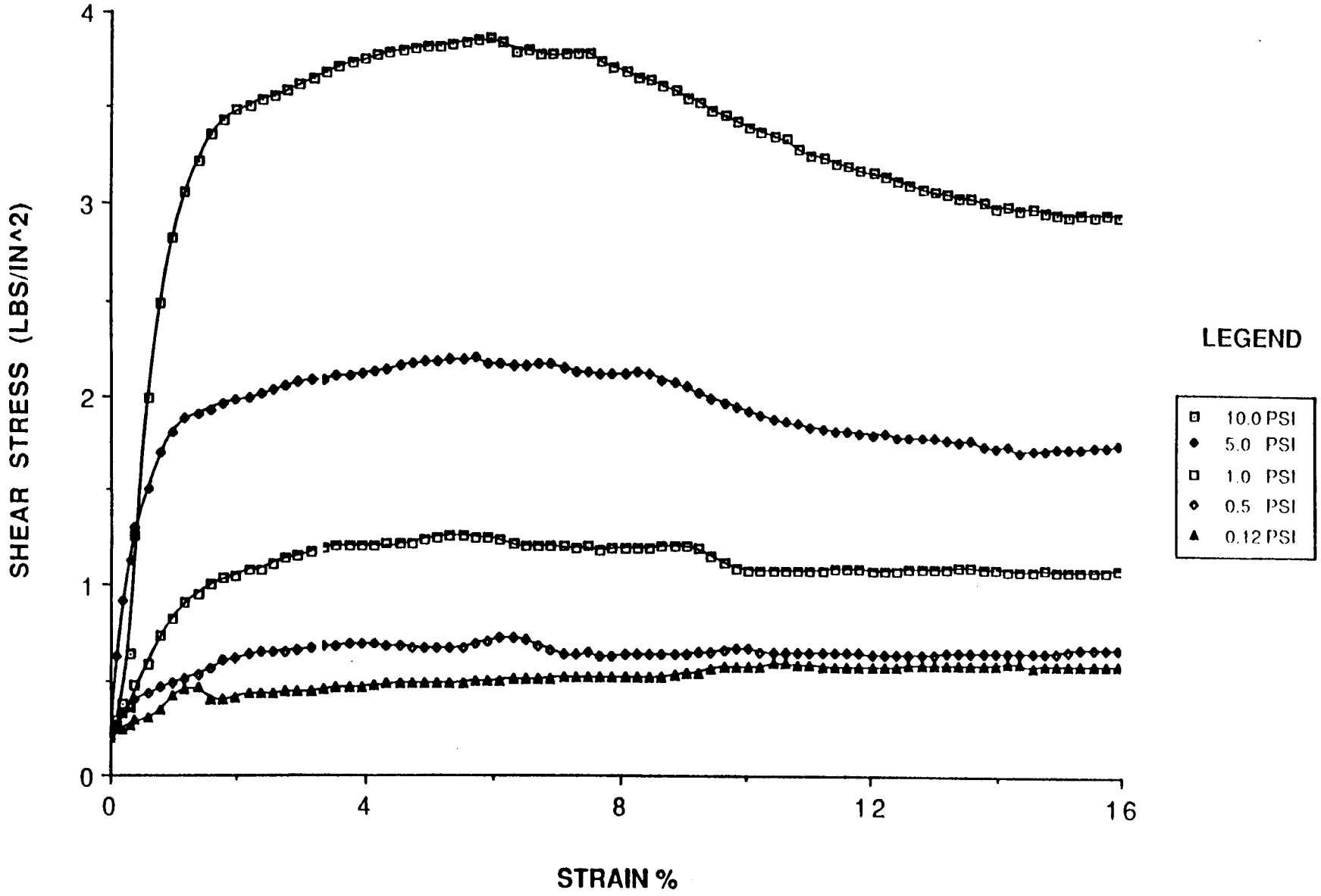


Fig. - Shear Stress Vs. strain for Gundseal®
Hydrated in Leachate Under "Constrained Swell" Conditions

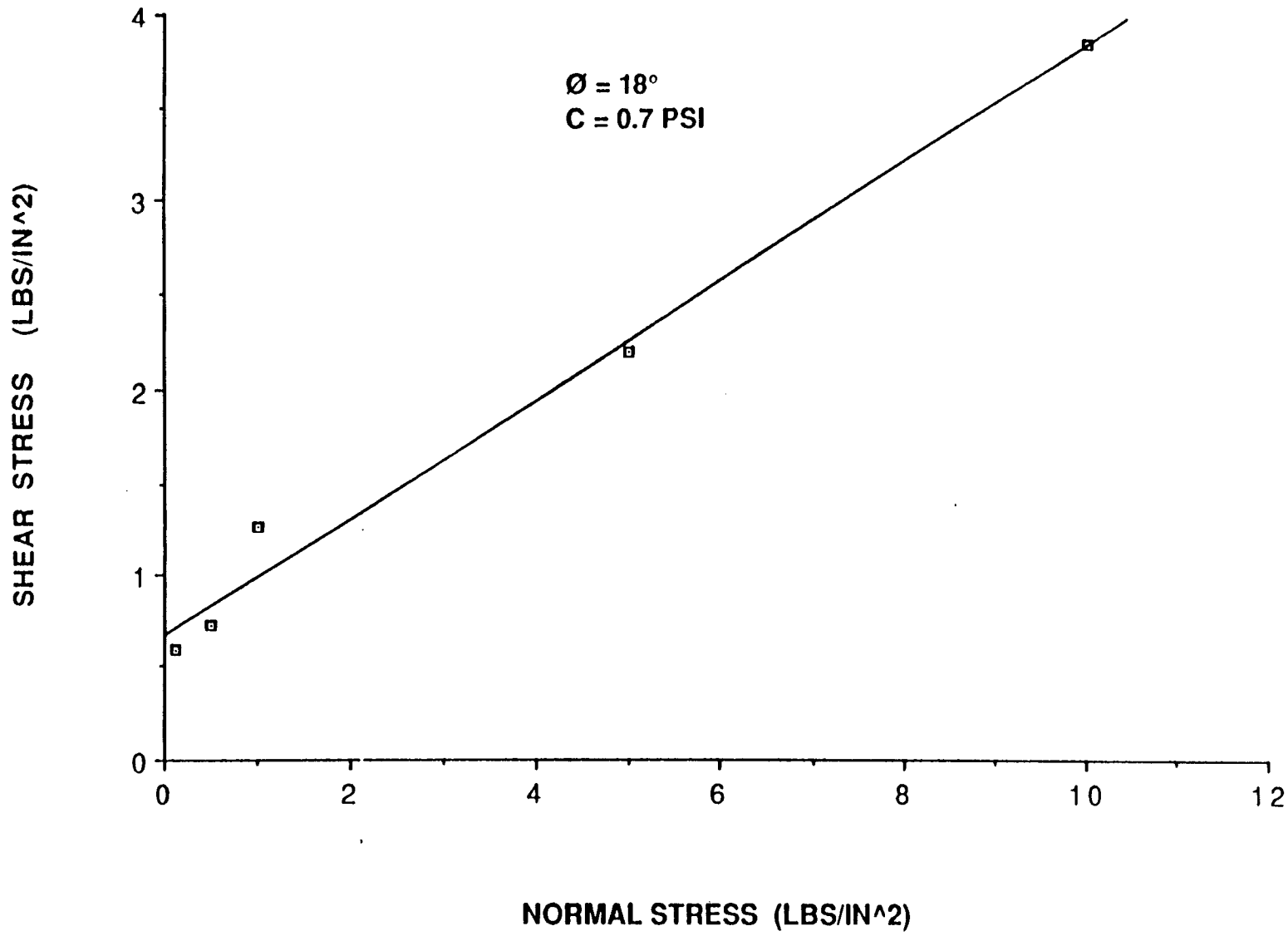


Fig. - Direct Shear Test Results for Gundseal®
Hydrated in Leachate Under "Constrained Swell" Conditions

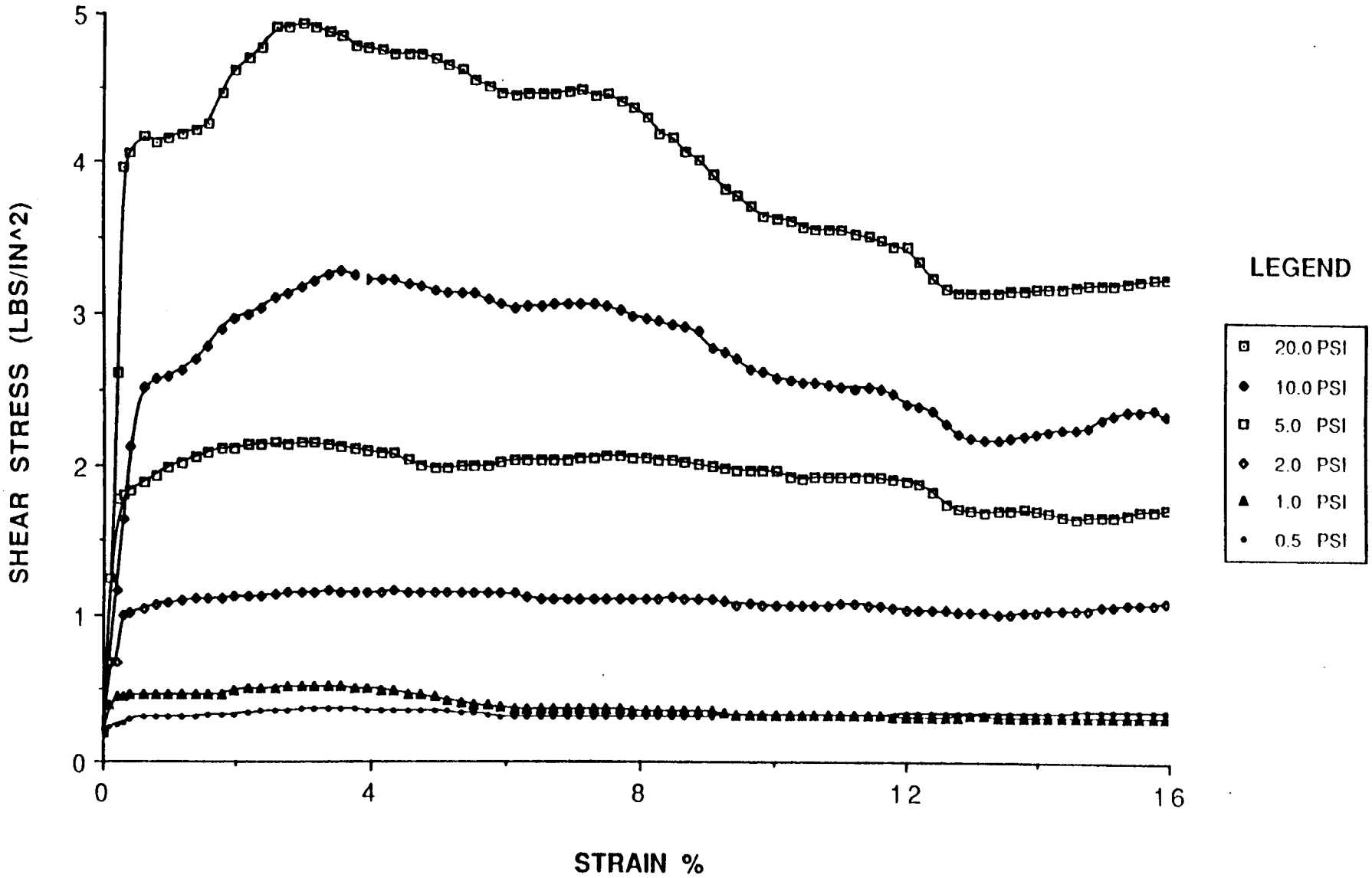


Fig. - Shear Stress Vs. Strain for Gundseal®
Hydrated in Leachate Under "Free Swell" Conditions

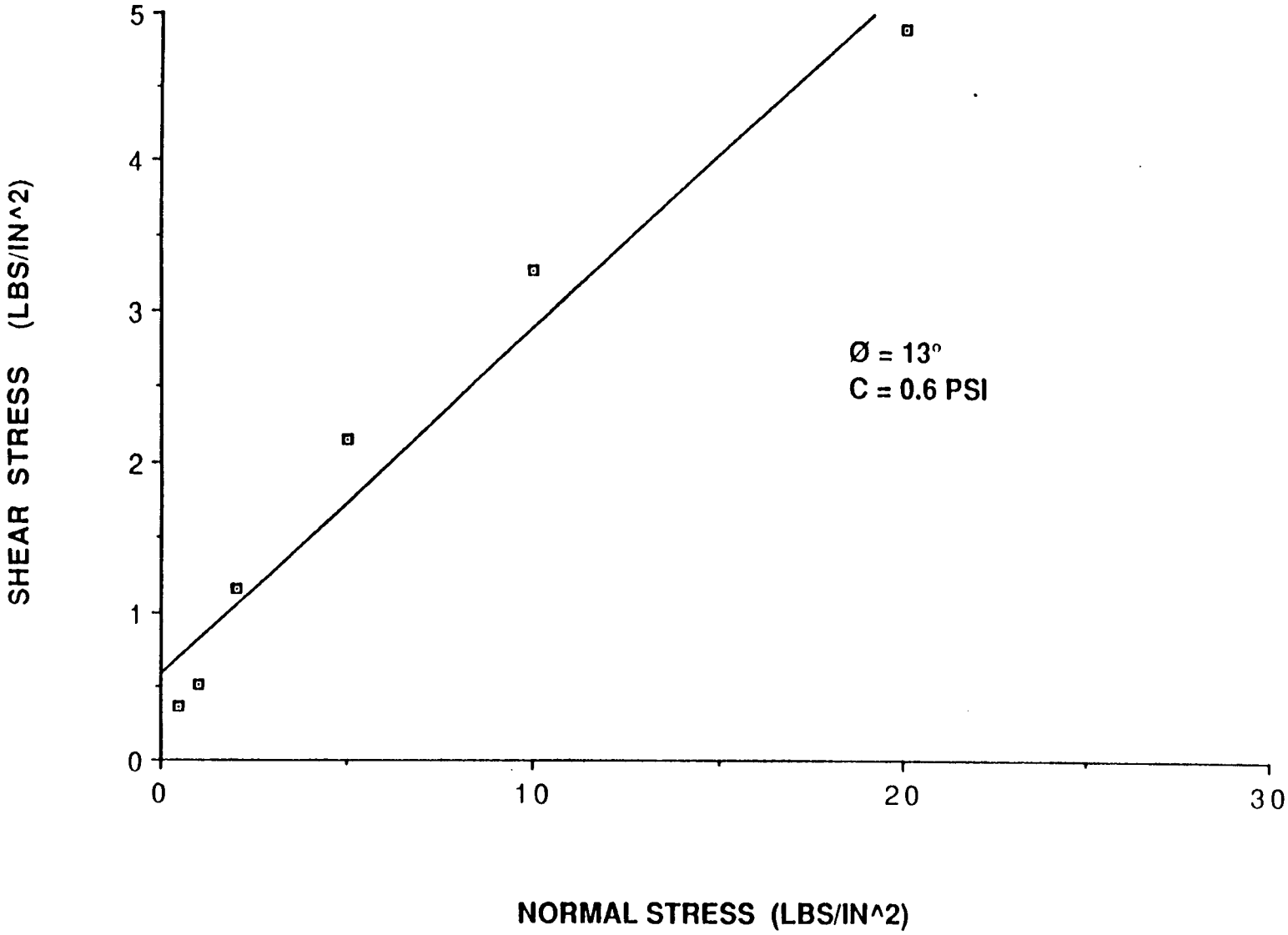


Fig. - Direct Shear Test Results for Gundseal®
Hydrated in Leachate Under "Free Swell" Conditions

Summary

The hydration and shear strength studies are currently focused on tap water hydration which will be finished in about two months. Of special interest is the selection of the next hydration leachate in order that sufficient amount can be obtained prior to completion of tap water studies to prevent any delay in the testing program.

FINAL REPORT

LABORATORY TESTING OF GUNDSEAL

Prepared for

Gundle Lining Systems Inc.
19103 Gundle Road
Houston, Texas 77073

Prepared by

GeoSyntec Consultants
Geomechanics and Environmental Laboratory
1600 Oakbrook Drive, Suite 565
Norcross, Georgia 30093

GeoSyntec Consultants Project Number: GL1614

15 June 1991

T-093

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Terms of Reference
1.2 Overview
1.3 Test Samples
1.4 Report Organization

2. TEST PROCEDURES

2.1 Task 1: EPA 9100 Compatibility Testing
2.2 Task 2: Freeze-Thaw Testing
2.3 Task 3: Desiccation Effects Testing
2.4 Task 4: Composite Action Testing
2.5 Task 5: Swell Potential Testing
2.6 Task 6: Healing Action Testing
2.7 Task 7: Seam Testing

3. TEST RESULTS

3.1 Task 1: EPA 9100 Compatibility Testing
3.2 Task 2: Freeze-Thaw Testing
3.3 Task 3: Desiccation Effects Testing
3.4 Task 4: Composite Action Testing
3.5 Task 5: Swell Potential Testing
3.6 Task 6: Healing Action Testing
3.7 Task 7: Seam Testing

4. CLOSURE

1. INTRODUCTION

1.1 Terms of Reference

This report was prepared by Mr. Stephen J. Zarlinski, E.I.T. and was reviewed by Mr. Scott M. Luettich, P.E. and Dr. Robert C. Bachus, of GeoSyntec Consultants. The bentonite mat testing program was initiated at the request of Mr. Eric D. Chiado of Almes & Associates, Inc. Consulting Engineers (Almes) and Mr. Scott Ortolon of Gundle Lining Systems Inc. (Gundle) on behalf of the Chambers Development Company, Inc. (Chambers), Pittsburgh, Pennsylvania. The work was conducted at GeoSyntec Consultants Geomechanics and Environmental Laboratory located in Norcross, Georgia.

1.2 Overview

GeoSyntec Consultants was requested to perform laboratory tests to evaluate the chemical compatibility and the performance of the bentonite component of the Gundseal product. The testing program was developed by Chambers and Almes to simulate potential worst-case field conditions. In order to test only the bentonite portion of the composite section, holes were deliberately introduced into the HDPE membrane portion of Gundseal composite.

The following seven distinct tasks made up the testing program:

- Task 1: EPA 9100 Compatibility Testing
- Task 2: Freeze-Thaw Testing
- Task 3: Desiccation Effects Testing
- Task 4: Composite Action Testing
- Task 5: Swell Potential Testing
- Task 6: Healing Action Testing
- Task 7: Seam Testing

1.3 Test Samples

The Gundseal product was provided directly to GeoSyntec Consultants by Gundle. In order to effectively test the bentonite component of the Gundseal product, Gundle provided the Gundseal test samples with 0.12-in. (0.3-cm) diameter holes drilled through the geomembrane backing. The holes were drilled on 0.3-in. (0.75-cm) centers. These holes were drilled only through the geomembrane backing and did not puncture the bentonite layer of the Gundseal. The holes were introduced for testing purposes only and are not normally found in the Gundseal product.

Clean sand was used to in many of the test conditions. In Tasks 1, 2, and 3, a 0.5-in. (13-mm) thick layer of sand was used in each of the test configurations involving flexible-wall triaxial permeameters. This layer is identified as the sand layer.

The 16-oz (454-g) nonwoven geotextile used in many of the tasks was provided to GeoSyntec Consultants by the Amoco Fabrics and Fibers Company (Amoco) and identified as Amoco 4516.

The leachate used in Task 1 was provided to GeoSyntec Consultants from Chambers Southern Alleghenies Landfill, located in Somerset County, Pennsylvania.

1.4 Report Organization

The remaining sections of this report are organized as follows:

- Section 2, Testing Procedures, provides the methods and conditions used to conduct Tasks 1 through 7. Photographs of the test equipment are provided.

- Section 3, Testing Results, provides appropriate tables and figures of the compiled test data and photographs of the test specimens.

2. TEST PROCEDURES

2.1 Task 1: EPA 9100 Compatibility Testing

Compatibility testing on Gundseal was performed to measure the effect of leachate on the hydraulic conductivity of the mat product over a prescribed period of time.

Testing was performed in accordance with the United States Environmental Protection Agency (USEPA) Method 9100 SW-846, Revision 1, 1987. The test conditions for Task 1 were as follows:

- Testing was conducted using flexible-wall triaxial permeameters, as shown in Photograph 2.1-1.

- Three replicate samples of the "drilled" Gundseal were tested.

- Each sample was trimmed to a diameter of 2.8 in. (70 mm) and assembled in the following test configuration (from bottom to top): porous stone/filter paper/sand layer/Amoco 4516 geotextile/Gundseal/Amoco 4516 geotextile/sand layer/filter paper/porous stone. The geotextile maintained the integrity of the bentonite component of the Gundseal by preventing migration of the sand into the bentonite during saturation and hydration.

- Hydration and saturation of the samples using de-aired tap water was conducted at an effective stress of 2.0 psi (14 kPa) for a time period of approximately 48 hours. Saturation was defined as a minimum Skempton's B-parameter of 0.95.

- Consolidation of the saturated test samples was performed at an effective stress of 5.0 psi (35 kPa). Pore-water displacement was monitored until primary consolidation was complete.

- To determine the baseline hydraulic conductivity, the samples were permeated using de-aired tap water. The average hydraulic gradient used for baseline permeation was approximately 50. For this testing program, initial hydration and saturation was conducted using de-aired tap water. Hydration with leachate may or may not yield different results.

- After establishing the baseline hydraulic conductivity, the permeant was switched to the leachate. Because of the slow permeation rates and the objective to increase the volume of leachate in contact with the Gundseal, the sand layer was replaced on all samples by an Amoco 4516 geotextile after approximately one week of testing. Permeation of the samples with the leachate continued for an additional 30 days. The hydraulic conductivity of the samples was monitored and reported daily during this period.

- Permeation of the test specimens was initially conducted at an average hydraulic gradient of approximately 50. In order to increase flow through the Gundseal during the prescribed time period, the average hydraulic gradients were increased to approximately 230.

- Because the final hydrated thickness of the Gundseal is unknown until the completion of testing and for comparison of the test data, the hydraulic conductivity was calculated using 0.30 in. (0.75 cm) for the Gundseal. These values were used in all calculations of hydraulic conductivity in Tasks 1 through 7.

2.2 Task 2: Freeze-Thaw Testing

The purpose of Task 2 was to determine the hydraulic conductivity of Gundseal after each of four freeze-thaw cycles. Testing was performed in accordance with the guidelines set forth in the United States Army

Corps of Engineers (USCOE) EM-1110-2-1906, Appendix VII, and the American Society for Testing and Materials (ASTM) D 560, *Standard Methods for Freezing-and-Thawing Tests of Compacted Soil-Cement Mixture.* The test conditions for Task 2 were as follows:

- Testing was conducted using flexible-wall triaxial permeameters, as shown in Photograph 2.1-1.

- One sample of the "drilled" Gundseal was tested.

- The sample was trimmed to a diameter of 2.8 in. (70 mm) and assembled in the following test configuration (from bottom to top): porous stone/filter paper/sand layer/Amoco 4516 geotextile/Gundseal/Amoco 4516 geotextile/sand layer/filter paper/porous stone. The geotextile maintained the integrity of the bentonite component of the Gundseal by preventing migration of the sand into the bentonite during saturation and hydration.

- Hydration and saturation of the sample using de-aired tap water was conducted at an effective stress of 2.0 psi (14 kPa) for a time period of approximately 48 hours. Saturation was defined as a minimum Skempton's B-parameter of 0.95.

- Consolidation of the saturated test sample was performed at an effective stress of 5.0 psi (34 kPa). Pore-water displacement was monitored until primary consolidation was complete.

- To determine the hydraulic conductivity, de-aired tap water was permeated at an average hydraulic gradient of approximately 235. Permeation of the specimen continued until three consistent values of hydraulic conductivity were obtained over a 24-hour time period and the inflow and outflow rates were approximately equivalent.

- The backpressure and confining pressure were then simultaneously decreased to maintain the effective stress difference across the sample. When the backpressure was reduced to zero, the confining pressure was released and the sample was removed from the triaxial cell. The membrane was removed and the sample was wrapped in parafilm to maintain the water content. The wrapped sample was placed on a platform and subjected to a small confining pressure of 0.4 psi (3 kPa).

- The specimen was placed in a freezer for 24 hours, after which time the sample was removed and allowed to thaw at room temperature for 24 hours. The sample was confined during the entire freezing and thawing process.

- After thawing, the parafilm was removed and the sample was placed in the flexible-wall triaxial permeameter and tested following the techniques used for the initial unhydrated sample (i.e., saturation, evaluation of Skempton's B-parameter, consolidation, and permeation). The process of freezing, thawing, and permeability testing constituted one complete freeze-thaw cycle.

- In order to expedite testing and to minimize potential mixing of the sand and bentonite, the sand layer was removed from the test configuration.

- The testing was terminated after four freeze-thaw cycles.

- It is recognized that in-situ freezing and thawing of the Gundseal will likely occur in one-dimension, from the ground surface downward. In order to simulate a worst-case condition, laboratory freezing occurred three-dimensionally.

2.3 Task 3: Desiccation Testing

The purpose of Task 3 was to determine the hydraulic conductivity of Gundseal after each of four desiccation cycles. Testing was performed in general accordance with guidelines set forth in the USCOE EM-1110-2-1906, Appendix VII, and in ASTM D 559, *Standard Methods for Wetting-and-Drying Tests of Compacted Soil-Cement Mixture*. The test conditions for Task 3 were as follows:

- Testing was conducted using flexible-wall triaxial permeameters, as shown in Photograph 2.1-1.

- One sample of "drilled" Gundseal was tested.

- The sample was trimmed to a diameter of 2.8 in. (70 mm) and assembled in the following test configuration for triaxial permeability testing: porous stone/filter paper/sand layer/Amoco 4516 geotextile/Gundseal/Amoco 4516 geotextile/sand layer/filter paper/porous stone. The geotextile maintained the integrity of the bentonite component of the Gundseal by preventing migration of the sand into the bentonite during saturation and hydration.

- Hydration and saturation of the sample using de-aired tap water was conducted at an effective stress of 2.0 psi (14 kPa) for a time period of approximately 48 hours. Saturation was defined as a minimum Skempton's B-parameter of 0.95.

- Consolidation of the saturated test sample was performed at an effective stress of 5.0 psi (34 kPa). Pore-water displacement was monitored until primary consolidation was complete.

- To determine the hydraulic conductivity, de-aired tap water was permeated at an average hydraulic gradient of approximately 215. Permeation of the specimen continued until three consistent

values of hydraulic conductivity were obtained over a 24 hour time period and the inflow and outflow rates were approximately equivalent.

- The backpressure and confining pressure were then simultaneously decreased to maintain the effective stress difference across the sample. When the backpressure was reduced to zero, the confining pressure was released and the sample was removed from the triaxial cell. The sample was placed on a platform and subjected to a small confining stress of 0.4 psi (3 kPa). The sample was placed in an oven for two weeks at a temperature of 40°C (104°F).

- After the two week drying period, the sample was placed in the flexible-wall triaxial permeameter and tested following the techniques used for the initial unhydrated sample (i.e., hydration and saturation, evaluation of Skempton's B-parameter, consolidation, and permeation). The process of desiccating, hydrating, and permeability testing constituted one complete desiccation test cycle.

- Because of the potential for mixing of the desiccated bentonite and the sand, the sand layer was removed from the testing configuration.

- A total of four desiccation cycles are being conducted.

- It is recognized that in-situ desiccation of the Gundseal will likely occur in one-dimension, from the ground surface downward. In order to simulate a worst-case condition, laboratory desiccating occurred three-dimensionally. The sample was desiccated in an oven at 40°C (104°F). This temperature was selected as a maximum average atmospheric temperature for field conditions.

2.4 Task 4: Composite Action Testing

The purpose of Task 4 was to measure the hydration characteristics of unhydrated Gundseal and the lateral spreading of the wetting front when water was introduced through a small hole in an overlying geomembrane. The testing was performed in general accordance with guidelines set forth in ASTM D 2434, *Standard Test Method for Permeability of Granular Soils*. The test conditions for Task 4 were as follows:

- A 4-in. (100-mm) diameter rigid-wall compaction permeameter was used.

- A 4-in. (100-mm) thick layer of clean sand was initially placed in the compaction mold. The sand was percolated with de-aired tap water from the bottom of the sample to the top in order to saturate the sand. A 60-mil thick smooth geomembrane with a 0.04-in. (1-mm) diameter hole cut in the center, as shown in Photograph 2.4-1, was placed over the saturated sand. The unhydrated Gundseal was placed over the geomembrane. The Amoco 4516 geotextile was placed over the Gundseal.

- The permeameter was inverted and flow with de-aired tap water was initiated down through the sand under approximately 12 in. (305 mm) of hydraulic head. The influent hydraulic head was reset periodically if necessary. Photograph 2.4-2 shows the equipment set-up.

- The apparent hydraulic conductivity of the composite specimen was monitored via the drop in the influent water with time using falling-head techniques. The apparent hydraulic conductivity was evaluated numerically using the entire cross-sectional area of the Gundseal specimen.

- The test was terminated after a period of 51 hours.

After termination of the test, the sample was disassembled and the specimen was removed. To determine the water content as a function of the lateral distance from the center hole in the geomembrane, three pieces were trimmed from the specimen at radii of 0 to 0.3r, 0.3r to 0.7r, and 0.7r to r, where r is the full radius of the specimen.

2.5 Task 5: Swell Potential

The purpose of Task 5 was to determine the swell potential of unhydrated Gundseal upon initial hydration. Testing was performed in accordance with ASTM D 4546, *Standard Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils*. The test conditions for Task 5 were as follows:

- Testing was performed using one-dimensional (floating-ring) consolidometers as shown in Photograph 2.5-1.

- Four samples of the "drilled" Gundseal were tested at varying confining stresses.

- Confining pressures of 2, 20, 60, and 110 psi (14, 138, 413, and 758 kPa, respectively) were applied to four unhydrated samples of Gundseal. The samples were hydrated and the vertical deformation was monitored as a function of elapsed time. Readings were taken until primary swelling or consolidation was complete.

2.6 Task 6: Healing Action

The purpose of Task 6 was to determine the ability of the Gundseal to heal defects or damage to the bentonite mat. The testing was performed in general accordance with guidelines set forth in ASTM D 2434,

Standard Test Method for Permeability of Granular Soils. The test conditions for Task 6 were as follows:

- Testing was performed using a 6-in. (150-mm) diameter rigid-wall permeameter as shown in Photograph 2.6-1. The constant-head permeameter was used to accommodate the potential range of flows.

- Each test specimen was assembled using unhydrated "drilled" Gundseal in the following composite configuration (from bottom to top): 2 in. (50 mm) clean sand/Amoco 4516 geotextile/ unhydrated Gundseal/Amoco 4516 geotextile/12 in. (300 mm) clean sand.

  - One sample was tested for baseline permeability without any defects;
  - One sample was tested with a 1-in. (25-mm) diameter hole cut in the center;
  - One sample was tested with a 2-in. (50-mm) diameter hole cut in the center; and
  - One sample was tested with a 3-in. (76-mm) long slit. The slit was cut to a width of 0.2 in. (5 mm) to approximate a natural tear in the material.

- The defects outlined above were created through the bentonite and geomembrane backing. It is recognized that an actual field tear may or may not puncture the entire geocomposite. The laboratory testing was a worst-case simulation.

- Flow was initiated down through the sand and the unhydrated Gundseal under approximately 12 in. (300 mm) of hydraulic head, which was maintained throughout the test.

- The hydraulic conductivity of the mat was monitored by measuring the quantity of effluent with time. The hydraulic conductivity

was determined using the entire cross-sectional area of the Gundseal specimen.

- Each test was terminated after a period of two days.

After termination of the tests, the samples were disassembled and the physical appearance of the samples was photographically documented.

2.7 Task 7: Seam Testing

The purpose of Task 7 was to evaluate the effectiveness of overlap seaming of the Gundseal product. Testing was performed in general accordance with guidelines set forth in ASTM D 2434, *Standard Test Methods for Permeability of Granular Soils*. The test conditions for Task 7 were as follows:

- Testing was performed using a 6 in. (152 mm) diameter rigid-wall permeameter as shown in Photograph 2.6-1.

- One sample of "drilled" Gundseal was tested using the following composite configuration (from bottom to top): 2 in. (50 mm) clean sand/unhydrated Gundseal/12 in. (300 mm) clean sand. The seam overlap of the bentonite mat was 3 in. (75 mm) wide. The sample was formed by overlapping two pieces of the Gundseal.

- Flow was initiated down through the sand and the unhydrated Gundseal under approximately 12 in. (300 mm) of hydraulic head, which was maintained throughout the test.

- The hydraulic conductivity of the mat was monitored by measuring the quantity of effluent with time. The hydraulic conductivity was determined using the entire cross-sectional area of the Gundseal specimen, and a hydrated single-layer thickness, as outlined in Task 1.

- The test was terminated after a period of five days.

After termination of the test, the sample was disassembled and the physical appearance of the sample was photographically documented.

3. TEST RESULTS

This section provides tables and figures of the compiled test data, photographs of the test specimens, and any visual observations that might be pertinent to the interpretation of the test results. Graphical presentations were generated from all acquired data points. Straight-line interpolation is shown between all acquired data, however for clarity, not all data points are labeled.

3.1 Task 1: EPA 9100 Compatibility Testing

3.1.1 Test Results

The physical conditions of the three Gundseal specimens, measured before and after the tests, are summarized in Table 3.1-1. Graphical presentations of the hydraulic conductivity as a function of elapsed time are presented in Figures 3.1-1, 2, and 3. Graphical presentations of the hydraulic conductivity as a function of the volume of liquid passed through the specimens (i.e., pore volumes) are presented in Figures 3.1-4, 5, and 6.

3.1.2 Observations

Because of the low hydraulic conductivities for Gundseal, and in order to maximize the volume of leachate, the sand layer in each test was removed during that test. This generally occurred shortly before the permeant was switched from water to leachate. In many cases the data indicated erratic behavior for a short time after the switch, but the hydraulic conductivities did eventually become consistent.

All sample specimens were initially permeated at a hydraulic gradient of 50. The resulting hydraulic conductivity measurements were somewhat variable. The hydraulic gradient was subsequently increased to 230 after approximately five days of testing. The test results tended to stabilize

after the gradient increase. The average hydraulic gradients that were used for the remainder of each test after the initial gradient increase is indicated on each figure.

In all cases, the data presented in the tables show that each sample swelled in thickness, and that each sample experienced an apparent loss of mass. The effluent water, however, was not visibly cloudy in any of the tests.

In each figure, a transition from water to leachate is indicated. The variability in the test results near this transition is likely the result of disturbance due to leachate injection and removal of the sand layer. Within a short period of time the test results stabilized.

3.2 Task 2: Freeze-Thaw Testing

3.2.1 Test Results

Physical conditions of the Gundseal test specimen, measured before the testing and upon completion of the fourth freeze-thaw cycle, are presented in Table 3.2-1. A graphical presentation of the hydraulic conductivity values at the end of each cycle is provided in Figure 3.2-1. Photographic documentation of the appearance of the test specimen before testing and upon completion of the fourth cycle is provided in Photographs 3.2-1, 2, and 3.

3.2.2 Observations

No visual observations of degradation of the Gundseal was observed during each of the freeze-thaw cycles. The sample appeared to be intact and no cloudiness of the effluent water during permeation was observed. There was, however, a recorded difference in dry mass between the initiation and the completion of the testing program.

3.3 Task 3: Desiccation Testing

3.3.1 Test Results

Physical conditions of the Gundseal test specimen, measured before the testing and upon completion of the fourth desiccation cycle, are presented in Table 3.3-1. A graphical presentation of the hydraulic conductivity values at the end of each cycle is provided in Figure 3.3-1. Photographic documentation of the appearance of the test specimen before testing and upon completion of the fourth cycle is provided in Photographs 3.3-1, 2, 3, 4, 5, and 6.

3.3.2 Observation

The Gundseal was confined by a vertical confining stress during desiccation in order to prevent excessive sample shrinkage. The bentonite flocculated upon drying even with the confining stress. Although the bentonite component of the Gundseal is attached to the geomembrane using an adhesive, a cracking pattern due to flocculation of the bentonite particles was observed. This observation is shown in Photograph 3.3-3. In all cases, the materials re-hydrated and regained their physical integrity and low hydraulic conductivity. The hydration of the desiccated samples occurred over a longer period of time than undesiccated samples, as would be expected.

3.4 Task 4: Composite Action Testing

3.4.1 Test Results

Results of the composite action test performed using Gundseal are presented in terms of the following two figures:

- Figure 3.4-1 shows the "apparent" hydraulic conductivity values plotted as a function of elapsed time. The apparent hydraulic

conductivity was calculated using the full specimen diameter of 4 in. (10 cm).

- Figure 3.4-2 shows a schematic diagram of the Gundseal composite action specimen. This figure shows the initial (unhydrated) water content and the water contents at the completion of testing, measured at radii of 0 to 0.3r, 0.3r to 0.7r, and at the completion of testing, 0.7r to r, where r is the full radius of the specimen.

Photographic documentation of the physical appearance of the test specimen after testing is shown in Photographs 3.4-1, 2, and 3.

3.4.2 Observations

The flow of influent water was monitored for the 51 hour time period. No effluent water was observed, indicating that all flow was absorbed by the Gundseal. Upon removal of the sample from the permeameter, no apparent wetting front was observed.

3.5 Task 5: Swell Potential Testing

3.5.1 Test Results

The physical conditions of the four Gundseal test specimens, measured before and after each test, are summarized in Table 3.5-1. Graphical presentation of the axial strain as a function of elapsed time for each of the four confining pressures is provided in Figure 3.5-1. In these figures, positive strain indicates swelling, negative strain indicates consolidation. Graphical presentation of the axial strain as a function of confining stress is provided in Figure 3.5-2.

3.5.2 Observations

Because the consolidometer uses a rigid wall floating ring, no change in the sample diameter is allowed to occur. No significant changes in mass occurred for the swell testing. The axial strains reported were calculated using the measured shrinkage or swell relative to the initial height of the geocomposite

3.6 Task 6: Healing Action Testing

3.6.1 Test Results

The physical conditions of the four Gundseal test specimens, measured before and after each flow test, are presented in Table 3.6-1. Graphical presentation of the hydraulic conductivity values, for the four Gundseal test specimens, as a function of elapsed time is provided in Figure 3.6-1. Photographic documentation of the appearance of the test specimens before and after testing is provided in Photographs 3.6-1, 2, 3, 4, 5, 6, 7, and 8.

3.6.2 Observations

In all cases, the effluent flow had a cloudy color indicating bentonite loss from each of the samples. The data show a mass loss from the initiation to the completion of testing. The Gundseal specimen tested with no defects apparently hydrated to a point that flow was below the detection limits of the permeameter.

3.7 Task 7: Seam Testing

3.7.1 Test Results

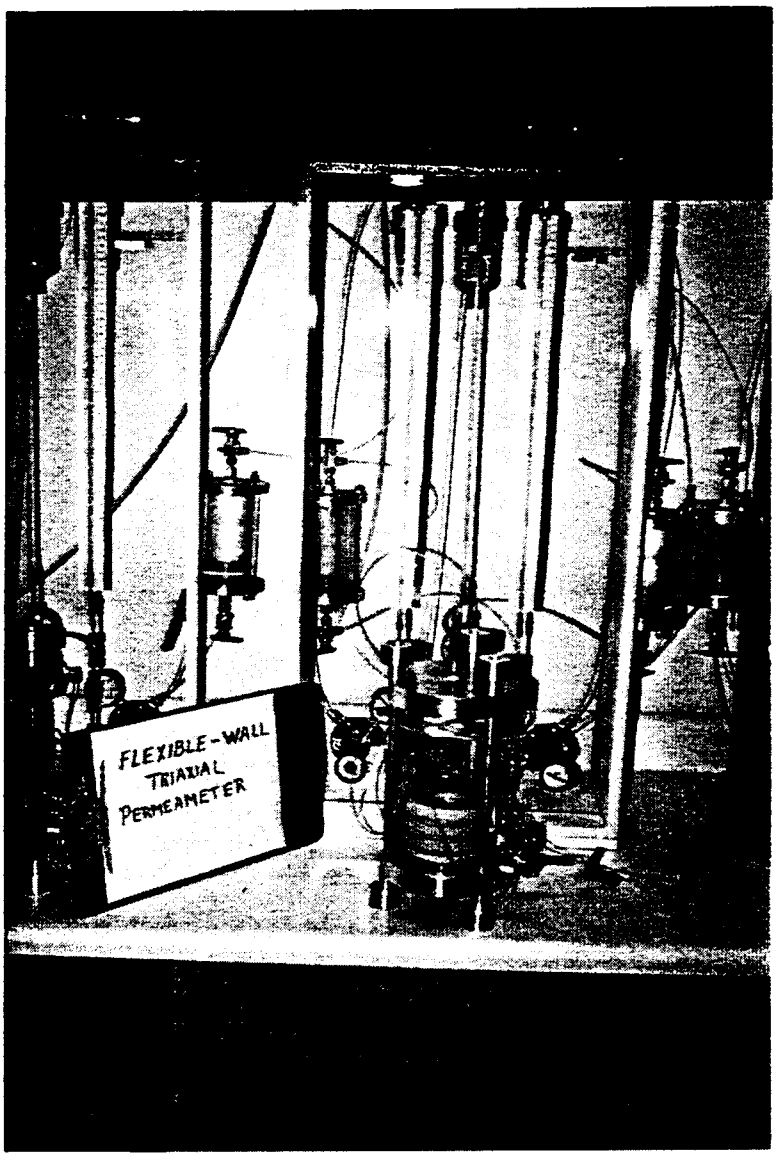
The physical conditions of the Gundseal seam test specimen are presented in Table 3.7-1. Graphical presentation of the hydraulic conductivity as a function of elapsed time is provided in Figure 3.7-1. Photographic documentation of the appearance of the seam test specimen before and after testing is provided in Photographs 3.7-1, 2, and 3.

3.7.2 Observations

The Gundseal seam sample initially had a high hydraulic conductivity. However, hydration of the bentonite did occur, as is indicated by the decreasing hydraulic conductivity values in Figure 3.7-1. The Gundseal seam sample hydrated to a point where the flow rate was below the detection limits of the equipment. This occurred after approximately four days of testing. The data show a mass loss for the Gundseal.

4. CLOSURE

These materials were supplied by the manufacturer and are assumed to be representative of the products which are commercially available. The laboratory test results in this report apply only to the materials tested. The testing was performed in accordance with the general engineering standards and conditions reported. This report is submitted for exclusive use by Chambers Development Company, Inc. and any appointed representatives; Almes & Associates, Inc., Consulting Engineers; and Gundle Lining Systems Inc..

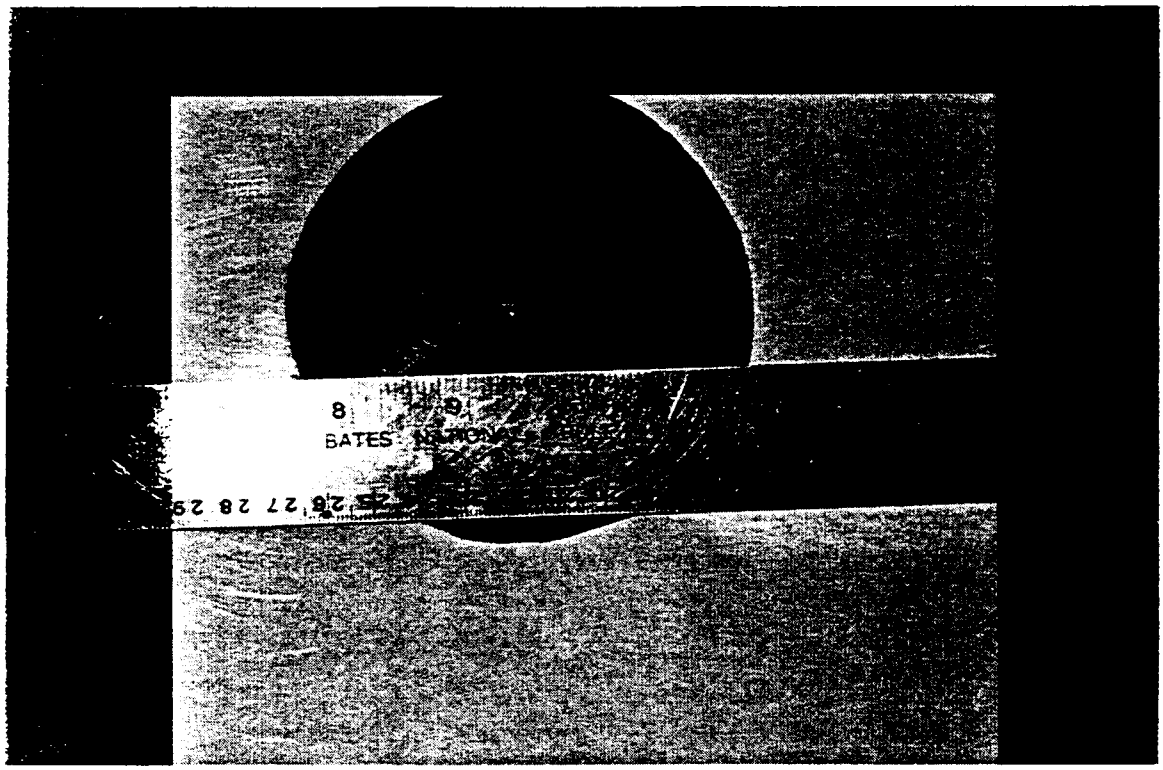


PERMEABILITY TEST EQUIPMENT

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	2.1-1
PROJECT NO.	GL1614
DOCUMENT NO.	
PAGE NO.	

308913

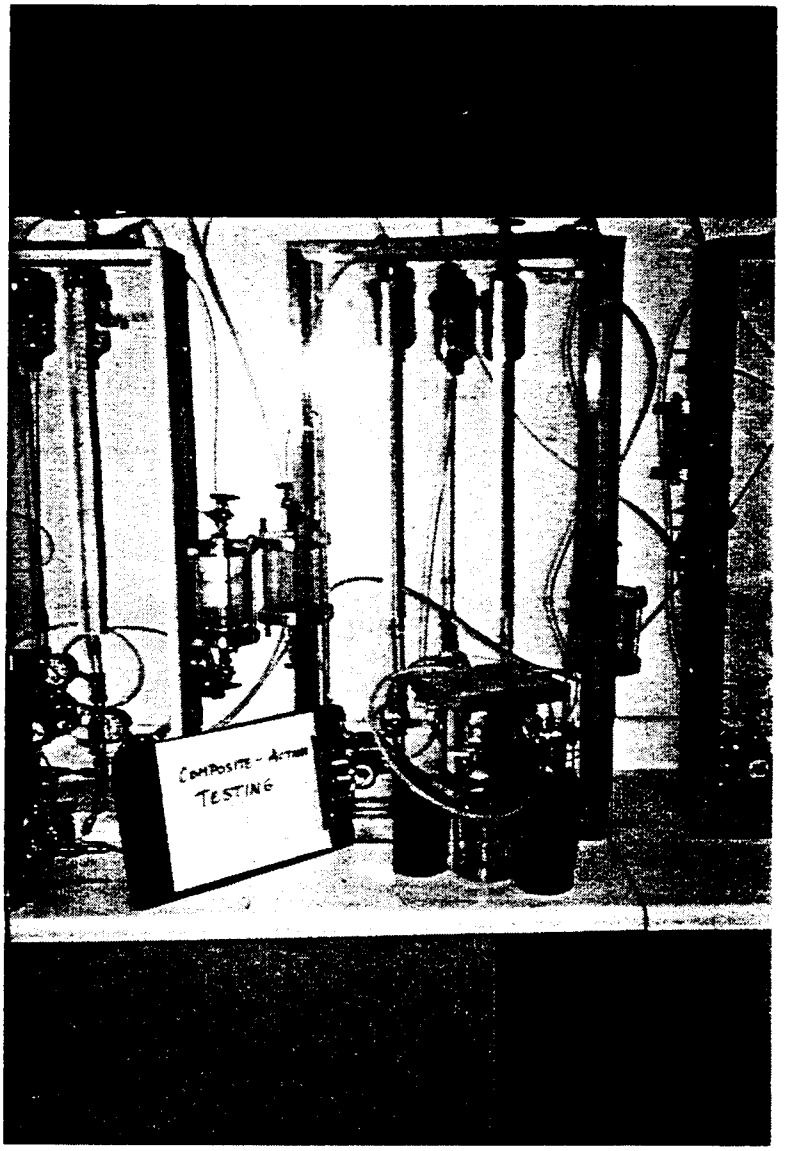


COMPOSITE ACTION TESTING

60-mil. GEOMEMBRANE WITH HOLE

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

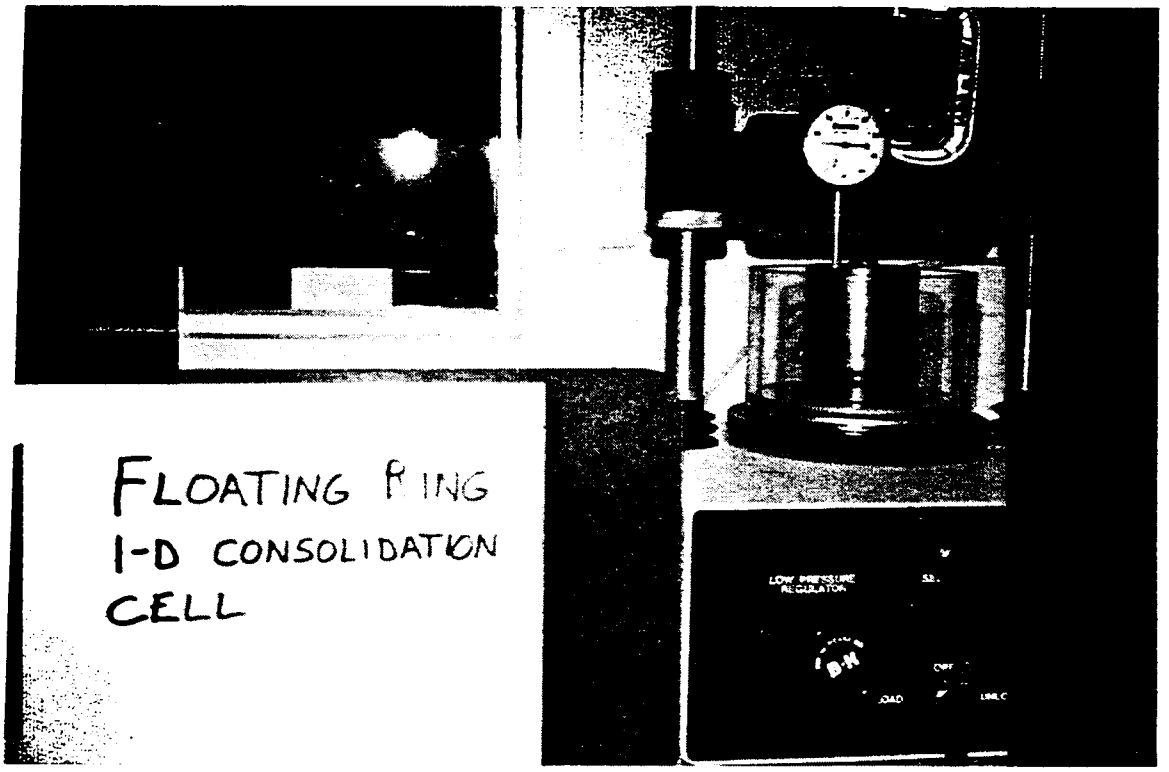
PHOTOGRAPH NO.	2.4-1
PROJECT NO.	GL1614
DOCUMENT NO.	
PAGE NO.	



COMPOSITE ACTION TEST EQUIPMENT

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

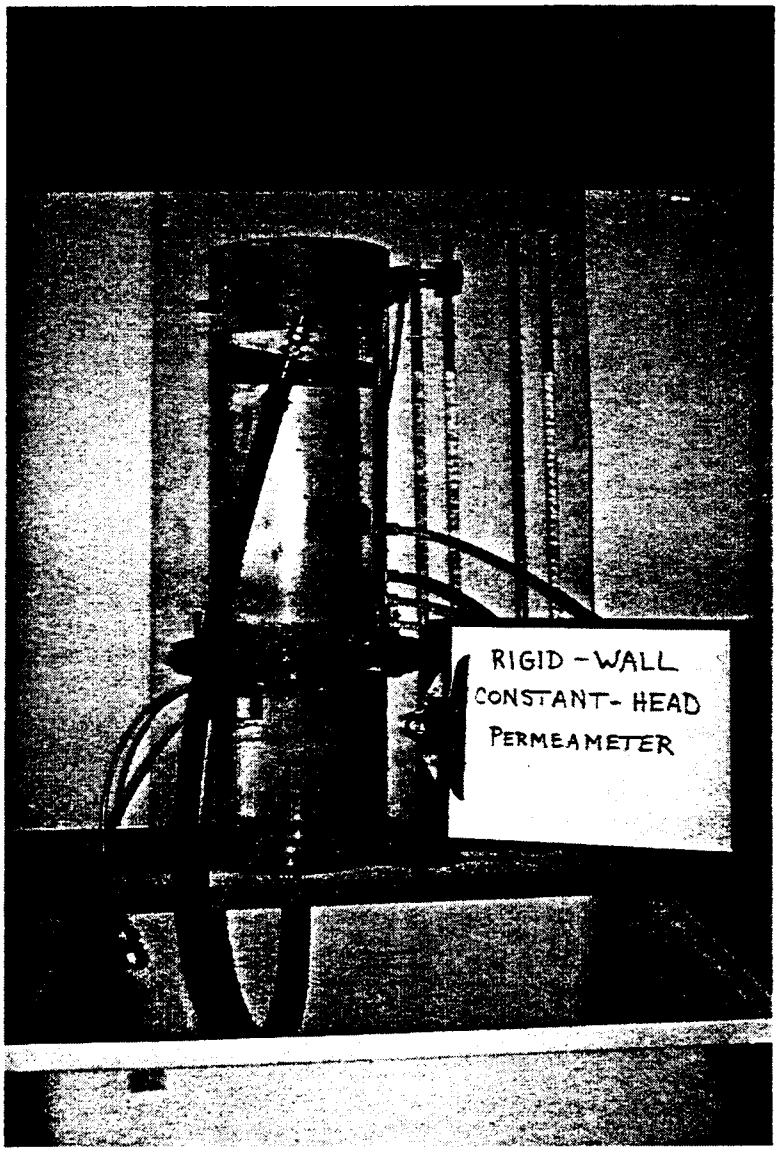
PHOTOGRAPH NO.	2.4-2
PROJECT NO.	GL1614
DOCUMENT NO.	
PAGE NO.	



SWELL POTENTIAL TEST CONSOLIDOMETER

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	2.5-1
PROJECT NO.	GL1614
DOCUMENT NO.	
PAGE NO.	



HEALING ACTION AND SEAM TEST EQUIPMENT

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	2.6-1
PROJECT NO.	GL1614
DOCUMENT NO.	
PAGE NO.	

GeoSyntec Consultants

TABLE 3.1-1

EPA 9100 COMPATIBILITY TESTING
GUNDSEAL SPECIMEN CONDITIONS

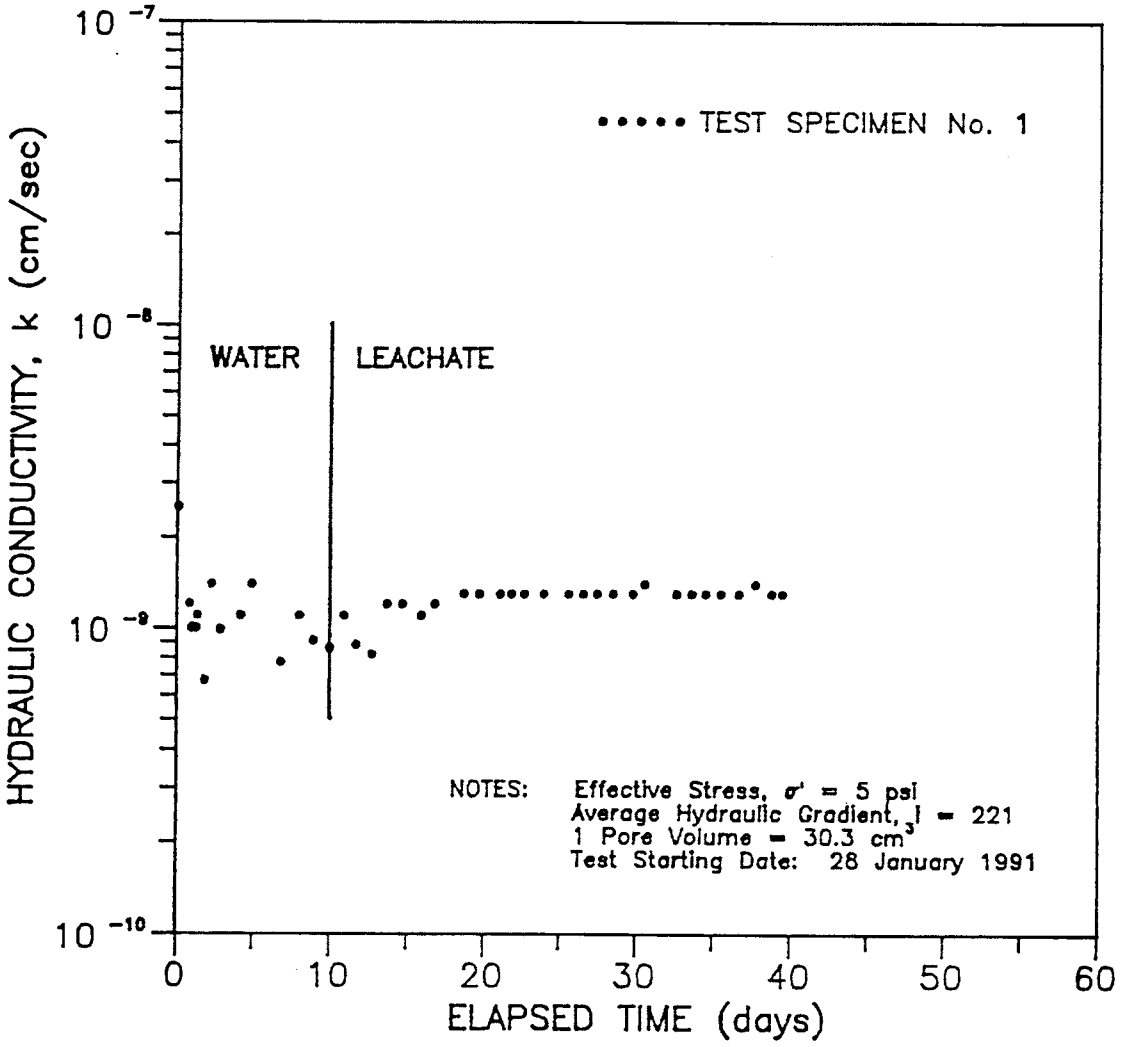
Gundle Lining Systems Inc.

Parameters	Specimen No. 1		Specimen No. 2		Specimen No. 3	
	Initial	Final	Initial	Final	Initial	Final
Thickness, in.	0.17	0.23	0.17	0.23	0.17	0.25
Diameter, in.	3.09	3.09	3.14	3.08	3.12	3.06
[1]Dry Mass, g	17.2	15.9	19.4	17.3	19.4	17.9
[2]Mass/Area, lb/ft^2	0.73	0.68	0.80	0.74	0.81	0.76
Water Content, %	12.3	119.5	10.3	118.5	12.6	125.1

Notes: [1] The dry mass includes the dry weight of the bentonite and the geomembrane backing.

[2] The mass/area is determined using the dry mass of the material normalized with respect to the cross-sectional area of the test specimen before drying.

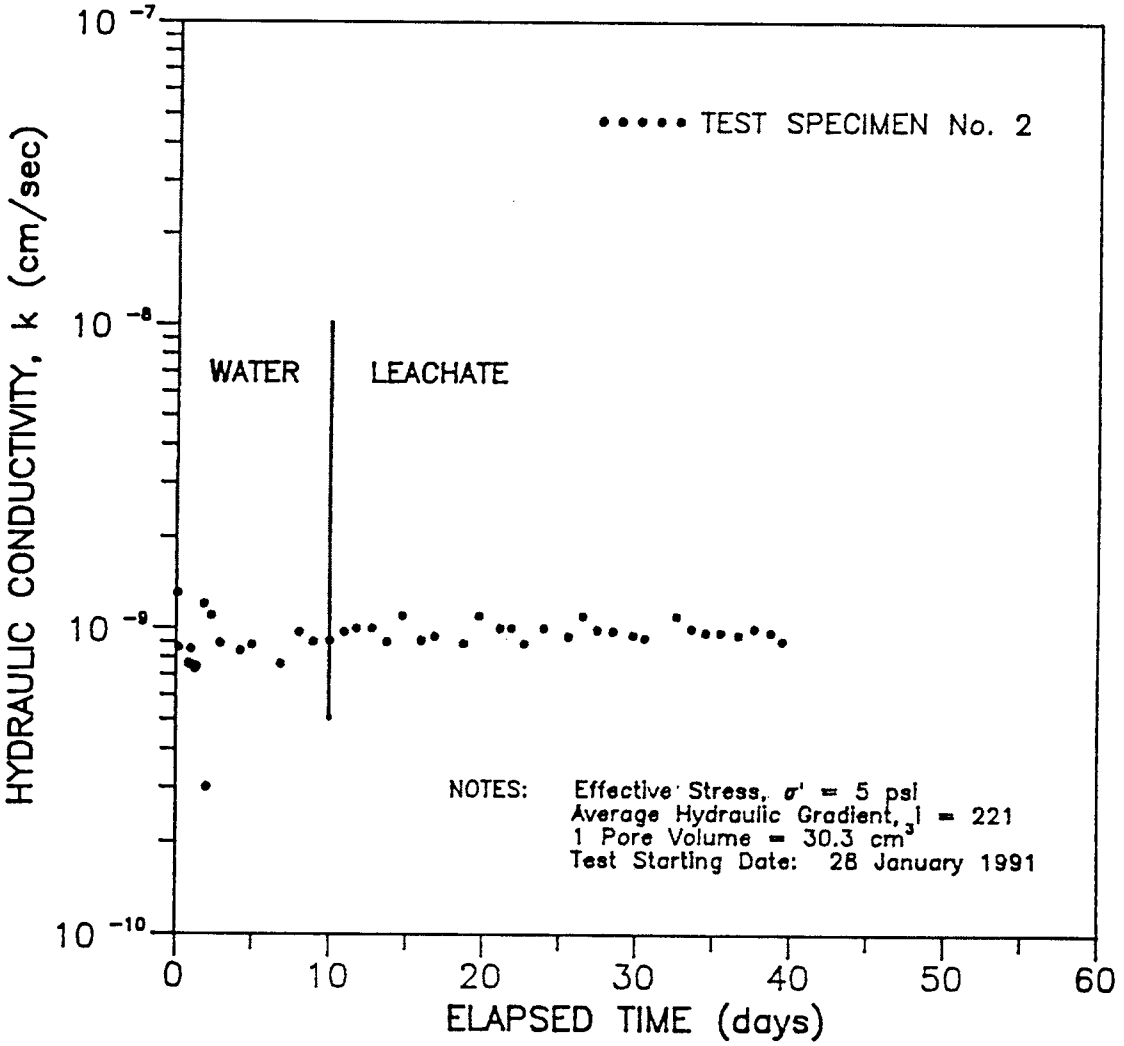
CHAMBERS DEVELOPMENT COMPANY, INC.
EPA 9100 COMPATIBILITY TESTING
GUNDSEAL SAMPLE #EL035



GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	3.1-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

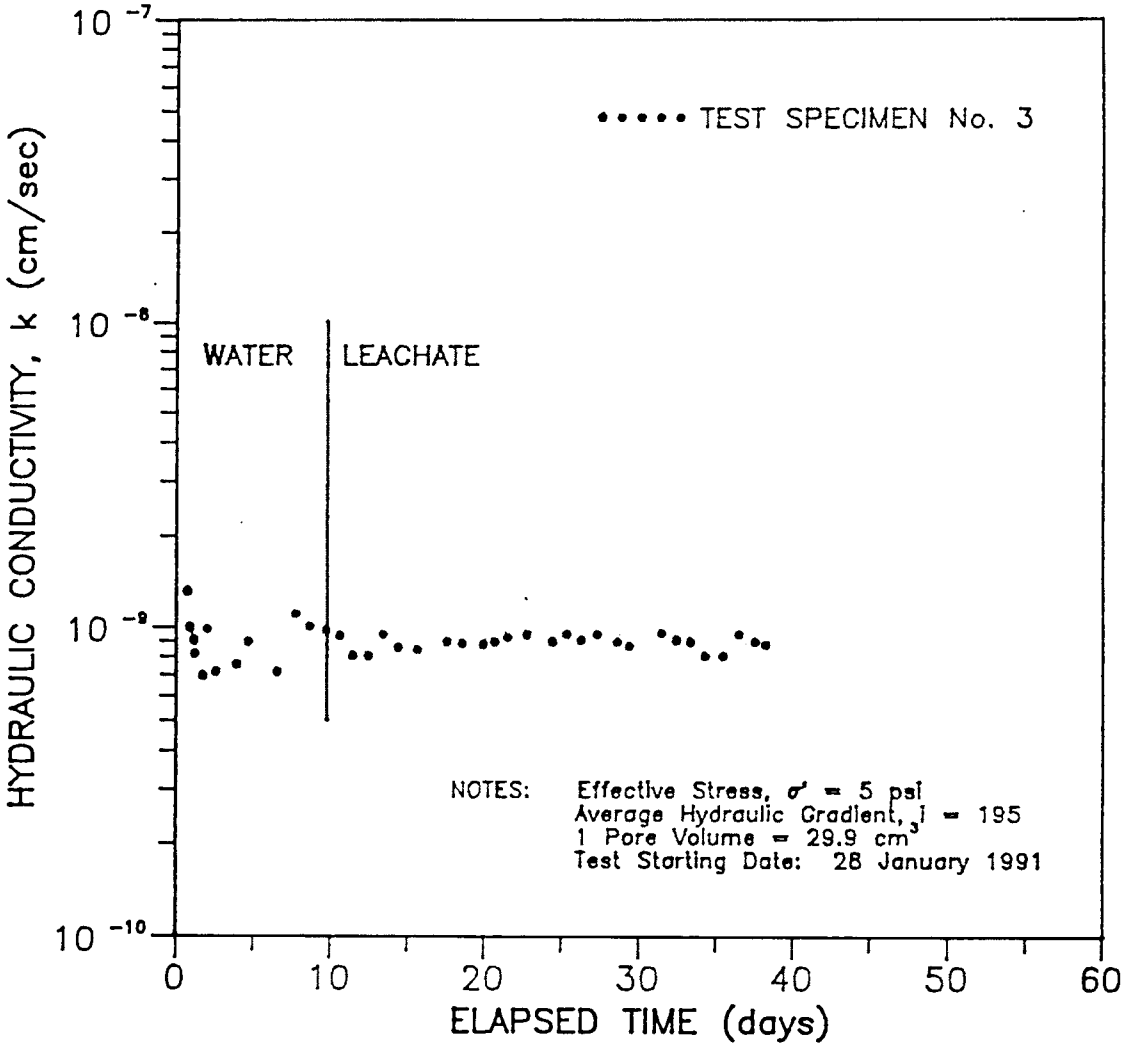
CHAMBERS DEVELOPMENT COMPANY, INC.
EPA 9100 COMPATIBILITY TESTING
GUNDSEAL SAMPLE #EL035



GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	3.1-2
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

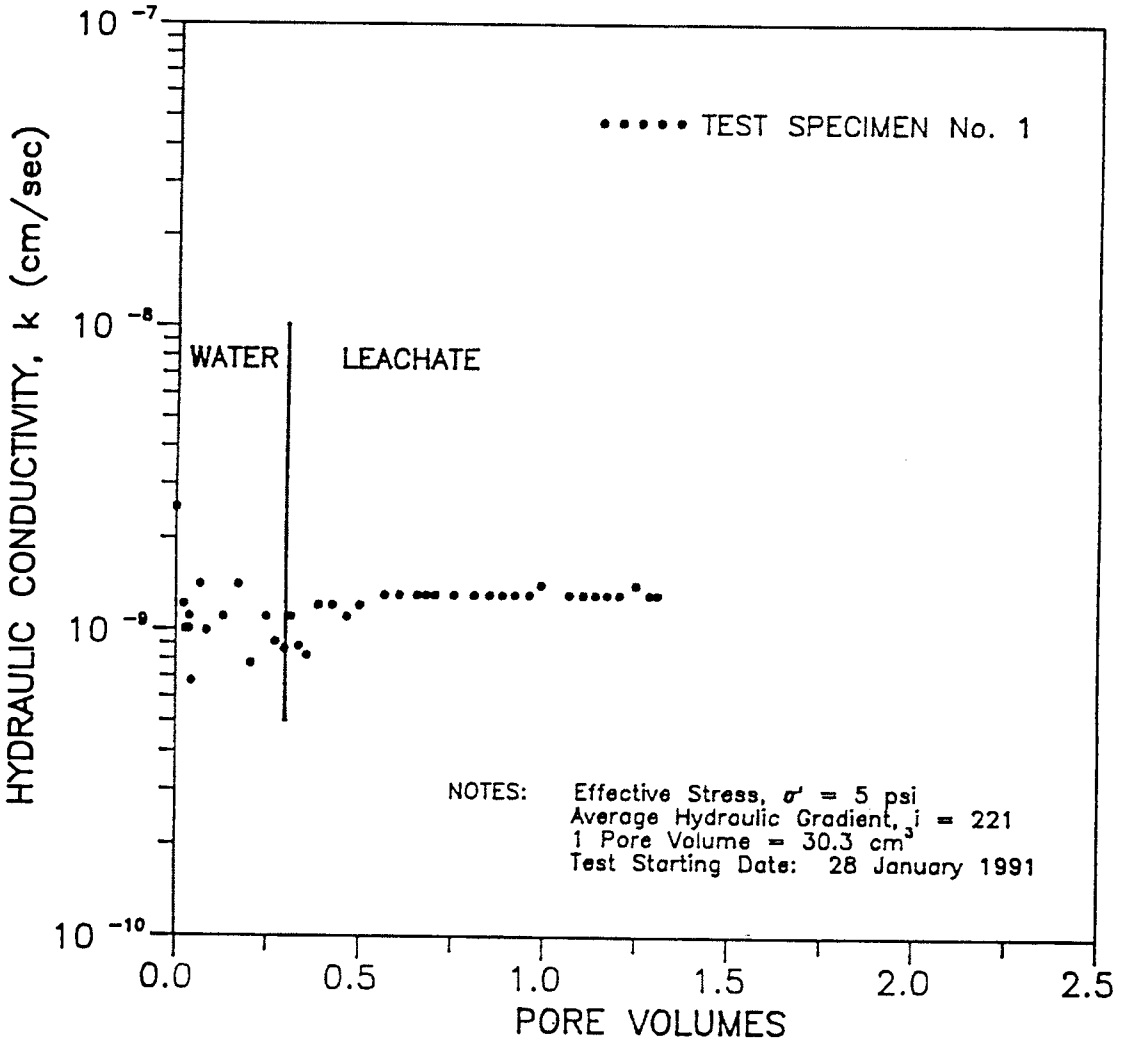
CHAMBERS DEVELOPMENT COMPANY, INC.
EPA 9100 COMPATIBILITY TESTING
GUNDSEAL SAMPLE #EL035



GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	3.1-3
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

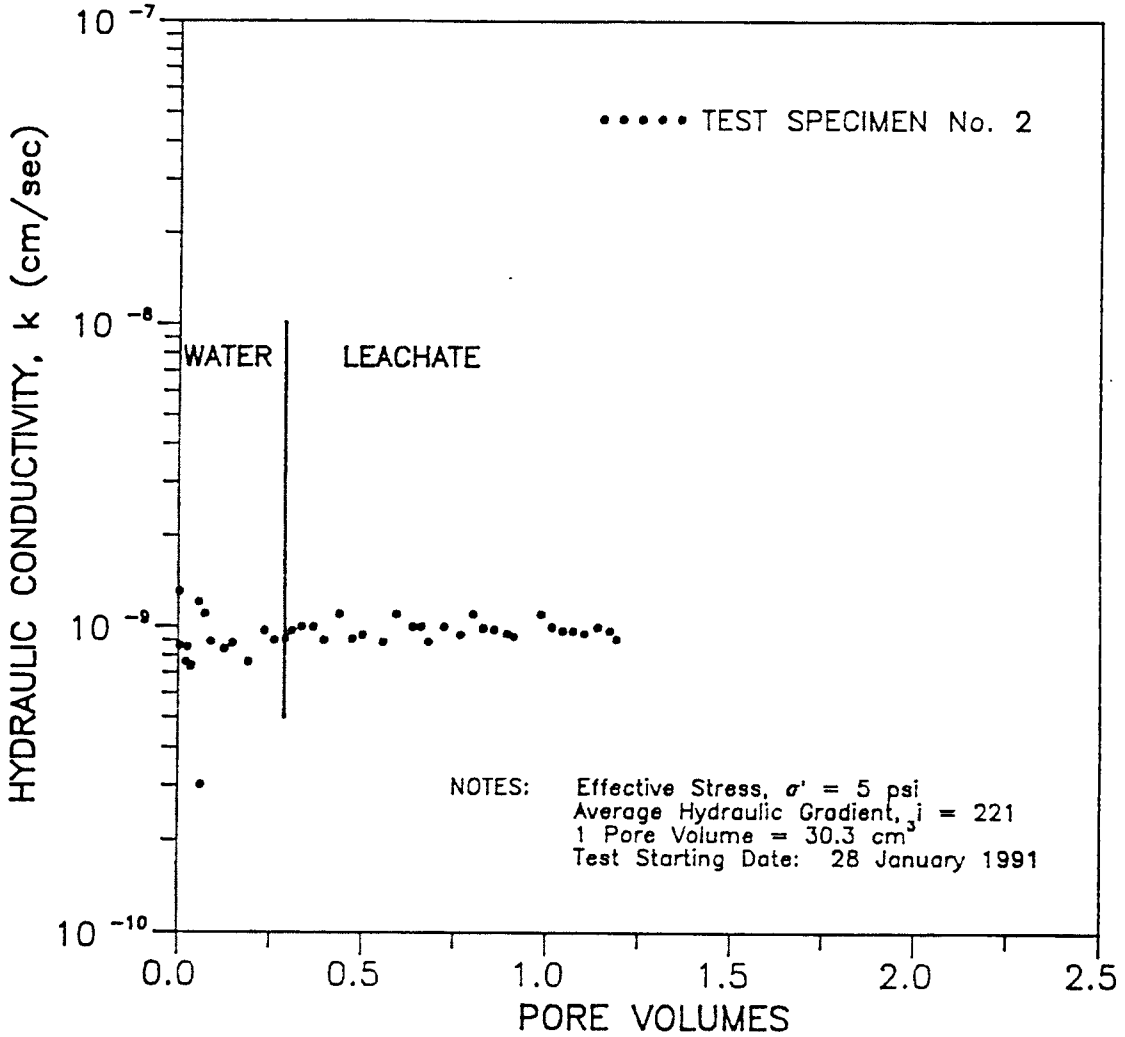
CHAMBERS DEVELOPMENT COMPANY, INC.
EPA 9100 COMPATIBILITY TESTING
GUNDSEAL SAMPLE #EL035



GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	3.1-4
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

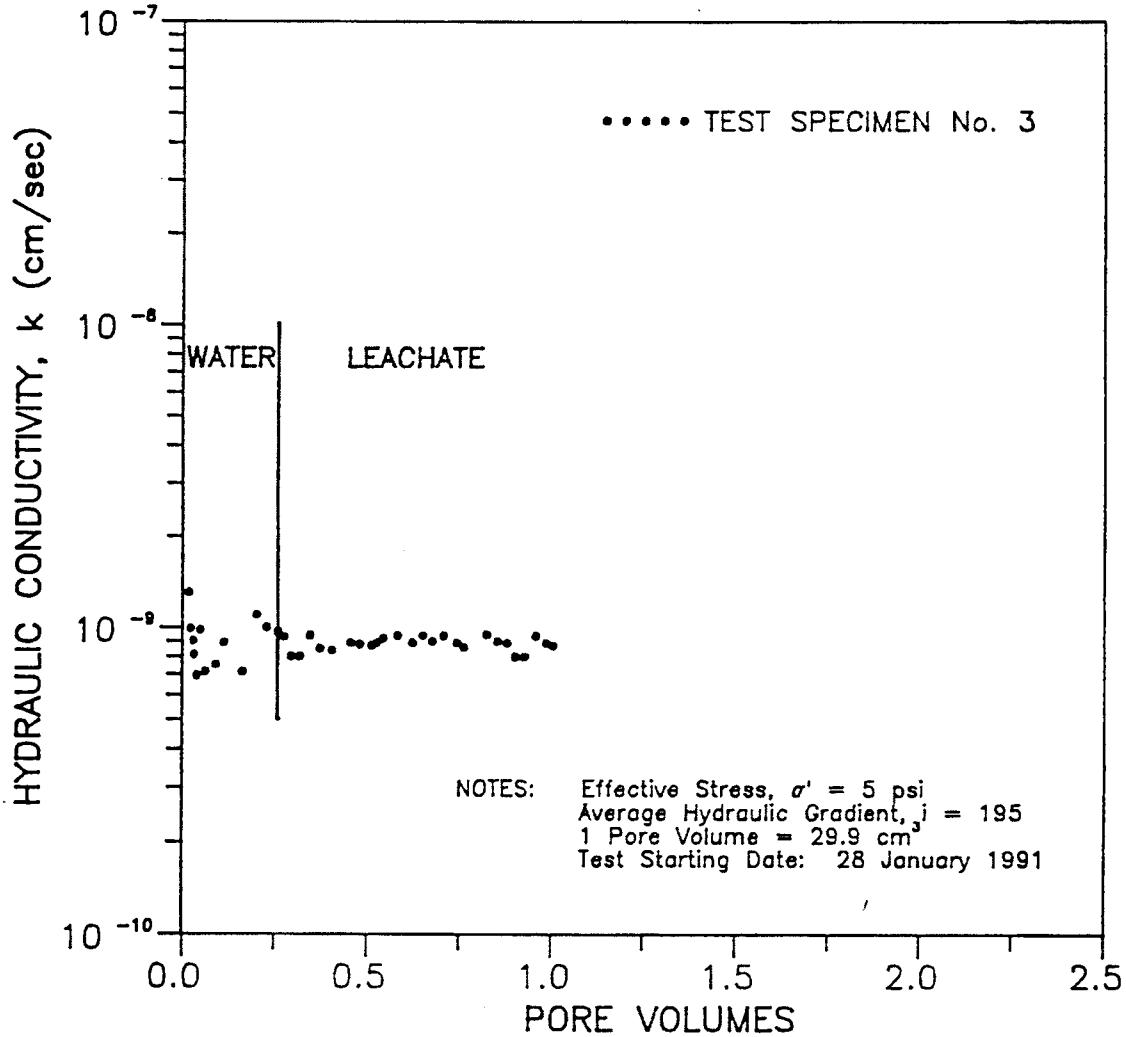
CHAMBERS DEVELOPMENT COMPANY, INC.
EPA 9100 COMPATIBILITY TESTING
GUNDSEAL SAMPLE #EL035



GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	3.1-5
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

CHAMBERS DEVELOPMENT COMPANY, INC.
EPA 9100 COMPATIBILITY TESTING
GUNDSEAL SAMPLE #EL035



GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	3.1-6
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

TABLE 3.2-1

FREEZE-THAW TESTING
GUNDSEAL SPECIMEN CONDITIONS

Gundle Lining Systems Inc.

Parameters	Initial	Final[1]
Thickness, in.	0.18	0.28
Diameter, in.	3.00	3.03
[2]Dry Mass, g	[4]19.00	15.60
[3]Mass/Area, lb/ft^2	0.85	0.70
Water Content, %	9.8	131.5

Notes:

1 Final conditions measured upon completion of fourth test cycle.

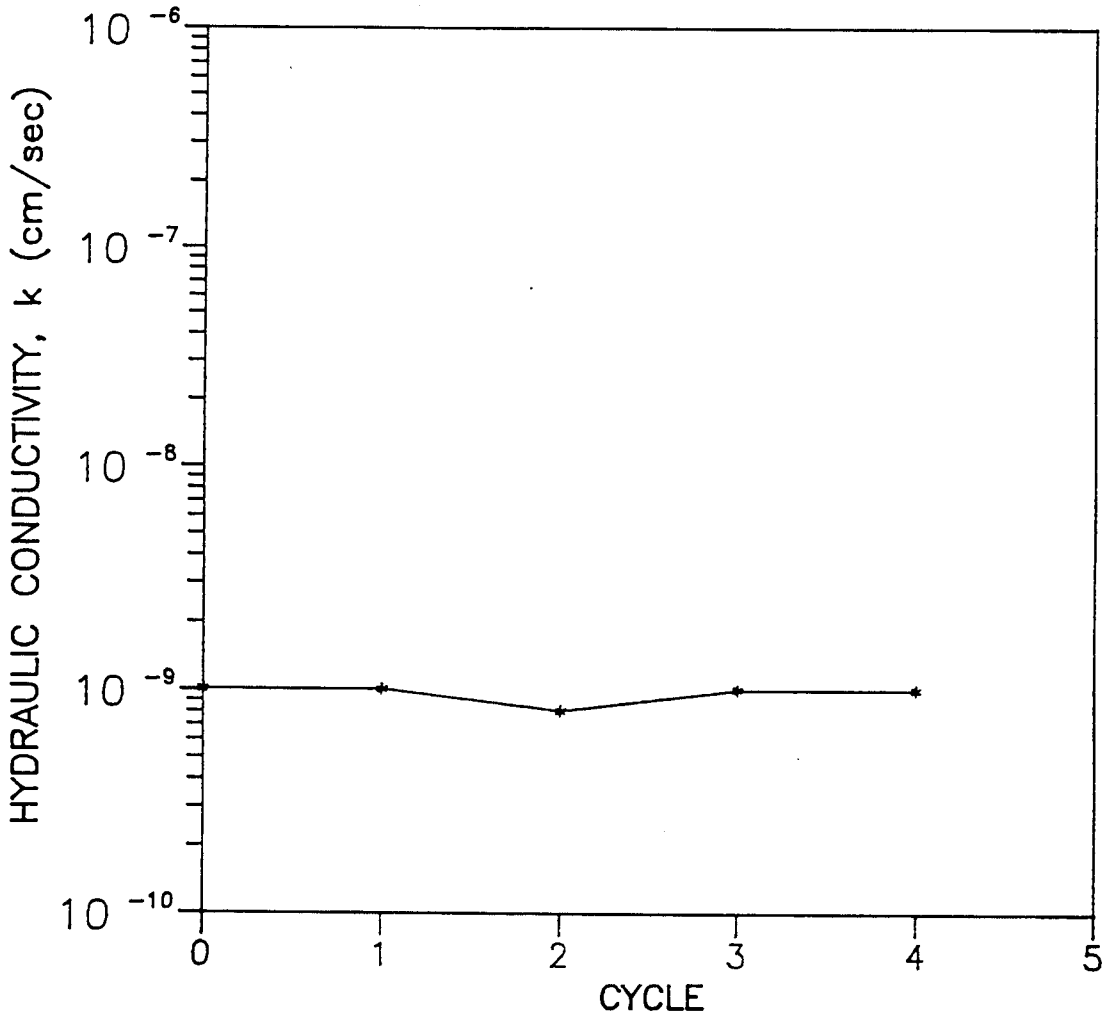
2 The dry mass includes the dry weight of the bentonite and the geomembrane backing.

3 The mass/area is determined using the dry mass of the material normalized with respect to the cross-sectional area of the test specimen before drying.

4 Data was unavailable for the test sample. A value representative of the Gundseal specimens used in other phases of the testing program was used for the freeze-thaw testing.

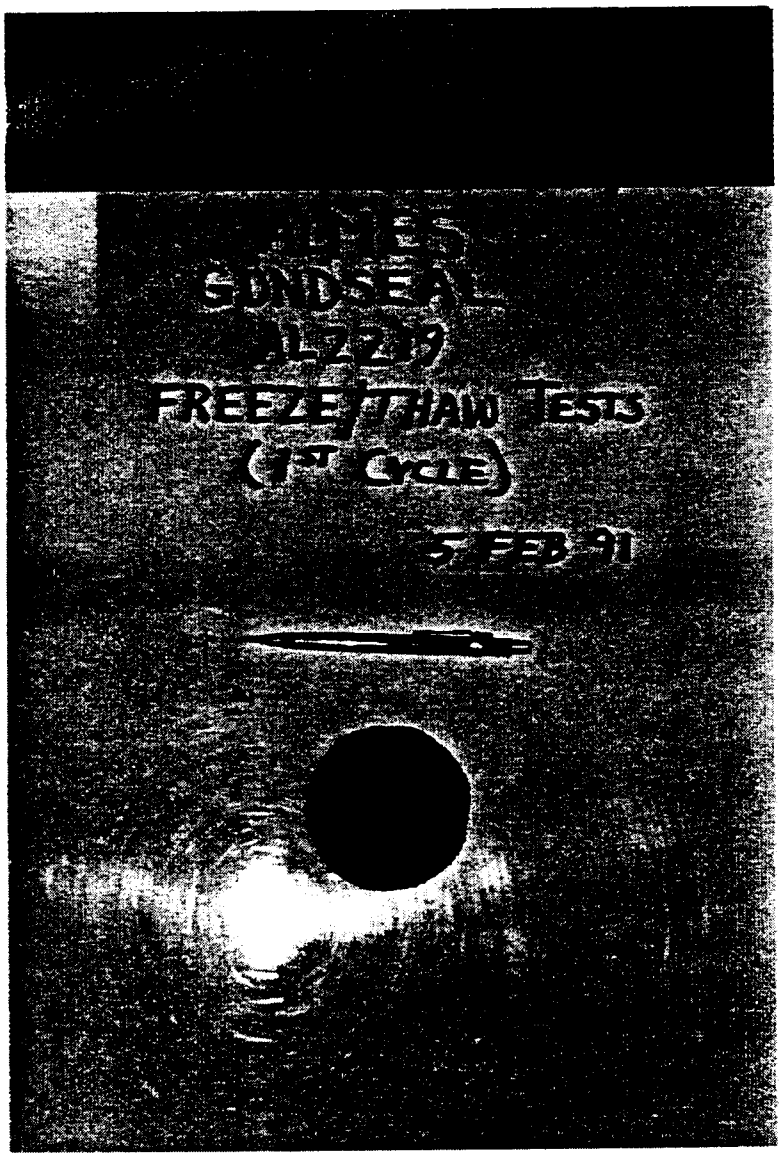
308913

CHAMBERS DEVELOPMENT COMPANY, INC.
FREEZE–THAW TEST
GUNDSEAL SAMPLE #AL2219



GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

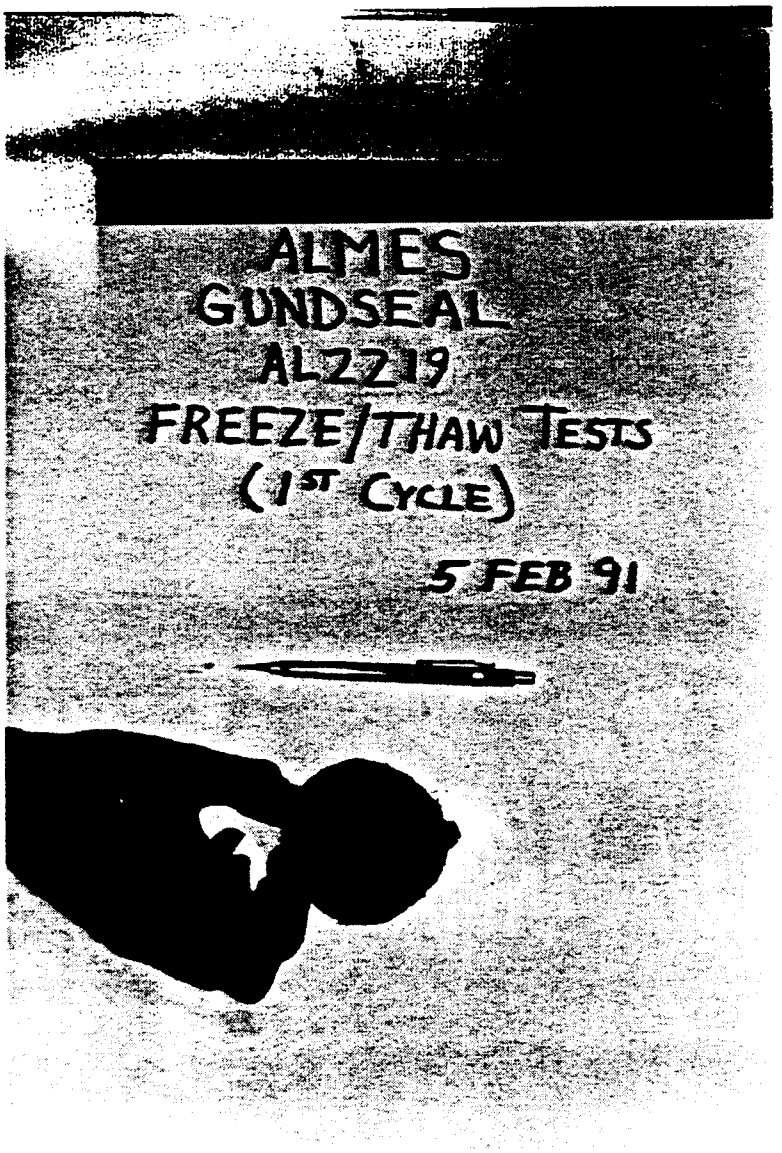
FIGURE NO.	3.2-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



AFTER FIRST CYCLE PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

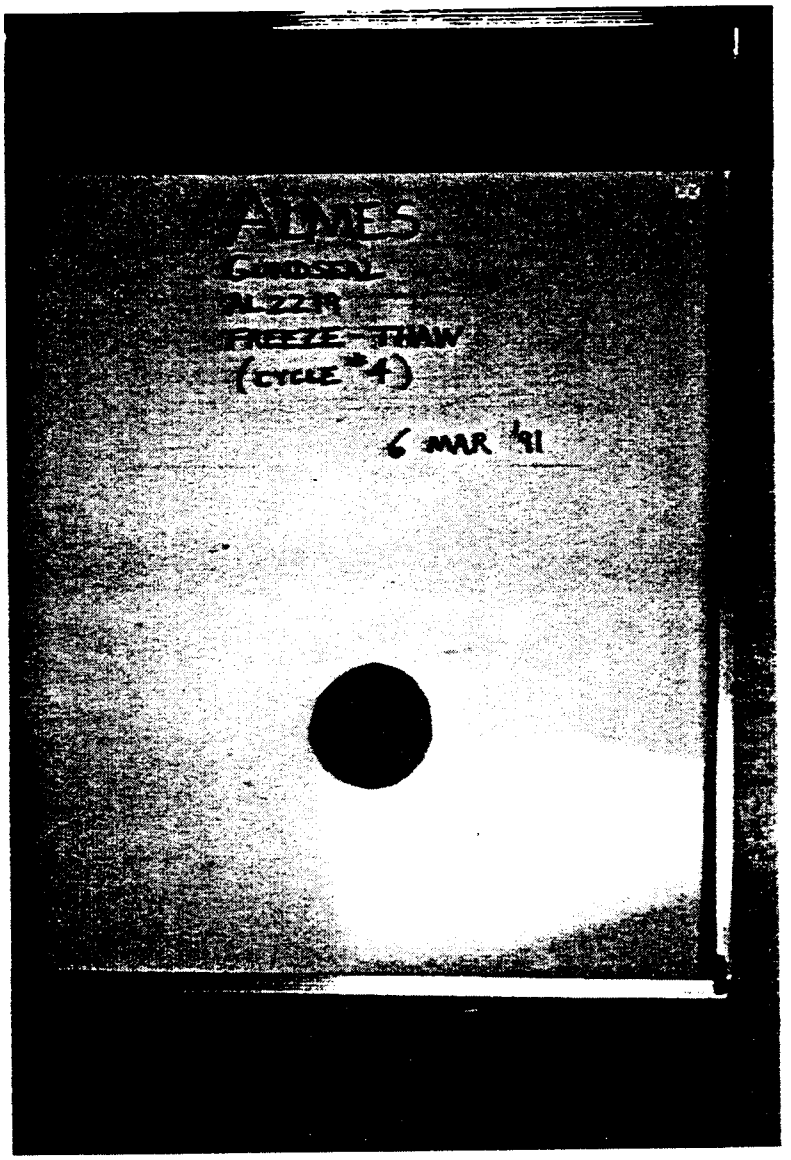
PHOTOGRAPH NO.	3.2-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



AFTER FIRST CYCLE PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	3.2-2
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



SAMPLE AT COMPLETION OF TESTING

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	3.2-3
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

TABLE 3.3-1

DESICCATION TESTING
GUNDSEAL SPECIMEN CONDITIONS

Gundle Lining Systems Inc.

Parameters	Initial	Final[1]
Thickness, in.	0.30	0.30
Diameter, in.	2.99	2.98
[2]Dry Mass, g	19.03	15.53
[3]Mass/Area, lb/ft^2	0.86	0.71
Water Content, %	10.0	158.2

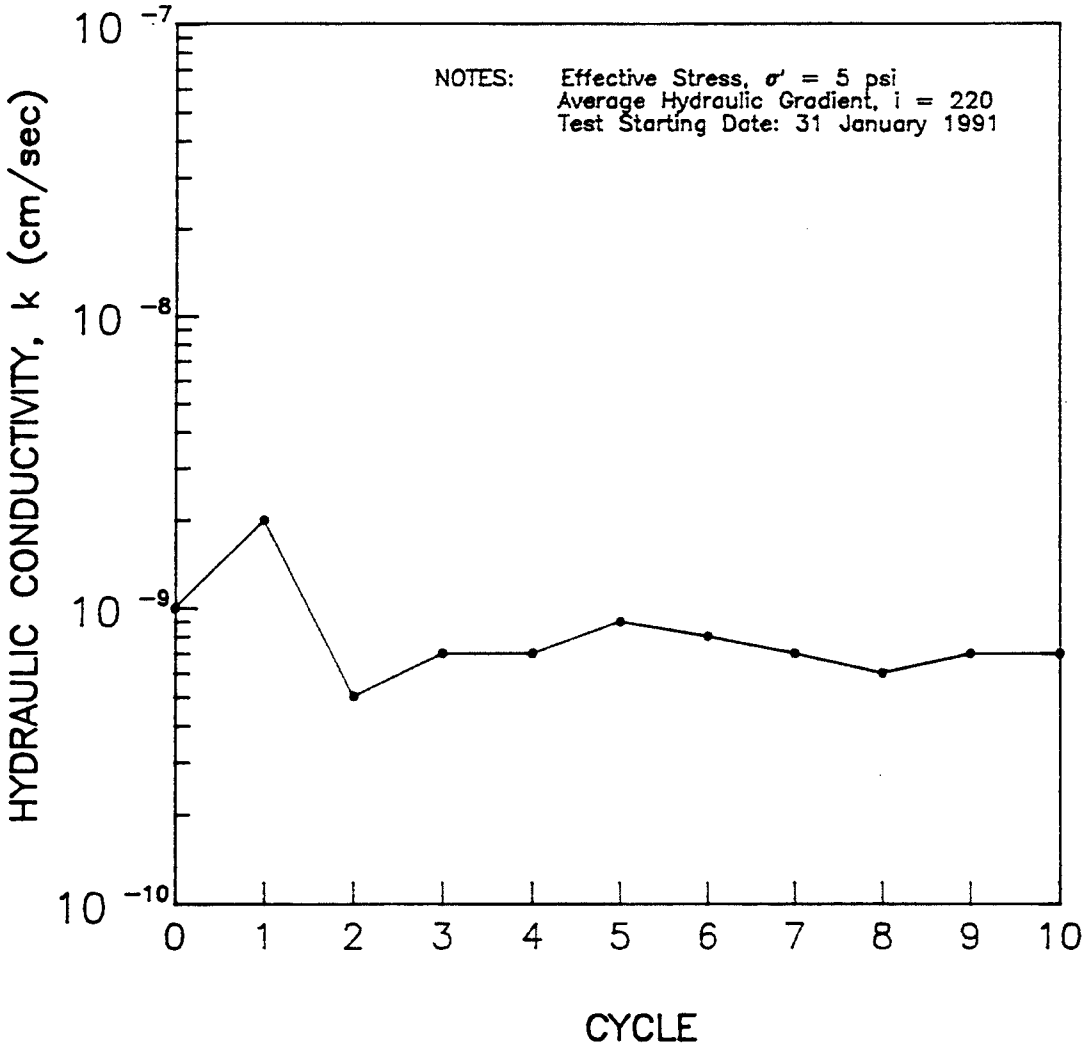
Note: [1] Final conditions measured upon completion of fourth test cycle.

[2] The dry mass includes the dry weight of the bentonite and the geomembrane backing.

[3] The mass/area is determined using the dry mass of the material normalized with respect to the cross-sectional area of the test specimen before drying.

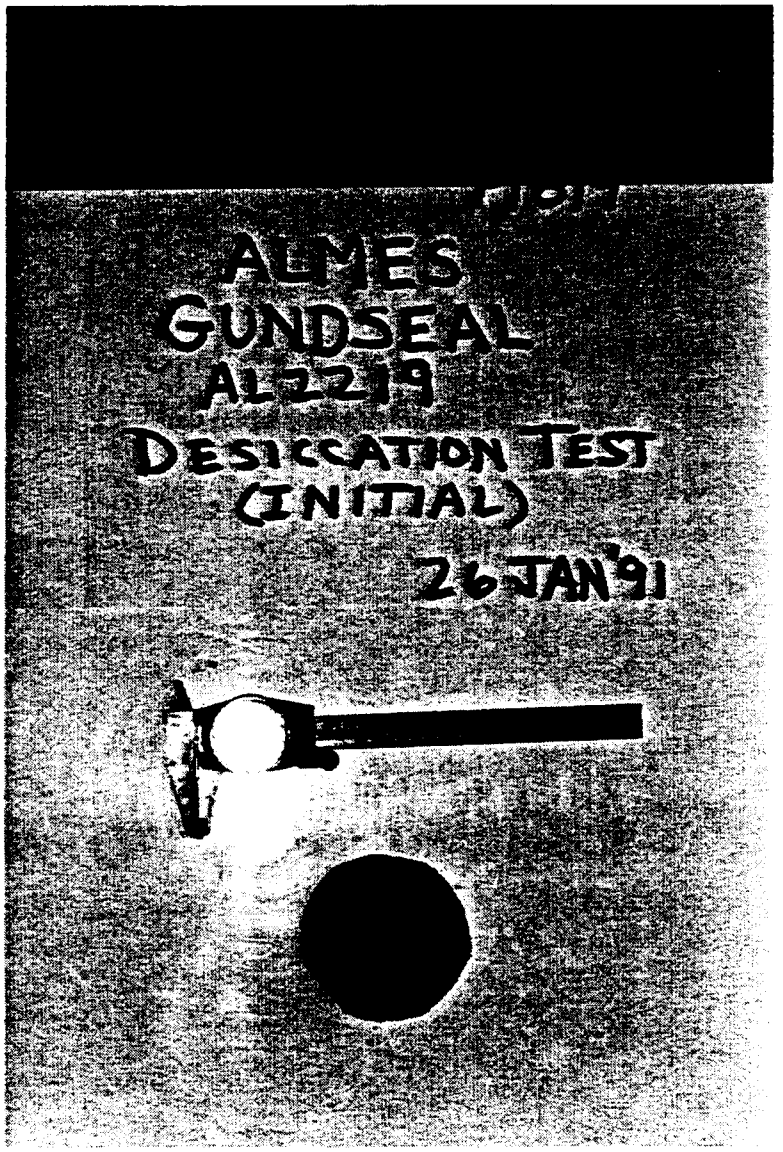
308919

GUNDLE LINING SYSTEMS, INC.
DESICCATION TEST



GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

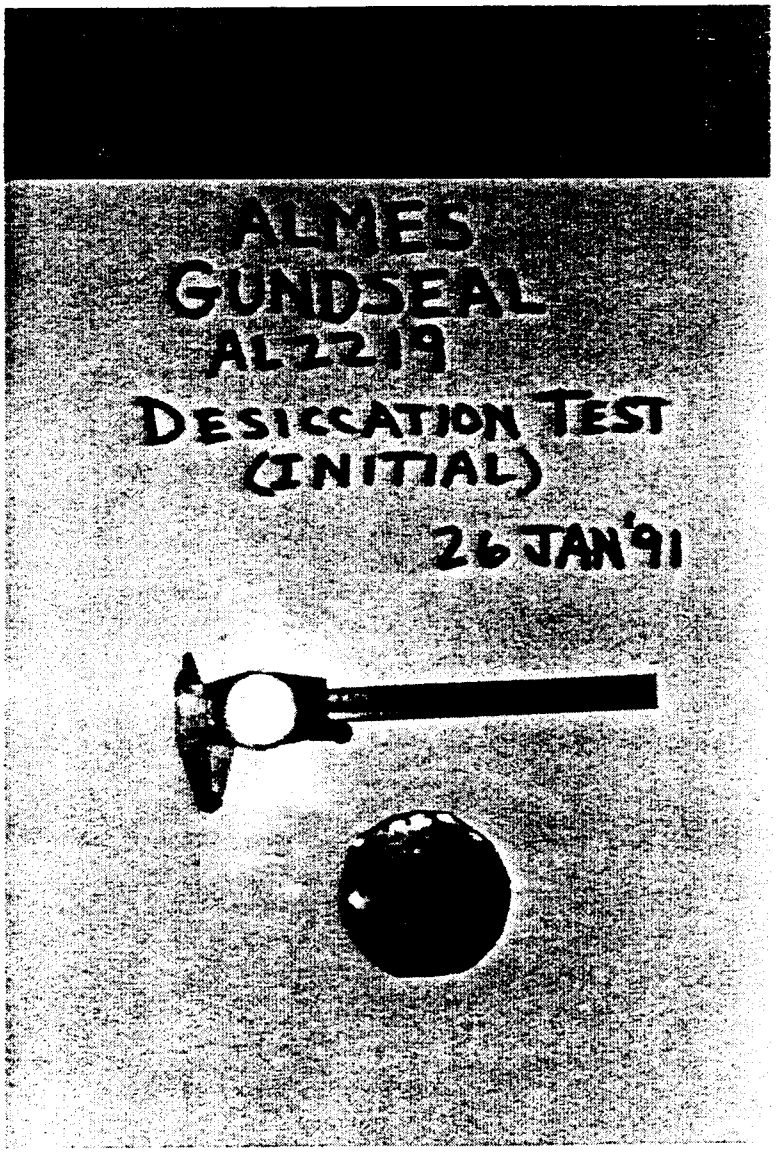
FIGURE NO.	3.3-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



SAMPLE AT INITIATION OF TESTING

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

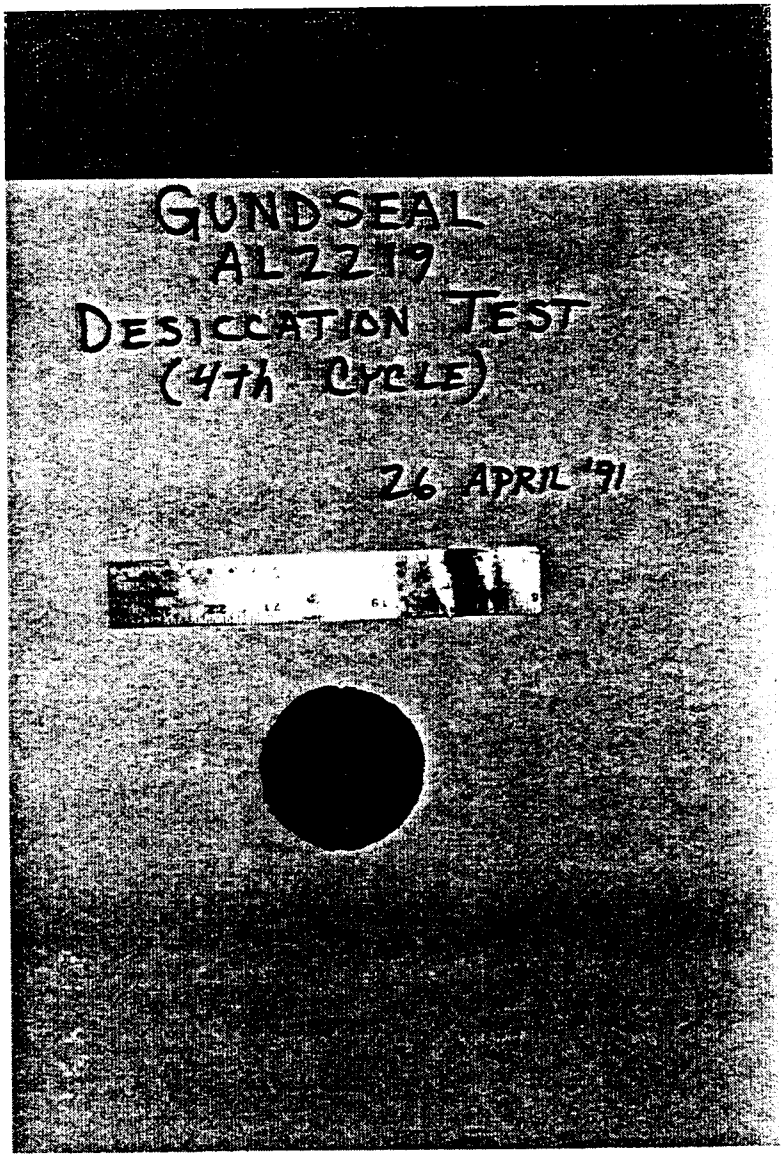
PHOTOGRAPH NO.	3.3-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



SAMPLE AT INITIATION OF TESTING

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

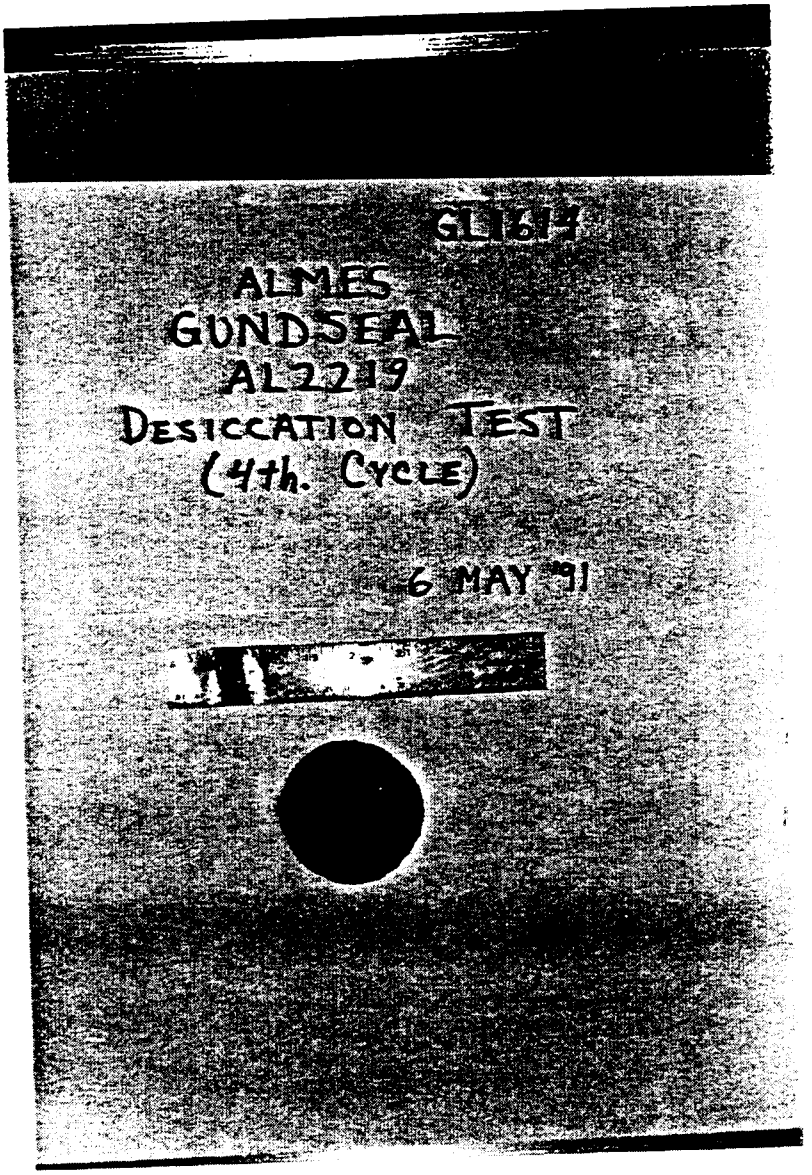
PHOTOGRAPH NO.	3.3-2
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



AFTER FOURTH CYCLE DESICCATION

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

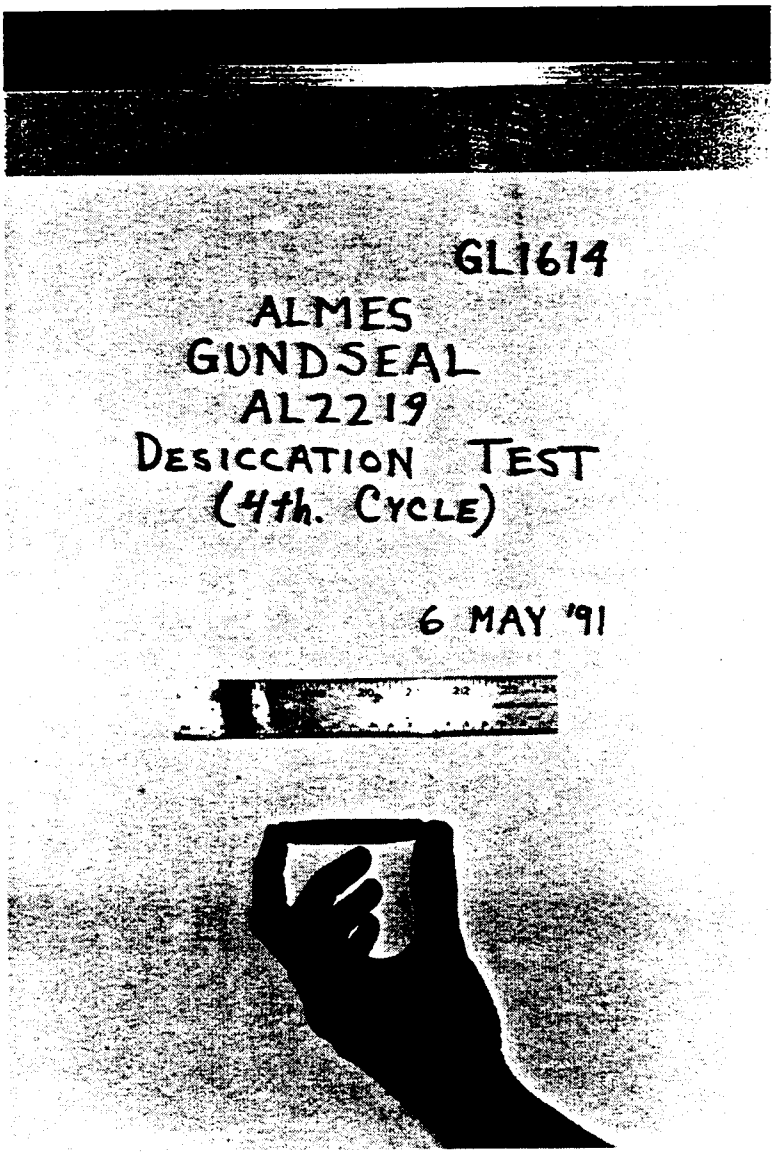
PHOTOGRAPH NO.	3.3-3
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



SAMPLE AT COMPLETION OF TESTING

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

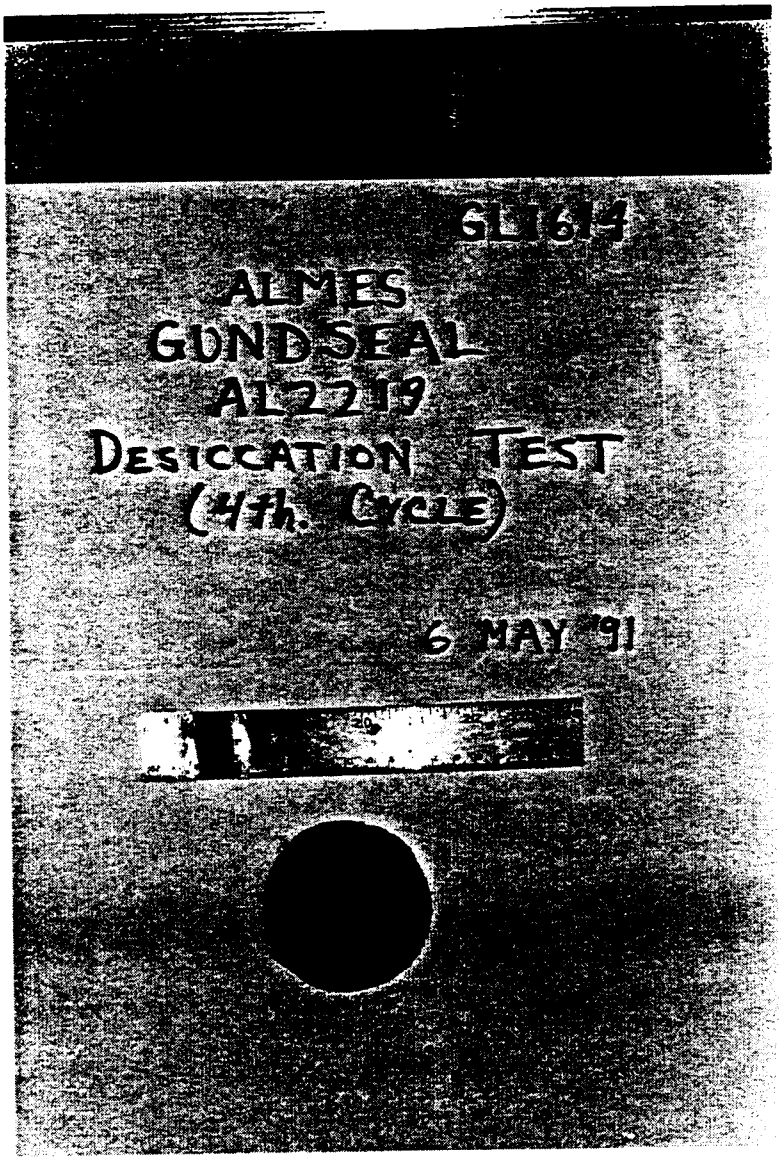
PHOTOGRAPH NO.	3.3-4
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



SAMPLE AT COMPLETION OF TESTING

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	3.3-5
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

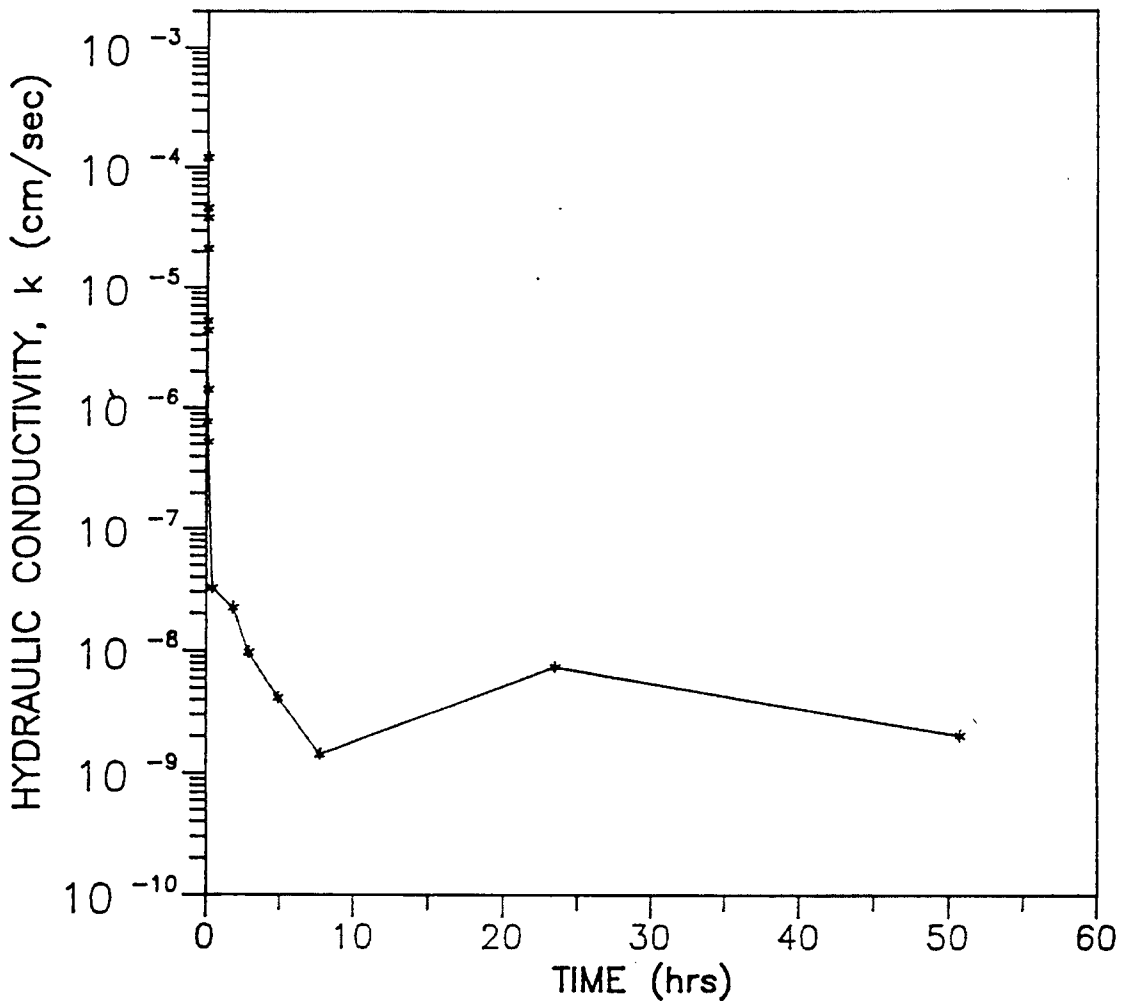


SAMPLE AT COMPLETION OF TESTING

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	3.3-6
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

CHAMBERS DEVELOPMENT COMPANY, INC.
COMPOSITE ACTION TEST
GUNDSEAL SAMPLE #AL2219

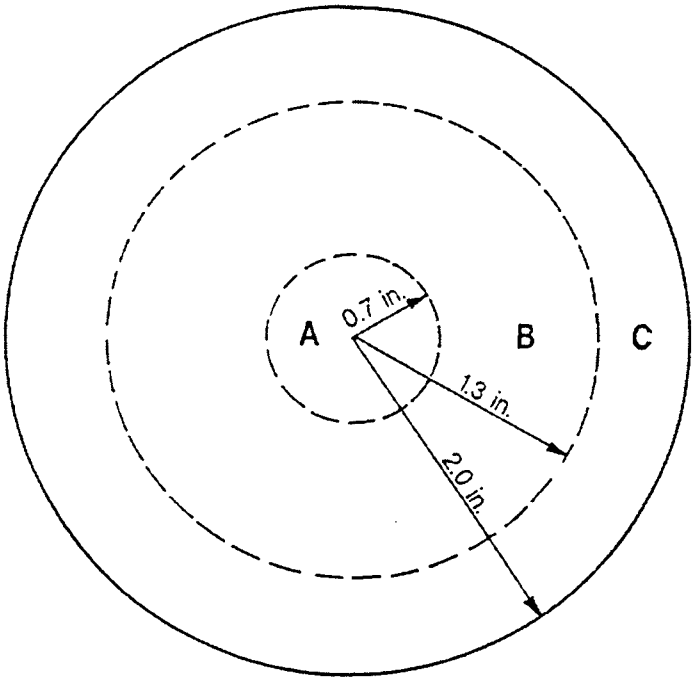


Notes:
Hydraulic Head: 12 in.
Test Configuration (from top to bottom): 4 in. Sand/ Geomembrane/Gundseal/Geotextile
Test Starting Date: 27 February 1991

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	3.4-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

COMPOSITE ACTION TESTING
GUNDSEAL SAMPLE #AL2219



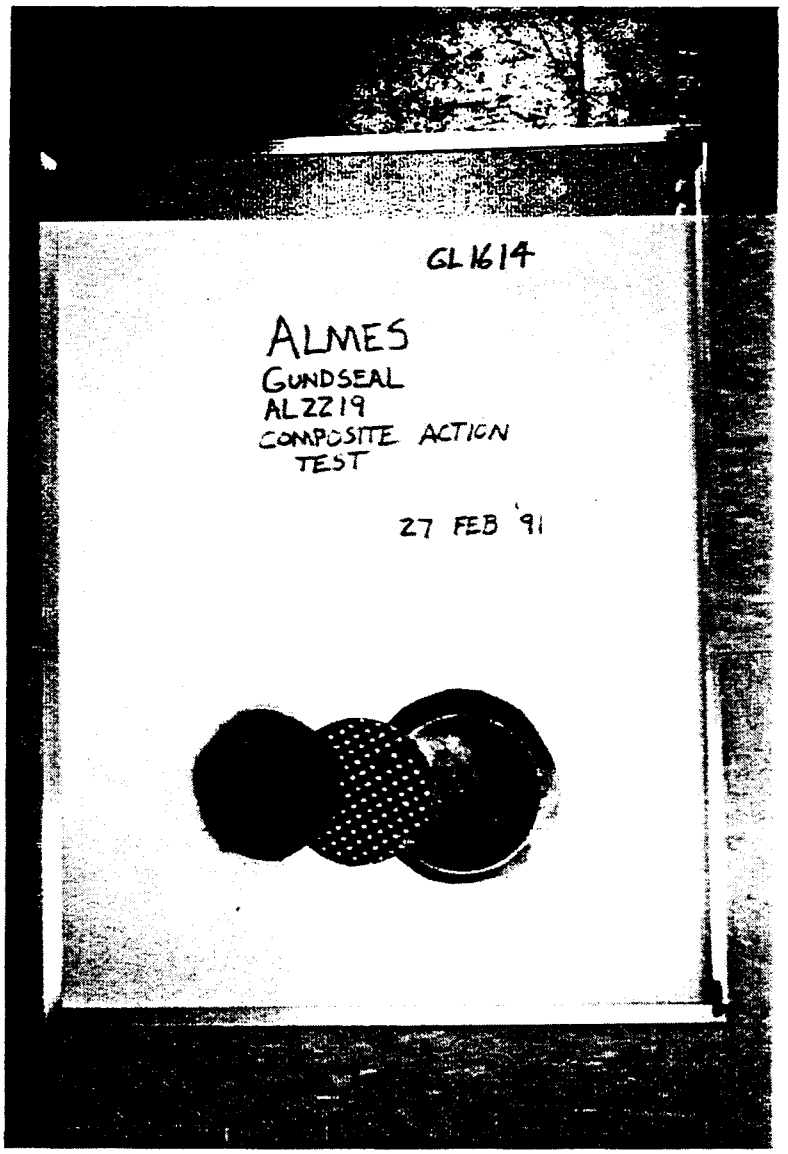
INITIAL SPECIMEN CONDITIONS: WATER CONTENT = 7.3%

FINAL SPECIMEN CONDITIONS: WATER CONTENTS:

- SECTION A = 77.2%
- SECTION B = 30.2%
- SECTION C = 24.0%

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

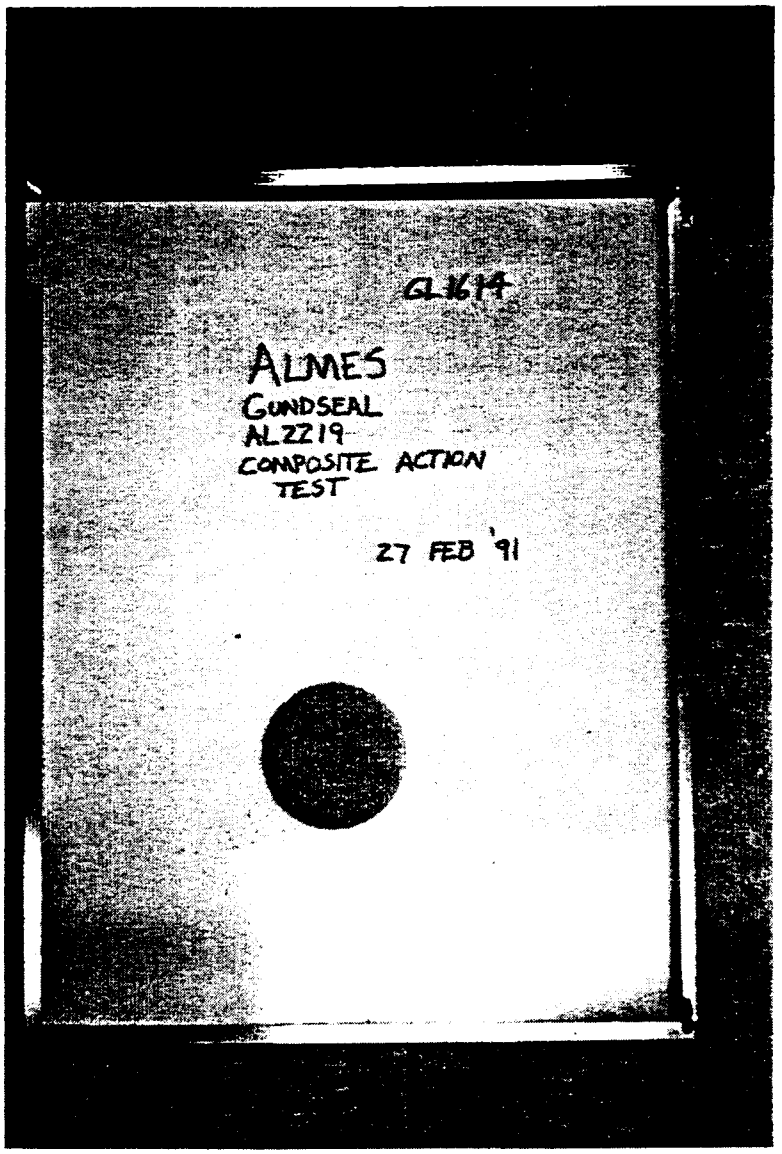
FIGURE NO.	3.4-2
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



TESTING CONFIGURATION

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

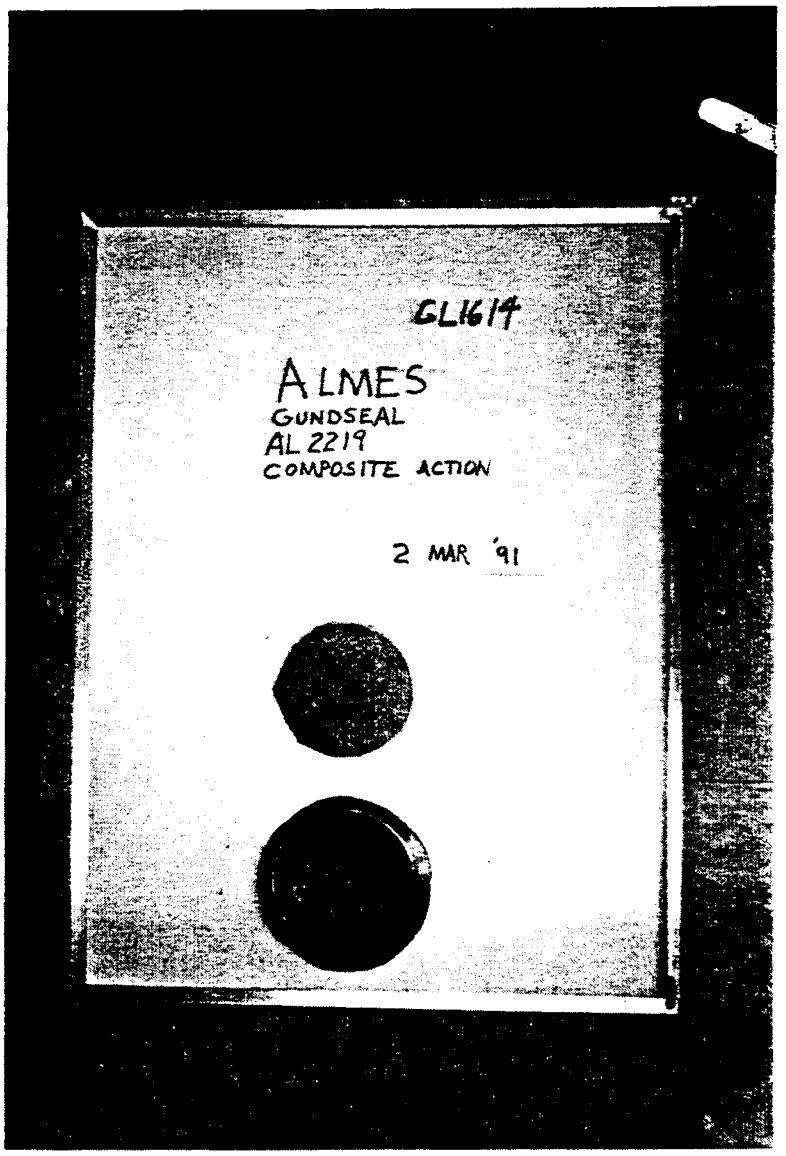
PHOTOGRAPH NO.	3.4-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



SAMPLE BEFORE TESTING

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	3.4-2
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



SAMPLE AFTER TESTING

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	3.4-3
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

TABLE 3.5-1

SWELL POTENTIAL TESTING
GUNDSEAL SPECIMEN CONDITIONS

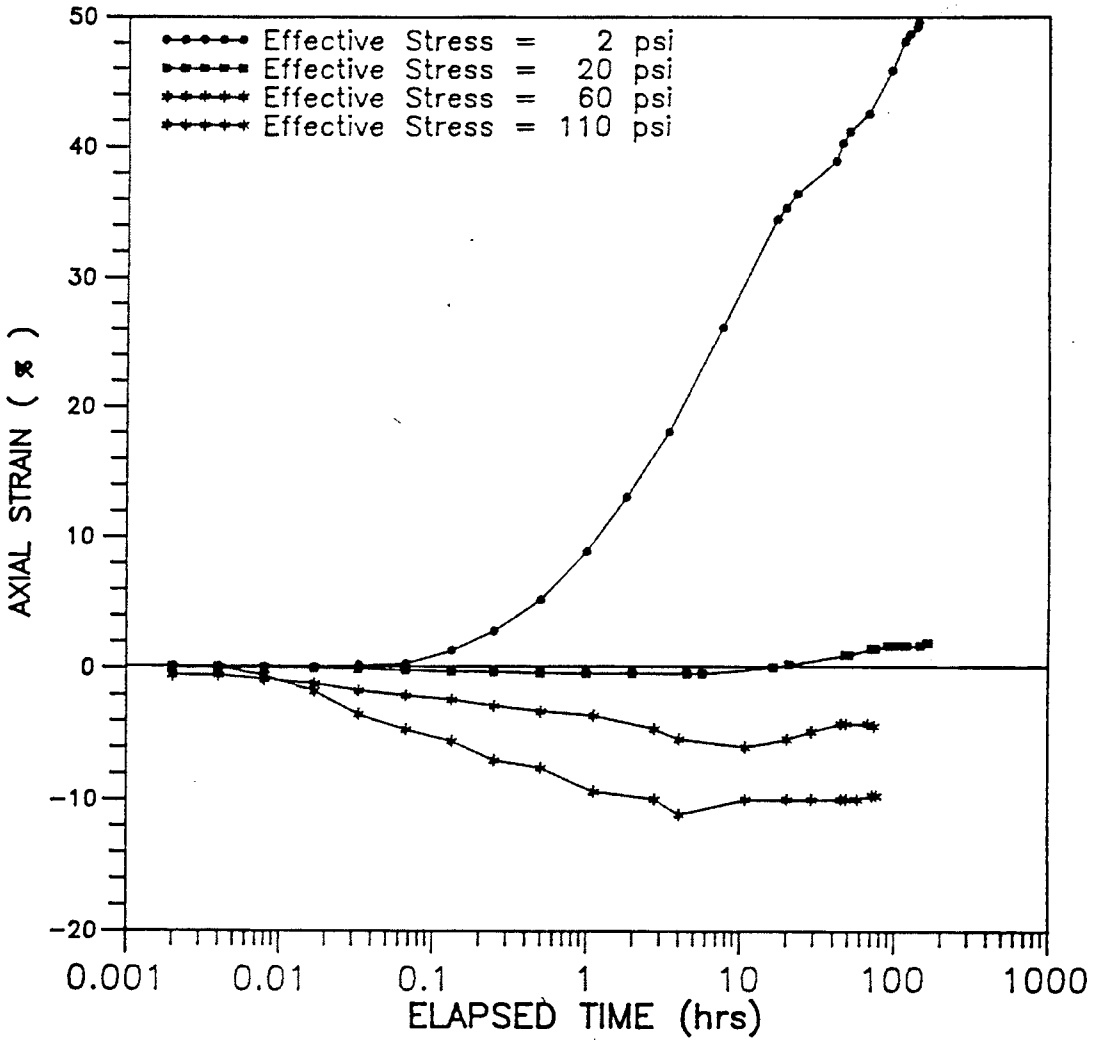
Gundle Lining Systems Inc.

Confining Stress	2 psi		20 psi		60 psi		110 psi	
Parameter	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Thickness, in.	0.18	0.28	0.17	0.18	0.17	0.16	0.17	0.12
Diameter, in.	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
[1]Dry Mass, g	11.8	11.9	12.1	11.9	12.7	12.0	11.0	11.2
[2]Mass/Area, lb/ft^2	0.77	0.76	0.81	0.78	0.70	0.79	0.72	0.71
Water Content, %	10.3	134.9	9.8	65.9	9.2	54.2	7.0	44.3

Notes: [1] The dry mass includes the dry weight of the bentonite and the geomembrane backing.

[2] The mass/area is determined using the dry mass of the material normalized with respect to the cross-sectional area of the test specimen before drying.

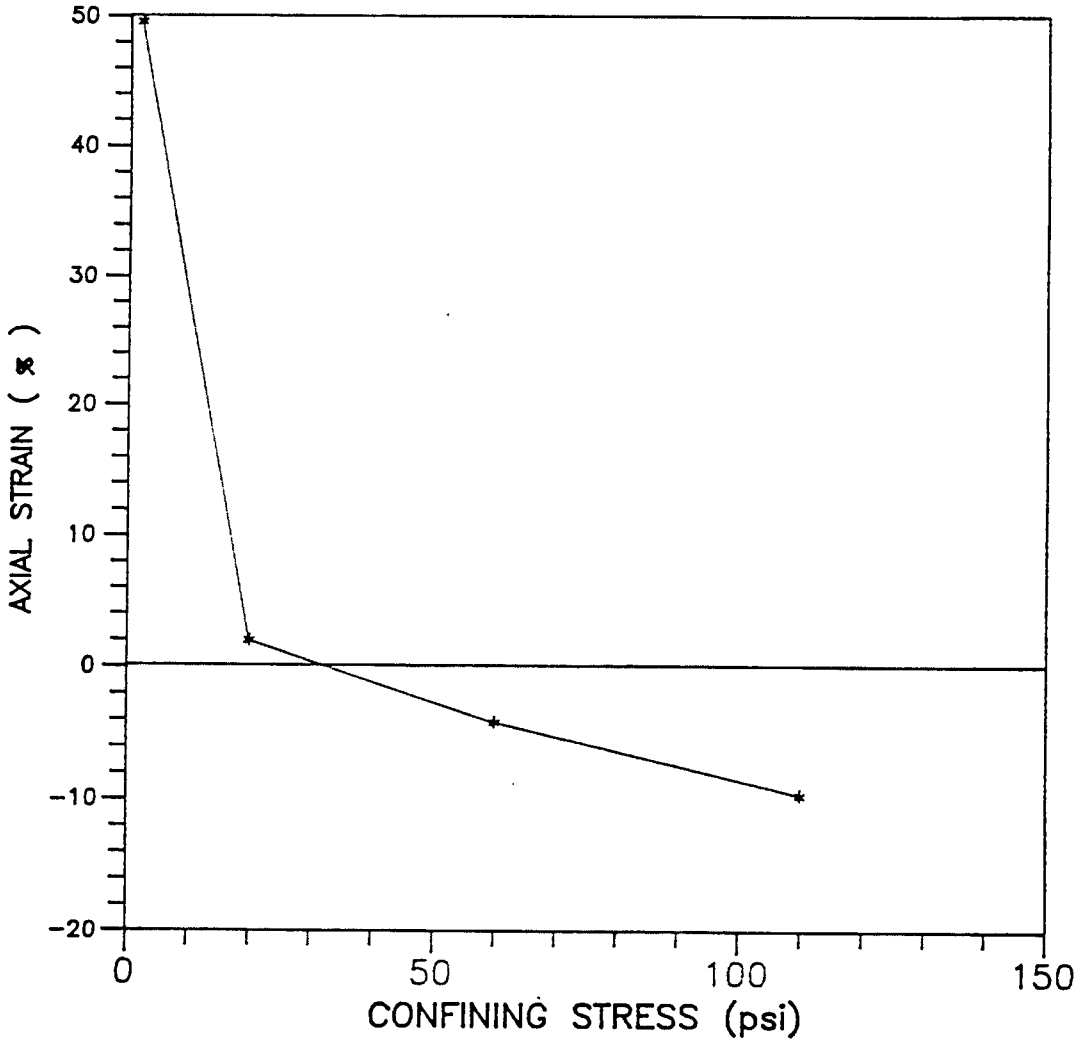
CHAMBERS DEVELOPMENT COMPANY, INC.
SWELL TEST
GUNDSEAL SAMPLE #AL2219



GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	3.5-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

CHAMBERS DEVELOPMENT COMPANY, INC.
SWELL TEST
GUNDSEAL SAMPLE #AL2219



GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	3.5-2
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

TABLE 3.6-1

HEALING ACTION TESTING
GUNDSEAL SPECIMEN CONDITIONS

Gundle Lining Systems Inc.

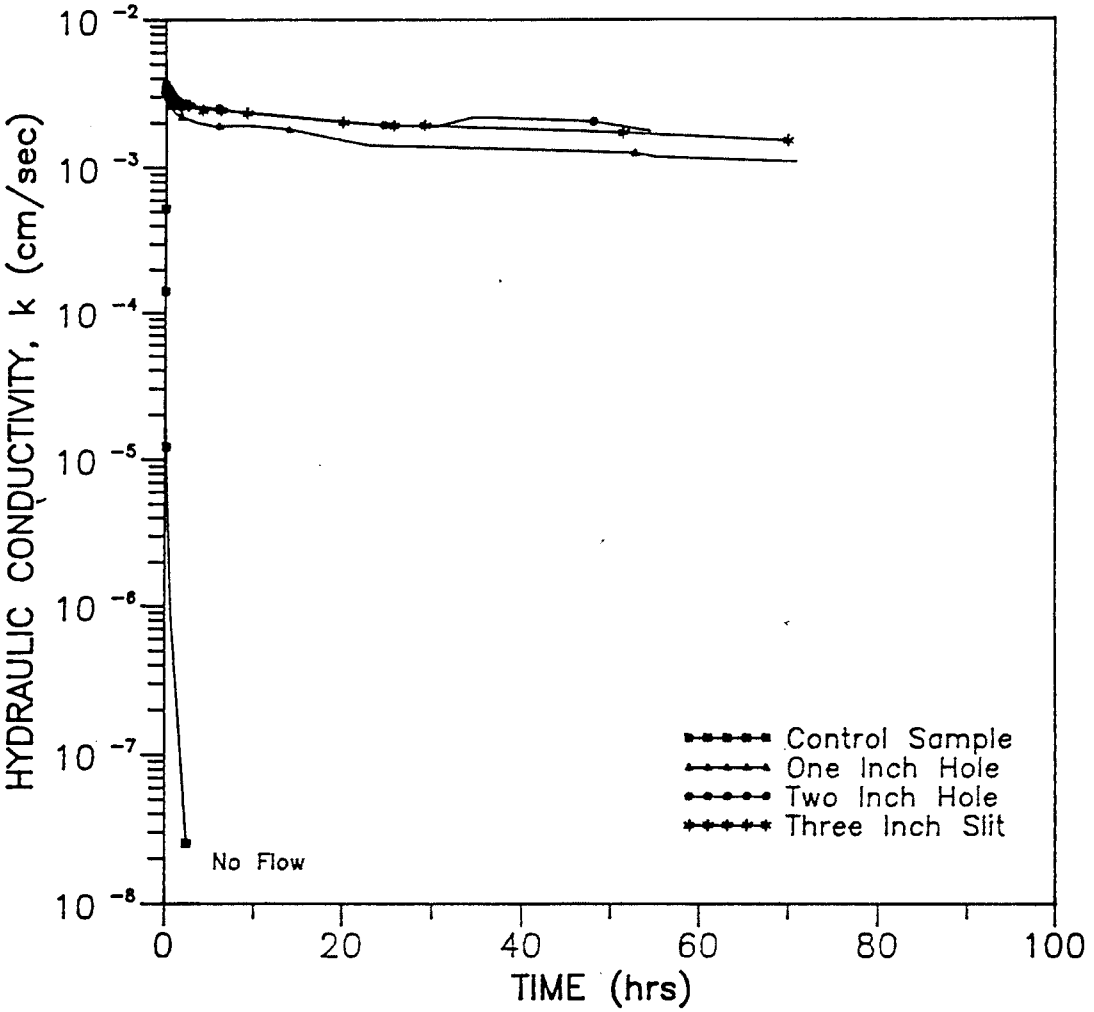
Specimen	Control		1-in. hole		2-in. hole		3-in. slit	
Parameter	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Thickness, in.	0.30	0.30	0.20	0.41	0.15	0.33	0.30	0.33
Diameter, in.	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
[1]Dry Mass, g	68.6	*	69.8	63.6	*	60.1	66.3	69.5
[2]Mass/Area, lb/ft^2	0.77	*	0.81	0.73	*	0.76	0.76	0.80
Water Content, %	9.0	*	9.3	195.2	10.2	151.5	9.0	115.5

Notes: [1] The dry mass includes the dry weight of the bentonite and the geomembrane backing.

[2] The mass/area is determined using the dry mass of the material normalized with respect to the cross-sectional area of the test specimen before drying.

* Data unavailable.

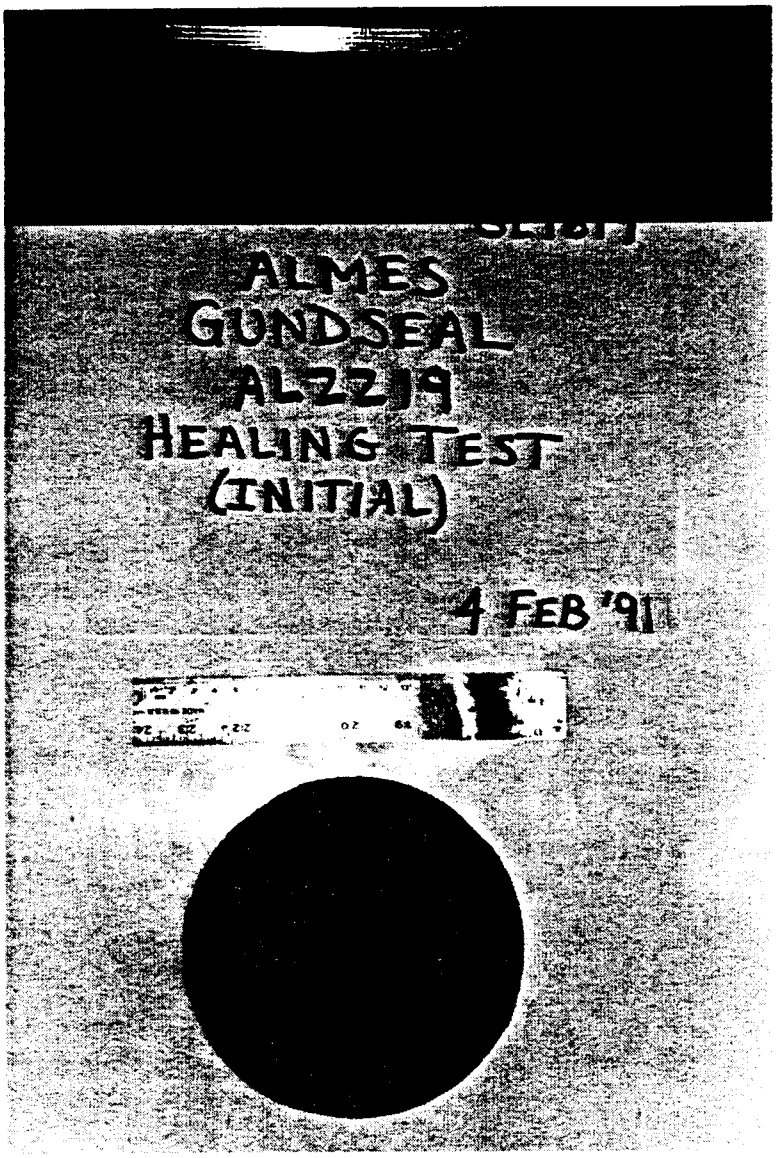
CHAMBERS DEVELOPMENT COMPANY, INC.
HEALING TEST
GUNDSEAL SAMPLE #AL2219



Notes:
Hydraulic Head: 12 in.
Test Configuration (from top to bottom): 2 in. Sand/Geotextile/Gundseal/Geotextile/12 in. Sand

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

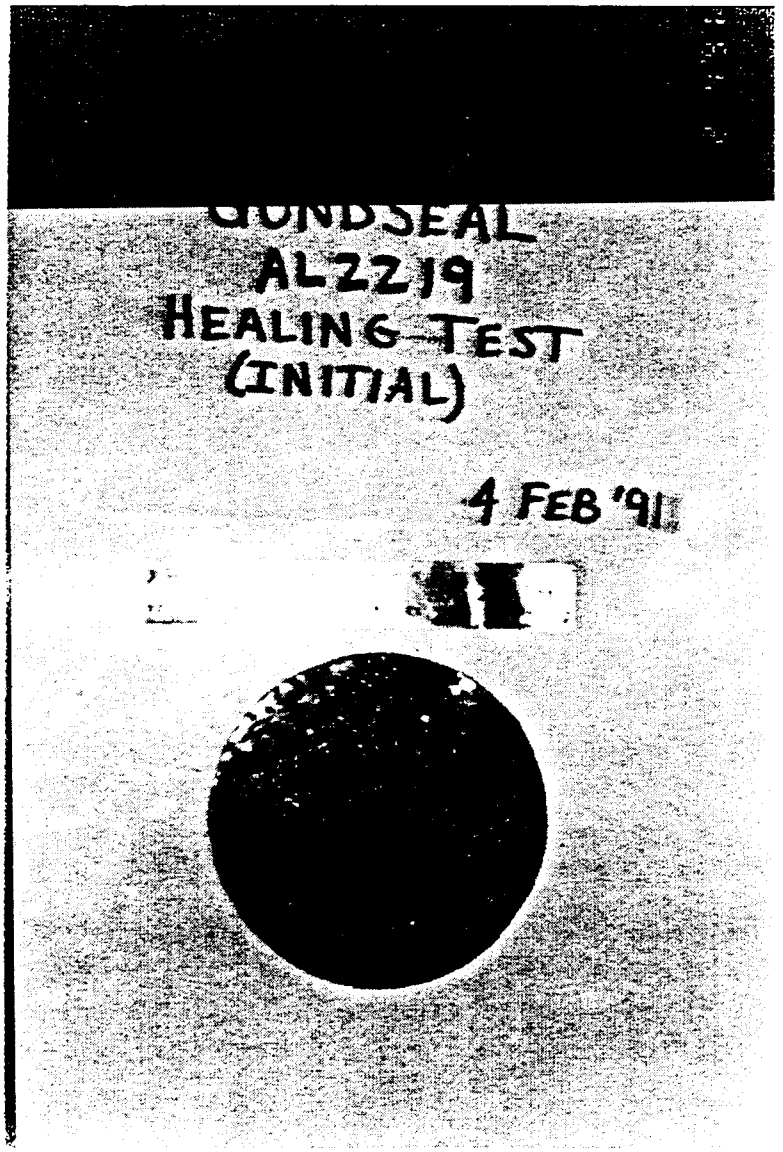
FIGURE NO.	3.6-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



BEFORE PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

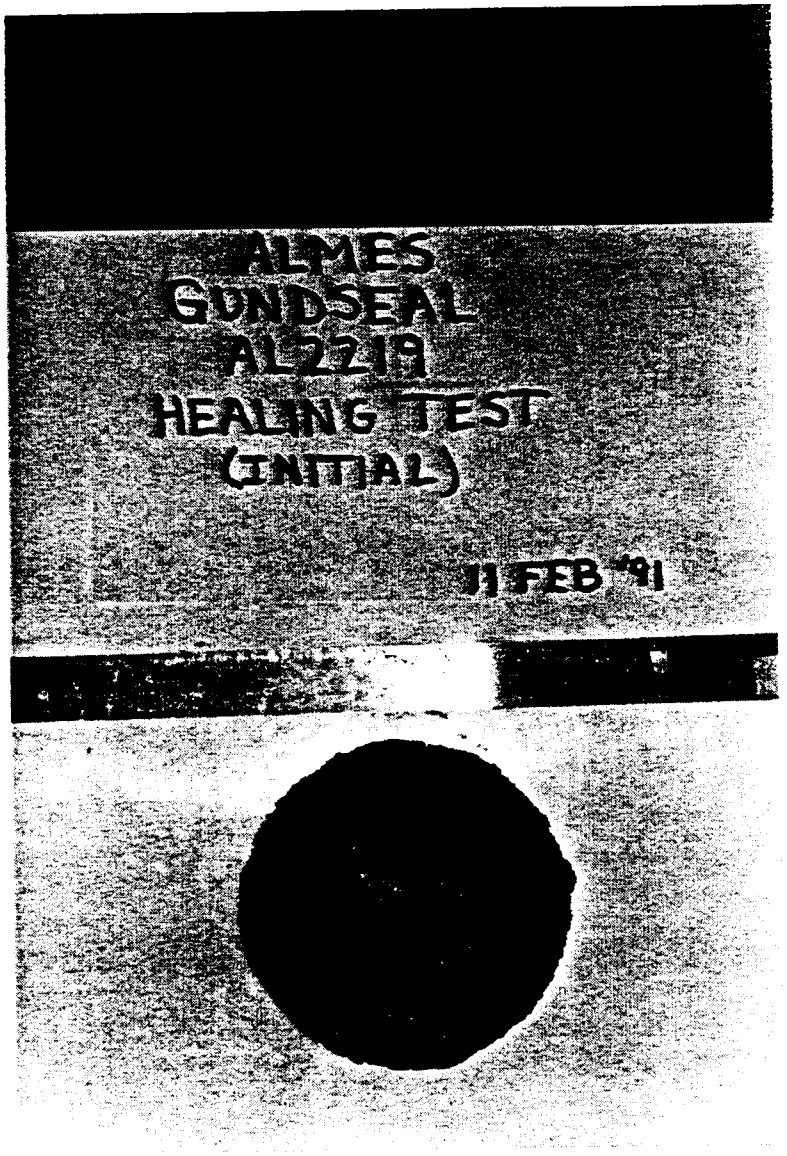
PHOTOGRAPH NO.	3.6-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



BEFORE PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

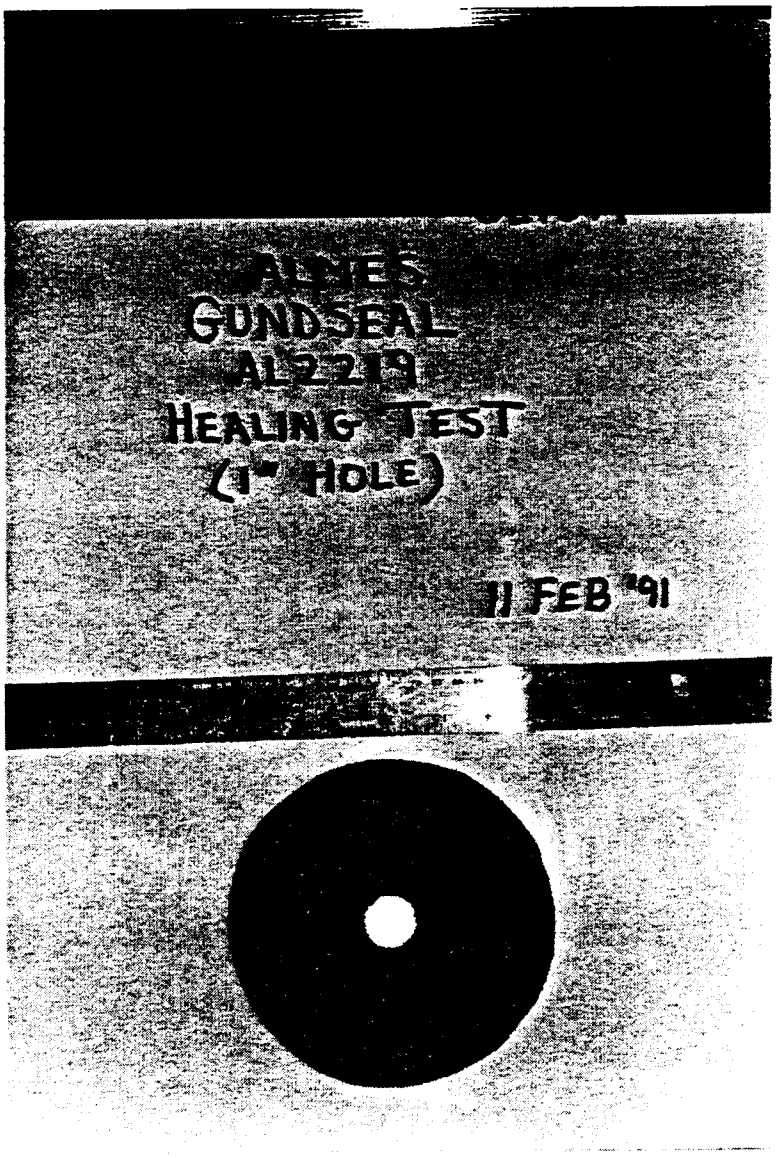
PHOTOGRAPH NO.	3.6-2
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



AFTER PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

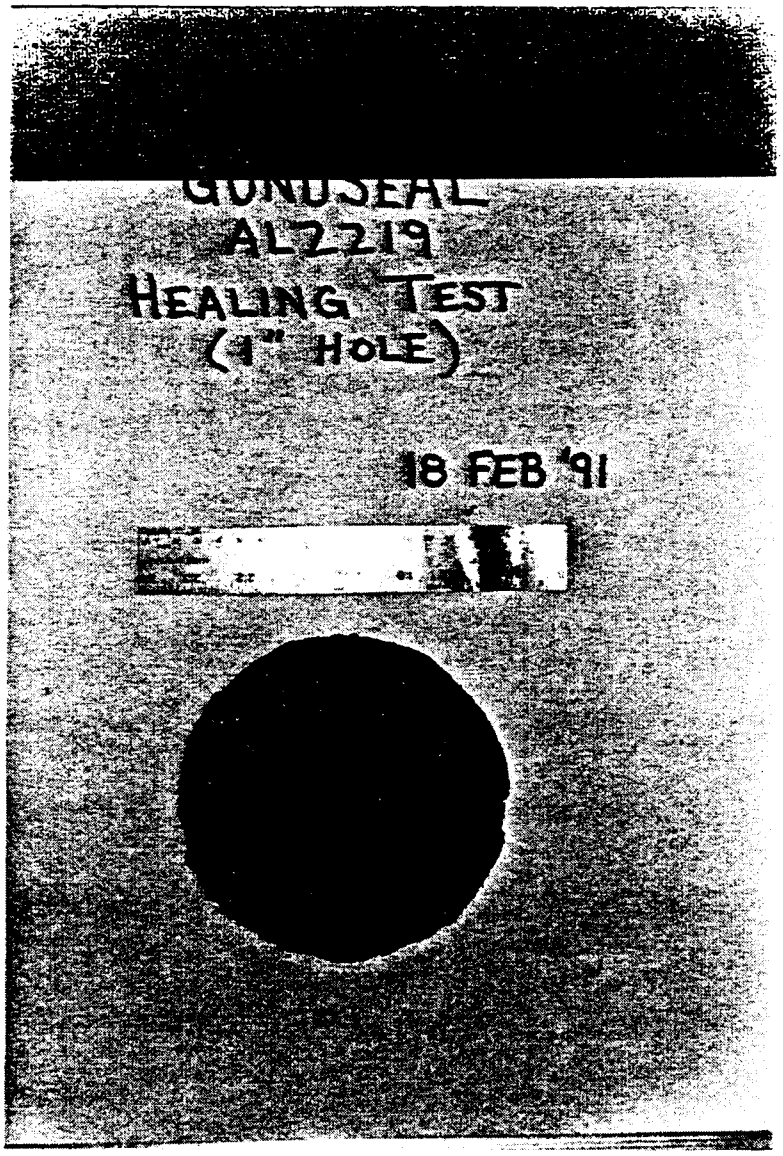
PHOTOGRAPH NO.	3.6-3
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



BEFORE PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

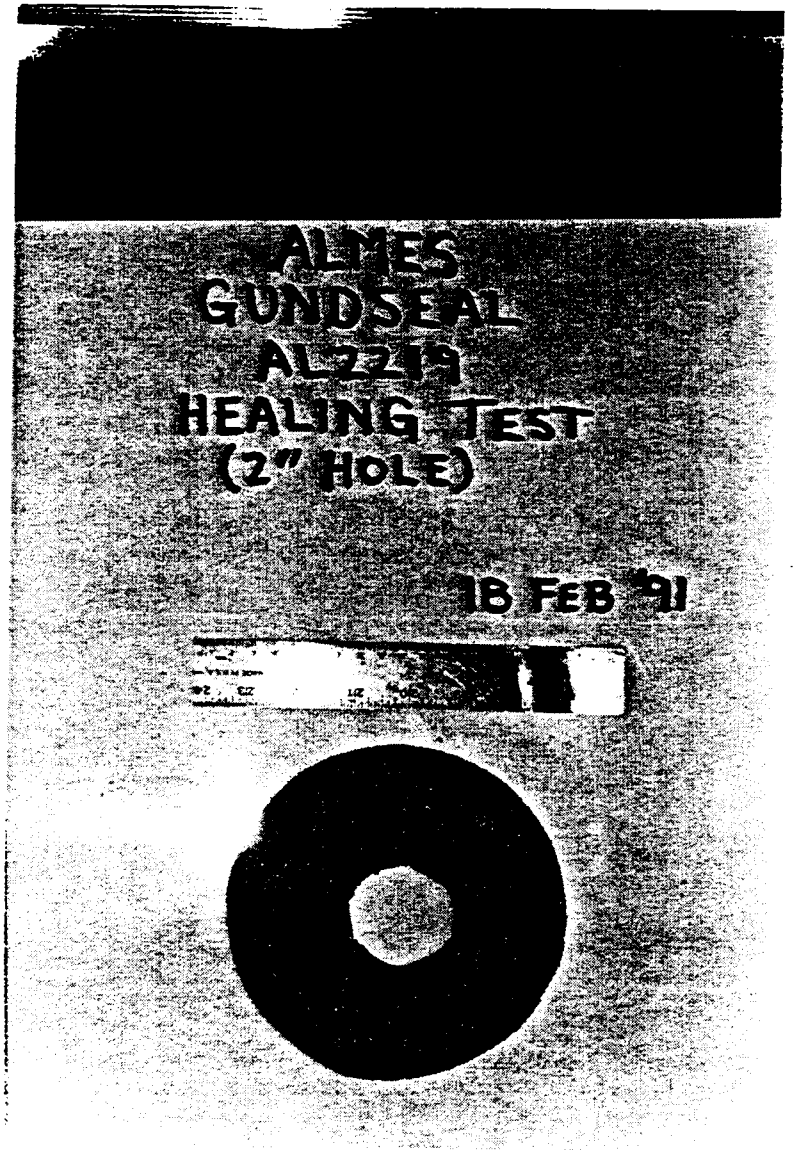
PHOTOGRAPH NO.	3.6-4
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



AFTER PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

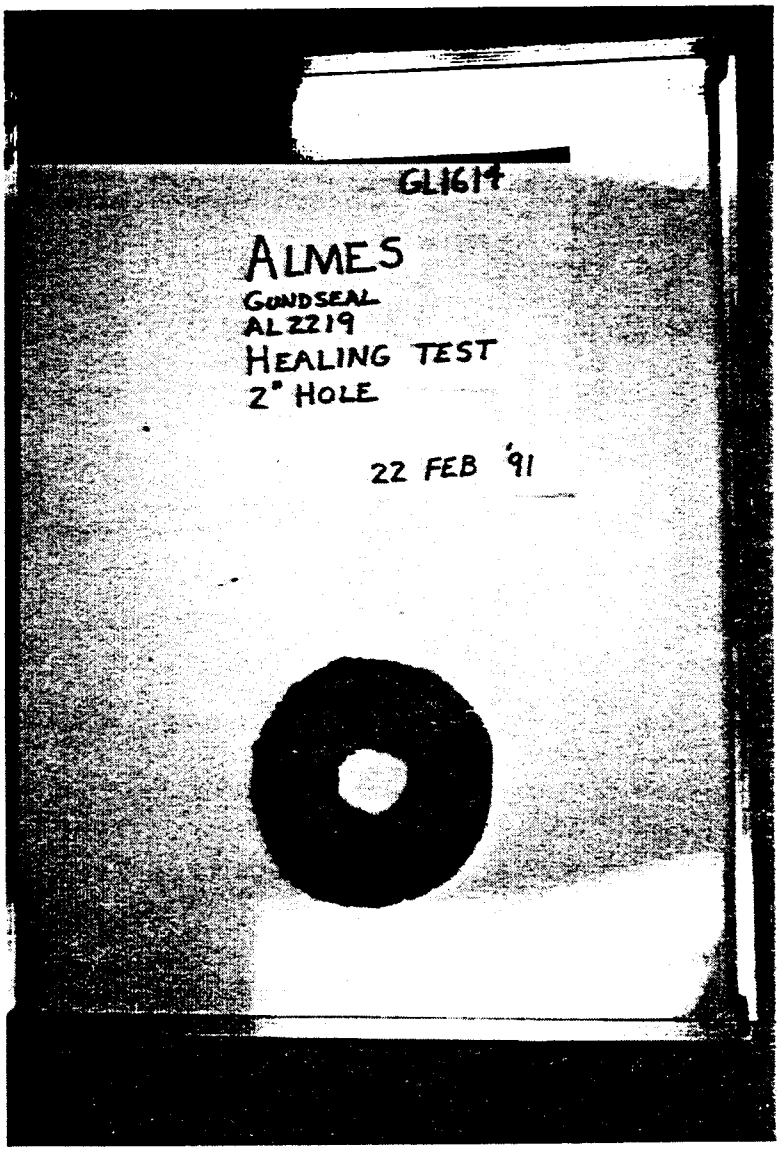
PHOTOGRAPH NO.	3.6-5
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



BEFORE PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

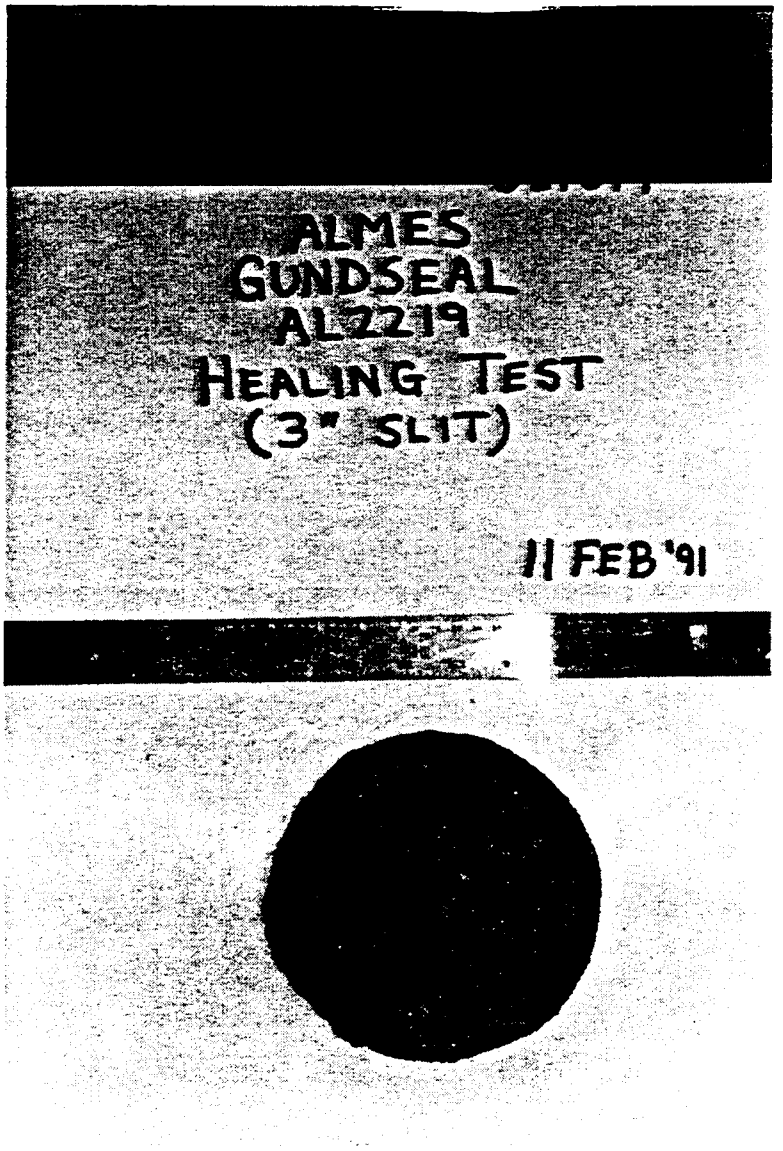
PHOTOGRAPH NO.	3.6-6
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



AFTER PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	3.6-7
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



AFTER PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	3.6-8
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

TABLE 3.7-1

SEAM TESTING
GUNDSEAL SPECIMEN CONDITIONS

Gundle Lining Systems Inc.

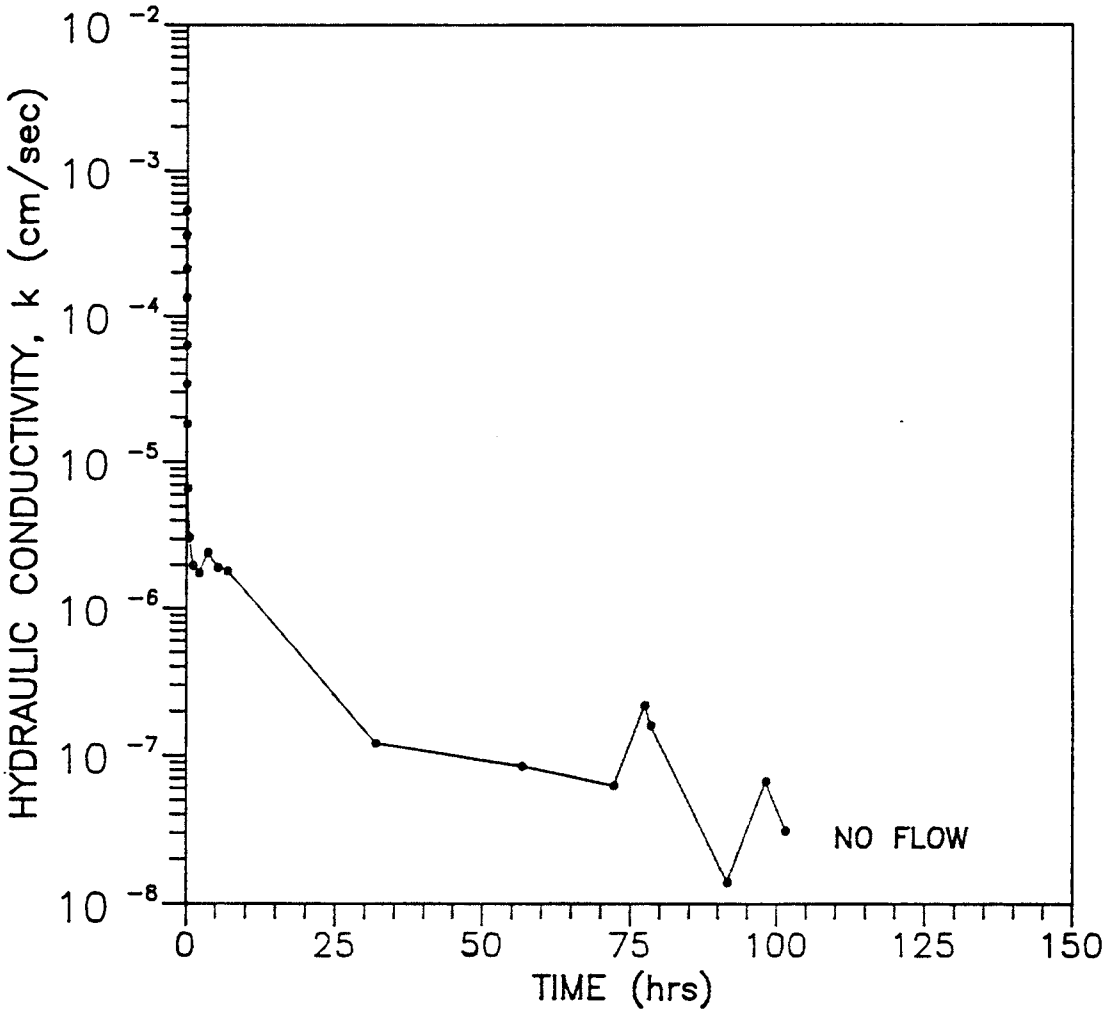
Parameters	Initial	Final
[1]Thickness, in.	0.16	0.30
Diameter, in.	6.00	6.00
[2]Dry Mass, g	108.1	103.0
[3]Mass/Area, lb/ft^2	0.74	0.71
Water Content, %	9.4	132.5

Notes: [1] Single layer thickness of bentonite and geomembrane.

[2] The dry mass includes the dry weight of the bentonite and the geomembrane backing.

[3] The mass/area is determined using the dry mass of the material normalized with respect to the cross-sectional area of both sections of the test specimen before drying.

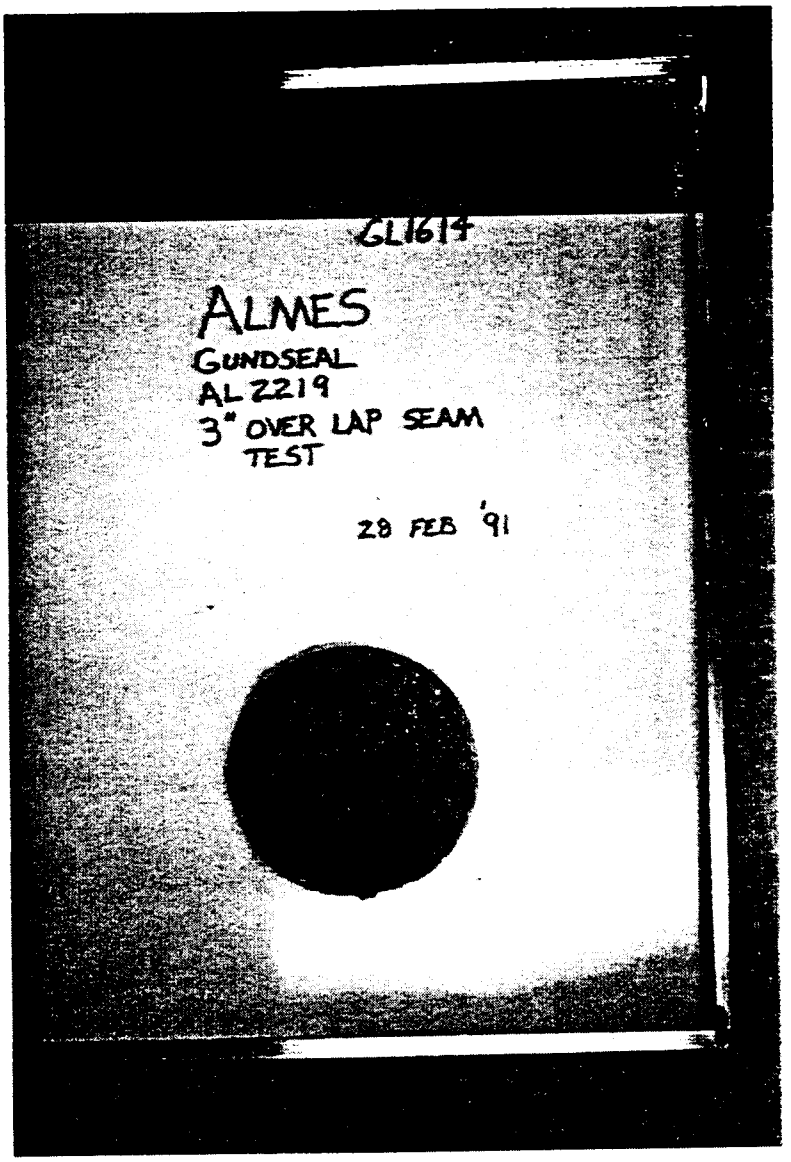
CHAMBERS DEVELOPMENT COMPANY, INC.
SEAM TEST
GUNDSEAL SAMPLE #AL2219



Notes:
Hydraulic Head: 12 in.
Test Configuration (from bottom to top): 2 in. Sand/ Gundseal (3 in. Overlap)/12 in. Sand

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

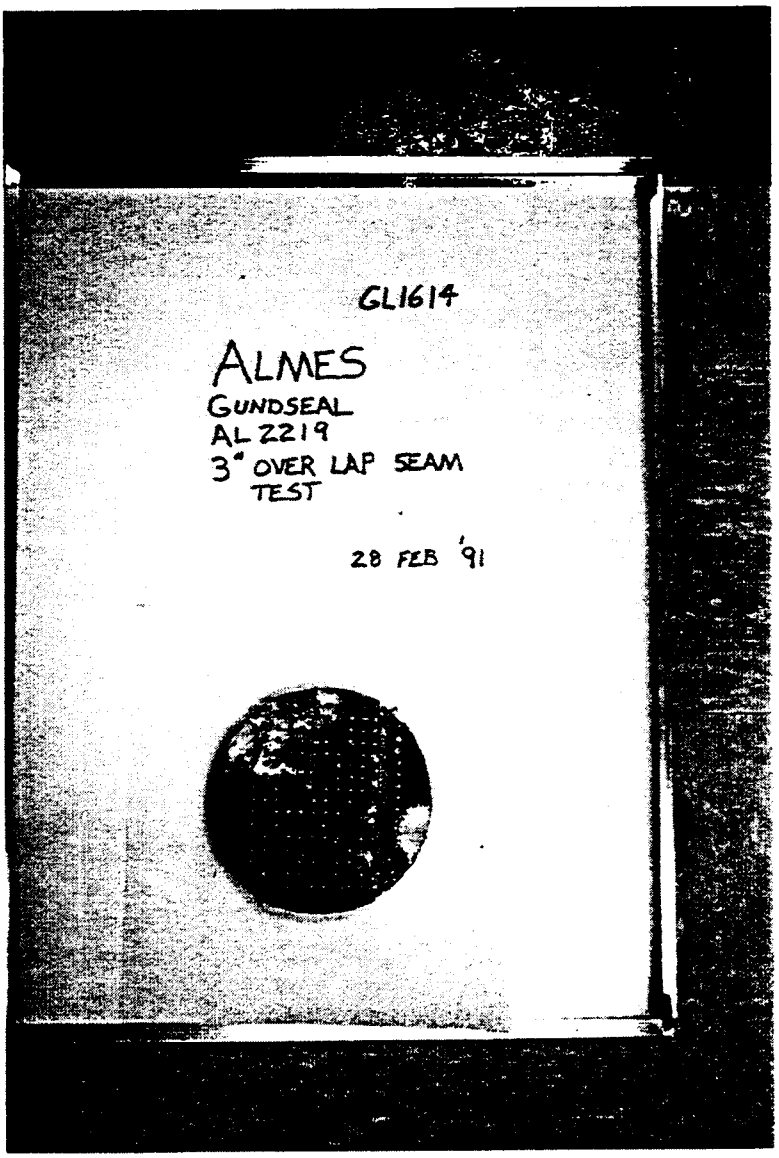
FIGURE NO.	3.7-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



AFTER PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

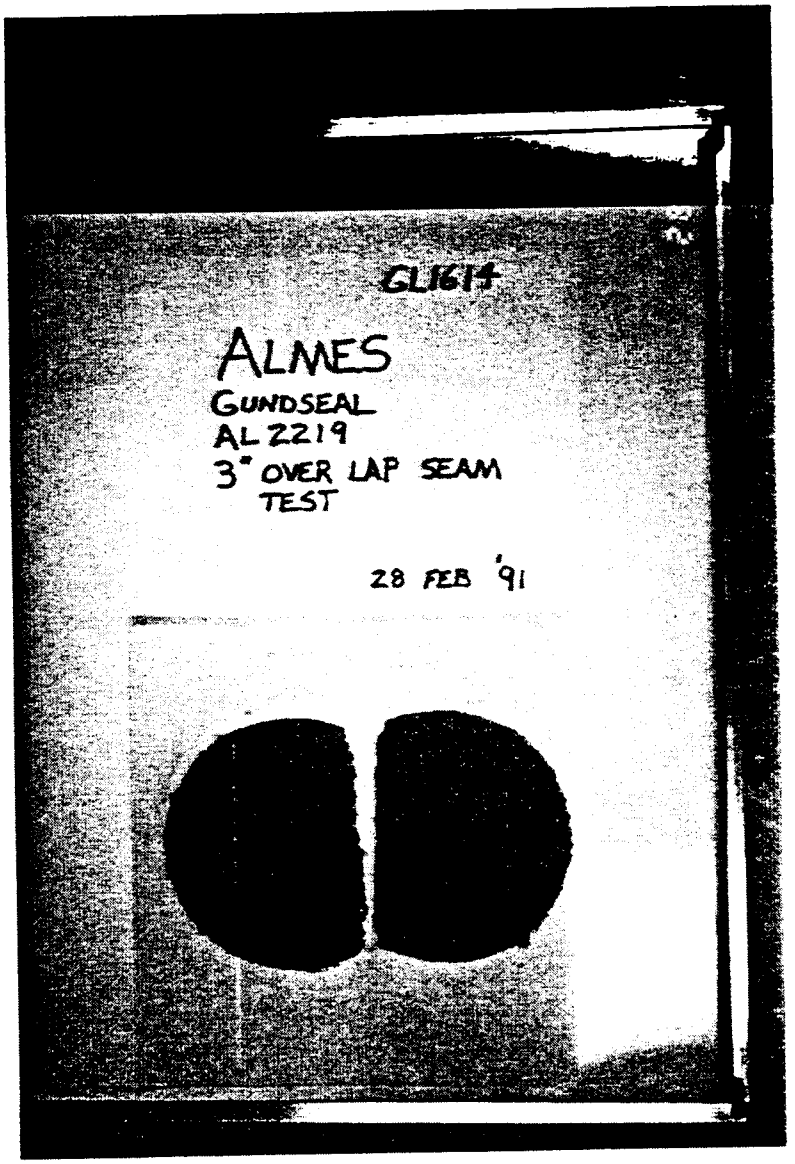
PHOTOGRAPH NO.	3.7-1
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



AFTER PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	3.7-2
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	



AFTER PERMEABILITY TEST

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

PHOTOGRAPH NO.	3.7-3
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91067
PAGE NO.	

EFFECTS OF PARTIAL WETTING OF GUNDSEAL ON STRENGTH AND HYDROCARBON PERMEABILITY

Prepared for
Gundle Lining Systems, Inc.
19103 Gundle Road
Houston, TX 77073

Prepared by

David E. Daniel and Hsin-yu Shan
The University of Texas
Department of Civil Engineering
Austin, TX 78712

February 21, 1992

ACKNOWLEDGMENTS

This research was sponsored by Gundle Lining Systems, Inc., Houston, Texas. The contact person from Gundle during the investigation was Mr. James Anderson. The authors wish to thank Mr. Anderson, Mr. Mark Cadwallader, and Mr. Fred Struve of Gundle for their continued support and for their suggestions and insights into issues concerning Gundseal and related products.

TABLE OF CONTENTS

Purpose 1

Approach 2

Equilibrium Water Content 2

Shear Strength 4

Permeability to Hydrocarbons 6

Materials and Methods 7

Gundseal Tested 7

Water Content Measurements 7

Soil Suction Measurements 7

Direct Shear Tests 9

Permeability 11

Results 12

Water Content-Suction Relationship 12

Rate of Water Content Change 15

Shear Strength 17

Permeability 17

Conclusions 20

Appendix A 32

Appendix B 40

PURPOSE

This report describes the results of a research project that was conducted to study the effects of partial wetting of Gundseal on: (1) the shear strength of the bentonite contained in Gundseal, and (2) the permeability of the bentonite in Gundseal to hydrocarbons. The objective of the research program was to develop independent test data to determine how Gundseal will respond to partial wetting when the material is placed against soil. Under such circumstances, the bentonite will likely draw moisture out of the adjacent soil and equilibrate at a water content that is greater than the dry (as-manufactured) material but less than fully-saturated material.

Tests were performed to determine:

1. The equilibrium water content of the bentonite when Gundseal is placed against soil.

2. The approximate rate of wetting of the bentonite when Gundseal is placed against soil.

3. The shear strength (short-term and long-term) of Gundseal over the full range of possible water content.

4. The permeability of the bentonite in Gundseal to hydrocarbons when the bentonite is wetted to various water contents prior to introduction of the hydrocarbons.

APPROACH

Equilibrium Water Content

If Gundseal is placed against soil, the bentonite will either absorb water from the soil or yield water to the soil, depending on the relative energy of water in the soil and in the bentonite. Water always flows down a gradient in energy, i.e., from higher to lower energy. For saturated materials, hydraulic heads provide a convenient means to determine which way water will flow. Water always flows from high hydraulic head to low hydraulic head.

Unsaturated soils are a little more complicated. The hydraulic heads in unsaturated soils are negative relative to atmospheric pressure and are not called "head" but instead are given names such as "soil water potential," "capillary pressure," "suction," and others. The term "suction" is used in this report as a matter of practical convenience. Suction is defined as the negative of the soil water potential expressed in units of pressure rather than length. Thus, for example, water in an unsaturated soil with a soil water potential of -33 ft has a suction of 1 bar (1 bar is approximately equal to 1 atmosphere of pressure--the bar is a commonly-used unit for reporting soil suction).

A perfectly saturated soil located at the water table has a suction of zero, i.e., the soil water is at atmospheric pressure. If an initially saturated soil is dried, a relationship can be found to exist between water content, w, and suction, s. The form of the relationship is shown in Figure 1. As water content is reduced, suction rises.

Water will always flow from zones of low suction to zones of high suction (i.e., from zones of high soil water potential to zones of low potential). For a homogeneous soil, this is analogous to stating that water will always flow from the wet areas to the dry areas. When two dissimilar soils (like sand and bentonite, for instance) are brought into contact with one another, water will flow from the soil with the lower suction to the soil with the higher suction. Water content differences do not necessarily indicate which way water flows. For instance, if bentonite at 17% water content is placed against sand at 2% water content, one cannot tell from this information alone whether the bentonite will tend to suck water out of the sand or the sand will tend to suck water out of the bentonite. However, knowledge of the suction of the bentonite at 17% water content and the suction of the sand at 2% water content will provide the answer concerning which way water will move. For the example of the sand and bentonite brought into

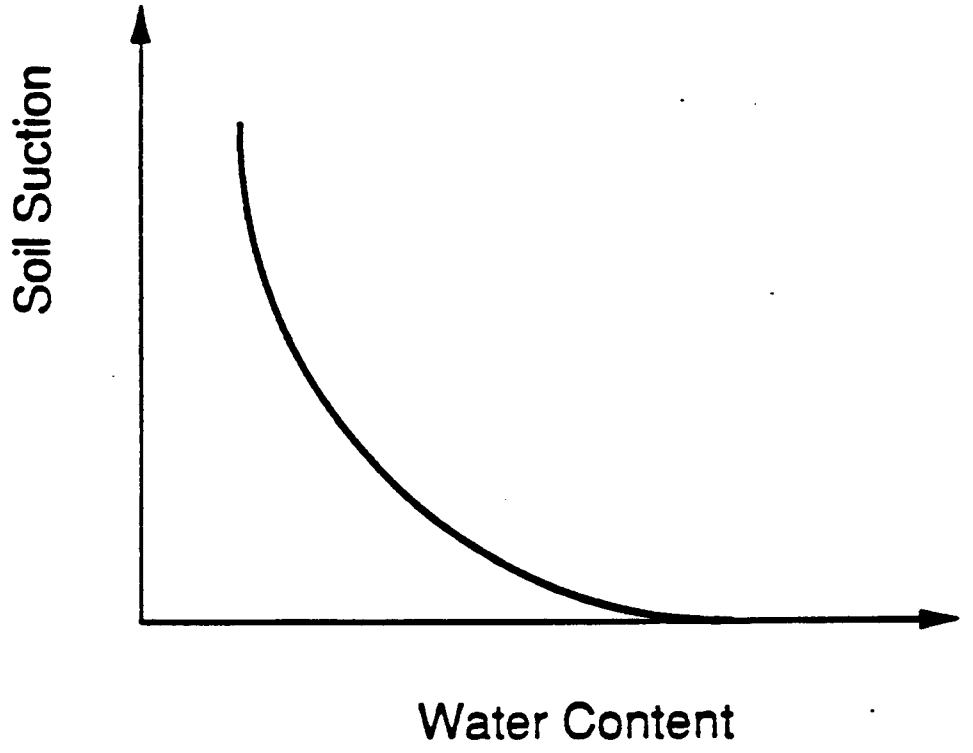


Figure 1. Water Content Versus Suction.

contact with one another, equilibrium is established when the suctions in the two materials reach the same values.

The relationship between water content and suction in the bentonite component of Gundseal was measured in this study. Once the water content - suction relationship is defined for the bentonite, it is a simple matter to estimate the equilibrium water content of Gundseal placed in contact with a soil having a known suction. Suppose a damp sand has a suction of 0.1 bar, and the water content of the bentonite in Gundseal at 0.1 bar is 50%. The water content of Gundseal as manufactured is approximately 17%. If the bentonite side of Gundseal were placed against this sand, the bentonite would draw water out of the sand. The mass of sand is so much larger than that of the bentonite that the water content and suction of the sand will probably not be significantly affected by the small loss of water to the bentonite. The bentonite in Gundseal would wet to a water content of 50%, at which point equilibrium between the sand and bentonite would be established; both would have a suction of 0.1 bar.

Later in this report, data are given for the relationship between water content and suction, for the bentonite in Gundseal. Typical suction values for various soils are presented, and probable equilibrium water contents for Gundseal used in various applications are reported. Also, the rate of wetting was studied, and this information is reported later, as well.

Shear Strength

The shear strength of dry bentonite can be much higher than that of wet bentonite. A major objective of this study was to determine how the shear strength of the bentonite in Gundseal varies as a function of water content.

To make this determination, test specimens were wetted to several water contents, allowed to equilibrate, and then set up in direct shear boxes (Figure 2). Two rates of shear were used: fast (0.26 mm/min) and slow (0.0003 mm/min). The slowest speed was selected to allow time for dissipation of all excess water pressure during shear, which usually corresponds to the most critical condition for moist or wet clay. The intent was to span the full range of possible water content (from "dry" bentonite to fully saturated bentonite) and a representative range in rate of shear.

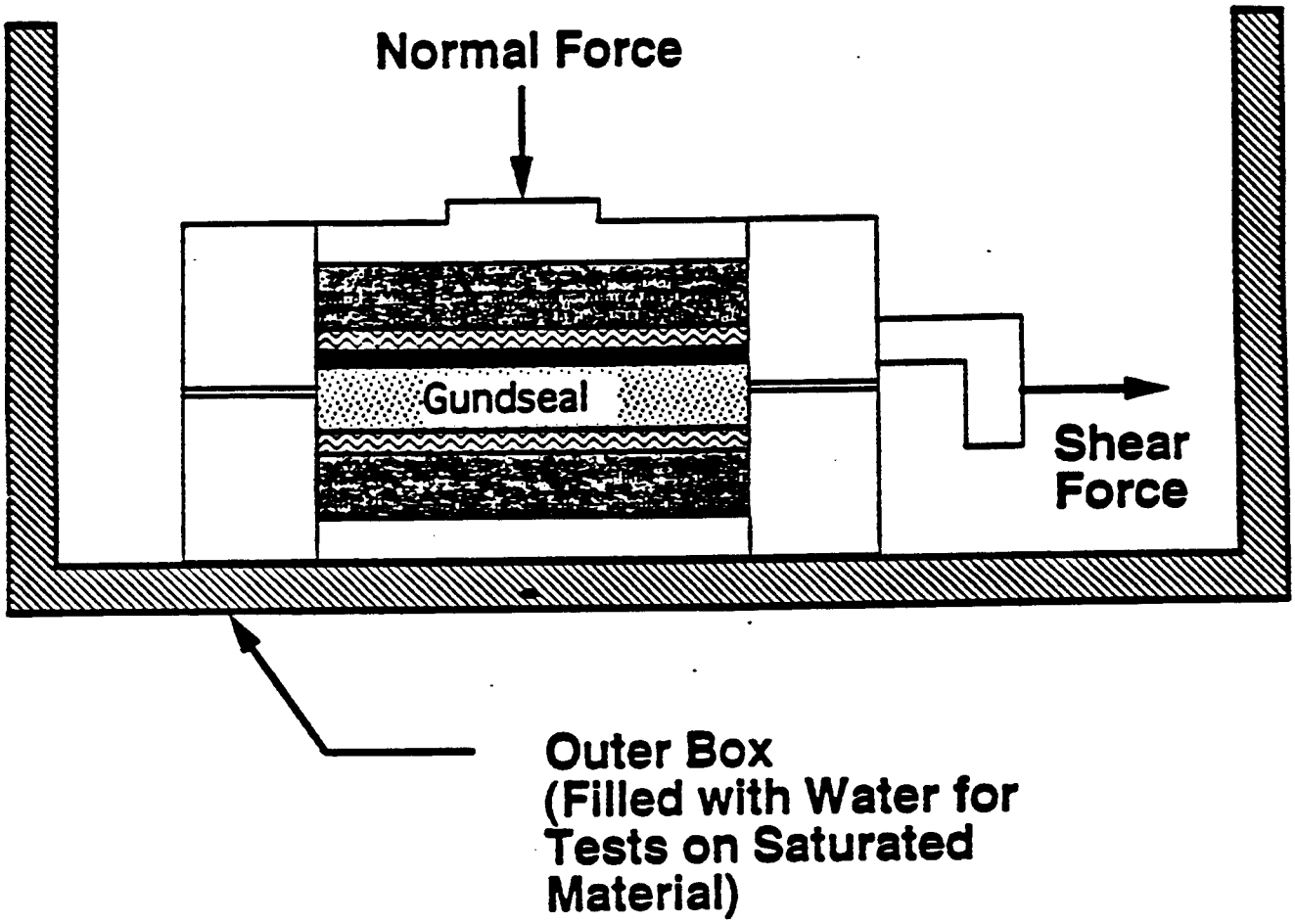


Figure 2. Direct Shear Apparatus.

Later in this report, the shear strength parameters (cohesion and angle of internal friction) are reported and related to water content and rate of shear.

Permeability to Hydrocarbons

The permeability of clays (particularly expandable clays such as smectite, which form bentonite) is known to be sensitive to the chemical properties of the permeating liquid. One of the several factors that can influence the permeability of clay is the dielectric constant of the fluid in the pores of the clay material. Water is a polar fluid with a high dielectric constant (81 at room temperature). Hydrocarbons tend to be non-polar and to have very low dielectric constants (often in the range of 1 to 10). When water is replaced by hydrocarbons in the pores of the clay, the electrical double layer surrounding the clay may collapse, causing an increase in permeability. If a dry clay is wetted with water, the clay minerals are said to "hydrate" and to swell. Dry clays may not hydrate and swell when exposed to hydrocarbons. The permeability of hydrated, swollen clay tends to be far lower than that of nonhydrated clay.

It is expected that water-saturated Gundseal will resist attack by hydrocarbons far better than dry Gundseal. However, no data were available prior to this study to confirm this hypothesis. Also, no data were available to indicate how wet the bentonite must be to have a low permeability to hydrocarbons. The objective of this study was to wet specimens of Gundseal without the HDPE sheet (just bentonite) to various water contents and then permeate the specimens with a variety of representative hydrocarbons to determine the effect of partial wetting.

MATERIALS AND METHODS

Gundseal Tested

A fresh piece of Gundseal was shipped from the factory to our laboratories at the beginning of the project. Standard material with a 0.5 mm (20 mil) thick high density polyethylene (HDPE) sheet was tested.

Test specimens were cut from random locations within the large piece of Gundseal. The bentonite in the material appeared to be uniform; thickness varied about ± 0.5 mm. All tests except permeability tests were performed on the HDPE/bentonite composite. Permeability tests were performed on the bentonite alone; the bentonite layer was carefully separated from the HDPE sheet with a knife for the permeability tests.

Water Content Measurements

All water content measurements were performed by drying specimens overnight at 110°C in accordance with procedures outlined in ASTM D-2216. All water contents reported herein are gravimetric values, i.e., mass of water lost upon drying divided by the oven-dry mass of solids and expressed as a percentage.

Soil Suction Measurements

Soil suctions were measured with two techniques. The first technique involved slowly wetting a piece of Gundseal that measured about 175 by 25 mm (7 by 1 inch), inserting the Gundseal in a large test tube, inserting a thermocouple psychrometer in the center of the test tube, and sealing the test tube with a rubber stopper (Figure 3). The psychrometers were supplied by Wescor, Inc., and were read with a Keithley microvoltmeter. The test tubes were stored in a heavily insulated container and were read about 2 weeks later, at which point equilibrium had been reached. The Gundseal specimen was then removed and oven dried to determine water content.

The second method of measurement involved inserting small pieces (about 25 mm, or 1 inch, square) of Gundseal in sealed containers that contained salt solutions with known vapor pressures. Test specimens were periodically removed and oven dried to determine water content. Equilibrium was not reached for many weeks. The salt solutions that were used and the corresponding equilibrium suction values were as follows:

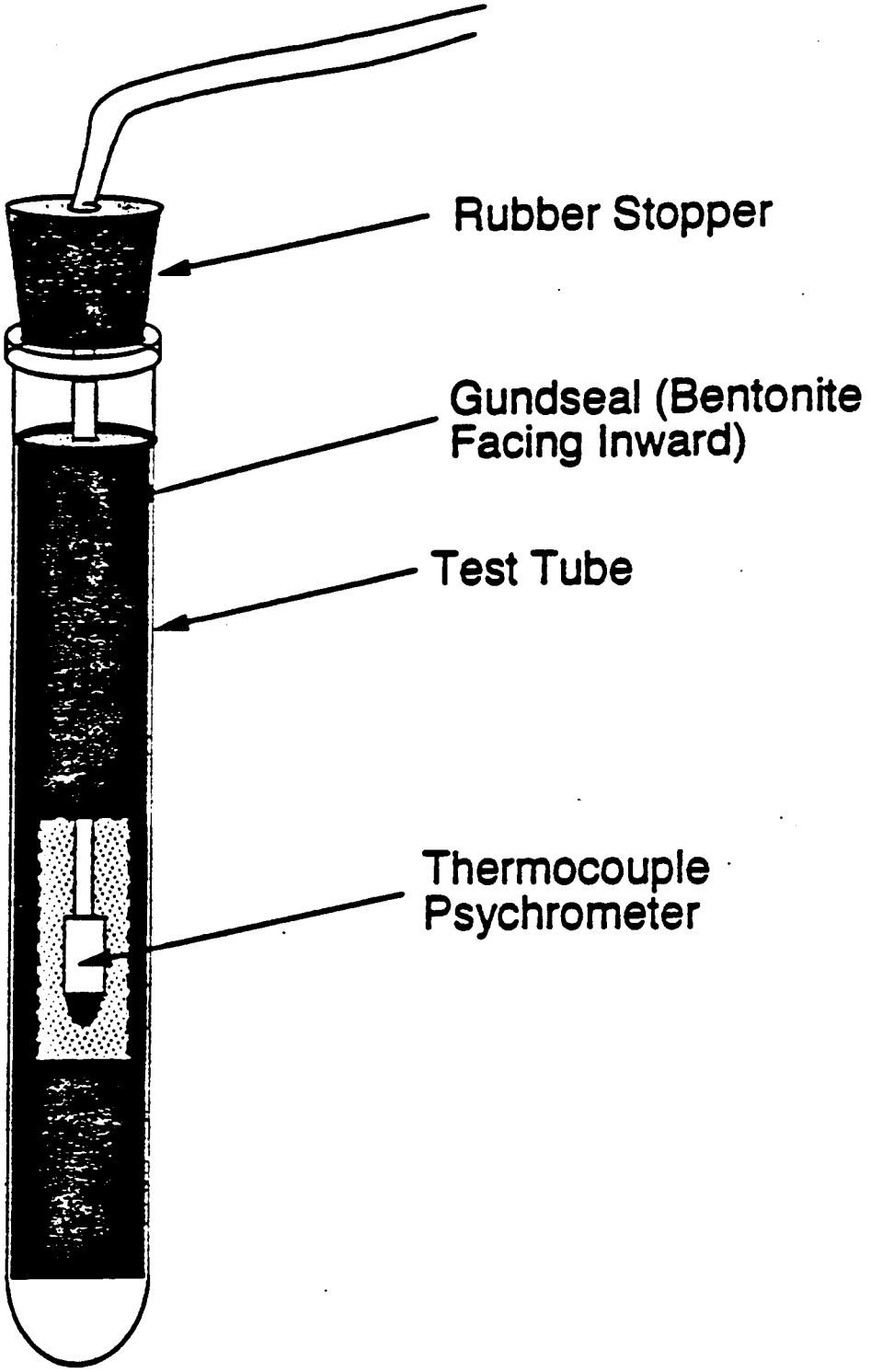


Figure 3. Suction Measurement with Thermocouple Psychrometer.

Salt Solution	Equilibrium Suction (bars)
0.0218 M NaCl	1
0.110 M NaCl	5
0.357 M NaCl	16
1.13 M NaCl	52

The water contents reported herein were measured on specimens that had been exposed to the controlled vapor pressures for 66 days.

To evaluate rate of wetting, 6 pieces of Gundseal, each measuring 100 by 25 mm (4 by 1 inch), were placed directly in contact with sand in 20-L (5 gal) buckets. The sand in each bucket was wetted to a different water content. The Gundseal specimens were buried below about 75 mm (3 inches) of sand, and every several days, a specimen was removed to determine the water content of both the bentonite and the sand beneath the bentonite. The last (sixth) sample was removed 42 to 44 days after each test had begun.

A grain-size distribution curve for the sand, developed with procedures described in ASTM D422, is shown in Figure 4.

Direct Shear Tests

Direct shear tests were performed in general accord with procedures outline in ASTM D-3080. Sixty millimeter (2.4-inch) diameter test specimens were cut from the large piece of Gundseal. The samples that were sheared in a dry condition were placed in the shear box, subjected to a normal load, and then sheared. Saturated samples had been sheared several months ago by the authors, and these tests were not repeated. To shear saturated samples, dry samples of Gundseal were first placed in the direct shear box, subjected to the desired normal load, and then wetted. Approximately two weeks were required before swelling ceased.

Partially wetted samples of Gundseal were moistened to water contents of approximately 50% or 100% outside of the shear box. The partially wetted specimens were then placed in a shear box, consolidated to the desired stress, and sheared at a rate of either 0.26 mm /min (16 mm/hr) or 0.0003 mm/min (0.02 mm/hr). The slow rate was selected to ensure full dissipation of excess pore water pressure generated during shear. Failure was forced through the bentonite as close to the center of the bentonite as possible. After shear, the specimens were removed and the water content was determined.

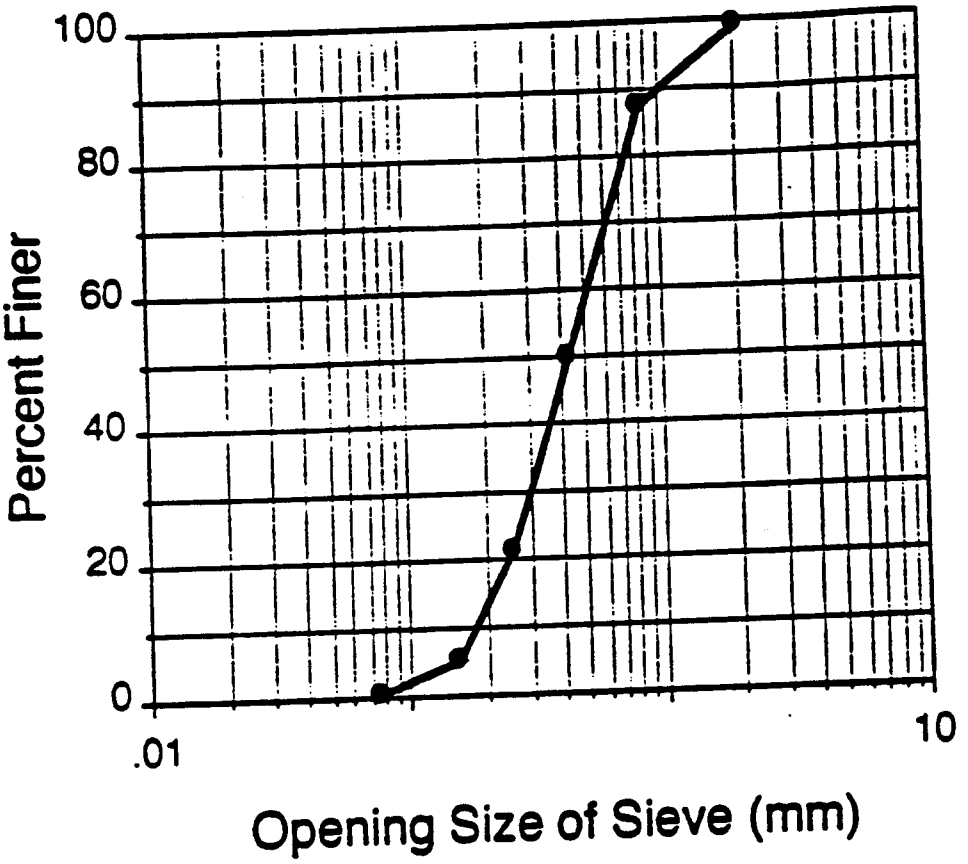


Figure 4. Grain Size Distribution Curve for Sand.

Permeability

Tests were performed to determine the permeability of the bentonite within Gundseal to various organic liquids. Tests were performed on 100-mm (4-inch) diameter specimens of Gundseal without the HDPE sheet. The tests were performed without back pressure in flexible-wall permeameters using a falling headwater and rising tailwater.

After the HDPE was removed from the Gundseal, specimens were slowly wetted to a nominal water content of 50%, 100% or 125%. Tests on dry and water-saturated materials were also performed. The specimens were carefully placed in flexible-wall permeameters equipped with stainless steel and Teflon® components. Teflon® sheeting separated the test specimens from the surrounding latex membranes. After the cells were assembled, the chambers were filled with water and the specimens were consolidated to a stress of 14 kPa (2 psi). Then the organic liquid of interest was introduced. However, for tests on water-saturated samples, the bentonite was first permeated with tap water and then with the organic liquid. The head of liquid was approximately 300 to 600 mm (1 to 2 ft), and the resulting hydraulic gradient was 80 to 120. The thicknesses of the specimens used for calculating permeability were 3.5, 4.0, 5.5, 6.0, and 6.5 mm for initial water contents of 17, 50, 100, 125, and 145%, respectively.

The organic liquids used in the investigation were benzene, gasoline, methanol, tert-butylethylether (MTBE), and trichloroethylene. Methanol was selected because it is a water-soluble, polar alcohol of intermediate dielectric constant. The other liquids are non-polar, non-water-miscible hydrocarbons. Benzene is lighter than water and TCE is heavier than water. Gasoline was selected because its storage in tanks is common. Regular unleaded gasoline obtained from a local service station was used. Some of the properties of the liquids used in this study (obtained from the literature) are summarized in Table 1.

Table 1. Typical Properties of Permeant Liquids

Liquid	Dielectric Constant	Density (g/cc)	Viscosity (cp)
Benzene	2.284	0.8765	0.652
Gasoline	--	0.68	0.43
Methanol	32.63	0.7914	0.597
MTBE	--	--	--
TCE	3.4	1.4996	0.55
Water	81	1	1.002

Note: Blank indicates information could not be located.

RESULTS

Water Content - Suction Relationship

Table 2 summarizes the water content and suction data that were obtained with the thermocouple psychrometer and vapor equilibrium methods. The relationship between water content and suction is graphed in Figure 5. The measured water contents ranged from 17% (dry Gundseal) to 145% (Gundseal soaked in water at a compressive stress of 14 kPa or 2 psi). The suctions ranged from 0 to about 50 bars.

Many engineers are unaccustomed to dealing with suction values. One or two points of reference may be helpful to some readers. One useful reference is 15 bars of suction, which is approximately equal to the wilting point of many plants. Plants can suck water out of unsaturated soils that have suctions between 0 and 15 bars. Plants will wilt and die if the soil suction exceeds about 15 bars. Most people have an intuitive sense for how dry a soil is when it will no longer support plant growth without watering the soil. If the bentonite in Gundseal is placed against soil at the wilting point (15 bars of suction in the soil), the water content of the bentonite would rise to about 50%. In all but very arid climates, it is safe to assume that the water content of Gundseal will be at least 50% if the bentonite is placed against the soil.

Table 2. Water Content - Suction Results

Water Content (%)	Suction (bars)	Method of Measurement
17	>75*	Thermocouple Psychrometer
17	43	Thermocouple Psychrometer
18	44	Thermocouple Psychrometer
24	49	Thermocouple Psychrometer
28	43	Thermocouple Psychrometer
29	52	Vapor Equilibrium
31	25	Thermocouple Psychrometer
46	14	Thermocouple Psychrometer
54	16	Vapor Equilibrium
56	8	Thermocouple Psychrometer
66	7	Thermocouple Psychrometer
79	6	Thermocouple Psychrometer
89	5	Vapor Equilibrium
96	4	Thermocouple Psychrometer
101	1	Vapor Equilibrium
145	0	Direct Soaking with 14 kPa (2 psi) Compressive Stress

*Suction of as-received Gundseal was too large to be measured with thermocouple psychrometers but was >75 bars, which is the limit of measurement of the thermocouple psychrometers that were used.

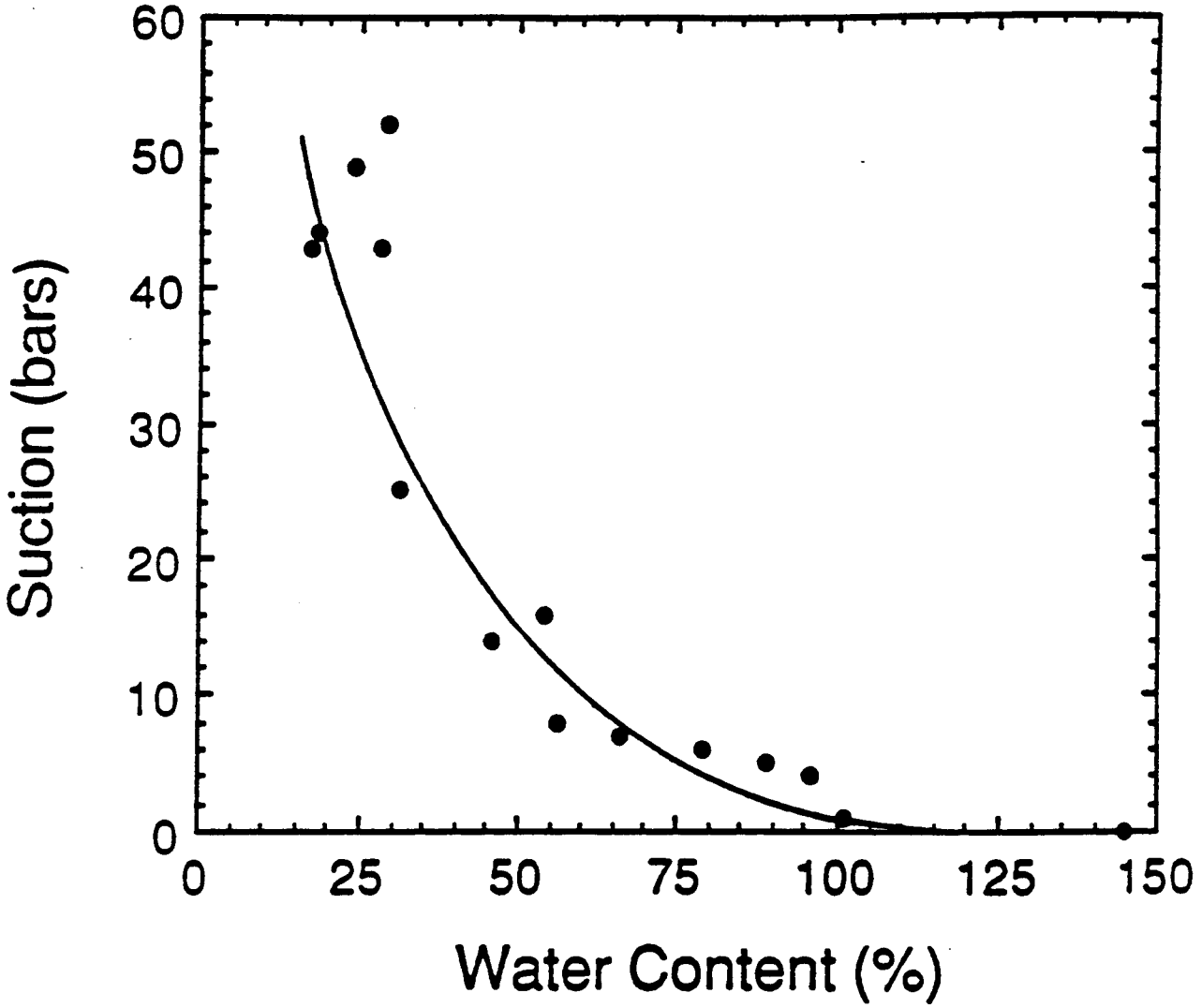


Figure 5. Relationship between Water Content and Suction for Bentonite in Gundseal.

Moist soils that support lush vegetation have suctions of 0 to 1 bar. The equilibrium water content of the bentonite in Gundseal placed upon such soils would be at least 100% and perhaps closer to 140%. The water content can actually approach 200% if the bentonite is placed on wet soil with practically no overburden stress.

As the reader examines the remainder of this report, he may wish to keep in mind several practical ranges of water content:

Soil Conditions	Approximate Water Content (%) of Bentonite in Gundseal Placed on Soil
Extremely Dry Soil that Will Not Support Plant Growth	< 50%
Damp Soil that Will Support Sparse Growth of Plants	50% - 100%
Moist Soil that Will Support Growth of Lush Vegetation	100% - 140%
Wet (Practically Saturated) Soil	> 140%

Rate of Water Content Change

Small samples of Gundseal were placed on the surface of sand in 20-L (5 gal.) buckets and were covered with 75 mm (3 in.) of sand. In one bucket, the sand was soaked and water was allowed to drain from the soil by gravity, at which point the sand was at its field capacity and the water content was approximately 17%. In other buckets, the sand was wetted to water contents of 10, 5, 3, 2 and 1%. Gundseal samples were removed every several days until the last sample was removed from each bucket 42 to 44 days after the tests were initiated.

The water content of the Gundseal samples is plotted versus time in Figure 6. The equilibrium water contents ranged from 50% for the driest sand to 190% for the wettest sand.

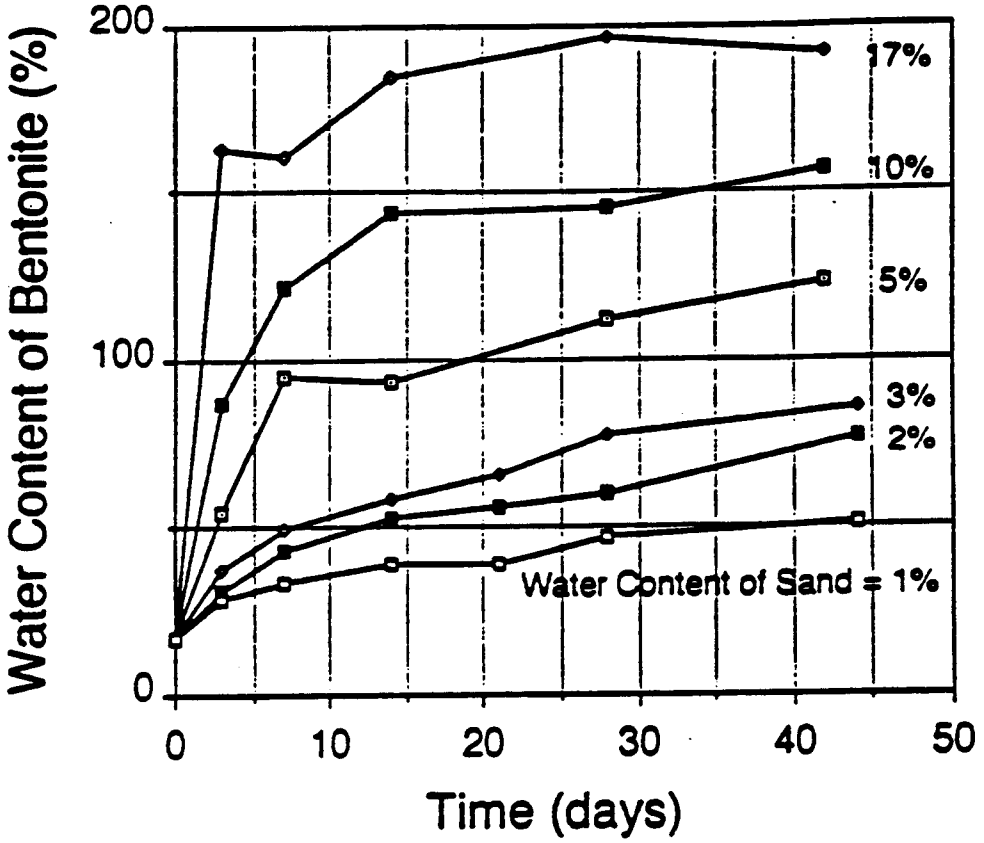


Figure 6. Water Content Versus Time for Samples of Gundseal Placed in Contact with Sand at Various Water Contents.

It was not clear that full equilibrium was reached even for the samples left in the buckets for 45 days. Most of the change in water content occurred in less than 1 week for the wettest sand and less than 2 to 3 weeks for the driest sand.

Shear Strength

The results of the direct shear tests are summarized in Table 3 and are plotted in Figure 7. Plots of shearing stress versus horizontal displacement are presented in Appendix A. The linear failure envelopes shown were computed by regression analysis. The corresponding values of cohesion and friction angle were as follows (Table 4):

The rate of shear had an important impact on the test results, even for "dry" Gundseal. Failure envelopes for nominal water contents of 17%, 50%, and 100% are shown in Figures 8, 9, and 10, respectively, with separate envelopes shown for fast and slow shear.

Permeability

Results of the permeability tests are summarized in Table 5. Complete results are presented in Appendix B. The permeability of the bentonite component of Gundseal to hydrocarbons was relatively high (on the order of 10^{-5} cm/s) when the initial water content (w_o) was 17% or 50%. However, when the water content was increased to 100% or greater, the permeability was low (on the order of 10^{-9} cm/s or less).

Plots of permeability versus pore volumes of flow are presented in Figures 11 through 16. One pore volume of flow is defined as a quantity of inflow equal to the volume of the pore space in the test specimen. No graph is shown in Figures 11 through 16 for cases in which no flow was measured.

Table 3. Results of Direct Shear Tests.

Water Content (%)		Shearing	Conditions at Failure	
Nominal	After Failure	Rate	Normal Stress (kPa)	Shearing Stress (kPa)
17	17	Fast	26.8	30.9
17	17	Fast	37.3	37.7
17	17	Fast	70.1	70.2
17	17	Fast	105	92.8
17	17	Fast	139	112
17	17	Slow	26.8	19.1
17	17	Slow	37.3	26.5
17	17	Slow	70.1	36.3
17	17	Slow	105	52.9
50	58	Fast	26.8	27.0
50	57	Fast	37.3	33.8
50	58	Fast	70.1	56.2
50	57	Fast	105	66.3
50	56	Fast	139	87.4
50	38	Slow	26.8	16.8
50	46	Slow	37.3	17.0
50	51	Slow	70.1	24.5
50	46	Slow	105	41.8
50	81.7	Slow	139	23.9
100	82	Fast	26.8	25.9
100	111	Fast	37.3	23.2
100	92	Fast	70.1	35.0
100	94	Fast	105	42.4
100	79	Fast	139	47.2
100	128	Slow	26.8	8.4
100	101	Slow	37.3	14.7
100	96	Slow	70.1	17.0
100	66	Slow	105	20.9
100	83.01	Slow	139	23.6
145	---	Slow	26.8	7.4
145	---	Slow	44.1	13.0
145	---	Slow	61.5	15.5
145	---	Slow	105	23.2
145	---	Slow	139	25.2

Notes:
1. Samples were wetted to the approximate desired water content, placed in direct shear box, consolidated under specified normal load, and then sheared.
2. Shearing speeds were 0.26 mm/min (fast shear) and 0.0003 mm/min (slow shear).
3. 1 psi = 6.89 kPa.

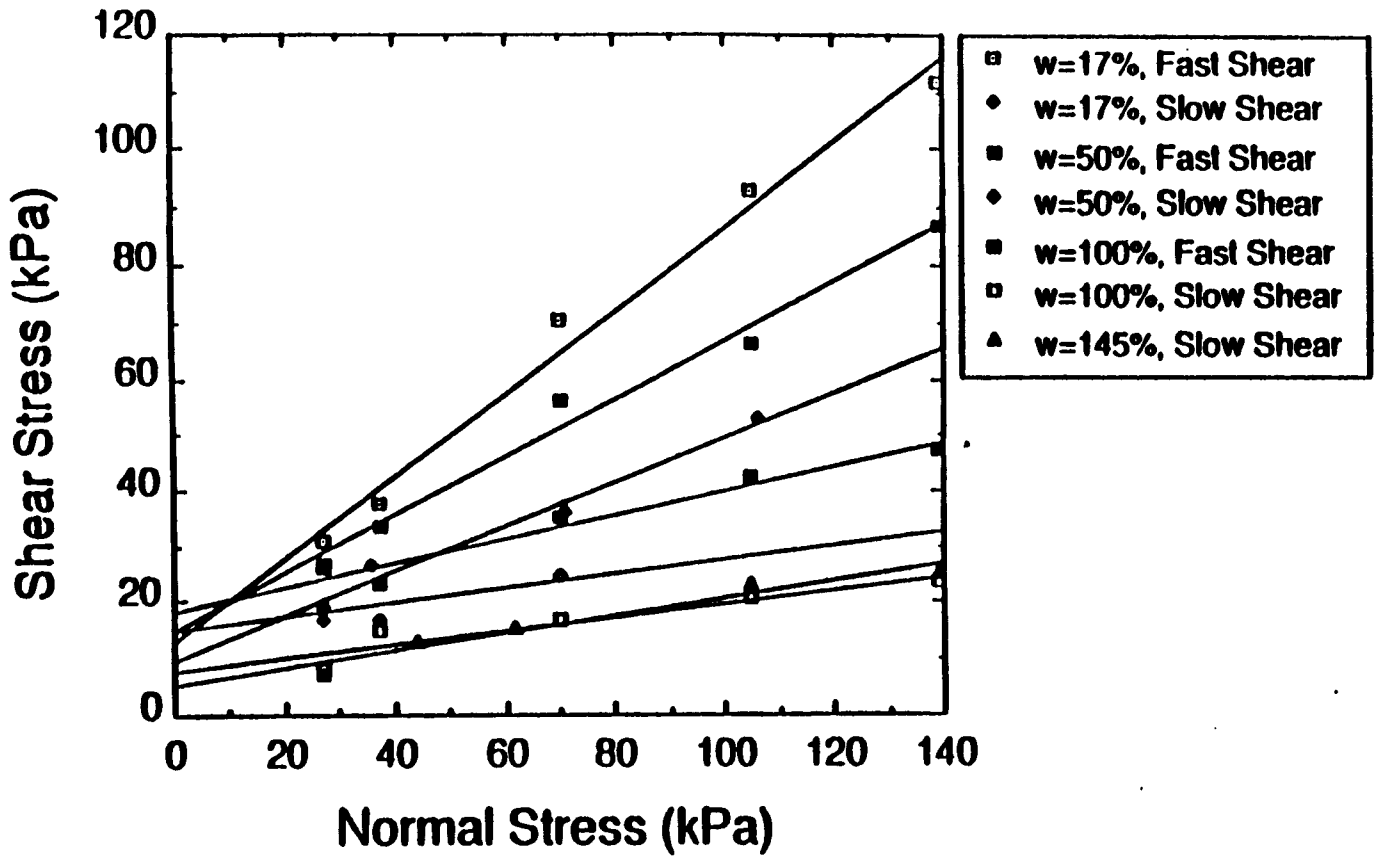


Figure 7. Mohr-Coulomb Diagrams for Gundseal Sheared at Various Water Contents.

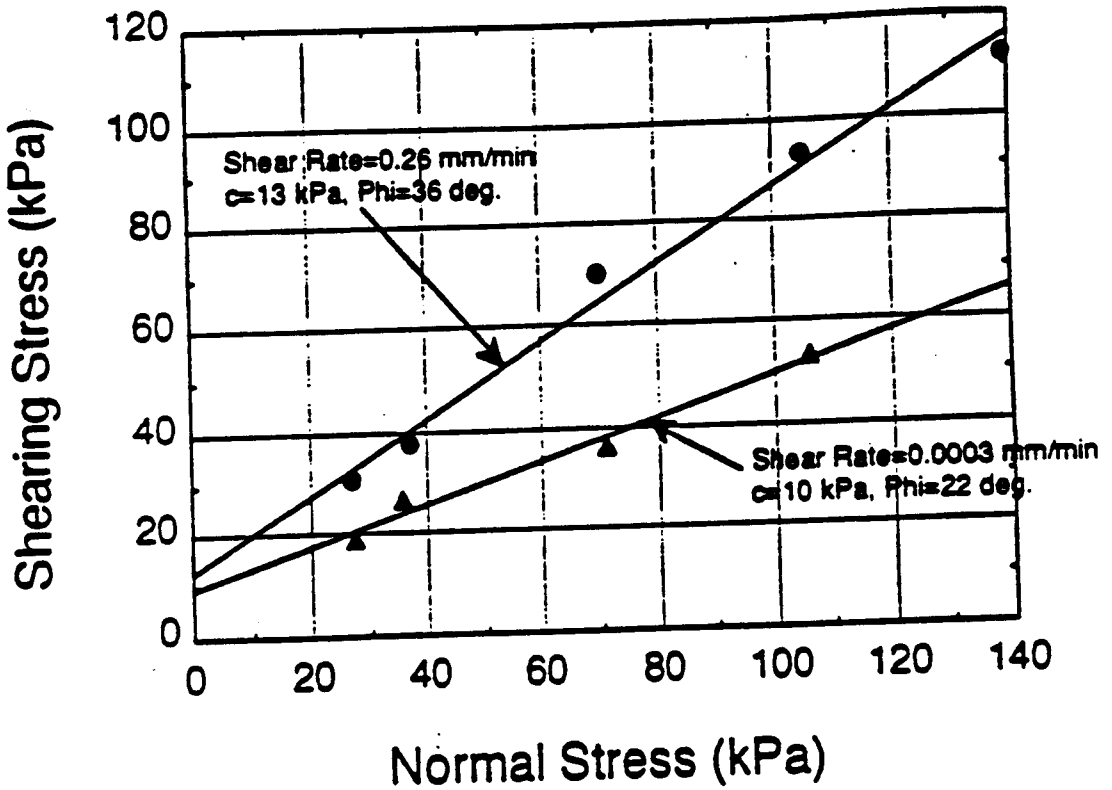


Figure 8. Failure Envelopes for Dry Gundseal Sheared Slowly and Quickly.

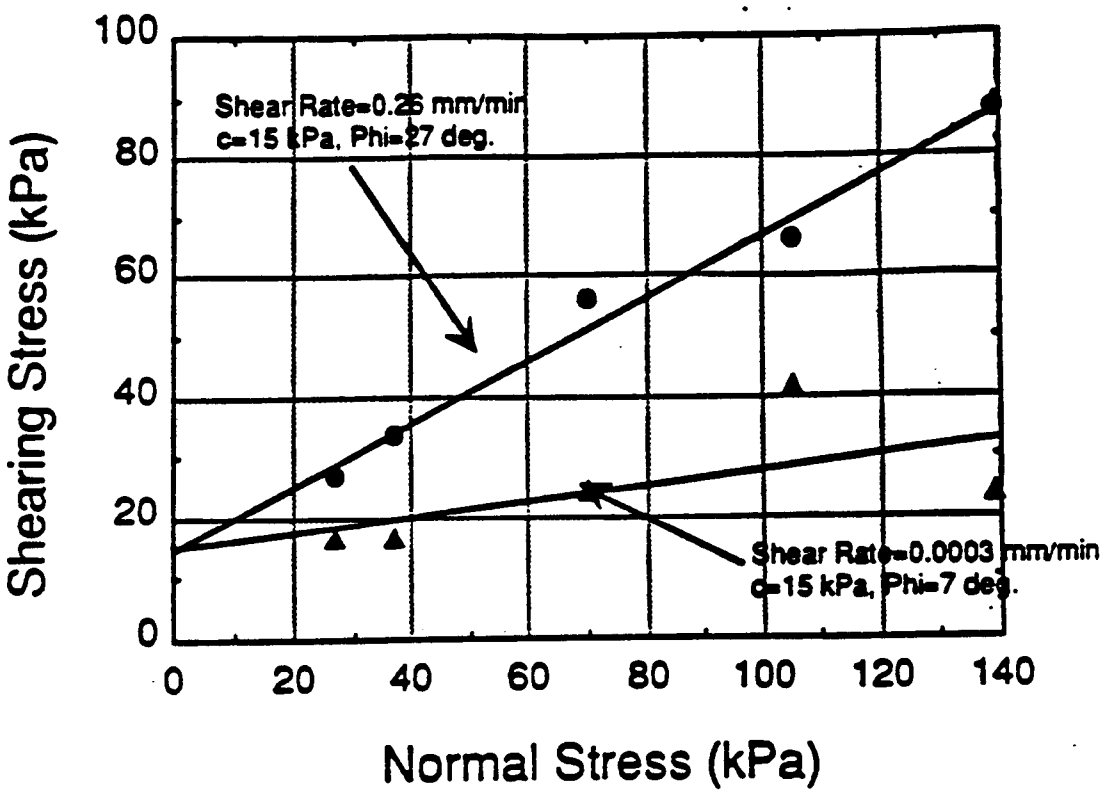


Figure 9. Failure Envelopes for Gundseal at Nominal Water Content of 50% Sheared Slowly and Quickly.

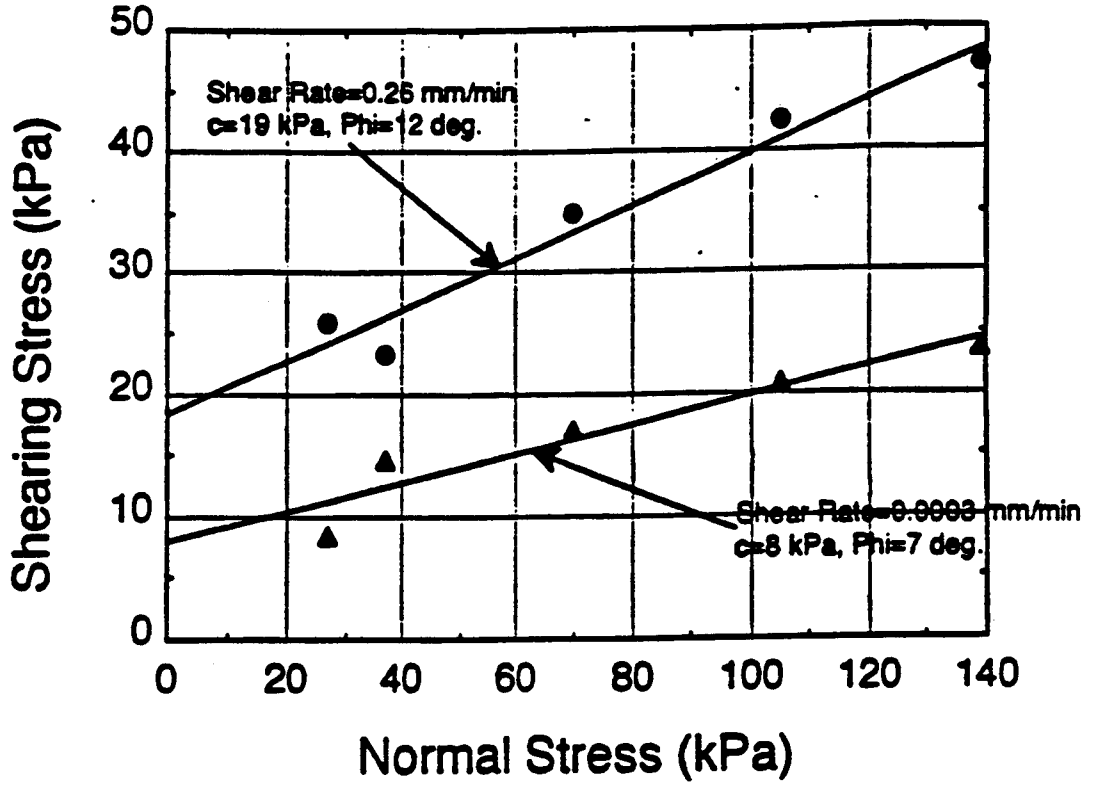


Figure 10. Failure Envelopes for Gundseal at Nominal Water Content of 100% Sheared Slowly and Quickly.

Table 4. Results of Least Square Regression Analysis.

Nominal Water Content (%)	Shearing Speed	Cohesion (kPa)	Friction Angle (degrees)
17	Fast	13	36
17	Slow	10	22
50	Fast	15	27
50	Slow	15	7
100	Fast	19	12
100	Slow	8	7
145	Slow	5	9

CONCLUSIONS

The following conclusions are drawn from the tests described in this report.

1. A relationship exists between the equilibrium water content of the bentonite in Gundseal and the soil water potential (soil suction) of the soil in contact with the bentonite. "Dry" (as-manufactured) Gundseal contains bentonite at a water content of approximately 17% and a soil suction of >75 bars. If the bentonite side of Gundseal is placed against a soil that has a suction of 15 bars (the wilting point of typical plants), the bentonite would absorb moisture from the soil and equilibrate at a water content of approximately 50%. In extremely arid areas (where the soil is so dry that vegetation has great difficulty establishing itself), Gundseal's water content would likely be no greater than 50% if the bentonite were placed against the soil. When the bentonite side of Gundseal is placed against damp soil that will support some growth of vegetation, the water content is likely to rise to 50% to 100%. If the bentonite side of Gundseal is placed against moist soil that will readily support growth of thick vegetation

Table 5. Summary of Results of Permeability Tests.

Permeant Liquid	Permeability (cm/s)				
	$w_0 = 17\%$	$w_0 = 50\%$	$w_0 = 100\%$	$w_0 = 125\%$	$w_0 = 145\%$
Benzene	3×10^{-5}	2×10^{-5}	5×10^{-9}	No Flow	No Flow
Gasoline	4×10^{-5}	4×10^{-5}	4×10^{-9}	No Flow	No Flow
Methanol	3×10^{-5}	3×10^{-5}	3×10^{-9}	No Flow	No Flow
MTBE	2×10^{-5}	3×10^{-6}	$<1 \times 10^{-9}$	No Flow	No Flow
TCE	4×10^{-5}	4×10^{-5}	3×10^{-8}	No Flow	No Flow
Water	2×10^{-9}	----	----	----	----

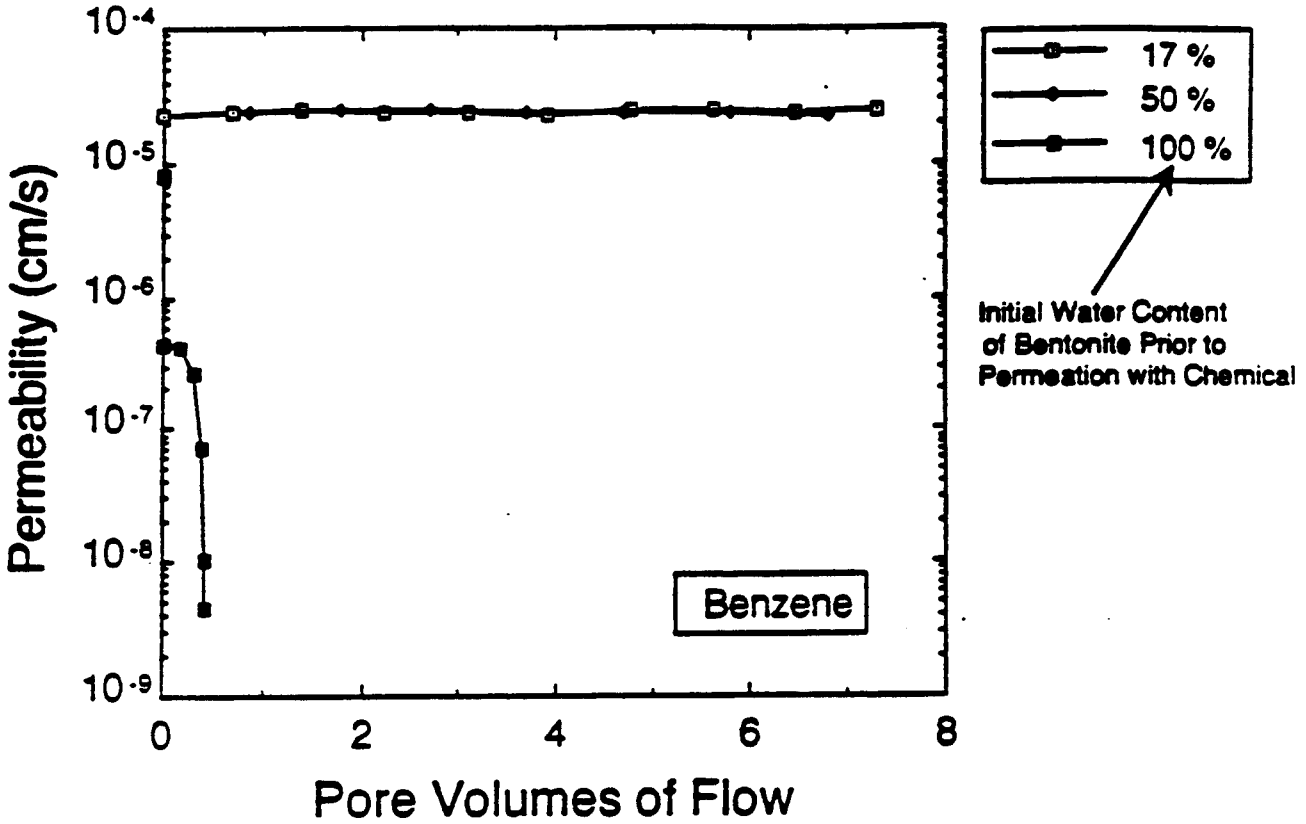


Figure 11. Coefficient of Permeability Versus Pore Volumes of Flow for Samples of Bentonite in Gundseal Permeated with Benzene.

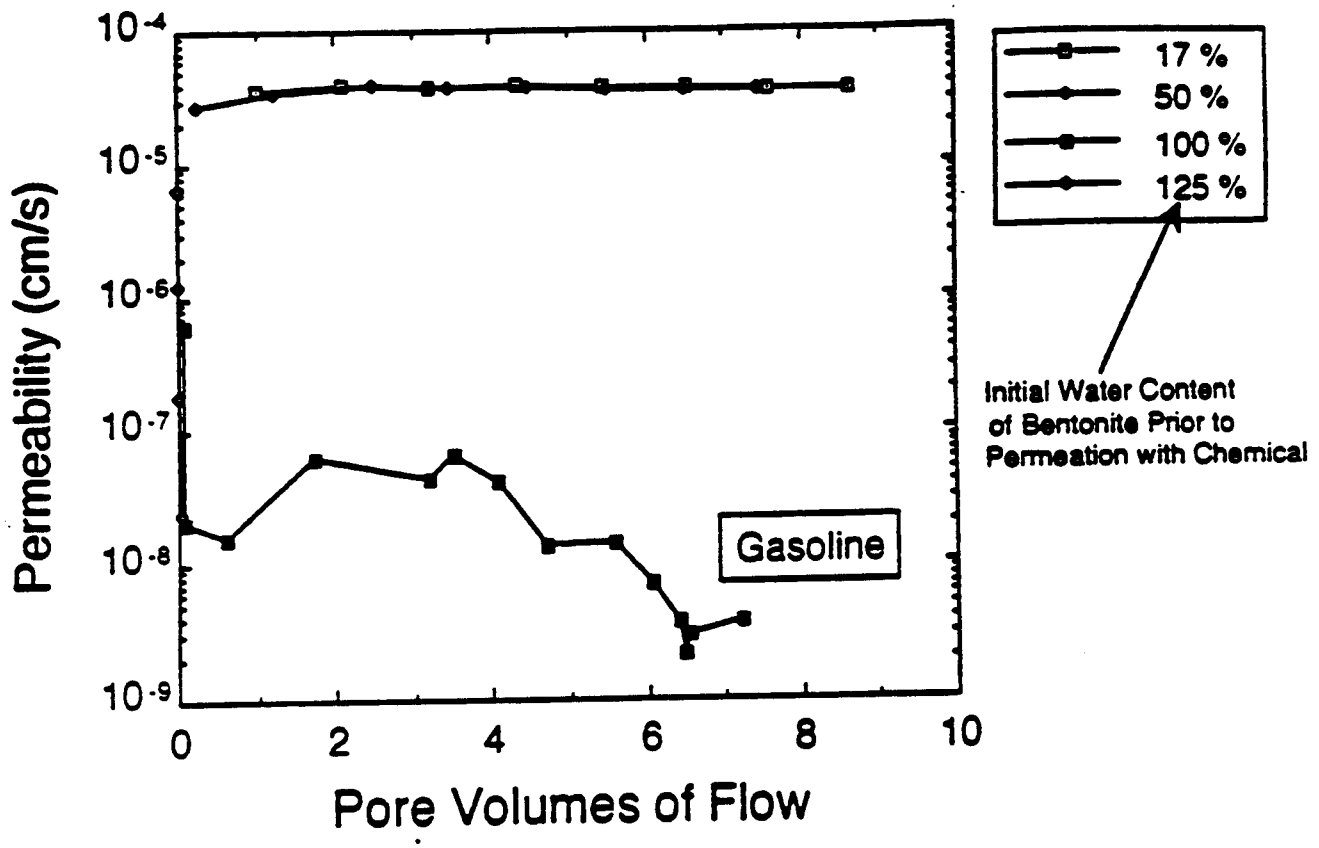


Figure 12. Coefficient of Permeability Versus Pore Volumes of Flow for Samples of Bentonite in Gundseal Permeated with Gasoline.

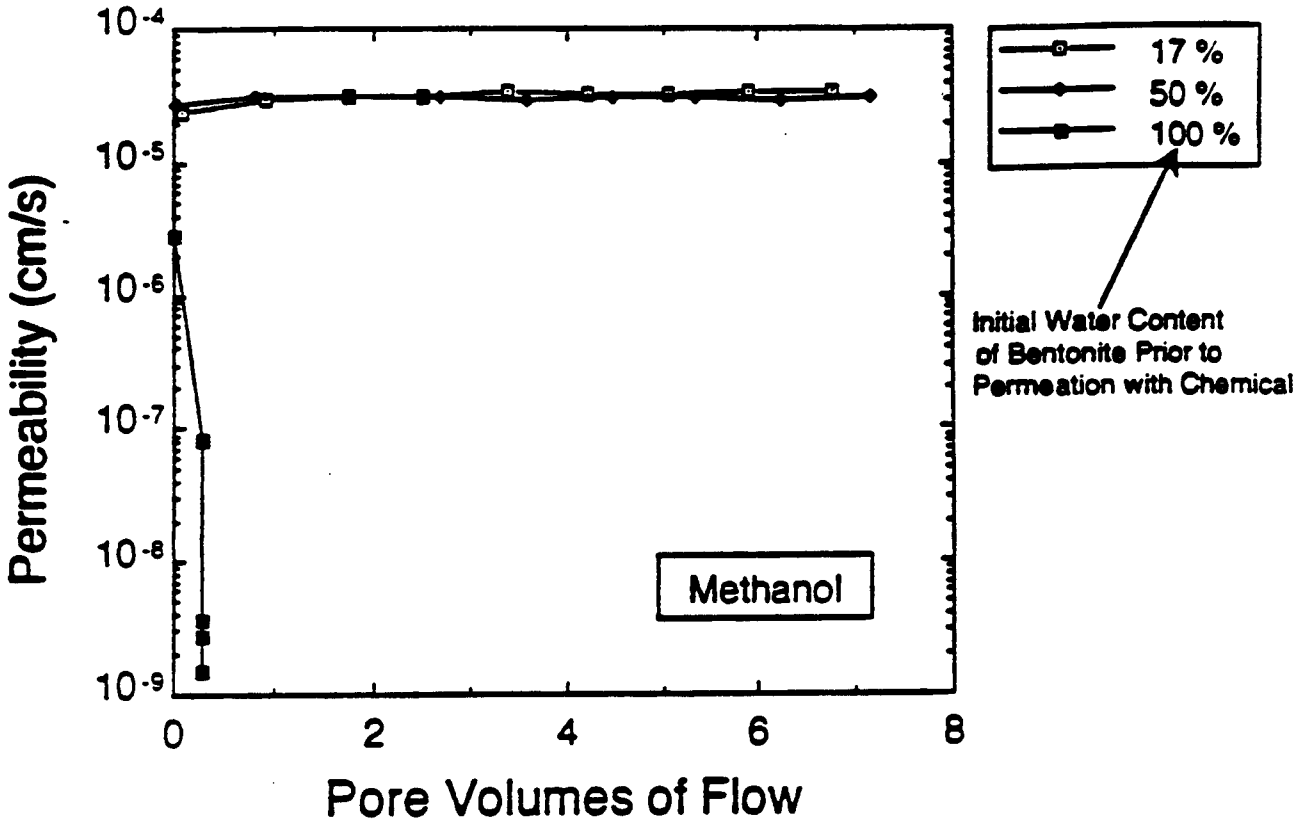


Figure 13. Coefficient of Permeability Versus Pore Volumes of Flow for Samples of Bentonite in Gundseal Permeated with Methanol.

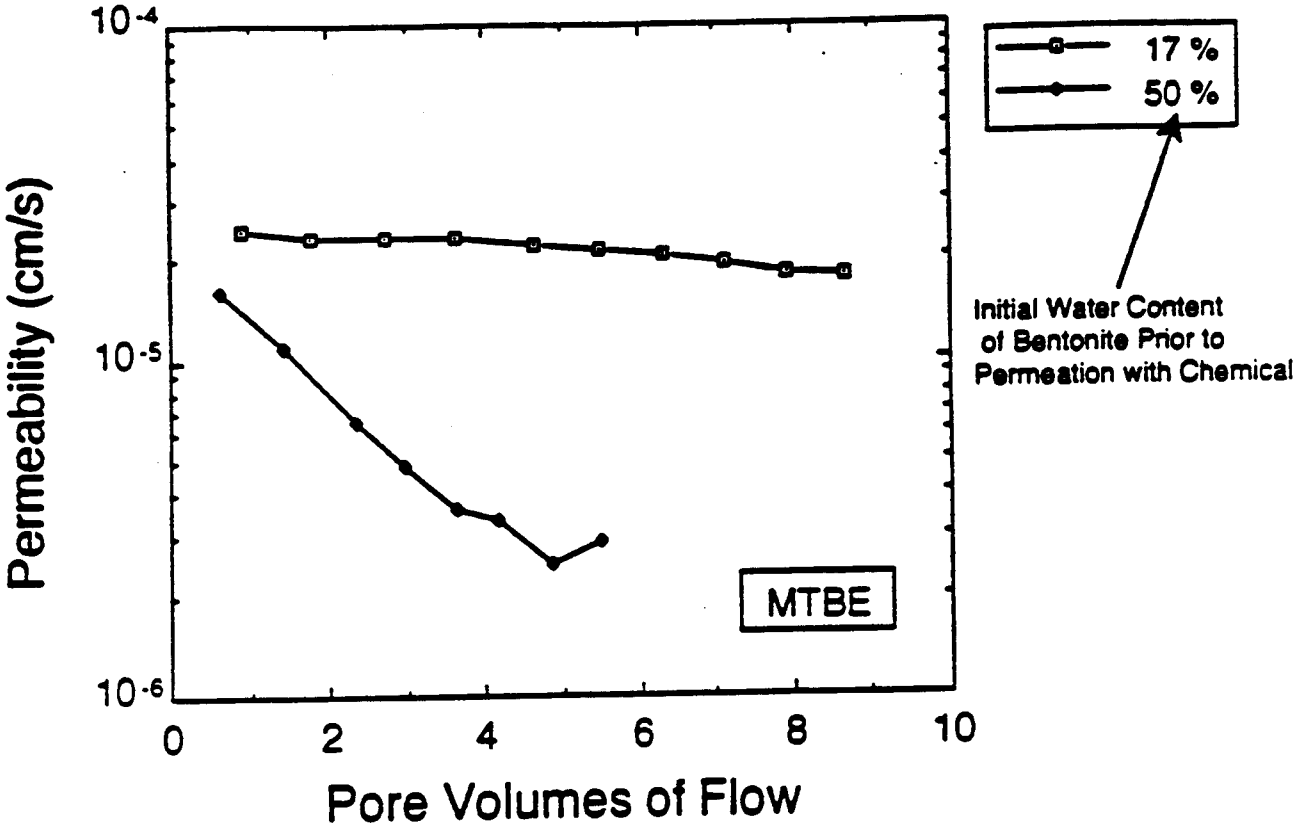


Figure 14. Coefficient of Permeability Versus Pore Volumes of Flow for Samples of Bentonite in Gundseal Permeated with MTBE.

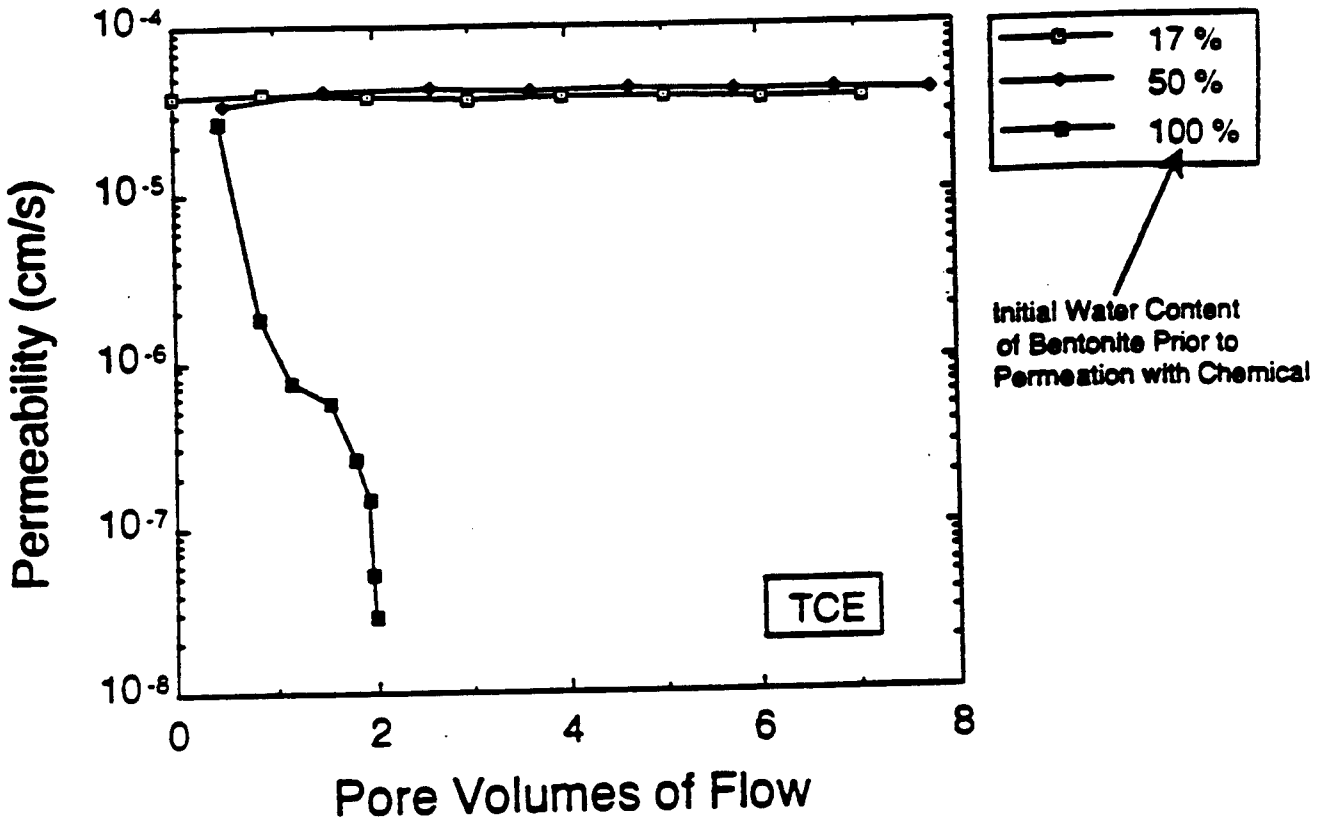


Figure 15. Coefficient of Permeability Versus Pore Volumes of Flow for Samples of Bentonite in Gundseal Permeated with Trichloroethylene.

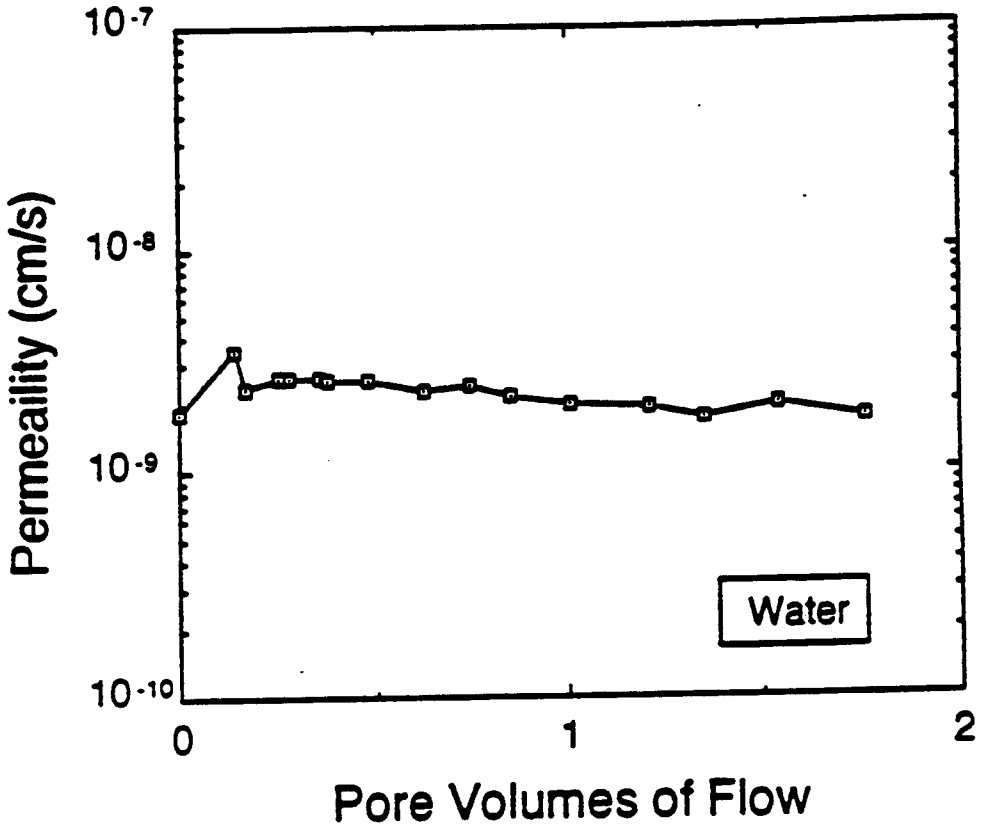


Figure 16. Coefficient of Permeability Versus Pore Volumes of Flow for Samples of Bentonite in Gundseal Permeated with Water.

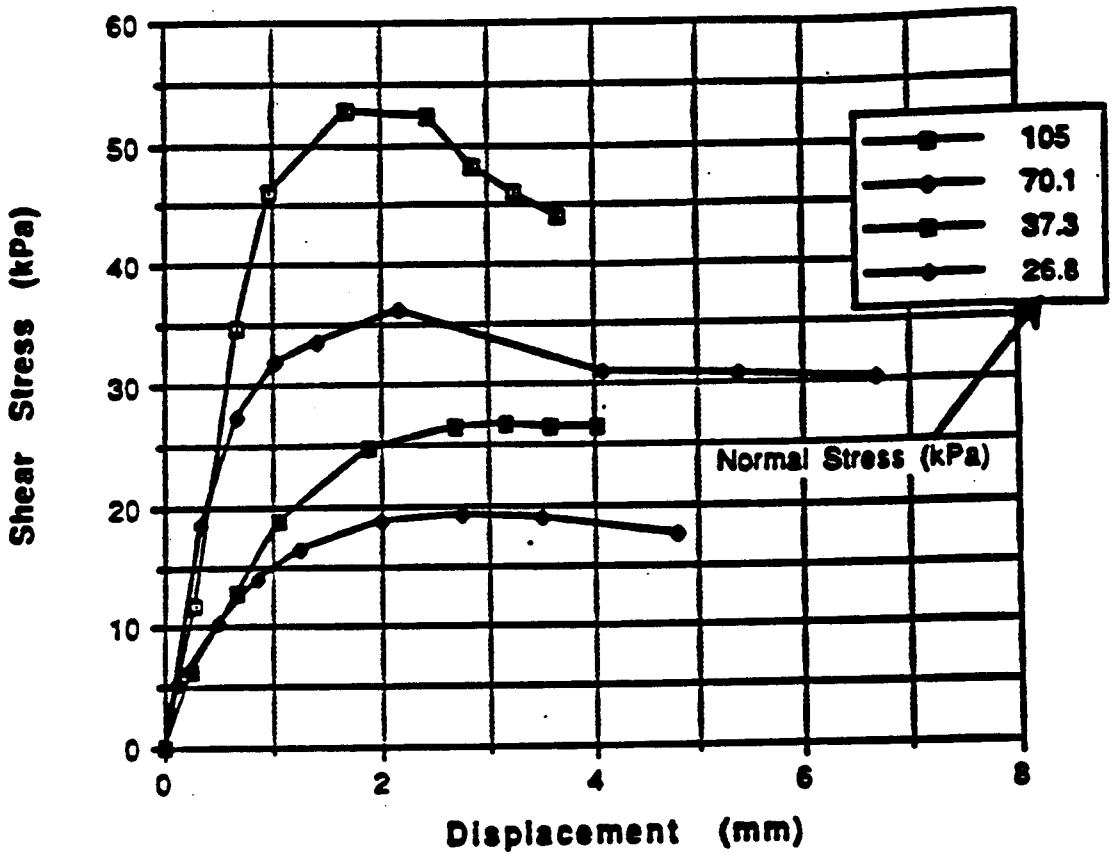
(i.e., soils with suctions less than 1 bar), the water content of the bentonite is likely to rise to 100% or more. If the bentonite in Gundseal is placed against wet (practically saturated) soil, the water content will likely rise to more than 140%. The time required for the bentonite in Gundseal to absorb water and reach the equilibrium water content is expected to be on the order of a few days to several weeks, based on the tests described herein. If there is any doubt about soil suction in the field the suction can be readily measured with a tensiometer, which is an inexpensive (< $100) device that yields a suction reading in less than a few hours.

2. The shear strength of the bentonite component of Gundseal was found to be sensitive to the water content of the bentonite and the rate of shear. For rapid shear on dry material, friction angles as high as 36 degrees were measured. For slow shear on saturated materials, friction angles on the order of 10 degrees were measured. When the bentonite was wetted to a nominal water content of 50%, the friction angle for slow shear was about the same as the friction angle for saturated bentonite. Thus, only a relatively small amount of wetting of the bentonite caused a significant reduction in shear strength.

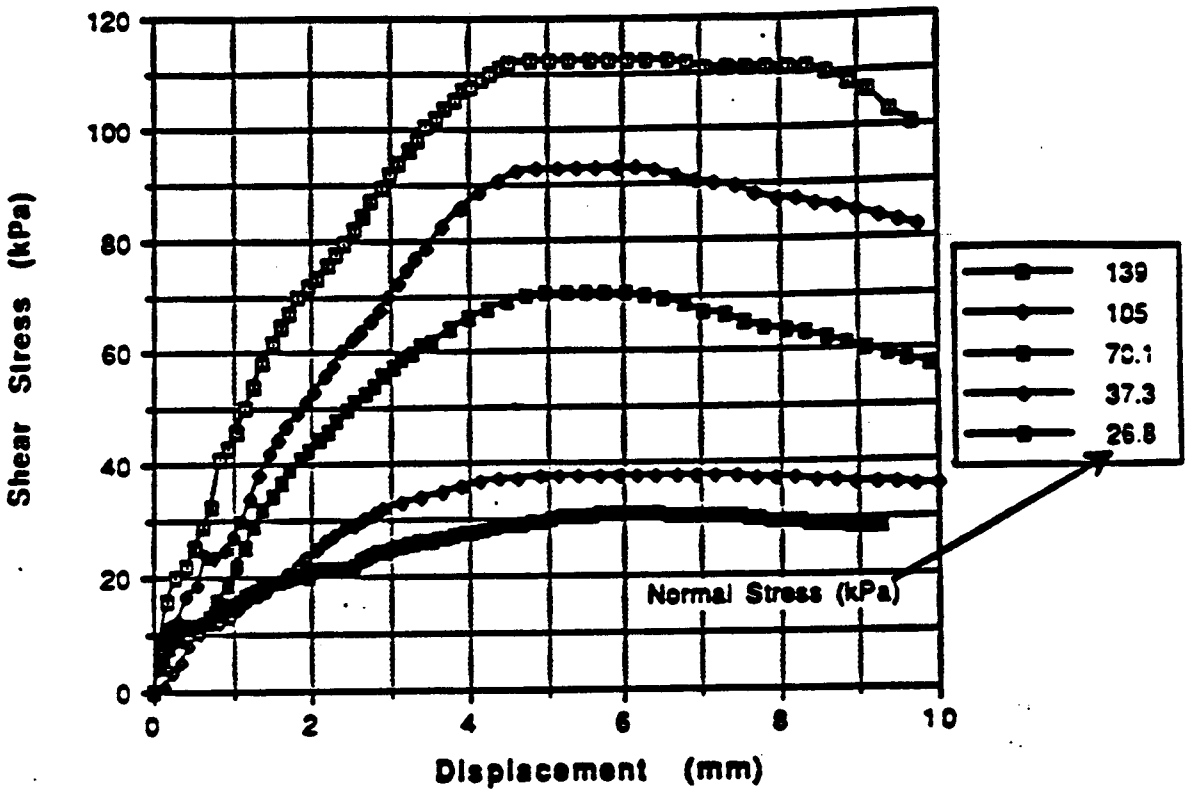
3. The permeability of the bentonite component of Gundseal to hydrocarbons was found to be very sensitive to the water content of the bentonite at the time that the hydrocarbon was introduced into the test specimens. For dry bentonite and bentonite moistened to a water content of 50%, the permeability to hydrocarbons was relatively high (on the order of 10^{-5} cm/s). When the bentonite was at a water content of 100% or greater, the permeability remained low (on the order of 10^{-9} cm/s or less) for the duration of the tests, which was approximately 2 months.

APPENDIX A

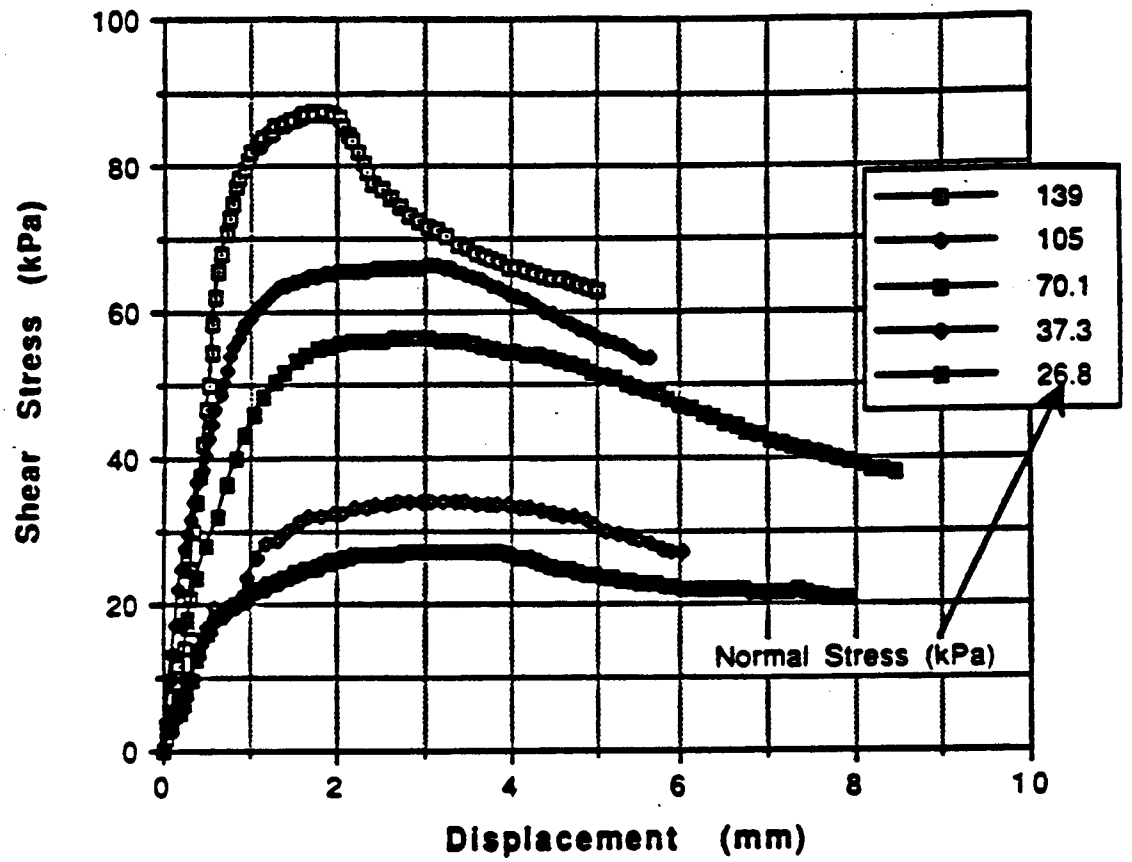
RESULTS OF DIRECT SHEAR TESTS



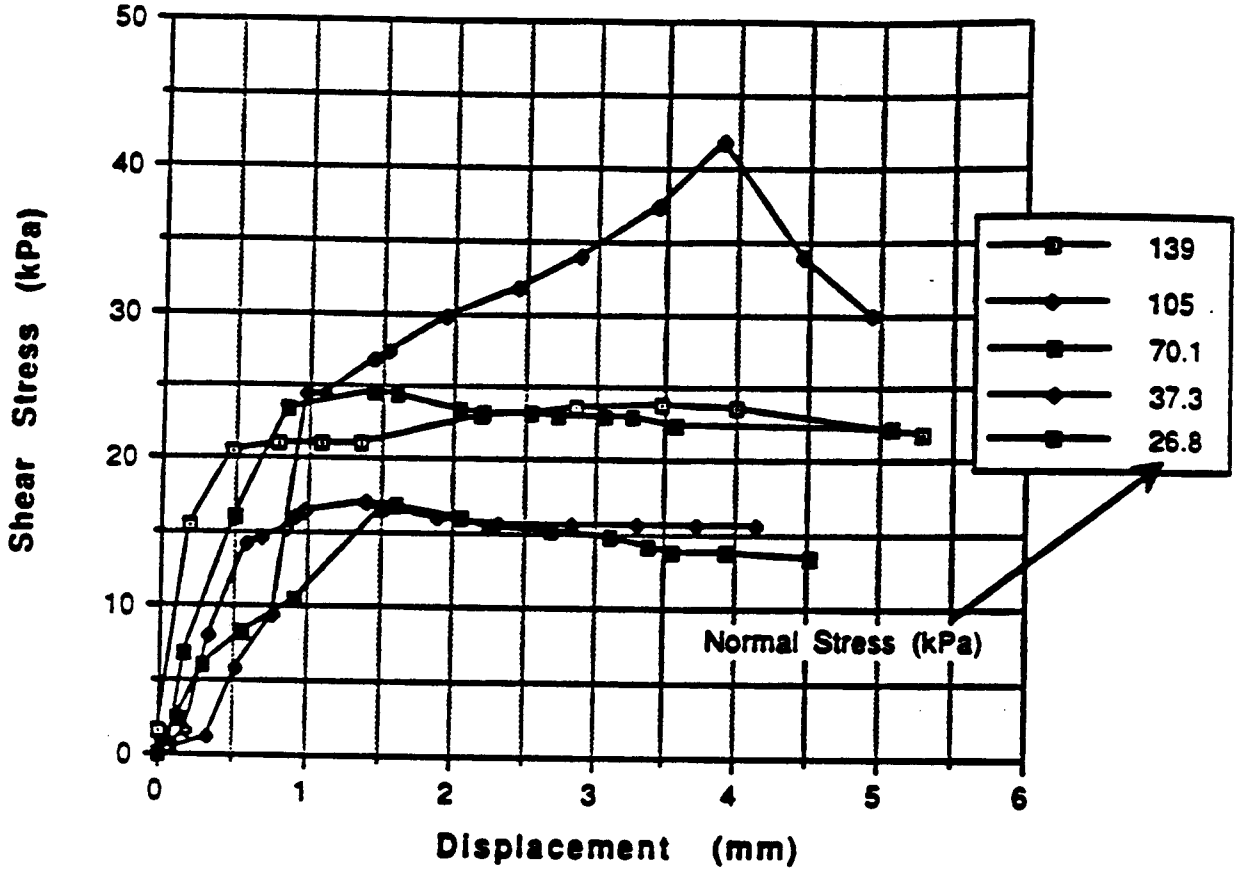
Stress-Displacement Curves of Gundseal with Initial Water Content of 17% (Shearing Rate=.0003mm/min)



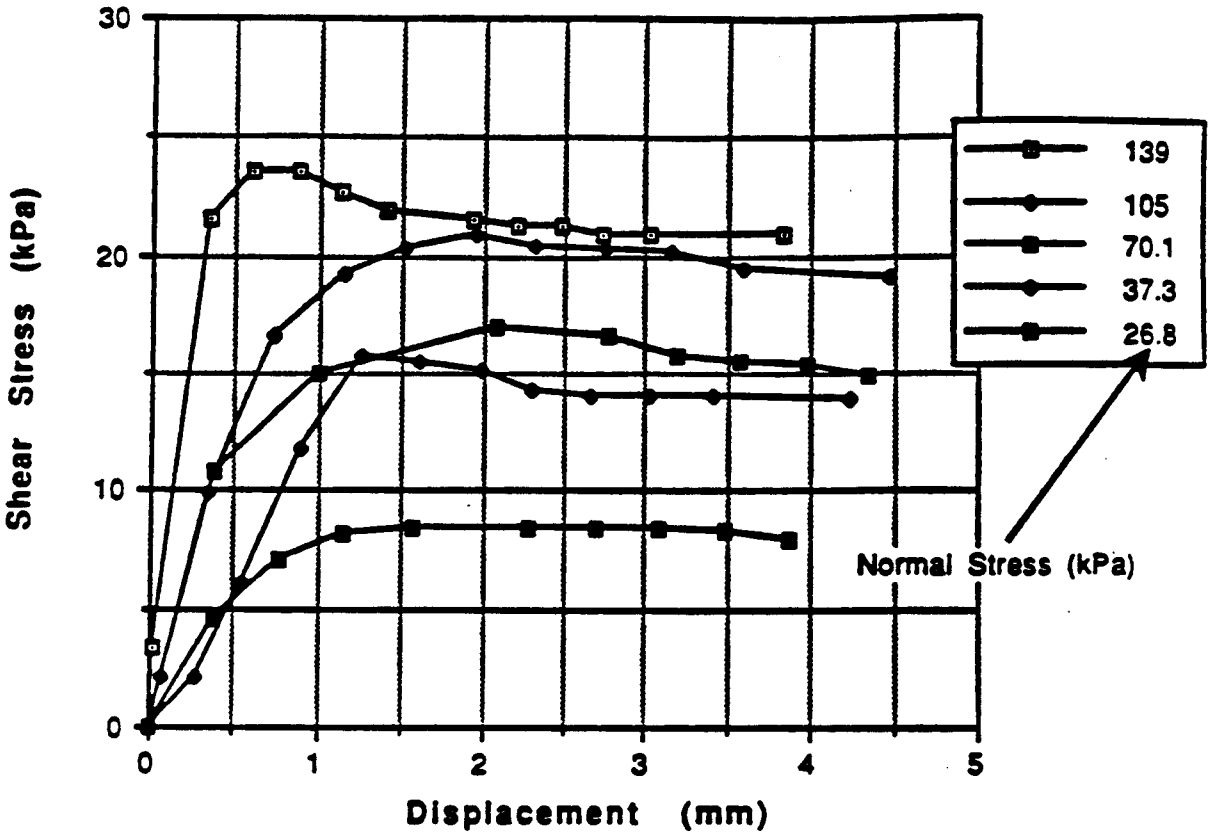
Stress-Displacement Curves of Gundseal with Initial Water Content of 17% (Shearing Rate=0.26mm/min)



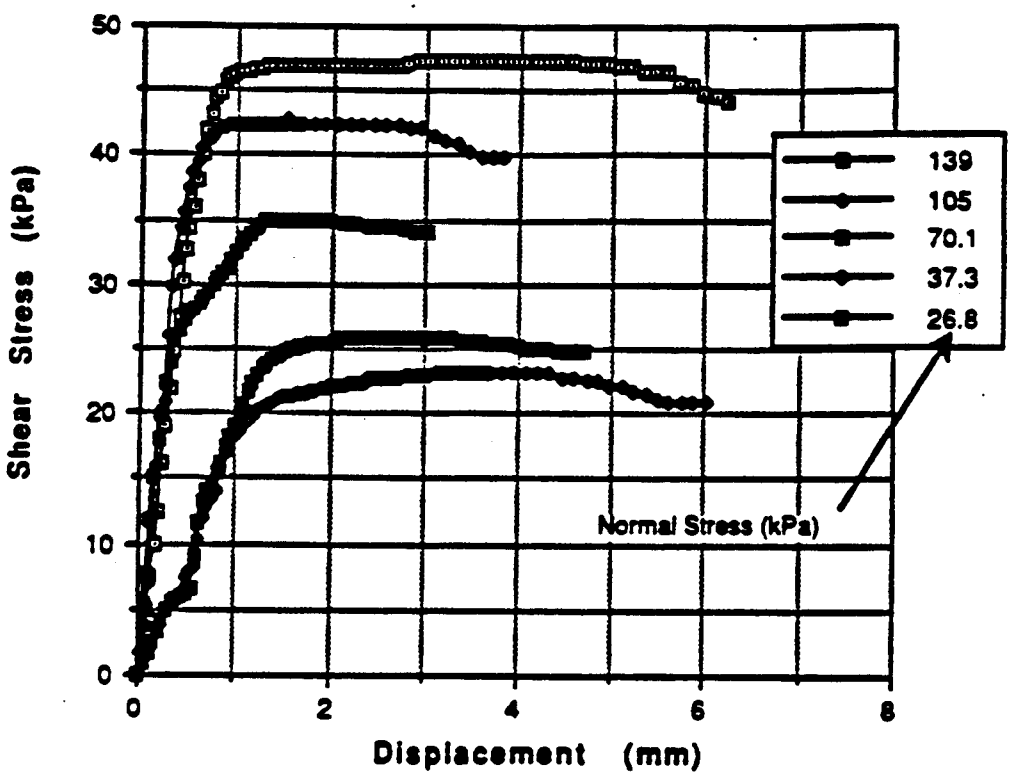
Stress-Displacement Curves of Gundseal with Initial Water Content of 50% (Shearing Rate=0.26mm/min)



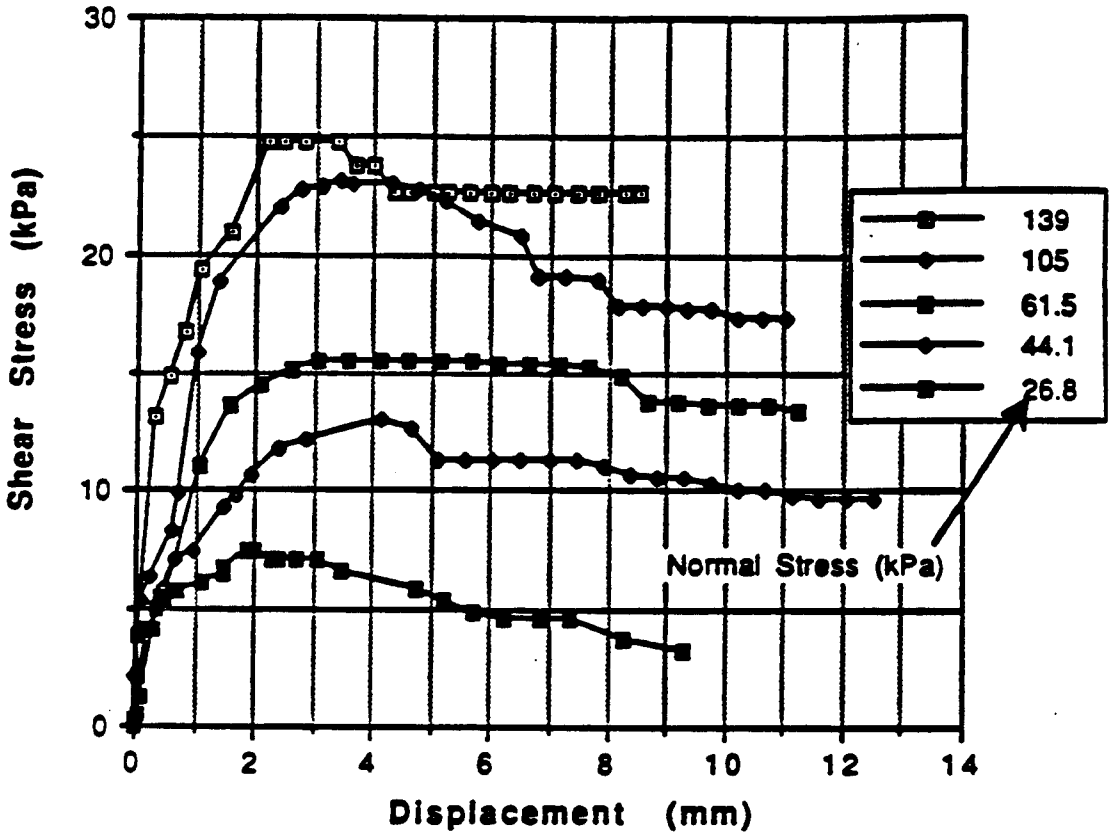
Stress-Displacement Curves of Gundseal with Initial Water Content of 50% (Shearing Rate=0.0003 mm/min)



Stress-Displacement Curves of Gundseal with Initial Water Content of 100% (Shearing Rate=0.0003 mm/min)



Stress-Displacement Curves of Gundseal with Initial Water Content of 100% (Shearing Rate=0.26mm/hr)



Stress-Displacement Curves of Saturated Gundseal
(Shearing Rate=0.0003 mm/min)

APPENDIX B

RESULTS OF PERMEABILITY TESTS

Results of Hydraulic Conductivity Tests of Gundseal

Falling/rising head hydraulic conductivity tests

Diameter of Gundseal specimens = 4.0 in.
Area of Gundseal specimens = 81.073 sq.cm
Thickness of Gundseal specimens (average):
17%: 0.35 cm 50%: 0.4 cm 100%: 0.55 cm
125%: 0.6 cm 145%: 0.65 cm
Confining (Cell) Pressure = 2.0 psi
Hydraulic gradient = 80 - 120
k: Hydraulic conductivity (cm/sec)
K: Intrinsic permeability (sq.cm)
* K of MTBE was not computed because value of viscosity is not available

Chemical	Water Content			
	17%	17%	50%	50%
	k (cm/sec)	K (cm^2)	k (cm/sec)	K (cm^2)
Bezene	2.5E-05	1.9E-10	2.4E-05	1.8E-10
Gasoline	3.7E-05	1.9E-10	3.6E-05	1.9E-10
Methanol	3.4E-05	2.6E-10	3.1E-05	2.4E-10
MTBE	1.7E-05		3.1E-06	
TCE	4.1E-05	1.5E-10	3.8E-05	1.4E-10

* Specimens of 17% and 50% was permeated with more than 6.0 PV of chemicals

Chemical	Water Content				
	100%	100%		125%	125%
	k (cm/sec)	K (cm^2)	PV	k (cm/sec)	K (cm^2)
Bezene	4.6E-09	3.5E-14	0.42*	No Outflow	-
Gasoline	3.8E-09	1.9E-14	7.20	No Outflow	-
Methanol	2.7E-09	2.1E-14	0.29*	No Outflow	-
MTBE	No Outflow**	-	-	No Outflow	-
TCE	3.0E-08	1.1E-13	1.99*	No Outflow	-

* All k for 100% water content are the last measurable values.
** Hydraulic gradients were maintained at least 2 months on all specimens indicated as No Outflow

Chemical	Water Content (Saturated-145%)			
	Tap Water		Chemical	
	k (cm/sec)	K (cm^2)	k (cm/sec)	K (cm^2)
Bezene	1.9E-09	1.4E-14	No Outflow	-
Gasoline	1.6E-09	1.2E-14	No Outflow	-
Methanol	9.4E-10	7.1E-15	No Outflow	-
MTBE	1.3E-09		No Outflow	-
TCE	2.0E-09	1.5E-14	No Outflow	-

* Chemicals were introduced after k to water reached equilibrium and > 2.0 PV of water.

Hydraulic Conductivity Test of w=50% Gundseal to Benzene							
Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K (cm^2)
60	20.6	17.6	17.6	0.87	0.85	2.37E-05	1.80E-10
50	18.5	19.1	36.7	1.8	1.03	2.53E-05	1.92E-10
50	17.4	18.2	54.9	2.7	1.05	2.47E-05	1.88E-10
60	19.3	20.3	75.2	3.7	1.05	2.40E-05	1.82E-10
60	19.3	20.2	95.4	4.69	1.05	2.37E-05	1.80E-10
65	20.9	22.1	117.5	5.78	1.06	2.37E-05	1.80E-10
60	19.4	20.6	138.1	6.79	1.06	2.32E-05	1.76E-10
						2.37E-05	1.80E-10

Hydraulic Conductivity Test of Dry Gundseal to Benzene

Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K (cm^2)
50	21.8	0	0	0	0	2.26E-05	1.72E-10
70	24	14	14	0.69	0.58	2.37E-05	1.80E-10
50	14.8	14.4	28.4	1.4	0.97	2.45E-05	1.86E-10
60	16.7	17.4	45.8	2.25	1.04	2.41E-05	1.83E-10
60	16.5	17.2	63	3.1	1.04	2.42E-05	1.83E-10
60	16	16.7	79.7	3.92	1.04	2.30E-05	1.75E-10
60	17.6	17.2	96.9	4.77	0.98	2.54E-05	1.93E-10
60	17	17.2	114.1	5.61	1.01	2.47E-05	1.88E-10
60	16.5	17.2	131.3	6.46	1.04	2.42E-05	1.84E-10
60	17.8	17.2	148.5	7.3	0.97	2.53E-05	1.92E-10
						2.49E-05	1.89E-10

Hydraulic Conductivity Test of w=100% Gundseal to Benzene

Date/Time	Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K (cm^2)
	120	21.7	0	0	0	0	8.34E-06	6.33E-11
	1200	11.8	0	0	0	0	4.41E-07	3.35E-12
	490	3.5	3.3	3.3	0.16	0.94	4.24E-07	3.22E-12
	720	3.1	3	6.3	0.31	0.97	2.73E-07	2.07E-12
11/4/91 11:32	1520	1.7	1.7	8	0.39	1	7.48E-08	5.68E-13
11/4/91 12:30	3480	0.6	0.4	8.4	0.41	0.67	1.04E-08	7.92E-14
11/4/91 14:18	6480	0.6	0.1	8.5	0.42	0.17	4.56E-09	3.46E-14

Test was continued until 1/5/92

Hydraulic Conductivity Test of w=125% Gundecal to Benzene

Test was started on 10/15/01 and continued until 12/13/01
No outflow was detected

Hydraulic Conductivity Test of w=125% Gundecal to Gasoline

Date/Time	Δt (sec)	In. reading	Qin (cc)	Hin (cm)	Out reading	Qout	Hout (cm)	Vout	PVout	Qout/Qin	h (cm)	h (cm/sec)	K
10/15/01 9:50		20.5		87.05	0		1.00				85.97		
10/15/01 9:57	80	33.5	13	74.05	0	0	1.00	0	0	0	72.97	0.94E-00	3.34E-11
10/15/01 11:50		17.5		90.05	0		1.00				88.97		
10/15/01 11:58	480	31.7	14.2	75.85	0.3	0.3	1.24	0.3	0.01	0.02	74.81	1.22E-00	0.23E-12
10/15/01 9:57		22.0		84.05	7		4.74				80.21		
10/15/01 10:32	2050	31.0	9.2	75.75	7	0	4.74	0.3	0.01	0	71.01	1.00E-07	0.00E-13
10/25/01 13:51		15.0		81.75	3.4		2.00				80.00		
10/25/01 14:55	3640	18.2	2.4	80.35	3.0	0.2	2.00	0.9	0.02	0.00	80.30	2.30E-00	1.21E-13

Test was continued until 12/14/01

Hydraulic Conductivity Test of w=125% Gundecal to Methanol

Test was started on 10/12/01 and continued until 12/10/01
No outflow was detected

Hydraulic Conductivity Test of w=125% Gundecal to MTBE

Test was started on 10/12/01 and continued until 12/10/01
No outflow was detected

Hydraulic Conductivity Test of w=125% Gundecal to TCE

Test was started on 10/12/01 and continued until 12/10/01
No outflow was detected

Hydraulic Conductivity Test of Dry Gundseal to Gasoline

Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K
50	20.4	20.4	20.4	1	1	3.54E-05	1.80E-10
50	20.9	22.3	42.7	2.1	1.07	3.93E-05	2.00E-10
50	20.9	22.4	65.1	3.2	1.07	3.85E-05	1.96E-10
50	21.8	23.2	88.3	4.34	1.06	3.99E-05	2.04E-10
50	21	22.4	110.7	5.44	1.07	3.87E-05	1.98E-10
50	21	22.2	132.9	6.54	1.06	3.77E-05	1.93E-10
50	20.2	21.6	154.5	7.6	1.07	3.65E-05	1.86E-10
50	20	21.4	175.9	8.65	1.07	3.64E-05	1.86E-10
						3.73E-05	1.90E-10

Hydraulic Conductivity Test of w=50% Gundseal to Gasoline

Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K
45	24.5	5	5	0.25	0.2	2.76E-05	1.41E-10
50	24.8	20.1	25.1	1.23	0.81	3.53E-05	1.80E-10
50	25.7	25.3	50.4	2.48	0.98	3.94E-05	2.01E-10
40	20.1	20.2	70.6	3.47	1	3.75E-05	1.91E-10
40	20.1	20.6	91.2	4.48	1.02	3.74E-05	1.91E-10
40	20.2	20.4	111.6	5.49	1.01	3.61E-05	1.84E-10
40	19.9	20.4	132	6.49	1.03	3.60E-05	1.84E-10
40	19.3	19.4	151.4	7.45	1.01	3.61E-05	1.84E-10
						3.64E-05	1.86E-10

Hydraulic Conductivity Test of w=100% Gundseal to Gasoline

	Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K
11/5/91 14:14	540	8	1.7	1.7	0.08	0.21	6.21E-07	3.17E-12
11/5/91 14:27	760	0.4	0	1.7	0.08	0	2.10E-08	1.07E-13
11/6/91 8:56	66540		0	1.7	0.08			
11/7/91 9:35	88740	28.3	10.3	12	0.59	0.36	1.64E-08	8.38E-14
11/7/91 16:40	25500	23	22.8	34.8	1.71	0.99	6.36E-08	3.24E-13
11/8/91 9:18	59580	30	30	64.8	3.19	1	4.37E-08	2.23E-13
11/8/91 11:09	6660	6.7	6.5	71.3	3.51	0.97	6.60E-08	3.37E-13
11/8/91 17:06	21420	11.2	11.1	82.4	4.05	0.99	4.26E-08	2.17E-13
11/13/91 10:42	84060	15.3	12.8	95.2	4.68	0.84	1.37E-08	7.01E-14
11/14/91 9:56	83640	19.5	18.1	113.3	5.57	0.93	1.47E-08	7.50E-14
11/15/91 8:55	82740			113.3	5.57			
11/16/91 9:40	89100	10.7	9.6	122.9	6.04	0.9	7.44E-09	3.80E-14
11/18/91 8:53	169980	8.7	7	129.9	6.39	0.8	3.76E-09	1.92E-14
11/19/91 10:05	90720	2.6	1.4	131.3	6.46	0.54	2.17E-09	1.11E-14
11/21/91 9:39	171240	6.8	1.9	133.2	6.55	0.28	3.00E-09	1.53E-14
11/25/91 10:45	349560	18	13.2	146.4	7.2	0.73	3.76E-09	1.92E-14

Test was continued until 1/11/92

Hydraulic Conductivity Test of Dry Gundseal to Methanol

Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K (cm^2)
45	20.8	1.4	1.4	0.07	0.07	2.37E-05	1.83E-10
50	18.9	17.1	18.5	0.91	0.9	2.99E-05	2.30E-10
40	17.9	17.5	36	1.77	0.98	3.22E-05	2.47E-10
41	15.9	15.3	51.3	2.52	0.96	3.14E-05	2.41E-10
41	17.5	17.7	69	3.39	1.01	3.39E-05	2.61E-10
41	17	16.9	85.9	4.22	0.99	3.31E-05	2.55E-10
41	17.1	17.1	103	5.07	1	3.37E-05	2.59E-10
41	17.1	17.1	120.1	5.91	1	3.38E-05	2.60E-10
41	17.5	17.5	137.6	6.77	1	3.49E-05	2.68E-10
						3.39E-05	2.61E-10

Hydraulic Conductivity Test of w=50% Gundseal to Methanol							
Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K (cm^2)
50	24.9	0.4	0.4	0.02	0.02	2.74E-05	2.11E-10
50	18.2	16.2	16.6	0.82	0.89	3.10E-05	2.39E-10
50	16.9	18.9	35.5	1.75	1.12	3.14E-05	2.41E-10
50	18.1	19	54.5	2.68	1.05	3.10E-05	2.39E-10
50	17.1	18	72.5	3.57	1.05	3.07E-05	2.36E-10
50	17.2	18.3	90.8	4.47	1.06	3.12E-05	2.40E-10
50	17.1	18	108.8	5.35	1.05	3.11E-05	2.39E-10
50	17.2	18.1	126.9	6.24	1.05	3.04E-05	2.34E-10
50	17.6	18.6	145.5	7.15	1.06	3.14E-05	2.41E-10
						3.10E-05	2.39E-10

Hydraulic Conductivity Test of w=100% Gundseal to Methanol

Date/Time	Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K (cm^2)
	300	16.3	0	0	0	0	2.84E-06	2.18E-11
10/31/91 17:12	2470	1.5	5.6	5.6	0.28	3.73	8.44E-08	6.50E-13
11/1/91 7:20	50880	2.7	0.2	5.8	0.29	0.07	2.71E-09	2.09E-14
11/1/91 15:11	28260	2	0	5.8	0.29	0	3.59E-09	2.76E-14
11/2/91 8:15	61440	1.8	0	5.8	0.29	0	1.52E-09	1.17E-14
11/4/91 7:19	169440	4.7	0	5.8	0.29	0	1.50E-09	1.16E-14

Test was continued until 1/5/92

Hydraulic Conductivity Test of Dry Gundseal to MTBE							
Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K (cm^2)
60	19.6	18.7	18.7	0.92	0.95	2.46E-05	9.22E-11
60	18.2	17.7	36.4	1.79	0.97	2.30E-05	8.63E-11
60	17.9	18.8	55.2	2.71	1.05	2.32E-05	8.72E-11
60	17.8	18.9	74.1	3.64	1.06	2.32E-05	8.72E-11
70	19.7	20.5	94.6	4.65	1.04	2.20E-05	8.27E-11
60	16.8	16.8	111.4	5.48	1	2.13E-05	7.98E-11
60	16.1	17.2	128.6	6.32	1.07	2.02E-05	7.57E-11
60	15	16.8	145.4	7.15	1.12	1.93E-05	7.23E-11
60	15.3	16	161.4	7.94	1.05	1.80E-05	6.76E-11
60	14.1	14.8	176.2	8.66	1.05	1.75E-05	6.55E-11
60	11.9	12.3	188.5	9.27	1.03	1.39E-05	5.23E-11
						1.72E-05	

Hydraulic Conductivity Test of w=50% Gundseal to MTBE

Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)
120	28	13	13	0.64	0.46	1.60E-05
120	15.3	16	29	1.43	1.05	1.09E-05
240	16.9	18.6	47.6	2.34	1.1	6.51E-06
240	13.2	12.7	60.3	2.97	0.96	4.86E-06
360	14.2	13.5	73.8	3.63	0.95	3.58E-06
360	12.8	11.1	84.9	4.17	0.87	3.32E-06
570	14	14	98.9	4.86	1	2.47E-06
420	12.3	12.7	111.6	5.49	1.03	2.86E-06
						3.06E-06

Hydraulic Conductivity Test of w=125% Gundseal to MTBE			
Test was started on 11/4/91 and continued until 1/2/92			
No outflow was detected			

Hydraulic Conductivity Test of Dry Gundseal to TCE

Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K (cm^2)
40	21.8	10	10	0.49	0.46	3.36E-05	1.26E-10
40	20.2	20.6	30.6	1.5	1.02	4.13E-05	1.55E-10
40	21.5	22	52.6	2.59	1.02	4.21E-05	1.58E-10
40	21.5	21.6	74.2	3.65	1	4.15E-05	1.56E-10
40	20.7	21	95.2	4.68	1.01	4.20E-05	1.57E-10
40	21.4	22	117.2	5.76	1.03	4.15E-05	1.56E-10
40	20.8	21.3	138.5	6.81	1.02	4.07E-05	1.53E-10
40	20.3	19.8	158.3	7.78	0.98	4.03E-05	1.51E-10
						4.11E-05	1.54E-10

Hydraulic Conductivity Test of w=50% Gundseal to TCE

Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K (cm^2)
40	27.2	0	0	0	0	3.84E-05	1.44E-10
50	22.8	18.4	18.4	0.9	0.81	3.91E-05	1.47E-10
50	21	21.4	39.8	1.96	1.02	3.86E-05	1.45E-10
50	20.3	21.2	61	3	1.04	3.71E-05	1.39E-10
40	19	20	81	3.98	1.05	3.83E-05	1.44E-10
50	20.4	21.3	102.3	5.03	1.04	3.81E-05	1.43E-10
50	19.8	20.7	123	6.05	1.05	3.75E-05	1.41E-10
50	20	20.7	143.7	7.07	1.04	3.69E-05	1.38E-10
						3.77E-05	1.41E-10

Hydraulic Conductivity Test of w=100% Gundseal to TCE

Date/Time	Δt (sec)	Qin (cc)	Qout	Vout	PVout	Qout/Qin	k (cm/sec)	K (cm^2)
	60	26	9.1	9.1	0.45	0.35	2.73E-05	1.02E-10
	360	10	7.8	16.9	0.83	0.78	1.87E-06	7.02E-12
11/4/91 12:04	810	9.7	6.3	23.2	1.14	0.65	7.51E-07	2.82E-12
11/4/91 12:27	1260	11.2	7.9	31.1	1.53	0.71	5.71E-07	2.14E-12
11/4/91 13:11	2550	10.3	5.2	36.3	1.79	0.5	2.64E-07	9.89E-13
11/4/91 13:57	2580	6.9	2.8	39.1	1.92	0.41	1.47E-07	5.52E-13
11/4/91 15:29	5520	5.4	1	40.1	1.97	0.19	5.35E-08	2.01E-13
11/4/91 19:27	14220	10	0.3	40.4	1.99	0.03	2.95E-08	1.11E-13
11/5/91 9:57	52200	17.8	0	40.4	1.99	0	1.68E-08	6.31E-14
11/5/91 14:13	15360	3.5	0	40.4	1.99	0	1.31E-08	4.91E-14

Test was continued until 1/5/92

APPENDIX F

SOILS AND FIELD TEST RESULTS

SOUTHWESTERN DIVISION LABORATORY, CORPS OF ENGINEERS
4815 Cass Street
Dallas, Texas 75235

SUBMITTAL OF SWDED-GL REPORT 15520 (18 pages)

PROJECT: CANNON AFB
Feature: LANDFILL NO. 5, CELL-3
SITE-1, CAP

Contract No.

TEST REQUEST NO.: E85920036
Dated: 27 FEB 1992
Received: 04 MARCH 1992

From: CHIEF
ENGRG/PLNG DIVISION
ALBUQUERQUE DISTRICT

MATERIAL: UNDISTURBED AND DISTURBED SOIL SAMPLES
No. and type of samples: ONE BAG SAMPLE AND TWO PUSH TUBES
Source or other identification: BORINGS: 3-1 AND 3-2

Date received: 2 MARCH 1992

REMARKS:

PERMEABILITY TEST RESULTS	PAGE 2
GRADATION CURVES	PLATES 1-3
COMPACTION TESTS	PLATES 4 AND 5
PERMEABILITY TESTS	PLATES 6-14
DRYING TEST PHOTO	PLATES 15 AND 16

Report sent to:
ALBUQUERQUE DISTRICT

Copy furnished:

Date: APR 28 1992

Name and title:
WILLIAM R. TANNER
Director
SWD Laboratory

Signature

Permeability Test Results

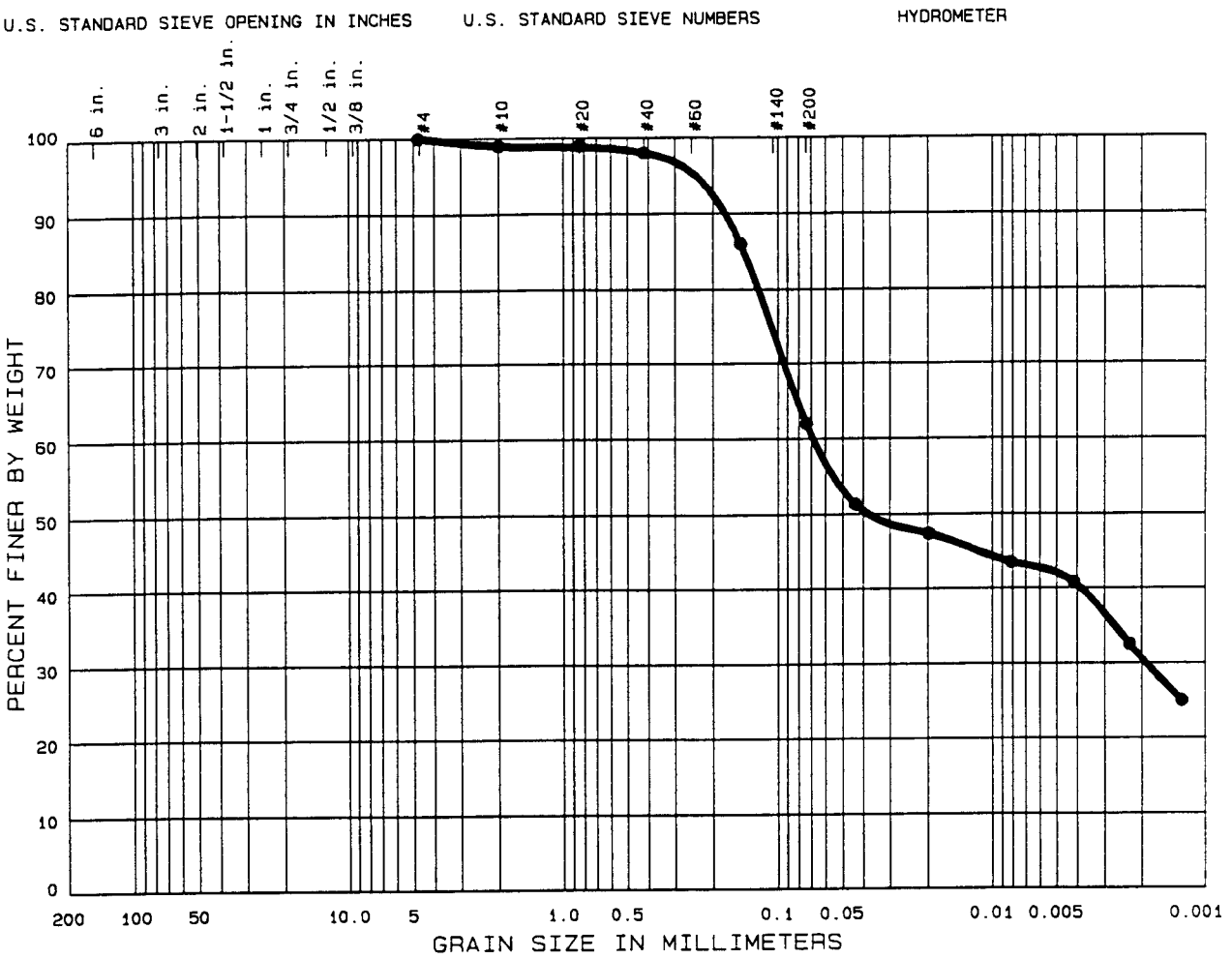
SWDED-GL Report No. : 15520

District: Albuquerque
Project: Cannon AFB
Feature: Landfill No. 5, Cell-3, Site-1, CAP
Sample No. 92/844 (bag samples)

Molded Water Content, %	+/- Optimum Water Content	Molded Dry Density, pcf	% of Std Max Dry Density	Permeability CM/SEC
25-Blows				
19.9	-3.2	92.5	96	2.5 X 10-6
23.9	+0.8	96.2	100	2.3 X 10-8
26.2	+3.1	94.2	98	7.0 X 10-9
28.4	+5.3	92.4	96	1.0 X 10-8
15-Blows				
23.8	+0.7	90.3	93	2.9 X 10-6
28.1	+5.0	91.6	95	2.6 X 10-9
30.0	+6.9	89.3	92	3.7 X 10-9
31.7	+8.6	87.2	90	3.5 X 10-9

Sample No. 92/842 (Undisturbed) 5.7 X 10-5

W.O. No. SWDED-GL 15520
Req. No.
Contract No.



	% COBBLES	% GRAVEL	% SAND	% SILT OR CLAY
●	0.0	0.0	38.0	62.0

	Sample No.	Elev or Depth	Nat W%	LL	PL	PI	C_c	C_u
●	92/842	UNKNOWN	10.1	40	12	28		

CLASSIFICATION

● SANDY LEAN CLAY (CL)

Remarks:

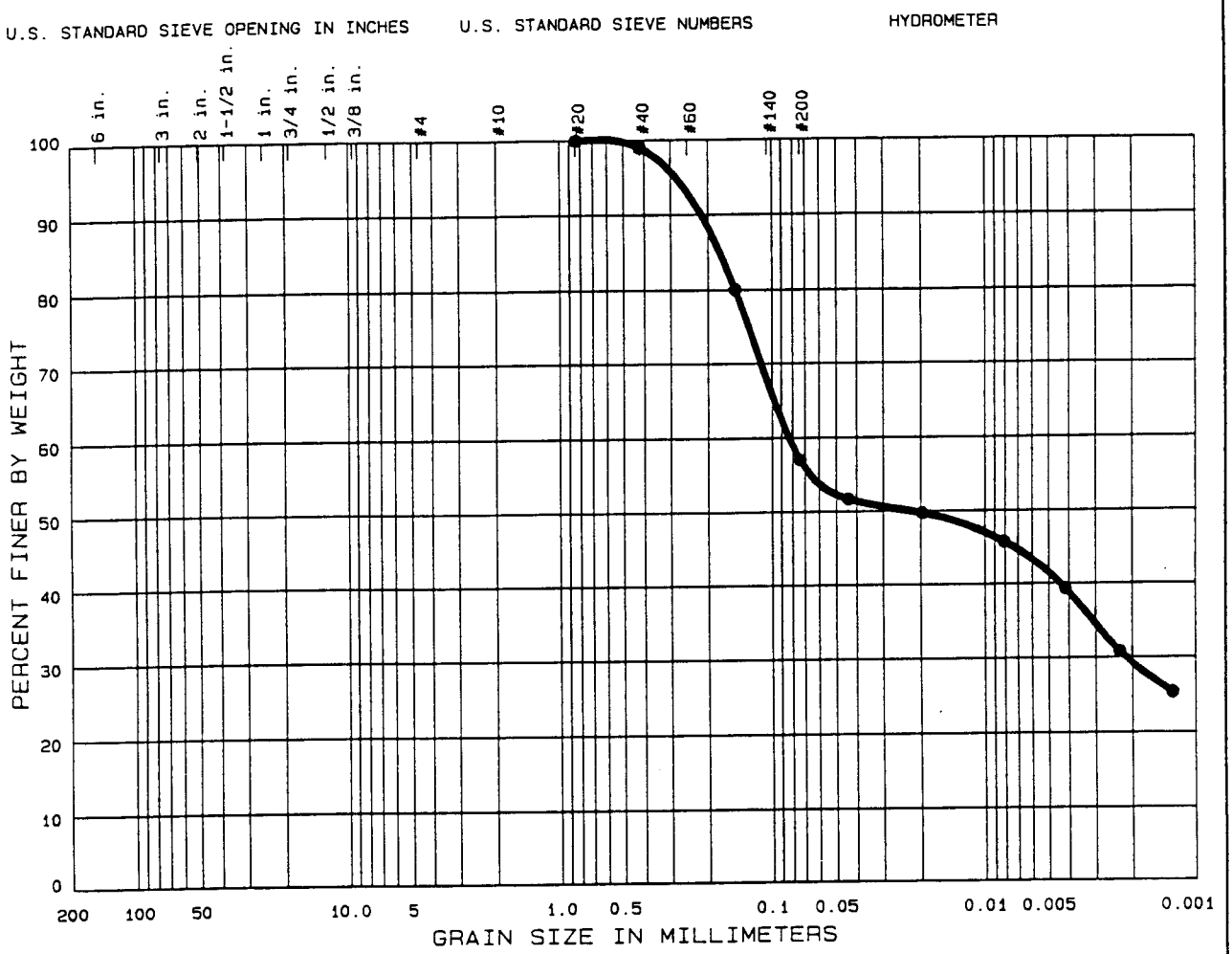
Project CANNON AFB - LANDFILL NO. 5
CELL-3, SITE-1, UNDISTURBED
Lab No. SWDED-GL REPORT 15520

Area

Boring No. 3-1 Date 11 MARCH 1992

GRADATION CURVES Plate-1

DEPARTMENT OF THE ARMY, SOUTHWESTERN DIVISION LABORATORY
CORPS OF ENGINEERS, 4815 CASS STREET, DALLAS, TX 75235



	% COBBLES	% GRAVEL	% SAND	% SILT OR CLAY
●	0.0	0.0	43.0	57.0

	Sample No.	Elev or Depth	Nat W%	LL	PL	PI	C_c	C_u
●	92/843	UNKNOWN	14.8	32	16	16		

CLASSIFICATION

● SANDY LEAN CLAY (CL)

Remarks:

Project CANNON AFB - LANDFILL NO. 5
CELL-3, SITE-1, UNDISTURBED
Lab No. SWDED-GL REPORT 15520

Area

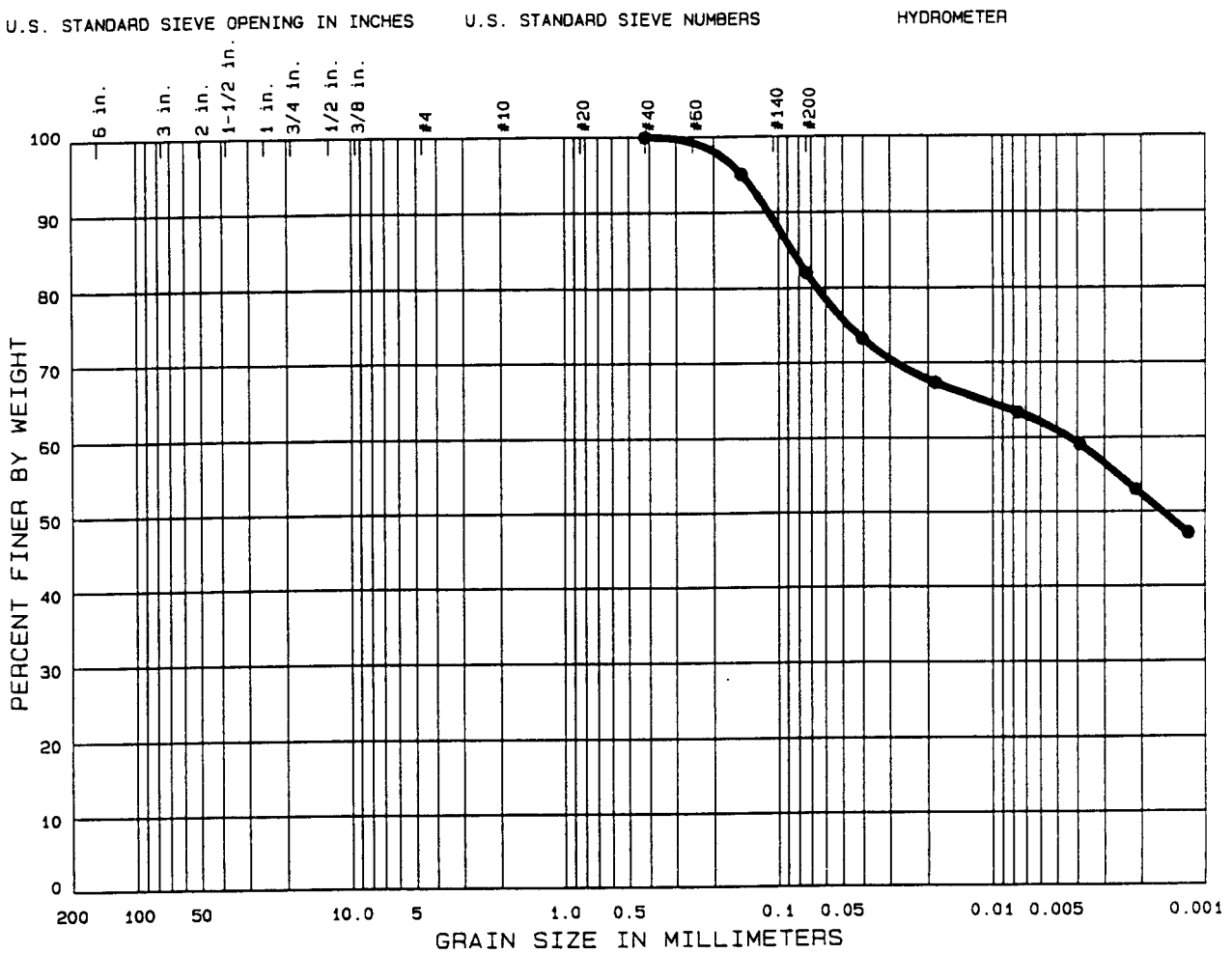
Boring No. 3-2 Date 11 MARCH 1992

GRADATION CURVES Plate 2

W.O. No. SWDED-GL 15520
Req. No.
Contract No.

DEPARTMENT OF THE ARMY, SOUTHWESTERN DIVISION LABORATORY
CORPS OF ENGINEERS, 4815 CASS STREET, DALLAS, TX 75235

W.O. No. SWDED-GL 15520
Req. No.
Contract No.



	% COBBLES	% GRAVEL	% SAND	% SILT OR CLAY
●	0.0	0.0	18.0	82.0

	Sample No.	Elev or Depth	Nat W%	LL	PL	PI	C_C	C_U
●	92/844	0.0' - 3.0'	5.0	61	20	41		

CLASSIFICATION

● FAT CLAY WITH SAND (CH)

Remarks:

Project CANNON AFB - LANDFILL NO. 5
CELL-3, SITE-1, CAP
Lab No. SWDED-GL REPORT 15520
Area
Boring No.
Date 11 MARCH 1992

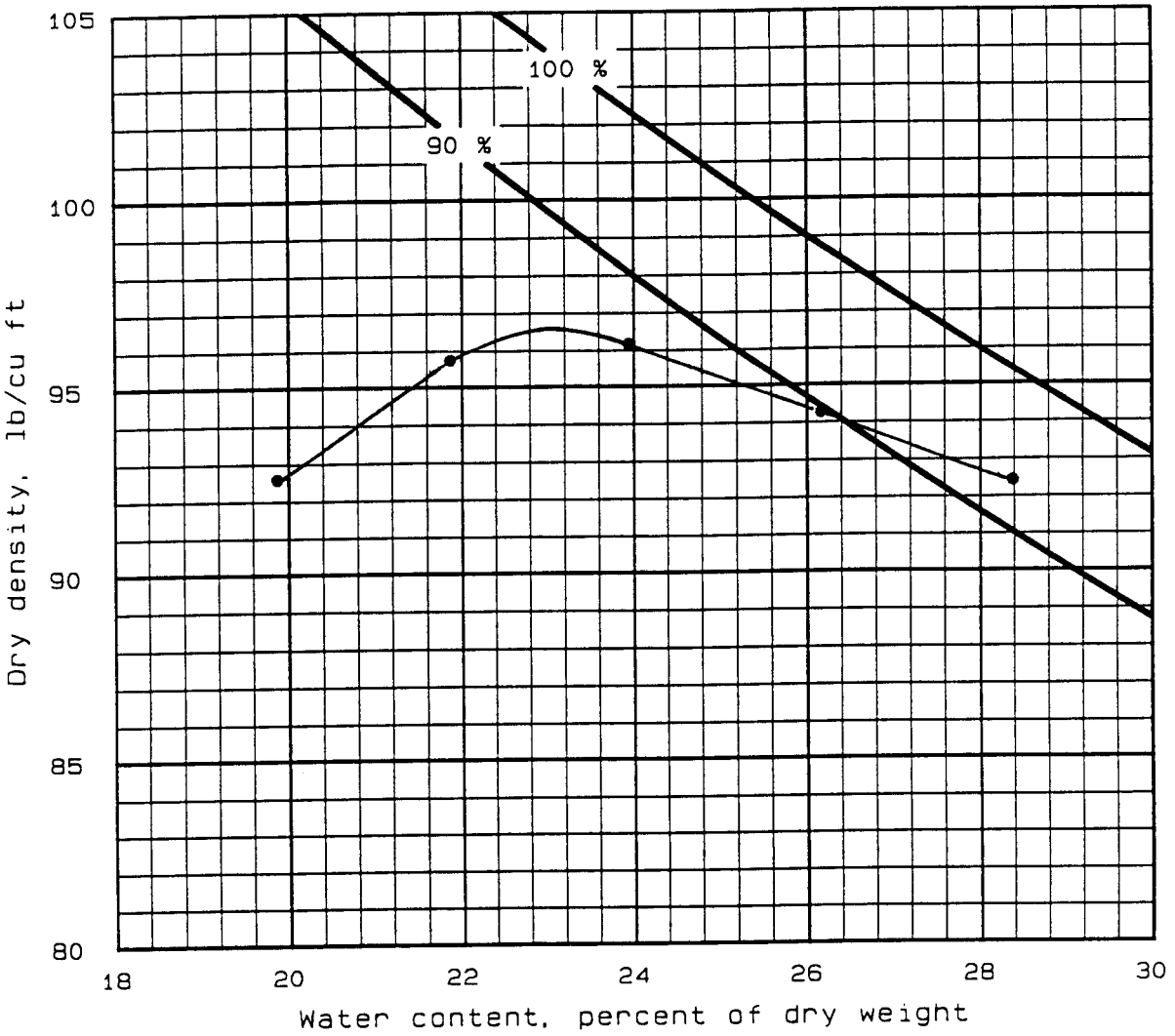
GRADATION CURVES

Plate 3

DEPARTMENT OF THE ARMY, SOUTHWESTERN DIVISION LABORATORY
CORPS OF ENGINEERS, 4815 CASS STREET, DALLAS, TX 75235

DEPARTMENT OF THE ARMY, SOUTHWESTERN DIVISION LABORATORY
CORPS OF ENGINEERS, 4815 CASS STREET, DALLAS, TX 75235

WORK ORDER NO. SWDED-GL 15520
Req. No.
Contract No.



Standard compaction test ASTM D698 Method A
25 blows per each of 3 layers, with 5.50 lb. sleeve rammer
and 12.0 inch drop. 4.0 inch diameter mold

Sample No.	Elev/ Depth	Classification	G	LL	PL	% > No.4	% > 3/4 in.
92/844	0.0'-	FAT CLAY WITH SAND	2.70	61	20	0	0
	3.0'	(CH)					

Sample No.	92/844		
Water content, percent	5.0	AS RECEIVED	
Optimum water content, percent	23.1		
Max dry density, lb/cu ft	96.6		

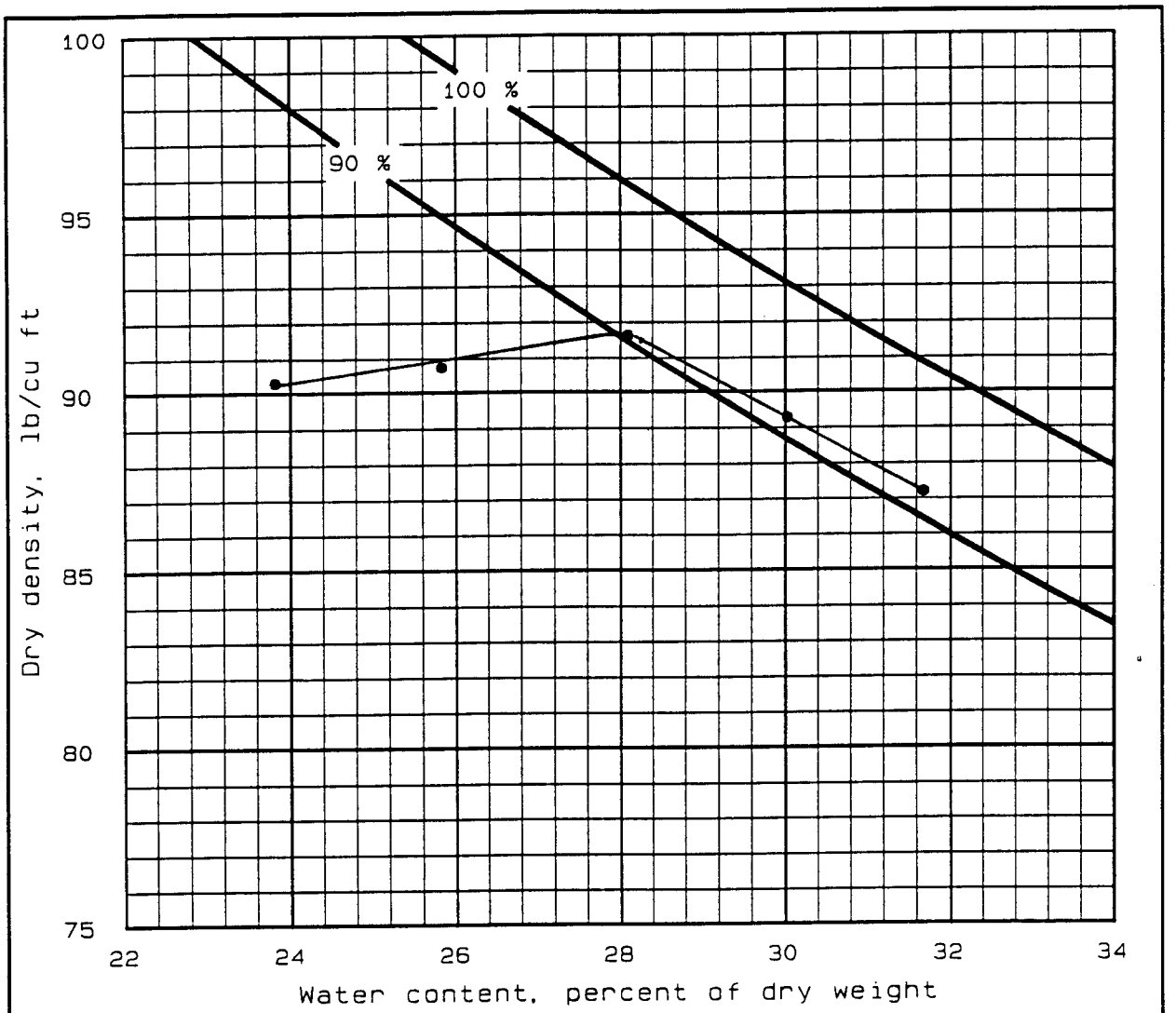
Remarks:

Project: CANNON AFB - LANDFILL NO. 5,
CELL-3, SITE-1, CAP, BAGS, 0.0'-3.0
Lab No.: 92/842
Area:
Plate 4
Boring No.: 3-1 Date: 4 MARCH 92

COMPACTION TEST REPORT

DEPARTMENT OF THE ARMY, SOUTHWESTERN DIVISION LABORATORY
CORPS OF ENGINEERS, 4815 CASS STREET, DALLAS, TX 75235

WORK ORDER NO. SWDED-GL 15520
Req. No.
Contract No.



15-Blow compaction test EM 1110-2-1906 Appendix VI
15 blows per each of 3 layers, with 5.50 lb. sleeve rammer
and 12.0 inch drop. 4.0 inch diameter mold

Sample No.	Elev/ Depth	Classification	G	LL	PL	% > No.4	% > 3/4 in.
92/844	0.0'-	FAT CLAY WITH SAND	2.70	61	20	0	0
	3.0'	(CH)					

Sample No.	92/844			
Water content, percent	5.0	AS RECEIVED		
Optimum water content, percent	27.9			
Max dry density, lb/cu ft	91.6			

Remarks:

Project: CANNON AFB - LANDFILL NO. 5,
CELL-3, SITE-1, CAP, BAGS, 0.0'-3.0
Lab No.: 92/842
Area:
Plate 5
Boring No.: 3-1 Date: 4 MARCH 92

COMPACTION TEST REPORT

PERMEABILITY TEST RESULTS SWDED-GL 15520

Type of Specimen: UNDISTURBED			Before Test:		After Test:
Diam(in): 6.09	Ht(in): 3.71		Water Content, wo:	10.1	wf: 19.8
Confining Pressure(psi):		90.0	Void Ratio, eo	0.522	ef: 0.522
Backpressure to saturate:		85.0	Saturation, So:	51.9	Sf: 101.7
Differential Head(psi):		1.0	Dry Density, lb/ft3:	109.6	109.6
Class.: SANDY LEAN CLAY (CL)			HYDRAULIC GRADIENT:	8	
LL 40	Gs 2.68		Project: CANNON AFB AFB - LANDFILL NO. 5		
PL 12	D10		CELL-3, SITE1, UNDISTURBED		
Permeant Liquid: WATER			Area:		
Remarks:			Boring No. 3-1		Smpl #92/842
			Depth: UNKNOWN		Date: 4 MAR 92

	Coefficient of Permeability at 20 deg C.	
Run 1	5.5E-05	CM/SEC
Run 2	6.0E-05	CM/SEC
Run 3	5.2E-05	CM/SEC
Run 4	6.3E-05	CM/SEC
Run 5	6.4E-05	CM/SEC
Run 6	5.2E-05	CM/SEC
Run 7	5.3E-05	CM/SEC
Run 8	5.3E-05	CM/SEC
Average	5.7E-05	CM/SEC

RUN 1 THUR 8

	init.	final
HEIGHT CHANGE, CONSOL, cm	0.00	
WEIGHT OF WET SOIL, g	3434.0	
WEIGHT OF DRY SOIL, g	3119.0	
AREA, cm^2	187.93	
VOLUME, cm^3	1775.0	1775.00
REDUCED HEIGHT OF SOIL,cm	2.438	

PERMEABILITY TEST RESULTS SWDED-GL 15520

Type of Specimen: REMOLDED			Before Test:		After Test:
Diam(in): 4.00	Ht(in): 4.57		Water Content, wo:	19.9	wf: 31.9
Confining Pressure(psi):		70.0	Void Ratio, eo	0.821	ef: 0.821
Backpressure to saturate:		65.0	Saturation, So:	65.5	Sf: 104.9
Differential Head(psi):		3.0	Dry Density, lb/ft3:	92.5	92.5
Class.: FAT CLAY WITH SAND (CH)			HYDRAULIC GRADIENT:	18	
LL 61	Gs 2.70		Project: CANNON AFB - LANDFILL NO. 5		
PL 20	D10		CELL-3, SITE-1, CAP		
Permeant Liquid: WATER			Area:		
Remarks: OPTIMUM MINUS 3.2 % AT			Boring No.:		Smpl #92/844
96 % MAX STD DENSITY			Depth: 0.0'-3.0'		Date: 6 MAR 92

Coefficient of
Permeability at 20 deg C.

Run 1	1.3E-05	CM/SEC
Run 2	1.4E-05	CM/SEC
Run 3	1.3E-05	CM/SEC
Run 4	1.1E-05	CM/SEC
Run 5	1.0E-05	CM/SEC
Run 6	5.7E-06	CM/SEC
Run 7	3.6E-06	CM/SEC
Run 8	2.8E-06	CM/SEC
Run 9	2.6E-06	CM/SEC
Run 10	2.2E-06	CM/SEC
Run 11	2.4E-06	CM/SEC
Average RUN 8,9,10,11	2.5E-06	CM/SEC

	INITAL	FINAL
HEIGHT CHANGE, CONSOL, cm	0.00	
WEIGHT OF WET SOIL, g	1674.2	
WEIGHT OF DRY SOIL, g	1396.3	
AREA, cm^2	81.07	
VOLUME, cm^3	941.6	941.60
REDUCED HEIGHT OF SOIL,cm	2.511	

PERMEABILITY TEST RESULTS SWDED-GL 15520

Type of Specimen: REMOLDED			Before Test:		After Test:
Diam(in): 4.00	Ht(in): 4.57		Water Content, wo:	23.9	wf: 28.4
Confining Pressure(psi):		70.0	Void Ratio, eo	0.752	ef: 0.752
Backpressure to saturate:		65.0	Saturation, So:	85.8	Sf: 102.0
Differential Head(psi):		3.0	Dry Density, lb/ft3:	96.2	96.2
Class.: FAT CLAY WITH SAND (CH)			HYDRAULIC GRADIENT:	18	
LL 61	Gs 2.70		Project: CANNON AFB - LANDFILL NO. 5		
PL 20	D10		CELL-3, SITE-1, CAP		
Permeant Liquid: WATER			Area:		
Remarks: OPTIMUM PLUS 0.8 % AT			Boring No.:		Smpl #92/844
STD MAX DENSITY			Depth: 0.0'-3.0'		Date: 6 MAR 92

Coefficient of
Permeability at 20 deg C.

Run 1	5.3E-08	CM/SEC
Run 2	3.8E-08	CM/SEC
Run 3	2.8E-08	CM/SEC
Run 4	2.4E-08	CM/SEC
Run 5	1.9E-08	CM/SEC
Run 6	2.2E-08	CM/SEC

Average RUN 3,4,5,6	2.3E-08	CM/SEC

	INITAL	FINAL
HEIGHT CHANGE, CONSOL, cm	0.00	
WEIGHT OF WET SOIL, g	1798.2	
WEIGHT OF DRY SOIL, g	1451.3	
AREA, cm^2	81.07	
VOLUME, cm^3	941.6	941.60
REDUCED HEIGHT OF SOIL,cm	2.610	

PERMEABILITY TEST RESULTS SWDED-GL 15520

Type of Specimen: REMOLDED		Before Test:		After Test:	
Diam(in): 4.00	Ht(in): 4.57	Water Content, wo:	26.2	wf:	27.7
Confining Pressure(psi):	70.0	Void Ratio, eo	0.788	ef:	0.788
Backpressure to saturate:	65.0	Saturation, So:	89.7	Sf:	94.9
Differential Head(psi):	3.0	Dry Density, lb/ft3:	94.2		94.2
Class.: FAT CLAY WITH SAND (CH)		HYDRAULIC GRADIENT:	18		
LL 61	Gs 2.70	Project: CANNON AFB - LANDFILL NO. 5			
PL 20	D10	CELL-3, SITE-1, CAP			
Permeant Liquid: WATER		Area:			
Remarks: OPTIMUM PLUS 3.1 % AT		Boring No.:		Smpl #92/844	
98 % MAX STD DENSITY		Depth: 0.0'-3.0'		Date: 6 MAR 92	

Coefficient of
Permeability at 20 deg C.

Run 1	2.8E-08 CM/SEC
Run 2	1.2E-08 CM/SEC
Run 3	8.2E-09 CM/SEC
Run 4	7.7E-09 CM/SEC
Run 5	6.0E-09 CM/SEC
Run 6	7.2E-09 CM/SEC

Average RUN 4,5,6 7.0E-09 CM/SEC

	INITAL	FINAL
HEIGHT CHANGE, CONSOL, cm	0.00	
WEIGHT OF WET SOIL, g	1794.1	
WEIGHT OF DRY SOIL, g	1421.6	
AREA, cm^2	81.07	
VOLUME, cm^3	941.6	941.60
REDUCED HEIGHT OF SOIL,cm	2.557	

PERMEABILITY TEST RESULTS SWDED-GL 15520

Type of Specimen: REMOLDED			Before Test:		After Test:
Diam(in): 4.00	Ht(in): 4.57		Water Content, wo:	28.4	wf: 28.9
Confining Pressure(psi):		70.0	Void Ratio, eo	0.824	ef: 0.824
Backpressure to saturate:		65.0	Saturation, So:	93.1	Sf: 94.7
Differential Head(psi):		3.0	Dry Density, lb/ft3:	92.4	92.4
Class.: FAT CLAY WITH SAND (CH)			HYDRAULIC GRADIENT:	18	
LL 61	Gs 2.70		Project: CANNON AFB - LANDFILL NO. 5		
PL 20	D10		CELL-3, SITE-1, CAP		
Permeant Liquid: WATER			Area:		
Remarks: OPTIMUM PLUS 5.3 % AT			Boring No.:		Smpl #92/844
97 % MAX STD DENSITY			Depth: 0.0'-3.0'		Date: 6 MAR 92

Coefficient of
Permeability at 20 deg C.

Run 1	1.2E-08 CM/SEC
Run 2	6.3E-09 CM/SEC
Run 3	1.0E-08 CM/SEC
Run 4	1.2E-08 CM/SEC
Run 5	9.4E-09 CM/SEC
Run 6	9.0E-09 CM/SEC

Average RUN 3,4,5,6	1.0E-08 CM/SEC

	INITAL	FINAL
HEIGHT CHANGE, CONSOL, cm	0.00	
WEIGHT OF WET SOIL, g	1789.9	
WEIGHT OF DRY SOIL, g	1394.0	
AREA, cm^2	81.07	
VOLUME, cm^3	941.6	941.60
REDUCED HEIGHT OF SOIL,cm	2.507	

PERMEABILITY TEST RESULTS SWDED-GL 15520

Type of Specimen: REMOLDED			Before Test:		After Test:
Diam(in): 4.00	Ht(in): 4.57		Water Content, wo:	23.8	wf: 31.5
Confining Pressure(psi):		80.0	Void Ratio, eo	0.866	ef: 0.866
Backpressure to saturate:		75.0	Saturation, So:	74.2	Sf: 98.2
Differential Head(psi):		3.0	Dry Density, lb/ft3:	90.3	90.3
Class.: FAT CLAY WITH SAND (CH)			HYDRAULIC GRADIENT:	18	
LL 61	Gs 2.70		Project: CANNON AFB - LANDFILL NO. 5		
PL 20	D10		CELL-3, SITE-1, CAP		
Permeant Liquid: WATER			Area:		
Remarks: OPTIMUM PLUS 0.7 % AT			Boring No.:		Smpl #92/844
93 % MAX STD DENSITY			Depth: 0.0'-3.0'		Date: 6 MAR 92

Coefficient of
Permeability at 20 deg C.

RUN-1	1.5E-05	CM/SEC	RUN-11	5.0E-06	CM/SEC
RUN-2	1.3E-05	CM/SEC	RUN-12	4.9E-06	CM/SEC
RUN-3	1.3E-05	CM/SEC	RUN-13	4.7E-06	CM/SEC
RUN-4	1.3E-05	CM/SEC	RUN-14	7.0E-06	CM/SEC
RUN-5	1.1E-05	CM/SEC	RUN-15	9.3E-06	CM/SEC
RUN-6	9.8E-06	CM/SEC	RUN-16	6.2E-06	CM/SEC
RUN-7	9.2E-06	CM/SEC	RUN-17	3.5E-06	CM/SEC
RUN-8	9.1E-06	CM/SEC	RUN-18	3.2E-06	CM/SEC
RUN-9	9.8E-06	CM/SEC	RUN-19	2.6E-06	CM/SEC
RUN-10	9.0E-06	CM/SEC	RUN-20	2.3E-06	CM/SEC

Average 2.9E-06 CM/SEC
RUN 17,18,19,20

	INITAL	FINAL
HEIGHT CHANGE, CONSOL, cm	0.00	
WEIGHT OF WET SOIL, g	1686.8	
WEIGHT OF DRY SOIL, g	1362.5	
AREA, cm^2	81.07	
VOLUME, cm^3	941.6	941.60
REDUCED HEIGHT OF SOIL,cm	2.451	

PERMEABILITY TEST RESULTS SWDED-GL 15520

Type of Specimen: REMOLDED			Before Test:		After Test:
Diam(in): 4.00	Ht(in): 4.57		Water Content, wo:	28.1	wf: 29.8
Confining Pressure(psi):		70.0	Void Ratio, eo	0.839	ef: 0.839
Backpressure to saturate:		65.0	Saturation, So:	90.4	Sf: 95.9
Differential Head(psi):		3.0	Dry Density, lb/ft3:	91.6	91.6
Class.: FAT CLAY WITH SAND (CH)			HYDRAULIC GRADIENT:	18	
LL 61	Gs 2.70		Project: CANNON AFB - LANDFILL NO. 5		
PL 20	D10		CELL-3, SITE-1, CAP		
Permeant Liquid: WATER			Area:		
Remarks: OPTIMUM PLUS 5.0 % AT			Boring No.:		Smpl #92/844
95 % MAX STD DENSITY			Depth: 0.0'-3.0'		Date: 6 MAR 92

Coefficient of
Permeability at 20 deg C.

Run 9	3.3E-09 CM/SEC
Run 10	4.2E-09 CM/SEC
Run 11	2.7E-09 CM/SEC
Run 12	2.2E-09 CM/SEC
Run 13	2.8E-09 CM/SEC

Average RUN 11,12,13	2.6E-09 CM/SEC

	INITAL	FINAL
HEIGHT CHANGE, CONSOL, cm	0.00	
WEIGHT OF WET SOIL, g	1770.9	
WEIGHT OF DRY SOIL, g	1382.4	
AREA, cm^2	81.07	
VOLUME, cm^3	941.6	941.60
REDUCED HEIGHT OF SOIL,cm	2.486	

PERMEABILITY TEST RESULTS SWDED-GL 15520

Type of Specimen: REMOLDED			Before Test:		After Test:
Diam(in): 4.00	Ht(in): 4.57		Water Content, wo:	30.0	wf: 30.9
Confining Pressure(psi):		70.0	Void Ratio, eo	0.887	ef: 0.887
Backpressure to saturate:		65.0	Saturation, So:	91.3	Sf: 94.0
Differential Head(psi):		3.0	Dry Density, lb/ft3:	89.3	89.3
Class.: FAT CLAY WITH SAND (CH)			HYDRAULIC GRADIENT:	18	
LL 61	Gs 2.70		Project: CANNON AFB - LANDFILL NO. 5		
PL 20	D10		CELL-3, SITE-1, CAP		
Permeant Liquid: WATER			Area:		
Remarks: OPTIMUM PLUS 6.9 % AT			Boring No.:		Smpl #92/844
92 % MAX STD DENSITY			Depth: 0.0'-3.0'		Date: 6 MAR 92

Coefficient of
Permeability at 20 deg C.

Run 1	4.7E-09 CM/SEC	Run 9	4.4E-09 CM/SEC
Run 2	1.0E-08 CM/SEC	Run 10	3.2E-09 CM/SEC
Run 3	7.8E-09 CM/SEC	Run 11	3.3E-09 CM/SEC
Run 4	5.7E-09 CM/SEC	Run 12	2.1E-09 CM/SEC
Run 5	-1.6E-08 CM/SEC	Run 13	4.0E-09 CM/SEC
Run 6	2.0E-08 CM/SEC	Run 14	3.8E-09 CM/SEC
Run 7	1.6E-09 CM/SEC	Run 15	3.6E-09 CM/SEC
Run 8	4.6E-09 CM/SEC	Run 16	3.4E-09 CM/SEC

Average 3.70E-09 CM/SEC
RUN 13,14,15,16

	INITAL	FINAL
HEIGHT CHANGE, CONSOL, cm	0.00	
WEIGHT OF WET SOIL, g	1751.4	
WEIGHT OF DRY SOIL, g	1347.2	
AREA, cm^2	81.07	
VOLUME, cm^3	941.6	941.60
REDUCED HEIGHT OF SOIL,cm	2.423	

PERMEABILITY TEST RESULTS SWDED-GL 15520

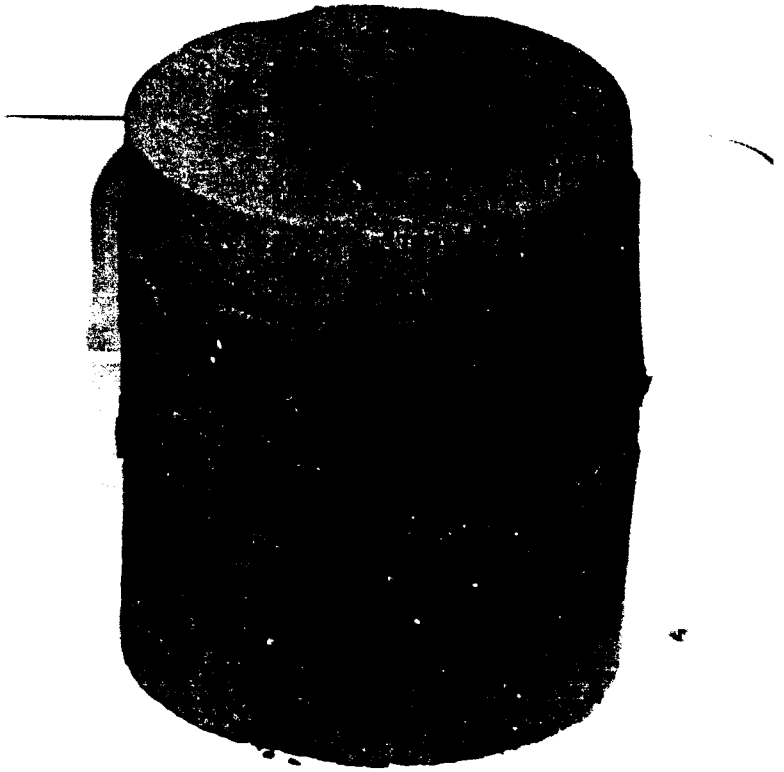
Type of Specimen: REMOLDED			Before Test:		After Test:
Diam(in): 4.00	Ht(in): 4.57		Water Content, wo:	31.7	wf: 32.5
Confining Pressure(psi):		80.0	Void Ratio, eo	0.933	ef: 0.933
Backpressure to saturate:		75.0	Saturation, So:	91.7	Sf: 94.0
Differential Head(psi):		3.0	Dry Density, lb/ft3:	87.2	87.2
Class.: FAT CLAY WITH SAND (CH)			HYDRAULIC GRADIENT:	18	
LL 61	Gs 2.70		Project: CANNON AFB - LANDFILL NO. 5		
PL 20	D10		CELL-3, SITE-1, CAP		
Permeant Liquid: WATER			Area:		
Remarks: OPTIMUM PLUS 8.6 % AT			Boring No.:		Smpl #92/844
90 % MAX STD DENSITY			Depth: 0.0'-3.0'		Date: 6 MAR 92

Coefficient of
Permeability at 20 deg C.

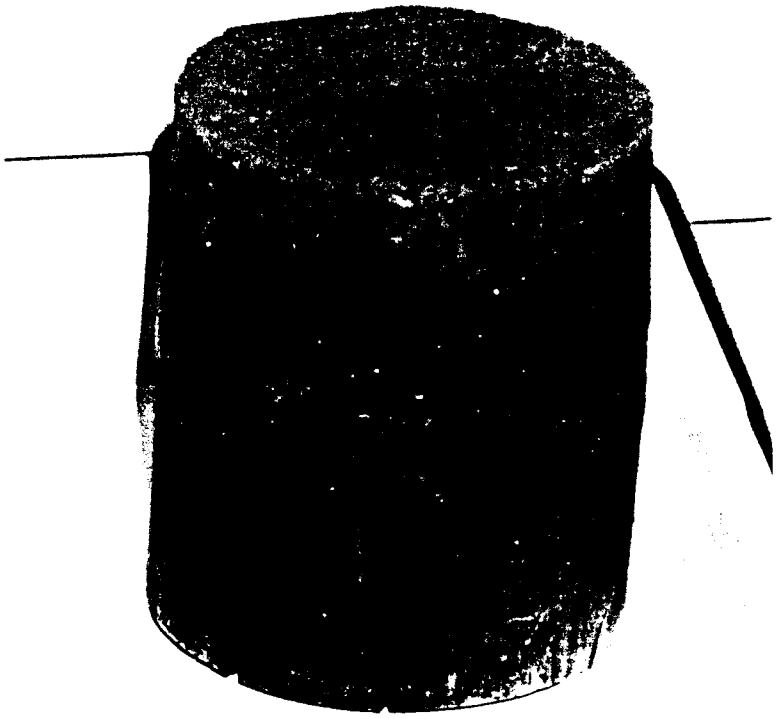
Run-1	-6.0E-09 CM/SEC
Run-2	3.9E-09 CM/SEC
Run-3	2.8E-09 CM/SEC
Run-4	3.9E-09 CM/SEC
Run-5	5.7E-09 CM/SEC
Run-6	1.0E-08 CM/SEC
Run 7	1.2E-08 CM/SEC
Run 8	3.4E-09 CM/SEC
Run 9	3.8E-09 CM/SEC
Run 10	3.1E-09 CM/SEC
Run-11	3.6E-09 CM/SEC
Average RUN 8,9,10,11	3.5E-09 CM/SEC

	INITAL	FINAL
HEIGHT CHANGE, CONSOL, cm	0.00	
WEIGHT OF WET SOIL, g	1732.0	
WEIGHT OF DRY SOIL, g	1315.1	
AREA, cm^2	81.07	
VOLUME, cm^3	941.6	941.60
REDUCED HEIGHT OF SOIL,cm	2.365	

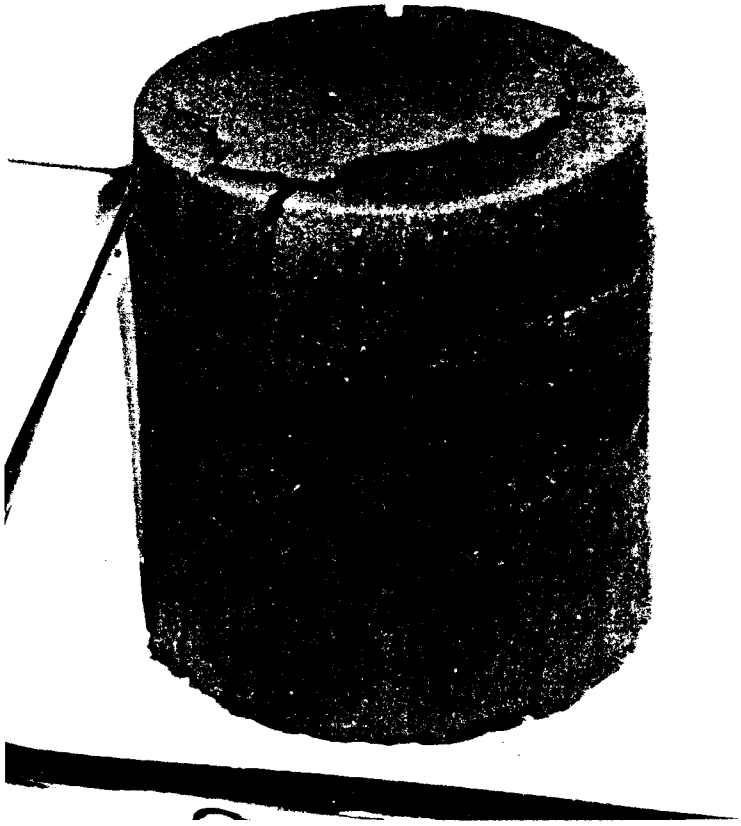
Sample 92/844 - Optimum
+ 0.8 % at Std Max Density
After permeability test and
24 hours air drying



Sample 92/844 - Optimum
+ 3.1 % at 98 % Std Max Density
After permeability test and
24 hours air drying



Sample 92/844 - Optimum
+ 5.3 % at 97 % Std Max Density
After permeability test and
24 hours air drying



HOLE #1 - EAST SIDE
LANDFILL#3, CELL#3
PERMEABILITY TEST
CANNON AFB, NM

d (cm)=	1.5	L (cm)=	0	
D (cm)=	10.16	dV=		(dho)
Z (cm)=	596.9	H (cm)=	628	(Z+Ra)
Ra (cm)=	31.1	a =	0	
b2 (cm)=	infinite	b1 =	1	
		G1 =	2.901689	

DATE	TIME	Reading Number	dT sec.	Rt cm	H1 cm	H2 cm	K1 cm/sec	C cm	H1' cm	K1' cm/sec	Visc Factor	K2' cm/sec	Cum Hrs	Remarks
3/5/92	14:00	1	13.66	1	67.5	0	2.17E-02		0.296235	2.17E-02				REFILLED
		2	12.84	1	65.5	0	2.24E-02		0.287879	2.20E-02				REFILLED
		3	12.66	1	64.9	0	2.25E-02		0.285368	2.22E-02				REFILLED
		4	12.34	1	64	0	2.28E-02		0.281596	2.24E-02				REFILLED
		5	12.46	1	63.5	0	2.24E-02		0.279499	2.24E-02				REFILLED
		6	12.23	1	62.7	0	2.26E-02		0.276140	2.24E-02				REFILLED
		7	12.15	1	62	0	2.25E-02		0.273198	2.24E-02				REFILLED
		8	11.9	1	61.5	0	2.28E-02		0.271094	2.25E-02				REFILLED
		9	12.3	1	61	0	2.19E-02		0.268989	2.24E-02				REFILLED
		10	11.73	1	60.2	0	2.26E-02		0.265618	2.24E-02				REFILLED
						AVG=	2.24E-02							
						sdv=	3.50E-04							
	16:46	1	18.28	1	91.2	0	2.15E-02		0.393467	2.15E-02				REFILLED
		2	18.15	1	90.4	0	2.15E-02		0.390237	2.15E-02				REFILLED
		3	17.11	1	86.1	0	2.18E-02		0.372817	2.16E-02				REFILLED
		4	17.9	1	89.3	0	2.16E-02		0.385791	2.16E-02				REFILLED
		5	17.9	1	89.7	0	2.16E-02		0.387408	2.16E-02				REFILLED
		6	17.8	1	89.3	0	2.17E-02		0.385791	2.16E-02				REFILLED
		7	18.04	1	88.4	0	2.12E-02		0.382148	2.16E-02				REFILLED
		8	17.65	1	88.2	0	2.16E-02		0.381337	2.16E-02				REFILLED
		9	17.81	1	88.4	0	2.15E-02		0.382148	2.15E-02				REFILLED
		10	17.99	1	90	0	2.16E-02		0.388621	2.16E-02				REFILLED
						AVG=	2.16E-02							
						sdv=	1.53E-04							

DATE	TIME	Reading Number	dT sec.	Rt cm	H1 cm	H2 cm	K1 cm/sec	C cm	H1' cm	K1' cm/sec	Visc Factor	K2' cm/sec	Cum Hrs	Remarks
3/5/92	22:30	1	17.47	1	89	0	2.20E-02		0.384577	2.20E-02				REFILLED
		2	16.53	1	82	0	2.15E-02		0.356109	2.18E-02				REFILLED
		3	17.34	1	86.5	0	2.16E-02		0.374442	2.17E-02				REFILLED
		4	17.41	1	87.8	0	2.18E-02		0.379716	2.17E-02				REFILLED
		5	17.75	1	89.3	0	2.17E-02		0.385791	2.17E-02				REFILLED
		6	17.84	1	88.5	0	2.14E-02		0.382553	2.17E-02				REFILLED
		7	17.46	1	87.5	0	2.17E-02		0.378500	2.17E-02				REFILLED
		8	18.17	1	90.8	0	2.16E-02		0.391852	2.17E-02				REFILLED
		9	17.92	1	89.3	0	2.15E-02		0.385791	2.17E-02				REFILLED
		10	17.59	1	88	0	2.16E-02		0.380527	2.17E-02				REFILLED
						AVG=	2.17E-02							
						sdv=	1.56E-04							
3/6/92	08:30	1	13.21	1	58.2	0	1.95E-02		0.257173	1.95E-02				REFILLED
		2	13.24	1	57.8	0	1.93E-02		0.255481	1.94E-02				REFILLED
		3	13.09	1	57.6	0	1.95E-02		0.254635	1.94E-02				REFILLED
		4	13.06	1	57.6	0	1.95E-02		0.254635	1.94E-02				REFILLED
		5	13.93	1	57.4	0	1.82E-02		0.253788	1.92E-02				REFILLED
		6	13	1	57.3	0	1.95E-02		0.253365	1.92E-02				REFILLED
		7	12.97	1	57.2	0	1.95E-02		0.252941	1.93E-02				REFILLED
		8	12.97	1	57	0	1.94E-02		0.252094	1.93E-02				REFILLED
		9	12.84	1	56.9	0	1.96E-02		0.251671	1.93E-02				REFILLED
		10	13.03	1	56.8	0	1.93E-02		0.251247	1.93E-02				REFILLED
						AVG=	1.93E-02							
						sdv=	3.79E-04							

DATE	TIME	Reading Number	dT sec.	Rt cm	H1 cm	H2 cm	K1 cm/sec	C cm	H1' cm	K1' cm/sec	Visc Factor	K2' cm/sec	Cum Hrs	Remarks
3-24-92	13:45	1	70.9	1	87.3	0	5.33E-03		0.377689	5.33E-03				REFILLED
		2	70.53	1	87.2	0	5.35E-03		0.377283	5.34E-03				REFILLED
		3	70.35	1	87.1	0	5.36E-03		0.376877	5.34E-03				REFILLED
		4	70.47	1	87	0	5.34E-03		0.376472	5.34E-03				REFILLED
		5	70.53	1	86.8	0	5.33E-03		0.375660	5.34E-03				REFILLED
		6	70.1	1	86.6	0	5.35E-03		0.374848	5.34E-03				REFILLED
		7	69.96	1	86.5	0	5.35E-03		0.374442	5.34E-03				REFILLED
		8	69.93	1	86.4	0	5.35E-03		0.374036	5.34E-03				REFILLED
		9	70.1	1	86.3	0	5.33E-03		0.373629	5.34E-03				REFILLED
		10	69.91	1	86.1	0	5.33E-03		0.372817	5.34E-03				REFILLED
						AVG=	5.34E-03							
						sdv=	1.08E-05							
3/25/92	11:00	1	72.86	1	85.6	0	5.09E-03		0.370784	5.09E-03				REFILLED
		2	72.79	1	84.5	0	5.03E-03		0.366308	5.06E-03				REFILLED
		3	72.72	1	84.4	0	5.03E-03		0.365901	5.05E-03				REFILLED
		4	72.68	1	84.3	0	5.03E-03		0.365493	5.05E-03				REFILLED
		5	72.58	1	84.2	0	5.03E-03		0.365086	5.04E-03				REFILLED
		6	72.43	1	84.1	0	5.03E-03		0.364679	5.04E-03				REFILLED
		7	72.52	1	84	0	5.02E-03		0.364271	5.04E-03				REFILLED
		8	72.37	1	83.9	0	5.03E-03		0.363863	5.04E-03				REFILLED
		9	72.15	1	83.8	0	5.04E-03		0.363456	5.04E-03				REFILLED
		10	72.28	1	83.7	0	5.02E-03		0.363048	5.04E-03				REFILLED
						AVG=	5.04E-03							
						sdv=	1.83E-05							

HOLE #2 - SOUTH SIDE
LANDFILL#3, CELL#3
PERMEABILITY TEST
CANNON AFB, NM

d (cm)=	1.5	L (cm)=	0	
D (cm)=	10.16	dV=		(dho)
Z (cm)=	596.9	H (cm)=	630	(Z+Ra)
Ra (cm)=	33.1	a =	0	
b2 (cm)=	infinite	b1 =	1	
		G1 =	2.901689	

DATE	TIME	Reading Number	dT sec.	Rt cm	H1 cm	H2 cm	K1 cm/sec	C cm	H1' cm	K1' cm/sec	Visc Factor	K2' cm/sec	Cum Hrs	Remarks
3/5/92	16:30	1	29.69	1	64.2	0	9.48E-03		0.281580	9.48E-03				REFILLED
		2	28.8	1	63.8	0	9.72E-03		0.279908	9.60E-03				REFILLED
		3	28.9	1	63.3	0	9.61E-03		0.277816	9.60E-03				REFILLED
		4	28.28	1	63	0	9.78E-03		0.276560	9.65E-03				REFILLED
		5	28.71	1	62.8	0	9.60E-03		0.275722	9.64E-03				REFILLED
		6	28.12	1	62.1	0	9.70E-03		0.272789	9.65E-03				REFILLED
		7	27.75	1	61.7	0	9.77E-03		0.271112	9.67E-03				REFILLED
		8	27.62	1	61.4	0	9.77E-03		0.269853	9.68E-03				REFILLED
		9	28.23	1	61.1	0	9.51E-03		0.268594	9.66E-03				REFILLED
		10	27.28	1	60.8	0	9.80E-03		0.267334	9.67E-03				REFILLED
						AVG=	9.68E-03							
						sdv=	1.09E-04							
3/5/92	22:15	1	27.8	1	54	0	8.58E-03		0.238629	8.58E-03				REFILLED
		2	27.38	1	53.9	0	8.70E-03		0.238205	8.64E-03				REFILLED
		3	27.22	1	53.8	0	8.74E-03		0.237780	8.67E-03				REFILLED
		4	27.03	1	53.7	0	8.78E-03		0.237356	8.70E-03				REFILLED
		5	26.91	1	53.6	0	8.80E-03		0.236932	8.72E-03				REFILLED
		6	26.84	1	53.5	0	8.81E-03		0.236507	8.74E-03				REFILLED
		7	26.29	1	53.4	0	8.98E-03		0.236082	8.77E-03				REFILLED
		8	26.71	1	53.3	0	8.82E-03		0.235658	8.78E-03				REFILLED
		9	26.68	1	53.2	0	8.82E-03		0.235233	8.78E-03				REFILLED
		10	26.82	1	53.2	0	8.77E-03		0.235233	8.78E-03				REFILLED
						AVG=	8.78E-03							
						sdv=	9.58E-05							

DATE	TIME	Reading Number	dT sec.	Rt cm	H1 cm	H2 cm	K1 cm/sec	C cm	H1' cm	K1' cm/sec	Visc Factor	K2' cm/sec	Cum Hrs	Remarks
3/6/92	06:30	1	39.91	1	72.9	0	7.96E-03		0.317719	7.96E-03				REFILLED
		2	39.65	1	72.8	0	8.00E-03		0.317307	7.98E-03				REFILLED
		3	39.91	1	72.7	0	7.94E-03		0.316894	7.97E-03				REFILLED
		4	39.9	1	72.7	0	7.94E-03		0.316894	7.96E-03				REFILLED
		5	39.81	1	72.5	0	7.94E-03		0.316068	7.96E-03				REFILLED
		6	39.48	1	72.5	0	8.01E-03		0.316068	7.97E-03				REFILLED
		7	39.35	1	72.4	0	8.02E-03		0.315655	7.97E-03				REFILLED
		8	39.42	1	72.3	0	8.00E-03		0.315241	7.98E-03				REFILLED
		9	39.3	1	72.2	0	8.01E-03		0.314828	7.98E-03				REFILLED
		10	39.49	1	72.1	0	7.96E-03		0.314415	7.98E-03				REFILLED
						AVG=	7.98E-03							
						sdv=	3.08E-05							
3/6/92	08:45	1	35.3	1	58.2	0	7.26E-03		0.256392	7.26E-03				REFILLED
		2	34.8	1	57.8	0	7.32E-03		0.254705	7.29E-03				REFILLED
		3	34.71	1	57.6	0	7.31E-03		0.253861	7.30E-03				REFILLED
		4	34.84	1	57.6	0	7.29E-03		0.253861	7.30E-03				REFILLED
		5	34.91	1	57.4	0	7.25E-03		0.253017	7.29E-03				REFILLED
		6	34.94	1	57.3	0	7.23E-03		0.252595	7.28E-03				REFILLED
		7	34.75	1	57.2	0	7.26E-03		0.252172	7.27E-03				REFILLED
		8	34.8	1	57	0	7.22E-03		0.251328	7.27E-03				REFILLED
		9	34.78	1	56.9	0	7.21E-03		0.250905	7.26E-03				REFILLED
		10	34.52	1	56.8	0	7.26E-03		0.250483	7.26E-03				REFILLED
						AVG=	7.26E-03							
						sdv=	3.43E-05							

DATE	TIME	Reading Number	dT sec.	Rt cm	H1 cm	H2 cm	K1 cm/sec	C cm	H1' cm	K1' cm/sec	Visc Factor	K2' cm/sec	Cum Hrs	Remarks
3/24/92	13:00	1	286.35	1	71.8	0	1.09E-03		0.313175	1.09E-03				
		2	285.28	1	71.6	0	1.09E-03		0.312348	1.09E-03				
		3	284.49	1	71.6	0	1.10E-03		0.312348	1.10E-03				
		4	279.96	1	70.5	0	1.10E-03		0.307795	1.10E-03				
		5	280.65	1	70.6	0	1.10E-03		0.308209	1.10E-03				
						AVG=	1.10E-03							
						sdv=	2.17E-06							
3/25/92	10:00	1	303.41	1	74.5	0	1.07E-03		0.324317	1.07E-03				
		2	302.96	1	74.4	0	1.07E-03		0.323905	1.07E-03				
		3	303.17	1	74.4	0	1.07E-03		0.323905	1.07E-03				
		4	302.56	1	74.3	0	1.07E-03		0.323493	1.07E-03				
		5	302.53	1	74.2	0	1.07E-03		0.323081	1.07E-03				
						AVG=	1.07E-03							
						sdv=	4.80E-07							

This document is part of the ASTM standards process and is for ASTM use only. It shall not be reproduced or circulated or quoted, in whole or in part, outside of ASTM committee activities except with the approval of the chairman of the committee having jurisdiction or the President of the Society.

Standard Test Method for Field Measurement of Hydraulic Conductivity of Porous Materials Using the Two-Stage Borehole Procedure[1]

This standard is issued under the fixed designation D ___; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers field measurement of apparent vertical and horizontal hydraulic conductivities (also referred to as *coefficients of permeability*) of porous materials using the two-stage, cased borehole technique. These apparent hydraulic conductivity values are the maximum for the vertical direction, and minimum for the horizontal direction. Determination of actual hydraulic conductivity values requires further analysis by a qualified engineer.

1.2 This test method may be utilized for compacted fills or natural deposits, above or below the water table, that have a mean hydraulic conductivity less than or equal to $1x10^{-5}$ m/s ($1x10^{-3}$ cm/sec).

1.3 Hydraulic conductivity greater than $1x10^{-5}$ m/s may be determined by ordinary borehole tests, e.g., U.S. Bureau of Reclamation E-18. However, the resulting value is an apparent conductivity.

1.4 For this field test method a distinction must be made between "saturated" (K_s) and "field-saturated" (K_{fs}) hydraulic conductivity. True saturated conditions seldom occur in the vadose zone except where impermeable layers result in the presence of perched water tables. During infiltration events or in the event of a leak from a lined pond, a "field-saturated" condition develops. True saturation does not occur due to entrapped air (1).[2] The entrapped air prevents water from moving in air-filled pores that, in turn, may reduce the hydraulic conductivity measured in the field by as much as a factor of two compared to conditions when trapped air is not present (2).[2] This field test method simulates the "field-saturated" condition.

1.5 Experience with this method has been predominately in materials having a degree of saturation of 70% or more, and where the stratification or plane of compaction is relatively horizontal. Its use in other situations should be considered experimental.

1.6 As in the case of all tests for hydraulic conductivity, the results of this test pertain only to the volume of soil permeated. Extending the results to the surrounding area requires both multiple tests and the judgement of qualified personnel. The number of tests required depends on among other things: the size of the area, the uniformity of the material in that area, and the variation in data from multiple tests.

1.7 The values stated in SI units are to be regarded as the standard, unless other units are specifically given. By tradition in U.S. practice, hydraulic conductivity is reported in centimeters per

[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.04 on Hydrologic Properties of Soil and Rocks.

Current edition approved June 29, 1990. Published October 1990.

[2] The boldface numbers in parentheses refer to a list of references at the end of the text.

[3] *Annual Book of ASTM Standards*, Vol. 04.08.

second, although the common SI units for hydraulic conductivity are meters per second.

1.8 *This standard does not purport to address the safety or environmental protection problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards*

D653 Terminology Relating to Soil, Rock, and Contained Fluids[3]

D5084 Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter

D5092 Design and Installation of Ground Water Monitoring Wells in Aquifers[3]

D5126 Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone[3]

2.2 *USBR Standards*

E18 Field Permeability Tests in Boreholes (3)[2]

3. Terminology

3.1 *Description of Terms Specific to This Standard*

3.1.1 *hydraulic conductivity, k*-the rate of discharge of water under laminar flow conditions through a unit cross-sectional area of a porous medium under a unit hydraulic gradient and standard temperature conditions (20°C).

DISCUSSION-The term *coefficient of permeability* is often used instead of *hydraulic conductivity*, but *hydraulic conductivity* is used exclusively in this test method. A more complete discussion of the terminology associated with Darcy's law is given in the literature (4). It should be noted that both natural soils and recompacted soils are usually not isotropic with respect to hydraulic conductivity. Except for unusual materials, $k_h > k_v$

3.1.2 *vertical conductivity,* k_v - The hydraulic conductivity in (approximately) the vertical direction.

3.1.3 *horizontal conductivity,* k_h - The hydraulic conductivity in (approximately) the horizontal direction.

3.1.4 *apparent vertical conductivity, K1* - The hydraulic conductivity as determined in Stage 1 of this test procedure assuming the tested medium to be isotropic. For ordinary soils, both compacted and natural, this is the maximum possible value for k_v.

3.1.5. *apparent horizontal conductivity, K2* - The hydraulic conductivity as determined in Stage 2 of this test procedure assuming the tested medium to be isotropic. For ordinary soils, both compacted and natural, this is the minimum possible value for k_h.

3.1.6 *test diameter* - The inside diameter (ID) of the casing.

3.2 *Other Terms.* For definitions of other terms used in this test method, see Terminology D653.

4. Summary of Test Method

4.1 The rate of flow of water into soil through the bottom of a sealed, cased borehole is measured in each of two stages, normally with a standpipe in the falling-head procedure. The standpipe can be refilled as necessary.

4.2 In Stage 1, the bottom of the borehole is flush with the bottom of the casing for maximum effect of k_v. The test is continued until the flow rate becomes quasi-steady.

4.3 For Stage 2, the borehole is extended below the bottom of the casing for maximum effect of k_h. This stage of the test is also continued until the flow rate becomes quasi-steady.

4.4 The direct results of the test are

the apparent hydraulic conductivities K1 and K2. The actual hydraulic conductivities k_v and k_h can be calculated from these values.

5. Significance and Use

5.1 This test method provides a means to measure both the vertical and horizontal hydraulic conductivities, especially in the low ranges associated with fine-grained clayey soils, $1x10^{-7}$ m/s to $1x10^{-11}$ m/s.

5.2 This test method is particularly useful for measuring liquid flow through soil moisture barriers such as compacted clay liners or covers used at waste disposal facilities, for canal and reservoir liners, for seepage blankets, and for amended soil liners such as those used for retention ponds or storage tanks. However, the thickness of the unit tested must be at least 6 times the test diameter. This requirement must be increased to 8 test diameters if the barrier is not underlain by a drainage blanket or by a material far less permeable than the barrier being tested.

5.3 The soil layer being tested must have sufficient cohesion to stand open during excavation of the borehole.

5.4 This test method provides a means to measure infiltration rate into a moderately large volume of soil. Tests on large volumes of soil can be more representative than tests on small volumes of soil. Multiple installations properly spaced provide a greater volume and an indication of spatial variability.

5.5 The data obtained from this method are most useful when the soil layer being tested has a uniform distribution of hydraulic conductivity and of pore space, and when the upper and lower boundary conditions of the soil layer are well-defined.

5.6 Changes in water temperature can introduce significant errors in the flow measurements. Temperature changes cause fluctuations in the standpipe levels which are not related to flow. This problem is most pronounced when a small diameter standpipe is used in soils of very low hydraulic conductivity.

5.7 The effects of temperature changes are taken into account by the use of a dummy installation, the temperature effect gauge (TEG). The base of the TEG must be sealed to prevent flow. The fluctuations of the TEG are due solely to ambient changes, and are used to correct the readings at the flowing tests.

5.8 If the soil being tested will later be subjected to increased overburden stress, then the hydraulic conductivities can be expected to decrease as the overburden stress increases. Laboratory hydraulic conductivity tests or these tests under varying surface load are recommended for studies of the influence of level of stress on the hydraulic properties of the soil.

6. Apparatus

6.1 *Boring/Reaming Tools*

6.1.1 *Drilling Equipment* - Equipment must be available to advance the borehole to the desired test level. This borehole diameter must be at least 5 cm (2 inches) larger than the outside diameter of the casing. The auger or bit used to advance the borehole below the casing for Stage 2 shall have a diameter about 1 cm (1/2 inch) less than the inside diameter of the casing. For tests in compacted materials above the water table, and wherever else possible, the borehole shall be advanced by dry augering. Either hand or mechanical augers are acceptable.

6.1.2 *Flat Auger* - The flat auger (Fig. 1) is used to prepare the borehole for casing installation. It shall be capable of reaming the bottom of the borehole to

a level plane perpendicular to the borehole axis. The flat auger shall have a diameter about 5 cm (2 inches) larger than the outside diameter of the casing.

6.1.3 *Reamer* - The reamer (Fig. 1) is used to complete the Stage 2 cavity. The base of the reamer shall be capable of reaming the bottom of the advanced borehole to a level plane, perpendicular to the borehole axis, and having the inside diameter of the casing. The barrel of the reamer shall have a diameter about 1 cm (0.5 inch) less than the inside diameter of the borehole. The vertical side of the cutting plate shall be serrated.

6.1.4 *Scarifier* - A bent fork, wire brush, or similar roughener small enough to fit easily within the casing and having a handle long enough to reach the bottom of Stage 2, is used to roughen the walls of the Stage 2 cavity.

6.2 *Borehole Casing*

6.2.1 *Casing* - The casing shall be watertight, but may be of any material or diameter. Its minimum ID shall be 10 cm (4 inches) unless the clearance provisions of Section 7.7 cannot be met. In such cases only, the ID may be reduced to 7.5 cm (3 inches). The wall thickness shall be adequate to prevent collapse under the lateral pressure of the overburden and swelling bentonite. Standard 10 cm (4 inch) ID Schedule 40 PVC threaded pipe is satisfactory. The bottom of the casing shall be cut off smooth and square. The casing shall have flush threads; external couplers interfere with sealing the annulus and internal couplers with advancing the borehole for Stage 2. Neither shall be used. The top of the casing shall be provided with a means of attaching the top assembly. Typical modifications include threading the top or attaching a flange. When threads are used, they must be flush. When a flange is used, the diameter shall be minimal so as not to interfere with sealing the annulus. The joint between top assembly and casing shall be provided with an O-Ring or other device to ensure watertightness.

6.2.2 *Top Assembly* - This consists of a cap attached (normally by gluing) to a short piece of threaded casing, as illustrated on Figure 2. The cap shall be domed or slanted upwards to minimize air entrapment. It shall be fabricated so as to receive the flow control system with a watertight joint. Provisions for bleeding any entrapped air shall be made. For the TEG (only), the top assembly may also be provided with a watertight fitting for the thermometer or thermocouple leads.

6.2.3 *Annular Sealant* - Bentonite is normally used to seal the annulus between the wall of the borehole and the wall of the casing. All sealants should be compatible with ambient geologic and geohydrologic conditions. Do not introduce any sealants into the casing.

6.2.3.1 *Directly Placed Sealant* - The annular sealant is best placed in the borehole dry and tamped for shallow installations. Bentonite should be granular or pelletized, sodium montmorillonite furnished in sacks or buckets from a commercial source and free of impurities which adversely impact the sealing process. Pellets consists of roughly spherical or disk shaped units of compressed bentonite powder. Granules consist of coarse particles of unaltered bentonite, typically smaller than 0.2 in. (50 mm). The diameter of pellets or granules selected should be less than one fifth the width of the annular space into which they are placed to reduce the potential for bridging. The directly placed sealant shall extend to the ground surface or to a minimum of 1 meter (3 feet) above the bottom of the casing, whichever is lesser. Either the placed sealant or the grouted sealant shall extend to the ground surface.

6.2.3.2 *Grouted Sealant.* The annular space may be grouted above the placed sealant. Any of the grouting methods of ASTM D5092 may be used.

6.2.3.3 *Sock* - The sock protects the soil at the bottom of the casing from disturbance when water is introduced and prevents collapse of the Stage 2 cavity. It is a cylinder composed of a semi-rigid, porous sidewall and bottom (such as a geogrid), lined with a geotextile, and filled with pea gravel or other highly pervious material. The hydraulic conductivity of all sock materials shall be at least 10 times the anticipated hydraulic conductivity of the tested stratum in the horizontal direction. The outer diameter is 0.6 cm (1/4 inch) less than the inner diameter of the casing. The length is approximately 8 cm (3 inches) longer than will be the borehole extension for Stage 2. Wires or other suitable means for retrieving the sock should be provided.

6.3 *Pressure/Flow System*

6.3.1 *Flow Control System* - The plumbing for the flow control system is illustrated on Figure 2. It can be composed of metal or plastic components. The system shall have sufficient flow area so that the unrestricted flow is at least 10 times the anticipated flow rate during the test. Nominal 1 cm (0.5 inch) components have been satisfactory for 10 cm (4 inch) diameter tests.

6.3.2 *Standpipe* - The standpipe, also shown on Figure 2, should be only as tall as needed to apply a maximum head (measured at the bottom of the casing) equal to or less than the head allowable by hydraulic fracturing considerations; the hydraulic head at the bottom of the casing should not exceed 1.5 times the total overburden pressure at that level. The standpipe must be transparent and strong enough to withstand wind forces. Clear Schedule 40 PVC has been found satisfactory. Inside diameters of 1 to 2 cm (0.5 to 0.75 inches) have been satisfactory for 10 cm (4 inch) diameter tests. Provisions shall be made to prevent precipitation from entering the standpipe and to minimize evaporation from it, while allowing equalization of air pressure. One satisfactory method is to set a 90° elbow on the top of the standpipe, cover the elbow's outlet with aluminum or similar foil, and prick a small (1mm±) hole in the foil for air pressure equalization.

6.3.3 *Scale* - The standpipe should be graduated or a scale affixed; either must have a resolution of 1 mm (1/16 inch). If a scale is used, its base should be on a known reference point of the flow control system which can be readily reestablished.

6.3.4 *Watch* - Readable to ls.

6.3.5 *Miscellaneous Hand Tools* - Adjustable and pipe wrenches, knife, strap wrenches (2) to fit casing, silicone grease such as automotive fan belt lubricant, PTFE (polytetra fluoroethylene) tape, refill hose, funnel to fit refill hose, 100 ml plastic cylinder flask.

6.4 *Temperature System* - A thermometer or thermocouple, readable to 0.5°C with a range of 0 to 50°C, long enough to extend to the bottom of the TEG.

6.5 *Tensiometer (Optional)* - Air-entry tensiometer capable of measuring soil suction to within 1 centibar.

6.6 *Survey Equipment* - Surveyor's level and rod, and a 15 - 30 meter (50 - 100 foot) tape.

6.7 *Miscellaneous*

6.7.1 *Plastic Sheeting* - Clear or white plastic sheeting, nominal thickness at least 0.1 mm (5 mils). Provide one 3x3 m (10x10 foot) sheet per test, including the TEG.

6.7.2 *Water Supply* - Preferably water of the same quality as that involved in the problem being examined, but having a

Turbidity of 5 NTU or less. Only potable water should be used if there is a possibility that the introduced water could enter the groundwater regime. All water to be introduced into the test apparatus shall be allowed to stand open at least 12 hours prior to use for deairing. See also Section 8.3.3 for temperature requirements.

6.7.3 *Antifreeze* - Where freezing conditions are anticipated, an antifreeze solution may be used as the permeating fluid in lieu of water. The temperature-kinematic viscosity relation of the solution must be determined and used in the appropriate equations of Section 9 - Calculations. Ethanol (ethyl alcohol) in potable form has been used as follows:

Table 1 - Ethanol Proportions

Minimum Temperature (°C)	Proportion Water/Ethanol
-5	5 : 1
-10	3 : 1
-15	2.3 : 1
-20	1.8 : 1
-25	1.5 : 1

However, it is the responsibility of the user to obtain any necessary regulatory approval for the solution used, since groundwater pollution may result from antifreeze compounds.

6.7.4 *Vacuum Cleaner (Optional)* - An industrial-type vacuum cleaner can be used to clear cuttings, etc., from the bottoms of Stages 1 and 2.

6.7.5 *Aluminum Foil* - 1 roll.

6.7.6 *Rubber Bands* -

6.7.7 *Flashlight* -

7. Test Site

7.1 On a compacted fill, each individual test requires an area approximately 4x4 m (13x13 feet). Tests shall not be located closer than 40 test diameters center-to-center. A group of at least 5 tests is suggested for evaluation of a typical test pad (up to 20x25m) for waste-retention structures. Larger areas may require more tests and the program should be designed on a sound statistical basis.

7.2 The layer being tested must maintain its full thickness at least 30 test diameters horizontally in all directions from the center of the test.

7.3 Stratification or the plane of compaction should be essentially horizontal.

7.4 If a compacted fill is being tested, the test area shall be covered with clear or white plastic immediately after the final lift is placed.

7.5 Compacted fills are typically underlain by either a permeable layer (such as a drainage blanket or an impermeable layer (such as a geomembrane). Such conditions shall be recorded, together with the potentiometric level (if any) within the fill. Where no such bottom condition exists, the nature of the underlying soil and depth to the groundwater potentiometric level shall be furnished. The thickness of the tested material near each test location shall be determined to the nearest 2cm (1 inch) by before-and-after survey or post-test borings.

7.6 In natural deposits, the stratigraphic sequence to at least 10 test diameters below the test level shall be determined by borings and the position of the potentiometric level in the tested stratum also determined. Borings shall not be made within 3.6 m (12 feet) of the test location before the test; any borings within 10 m (30 feet) of the test location shall be grouted prior to testing.

7.7 The minimum allowable thickness for the layer being tested depends on the boundary conditions. Minimum allowable test geometries are

given below for typical cases. Here, "relatively pervious" means having a vertical permeability at least 10 times that of the layer being tested, and "relatively impervious" means having a permeability less than 1/10 that of the layer being tested.

7.7.1 Where the layer being tested extends to the ground surface and is underlain by either a relatively pervious or relatively impervious layer, the thickness of the layer being tested shall not be less than 1/6 the test diameter. The casing shall extend at least 2.5 test diameters below the top of the ground surface and the bottom of Stage 2 shall be at least 2.0 test diameters above the bottom of the stratum being tested, leaving room for a Stage 2 extension of 1.5 test diameters. If the underlying material does not meet the criteria of Section 7.7, the bottom of Stage 2 shall be at least 4.0 test diameters above the bottom of the stratum being tested. The casing embedment remains the same, so that the required thickness of the layer being tested becomes 8.0 test diameters.

7.7.2 Where the layer being tested does not extend to the ground surface but is overlain by a relatively pervious material, the clearances of Section 7.7.1 shall apply except that the casing shall extend at least 2.5 test diameters below the top of the stratum being tested. If the overlying stratum is relatively impervious, the casing shall extend at least 5.0 diameters below the top of the stratum being tested.

8. Procedures

8.1 *Set and Seal Casing* - This is the single most important step in the entire procedure and must be done with care.

8.1.1 *Drill Borehole* - Drill the borehole in a direction perpendicular to the stratification or plane of compaction, which may or may not be perpendicular to the ground surface. The angle of inclination, if any, shall be measured and reported. The hole must be at least 5 cm (2 inches) larger in diameter than the outside diameter of the casing. Stop the borehole when its maximum depth (usually the point of the auger or bit) is at least 2.5 cm (1 inch) above the desired bottom-of-casing level.

8.1.2 *Ream Borehole* - Using the flat auger, ream the borehole to depth and to a diameter about 5 cm (2 inches) larger than the outside diameter of the casing. The bottom shall be smooth, flat, and free from cuttings and/or particles exceeding 1/4 the test diameter. An industrial-type vacuum cleaner can be used for this cleaning.

8.1.3 *Insert Casing* - Set the casing within and parallel to the axis of the borehole, centered as much as possible, with a minimum 1 cm (0.5 inch) annular space between the wall of the borehole and the outside of the casing. The top of the casing should be as close to ground surface as possible, but not less than 2 cm (1 inch) for internally threaded casing or 2 cm (1 inch) plus the length of the threaded section for an externally-threaded casing. Seat the casing firmly by hand. Measure the depth from top-of-casing to bottom-of-hole to ensure proper depth and seating.

8.1.4 *Seal Casing (Dry Holes)* - For dry holes, first crush bentonite to form a well-graded mixture ranging from powder to about 0.2 cm (1/16 inch) in a sufficient quantity to fill about 1 cm (0.5 inch) of the annulus. Pour this mixture into the annulus with a uniform distribution. Then, add sufficient dry crushed or pelletized bentonite to fill the annulus another 1 cm (0.5 inch). Tamp this layer lightly with a wooden dowel or equivalent, smaller than the minimum annulus. Introduce water until it is just visible at the top of the bentonite. Note and record

whether or not water has entered the interior of the casing. Add 2.5 cm (1 inch) of dry crushed or pelletized bentonite, tamp as before, and add water as before. Continue in these 2.5 cm (1 inch) increments to the ground surface, or a minimum of 1 meter (3 feet) above the bottom of the casing for deep installations. Sealing above that level shall extend to the ground surface, and may be with the same procedure or by grouting following Standard Practice D5092. Upon completion of sealing, note and record whether water has entered the interior of the casing, and remeasure the depth from top-of-casing to bottom-of-hole to ensure that the casing has not moved. Set the sock.

8.1.5 *Seal Casing (Wet Holes)* - The following procedure shall be used where the borehole cannot be advanced to test level in the dry. The casing shall be pushed (not driven) approximately 2 cm (1 inch) into the soil at the bottom of the borehole. Sufficient bentonite pellets to fill approximately 8 cm (3 inches) of the annular space shall be placed and tamped. This procedure shall be followed until the bentonite seal reaches at least 1 meter (3 feet) above the bottom-of-casing level. Hydration water shall be added if the top of the seal rises above the water level in the annulus. Sealing above the 1 meter (3 foot) level may be by the same procedure or by grouting following Standard Practice D5092. After the seal has hydrated a minimum of 12 hours, empty the casing, and use the reamer to advance the borehole to exactly the bottom-of-casing level. If the tested stratum is pervious, empty the casing only to groundwater level to avoid disturbance of the tested stratum from water flow into the casing. Set the sock, then introduce and remove water as necessary to remove suspended solids.

Note 1 - Sealing in wet holes cannot be controlled as well as in dry holes and the results may be somewhat less representative.

8.1.6 *Surface Protection* - For tests in compacted fills, replace the clear or white plastic square around the casing. Use sand, gravel, sandbags, or other weights to keep the plastic in-place during high winds. Place a cap over the casing top to prevent desiccation or rainfall entry during the hydration period.

8.1.7 *Tensiometers* - (Optional) Determine the soil's suction value at test level (unsaturated soils only). Make a minimum of three such determinations.

8.1.8 *Hydration* - Allow the bentonite (and grout, if any) to hydrate a minimum of 12 hours before applying head to the test.

8.1.9 *Temperature Effect Gauge* - This unit is to be set in the same manner as described above, except that the borehole is slightly deeper to accommodate the bottom cap, it is not necessary to ream the hole bottom flat, and crushing bentonite for the bottom 1 cm (0.5 inch) of the seal can be omitted.

8.2 *Assemble Flow Control System and Standpipe* - The cap, flow control system and standpipe should be assembled as illustrated on Figure 2. PTFE tape and silicone grease should be used to waterproof all joints. Check the assembly for leaks by attaching it to a spare TEG casing and filling with water. No leakage can be tolerated.

8.3 *Conduct Stage 1*

8.3.1 *Check Embedment* - Recheck the casing to ensure the correct embedment has been maintained. Also, note and record the presence or absence of water inside the casing; if present, record the depth.

8.3.2 *Insert Sock* - Place the sock to the bottom of the casing. Tying the retrieval wires to a cork float aids in their recovery.

8.3.3 *Fill Casing* - Fill the casing slowly with water, but no higher than 2 cm (1 inch) below the base of any internal threads. Introduce the water in such a manner that it does not erode the exposed soil at the bottom of the casing. The water should be warmer than the soil in the tested zone, or groundwater if present above bottom-of-casing, to prevent air bubbles from coming out of solution.

8.3.4 *Add Flow Control System and Standpipe* - Screw the top assembly with these items onto the casing, sealing the joint with the O-Ring, PTFE tape, and silicone grease. Prevent casing rotation with a strap wrench while tightening the top assembly. Attach the scale to the standpipe with clear wrapping tape or equivalent means, with the zero down. Measure and record the distance from the bottom of the casing to the zero point on the scale.

8.3.5 *Fill and Check Test System* - Open valve "A" (Fig. 2) and fill the remainder of the casing, flow control system, and standpipe with water. The maximum water level should not exceed that which produces the theoretical hydraulic fracturing pressure at the bottom of the casing. All filling should be via the refill hose, not down the standpipe, so as to avoid having water droplets above the water level in the standpipe. Close valve "A". Check the casing/cap joint and all other joints carefully for water leaks by wiping the joints dry and watching for the formation of water drops at the joints. No leakage can be tolerated.

8.3.6 *Begin Stage 1 of the Test* - Record the date and time (to 1s), plus the scale reading corresponding to the bottom of the meniscus of the water in the standpipe. Take additional such readings at least according to the schedule in Table 2, using whichever method produces the greater number of readings:

Table 2 - Reading Intervals

Elapsed Time (hours)	Total Change in Scale Reading (cm)	(in)
0.5	2	1
1.0	5	2
2.0	10	4
4.0	20	8
8.0	40	16

Thereafter, the frequency of readings will depend on the behavior of the test. In soils of low hydraulic conductivity, daily or twice-daily readings may be adequate after 2 to 3 days. At each reading of the test, record the scale reading and bottom water temperature of the TEG. A typical form for recording test data is given as Figure 3.

8.3.7 *Refills* - One standpipe full of water may not be adequate for a full Stage. When the water level in the standpipe becomes low, refill in the same manner as the initial filling of the standpipe. Record the new water level and its associated time, TEG reading, and TEG temperature and note as "Refill". When the person conducting the test will be away for some length of time, such as overnight, check the drop rate against the expected time to determine whether or not refilling is necessary.

8.3.8 *Criteria for Termination* - Each stage may be terminated when a plot of log (apparent conductivity) vs log (time) fluctuates about a stable value of apparent conductivity. This is achieved when arithmetic time-weighted averages (see Equations 10 and 11) neither fluctuate by more than 20% nor show an upward or downward trend with time. These averages must maintain the above behavior for at least the time spans listed in Table 3.

Table 3 - Minimum Stable Time Spans

Apparent Conductivity K1 or K2 (m/sec)	Stable Time Span (hrs.)
$>10^{-8}$	12
10^{-8} - 10^{-9}	24
10^{-9} - 10^{-10}	48
10^{-10} - 10^{-11}	72

8.4 *Conduct Stage 2*

Note 2 - If the test is solely to verify that the actual vertical hydraulic conductivity k_v is less than some specified value and the apparent vertical conductivity K1 is less than that value, Stage 2 may be omitted.

8.4.1 *Empty the Casing* - Remove the sock and the top assembly with its attached equipment. Siphon, vacuum, and/or bail all water from within the casing for tests where the casing was set in a dry hole. Otherwise, siphon/vacuum/bail to the groundwater level of the stratum being tested.

8.4.2 *Advance the Borehole* - Extend an open borehole having the same diameter as the inside of the casing to a depth below bottom-of-casing not less than 1.0 test diameters nor more than 2.5 test diameters. The soil being tested shall continue for at least the clearances listed in Section 7.7. It is desirable to secure an undisturbed sample of the tested zone with a thinwall sampler (D1587 or D2922), but this is not recommended for soils containing gravel-sized particles. The thinwall sampler or auger/bit shall have a diameter 1 cm (0.5 inch) or more smaller than the casing ID, and sampling or drilling shall be terminated with the deepest point being at least 2 cm (1 inch) above the proposed bottom of the borehole.

8.4.3 *Ream the Borehole* - Ream the borehole to the desired depth and diameter using the reamer to minimize sidewall smear. Roughen the inside walls using a method which will ensure that the sides of the borehole are not smeared. The bottom should be prepared as outlined in Section 8.1.2.

8.4.4 *Replace the Sock* - Place the sock to the bottom of the borehole. Alternatively, but only where an inclusion of high-conductivity material in the tested stratum is of no consequence, the hole may be filled to 8 cm (3 inches) above the casing bottom with pea gravel.

8.4.5 *Reassemble the System* - Refill the casing with water as described in Section 8.3.3, reattach and seal the top assembly with its equipment, and refill the standpipe through the refill hose. Concurrently, empty and refill the TEG with water having the same temperature (within 1°C) as that used in the test.

8.4.6 *Perform Stage 2* - Conduct this portion of test as outlined previously for Stage 1. The termination criteria are the same. See Figure 3 for a typical form for recording the data.

8.5 *Demobilization* - Remove and store the top assembly with its attached systems. For tests in compacted fills, empty the casing, remove sock and casing, then backfill the resulting hole with layers of tamped and wetted bentonite pellets or as directed. Casings for tests in natural deposits can be left as piezometers or plugged and abandoned like monitoring wells, as directed.

9. Calculation

9.1 *Equations* - The data from the tests shall be calculated using the following equations:

9.1.1 *Stage 1*

$$K1 = R_t\, G_1\, Ln(H1/H2')/(t_2-t_1) \qquad (1)$$

where

$$G_1 = (\pi d^2/11D_1)[1+a(D_1/4b_1)] \quad (2)$$

R_1 = ratio of kinematic viscosity of permeant at temperature of test permeant during time increment t_1 to t_2 to that of reference fluid and temperature. For most tests, this means water at 20°C (68°F) - See Table 1 of Test Method D5084 for water as the permeant.

d = Inside diameter (ID) of standpipe (cm)

D_1 = effective diameter of Stage 1 (cm), equals inside diameter of casing under dry hole conditions when no inward seepage was noted when setting casing, otherwise equals outside diameter of casing

a = +1 for impermeable base at b_1
= 0 for infinite ($+20D_1$) depth of tested material.
= -1 for permeable base at b_1

b_1 = thickness of tested layer between bottom of casing and top of underlying stratum (cm).

H1 = effective head at beginning of time increment (cm), equal to distance from top of water in standpipe to top of underlying stratum or groundwater, whichever is shallower. For calculation purposes, H1 shall not exceed the height of the water column above the bottom of the casing plus 20 test diameters

H2' = corrected effective head (cm) at end of time increment, calculated in the same manner as H1, = H2 - c

c = change in TEG scale reading between times t_1 and t_2 (cm). An increase in the height of water in the TEG standpipe is positive

t_1 = time at beginning of increment (s)

t_2 = time at end of increment (s)

9.1.2 *Stage 2*

$$K2 = R_1 G2 \, Ln(H1/H2')/(t_2-t_1) \quad (3)$$
$$G2 = (d^2/16FL)G3 \quad (4)$$
$$G3 = 2Ln(G4)+a\,Ln(G5) \quad (5)$$
$$G4 = L/D + [1+(L/D)^2]^{1/2} \quad (6)$$
$$G5 = \frac{[4b_2/D+L/D]+[1+(4b_2/D+L/D)^2]^{1/2}}{[4b_2/D-L/D]+[1+(4b_2/D-L/D)^2]^{1/2}} \quad (7)$$
$$F = 1 - 0.5623\,Exp(-1.566\,L/D) \quad (8)$$

where:

L = length of Stage 2 extension below bottom of casing (cm)

D = inside diameter of Stage 2 extension (cm). It shall be at least equal to the casing ID.

b_2 = distance from center of Stage 2 extension to top of underlying stratum or groundwater (cm).

The other terms are as previously defined.

9.2 Calculate K1 for each time increment of Stage 1 using Equation (1).

9.3 Calculate cumulative infiltration volume (V1) through the end of each Stage 1 time increment using Equation (9).

$$V = (\pi d^2/4)\ \Sigma\,(H1-H2') \quad (9)$$

9.4 Calculate the time-weighted average K1' of the K1 values of Stage 1 for its quasi-steady period only using Equation (10).

$$K1' = \Sigma K1_i(t_2-t_1)i/\Sigma(t_2-t_1)i \quad (10)$$

where:

i denotes a specific time increment

9.5 Calculate K2 for each time increment of Stage 2 using Equation (3).

9.6 Calculate cumulative infiltration volume (V2) through the end of each Stage 2 time increment using Equation (9).

9.7 Calculate the time-weighted average K2' of the K1 values of Stage 1 for its quasi-steady period only using Equation (11).

$$K2' = \Sigma\, K2_i(t_2-t_1)i/\Sigma(t_2-t_1)i \quad (11)$$

10. Report

10.1 Report the following information:

10.1.1 A data sheet such as the one shown in Figure 3 for each Stage,

10.1.2 A log-log plot of apparent conductivity versus time such as that shown in Figure 4,

10.1.3 The time-weighted average values, K1' and K2',

10.1.4 Air-entry soil suction value (Optional).

10.2 Additional optional information that can be presented in the report includes the following:

10.2.1 Thickness of layer tested,

10.2.2 A description of material beneath the layer tested,

10.2.3 Total and dry density of the layer tested,

10.2.4 Initial moisture content of the layer tested,

10.2.5 Initial degree of saturation,

10.2.6 Moisture contents of samples taken after termination of test, with locations and depths referenced to the test,

10.2.7 Classification data on the layer tested,

10.2.8 Laboratory tests for hydraulic conductivity on the layer tested.

11. Precision and Bias

11.1 *Precision* - Due to the nature of the soil or rock materials tested by this test method, it is either not feasible or too costly at this time to produce multiple specimens which have uniform physical properties. Any variation observed in the data is just as likely to be due to specimen variation as to operator or other testing variations. Subcommittee D18.04 welcomes proposals that would allow for development of a valid precision statement.

11.2 *Bias* - There is no accepted reference value for this test method, therefore, bias cannot be determined.

12. Keywords

12.1 In-place hydraulic conductivity, vertical hydraulic conductivity, horizontal hydraulic conductivity.

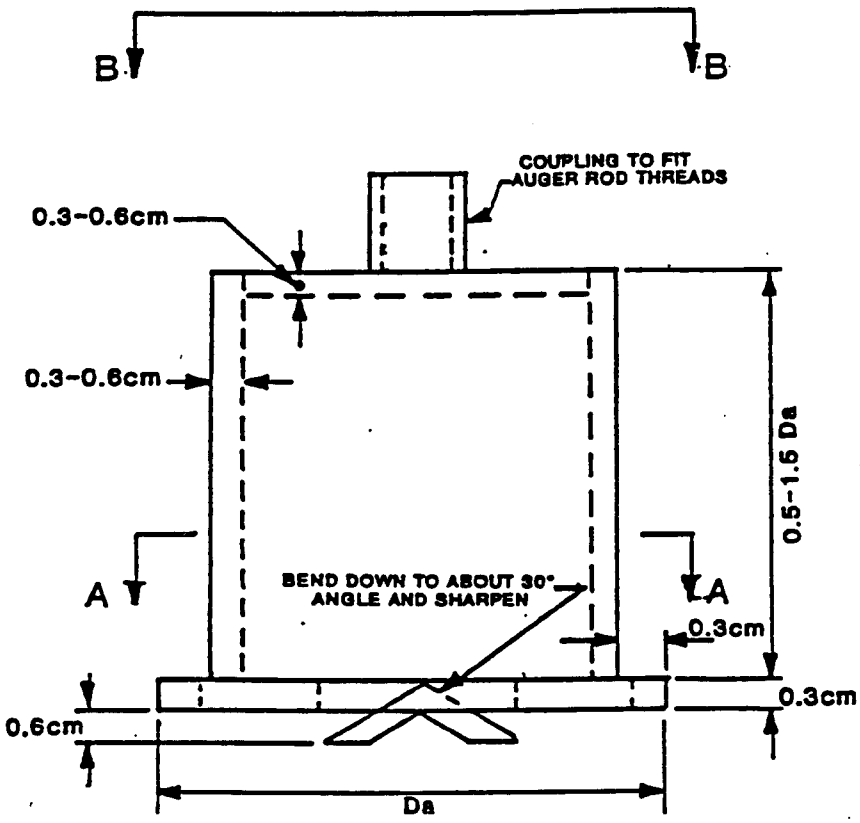
References

(1) Bouwer, H. "Rapid Field Measurement of Air Entry Value and Hydraulic Conductivity of Soil as Significant Parameters in Flow System Analysis" Water Resources Research, Vol. 2, No. 4, 1966, pp. 729-738.

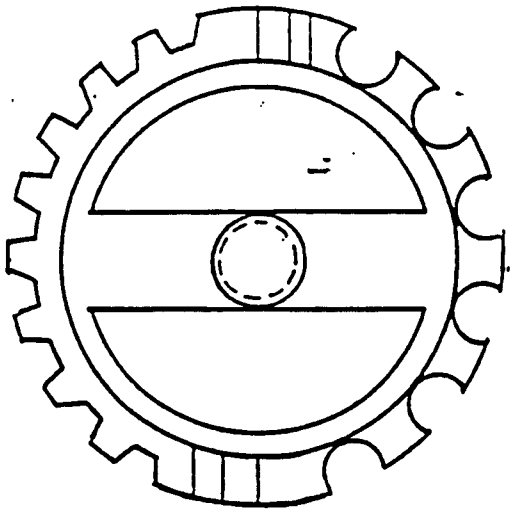
(2) Reynolds, D. and Elrick, D.E. "A Method for Simultaneous *In-Situ* Measurement in the Vadose Zone of Field-Saturated Hydraulic Conductivity, Sorptivity and the Conductivity-Pressure Head Relationship" Groundwater Monitoring Review, Vol. 6, NO. 4, 1986, pp. 84.

(3) U.S. Department of the Interior, Bureau of Reclamation, Earth Manual, Second Edition, 1974, pp. 573-578.

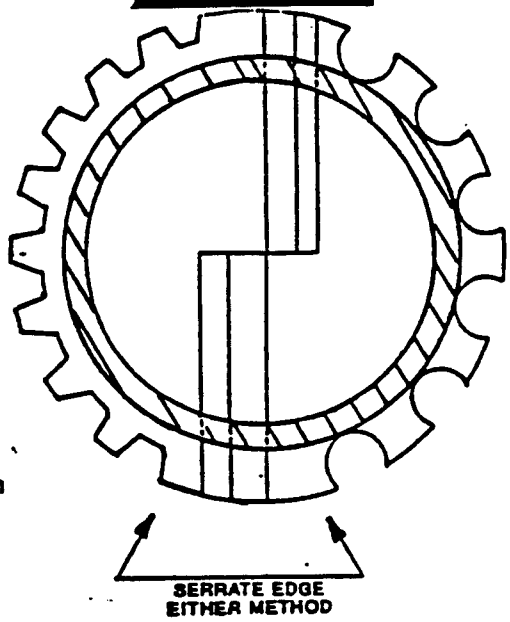
(4) Bouwer, H. "Intake Rate: Cylinder Infiltrometer". Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods, Agronomy Monograph No. 9, American Society of Agronomy, Madison, WI, 1986, pp. 825-844.



ELEVATION



SECTION B-B



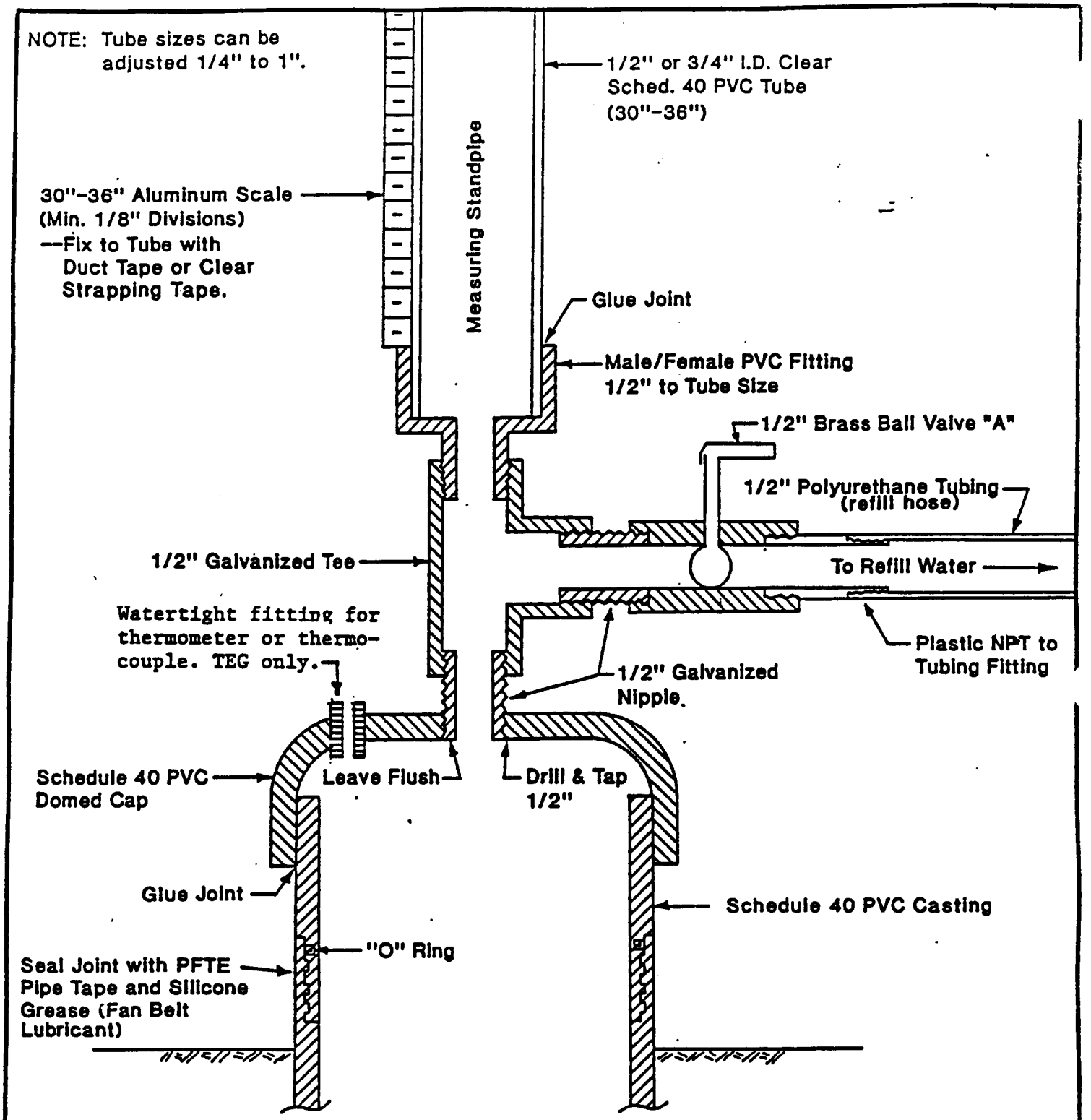
SECTION A-A

not to scale

NOTE: FOR FLAT AUGER, Da=D+5cm
FOR REAMER, Da=D -0.1 cm

FLAT BOTTOM REAMING AUGER

FIGURE: 1



FLOW MEASURING SYSTEM

(example)

NOTE: Use PTFE Tape and Silicone Grease on all piping joints.

00 048

FIGURE: 2

7/20/2
RONR

Remarks	Hrs.	(cc)

CONTINUOUS

STOP

cceptable for

p of slab configuration
tooling, etc) will deviate
ct drawings at the

an not ensure that the
emain centered in the drilled
ns Epoxy placement. This could
e epoxy coverage at waterstop.
Clano

STEI TWO-STAGE FIELD PERM
STAGE 2 CALCULATIONS

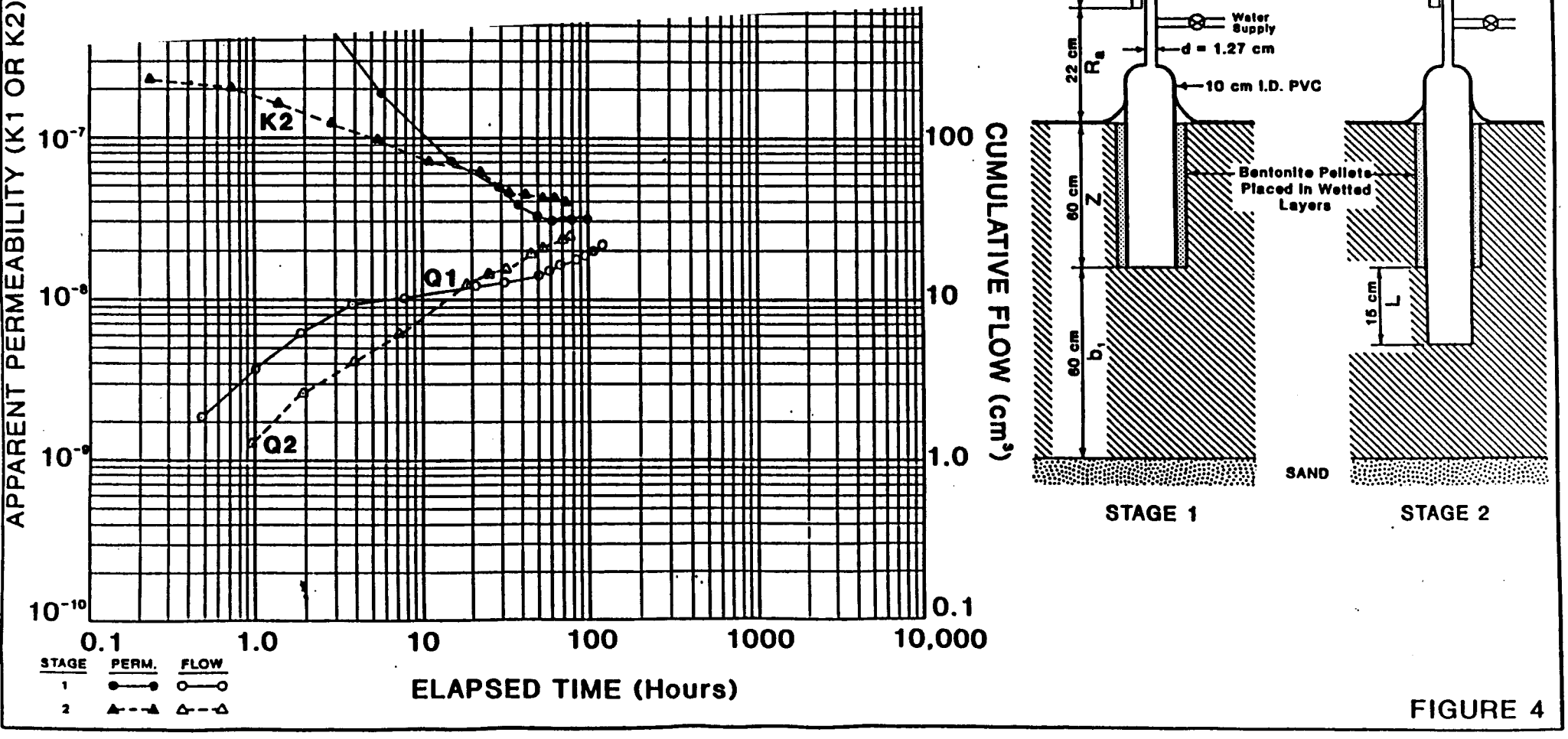


FIGURE 4

00 050

TO VIEW THE MAP AND/OR MAPS WITH THIS DOCUMENT, PLEASE CALL THE HAZARDOUS WASTE BUREAU AT 505-476-6000 TO MAKE AN APPOINTMENT