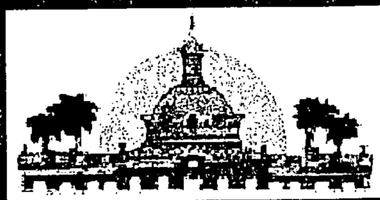
Construction Permit Application
Phases V and VI Improvements

Southeast County Landfill
Hillsborough County, Florida



Prepared for:

Hillsborough County
Solid Waste Management Department
P.O. Box 1110
Tampa, Florida 33601

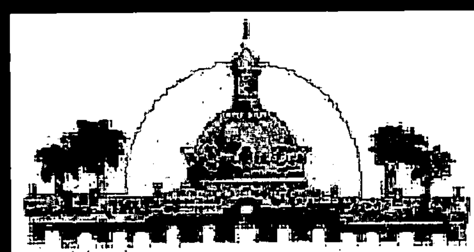
Prepared by:

SCS Engineers
3012 U.S. Highway 301 North, Suite 700
Tampa, Florida 33619
(813) 621-0080

June 26, 1998
File No. 0995029.23

Construction Permit Application
Phases V and VI Improvements

Southeast County Landfill
Hillsborough County, Florida



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CONSTRUCTION PERMIT APPLICATION
PHASES V AND VI IMPROVEMENTS

SOUTHEAST COUNTY LANDFILL

Prepared For:

Hillsborough County
Solid Waste Management Department
P. O. Box 1110
Tampa, Florida 33601

Prepared By:

SCS Engineers
3012 U.S. Highway 301 North, Suite 700
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(813) 621-0080

June 26, 1998
File No. 0995029.23

Environmental Consultants

3012 U.S. Highway 301 North
Suite 700
Tampa, FL 33619-2242

813 621-0080
FAX 813 623-6757

SCS ENGINEERS

June 26, 1998
File No. 0995029.13

Mr. Kim B. Ford, P.E.
Florida Department of Environmental Protection
Southwest District
3804 Coconut Palm Drive
Tampa, Florida 33619

Subject: Phases V and VI Leachate Collection and Removal System Improvements
Southeast County Landfill, Hillsborough County, Florida

Dear Kim:

On behalf of the Hillsborough County Solid Waste Management Department (HCSWMD), SCS Engineers (SCS) is pleased to submit three copies of the construction permit application for improvements to the leachate collection and removal system in Phases V and VI of the Southeast County Landfill. The $1,000 permit review fee is also enclosed.

Your prompt review of this application is requested. The HCSWMD would like to begin construction of the improvements by August 1, 1998. The HCSWMD and SCS are ready to meet with you to promptly resolve any questions or provide additional information.

Please do not hesitate to call if you have any questions.

Very truly yours,

Larry E. Ruiz
Senior Project Engineer

Robert B. Gardner, P.E.
Vice President
SCS ENGINEERS

LER/RBG:ler
attachments

cc: Patricia V. Berry, HCSWMD
Paul Schipfer, EPC

CONTENTS

DEP Form # 62.701.900(1) Form Title Solid Waste Management Facility Permit Effective Date May 19, 1994 DEP Application No. ____________ (Filled by DEP)

Florida Department of Environmental Protection

Twin Towers Office Bldg. • 2600 Blair Stone Road • Tallahassee, FL 32399-2400

RECEIVED
JUN 26 1998
DEP

SECTION I

STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL PROTECTION

SOLID WASTE MANAGEMENT FACILITY PERMIT

APPLICATION INSTRUCTIONS AND FORMS

STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL PROTECTION

APPLICATION FOR PERMIT TO CONSTRUCT, OPERATE, MODIFY OR CLOSE A SOLID WASTE MANAGEMENT FACILITY

Please Type or Print

A. GENERAL INFORMATION

1. Type of facility:

Disposal [X]

Class I Landfill	[X]	Ash Monofill	[ ]
Class II Landfill	[ ]	Asbestos Monofill	[ ]
Class III Landfill	[ ]	Industrial Solid Waste	[ ]
Other	[ ]		

Volume Reduction [ ]

Incinerator	[ ]	Pulverizer/Shredder	[ ]
Composting	[ ]	Compactor/Baling Plant	[ ]
Materials Recovery	[ ]	Energy Recovery	[ ]
Other	[ ]		

2. Type of application:

Construction	[X]	Construction/Operation	[ ]
Operation	[ ]	Closure	[ ]

3. Classification of application:

New	[ ]	Substantial Modification	[X]
Renewal	[ ]	Minor Modification	[ ]

4. Facility name: Southeast County Landfill

5. DEP ID number: SO29-256427 County: Hillsborough

6. Facility location (main entrance): 8.8 miles east of U.S. 301 on County Road 672

7. Location coordinates:

Section: 13,14,15,18,19,22,23,24 Township: 31 & 32 S Range: 21 E

UTMs: Zone N/A ______ km E N/A km N

Latitude: 27° 46' 25" Longitude: 82° 11' 15"

8. Applicant name (operating authority): Hillsborough County Solid Waste Management Department

Mailing address: P.O. Box 1110 (Street or P.O. Box) Tampa (City) FL (State) 33601 (Zip)

Contact person: Daryl H. Smith Telephone: (813) 272-5680

Title: Director, Solid Waste Management Department

9. Authorized agent/Consultant: SCS Engineers

Mailing address: 3012 U.S. Highway 301 North, Suite 700 Tampa FL 33619
Street or P.O. Box City State Zip

Contact person: Mr. Robert B. Gardner Telephone: (813) 621-0080

Title: Vice President

10. Landowner (if different than applicant): Same

Mailing address: ______
Street or P.O. Box City State Zip

Contact person: ______ Telephone: ( )

11. Cities, towns and areas to be served: Tampa, Temple Terrace, Plant City, Hillsborough County

12. Population to be served:

Current: 573,013 Five-Year Projection: 634,884

13. Volume of solid waste to be received: 2,200 ~~yds³/day~~ tons/day ~~gallons/day~~

14. Date site will be ready to be inspected for completion: Existing Landfill

15. Estimated life of facility: 29 years

16. Estimated costs:

Total Construction: $ Existing Landfill (N/A) Closing Costs: $13,634,000

17. Anticipated construction starting and completion dates:

From: Date of FDEP Approval To: 6 Months After FDEP Approval

B. DISPOSAL FACILITY GENERAL INFORMATION

. Provide brief description of disposal facility design and operations planned by this application:

See Engineering Report Section 1

2. Facility site supervisor: Meredith Matthews

Title: Senior Engineering Technician, HCSWMD   Telephone: (813) 671-7707

3. Disposal area: Total 162.2 (±) acres; Used 120.4 (±) acres; Available 162.2 (±) acres

4. Weighing scales used: Yes [X] No [ ]

5. Security to prevent unauthorized use: Yes [X] No [ ]

6. Charge for waste received: ____ $/yds^3 34.00 $/ton

7. Surrounding land use, zoning:

Residential	[ ]	Industrial	[ ]
Agricultural	[X]	None	[ ]
Commercial	[ ]	Other	[ ]

8. Types of waste received:

Residential	[X]	C & D debris	[X]
Commercial	[X]	Shredded/cut tires	[X]
Incinerator/WTE ash	[X]	Yard trash	[ ]
Treated biohazardous	[ ]	Septic tank	[ ]
Water treatment sludge	[X]	Industrial	[X]
Air treatment sludge	[X]	Industrial sludge	[X]
Agricultural	[X]	Domestic sludge	[ ]
Asbestos	[X]		
Other	[ ]		

9. Salvaging permitted: Yes [ ] No [X]

10. Attendant: Yes [X] No [ ] Trained operator: Yes [X] No [ ]

11. Spotters: Yes [X] No [ ] Number of spotters used: 1 minimum

12. Site located in: Floodplain [ ] Wetlands [ ] Other [X] upland, closed phosphate mine site

13. Property recorded as a Disposal Site in County Land Records: Yes [X] No [ ]

14. Days of operation: 6 days per week

15. Hours of operation: 7:30 a.m. to 5:30 p.m., Monday through Saturday

16. Days Working Face covered: 6 days per week

17. Elevation of water table: varies Ft. NGVD

18. Number of monitoring wells: 11

9. Number of surface monitoring points: 4

20. Gas controls used: Yes [X] No [ ] Type controls: Active [ ] Passive [X]

Gas flaring: Yes [ ] No [X] Gas recovery: Yes [ ] No [X]

21 Leachate control method - liner type:

Natural soils	[ ]	Double geomembrane	[ ]
Single clay liner	[ ]	Geomembrane & composite	[ ]
Single geomembrane	[ ]	Double composite	[ ]
Single composite	[ ]	None	[ ]
Slurry wall	[ ]		
Other	[X]	4 to 18 feet thick phosphatic clay layer	

22. Leachate collection method:

Collection pipes	[X]	Sand layer	[X]
Geonets	[ ]	Gravel layer	[ ]
Well points	[ ]	Interceptor trench	[ ]
Perimeter ditch	[ ]	None	[ ]
Other	[X]	Pump station	

23. Leachate storage method:

Tanks	[X]	Surface impoundments	[ ]
Other	[ ]		

24. Leachate treatment method:

Oxidation	[ ]	Chemical treatment	[ ]
Secondary	[ ]	Settling	[ ]
Advanced	[ ]	None	[ ]
Other	[X]	Powder activated carbon treatment on-site	

25. Leachate disposal method:

Recirculated	[X]	Pumped to WWTP	[X]
Transported to WWTP	[X]	Discharged to surface water	[ ]
Injection well	[ ]	Evaporation (ie: Perc Pond)	[ ]
Other	[X]	Spray irrigation	

26. For leachate discharged to surface waters:

Name and Class of receiving water: N/A

27. Storm Water:

Collected: Yes [X] No [ ] Type of treatment: Detention/Filtration

Name and Class of receiving water: Long Flat Creek, Class III

28. Management and Storage of Surface Waters (MSSW) Permit number or status:

Southwest Florida Water Management District Permit No: 100330

National Pollution Discharge Elimination System Permit No. FLR05B138

T. CERTIFICATION BY APPLICANT AND ENGINEER OR PUBLIC OFFICER

A. Applicant

The undersigned applicant or authorized representative of Hillsborough County is aware that statements made in this form and attached information are an application for a Construction Permit from the Florida Department of Environmental Protection and certifies that the information in this application is true, correct and complete to the best of his knowledge and belief. Further, the undersigned agrees to comply with the provisions of Chapter 403, Florida Statutes, and all rules and regulations of the Department. It is understood that the Permit is not transferable, and the Department will be notified prior to the sale or legal transfer of the permitted facility.

[signature]
Signature of Applicant or Agent

Daryl H. Smith, Director
Name and Title

Date: 6/26/98

Attach a letter of authorization if agent is not a governmental official, owner, or corporate officer.

B. Professional Engineer Registered in Florida or Public Officer as required in Section 403.707 and 403.707(5), Florida Statutes.

This is to certify that the engineering features of this solid waste management facility have been designed/examined by me and found to conform to engineering principals applicable to such facilities. In my professional judgement, this facility, when properly maintained and operated, will comply with all applicable statutes of the State of Florida and rules of the Department. It is agreed that the undersigned will provide the applicant with a set of instructions of proper maintenance and operation of the facility.

[signature] Signature	SCS Engineers, 3012 U.S. Highway 301 North, Suite 700 Mailing Address
Robert B. Gardner Name and Title (please type)	Tampa, Florida 33619 City, State, Zip Code
39233 Florida Registration Number (please affix seal)	(813) 621-0080 Telephone Number
	Date: 6/26/98

ROBERT B. GARDNER CERTIFICATE NO. 39233 STATE OF FLORIDA REGISTERED ENGINEER

SECTION 2
DESIGN ENGINEERING REPORT

PURPOSE

The purpose of this report is to present the basis of design for proposed improvements to the leachate collection and removal system (LCRS) in Phases V and VI of the Southeast County Landfill (SCLF). The improvements include construction of additional leachate collection trenches backfilled with chipped tires to improve leachate collection efficiency and installation of temporary rain covers over non-active areas in Phases V and VI to minimize leachate generation. This report is prepare pursuant to the construction permit application as contained in Section 1.

SITE BACKGROUND

The SCLF is located on County Road 672, 8.8 miles east of U.S. Highway 301 in Hillsborough County, Florida. The SCLF has a permitted area of approximately 162 acres. The SCLF is operating under the Florida Department of Environmental Protection (FDEP) permit No. SO29-256427 issued on October 30, 1996. The County owns the facility that currently includes a Class I disposal area, a waste tire processing facility, and a leachate treatment and reclamation facility. The SCLF is operated by Waste Management, Inc. of Florida (WMI) under contract with the County.

EXISTING DESIGN

The SCLF utilizes on-site phosphatic clays, raging in thickness from 4 to 18 feet, as a component of the bottom liner system, with permeabilities of 1×10^{-7} cm/sec or less before consolidation. The low point in the SCLF is projected to occur in Phase VI, where the thickest phosphatic clay deposits coincide with the greatest anticipated landfill load (Ardaman 1983). The existing design of LCRS in Phases V and VI (i.e., leachate collection trench locations and sump location) was based on the calculated settlement of the phosphatic clay deposits.

The existing configuration of the LCRS is shown on Drawing No. 3 of Attachment A. In general, the existing leachate collection trenches in Phases V and VI are located at 400 feet on center, and are located to convey leachate towards the low area in Phase VI. Temporary pump stations are provided to allow for collection of leachate during different stages of the filling sequence. The LCRS in Phases V and VI consists of an 8-inch diameter perforated HDPE pipe placed on 4 inches of granite rock inside a two foot wide by two-foot deep trench. The trench is backfilled with granite rock and wrapped with a non-woven geotextile. The LCRS is covered with a minimum of 3 feet of sand that serves as the drainage layer. The details of the LCRS are shown in Appendix N of the Permit Responses November 18, 1994).

Currently, the LCRS in Phases V and VI, is being utilized as a stormwater underdrain system since solid waste has not been placed in these phases.

PROPOSED MODIFICATIONS

The proposed modifications will improve leachate collection efficiency and reduce the amount of leachate generated. The following modifications are proposed to the LCRS in Phases V and VI.

- Install additional highly permeable leachate collection trenches as shown on Detail No. 2, Drawing No. 4 of Attachment A. The trenches include the use of chipped tires as backfill in lieu of granite rock. As shown in Attachment B, the chipped tires have adequate hydraulic and structural characteristics for the intended use. Geotextiles wrap will be placed around the chipped tires in order to provide and adequate filter. The product literature is found in Attachment C. The proposed geotextile is a woven monofilament. The larger opening size of the geotextile will minimize clogging from fill and biological growth, and will also prevent sand from filtering through the geotextile. The modifications to the LCRS will be installed in accordance with the specifications presented in Attachment D. The County will provide on-site monitoring of the construction to document compliance with the permit modification.

- Use of rain tarps over non-active areas during the initial stages of filling (Phases V and VI Lifts 7A and 7B).

PERFORMANCE EVALUATION

As shown on Table 2-1, in the long term, the existing LCRS would maintain leachate head over the liner at acceptable levels. However, during initial filling operations it would not provide adequate removal of leachate to maintain leachate levels as required. Therefore, the County evaluated ways for improving leachate collection efficiency.

The governing criteria of the LCRS is that it must maintain leachate levels at or below the levels required by 62-701.400(3) Florida Administrative Codes (FAC) and the Leachate Management Plan (LMP) as required by the Permit Specific Condition No. 17. Leachate levels in a landfill are a function of the impingement rate (e), the leachate travel distance (L), slope of the liner (tanβ), and the hydraulic conductivity of the drainage layer (k) (Giroud, 1992). The equation to estimate the leachate head over the liner, in the absence of pore pressure, is as follows:

$$T_{max} = \frac{CL\,[\,(4e/k + (\tan\beta)^2)]^{1/2} - \tan\beta)}{2\cos\beta}$$

Where:

T_{max}	=	Maximum head over liner (inches)
L	=	Length of horizontal projection of the leachate collection layer from top to collector (meters)
e	=	Impingement rate (meter/sec)
k	=	Saturated hydraulic conductivity of the drainage layer (m/sec)
tanβ	=	Slope to collection pipe (dimensionless)
C	=	Constant (39.37 inch/meter)

The LCRS at the SCLF has been installed, therefore modification of these variables was not considered. The only two ways to further minimize head over the liner at this point is to

TABLE 2-1. PHASES V AND VI LEACHATE COLLECTION AND REMOVAL SYSTEM ANALYSIS, SOUTHEAST COUNTY LANDFILL

Scenario	Description	Depth Over Liner		Clay Slope[2] (%)	Pipe Distance[3] (feet)	Head Over Liner Including Clay Pore Pressure[4]	
		FDEP[1] Equation (inches)	HELP Model (inches)			Year 1 (110 inches)[5]	Year 7 (43-inches)[5]
	Existing Configuration						
1	Beginning of filling sequence.	124	81	0.5	400	14	N/A
2	Beginning of filling sequence using tarp on non-active areas.	<1	<1	0.5	400	-109	-42
3	After placement of 30 ft. waste.	19	3	1.6	400	-91	-40
4	Final Closure.	9	<1	1.6	400	-101	-42
	New Trenches Configuration						
5	Beginning of filling sequence.	75	55	0.5	200	-35	N/A
6	Beginning of filling sequence using tarp on non-active areas.	<1	<1	0.5	200	-109	-42
7	Intermediate filling using intermediate cover over non-active areas. (Lifts 7C through 7D, 15 feet of waste).	12	5	1.0	200	-98	-38

1. Moore's Equation as modified by J. P. Giroud and presented in the FDEP memorandum entitled "Municipal Solid Waste Landfill Alternate Design Closure Guidance" dated February 10, 1995.
2. Top of the clay as it slopes towards the collection pipe.
3. Distance leachate travels to reach collection pipe.
4. (-) represents an upward gradient.
5. Upward pore pressure based on loading and consolidation curves prepared by Ardaman and Associates, Inc. dated March 7, 1994.

reduce the leachate drainage length (L) and the impingement rate (e). The proposed modifications by the County address both variables. The proposed modifications include reducing the drainage length of the existing conditions from 400 feet on center to 200 feet on center and the installation of the rain tarps during the initial filling sequence in Phases V and VI to reduce the impingement rate.

The Hydraulic Evaluation of Landfill Performance (HELP) model and the Giroud equation were used to evaluate the proposed improvements. The head over liner was calculated for areas within Phases V and VI that exhibited the longest distance for the leachate to travel to reach a collection point. For the evaluation, the varying slope of the phosphatic clay was calculated at approximately 0.5 percent. The calculations are presented in Attachment E. The estimated performance of the configurations evaluated is summarized in Table 2-1. The configurations evaluated are described below.

__Existing LCRS Configurations__

Scenario 1: Beginning of filling sequence representing worst case condition where Phases V or VI begin to receive waste and the entire phase non-active areas are open without a cover system.

Scenario 2: Beginning of filling sequence where Phases V or VI begin to receive waste and the entire phase non-active areas are covered with rain tarp.

Scenario 3: After Lift 7 with 30 feet of waste and soil intermediate cover.

Scenario 4: After final closure, following consolidation.

__LCRS Configurations with New Trenches__

Scenario 5: Beginning of filling sequence where Phases V or VI begin to receive waste and the entire phase non-active areas are open without a cover system.

Scenario 6: Condition with no waste to emulate the initial scenario when the cell receives the first load of waste (Lifts 7A and 7B, see Appendix A - Drawing No. 6 of the Permit). This scenario includes the use of geotarp over non-active areas.

Scenario 7: Condition after the placement of 15-feet or more of waste (Lifts 7C through 7E, see Appendix A - Drawing No. 7 of the Permit). This scenario includes the use of soil intermediate cover as described in Section 5.4.1.4 of the Permit.

As previously stated, results indicate that the existing LCRS (without improvements) would not maintain a head over liner below 12 inches during the initial filling stage of Phases V and VI (i.e. Scenario No. 1). Although this is a temporary condition, the County proposes to install additional leachate collection trenches to provide additional redundancy in the system and meet the requirements of the LMP and 62-701.400(3) FAC. The additional redundancy has the benefit of reducing the leachate drainage length, thereby reducing head over liner. In addition the County will begin the use of rain tarps over non-active areas of Phases V and VI as authorized in the Permit Specific Condition No. 14(b). The use of rain tarps will have beneficial impacts regardless of which scenario is used.

CONSTRUCTION SEQUENCE

The County anticipates to begin waste filling in Phase V as early as January 1999; Therefore, a prompt review and comments from the FDEP will be appreciated since the County would like to begin construction of the improvements as soon as possible. Excluding delays due to unforeseen conditions, the planned schedule for the multiple work activities at the SCLF is as follows:

- Submit construction application for improvements on June 26, 1998.
- Receive construction permit from the FDEP by July 31, 1998.
- Begin construction of improvements in Phases V and VI by August 1, 1998.
- Complete construction of the Permanent Pump Station "B" by August 15, 1998.
- Complete improvement construction by September 1, 1998.

- Begin installation of geotarp by September 1, 1998.
- Submit operation permit application for Phases V and VI by September 1, 1998.
- Receive operation permit modification from the FDEP by November 1, 1998.

SUMMARY

The proposed modifications provide additional redundancy in the leachate collection system, improve the efficiency of the leachate collection system, make beneficial use of a waste product (chipped tires), reduce leachate generation, and reduce leachate treatment and disposal costs.

REFERENCES

1. Ardaman & Associates, Inc. *"Hydrogeological Investigation, Southeast County Landfill Hillsborough County, Florida",* February 1983.

2. Ardaman & Associates, Inc. *"Geotechnical Investigation, Southeast Landfill",* 1994.

3. Giroud, J.P. Landfill Design Series: Volume 4, *"Cell Design and Construction",* University of Florida TREEO Center, 1992, p. 109.

4. SCS Engineers, *"Operation Permit Renewal Application, Southeast County Landfill, Hillsborough County, Florida"*, August 1994.

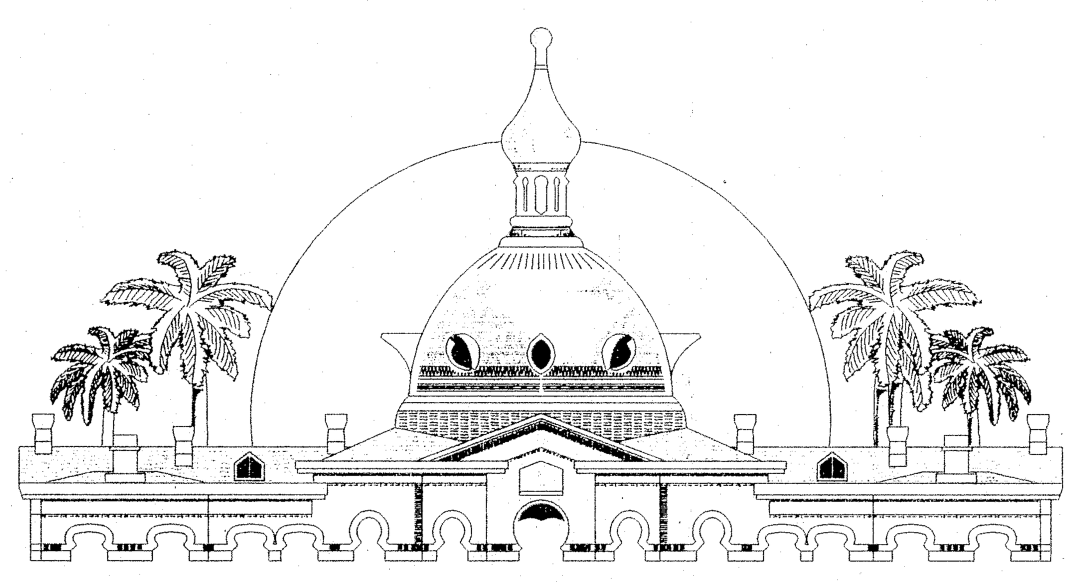
ATTACHMENT A

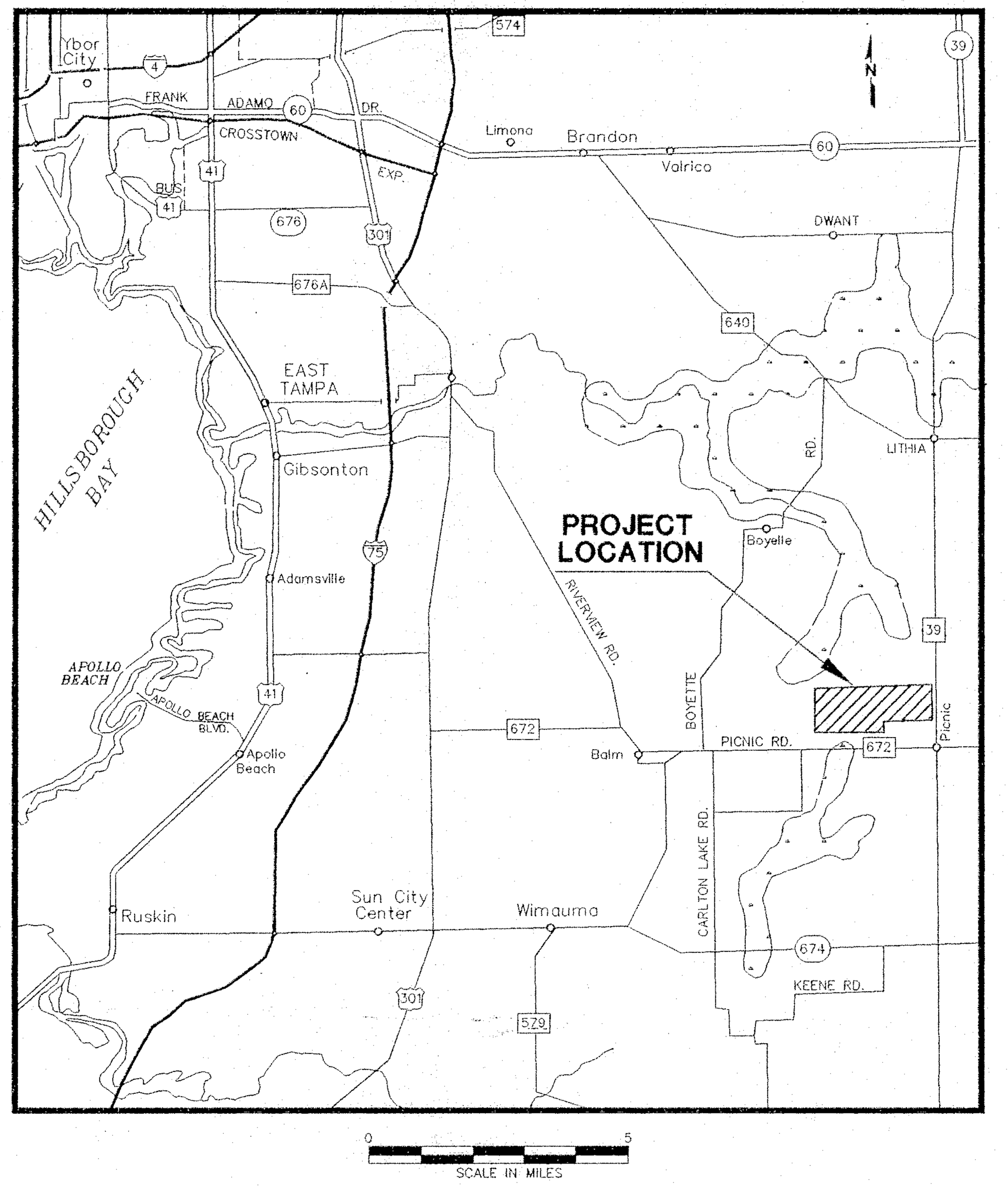
PERMIT DRAWINGS

1577829 (1)

SOUTHEAST COUNTY LANDFILL
PHASES V AND VI LEACHATE COLLECTION
REMOVAL SYSTEM IMPROVEMENTS

COUNTY OF HILLSBOROUGH, FLORIDA
SOLID WASTE MANAGEMENT DEPARTMENT
TAMPA, FLORIDA



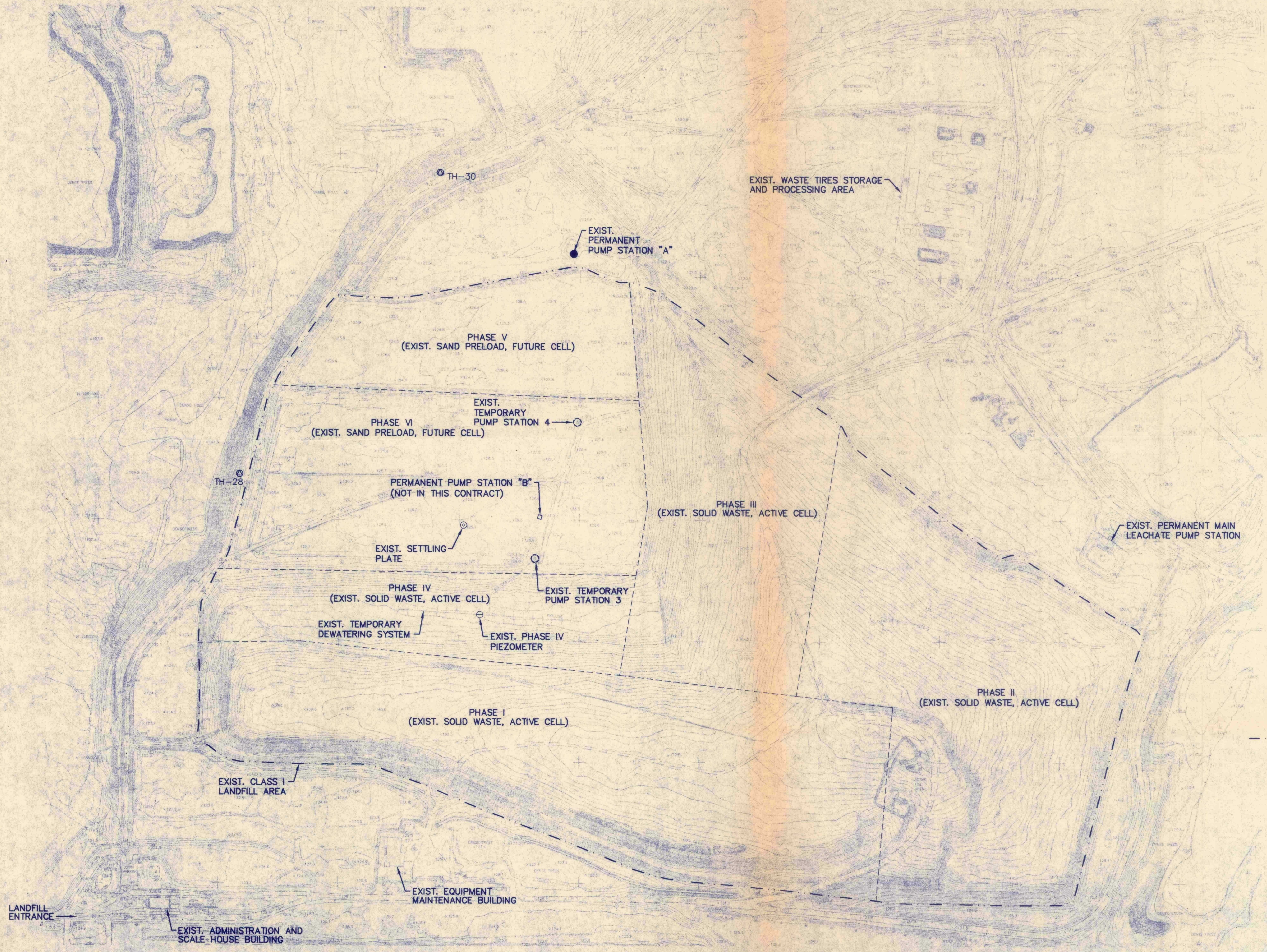


LOCATION MAP

DRAWING INDEX

SCS ENGINEERS
ENVIRONMENTAL CONSULTANTS
3012 U.S. 301 N. SUITE 700
TAMPA, FLORIDA 33619
(813) 621-0080
WWW.SCSENG.COM

0995029.23\LCRS TITLE



N

200 0 200 400
SCALE IN FEET

LEGEND

- — - — APPROXIMATE LANDFILL FOOTPRINT
- ⊚ TH-30 EXISTING GROUNDWATER MONITORING WELL

EXISTING TOPOGRAPHY COMPILED FROM AERIAL SURVEY BY AEROMAP U.S. DATED 11-15-97.

REV.	DATE	DESCRIPTION	CK. BY
△			
△			
△			
△			
△			
△			

JUN 2 1998

DRAWING TITLE: **SITE PLAN**

PROJECT TITLE: **SOUTHEAST COUNTY LANDFILL PHASES V AND VI EACHATE COLLECTION REMOVAL SYSTEM IMPROVEMENTS**

CLIENT: **HILLSBOROUGH COUNTY SOLID WASTE MANAGEMENT DEPARTMENT TAMPA, FLORIDA**

SCS ENGINEERS
STEARNS, CONRAD AND SCHMIDT
CONSULTING ENGINEERS
3012 U.S. HWY. 301 NORTH, SUITE 700, TAMPA, FL 33619
PH (813) 621-0080 FAX NO. (813) 623-6757

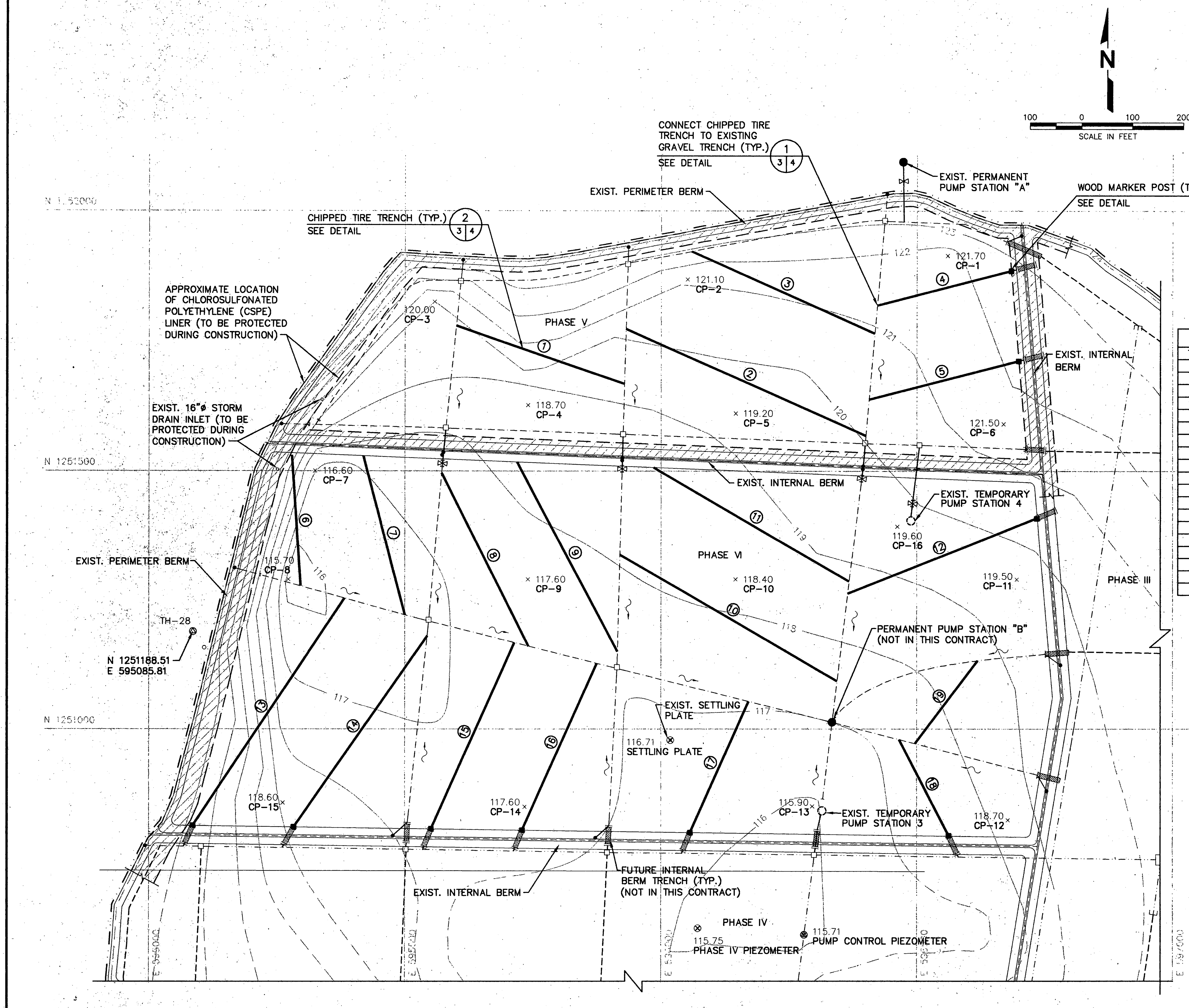
PROJ. NO. 0995029.23	DWN. BY: BLJ	Q/A RVW BY: RBG
DSN. BY: LER/KAS	CHK. BY: LER	APP. BY: RBG

CADD FILE: LCRS\SITEPLAN

DATE: JUNE 2, 1998

SCALE: 1"=200'

DRAWING NO. 2 of 4



CHIPPED TIRE TRENCH LOCATIONS			
TRENCH NUMBER	START NORTHING AND EASTING	END NORTHING AND EASTING	LENGTH
1	N. 1251779 E. 595600	N. 1251668 E. 595928	347
2	N. 1251568 E. 596400	N. 1251773 E. 595931	512
3	N. 1251765 E. 596418	N. 1251921 E. 596059	391
4	N. 1251885 E. 596684	N. 1251818 E. 596422	270
5	N. 1251712 E. 596699	N. 1251638 E. 596406	302
6	N. 1251277 E. 595296	N. 1251530 E. 595279	254
7	N. 1251221 E. 595500	N. 1251529 E. 595419	319
8	N. 1251160 E. 595741	N. 1251496 E. 595571	377
9	N. 1251150 E. 595915	N. 1251517 E. 595719	416
10	N. 1251338 E. 595919	N. 1251093 E. 596344	490
11	N. 1251507 E. 595985	N. 1251286 E. 596368	442
12	N. 1251409 E. 596735	N. 1251262 E. 596365	399
13	N. 1251253 E. 595382	N. 1250813 E. 595086	531
14	N. 1251180 E. 595544	N. 1250810 E. 595282	453
15	N. 1251167 E. 595714	N. 1250806 E. 595551	396
16	N. 1251127 E. 595874	N. 1250804 E. 595729	355
17	N. 1251054 E. 596171	N. 1250799 E. 596056	279
18	N. 1250792 E. 596563	N. 1250979 E. 596465	211
19	N. 1250972 E. 596496	N. 1251133 E. 596619	202

LEGEND

- EXIST. APPROXIMATE LANDFILL LIMITS
- EXIST. NON-PERFORATED HDPE PIPE
- EXIST. 8"ø PERFORATED PVC PIPE
- EXIST. 8"ø PERFORATED HDPE PIPE
- EXIST. LEACHATE COLLECTION TRENCH
- APPROX. LOCATION OF REVISED TOP OF CLAY ELEVATION PER FIELD INVESTIGATION (5/18/98)
- APPROX. BORING LOCATION AND TOP OF CLAY ELEVATION (ARDAMAN & ASSOC. FIELD EXPLORATION, DECEMBER 1993)
- EXIST. FLANGE CONNECTION
- EXIST. HEADER CONNECTION
- EXIST. PERFORATED FILTERED END CAPS PHASES V-VI
- EXIST. 8"ø SOLID HDPE PIPE CLEANOUT
- EXIST. GATE VALVE
- EXIST. TEMPORARY PUMP STATION
- ① CHIPPED TIRE TRENCH LOCATION AND DESIGNATION
- APPROXIMATE LOCATION OF CSPE LINER (TO BE PROTECTED DURING CONSTRUCTION)
- × 121.70 CP-1 LOCATION, ELEVATION, AND DESIGNATION OF CLAY TEST PROBE (5/18/98)

REV | DATE | DESCRIPTION | CK BY

DRAWING TITLE
IMPROVEMENTS LAYOUT

PROJECT TITLE
SOUTHEAST COUNTY LANDFILL PHASES V AND VI EACHATE COLLECTION REMOVAL SYSTEM IMPROVEMENTS

CLIENT
HILLSBOROUGH COUNTY SOLID WASTE MANAGEMENT DEPARTMENT
TAMPA, FLORIDA

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PROJ. NO. 0995029.23 | DWN. BY: BLJ | Q/A RVW BY: RBG
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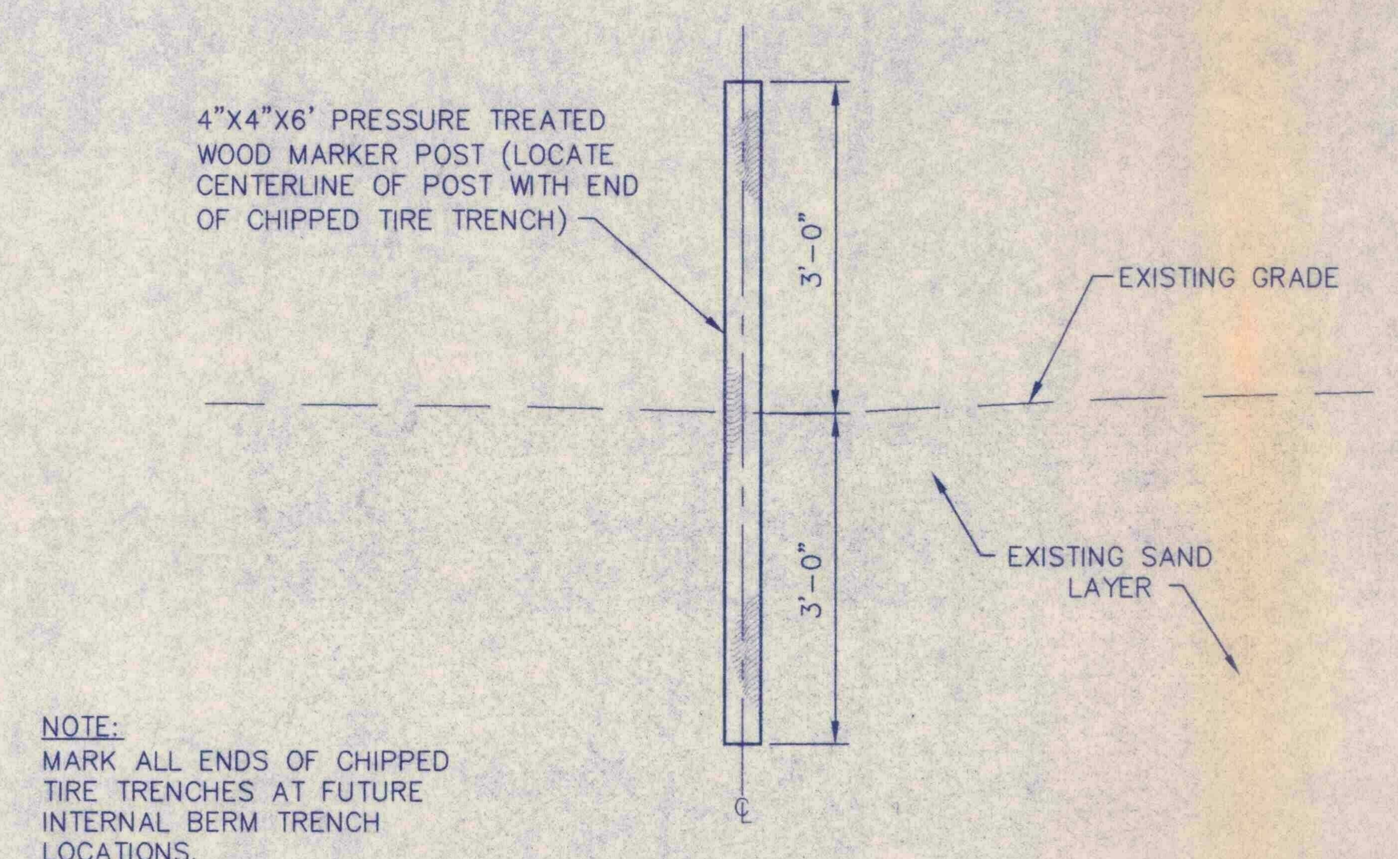

WOOD MARKER POST DETAIL 3 / 3 | 4
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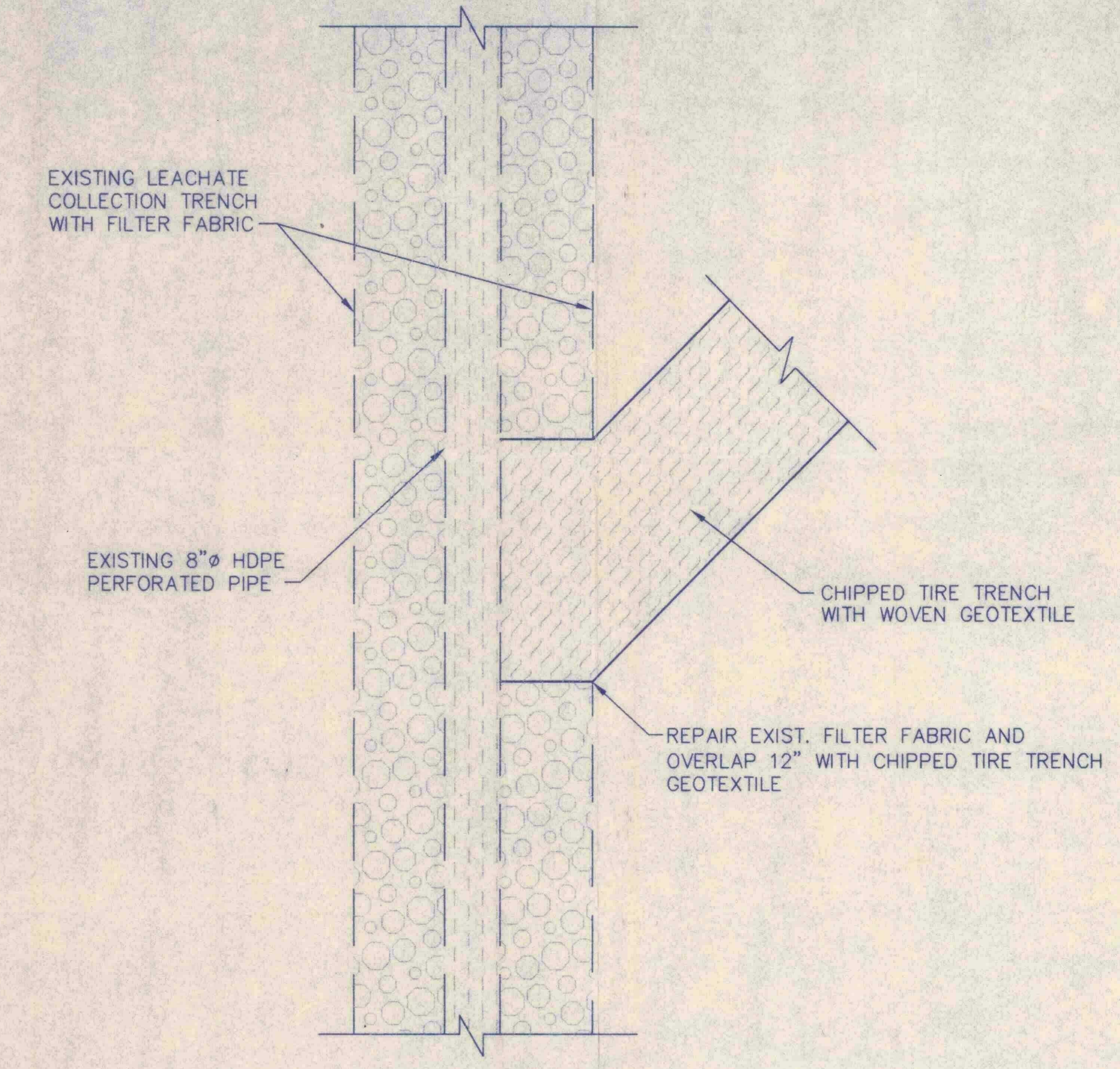

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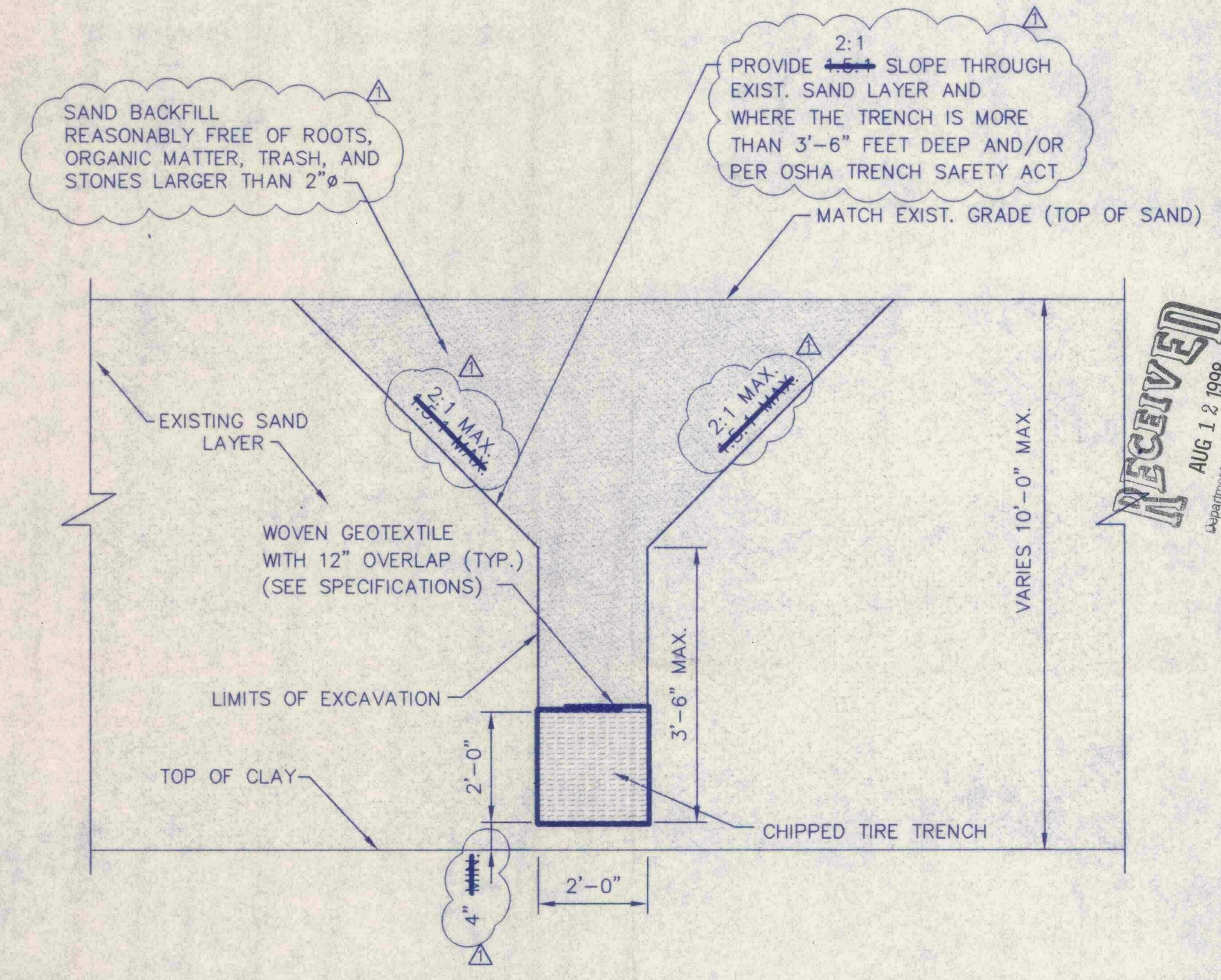

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PROJECT TITLE: **SOUTHEAST COUNTY LANDFILL PHASES V AND VI EACHATE COLLECTION REMOVAL SYSTEM IMPROVEMENTS**

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ATTACHMENT B

RESEARCH LITERATURE ON CIVIL ENGINEERING APPLICATIONS OF CHIPPED TIRES

SCRAP TIRE UTILIZATION IN LANDFILL APPLICATIONS

PRESENTED BY: JOHN DEMPSEY

AUTHORS: RICHARD DONOVAN, PE (HDR Engineering, Inc.)
JOHN DEMPSEY, PE (HDR Engineering, Inc.)
STEVE OWEN, PE (City of Lincoln, Nebraska)

ABSTRACT

This paper presents the results of an engineering feasibility study and preliminary design aspects of using scrap tires in landfill applications. The paper specifically evaluates scrap tire use in construction of landfill liners, leachate collection systems, and landfill gas control systems. Included in the paper is a review of available data and actual field application. Market and supply considerations are addressed relative to material properties and purchase costs.

The design evaluation includes a comparison of the properties of the scrap tires with the properties of soils typically used in similar applications. A preliminary ranges of design parameters, e.g., friction angles, compressibility, hydraulic conductivity is presented. The paper included preliminary cost/benefit analyses and cost estimates specific to one midwestern location. The comprehensive nature of the data collection and applicability assessment should allow this paper to be used as both a reference and guidance document for further site specific analysis and design considerations.

SECTION 1 - INTRODUCTION

The purpose of this paper is to present the results of an engineering feasibility study and preliminary design aspects of using scrap tires in landfill applications. Specific evaluations include the possible use of scrap tires in the construction of the liner and leachate collection system, ground water control system, final cover system and the landfill gas control systems. Included in this paper is a review of available data and actual field applications. The design evaluation includes a comparison of the properties of scrap tires with properties of soils typically used in similar applications. This paper is based upon a detailed report prepared for the City of Lincoln, Nebraska's landfills.

1.1 Background

The background research includes a collection of literature and case history information and a review of the information for applicability to landfills. This paper is divided into the following sections:

- Processing and Properties of Tire Chips - presents tire processing technologies and the physical properties of tire chips.

- Landfill Applications and Case Histories - describes tire chip applications and presents case histories utilizing tire chips in landfill construction and closure.

- Preliminary Designs - presents design computations, tire utilization estimates, specification requirements and construction details for tire chip substitution in a leachate collection layer, a gas vent layer, and a perimeter gas collection trench. Two supplemental uses, retaining wall backfill and haul road subgrade insulation, are considered in lesser detail.

- Local Market Survey - presents available sources of tire chips, unit costs and cost estimates for the preliminary designs.

- Conclusions - presents conclusions, identifies data gaps and regulatory issues and discusses implementation issues.

A preliminary range of design parameters, e.g., friction angles, compressibility, hydraulic conductivity is presented. The paper includes preliminary cost/benefit analyses and cost estimates specific to the City of Lincoln's landfills.

SECTION 2 - PROCESSING AND PROPERTIES OF TIRE CHIPS

2.1 Tire Processing Methods

This section presents an overview of the processing methods used to produce marketable scrap-tire byproducts (5). Processing can consist of two or more operations, depending on the anticipated end use.

The following discussion is limited to the typical processes necessary to produce scrap-tire byproducts for use in civil engineering applications. This category of use includes alternative landfill construction materials.

First phase processing reduces the whole tire to a "rough shred" size of three to six inches in width by three to twelve inches in length. The initial size depends on the type and condition of the processing equipment and the production volume. Slow speed, shear shredders are commonly used for this processing phase. Civil engineering applications for rough shred are limited because of workability difficulties from the tangled mass of exposed bead and belt wire.

Second phase processing reduces the rough shred to a smaller "chip," nominally two to three inches in width and length. Again, slow speed, shear shredders are commonly used for this processing phase. This second phase processing reduces, but does not eliminate, the bead and belt wire. The smaller chips typically have two to three inch wire protrusions. These smaller chips have improved workability. Tire chips may be handled, spread and compacted with conventional construction equipment.

Civil engineering applications of tire chips include the substitution of chips for conventional soil materials in pavement base courses, retaining wall backfills, and landfill construction and closure.

Third phase processing reduces the chip to "granulated rubber," with a maximum 0.50 inch size and a minimum of non-rubber materials (steel and fabric). Civil engineering applications of granulated rubber include pavement joint sealants and rubber modified asphalt.

2.2 Physical Properties

The feasibility of substituting tire chips for a given soil component should be based on demonstrating the equivalency of the tire chip performance to that of the soil component. The use of conventional soil materials in landfill construction and closure is based on an evaluation of the shear strength, compressibility, permeability (hydraulic conductivity), and durability of the soil (30).

The following summarize a review of the literature on the physical properties of tire chips and their implications for use as landfill construction components. The discussion generally focuses on the use of tire chips as an equivalent granular material. The smaller granulated rubber materials are not considered, since they have a higher production cost and broader level of reuse.

2.2.1 Shear Strength

ASTM D 653 (4) defines shear strength as, "...the maximum resistance of a soil or rock to shearing stresses." Shear strength is a design consideration that effects bearing capacity and slope stability of landfill components.

This shear strength is expressed by the angle of internal friction, ø, measured in degrees. Typical granular soils have ø angles ranging from 27 degrees (for loose, silty sand) to 55 degrees (for dense, medium size gravel).

Tire chips have a reported range in ø from 24 to 38 degrees, depending on chip size, magnitude of bead wire entanglement and degree of saturation (6, 7 and 12). An evaluation of eight shear strength envelopes presented by Humphrey (12) suggests a lower bound ø angle of 24 degrees. This shear strength is equivalent to the lower end of the granular soil range.

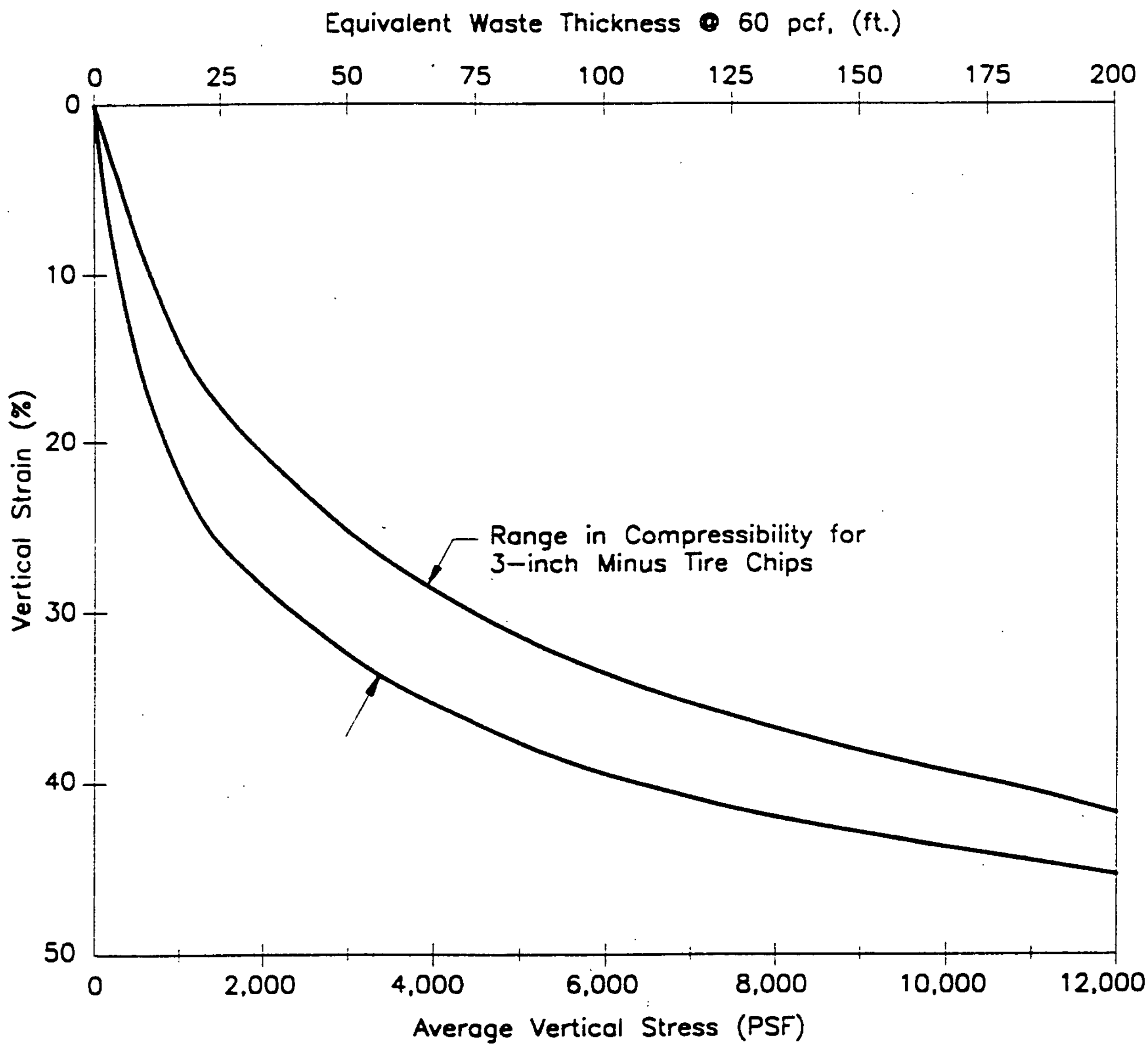
Shear strength is a major design consideration for construction of a tire chip layer on a lined or unlined side slope (6). The shear strength of a tire chip layer is similar to a loose granular soil. The shear strength at the interface between a tire chip layer and a geosynthetic material can be influenced by tire and geosynthetic textures and may be comparable to soil geomembrane shear strengths (6). However, they could be significantly different (4). Project specific testing should be conducted for each tire chip source or tire chip-geosynthetic combination to establish an adequate safety factor against a slope stability failure.

2.2.2 Compressibility

ASTM D 653 (4) defines compressibility as the, "...property of a soil or rock pertaining to its susceptibility to decrease in volume when subjected to load." Compressibility is a design consideration that effects settlement of landfill components.

Tire chips differ markedly from soils in that the chips themselves are compressible in addition to the compressibility of the mass. Tire chips have a reported range in compressibility from 5 to 50 percent, depending on the applied normal stress. A summary of the range in compressibility data presented by Duffy (7), Humphrey (12) and Narejo (14) is presented on Figure 2-1.

Compressibility is a major design consideration for applications under high compressive stresses, such as leachate collection layers. For example, Figure 2-1 indicates that a 12-inch thick tire chip layer under a 100 feet of waste would compress approximately 35 percent, or 4.2 inches, leaving an effective thickness of 7.8 inches.



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Tire Chip Compressibility

Figure 2-1

The anticipated compression of a tire chip layer can be offset by using a thicker layer than for conventional granular materials. Substitution ratios from 100 percent to 200 percent of a granular drainage layer thickness have been used (17, 21, 26).

2.2.3 Permeability

ASTM D 653 (4) defines permeability as, "...the capacity of a rock to conduct liquid or gas." Permeability is a design consideration that effects leachate flow and landfill gas migration.

RCRA Subtitle D regulations address the requirements for leachate and gas control (16, 30). These regulations require a leachate collection system, "...designed and constructed to maintain less than a 30-cm depth of leachate over the liner." Regulations for gas migration require control within facility structures and at the facility property boundary.

A granular soil, having a permeability of 0.01 cm/sec or greater, generally is required to meet the regulatory depth limit. Washed gravel, sand or sand-gravel mixtures are used to meet this requirement. Similar materials are often used in gas migration control layers and trenches.

Data reported on horizontal and vertical permeability tests (7, 8, 12, 14, 29) are summarized on Figure 2-2. The scatter in the data is due to differences in chip size, initial density, hydraulic gradients and confining pressures among the studies.

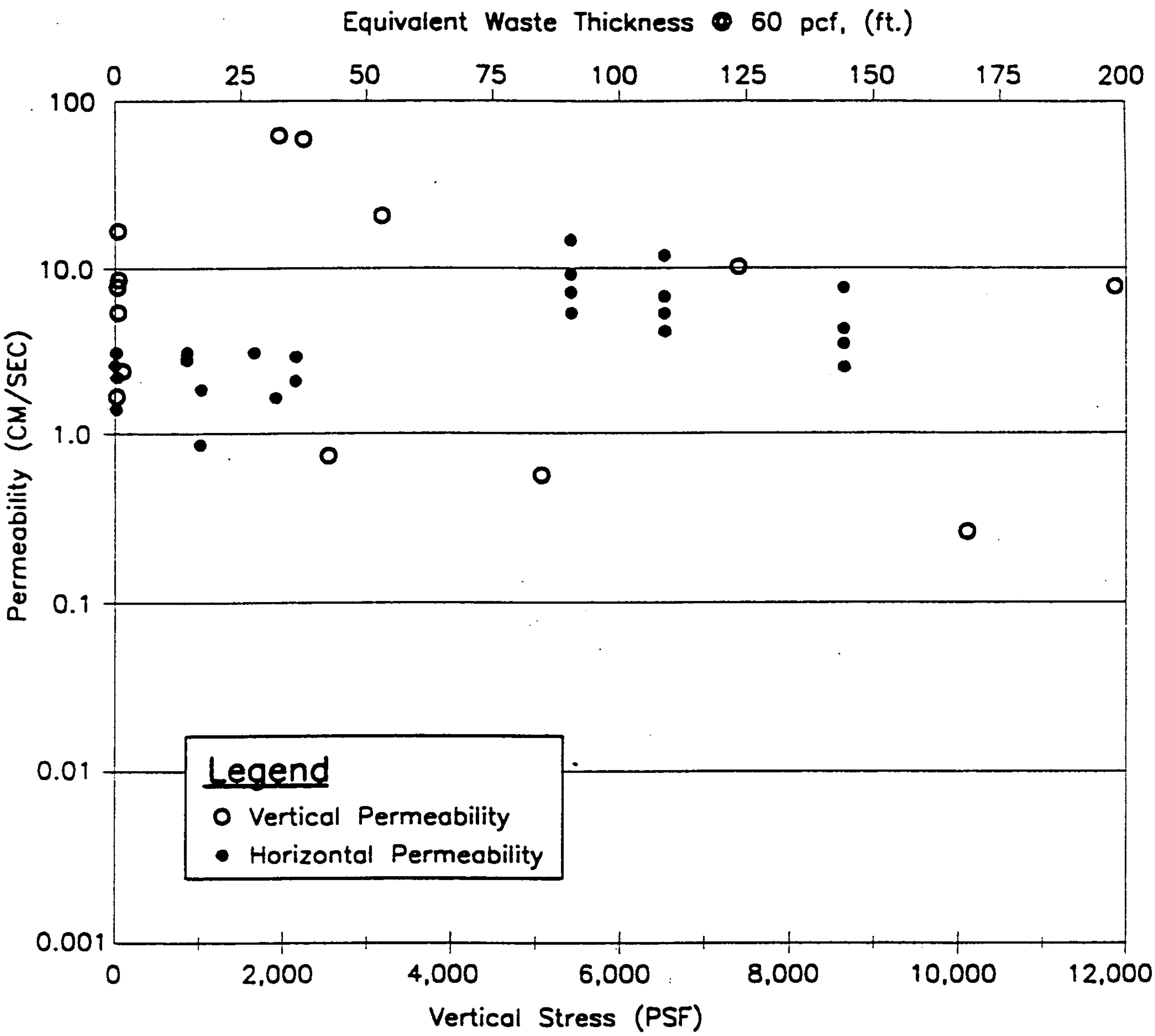
The permeabilities decreased under normal load due to compression of the chips and reduction in void volume. The higher horizontal permeability is attributed to horizontal layering of the relatively flat chips. The results indicate the minimum permeability is 0.10 cm/sec, exceeding the minimum sand-gravel value of 0.01 cm/sec by an order of magnitude. *

Permeability is a major design consideration for most landfill tire chip applications. This property is effected by the compressibility of the tire chip layer (Figure 2-1) as noted above. The anticipated reduction in permeability of a tire chip layer can be offset by using a thicker layer than for conventional granular materials.

HELP modeling can be used to evaluate the effect of reduced permeability on leachate or infiltration head buildup. Substitution ratios from 100 percent to 200 percent of a granular drainage layer thickness have been used (17, 21, 26).

2.2.4 Filtration

ASTM D 653 (4) defines a filter as, "...a layer or combination of layers of pervious materials designed and installed in such a manner as to provide drainage, yet prevent the movement of soil particles due to flowing water." Filtration is a design consideration that effects clogging and plugging between adjacent layers.



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Tire Chip Permeability

Figure 2-2

The gradation of tire chips is similar to a poorly-graded gravel (12) and consists of relatively flat pieces. This structure provides high permeability, but is not effective as a graded filter. Either a thick non-woven geotextile or a graded sand-gravel filter is required to provide filtration and puncture resistance between a soil layer and an adjacent tire chip layer.

Filtration is a major design consideration for all tire chip applications in contact with adjacent soil layers. Non-woven geotextiles have been used to provide the filtration function and prevent plugging and clogging of the tire chips (2, 26). Thick non-woven geotextiles also offer puncture resistance. However, tire chip substitution in gas collection trenches (20) and leachate recirculation systems (28) have not included a filtration geotextile.

2.2.5 Puncture Resistance

As noted in the discussion of tire processing methods, the tire chips contain bead and belt wire protrusions. These wires could puncture a synthetic liner (geomembrane) if placed against this material. Puncture resistance is a major design consideration for tire chip-synthetic liner interfaces.

One project, the DSI Superfund Site (2, 22), did use tire chips placed directly against a synthetic liner. The acceptance of this application was based on demonstration in a material-specific test pad and HELP infiltration modeling.

However, the consensus of opinion (7, 14, 17, 21) seems to hold that a granular cushion layer should be used between a geomembrane and a tire chip layer. Puncture of a clay liner is a lesser concern, since the nominal 2 feet thickness provides adequate protection.

A thick, non-woven geotextile may provide another alternative, depending on the magnitude of bead and belt wire protrusions in the tire chips. No data or testing has been obtained to document this hypothesis.

2.2.6 Leachability and Durability

The interaction between water infiltration or landfill leachate and tire chips suggests the following considerations:

- Leaching of metals and other constituents may occur from the tire chips.
- Degradation or decomposition of the tire chip itself is not likely.
- Attenuation of volatiles in the leachate stream may occur, similar to granular activated carbon sorption.

Toxicity Characteristic Leaching Procedure (TCLP) testing summarized by the Scrap Tire Management Council (27) indicates, "...none of the cured rubber products tested exceeded TCLP regulatory limits. In fact, most compounds detected were found at trace levels, ranging from 10 to 100 times less than the TCLP limits and the EPA's Drinking Water Standard MCL values."

Laboratory leaching tests have been conducted by the Wisconsin State Laboratory of Hygiene to evaluate the impact of tire chips on ground water quality (13). The test protocol used three sequential elutions with distilled water as the extraction fluid. A comparison of the test results with Nebraska ground water numerical standards (15) suggests the following:

- Iron, manganese and zinc increased in concentration from the first to the third elutions, suggesting continued release from the bead and belt wire.
- Only manganese exceeded the Nebraska numerical standard (0.25 mg/l versus 0.05 mg/l standard).
- Organics generally decreased from the first to the third elution, suggesting that washing of contaminants from the tire surface was occurring, rather than a release from tire material.

Samples obtained by Humphrey (12) from a field lysimeter beneath a tire chip road subgrade indicated the same trend in metals and organics. Both iron and manganese were observed at levels above the Nebraska standards (15).

In contrast, chemical tests conducted on infiltration draining through a tire chip cap drainage layer in the DSI Superfund Site closure cap (2, 22) did not indicate elevated levels of any volatiles or metals.

No EPA Method 9090 data has been reported on the durability of tire chips. However, anecdotal evidence (7, 14) suggests that municipal solid waste leachate does not degrade or decompose tire chips.

Batch and column laboratory tests conducted at the University of Wisconsin (18, 19) suggest tire chips offer some sorption capacity, similar to granular activated carbon, for both vapor and liquid phase volatile organic compounds (VOC). The reported removal efficiencies varied from 30 to 99 percent, depending on air/water flow ratios, VOC concentrations and tire chip characteristics (gradation, porosity and surface area).

Leachability is a major design consideration for tire chip applications in contact with ground water or subject to infiltration into ground water.

2.3 Flammability

Recent articles have reported on the fires erupting from within tire chip fills constructed in Oregon and Washington. The combustion potential of tire chips is undeniable and is the primary benefit for tire-derived-fuel (TDF) applications.

Research by Humphrey for the Federal Highway Administration indicates these tire chip fires have the following common denominators:

- Thick fills, nominally 50 feet deep; and
- A mixture of soil and tire chips, to provide a fill that is less compressible than tire chips alone.

Humphrey suggests that the soils contained microbes which digest the petroleum constituents of the tire chips, similar to bioremediation of petroleum contaminated soils. The thick fills absorbed the heat generated by this reaction, until the combustion temperature was reached.

Neither of these two factors are anticipated to impact the tire chip use in landfill applications, since:

- Thinner layers are used; and
- Mixing soil with tire chips generally reduces the permeability of the mixture, which defeats the primary advantage of the tire chips.

2.4 Summary

Tire chips have quantifiable engineering properties similar to granular soils. The major design considerations associated with the importance of each physical property are presented in Table 2-1.

Table 2-1
Major Design Considerations

PROPERTY	APPLICATION
Shear Strength	On side slopes
Compressibility	Under high normal stresses
Permeability	Lateral or vertical fluid flow
Filtration	In contact with soil materials.
Puncture	In contact with synthetic liners
Leachability	In contact with groundwater or infiltration

SECTION 3 - LANDFILL APPLICATIONS AND CASE HISTORIES

3.1 Applications

A typical landfill section is shown on Figure 3-1. The major systems and their components consist of:

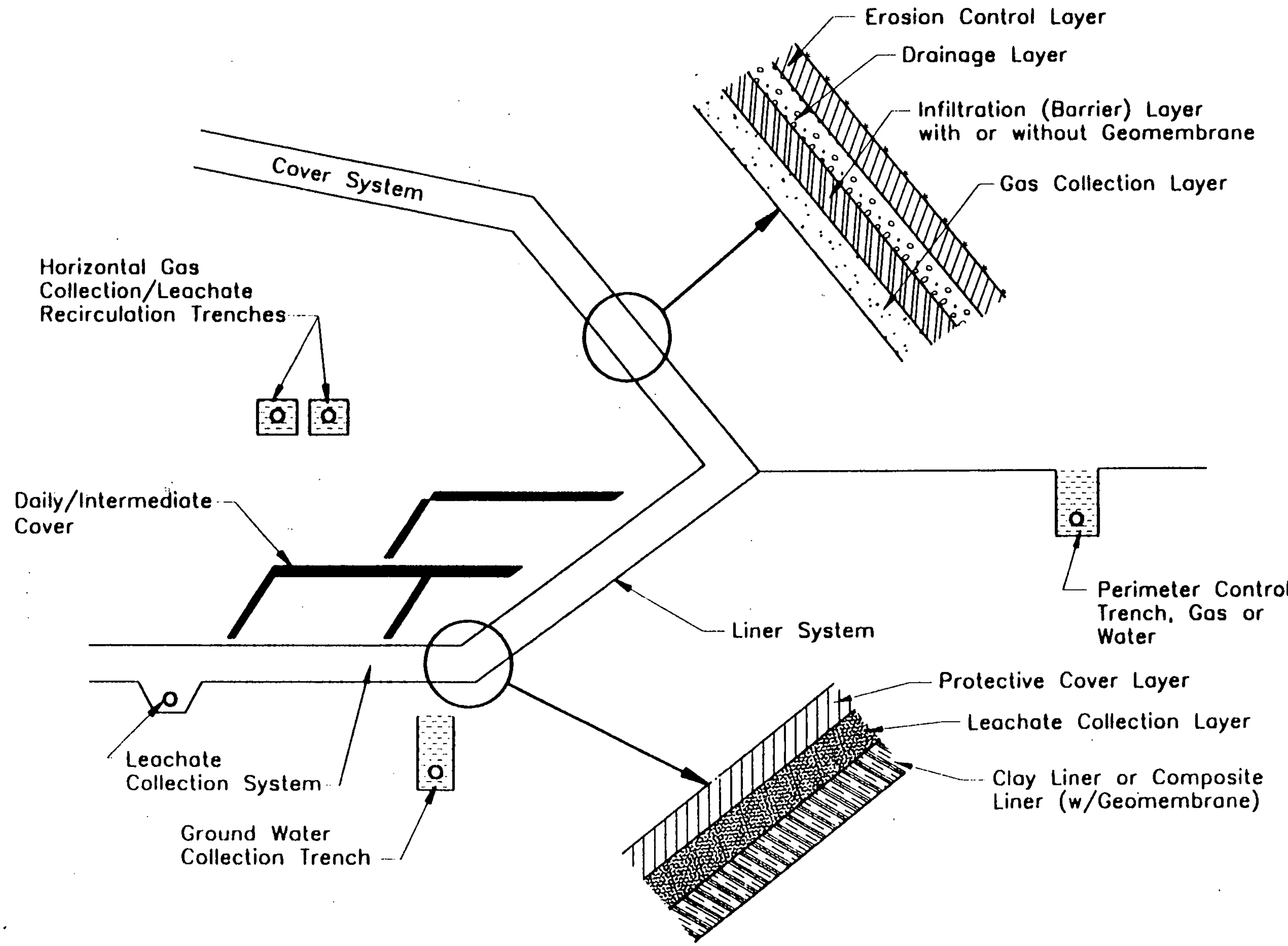
• Closure Cap System	erosion control layer drainage layer infiltration (barrier) layer
• Leachate Collection and Recovery System	leachate collection layer collection piping and bedding leachate recirculation trenches
• Composite Liner System	geomembrane compacted clay liner
• Landfill Gas Control System	horizontal collection and venting layer gas migration control trenches
• Groundwater Control System	groundwater control trenches
• Operational Layers	protective cover soil daily and intermediate cover

The following describe these typical landfill components and design considerations associated with substituting tire chips in these components. Case histories are identified which have used tire chips in these applications.

The closure cap infiltration layer and the composite liner components were not considered further, since they function as impermeable layers, a property tire chip layers do not possess.

3.2 Closure Cap System

Potential applications in a landfill cap system include the drainage layer. The purpose of a drainage layer is to remove percolation and minimize head build up on the infiltration layer. These drainage layers typically are located directly above the infiltration layer. Conventional drainage materials used in these layers include granular soils and geosynthetics (geotextiles and geonets).



Typical Landfill Component
Figure 3-1

Design considerations for these conventional drainage materials include shear strength (on side slopes), permeability, and filtration. The use of tire chips would add considerations of puncture resistance (against a synthetic liner) and leachability.

The DSI Superfund Site closure cap (2, 22), used tire chips in a cap drainage layer directly above the synthetic liner (60-mil Very Low Density Polyethylene). The acceptance of this application was based on a field test section and HELP modeling to evaluate the effect of a higher puncture frequency on infiltration.

3.3 Landfill Leachate Collection/Recovery System

Potential tire chip uses in a landfill leachate collection/recovery system include the collection layer, the pipe bedding, and the recirculation trench backfill.

3.3.1 Leachate Collection Layer

The purpose of a leachate collection layer is to provide positive control and discharge of landfill leachate. These layers typically are located directly above the geomembrane component of the composite liner system. Conventional materials used in the leachate collection layer include granular soils and geosynthetics (geotextiles and geonets). Design considerations for these conventional leachate collection materials include shear strength (side slopes), permeability, filtration and puncture resistance. The use of tire chips would add a consideration of compressibility.

Tire chip leachate collection layers have been used in the following projects:

- Quarry Sanitary Landfill and Recycling Center (17);
- Muskogee Community Landfill (21);
- North Texas Municipal Water District Landfill (1); and
- Sioux City Landfill (10).

The tire chips were placed directly on a thick compacted clay liner (1) or on a granular cushion over the synthetic component of a composite liner system (17, 21).

3.3.2 Pipe Bedding

The purpose of a pipe bedding layer is to provide discharge capacity and structural support to the leachate collection pipe.

These layers typically are located in a collection trench directly above the geomembrane component of the composite liner system. Conventional materials used in these layers are granular soils. Design considerations for these conventional drainage materials include compressibility, permeability, filtration and puncture resistance.

The compressibility of tire chips is a major limitation for this application, since the performance of plastic leachate collection piping depends on an incompressible backfill support (6). No case histories have used tire chips as a leachate collection pipe bedding material.

3.3.3 Leachate Recirculation Trenches

The purpose of a leachate recirculation trench is to inject leachate collected from the leachate collection and recovery system back into the waste mass. These trenches typically are constructed within the waste during the progress of waste deposition. Conventional backfill materials used in these trenches are granular soils. Design considerations for these conventional backfill materials include filtration and permeability. In this application, the compressibility of the tire chips is comparable to the surrounding waste and is not a major limitation.

Tire chips were used in the Alachua County Southwest Landfill (28) recirculation trench backfill. No geotextiles or other filter media were used.

3.4 Landfill Gas Control Systems

Potential uses in landfill gas control systems include collection and venting layers and gas migration control trenches.

3.4.1 Gas Collection and Venting Layer

The purpose of a gas collection and venting layer is to provide control and discharge of landfill gas under active or passive extraction. These layers typically are located directly beneath the infiltration layer in the closure cap. Conventional materials used in these layers include granular soils and geosynthetics (geotextiles and geonets).

Design considerations for these conventional materials include shear strength (on side slopes), permeability, and filtration. The use of tire chips would add considerations of puncture resistance (against a synthetic liner) and leachability.

No case histories have been identified that used tire chips in the gas collection and venting layer. However, it is anticipated that their performance would be similar to that of the cap drainage layer case history presented previously.

3.4.2 Gas Control Trenches

The purpose of a gas migration control trench is to minimize lateral migration and control and discharge of landfill gas under active or passive extraction. These trenches typically are located outside the landfill footprint. Conventional materials used in these layers include granular soils and geosynthetics. Design considerations for these conventional drainage materials include filtration and permeability. The use of tire chips would add a consideration of leachability, if the trench was excavated into the water table.

Tire chips were used as gas control trench backfill at the Norton County Landfill Incinerator (20). This trench was excavated above the water table, so leaching was not a design concern. No geotextiles or filter media were used between the native soil trench walls and the tire chips.

3.5 Groundwater Control Systems

Potential uses in groundwater control systems include groundwater control trenches. The purpose of these trenches is to provide positive control and discharge of groundwater. Conventional backfill materials used in these trenches include granular soils and geosynthetics. Design considerations for these conventional backfill materials include filtration and permeability. The use of tire chips would add considerations of compressibility (under high fills) and leachability.

3.6 Operational Uses

Potential tire chip applications in landfill operations include protective cover soil; and daily and intermediate cover.

3.6.1 Protective Cover Soil

The purpose of a cover soil layer is to protect the underlying leachate collection and composite liner systems from damage during construction and operation. These layers typically are located directly above the leachate collection layer.

Conventional materials used in these layers include soils or select waste, depending on the permeability requirements of the cover and the design capacity of the leachate collection and recovery system. Designs based on handling rainfall and run-on as leachate will require a permeable cover soil to move the water down to the leachate collection system. Designs based on handling rainfall and run-on as storm water runoff will require a less permeable cover soil. Design considerations for these conventional cover soil materials include shear strength (side slopes), filtration and permeability.

The use of tire chips would add a considerations of compressibility. The high permeability of tire chips is a major limitation for this application if a less permeable cover is desired.

Tire chips have been used as a permeable protective cover at the Quarry Sanitary Landfill and Recycling Center (17) and the East Oak Landfill (26).

3.6.2 Daily and Intermediate Cover

The purpose of daily and intermediate covers is to control disease vectors, fires, odors, blowing litter, scavenging, and minimize infiltration and leachate generation. Intermediate cover also serves to support vegetative growth. Conventional materials used in these layers are soils and synthetic materials.

The high permeability of tire chips can be a limitation for this application, since the high void space in a tire chip layer limits its effectiveness in controlling disease vectors, odors, and infiltration. In addition, the tire chips are flammable. However, tire chips may be an appropriate daily cover for controlling litter and deterring scavenging when an area will be filled in the near term. The Roberts County landfill reported that a 50/50 mix of tire chips with clay kept daily cover stockpiles from freezing and result in material which was easy to work with and spread evenly in thin or thick lifts (3).

3.7 Summary

These case histories suggest a wide geographic acceptance of tire chips as a substitute for conventional granular materials in landfill applications. The case histories indicate that none of the major design considerations presented on Table 2-1 preclude the use of tire chips. Laboratory test results and design analyses can address these considerations and establish the feasibility of using tire chips in a specific landfill application.

Tire chips are suitable for the following landfill applications:

- Closure cap drainage layers (depending on water quality limitations)
- Leachate collection layers
- Leachate recirculation trenches
- Landfill gas collection layers and trenches (above the ground water table)
- Groundwater control trenches (depending on water quality limitations)
- Daily and intermediate cover supplement

Tire chips have limitations for the following landfill applications:

- Protective cover soil
- Daily or intermediate cover soil
- Leachate collection pipe bedding

SECTION 4 - PRELIMINARY DESIGNS

4.1 Design Approach

This section presents preliminary designs for a landfill leachate collection layer, a gas venting layer and a perimeter gas control trench using tire chips as the permeable material. The designs were prepared for the City of Lincoln's landfills. The design approach consisted of the following steps:

- Establish the major design considerations for each component.
- Evaluate the required physical properties of the conventional materials and the tire chips.
- Conduct analyses to demonstrate equivalent performance of the tire chips.
- Determine costs for each alternative.
- Establish specification requirements, including Quality Control and Quality Assurance activities.
- Prepare design sketch and details.

4.2 Leachate Collection Layer

The major design considerations for a leachate collection layer are:

- Permeability under high waste fill stresses.
- Puncture damage to the underlying geomembrane component of the composite liner system.
- Effective filtration to prevent clogging.

The leachate collection layer for the recently completed Phase 6 of the Bluff Road Landfill consists of 6 inches of Nebraska Department of Roads (NDOR) "Gravel for Surfacing" material (11). This section was optimized during design to provide a cost effective leachate collection layer.

Analyses and laboratory testing conducted during the design phase demonstrated the following performance of this material:

- A permeability of 0.2 cm/sec.

- Adequate puncture resistance against the underlying geomembrane.

- Potential clogging from the overlying protective cover soil. A non-woven geotextile was incorporated as a filtration layer between these layers.

Analyses were conducted to demonstrate the performance of tire chips as an equivalent leachate collection material. The tire chip physical properties were taken from the data presented in Section 2.

The results of these analyses indicated that a nominal 4 inches of tire chips provides equivalent flow capacity (transmissivity) as 6 inches of the NDOR gravel. However, thicker layers, on the order of 9 to 12 inches, may be required to accommodate conventional placement techniques and construction tolerances.

Since the leachate collection system at the Landfill includes only 6 inches of granular drainage material, no cost savings may be realized. The cost benefits may actually be negative since the tire chips would occupy marketable landfill air space.

If the City of Lincoln were to undertake the demonstration of an alternate liner using only recompacted clay, tire chips may be feasible. In this case, the granular cushion would not be required and the 6 inches of NDOR gravel could be replaced by the tire chips.

Approximately 44,000 tires per acre could be utilized in either leachate collection system option. Cost estimates for this application are presented in Section 5.

4.3 Gas Venting Layer

The major design considerations for a gas venting layer in a landfill closure cap are:

- Permeability for gas transmission (dispersivity).

- Shear strength for side slope sliding stability.

- Effective filtration to prevent clogging.

Preliminary closure cap designs have been presented in the Permit Application (11). The proposed closure cap side slopes are 1V:4H. The preliminary designs consisted of the following components:

- An 18 inch thick erosion layer; overlying

- An 18 inch thick infiltration layer, consisting of a recompacted clay layer or a composite clay layer and geomembrane; overlying

- A 6 to 12 inches thick granular soil gas venting layer. The need for this layer may be subject to change, based upon New Source Performance Standards (NSPS) requirements for active gas extraction.

Analyses were conducted to demonstrate the performance of tire chips as an equivalent gas venting material. The tire chip physical properties were taken from the data presented in Section 2. The results of these analyses indicated the following:

- A tire chip gas venting layer has approximately 100 percent more dispersivity (gas flow capacity) than conventional aggregate backfill.

- Side slope stability of a tire chip layer is slightly less than for a granular soil layer; however, the factor of safety is adequate.

- Filtration performance of tire chips is comparable to conventional aggregates.

- Approximately 87,000 tires per acre of closure cap could be utilized in this application. Cost estimates for this application are presented in Section 5.

- Placement of the overlying recompacted clay layer could be complicated by the compressibility of the underlying tire chips. However, this construction sequence is typical of tire chip applications used in road subgrades (12).

- Additional design, construction and quality assurance costs are negligible for this application.

4.4 Gas Control Trench

The major design considerations for a perimeter gas control trench are:

- Permeability for gas transmission (dispersivity).

- Effective filtration to prevent clogging.

- Leachability of tire chips below the water table.

The alternative designs consisted of the following components:

- A trench, nominally 18 feet deep by 5,000 feet long, excavated 1 to 2 feet below the water table.

- Granular soil backfill and 2 feet thick clay cap.

- Perforated piping and vents installed near the top of the trench.

- Optional geomembrane on the down gradient side of the trench to provide a barrier against continued gas migration across the collection trench.

A slurry wall barrier was also considered in the original evaluation (9). This barrier is potentially better than either vented trench design, but was not considered in the present analysis because of the emphasis on tire chips versus conventional aggregate backfill.

Analyses were conducted to demonstrate the performance of tire chips as an equivalent granular backfill. The tire chip physical properties were taken from the data presented in Section 2. The results of these analyses indicated the following:

- A tire chip backfilled gas collection trench has approximately 100 percent more dispersivity (gas flow capacity) than conventional aggregate backfill. This higher dispersivity might eliminate the need for the downgradient geomembrane.

- Tire chip performance is comparable to conventional aggregates in puncture and filtration.

- Tire chips below the ground water table may leach metals. A composite section. using conventional aggregates below the water table and tire chips above, may be preferable.

- Approximately 300,000 tires could be utilized in this application. Cost estimates are presented in Section 5.

- Additional design, construction and quality assurance costs are negligible for this application.

4.5 Materials Specifications

Construction specifications for recent tire chip fills have been based on the "methods and materials" format used by various state roads departments (12). The "materials" portion of these specifications have established requirements only for the tire chip maximum size, chip gradation, and maximum wire percentage. The "methods" portions of these specifications have required a prescriptive construction sequence consisting of spreading tire chips with track mounted equipment to provide a maximum 12 inches compacted layer thickness; and compacting with 5-6 passes of a vibrator smooth drum roller or crawled tractor.

The measurement and payment portion of these specifications have been based on in-place unit prices. Both cubic yard and ton unit prices have been used. The ton basis is preferred due to the high compressibility of the tire chips.

HDR developed a preliminary specification for City of Lincoln landfill construction and closure using tire chips. This specification is based on a performance requirement (design-by-function) for the materials, a method specification for construction, and a per ton basis for measurement and payment.

This preliminary specification was based on the Construction Specification Institute (CSI) three-part format and deals only with tire chip component of construction. The test methods for the tire chip physical properties are based on methodology presented in the ASTM draft "Specification for Use of Scrap Tires in Civil Engineering Applications" which was prepared by Dr. Dana Humphrey and is currently being balloted at the ASTM subcommittee level.

SECTION 5 - LOCAL MARKETS

5.1 Local Recyclers

Nebraska tire recyclers were surveyed regarding physical properties and costs of available tire chip products. All recyclers use slow speed, shear shredders to produce tire chips. Recyclers use mobile shredding and support equipment.

Two recyclers produce a 2 to 3 inch nominal size tire chip for use in civil engineering applications. One also produces a 1 inch tire chip for use as tire derived fuel at the Nebraska Public Power District Sheldon Station, in Hallam, Nebraska.

5.2 Physical Properties

Neither recyclers had any technical data on the engineering and physical properties of their tire chips. The only requirements for their civil engineering applications have been size and gradation limits, ranging from rough shred size to a 3 inch nominal chip size. The 2-3 inch nominal tire chip size would fall within the property ranges presented in Section 2.

5.3 Tire Chip Yield

The tire chip yield, in tires per cubic yard of volume, depends upon the tire chip size and degree of compaction. Reported values for tire chips range from 35 tires per cubic yard (7) to 75 tires per cubic yard (12), in loose and compacted conditions, respectively. Based on an average passenger car tire weight of 20 pounds per tire, the range in tire chip yields is presented on Table 5-1, below.

Table 5-1
Tire Yield

Tire Chip Size	Density	Avg. Unit Weight (lbs./cy)	Avg. yield (tires/cy.)
Rough shreds	loose	500	25
	dense	1200	60
2-3 inch chips	loose	700	35
	dense	1500	75

5.4 Unit Costs

The cost of recycled tire chips is driven by two considerations:

1. The nominal tire chip size; and
2. The allowable amount of bead and belt wire.

The slow speed shredders use sets of knife blades or geared shafts to shred the tires and produce the tire chips. After shredding, the chips fall onto a classifier screen, which is set for the desired chip size. Chips smaller than the screen openings fall through the screen, while oversize chips are cycled back through the shredder. This additional processing to a smaller tire chip size increases costs due to higher knife wear and a lower production rate.

Loose bead and belt wire may be removed by an in-line magnet after the tire chips fall through the sizing screens. Higher levels of removal are accomplished by debeading the whole tire prior to shredding and/or processing the tire chips to a smaller size. Both steps increase tire chip costs.

Typical production costs (23, 25) for the various tire chip sizes are presented on Table 5-2. The yield data from Table 5-1 was used to compute costs per cubic yard of tire chips.

Table 5-2
Tire Chip Costs

Tire Chip Size (Nominal size)	Production Rate (Tires/hour)	Cost		
		($/Ton)	($/loose cy)	($/compact cy)
Rough Shred	3,000	5.00	1.25	3.00
2-3 inches	2,000	20.00	7.00	15.00

Shipping costs per ton were assumed to be similar to other construction materials. However, the low unit weight of tire chips will result in volume, rather than weight, controlling loaded truck capacity.

5.5 Cost Estimates

Cost estimates for the three preliminary designs presented in Section 4 are summarized Table 5-3 below. This table presents the delivered materials costs for conventional aggregates and the tire chip alternate. Construction equipment and methods are the same for either material alternative and were not considered further.

Table 5-3
Cost Estimates

Landfill Application	Unit of Measure	Tire Chips	Granular Aggregate	Tire Utilization
Liquids Collection on Geomembrane	Acre	$20,900	$ 11,800	44,000
Liquids Collection on Clay Liner	Acre	$ 9,100	$ 11,800	44,000
Gas Collection Layer	Acre	$18,300	$ 23,500	87,100
Gas Collection Trench	5,000 l.f.	$93,800	$137,700	300,000

SECTION 6 - CONCLUSIONS

6.1 Summary

A review of the literature on tire chip utilization indicated the following:

- Tire chips have been used in landfill construction and closure as an alternative to conventional granular materials.
- Tire chips have the physical properties of a compressible granular material.
- The computational methods used to demonstrate tire chip performance essentially are the same methods used for granular materials.

6.2 Data Gaps

Two areas have been identified that could effect the broader acceptance of tire chips for landfill applications:

- Lack of standardized test methods for tire chips.
- The puncturing potential of adjacent layers of synthetic liners.

Current physical tests on tire chips are been conducted using modified ASTM methods for soils or aggregate. However, to provide uniformity in procurement and performance evaluation, a construction specification would need to identify appropriate ASTM methods and detail the permissible method deviations.

This task is in the early stages of development within ASTM Committee D-34, "Waste Management." A draft specification, Z5499Z, "Specifications for Use of Scrap Tires in Civil Engineering Applications," has been balloted at the ASTM subcommittee level and has been proposed for balloting by the main committee.

The consensus of opinion suggests bead and belt wire embedded in tire chips may puncture a synthetic liner. Only one case history was identified which used tire chips in contact with a synthetic liner. Current practice suggests that a nominal 6 inch soil cushion provides adequate puncture protection between a tire chip layer and a geomembrane. These data gaps are not significant obstacles to the broader use of tire chips in landfill applications.

6.3 Regulatory Issues

A review of the literature and case histories suggests that two issues could impact the regulatory acceptance of tire chips:

- Technical equivalency compared to conventional granular materials.
- Water quality impacts.

As noted in the previous sections, the physical properties fall within the ranges for conventional granular materials. Analytical methods (30), combined with laboratory test results, are available to demonstrate the technical equivalency of tire chips.

The water quality issue could be a concern for applications where the tire chips are in contact with ground water or infiltration, such as closure cap drainage layers, ground water control structures, or gas migration control trenches excavated into the water table.

6.4 Landfill Program Viability

The viability of tire chips for use in landfill applications has been established based on technical considerations of tire chip performance and case histories.

Cost savings for a specific tire chip application will depend on local materials costs and additional design features, i.e., granular cushion layers or geotextile filters.

General program considerations are presented below.

6.4.1 Applications

Tire chips are technically viable for the following applications:

- Closure cap drainage layers;
- Leachate collection layer;
- Gas collection layers and trenches;
- Ground water control trenches (portions above the water table); and
- Daily, intermediate and protective cover.

Tire chips may not be economically viable for leachate collection layers directly above the geomembrane component of a composite liner or capping system.

Tire chips are generally not appropriate for the following applications:

- Leachate collection pipe bedding; and
- Daily, intermediate and protective cover.

However, mixing of tire chips with soil may allow them to be used in cover systems. The alternative designs using tire chips are based on current RCRA (30) regulations and guidance. Changes to these regulations could effect the technical viability of tire chips in landfill gas applications.

6.4.2 Potential Benefits

The utilization of tire chips in civil engineering applications is an emerging market, subject to variability in costs of materials and contractors' perceptions of risk associated with tire chip construction.

The viable applications for tire chip utilization in the City of Lincoln landfill program offer an opportunity for beneficial reuse of a significant number of scrap tires and a cost savings compared to conventional aggregates.

Based on the "rule-of thumb" of one scrap tire per person per year and a Lincoln population of 204,100 (*1996 Commercial Atlas*), 204,100 scrap tires are generated every year. These tires could be utilized in the City of Lincoln landfill program as follows:

- The gas collection trench could utilize over one year's scrap tire generation; or
- A 5 acre leachate collection layer could utilize one year's scrap tire generation; or
- A 3 acre gas collection layer in the closure cap could utilize one year's scrap tire generation.

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30

LABORATORY TESTING
SUMMARY REPORT
TIRE CHIP EVALUATION
PERMEABILITY AND LEACHABILITY
ASSESSMENTS

ADDENDUM NO. 24-NR

PERFORMED FOR:

Waste Management of North America, Inc.
Northeast Region EMD Office
1121 Bordentown Road
Morrisville, PA 19067

PERFORMED BY:

J&L Testing Company, Inc.
938 South Central Avenue
Canonsburg, PA 15317

MAY 31, 1989

J & L TESTING COMPANY, INC.

GEOTECHNICAL, GEOMEMBRANE, GEOTEXTILE AND CONSTRUCTION MATERIALS TESTING AND RESEARCH

May 31, 1989

Job No. 89R414-01
Addendum No. 24-NR

Waste Management of North America, Inc.
Northeast Region EMD Office
1121 Bordentown Road
Morrisville, PA 19067

Attention: Mr. Anthony W. Eith, P.E.
Manager - Engineering Services

RE: SUMMARY REPORT
TIRE CHIP EVALUATION
PERMEABILITY AND LEACHABILITY
ASSESSMENTS

Gentlemen:

Presented herein are the results of our test program assessing the use of tire chips as a lower drainage medium in municipal landfills.

LEACHABILITY EVALUATION

As part of our test program the potential for tire chips to release contaminates when exposed to leachate was assessed. To evaluate the potential, leachate column tests were performed using leachate from the Lakeview Landfill.

The test procedure involved the placement of tire chips in leachate columns (8" diameter x 48" long) and controlling the flow of leachate through the tire chips. Analytical tests were performed on the leachate prior to exposure to the tire chips and at prescribed time intervals on effluent leachate samples after exposure to evaluate changes in the constituents. The tests were performed in two (2) columns at temperatures of 23°C and 50°C. Figure 1 presents a schematic of the leachate column apparatus. Approximately 45 gallons of leachate passed through each column over a 90-day period. Leachate samples were extracted at 0 (raw leachate), 30, 60 and 90 day intervals. Analytical tests were performed to obtain the following parameters over this time period:

The tire chips removed from the 50°C leachate column are being maintained (saturated) at a load of approximately 13,000 psf to evaluate any extended term effects. As of May 30, 1989 no change in permeability was evident. We will however periodically perform permeability testing of this sample and report the data if the the values change from those presented herein.

Data sheets titled, "Co-efficient of Permeability" presenting the actual permeability test data and applicable physical properties are presented in Appendix A. Table 2 presents a summary of the physical properties data. The enclosed Figure 3 includes illustrations of load vs. permeability and load vs. strain for each of the tests.

We appreciate the opportunity to provide WMNA with our speciality services in these highly critical areas of research.

If you have any questions regarding the enclosed data, please call.

Sincerely,

J&L TESTING COMPANY, INC.

Dean E. Ferry
Manager - Geotechnical Research & Development

DEF/sjs
L-S#498

TABLES

TABLE 1

SUMMARY OF ANALYTICAL TEST DATA

SAMPLE IDENTIFICATION:	RAW LEACHATE LANCY	RAW LEACHATE NUS	30 DAY TEST 23°C	30 DAY TEST 50°C	60 DAY TEST 23°C	60 DAY TEST 50°C	90 DAY TEST (1) 23°C	90 DAY TEST (1) 50°C
PARAMETER, mg/l	Sample Date 4-13-89	Sample Date 2-27-89						
pH	8.0	7.3	7.3	8.0	7.3	8.1	6.9	7.8
Reactivity - Cyanide	<2.0	<10	<10	<10	<2.0	<2.0	<2.0	<2.0
Reactivity - Sulfide	30	30	30	15	<10	<10	<10	13
Arsenic	0.009	0.017	0.007	0.015	0.02	0.02	0.006	0.004
Barium	0.05	0.2	0.7	<0.1	0.09	0.04	0.24	0.04
Cadmium	<0.004	<0.005	<0.005	<0.005	<0.004	<0.004	<0.008	<0.008
Chromium	0.01	0.03	0.09	<0.03	0.03	<0.006	0.04	0.02
Lead	0.12	<0.05	<0.05	<0.05	<0.1	<0.1	<0.010	<0.010
Mercury	<0.0002	<0.0004	<0.0004	<0.0004	<0.0002	<0.0002	<0.0002	<0.0002
Selenium	<0.002	<0.005	<0.005	<0.005	<0.01	<0.01	<0.004	<0.004
Silver	0.01	<0.02	<0.02	<0.02	<0.01	<0.01	0.02	0.02

NOTE:

1) Following retrieval of the 60 day sample, fresh leachate was added to the reserve tank supplying the leachate columns. This may have effected the 90 day test results.

TABLE 2

SUMMARY OF PHYSICAL PROPERTIES
PERMEABILITY TEST SAMPLES

SAMPLE IDENTIFICATION	NORMAL LOAD (psf)	WEIGHT (cm)	VOLUME $(cm)^3$	DENSITY (pcf)
Test Date:	2500	33.0	28,248	49.7
2-13-89	5000	27.9	23,882	58.8
(Water)	10000	24.1	20,630	68.1
	15000	22.9	19,602	71.6
Test Date:	0	28.2	24,139	58.2
4-26-89	2500	26.2	22,427	62.6
(Water)	5000	24.6	21,058	66.7
	10000	23.1	19,774	71.0
	15000	22.1	18,918	74.2
	20000	20.6	17,634	79.6
Test Date:	2500	22.9	19,602	47.5
5-22-89	5000	19.7	16,863	55.2
(Leachate From	10000	17.1	14,638	63.6
Column @ 23°C)	15000	15.2	13,011	71.5
	20000	14.6	12,498	74.5
Test Date:	2500	24.1	20,630	47.3
5-23/24-89	5000	22.1	18,918	51.5
(Leachate From	10000	19.3	16,521	59.0
Column @ 50°C)	15000	18.0	15,408	63.3
	20000	17.5	14,980	65.1

FIGURES

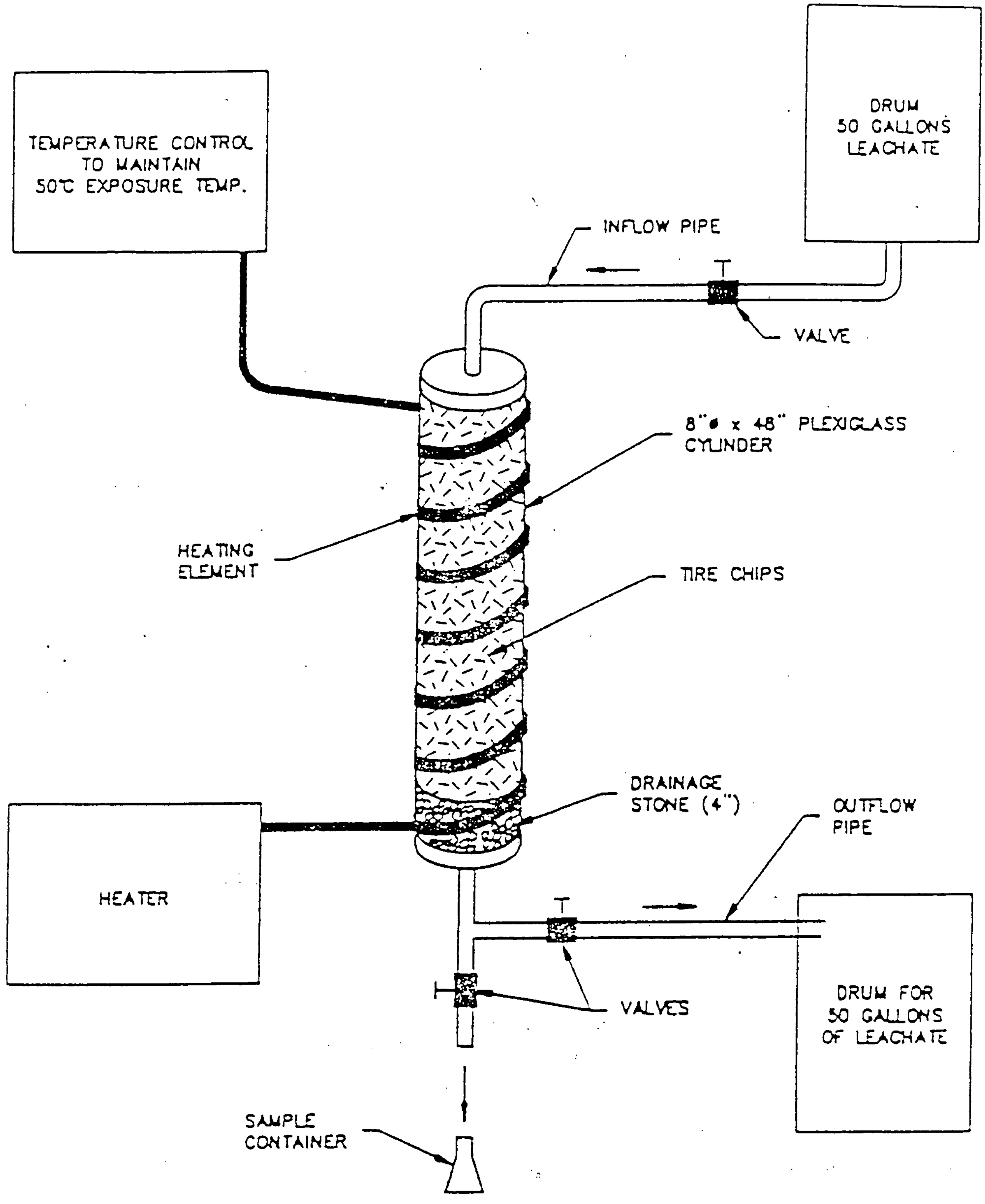

FIGURE 1

LEACHATE COLUMN APPARATUS SCHEMATIC

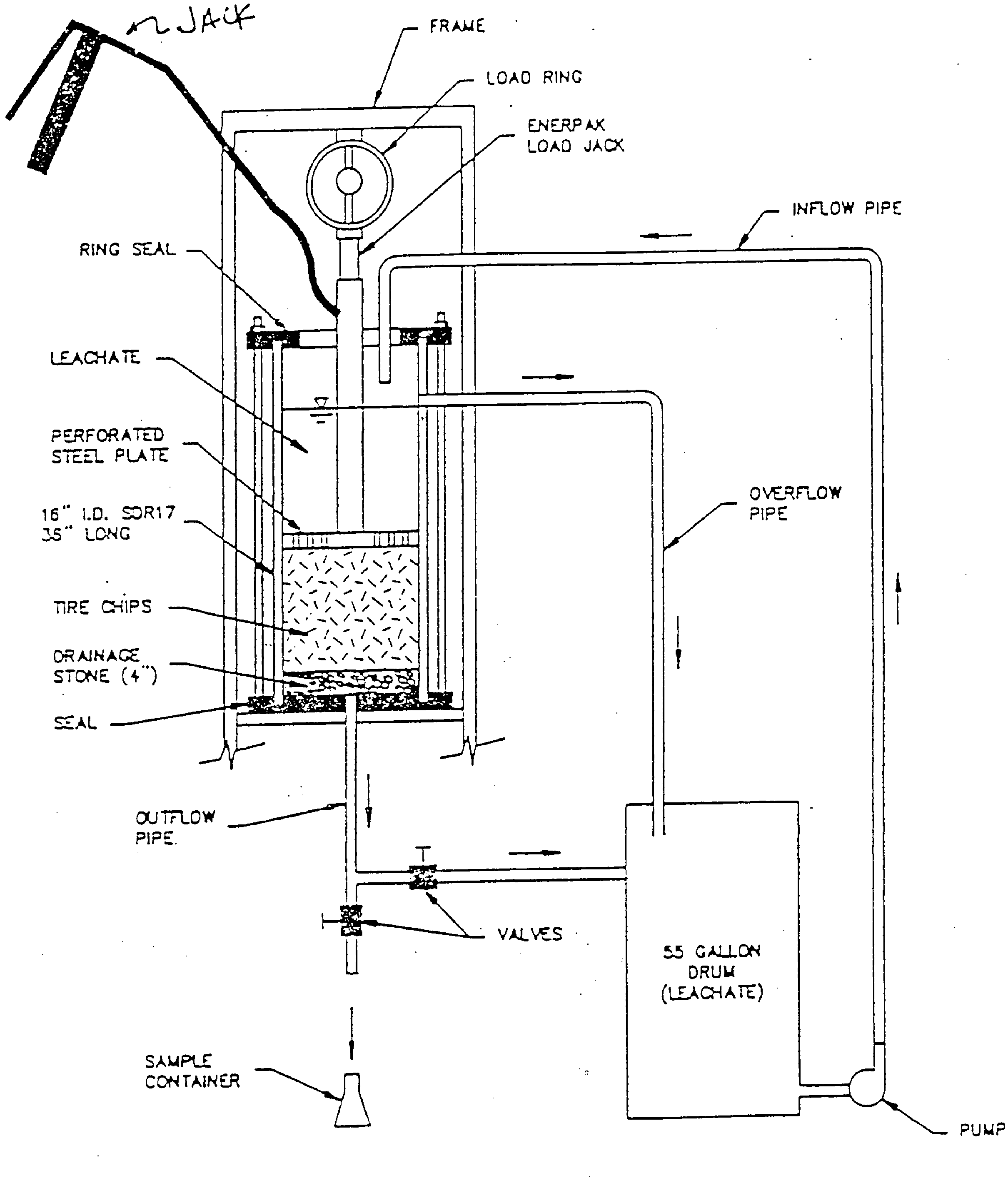

FIGURE 2

CONSTANT HEAD PERMEABILITY APPARATUS
SCHEMATIC

TEST RESULTS
TIRE CHIP PERMEABILITY

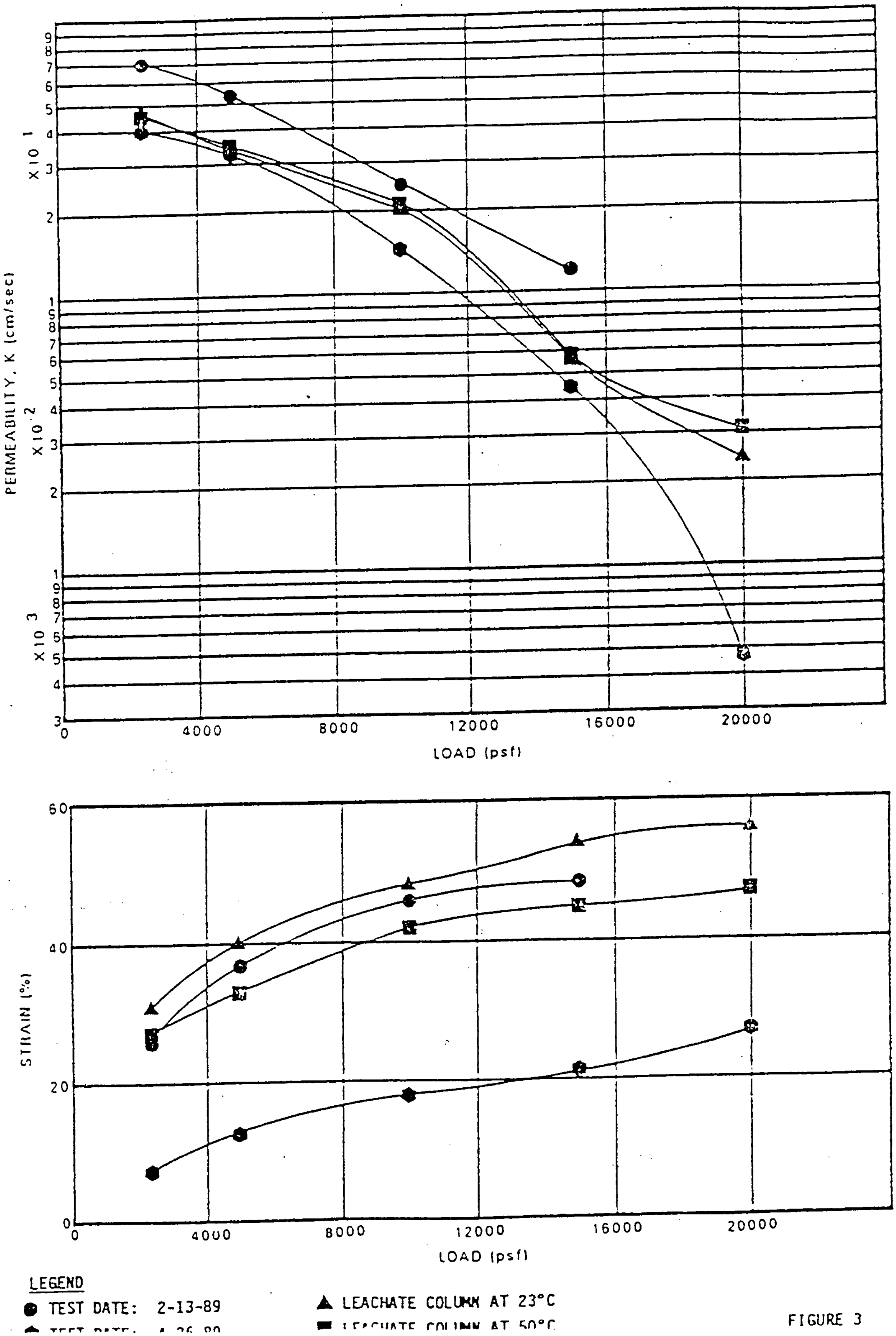

FIGURE 3

APPENDIX A

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project Tire Chip Evaluation Job No. 89R414-01

Location of Project WMNA

Description of Soil Chipped Tires

Tested by DEF Date of Testing 2-13-89

Constant Head

Mold dimensions: Diam. 33.0 cm; Ht. 33.0 cm; Area 856 cm²; Vol. 28,248 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = --- Unit wt. 49.7 pcf

Wt. of soil = 24,498 gm

h = 69 cm

Test data — *Test data used* NORMAL STRESS = 2,500 psf

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	16.7	16,324	10				
2	16.9	16,324	10				
3	17.0	16,324	10				
4							
				Average[a]	16.9	16,324	10

$k_T = QL/Aht = \dfrac{(16,324\ cm^3)\ 33.0\ cm}{(856\ cm^2 \times 16.9\ sec)\ 69\ cm}$

$= 5.4 \times 10^{-1}$ cm/sec

$\eta_T/\eta_{20} = 1.3012$

$k_{20} = k_T\eta_T/\eta_{20} = 7.0 \times 10^{-1}$ cm/sec

Falling Head

Standpipe = [burette, other (specify)] ____

Area of standpipe, a = ____ sq cm

Test data[b] — *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ____

$k_T = \dfrac{2.3aL}{At}\operatorname{Log} h_1/h_2$ = ____ = ____ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ____ = ____ cm/sec

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b]This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project Tire Chip Evaluation Job No. 89R414-01

Location of Project WMNA

Description of Soil Chipped Tires

Tested by DEF Date of Testing 2-13-89

Constant Head

Mold dimensions: Diam. 33.0 cm; Ht. 27.9 cm; Area 850 cm²; Vol. 23,882 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = --- Unit wt. 58.8 pcf

Wt. of soil = 24,498 gm

h = 69 cm

Test data *Test data used* Normal Stress = 5,000 psf

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	20.2	16,324	10				
2	18.6	16,324	10				
3	18.2	16,324	10				
4							
				Average[a]	19.0	16,324	10

$k_T = QL/Aht = \frac{(16{,}324\ cm^3)\ 27.9\ cm}{(856\ cm^2 \times 19.0\ sec)\ 69\ cm}$

$= 4.1 \times 10^{-1}$ cm/sec

$\eta_T/\eta_{20} = 1.3012$

$k_{20} = k_T\eta_T/\eta_{20} = 5.3 \times 10^{-1}$ cm/sec

Falling Head

Standpipe = [burette, other (specify)] ______

Area of standpipe, a = ______ sq cm

Test data[b] *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ______

$k_T = \frac{2.3aL}{At} \text{Log } h_1/h_2$ = ______ = ______ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ______ = ______ cm/sec

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.
[b]This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project: Tire Chip Evaluation — Job No. 89R414-01

Location of Project: WMNA

Description of Soil: Chipped Tires

Tested by: DEF — Date of Testing: 2-13-89

Constant Head

Mold dimensions: Diam. 33.0 cm; Ht. 24.1 cm; Area 856 cm²; Vol. 20,630 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = ---

Wt. of soil = 24,498 gm

Unit wt. 68.1 pcf

h = 69 cm

Test data / *Test data used* Normal Stress = 10,000 psf

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	34.1	16,324	10				
2	34.7	16,324	10				
3	36.2	16,324	10				
4							
				Average[a]	35.0	16,324	10

$k_T = QL/Aht = \frac{(16{,}324\ cm^3)\ 24.1\ cm}{(856\ cm^2 \times 35.0\ sec)\ 96\ cm} = 1.9 \times 10^{-1}$ cm/sec

$\eta_T/\eta_{20} =$ 1.3012

$k_{20} = k_T \eta_T/\eta_{20} =$ 2.5×10^{-1} cm/sec

Falling Head

Standpipe = [burette, other (specify)] -

Area of standpipe, a = ______ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t, sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no.	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

$\eta_T/\eta_{20} =$ ______

$k_T = \frac{2.3aL}{At} \text{Log}\ h_1/h_2 =$ ______ = ______ cm/sec

$k_{20} = k_T \eta_T/\eta_{20} =$ ______ = ______ cm/sec

[a] Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b] This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project: Tire Chip Evaluation   Job No.: 89R414-01

Location of Project: WMNA

Description of Soil: Chipped Tires

Tested by: DEF   Date of Testing: 2-13-89

Constant Head

Mold dimensions: Diam. 33.0 cm; Ht. 22.9 cm; Area 856 cm²; Vol. 19,602 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = ---   Unit wt.: 71.6 pcf

Wt. of soil = 24,498 gm

h = 69 cm

Test data   *Test data used* Normal Stress = 15,000 psf

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	65	16,324	10				
2	68	16,324	10				
3							
4							
				Average[a]	67	16,324	10

$k_T = QL/Aht = \dfrac{(16{,}324\ \text{cm}^3)\ 22.9\ \text{cm}}{(856\ \text{cm}^2 \times 67\ \text{sec})\ 69\ \text{cm}}$ η_T/η_{20} = 1.3012

$=$ 9.4×10^{-2} cm/sec $k_{20} = k_T\eta_T/\eta_{20} =$ 1.2×10^{-1} cm/sec

Falling Head

Standpipe = [burette, other (specify)] -

Area of standpipe, a = ______ sq cm

Test data[b]   *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no.	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ______

$k_T = \dfrac{2.3aL}{At}\text{Log}\, h_1/h_2$ = ______ = ______ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ______ = ______ cm/sec

[a] Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b] This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

J & L TESTING COMPANY

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project: Tire Chip Evaluation — Job No. 89R414-01

Location of Project: Waste Management of North America, Inc.

Description of Soil: Chipped Tires

Tested by: DEF — Date of Testing: 4-26-89

Constant Head

Mold dimensions: Diam. 33.0 cm ; Ht. 28.2 cm ; Area 856 cm² ; Vol. 24139 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = ---

Unit wt. 58.2 pcf

Wt. of soil = 22498 gm

h = 69 cm

TOTAL STRAIN = 0

NORMAL STRESS = 0

Test data / *Test data used*

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	15	16324	21				
2							
3							
4							
				Average [a]	15	16324	21

$k_T = QL/Aht = \frac{(16324\ cm^3)\ 28.2\ cm}{(856\ cm^2 \times 15\ sec)\ 69\ cm} = 5.2 \times 10^{-1}$ cm/sec

$\eta_T/\eta_{20} =$ 0.9761

$k_{20} = k_T\eta_T/\eta_{20} =$ 5.1×10^{-1} cm/sec

Falling Head

Standpipe = [burette, other (specify)] ______

Area of standpipe, a = ______ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no.	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

$\eta_T/\eta_{20} =$ ______

$k_T = \frac{2.3aL}{At} \text{Log}\, h_1/h_2 =$ ______ = ______ cm/sec

$k_{20} = k_T\eta_T/\eta_{20} =$ ______ = ______ cm/sec

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b]This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

J & L TESTING COMPAN[Y]
Geotechnical Testi[ng]

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project Tire Chip Evaluation Job No. 89R414-01

Location of Project Waste Management of North America, Inc.

Description of Soil Chipped Tires

Tested by DEF Date of Testing 4-26-89

Constant Head

Mold dimensions: Diam. 33.0 cm; Ht. 26.2 cm; Area 856 cm^2; Vol. 22427 cm^3

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = --- Unit wt. 62.6 pcf

Wt. of soil = 22498 gm Total Strain = 7.2%

h = 69 cm Normal Stress = 2500 psf

Test data / *Test data used*

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	17	16324	21				
2							
3							
4							
				Average[a]	17	16324	21

$k_T = QL/Aht = \frac{(16324\ cm^3)\ 26.2\ cm}{(856\ cm^2 \times 17\ sec)\ 69\ cm} = 4.3 \times 10^{-1}$ cm/sec

$\eta_T/\eta_{20} = 0.9761$

$k_{20} = k_T\eta_T/\eta_{20} = 4.2 \times 10^{-1}$ cm/sec

Falling Head

Standpipe = [burette, other (specify)] ______

Area of standpipe, a = ______ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ______

$k_T = \frac{2.3aL}{At}\text{Log}\ h_1/h_2$ = ______ = ______ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ______ = ______ cm/sec

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b]This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

J & L TESTING COMPANY

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project Tire Chip Evaluation Job No. 89R414-01

Location of Project Waste Management of North America, Inc.

Description of Soil Chipped Tires

Tested by DEF Date of Testing 4-26-89

Constant Head

Mold dimensions: Diam. 33.0 cm ; Ht. 24.6 cm ; Area 856 cm² ; Vol. 21058 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = --- Unit wt. 66.7 pcf

Wt. of soil = 22498 gm Total Strain = 12.6%

h = 69 cm Normal Stress = 5000 psf

Test data / *Test data used*

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	20	16324	21				
2							
3							
4							
				Average[a]	20	16324	21

$k_T = QL/Aht = \dfrac{(16324\ cm^3)\ 24.6\ cm}{(856\ cm^2 \times 20\ sec)\ 69\ cm}$ = 3.4×10^{-1} cm/sec

η_T/η_{20} = 0.9761

$k_{20} = k_T\eta_T/\eta_{20}$ = 3.3×10^{-1} cm/sec

Falling Head

Standpipe = [burette, other (specify)] ____________

Area of standpipe, a = ____________ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no.	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ____________

$k_T = \dfrac{2.3aL}{At}\text{Log}\ h_1/h_2$ = ____________ = ____________ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ____________ = ____________ cm/sec

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b]This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project: Tire Chip Evaluation Job No. 89R414-01

Location of Project: Waste Management of North America, Inc.

Description of Soil: Chipped Tires

Tested by: DEF Date of Testing: 4-26-89

Constant Head

Mold dimensions: Diam. 33.0 cm; Ht. 23.1 cm; Area 856 cm²; Vol. 19774 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = --- Unit wt. 71.0 pcf

Wt. of soil = 22498 gm

h = 69 cm

Total Strain = 18.0%

Normal Stress = 10,000 psf

Test data / *Test data used*

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	42	16324	21				
2							
3							
4							
				Average[a]	42	16324	21

$$k_T = QL/Aht = \frac{(16324\ cm^3)\ 23.1\ cm}{(856\ cm^2 \times 42\ sec)\ 69 cm} = 1.5 \times 10^{-1}\ \text{cm/sec}$$

$$\eta_T/\eta_{20} = 0.9761$$

$$k_{20} = k_T\eta_T/\eta_{20} = 1.5 \times 10^{-1}\ \text{cm/sec}$$

Falling Head

Standpipe = [burette, other (specify)] ____

Area of standpipe, a = ____ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no.	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ____

$k_T = \frac{2.3aL}{At}\text{Log}\ h_1/h_2$ = ____ = ____ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ____ = ____ cm/sec

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b]This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project: Tire Chip Evaluation — Job No.: 89R414-01

Location of Project: Waste Management of North America, Inc.

Description of Soil: Chipped Tires

Tested by: DEF — Date of Testing: 4-26-89

Constant Head

Mold dimensions: Diam. 33.0 cm; Ht. 22.1 cm; Area 856 cm²; Vol. 18918 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = ---

Wt. of soil = 22498 gm

h = 69 cm

Unit wt. 74.2 pcf

TOTAL STRAIN = 21.6%
NORMAL STRESS = 15,000 psf

Test data / *Test data used*

Test No	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	131	16324	21				
2							
3							
4							
				Average[a]	131	16324	21

$$k_T = QL/Aht = \frac{(16324\ cm^3)\ 22.1\ cm}{(856\ cm^2 \times 131\ sec)69\ cm} = 4.7 \times 10^{-2}\ \text{cm/sec}$$

η_T/η_{20} = 0.9761

$k_{20} = k_T\eta_T/\eta_{20}$ = 4.6×10^{-2} cm/sec

Falling Head

Standpipe = [burette, other (specify)] ______

Area of standpipe, a = ______ sq cm

Test data[b] / *Test data used*

Test no	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ______

$k_T = \frac{2.3aL}{At}\log h_1/h_2$ = ______ = ______ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ______ = ______ cm/sec

[a]Use averaged values only if there is a small difference in test temperature, say, 1-2°C.

[b]This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project Tire Chip Evaluation Job No 89R414-01

Location of Project Waste Management of North America, Inc.

Description of Soil Chipped Tires

Tested by DEF Date of Testing 4-26-89

Constant Head

Mold dimensions: Diam. 33.0 cm ; Ht. 20.6 cm ; Area 856 cm^2 ; Vol. 17634 cm^3

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = --- Unit wt. 79.6 pcf

Wt. of soil = 24498 gm Total Strain = 27%

h = 69 cm Normal Stress = 20,000 psf

Test data / *Test data used*

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	1200	16324	21				
2	1110	16324	21				
3	1170	16324	21				
4							
				Average[a]	1160	16324	21

$k_T = QL/Aht = \dfrac{(15324\ cm^3)\ 20.6\ cm}{(856\ cm^2 \times 1160\ sec)\ 69\ cm}$ $= 4.9 \times 10^{-3}$ cm/sec

η_T/η_{20} = 0.9761

$k_{20} = k_T\eta_T/\eta_{20}$ = 4.8×10^{-3} cm/sec

Falling Head

Standpipe = [burette, other (specify)] ______

Area of standpipe, a = ______ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no.	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ______

$k_T = \dfrac{2.3aL}{At} \log h_1/h_2$ = ______ = ______ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ______ = ______ cm/sec

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b]This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project Tire Chip Evaluation   Job No 89R414-01

Location of Project WMNA

Description of Soil Chipped Tires 23°C ▲

Tested by DEF   Date of Testing 5-22-89

Constant Head

Mold dimensions: Diam. 33.0 cm ; Ht. 22.9 ; Area 856 cm^2 ; Vol. 19602 cm^3

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = ---

Wt. of soil = 14914 gm

h = 69 cm

Unit wt. 47.5 pcf

Total Strain = 31%

Normal Stress = 2500 psf

Test data / *Test data used*

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	14	16324	21				
2	12	16324	21				
3	13	16324	21				
4							
				Average [a]	13	16324	21

$$k_T = QL/Aht = \frac{(16324\ cm^3)\ 22.90\ cm}{(856\ cm^2 \times 69\ cm)\ 13\ sec.} = 49 \times 10^{-1}\ cm/sec$$

$$\eta_T/\eta_{20} = 0.9761$$

$$k_{20} = k_T\eta_T/\eta_{20} = 4.8 \times 10^{-1}\ cm/sec$$

Falling Head

Standpipe = [burette, other (specify)] ____

Area of standpipe, a = ____ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no.	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ____

$k_T = \frac{2.3aL}{At} \text{Log}\ h_1/h_2$ = ____ = ____ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ____ = ____ cm/sec

[a] Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b] This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project Tire Chip Evaluation Job No 89R414-01

Location of Project WMRA

Description of Soil Chipped Tires 23°C

Tested by DEF Date of Testing 5-22-89

Constant Head

Mold dimensions: Diam. 33.0 cm ; Ht. 19.7 cm ; Area 856 ; Vol. 16863 cm^3

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = --- Unit wt.: 55.2 pcf

Wt. of soil = 14914 gm Total Strain = 40%

h = 69 cm Normal Stress = 5000 psf

Test data / *Test data used*

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	17	16324	21				
2	16	16324	21				
3	16	16324	21				
4							
				Average[a]	16	16324	21

$$k_T = QL/Aht = \frac{(16324\ cm^3)\ 19.7\ cm}{(856\ cm^2 \times 69\ cm)16} = 3.4 \times 10^{-1}\ \text{cm/sec}$$

η_T/η_{20} = 0.9761

$k_{20} = k_T\eta_T/\eta_{20}$ = 3.3×10^{-1} cm/sec

Falling Head

Standpipe = [burette, other (specify)] ______

Area of standpipe, a = ______ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ______

$k_T = \frac{2.3aL}{At} \text{Log}\ h_1/h_2$ = ______ = ______ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ______ = ______ cm/sec

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b]This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

J & L TESTING COMPANY

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project Tire Chip Evaluation Job No 89R414-01

Location of Project WMNA

Description of Soil Chipped Tires 23°C

Tested by DEF Date of Testing 5-22-89

Constant Head

Mold dimensions: Diam. 33.0 cm ; Ht. 17 cm ; Area 856 cm^2 ; Vol. 14638 cm^3

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = --- Unit wt. 63.6 pcf

Wt. of soil = 14914 gm

h = 69 cm

Total Strain = 48%

Normal Stress = 10000 psf

Test data / *Test data used*

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	24	16863	21				
2	23	16863	21				
3	24	16863	21				
4							
				Average[a]	24	16863	21

$k_T = QL/Aht = \frac{(16863\ cm^3)\ 17.1\ cm}{(856\ cm^2 \times 69\ cm)\ 24\ sec.} = 2.0 \times 10^{-1}$ cm/sec

$\eta_T/\eta_{20} =$ 0.9761

$k_{20} = k_T\eta_T/\eta_{20} =$ 2.0×10^{-1} cm/sec

Falling Head

Standpipe = [burette, other (specify)] ________

Area of standpipe, a = ________ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no.	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ________

$k_T = \frac{2.3aL}{At}\text{Log}\ h_1/h_2$ = ________ = ________ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ________ = ________ cm/sec

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b]This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

J & L TESTING COMPANY

Geotechnical Testing

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project Tire Chip Evaluation Job No 89R414-01

Location of Project WMHA

Description of Soil Chipped Tires 23°C ▲

Tested by DEF Date of Testing 5-22-89

Constant Head

Mold dimensions: Diam. 33.0 cm ; Ht. 15.2 cm ; Area 856 cm^2 ; Vol. 13011 cm^3

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = --- Unit wt. 71.5 pcf

Wt. of soil = 14914 gm

h = 69 cm

Total Strain = 54%
Normal Stress = 15000 psf

Test data / *Test data used*

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	72	16863	21				
2	75	16863	21				
3	73	16863	21				
4							
				Average[a]	73	16863	21

$$k_T = QL/Aht = \frac{(16863\ cm^3)\ 15.2\ cm}{(856\ cm^2 \times 69\ cm)\ 73\ sec.} = 5.9 \times 10^{-2}\ cm/sec$$

$$\eta_T/\eta_{20} = 0.9761$$

$$k_{20} = k_T\eta_T/\eta_{20} = 5.8 \times 10^{-2}\ cm/sec$$

Falling Head

Standpipe = [burette, other (specify)] ________

Area of standpipe, a = ________ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no.	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ________

$k_T = \frac{2.3aL}{At} \text{Log}\, h_1/h_2$ = ________ = ________ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ________ = ________ cm/sec

[a] Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b] This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

J & L TESTING COMPANY
Geotechnical Testing

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project: Tire Chip Evaluation   Job No: 89R414-01

Location of Project: N/A

Description of Soil: Chipped Tires 23°C

Tested by: DEF   Date of Testing: 5-22-89

Constant Head

Mold dimensions: Diam. 33.0 cm   Ht. 14.6 cm   Area 856 cm²   Vol. 12498 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = ---   Unit wt. 74.5 pcf

Wt. of soil = 14914 gm

h = 69 cm

Total Strain = 56%

Normal Stress = 20,000 psf

Test data / *Test data used*

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	161	16863	21				
2	178	16863	21				
3	170	16863	21				
4							
				Average [a]	170	16863	21

$k_T = QL/Aht = \dfrac{(16863\ cm^3)\ 14.6\ cm}{(856\ cm^2 \times 69\ cm)\ 170\ sec.} = 2.5 \times 10^{-2}$ cm/sec

$\eta_T/\eta_{20} = 0.9761$

$k_{20} = k_T \eta_T/\eta_{20} = 2.4 \times 10^{-2}$ cm/sec

Falling Head

Standpipe = [burette, other (specify)] ______

Area of standpipe, a = ______ sq cm

Test data [b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no.	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ______

$k_T = \dfrac{2.3aL}{At} \text{Log}\ h_1/h_2$ = ______ = ______ cm/sec

$k_{20} = k_T \eta_T/\eta_{20}$ = ______ = ______ cm/sec

[a] Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b] This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

J & L TESTING COMPANY
Geotechnical Testing

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project: Tire Chip Lvaluation   Job No.: 89R414-01

Location of Project: WMKA

Description of Soil: Chipped Tires 50°C

Tested by: DEF   Date of Testing: 5-23-89

Constant Head

Mold dimensions: Diam. 33.0 cm ; Ht. 24.1 cm ; Area 856 cm² ; Vol. 20630 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = ---   Unit wt. 47.3 pcf

Wt. of soil = 15621 gm   Total Strain = 27%

h = 69 cm   Normal Stress = 2500 psf

Test data

Test No.	t, sec	Q, cu cm	T, °C
1	14	16324	21
2	14	16324	21
3	14	16324	21
4			

Test data used

Test No.	t, sec	Q, cu cm	T, °C
Average[a]	14	16324	21

$$k_T = QL/Aht = \frac{(16324\ cm^3)\ 24.1\ cm}{(856\ cm^2 \times 69\ cm)\ 14\ sec.} = 4.8 \times 10^{-1}\ \text{cm/sec}$$

$$\eta_T/\eta_{20} = 0.9761$$

$$k_{20} = k_T\eta_T/\eta_{20} = 4.6 \times 10^{-1}\ \text{cm/sec}$$

Falling Head

Standpipe = [burette, other (specify)] ________

Area of standpipe, a = ________ sq cm

Test data[b]

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C
1						
2						
3						
4						

Test data used

Test no.	h_1, cm	h_2, cm	t, sec	T, °C
Average				

η_T/η_{20} = ________

$k_T = \frac{2.3aL}{At}\text{Log}\ h_1/h_2$ = ________ = ________ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ________ = ________ cm/sec

[a] Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b] This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project: Tire Chip Evaluation   Job No: 89R414-01

Location of Project: WHNA

Description of Soil: Chipped Tires 50°C

Tested by: DCF   Date of Testing: 5-24-89

Constant Head

Mold dimensions: Diam. 33.0 cm; Ht. 22.1 cm; Area 856 cm²; Vol. 18918 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = ---   Unit wt. 51.5 pcf

Wt. of soil = 15621 gm   Total Strain = 33%

h = 69 cm   Normal Stress = 5000 psf

Test data / *Test data used*

Test No.	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T, °C
1	17	16324	21				
2	17	16324	21				
3	17	16324	21				
4							
				Average[a]	17	16324	21

$$k_T = QL/Aht = \frac{(16324\ cm^3)\ 22.1\ cm}{(856\ cm^2 \times 69\ cm)\ 17\ sec.} = 3.6 \times 10^{-1}\ cm/sec$$

$$\eta_T/\eta_{20} = 0.9761$$

$$k_{20} = k_T\eta_T/\eta_{20} = 3.5 \times 10^{-1}\ cm/sec$$

Falling Head

Standpipe = [burette, other (specify)] ____

Area of standpipe, a = ____ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no.	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ____

$k_T = \frac{2.3aL}{At}\text{Log}\,h_1/h_2$ = ____ = ____ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ____ = ____ cm/sec

[a] Use averaged values only if there is a small difference in test temperature, say, 1–2°C.
[b] This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

J & L TESTING COMPANY
Geotechnical Testing

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project: Tire Chip Evaluation Job No: 89R414-01

Location of Project: WMNA

Description of Soil: Chipped Tires 50°C

Tested by: DEF Date of Testing: 5-24-89

Constant Head

Mold dimensions: Diam. 33.0 cm; Ht. 19.3 cm, Area 856 cm^2, Vol. 16521 cm^3

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = --- Unit wt. 59.0 pcf

Wt. of soil = 15621 gm Total Strain = 42%

h = 69 cm Total Stress = 10000 psf

Test data / *Test data used*

Test No.	t, sec	Q, cu cm	T, °C	Test No	t, sec	Q, cu cm	T, °C
1	23	16324	21				
2	25	16324	21				
3	25	16324	21				
4	24	16324	21				
				Average [a]	25	16324	21

$k_T = QL/Aht = \frac{(16324\ cm^3)\ 19.3\ cm}{(856\ cm^2 \times 69\ cm)\ 25\ sec.} = 2.1 \times 10^{-1}$ cm/sec

$\eta_T/\eta_{20} = 0.9761$

$k_{20} = k_T\eta_T/\eta_{20} = 2.1 \times 10^{-1}$ cm/sec

Falling Head

Standpipe = [burette, other (specify)] ____

Area of standpipe, a = ____ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no	h_1, cm	h_2, cm	t, sec	T, °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ____

$k_T = \frac{2.3aL}{At} \text{Log } h_1/h_2$ = ____ = ____ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ____ = ____ cm/sec

[a] Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b] This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head)

Project: Tire Chip Evaluation Job No: 89R414-01

Location of Project: WMNA

Description of Soil: Chipped Tires 50°C

Tested by: DEF Date of Testing: 5-24-89

Constant Head

Mold dimensions: Diam. 33.0 cm; Ht. 18.0 cm; Area 856 cm²; Vol. 15408 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = --- Unit wt. 63.3 pcf

Wt. of soil = 15621 gm

h = 69 cm

Total Strain = 45%
Normal Stress = 15000 psf

Test data

Test No.	t, sec	Q, cu cm	T, °C
1	83	16324	21
2	82	16324	21
3	93	16324	21
4	87	16324	21

Test data used

Test No.	t, sec	Q, cu cm	T, °C
Average[a]	86	16324	21

$k_T = QL/Aht = \frac{(16324\ cm^3)\ 18.0\ cm}{(856\ cm^2 \times 69\ cm)\ 86\ sec.} = 5.8 \times 10^{-2}$ cm/sec

$\eta_T/\eta_{20} = 0.9761$

$k_{20} = k_T \eta_T/\eta_{20} = 5.6 \times 10^{-2}$ cm/sec

Falling Head

Standpipe = [burette, other (specify)] ____________

Area of standpipe, a = ____________ sq cm

Test data[b]

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C
1						
2						
3						
4						

Test data used

Test no.	h_1, cm	h_2, cm	t, sec	T, °C
Average				

η_T/η_{20} = ____________

$k_T = \frac{2.3aL}{At} \text{Log } h_1/h_2$ = ____________ = ____________ cm/sec

$k_{20} = k_T \eta_T/\eta_{20}$ = ____________ = ____________ cm/sec

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.
[b]This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

J & L TESTING COMPANY
Geotechnical Testing

COEFFICIENT OF PERMEABILITY (Constant Head Falling Head)

Project Tire Chip Evaluation Job No 89R414-01

Location of Project WMNA

Description of Soil Chipped Tires 50°C

Tested by DEF Date of Testing 5-24-89

Constant Head

Mold dimensions: Diam. 33.0 cm ; Ht. 17.5 cm . Area 856 cm² ; Vol. 14980 cm³

Wt. of mold + gasket + base = ---

Wt. of mold + gasket + base + soil = --- Unit wt. 65.1 pcf

Wt. of soil = 15621 gm

h = 69 cm

Total Strain = 47%
Normal Stress = 20000 psf

Test data / *Test data used*

Test No	t, sec	Q, cu cm	T, °C	Test No.	t, sec	Q, cu cm	T °C
1	145	16324	21				
2	154	16324	21				
3	155	16324	21				
4							
				Average[a]	151	16324	21

$k_T = QL/Aht = \dfrac{(16324\ cm^3)\ 17.5\ cm}{(856\ cm^2 \times 69\ cm)\ 151\ sec.} = 3.2 \times 10^{-2}$ cm/sec

η_T/η_{20} = 0.9761

$k_{20} = k_T\eta_T/\eta_{20}$ = 3.1 x 10-2 cm/sec

Falling Head

Standpipe = [burette, other (specify)] ______

Area of standpipe, a = ______ sq cm

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t sec	Q_{in}, cu cm	Q_{out}, cu cm	T, °C	Test no	h_1, cm	h_2, cm	t, sec	T °C
1											
2											
3											
4											
							Average				

η_T/η_{20} = ______

$k_T = \dfrac{2.3aL}{At} \log h_1/h_2$ = ______ = ______ cm/sec

$k_{20} = k_T\eta_T/\eta_{20}$ = ______ = ______ cm/sec

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.
[b]This test can be considerably simplified by using the same values of h_1 and h_2 each time, otherwise, you cannot average these values regardless of T.

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J&L TESTING COMPANY, INC.

GEOTECHNICAL AND GEOSYNTHETICS MATERIALS TESTING AND RESEARCH

December 24, 1996
96R2129-01

Seneca Meadows, Inc.
1786 Salcman Road
Waterloo, NY 13165

Attn: James Daigler

RE: HYDRAULIC CONDUCTIVITY TEST RESULTS
TIRE CHIPS FROM SENECA MEADOWS SITE

Dear Mr. Daigler

J&L Testing Company, Inc. (JLT) is pleased to submit herein the results of hydraulic conductivity tests performed on tire chips provided by Seneca Meadows, Inc.. A description of the testing apparatus, sample preparation and testing and a discussion of the test results are presented in the following sections.

TESTING APPARATUS

A schematic of the test unit for this work is presented on Figure 1 with a photograph of the unit enclosed in Appendix A. This unit was specifically designed to accommodate samples such as large aggregate as well as other high permeability or compressible materials such as tire chips. The unit has an inner diameter of 13 inches and can accommodate a maximum sample length of approximately 26 inches.

A load ram and load cell is fitted to the top of the structural frame and designed to apply a maximum load of approximately 30.000 psf. The system was designed to meet ASTM D-2434 test requirements for coarse materials.

SAMPLE PREPARATION AND TESTING

Weighed fragments of tire chips were placed in lifts until a 24-inch depth was achieved and the total weight and height of the sample were recorded. Hydraulic Conductivity testing then commenced at a normal load of 0 psf. A total of 6 replicate readings were recorded on forms for later reduction of the data. The load was then increased to 3000 psf. The compression of the tire chips was recorded and testing at this load commenced with six (6) replicate readings taken. This process was repeated for 6000 psf, 10.000 psf. 13.000 psf and 16.000 psf. Copies of these data sheets are presented in Appendix B.

TEST RESULTS

TABLE 1
SUMMARY OF RESULTS

Load (psf)	Permeability (cm/sec)	Sample Height (inches)	Density (pcf) #/cy
0	$3.22x10^5$	24	36.2
3000	$5.01x10^3$	16.5	52.7
6000	$1.05x10^3$	14.5	59.9
10,000	$2.7x10^2$	13.5	64.4
13,000	$1.42x10^2$	12.7	68.1
16,000	$6.81x10^1$	12.5	69.5

The data derived from this test was reduced (Table 1) and plotted as Permeability vs. Normal Load and Sample Height vs. Normal Load as presented on Figures 2 and 3, respectively. Under a 16,000 psf load, the sample thickness reduced by about 50% with a reduction in permeability of about four (4) orders of magnitude. The results show that the hydraulic conducitivity and compression under the applied normal load are both consistent with results of other tests performed on similar tire chips.

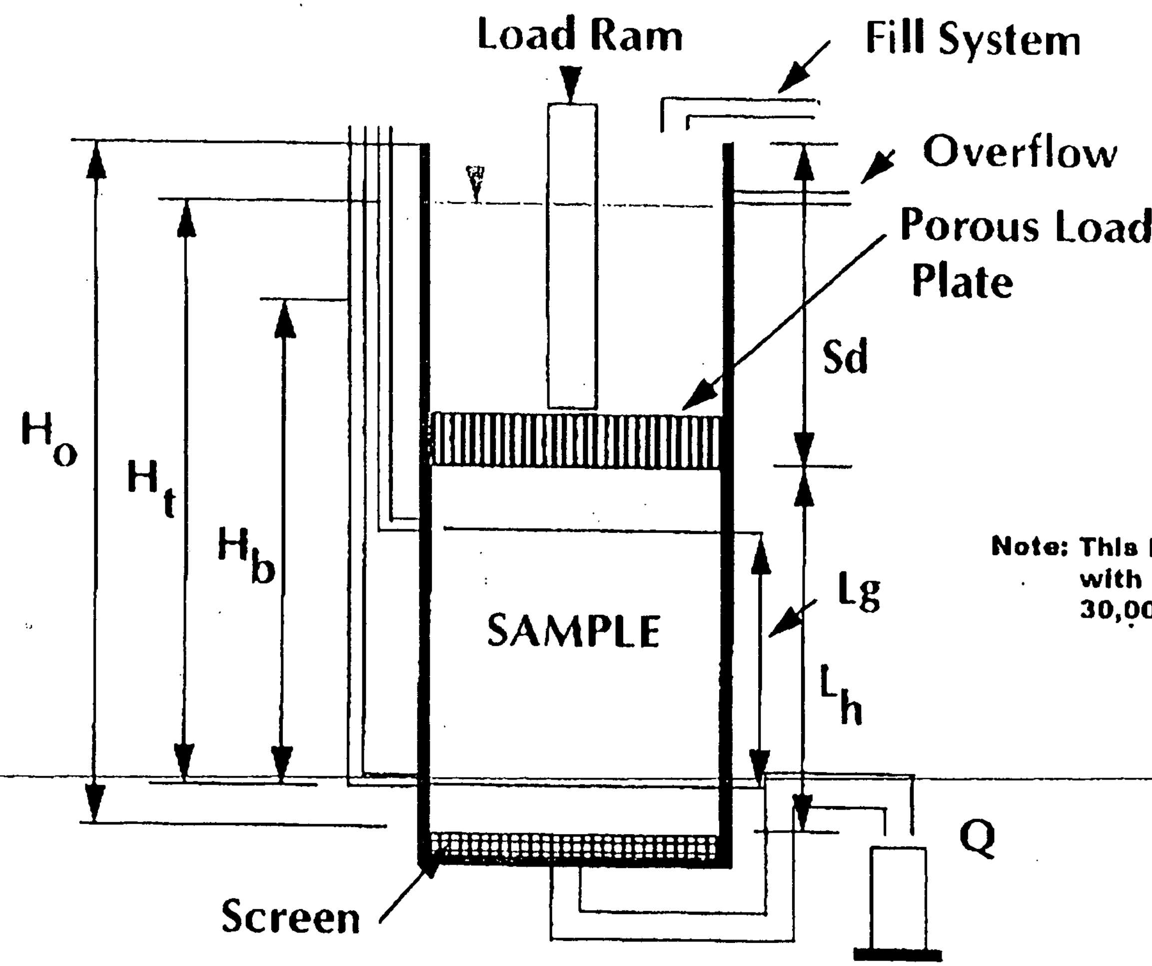
Photographs of the tire chips used for this test are enclosed in Appendix A. Should you have any questions, comments or require additional information, please call. We look forward to servicing you in the future. Thank you.

Sincerely,

J&L TESTING COMPANY, INC.

John Boschuk, Jr., P.E., REP
Technical Consultant

Enclosures
JB/rdg
wpwin60\letter.96616



Note: This is a 13 inch diameter unit with a maximum capacity of 30,000 psf.

PERMEAMETER SCHEMATIC
ASTM D-2434
FIGURE NO 1

FORM: PERM12in

PERMEABILITY vs NORMAL LOAD

TIRE CHIP TEST PROGRAM
SENECA MEADOWS, INC.

13 in Permeameter ASTM D-2434

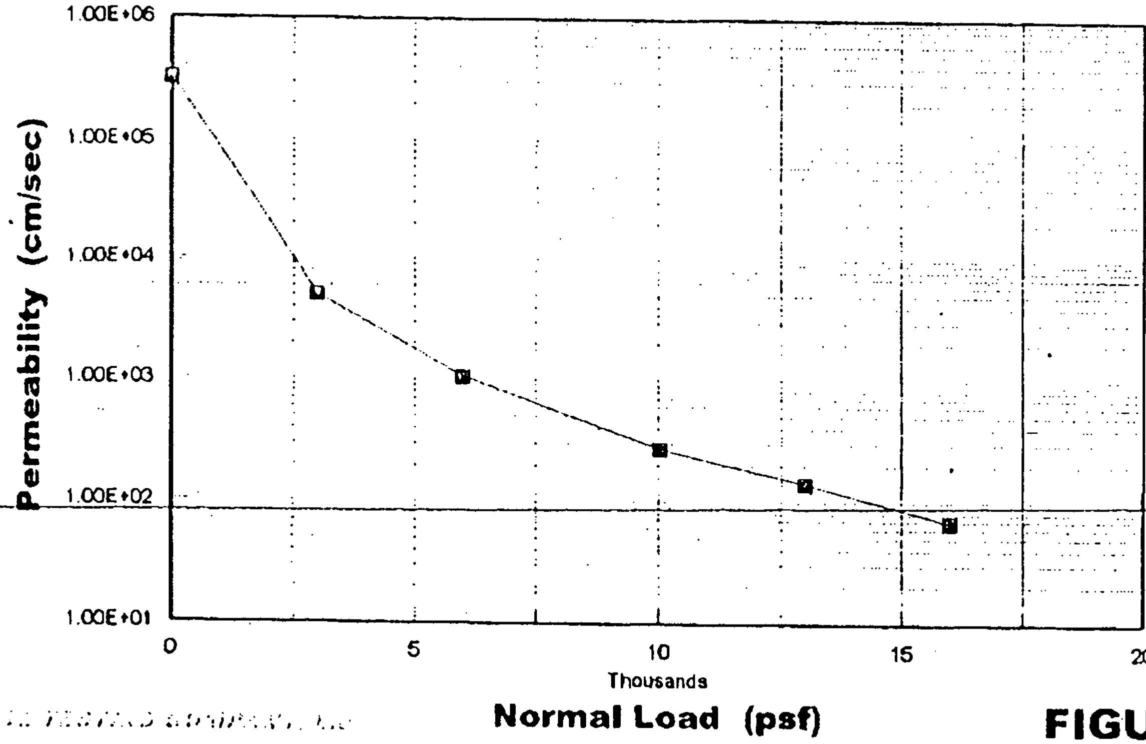


FIGURE NO 2

SAMPLE HEIGHT vs NORMAL LOAD

TIRE CHIP TEST PROGRAM

SENECA MEADOWS, INC.

24 INCH INITIAL THICKNESS

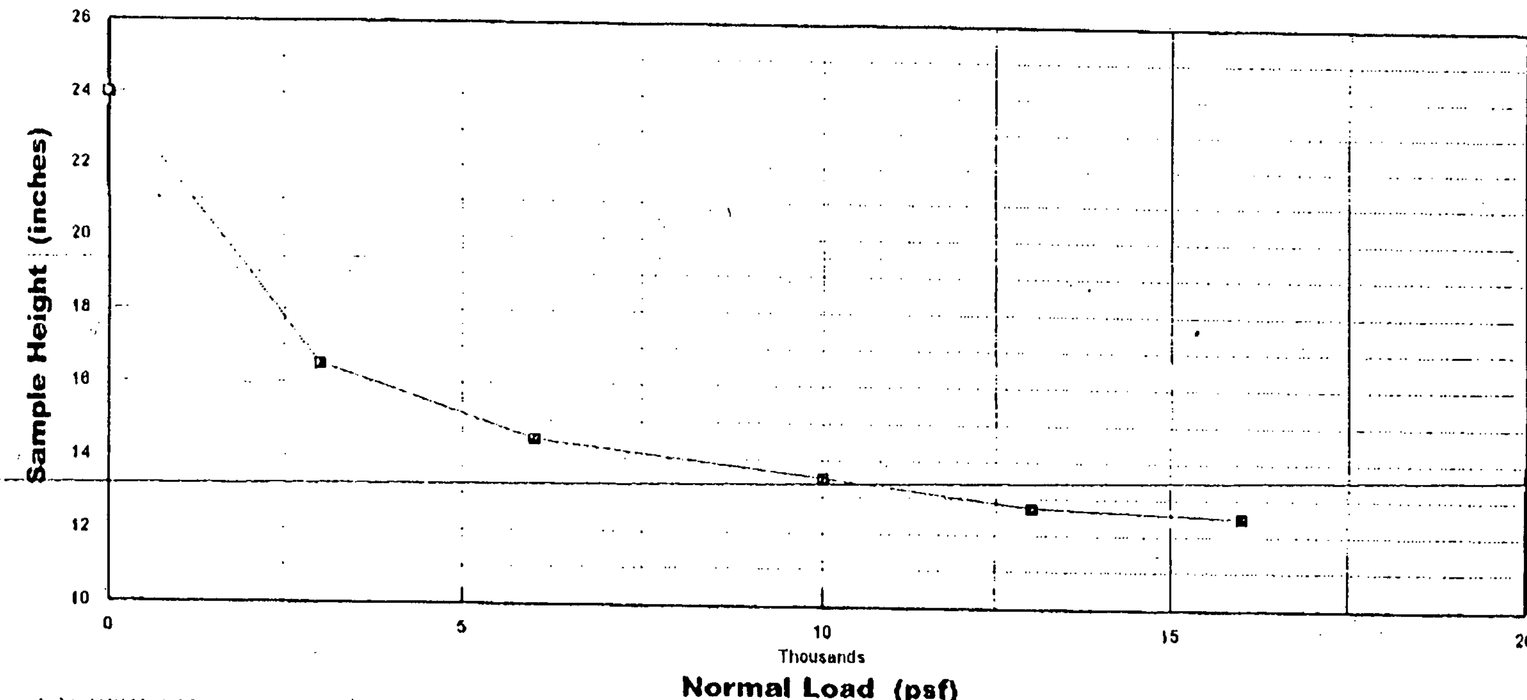
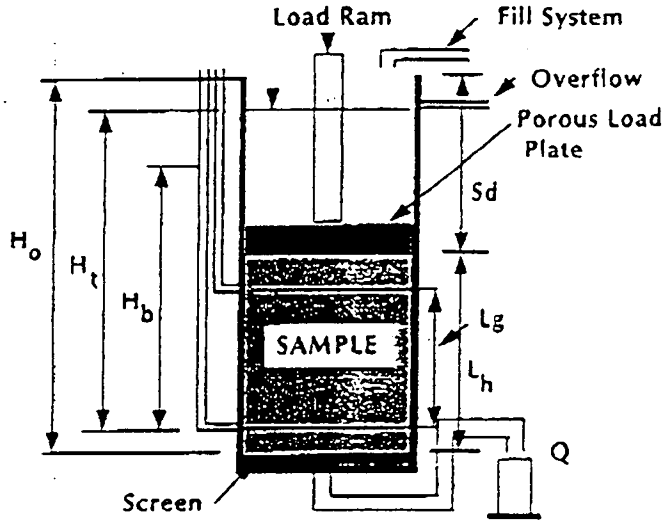


FIGURE NO 3

BEST AVAILABLE COPY

CONSTANT HEAD PERMEABILITY TEST
UNDER LOAD
ASTM D-2434



Ho = 34.5 inches
Sd = 10.5 inches

Lg = 22.25 inches
Diameter = 13 inches

PROJECT INFORMATION

JOB No.: 96S2129-01
CLIENT: SENECA MEADOWS, INC
PROJECT: SENECA LANDFILL
MATERIAL: TIRE CHIPS

TEST SAMPLE DATA

WT. OF SAMPLE, W (lb) 66.750
(Lh = Ho - Sd)
HEIGHT OF SAMPLE, Lh (in) 24.000
X-SECTION AREA, A, (sf) 0.922
VOLUME OF SAMPLE, V (cf) 1.844

DENSITY, (pcf) 36.198

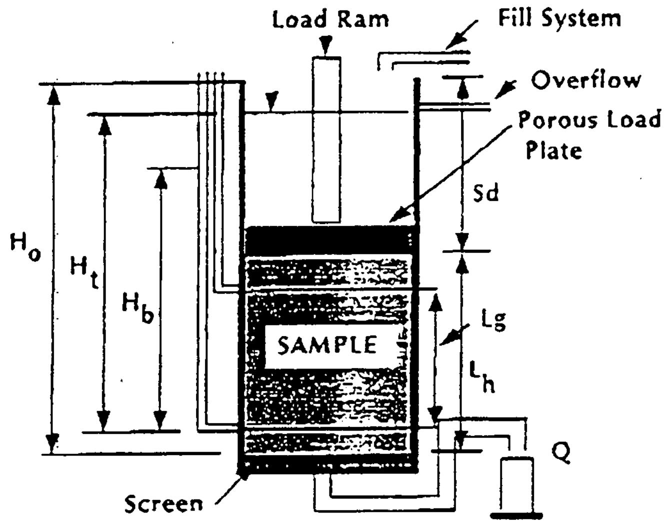
APPLIED STRESS, (psf) 0

REPLICATE No.	HEAD (Ht) in	HEAD (Hb) in	HEAD LOSS (Ht-Hb)	FLOW, Q cc	TIME, t seconds	TEMP., T deg. C	PERMEABILITY cm/sec
1	25.563	25.56	0.003	1033	4.65	15	339015.89
2	25.563	25.56	0.003	1064	5.05	15	321531.06
3	25.563	25.56	0.003	1047	5.02	15	318284.62
4	25.563	25.56	0.003	995	4.93	15	307998.68
5	25.563	25.56	0.003	1100	5.27	15	318533.24
6	25.563	25.56	0.003	1080	5.08	15	324438.76

Average Permeability = 321633.71

Tested By: [signature] Date: 12/20/96 Checked By: [signature] Date: 12/23/96

CONSTANT HEAD PERMEABILITY TEST
UNDER LOAD
ASTM D-2434



Ho = 34.5 inches
Sd = 18 inches

Lg = 22.25 inches
Diameter = 13 inches

PROJECT INFORMATION

JOB No.: 96S2129-01
CLIENT: SENECA MEADOWS, INC
PROJECT: SENECA LANDFILL
MATERIAL: TIRE CHIPS

TEST SAMPLE DATA

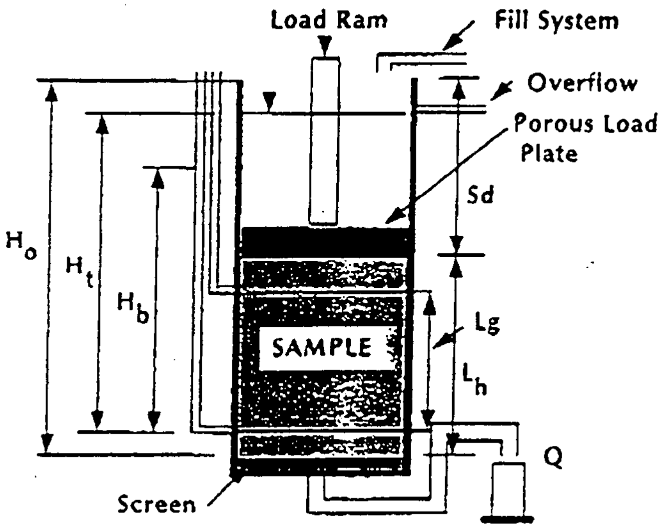
WT. OF SAMPLE, W (lb)	66.750
(Lh = Ho - Sd)	
HEIGHT OF SAMPLE, Lh (in)	16.500
X-SECTION AREA, A, (sf)	0.922
VOLUME OF SAMPLE, V (cf)	1.268
DENSITY, (pcf)	52.652
APPLIED STRESS, (psf)	3000

REPLICATE No.	HEAD (Ht) in	HEAD (Hb) in	HEAD LOSS (Ht-Hb)	FLOW, Q cc	TIME, t seconds	TEMP., T deg. C	PERMEABILITY cm/sec
1	25.5	25.375	0.125	1053	5.24	15	5060.04
2	25.5	25.375	0.125	1075	5.31	15	5097.66
3	25.5	25.375	0.125	1079	5.63	15	4825.80
4	25.5	25.375	0.125	1034	5.27	15	4940.45
5	25.5	25.375	0.125	1059	5.31	15	5021.78
6	25.5	25.375	0.125	1008	4.99	15	5086.47
						Average Permeability =	**5005.37**

Tested By: *MM* Date: *12/20/96* Checked By: *[signature]* Date: *12/23/96*

J&L TESTING CO., INC. P123K-1.WK4

CONSTANT HEAD PERMEABILITY TEST
UNDER LOAD
ASTM D-2434



Ho = 34.5 inches
Sd = 20 inches

Lg = 22.25 inches
Diameter = 13 inches

PROJECT INFORMATION

JOB No.: 96S2129-01
CLIENT: SENECA MEADOWS, INC
PROJECT: SENECA LANDFILL
MATERIAL: TIRE CHIPS

TEST SAMPLE DATA

WT. OF SAMPLE, W (lb) 66.750
(Lh = Ho - Sd)
HEIGHT OF SAMPLE, Lh (in) 14.500
X-SECTION AREA, A, (sf) 0.922
VOLUME OF SAMPLE, V (cf) 1.114

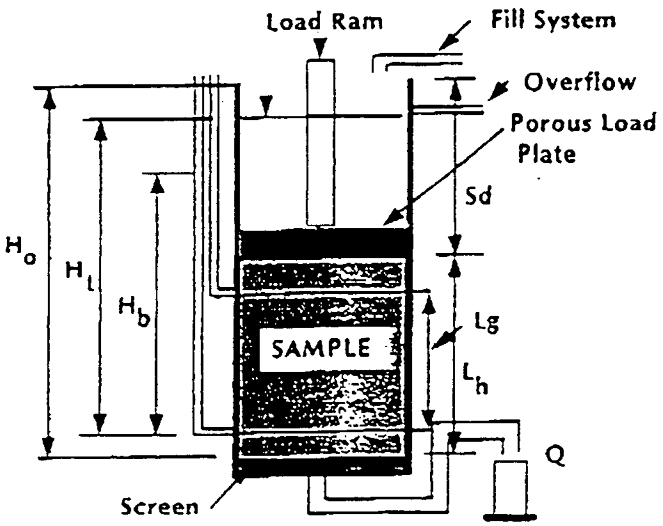
DENSITY, (pcf) 59.915

APPLIED STRESS, (psf) 6000

REPLICATE No.	HEAD (Ht) in	HEAD (Hb) in	HEAD LOSS (Ht-Hb)	FLOW, Q cc	TIME, t seconds	TEMP., T deg. C	PERMEABILITY cm/sec
1	25.5	25	0.5	1047	5.43	15	1066.66
2	25.5	25	0.5	1016	5.39	15	1042.76
3	25.5	25	0.5	1046	5.46	15	1059.79
4	25.5	25	0.5	1008	5.35	15	1042.29
5	25.5	25	0.5	1038	5.48	15	1047.85
6	25.5	25	0.5	1031	5.57	15	1023.96
						Average Permeability =	**1047.22**

Tested By: NM Date: 12/20/96 Checked By: [signature] Date: 12/23/96

CONSTANT HEAD PERMEABILITY TEST
UNDER LOAD
ASTM D-2434



Ho = 34.5 inches
Sd = 21 inches

Lg = 22.25 inches
Diameter = 13 inches

PROJECT INFORMATION

JOB No.: 96S2129-01
CLIENT: SENECA MEADOWS, INC
PROJECT: SENECA LANDFILL
MATERIAL: TIRE CHIPS

TEST SAMPLE DATA

WT. OF SAMPLE, W (lb)	66.750
(Lh = Ho - Sd)	
HEIGHT OF SAMPLE, Lh (in)	13.500
X-SECTION AREA, A, (sf)	0.922
VOLUME OF SAMPLE, V (cf)	1.037
DENSITY, (pcf)	64.353
APPLIED STRESS, (psf)	10,000

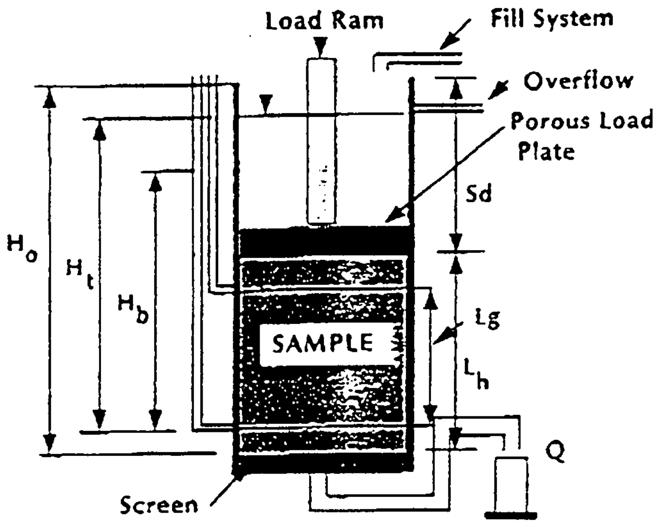
REPLICATE No.	HEAD (Ht) in	HEAD (Hb) in	HEAD LOSS (Ht-Hb)	FLOW, Q cc	TIME, t seconds	TEMP., T deg. C	PERMEABILITY cm/sec
1	25.5	23.75	1.75	1025	5.6	15	269.35
2	25.5	23.75	1.75	1036	5.64	15	270.31
3	25.5	23.75	1.75	1028	5.46	15	277.06
4	25.5	23.75	1.75	1026	5.54	15	272.53
5	25.5	23.75	1.75	1038	5.61	15	272.28
6	25.5	23.75	1.75	1040	5.68	15	269.44

Average Permeability = 271.83

Tested By: MW Date: 12/20/96 Checked By: [signature] Date: 12/23/96

J&L TESTING CO., INC. P1210K-1.WK4

CONSTANT HEAD PERMEABILITY TEST
UNDER LOAD
ASTM D-2434



Ho = 34.5 inches
Sd = 21.75 inches

Lg = 22.25 inches
Diameter = 13 inches

PROJECT INFORMATION

JOB No.: 96S2129-01
CLIENT: SENECA MEADOWS, INC
PROJECT: SENECA LANDFILL
MATERIAL: TIRE CHIPS

TEST SAMPLE DATA

WT. OF SAMPLE, W (lb)	66.750
(Lh = Ho - Sd)	
HEIGHT OF SAMPLE, Lh (in)	12.750
X-SECTION AREA, A, (sf)	0.922
VOLUME OF SAMPLE, V (cf)	0.980
DENSITY, (pcf)	68.138
APPLIED STRESS, (psf)	13,000

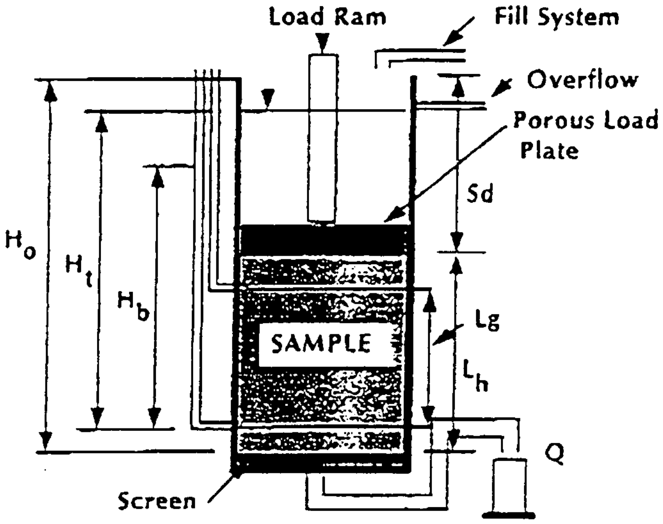
REPLICATE No.	HEAD (Ht) in	HEAD (Hb) in	HEAD LOSS (Ht-Hb)	FLOW, Q cc	TIME, t seconds	TEMP. T deg. C	PERMEABILITY cm/sec
1	25.5	22.375	3.125	1033	5.87	15	136.96
2	25.5	22.375	3.125	1041	5.64	15	143.65
3	25.5	22.375	3.125	1049	5.71	15	142.98
4	25.5	22.375	3.125	1054	5.73	15	143.16
5	25.5	22.375	3.125	1011	5.41	15	145.44
6	25.5	22.375	3.125	1052	5.81	15	140.92
						Average Permeability =	**142.19**

Tested By: MM Date: 12/4/96 Checked By: [signature] Date: 12/23/96

J&L TESTING CO., INC.

P1213K-1.WK4

CONSTANT HEAD PERMEABILITY TEST
UNDER LOAD
ASTM D-2434



Ho = 34.5 inches
Sd = 22 inches

Lg = 22.25 inches
Diameter = 13 inches

PROJECT INFORMATION

JOB No.: 96S2129-01
CLIENT: SENECA MEADOWS, INC
PROJECT: SENECA LANDFILL
MATERIAL: TIRE CHIPS

TEST SAMPLE DATA

WT. OF SAMPLE, W (lb)	66.750
(Lh = Ho - Sd)	
HEIGHT OF SAMPLE, Lh (in)	12.500
X-SECTION AREA, A, (sf)	0.922
VOLUME OF SAMPLE, V (cf)	0.960
DENSITY, (pcf)	69.501
APPLIED STRESS, (psf)	16.000

REPLICATE No.	HEAD (Ht) in	HEAD (Hb) in	HEAD LOSS (Ht-Hb)	FLOW, Q cc	TIME, t seconds	TEMP., T deg. C	PERMEABILITY cm/sec
1	25.5625	19.3125	6.25	1093	5.94	15	70.20
2	25.5625	19.3125	6.25	1014	5.88	15	65.79
3	25.5625	19.3125	6.25	1025	5.76	15	67.89
4	25.5625	19.3125	6.25	1026	5.81	15	67.37
5	25.5625	19.3125	6.25	1082	5.86	15	70.44
6	25.5625	19.3125	6.25	1027	5.85	15	66.98
						Average Permeability =	**68.11**

Tested By: [signature] Date: 12/2/96 Checked By: [signature] Date: 12/3/96

Processing Scrap Tires for Landfill Projects

Use of chipped or granulated tires in landfill construction projects has increased in recent years. Broader acceptance and use of tires might occur if uniform engineering data and performance guidelines for tires replacing soil were more widely available.

By Richard Donovan, P.E.

Numbering in the billions in discard stockpiles and a couple hundred million added each year, scrap tires are plentiful, even with millions being shredded for fuel or burned whole in cement kilns. So, the search for other beneficial uses for tires continues. One growth market is using tires in construction projects, specifically landfill construction projects. Layers of tires can be used in liner, leachate collection, groundwater control, final cover and landfill gas control systems.

The use of tires in landfill construction projects has increased dramatically in recent years; but greater use is still hampered by lack of definitive engineering data and guidelines on the properties of scrap tires. A recent engineering feasibility study for using tires in a landfill owned by the City of Lincoln, NE, has begun to close this data gap. The study provided a comparison of the properties of scrap tires with the properties of soils typically used in similar applications.

Processing Tire Chips

Methods to produce marketable chips from scrap tires typically boil down to two phases. First phase processing—commonly done in slow speed, shear shredders—reduces whole tires to a "rough shred" size of three to six inches wide by three to 12 inches long. These rough shreds are not usually used in civil engineering applications because the tangled mass of exposed bead and belt wire makes them difficult to work. Thus, second phase processing (also usually managed by slow speed, shear shredders), reduces the rough shred to smaller "chips," nominally two to three inches in width and length.

This round of shredding reduces, but does not eliminate, the bead and belt wire. The smaller chips typically have two to three inch wire protrusions. Still, these smaller chips are more workable. They can be handled, spread and compacted with conventional construction equipment, so they are suitable substitutes for conventional soil materials in road pavement base courses, retaining wall backfills and landfill construction and closure.

The tire chip yield, in tires per cubic yard of volume, depends on the tire chip size and degree of compaction. Based on an average passenger car tire weight of 20 pounds per tire, the tire chip yield ranges from about 25 tires per cubic yard (loose rough shreds) to about 75 tires per yard (dense two- to three-inch chips).

The decision to use tire chips as an alternative material in land-

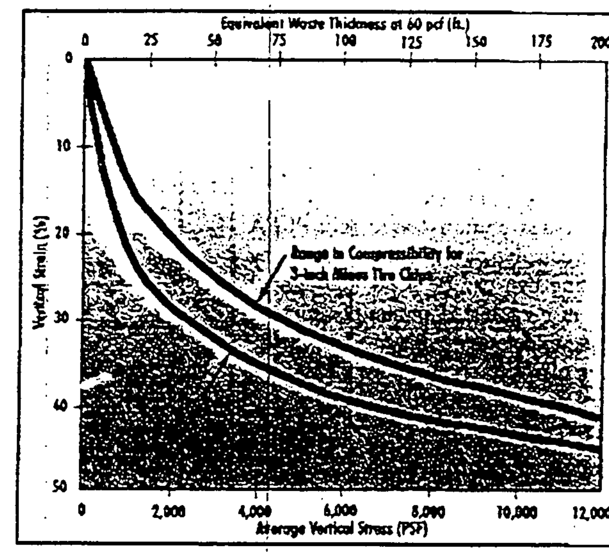


Figure 1. Tire Chip Compressibility.

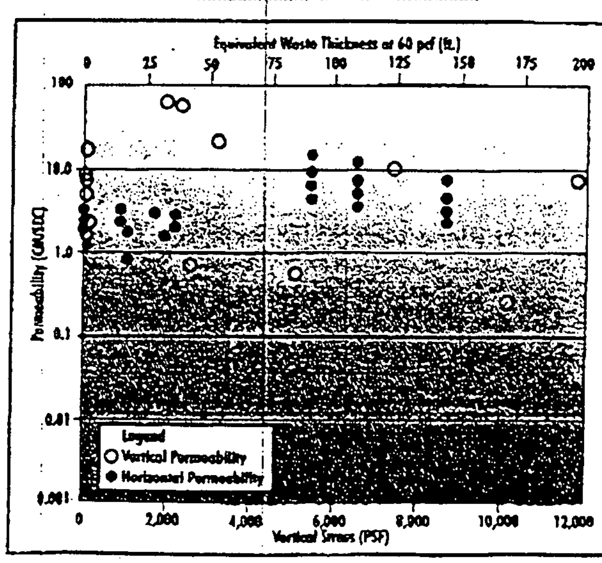


Figure 2. Tire Chip Permeability.

-fill construction will boil down to technical and economic feasibility. Regarding economics, cost savings from using tires will depend on the cost to process tires (or to buy chips, which is also dependent on the cost to process tires) compared to the cost of using local conventional materials.

The cost to process tire chips is driven by two considerations: the desired nominal chip size and the allowable amount of bead and belt wire. Slow speed shredders use sets of knife blades or geared shafts to shred the tires. After shredding, the chips fall onto a classifier screen, so that oversized chips are cycled back through the shredder. This additional processing to a smaller tire chip size increases costs due to higher knife wear and a lower production rate.

Loose bead and belt wire may be removed by an in-line magnet after screening the tire chips. Higher levels of removal are accomplished by debeading the whole tire before shredding. Both steps increase tire chip costs. Table 1 presents typical production costs for the various tire chip sizes.

Physical Properties

The use of soil materials in landfill construction and closure is based on an evaluation of shear strength, compressibility, permeability (hydraulic conductivity) and durability of the soil. The decision to substitute tire chips for soil should be based on demonstrated equivalency to these same characteristics. The major design considerations associated with these physical properties are discussed in the following sections and summarized in Table 2.

❑ **Shear Strength.** Shear strength, or the maximum resistance of a soil or rock to shearing stresses, affects bearing capacity and slope stability of landfill components. Shear strength is expressed by the angle of internal friction, measured in degrees. Typical granular soils have internal friction angles ranging from 27 degrees (for loose, silty sand) to 55 degrees (for dense, medium size gravel). Reported internal friction angles for tire chips range from 24 to 38 degrees, depending on chip size, magnitude of bead wire entanglement and degree of saturation. The lower value of 24 degrees provides a shear strength equivalent to loose granular soil.

Shear strength is a major design consideration when building a layer of tire chips on a lined or unlined side slope. The shear strength at the interface between a tire chip layer and a geosynthetic material can be influenced by tire and geosynthetic textures and may be comparable to soil/geomembrane shear strengths. To ensure sideslope stability, project-specific testing should be conducted for each tire chip source or tire chip/geosynthetic combination.

❑ **Compressibility.** Compressibility of a soil or other material—that is, its susceptibility to decrease in volume when subjected to load—is a major design consideration for leachate collection layers or other landfill components that will come under high compressive stress. Material selection can greatly affect landfill settlement. Tire chips differ markedly from soils in that the chips themselves are compressible in addition to the compressibility of the mass. Figure 1 presents a graphic summary of the compressibility of tire chips having nominal size of three inch minus. Tire chips have a compressibility from five to 50 percent, depending on the applied normal stress. For example, a 12-inch layer of tire chips under 100 feet of waste would compress about 35 percent, or 4.2 inches, leaving an effective thickness of 7.8 inches. The anticipated compression of a tire chip layer can be offset by using a thicker layer than for conventional granular materials. Tire chip layers have ranged up to twice the thickness of the granular drainage layer they were replacing.

Table 1. The Cost to Produce Tire Chips.

Tire Chip Size (Nominal size)	Chipping Rate (tires/hour)	$/Ton	$/cy (Loose)	$/cy (Compact)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 2. Design Considerations for Using Tires in Landfills.

Characteristic	Landfill Application
Shear Strength	[illegible]

❑ **Permeability.** Permeability, or the capacity of a material to conduct liquid or gas, is important when selecting landfill construction materials because the materials can affect leachate flow as well as landfill gas migration. Ensuring that tires will meet regulatory minimum standards under Subtitle D of the Resource Conservation and Recovery Act is part of the evaluation for substituting the material. Subtitle D requires a leachate collection system constructed to maintain less than a 30 cm depth of leachate over the liner; in addition, they call for a design to prevent gas migration outside of the facility property boundary.

To prevent leachate buildup over a liner, Subtitle D regulations generally require a granular soil having permeability of 0.01 cm/sec or greater, depending on the leachate pipe spacing and cell floor grade. Washed gravel, sand or sand-gravel mixtures typically are used to meet this requirement as well as to meet flow requirements in gas migration control layers and trenches. Figure 2 summarizes test data reported on the vertical and horizontal permeability of tire chips. The data scatter is due to differences in chip size, initial density, hydraulic gradients and confining pressures among the studies. Despite the variability, the data indicate that tire chips can attain the minimum permeability of 0.10 cm/sec.

As might be expected, the permeabilities decrease under normal load due to compression of the chips and reduction in void volume. The anticipated reduction of permeability can be offset by using a thicker layer of tire chips than the conventional material. Hydrologic Evaluation of Landfill Performance (HELP) modeling can be used to evaluate the effect of reduced permeability on leachate or infiltration head buildup.

❑ **Filtration.** According to ASTM standards, a filter is a layer or layers of materials that provide drainage and prevent the movement of soil particles through the layer. Filtration is a major design consideration for tire chip applications, especially when used adjacent to soil layers, since the tire chip layer is susceptible to clogging or plugging. Tire chips, consisting of relatively flat pieces, have gradation similar to a poorly-graded gravel, consisting of relatively flat pieces; while this structure provides high permeability, it is not effective as a graded filter. Thus, either a thick, non-woven geotextile or a graded sand-gravel filter is needed between a soil layer and an adjacent tire chip layer to provide filtration and puncture resistance. In some cases, using tire chips instead of gravel in gas collection trenches and leachate recirculation systems has not required a filtration geotextile.

❑ **Puncture Resistance.** As noted earlier, bead and belt wire protrude from most tire chips. These wires could puncture a geomembrane liner, if placed against the liner. Care must be taken when planning such tire-geomembrane interfaces. In at least one instance, regulators have approved the use of tire chips placed directly against a synthetic liner, but only after a demonstration in a material-specific test pad and HELP infiltration modeling. However, the consensus of opinion seems to hold that a granular cushion layer, nominally six inches of soil, should be used between a geomembrane and a tire chip layer.

Puncture of a clay liner is a lesser concern, since the nominal two-foot thickness provides adequate protection. A thick, nonwoven geotextile may provide an alternative to a granular cushion, depending on the magnitude of bead and belt wire protrusions in the tire chips. No data or testing has been obtained to document this hypothesis.

❑ **Leachability and Durability.** To consider using tire chips in landfill construction, you also have to address the potential that tires may leach materials after coming into contact with water or leachate in the landfill. Among the concerns is that tire chips may leach metals or other constituents, even though degradation or decomposition of the tire chips themselves is not likely. A number of tests summarized by the Scrap Tire Management Council (STMC) show that leaching from tires is not likely to be a concern: none of several cured rubber products tested in Toxicity Characteristic Leaching Procedure (TCLP) exceeded regulatory limits. In fact, the STMC report says, "most compounds detected were found at trace levels, ranging from 10 to 100 times less than the TCLP limits and the EPA's Drinking Water Standard MCL values."

The Wisconsin State Laboratory of Hygiene also conducted laboratory leaching tests to evaluate the impact of tire chips on groundwater quality. The test protocol used three sequential elutions with distilled water as the extraction fluid. A comparison of the test results with Nebraska's groundwater standards revealed that:

❑ Iron, manganese and zinc increased in concentration from the first to the third elution, suggesting continued release from the bead and belt wire.

❑ Only manganese exceeded the Nebraska numerical standard (0.25 mg/L compared to the standard of 0.05 mg/L).

❑ Organics generally decreased from the first to the third elution, suggesting that washing of contaminants from the tire surface was occurring, rather than a release from tire material.

Samples obtained by another researcher from a field lysimeter beneath a tire chip road subgrade indicated the same trend in metals and organics. Both iron and manganese were observed at levels above the Nebraska standards.

In contrast, chemical tests conducted on water that infiltrated a Superfund landfill closure cap incorporating a tire chip drainage layer indicated no elevated levels of any volatiles or metals. In fact, there is even some evidence to suggest that tire chips may act somewhat like granular activated carbon, absorbing volatiles in the leachate stream and reducing their concentrations in the leachate requiring treatment. Batch and column laboratory tests conducted at the University of Wisconsin showed that tire chips adsorbed both vapor and liquid phase volatile organic compounds (VOCs). The reported removal efficiencies varied from 30 to 99 percent, depending on air/water flow ratios, VOC concentrations and tire chip characteristics (gradation, porosity and surface area).

❑ **Flammability.** Recent articles have reported on the fires erupting from within tire chip fills constructed in Oregon and Washington. The combustion potential of tire chips is undeniable: indeed, the heat content of tire chips makes them attractive as a fuel and is the reason why fuel is the number one use for scrap tires today.

Research for the Federal Highway Administration indicates that two common factors have been involved in tire chip fires: 1) the fills have been thick (nominally 50 feet deep); and 2) they have had a mixture of soil and tire chips. While mixing soil and tire chips provided the benefit of less compressibility than tire chips alone, the researchers suggested that the soils contained microbes which digested the petroleum constituents of the tire chips. The thick fills absorbed the heat generated by this reaction, until the combustion temperature was reached. Neither factor should influence the use of tire chips in landfill construction, since these applications use thinner layers of tires, and because combining soil with tire chips would reduce the permeability of the mixture, which defeats the primary advantage of the tire chips.

In the aftermath of the tire fill fires, several organizations have come together to develop guidelines to reduce the risks of tire fill fires. *[See "Top of the Heap," page 13 in this issue, for more information on reducing risks of tire fill fires.—Editor]*

Conclusion

This review of quantifiable physical properties indicates that tire chips are a technically viable substitute for soils or other granular materials in many landfill construction projects. They have suitable properties to make them useful in landfill closure cap drainage layers, leachate collection layers, gas collection layers and other areas where high permeability is sought.

The use of tire chips has increased in a number of civil engineering projects, but not without some problems, including tire fill fires. But their use in landfill construction and closure as an alternative to conventional granular materials has increased with generally positive results. In the next issue, Part II of this article will look at specific case histories using tires in landfill projects.

Acknowledgements

This report is based on a previous report, *Tire Utilization Study, Engineering Feasibility and Preliminary Design*, prepared for the City of Lincoln, NE. The original report determined the applicability of using tire chips in several applications at the city's landfills. This report was funded by the City of Lincoln and the Nebraska Department of Environmental Quality's Scrap Tire Reduction and Recycling Incentive Fund.

The Nebraska State Recycling Association used the Lincoln-specific applications to prepare this *Tire Chip Utilization Study, Landfill Applications*, which uses generic applications that are appropriate to other areas of the state. Funding for this report was provided by the Nebraska Environmental Trust Fund. This report is endorsed by the Nebraska Department of Environmental Quality. Application review time by the department can be greatly reduced if the guidance provided in this report is followed.

For more information, contact Richard Donovan, HDR Engineering, 8404 Indian Hills Drive., Omaha, NE 68114; (402) 399-1211. A full set of references for the research supporting this article is available from the author.

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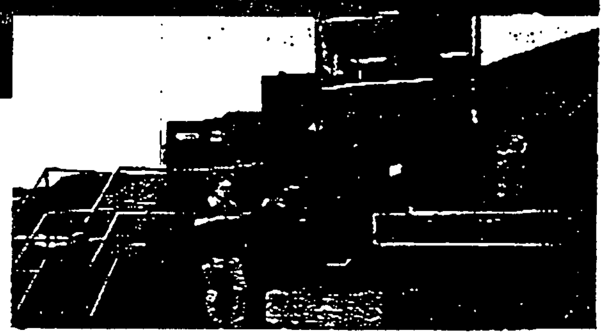



Using Tires in Landfill Construction, Part II

This article presents the results that came out of a study conducted by the City of Lincoln, NE, which centered around the use of scrap tires in a city-owned landfill. The results indicate that there are viable landfill applications for scrap tires.

By Richard Donovan, P.E., HDR Engineering Inc.

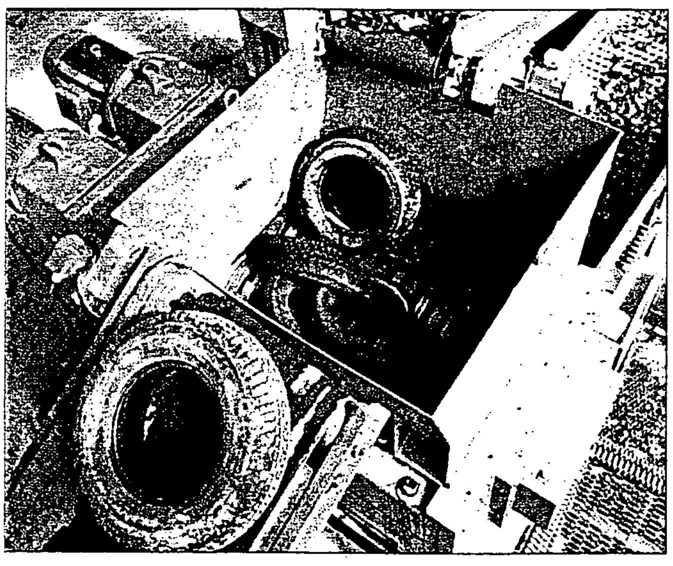
As we reported in our November/December 1997 issue, there is a continuing effort to find profitable and useful applications for scrap tires. Scrap tires are being used in landfill construction projects, but despite their increasing use, there is still a lack of engineering data on scrap tire properties. However, a recent feasibility study, began to close this data gap. Conducted by the City of Lincoln, NE, the study focused on the use of scrap tires in a city-owned landfill. This article focuses on some of the results that came out of this study, namely some of the viable landfill applications for scrap tires, and the design criteria involved when using scrap tires in a landfill project.

Applications

There are essentially six major systems in a typical landfill: a closure cap system which consists of an erosion control layer, a drainage layer, and an infiltration or barrier layer; a leachate collection and recovery system composed of a leachate collection layer, collection piping and bedding, and leachate recirculation trenches; composite liner system consisting of a geomembrane and a compacted clay liner; landfill gas control system which has a horizontal collection and venting layer and gas migration control trenches; groundwater control system which consists of groundwater control trenches; and the operational layers which consist of protective cover soil and daily and intermediate cover.

Each of the landfill components in each system, except the infiltration layer of the closure cap system and the components of the composite liner system, were examined in order to determine the viability of substituting tire chips for the standard materials used in these components. The excluded components were not examined because they function as impermeable layers a property that tire chip layers do not possess.

Closure Cap Systems. A potential application for tire chip use in a landfill closure cap system includes the drainage layer which removes percolation and minimizes head build-up on the infiltration layer. These drainage layers typically are located directly above the infiltration layer. Conventional drainage materials used in these layers include granular soils and geosynthetics, such as geotextiles and geonets. Design considerations for these conventional drainage materials include shear strength on the side slopes, permeability, and filtration. The use of tire chips would add design and construction considerations of puncture resistance with respect to a synthetic liner and leachability. The DSI Superfund Site closure cap used tire chips in a cap drainage layer directly above the 60-mil very low density polyethylene synthetic liner.



Scrap tires are being used in landfill construction projects, namely in liners, leachate collection systems, groundwater control systems, final covers, and gas control systems.

Leachate Collection and Recovery Systems. Potential tire chip uses in a landfill leachate collection/recovery system include the collection layer, the pipe bedding, and the recirculation trench backfill. The purpose of a leachate collection layer is to provide positive control and discharge of landfill leachate. These layers typically are located directly above the geomembrane component of the composite liner system. Conventional materials used in the leachate collection layer include granular soils and geosynthetics, such as geotextiles and geonets. Design considerations for these materials include shear strength on the side slopes, permeability, filtration, and puncture resistance. The use of tire chips would add a design and construction consideration of compressibility. Tire chip leachate collection layers have been used in projects at Quarry Sanitary Landfill and Recycling Center, Muskogee Community Landfill, North Texas Municipal Water District Landfill, and Sioux City Landfill.

The purpose of a pipe bedding layer is to provide discharge capacity and structural support to the leachate collection pipe. These layers typically are located in a collection trench directly above the geomembrane component of the composite liner system. Conventional materials used in these layers are granular soils. Design considerations for these materials include compressibility, permeability, filtration, and puncture resistance. The compressibility of tire chips is a major limitation for this application, since the performance of plastic leachate collection piping depends on an incompressible backfill support. No case histories have used tire chips as a leachate collection pipe bedding material.

The purpose of a leachate recirculation trench is to inject leachate collected from the leachate collection and recovery system back into the waste mass. These trenches typically are constructed within the waste during the progress of waste deposition. Conventional backfill materials used in these trenches are granular soils. Design considerations for these conventional backfill materials include filtration and permeability. The compressibility of the tire chips is comparable to the surrounding waste and is not a major limitation. Tire chips were used in the Alachua County Southwest Landfill recirculation trench backfill.

Landfill Gas Control Systems. Potential uses for tire chips in landfill gas control systems include collection and venting layers and gas migration control trenches. The purpose of a gas collection and venting layer is to provide control and discharge of landfill gas under active or passive extraction. These layers typically are located directly beneath the infiltration layer in the closure cap. Conventional materials used in these layers include granular soils and geosynthetics, such as geotextiles and geonets. Design considerations include shear strength on the side slope, permeability, and filtration. Additional design and construction considerations are puncture resistance against a synthetic liner and leachability. Although no case histories have been identified here, it is anticipated that tire chip performance would be similar to that of the cap drainage layer case history cited previously.

The purpose of a gas migration control trench is to minimize lateral migration and control and discharge of landfill gas under active or passive extraction. These trenches typically are located outside the landfill footprint. Conventional materials used in these layers include granular soils and geosynthetics. Design considerations include filtration and permeability. The use of tire chips would require consideration of leachability, if the trench was excavated into the water table. Tire chips were used as gas control trench backfill at the Norton County Landfill Incinerator. This trench was excavated above the water table, so leaching was not a design concern.

Groundwater Control Systems. Potential uses for tire chips in groundwater control systems include groundwater control trenches. The purpose of these trenches is to provide positive control and discharge of groundwater. Conventional backfill materials used in these trenches include granular soils and geosynthetics. Design considerations include filtration and permeability. Using tire chips would also require consideration of compressibility under high fills and leachability.

Operational Uses. Potential applications in landfill operations include protective cover soil and daily and intermediate cover, which are typically located directly above the leachate collection layer.

The purpose of a cover soil layer is to protect the underlying leachate collection and composite liner systems from damage during construction and operation. Conventional materials used in these layers include soils or select waste, depending on the permeability requirements of the cover and the design capacity of the leachate collection and recovery system. Designs based on handling rainfall and run-on as leachate will require a permeable cover soil to move the water down to the leachate collection system. Designs based on handling rainfall and run-on as storm water runoff will require a less permeable cover soil. Design considerations include shear strength on the side slopes, filtration, and permeability. Compressibility is an additional design and construction consideration. The high permeability of tire chips is a major limitation for this application if a less permeable cover is desired. Tire chips have been used as a permeable protective cover at the Quarry Sanitary Landfill and Recycling Center and the East Oak Landfill.

The purpose of daily and intermediate covers is to control disease vectors, fires, odors, blowing litter, and scavenging. In addition, these covers are used to minimize infiltration and leachate generation. Intermediate cover also serves to support vegetative growth. Conventional materials used in these layers are soils and synthetic materials. The high permeability of tire chips can be a limitation for this application, since the high void space in a tire chip layer limits its effectiveness in controlling disease vectors, odors, and infiltration. In addition, the tire chips are flammable. However, tire chips may be an appropriate daily cover for controlling litter and deterring scavenging when an area will be filled in the near term. The Roberts County landfill reported that a 50/50 mix of tire chips with clay kept daily cover stockpiles from freezing and resulted in material that was easy to work with and spread evenly in thin or thick lifts.

Applications Summary

These case histories suggest a wide geographic acceptance of tire chips as a substitute for conventional granular materials in landfill applications. The histories indicate that none of the major design considerations preclude the use of tire chips. Laboratory test results and design analyses can address these considerations and establish the feasibility of using tire chips in a specific landfill application.

Tire chips are suitable for the following landfill applications: closure cap drainage layers; leachate collection layers leachate recirculation trenches; landfill gas collection layers and trenches; groundwater control trenches; and daily and intermediate cover supplement. Tire chips have limitations in protective cover soil applications, daily or intermediate cover soil applications, and leachate collection pipe bedding applications.

Design Approach

Preliminary designs for a landfill leachate collection layer, a gas venting layer, and a perimeter gas control trench using tire chips as the permeable material were prepared for the City of Lincoln's landfills. The design approach consisted of: establishing the major design considerations for each component of the system; evaluating the required physical properties of the conventional materials and the tire chips; conducting analyses to demonstrate equivalent performance of the tire chips; determining costs for each alternative; establishing specification requirements, including quality control and quality assurance activities; and preparing design sketches and details.

Leachate Collection Layer. The major design considerations for a leachate collection layer are: permeability under high waste fill stresses; puncture damage to the underlying geomembrane component of the composite liner system; and effective filtration to prevent clogging. The leachate collection layer for the recently completed Phase 6 of the Bluff Road Landfill consists of six inches of Nebraska Department of Roads (NDOR) "Gravel for Surfacing" material.

Analyses and laboratory testing conducted during the design phase demonstrated that this material had a permeability of 0.2 cm/sec and adequate puncture resistance against the underlying geomembrane. However, potential clogging conditions existed from the overlying protective cover soil. Thus, a non-woven geotextile material was incorporated as a filtration layer between these layers. Analyses were conducted to demonstrate the performance of tire chips as an equivalent leachate collection material. The results of these analyses indicated that a nominal four inches of tire chips provides equivalent flow capacity or transmissivity as six inches of the NDOR gravel.

Since the leachate collection system at the landfill includes only six inches of granular drainage material, no cost savings may be realized here. The cost benefits may actually be negative since the tire chips would occupy marketable landfill air space. If the City of Lincoln were to undertake the demonstration of an alternate liner using only recompacted clay, tire chips may be feasible. Approximately 44,000 tires per acre could be used in either leachate collection system option.

Gas Venting Layer. The major design considerations for a gas venting layer in a landfill closure cap are: permeability for gas transmission or dispersivity; shear strength for side slope stability; and effective filtration to prevent clogging. The proposed closure cap side slopes are 1V:4H. The preliminary designs consisted of an 18-inch thick erosion layer, overlying an 18-inch thick infiltration layer, consisting of a recompacted clay layer or a composite clay layer and geomembrane. The infiltration layer overlies a six- to 12-inch thick granular soil gas venting layer.

Results of analyses conducted to demonstrate tire chip performance as an equivalent gas venting material indicated that a tire chip gas venting layer has approximately 100% more dispersivity than conventional aggregate backfill. Results also indicated side slope stability of a tire chip layer is slightly less than for a granular soil layer, however, the factor of safety is adequate. Results further indicated that filtration performance of tire chips is comparable to conventional aggregates. Approximately 87,000 tires per acre of closure cap could be used in this application. The results suggested placement of the overlying recompacted clay layer could be complicated by the compressibility of the underlying tire chips. However, this construction sequence is typical of tire chip applications used in road subgrades. Finally, the results demonstrated that additional design, construction, and quality assurance costs are negligible for this application.

Gas Control Trench. The major design considerations for a perimeter gas control trench are: permeability for gas transmission, effective filtration to prevent clogging, and leachability of tire chips below the water table. The alternative designs consisted of a trench, nominally 18 feet deep by 5,000 feet long, excavated one to two feet below the water table; granular soil backfill; and two-foot thick clay cap. The design also consisted of perforated piping and vents installed near the top of the trench. Optionally, the design consisted of a geomembrane on the down gradient side of the trench to provide a barrier against continued gas migration across the collection trench. A slurry wall barrier was also considered in the original evaluation. This barrier is potentially better than either vented trench design but was not considered in the present analysis because of the emphasis on tire chips versus conventional aggregate backfill.

Results of analyses conducted to demonstrate tire chip performance as an equivalent granular backfill indicated that a tire chip backfilled gas collection trench has approximately 100% more dispersivity than conventional aggregate backfill. This higher dispersivity might eliminate the need for the downgradient geomembrane. The analyses found that tire chip performance is comparable to conventional aggregates in puncture and filtration. However, tire chips below the ground water table may leach metals. The results suggested that approximately 300,000 tires could be used in this application, and additional design, construction, and quality assurance costs are negligible for this application.

Materials Specifications

Construction specifications for recent tire chip fills have been based on the methods and materials format used by various state roads departments. HDR Engineering Inc. developed a preliminary specification for the City of Lincoln's landfill construction and closure using tire chips. This specification is based on a performance requirement of design-by-function for the materials, a method specification for construction, and a per ton basis for measurement and payment. This preliminary specification was based on the Construction Specification Institute (CSI) three-part format and deals only with tire chip component of construction. The test methods for the tire chip's physical properties are based on methodology presented in the ASTM draft "Specification for Use of Scrap Tires in Civil Engineering Applications."

Acknowledgments

See our November/December 1997 issue.

For more information contact Richard Donovan, HDR Engineering Inc., 8404 Indian Hills Dr., Omaha, NE, 68114; (402) 399-1211. A full set of references for the research supporting this article is available from the author.

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USE OF SHREDDED TIRES AS AN OPERATIONS LAYER IN A SUBTITLE D LANDFILL LINER PROJECT

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H. James Lee, Jr.
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Sacramento, CA.

ABSTRACT

The "operations layer" is a critically important component in the construction of a landfill liner to meet Federal RCRA Subtitle D and State of California, Chapter 15 requirements. The operations layer is installed over the liner "sandwich" to preserve the integrity of the underlying LCRS and geosynthetic liner components. The operations layer also serves as the foundation upon which the initial waste lifts are placed. Most often the operations layer consists of 12" to 24" of compacted dirt.

This paper will describe the use of shredded tires, in lieu of compacted dirt, as the operations layer in a landfill liner construction project and explore the cost and construction related advantages the authors perceive with its use. By utilizing shredded tires, a waste material which would otherwise be landfilled, significant costs associated with the use of soil were avoided. These costs included those associated with importation, installation and compaction of the soil layer and the "opportunity cost" associated with the lost airspace which would otherwise be available for waste disposal. Furthermore, in comparison with the use of soil, installation of the tires required significantly less equipment and was accomplished in a comparable amount of time. The shredded tire operations layer achieved these advantages and met all regulatory requirements.

PROJECT DESCRIPTION

L and D Landfill (L and D) is a privately owned and operated, limited Class III landfill and materials recovery facility in Sacramento, California. L and D Landfill is authorized to receive construction and demolition and other non-hazardous, non-putrescible wastes.

In 1996, L and D completed the first 4 acre increment of an ultimate 65 acre expansion project which will increase total landfill area to 157 acres.

Regulatory Requirements

The design and construction of the 4 acre lined area was approved by the State of California Central Valley Regional Water Quality Control Board. Their approval, contained in waste discharge requirements for the site, was for an "engineered alternative" to prescriptive Federal RCRA Subtitle D and State of California, Chapter 15 requuirements.

Liner Components:

The "engineered alternative" consisted of a composite liner, described from bottom to top, as follows:

- a 6" gravel layer serving as a capillary break (in areas with less than 5' of separation between waste and underlying groundwater);
- a graded foundation layer;

- a geosynthetic clay liner;
- a primary liner consisting of a 60 mil HDPE geomembrane;
- a geotextile cushion layer;
- a leachate collection and recovery system (LCRS) comprised of 6 inches of gravel;
- a geotextile filter layer;
- and 12 inches of soil or "select waste" to serve as an operations layer.

These liner components are graphically represented in Figure 1.

OPERATIONS LAYER

Regulatory Approval

Waste discharge requirements allowed the use of 12" of "select waste" as the operations layer, with Regional Board staff approval, in lieu of 12" of soil. L and D petitioned the Board for use of shredded tires as the select waste of choice. The Board granted approval of our request eventhough there was no established precedent for use of this material. Board staff accepted the contention of L and D's design engineer and QA/QC contractor that the shredded tires would be an adequate substitute for soil and would acceptably meet the water quality related objective of the operations layer; i.e, protection of the integrity of the underlying liner components.

Performance Objectives

In addition to the aforementioned objective of protection of the liner, L and D was interested in achieving other performance objectives for the operational layer which are summarized and then individually discussed below:

- Use of an available, no-cost waste material in lieu of a potentially scarce and comparatively expensive construction material.
- No damage to the LCRS during tire placement.
- Ease and speed of installation.
- Adequate foundation for waste placement.
- No adverse impacts on leachate quality.

Use of an available waste material:

A tire recycling company, Total Tire Recycling, Inc., was located only a few miles from the landfill and had been delivering shredded tires for disposal for several years. These tire shreds were of variable sizes but generally were 12"-18" in length and 6"-12" in width.

The availabililty of shredded tires is not unique to the Sacramento area. Similar tire recycling operations are becoming more prevalent with state and federal mandates precluding the landfilling of whole tires, restricting the stockpiling of tires because of environmental and public health concerns and encouraging the recycling and reuse of these materials.

Shredded tires are an increasingly available commodity. Dirt, on the other hand, can be a scarce resource. Fortunately, L and D Landfill has a readily available supply of dirt but many landfills are "dirt poor" having to import dirt for their daily and intermediate cover and other landfill construction related activities.

No damage to the LCRS during tire placement:

Shredded tires are comparatively light, with an estimated bulk density of 350-400 pounds per cubic yard. Placement of the tires to establish the operations layer was accomplished utilizing a single piece of equipment, a Furukawa front-end loader with a 12 cubic yard bucket. This loader was used to pick up and spread tires delivered to the landill in 55 cubic yard rolloff boxes and stockpiled immediately adjacent to the liner construction area.

The combined weight of the loader and its load and the distribution of that weight over the large tires of the loader was such that no significant disturbance resulted from movement of the loader on the LCRS. Potential LCRS damage was further minimized by having the loader operator initially establish a pad of shredded tires from which to work.

Ease and speed of installation:

The operations layer was built bucket load by bucket load; the loader operator, through deft maneuvering of his bucket load of tires, would "sift" the contents until the required layer thickness was achieved. Since trucks cannot follow behind the loader to deliver tires to the "working face" the loader must ferry between the tire stockpile and the advancing "tire front". Although we chose not to do so, this inefficiency can be minimized through the use of additional loaders to ferry tires to the "front" and/or place tires as necessary.

Using this method, the 4 acre operations layer was built in 3, 10 hour days or a rate of 1.3 acres per day. Approximately 6,450 cubic yards of tires were used in the construction of the operations layer. By utilizing additional loaders, this rate could be commensureatly increased as necessary.

Movement and placement of dirt to establish an operations layer is not necessarily more expeditious. Uncompacted soil is comparatively "heavy" with a bulk density exceeding 2500 pounds per cubic yard and a range of "heavy" equipment must be used to move and place this material. This equipment could include transfer trucks to deliver the dirt from a remote stockpile and/or use of scrapers; and a dozer to push, place and level. None of this equipment could work directly on the LCRS without causing damage to it.

An initial pad would have to be constructed and then a "dirt front" advanced by use of a dozer. The dozer could effectively consolidate the dirt to allow scrapers or even transfer trucks to follow behind it to off-load, thus potentially facilitating and expediting the construction process. It is quite conceivable that depending on the amount of equipment that you wanted to "throw at the problem", that placement of dirt could be accomplished in less time than shredded tires. However, in our experience this advantage is more imagined than real. This is especially true since we were able to obtain phased or interim approvals from the Regional Board to commence placement of waste just about as soon as we finished a large enough portion of the liner project to be operationally significant. For this and other reasons outlined in this paper, we judged the potential advantages of the conventional construction approach with dirt to be relatively insignificant vis a vis the cumulative advantages of the use of shredded tires.

Adequate foundation for waste placement:

We found that the shredded tires did provide an adequate foundation for subsequent waste placement as long as certain precautions were taken in establishing the initial lift of waste. Because of the significant amount of void space and the compressibility of the tire layer, care had to be taken to segregate those waste loads with large pieces of debris which could not be compacted without penetrating the liner sandwich. Since we had areas other than the newly lined area to dispose of waste, this proved to be only a minor concern. It goes without saying that this is problem which would be less critical, with a compacted earth operations layer.

No adverse effects on leachate quality:

There was some initial concern by Regional Board staff that any residual petroleum products on the tires or a chemical reaction of the leachate with the metal in the tire reinforcement might adversely impact leachate quality. Initial sampling of leachate has shown no discernible adverse effects from this source.

QA/QC Considerations

The normal QA/QC technique employed to ascertain that the appropriate thickness of a material has been placed would be to survey the area before and after material placement. However, measurement of the tire layer was not amenable to this approach due to its compressibility. Our QA/QC contractor elected to utilize the simple but adequately effective technique of random spot checks taken with a ruler as the tires were being placed. This technique served to facilitate the placement of tires to the appropriate depth by providing "feedback" to the loader operator as necessary but also provided the data for the subsequent certification of results to the Regional Board.

COST COMPARISONS - SHREDDED TIRES VS. DIRT OPERATIONS LAYER

We estimate the per acre cost of a shredded operations layer to be approximately $600/per acre based on an approximate 4 acre job. This figure is based on our experience and the following assumptions:

- Shredded tires provided at no charge.
- Shredded tires are delivered at no charge and stockpiled adjacent to the working area.
- Use of a manned, front end loader @ $80/hr. over a 3 day, 30 hour period.

In comparison, we estimate the minimum 12" compacted dirt operation layer construction costs for a 4 acre project to be approximately $2,900/per acre. This figure does not take into consideration the "opportunity cost" of the lost "airspace" (which would otherwise be avaliable for waste disposal) occupied by the operations layer itself. This figure assumes the following:

- Dirt is available at no cost.
- Dirt is transported to the site at no cost and is stockpiled close to the construction area for pick up and placement by scrapers.
- Two manned scrapers at $135/hr each and 1 dozer at $115/hr are utilized over a 3 day, 30 hour period. (The scrapers deliver 18 cubic yards of dirt to be placed by the dozer every 5 minutes).
- Potential opportunity costs for lost airspace are not included but would most likely significantly exceed the installation costs.

CONCLUSION

Our experience with use of shredded tires to construct an operations layer was overwhelmingly favorable. We found it saved time and money during the construction, preserved valuable air space and met all regulatory requirements. The only negative perceived with its use is the extra care that must be taken during the establishment of initial waste lifts. This minor drawback is easily overcome with attention to initial waste placement.

Construction planning and management for the entire project was provided by the site operator, L and D Landfill Limited Partnership. L and D staff provided input to, and oversight of, the activities of the landfill liner design engineers; negotiated with and secured all necessary permits and approvals from regulatory agencies for the liner construction; excavated and rough graded the liner foundation layer and installed the operations layer utilizing company staff and equipment; and scheduled and coordinated the activities of, liner installers and QA/QC contractors. By being involved in all aspects of the liner construction, L and D Landfill Limited Partnership maintained tight operational and cost control of the project. L and D was ably assisted in this endeavor by the efforts and cooperation of our team of consultants, engineers and contractors including Applied Science and Engineering (planning and design); Vector Engineering, Inc. (QA/QC); EMCON (QA/QC); Topside Construction, Inc. (final grading and capillary break and LCRS construction); Barber-Webb Company, Inc. (geosynthetics installation); Morton & Pitalo, Inc. (surveying); and Total Tire Recycling, Inc. (shredded tires). The authors would like to particularly thank and acknowledge John Boss of EMCON, Dr. Richard Armstrong of Applied Science and Engineering and Gary Matranga and Michael Payan of Total Tire Recycling for their help and assistance with this paper.

Innovative Leachate Management: Options and Answers

Three East Texas landfills are the case studies for this look at how to innovatively manage landfill leachate.

This article examines the leachate collection system designs and management practices at three landfills in East Texas operated by Laidlaw Waste Systems, Inc. (Burlington, Ontario; now a unit of Allied Waste Industries, Inc., Scottsdale, Ariz.). Initially, the collection system options are discussed including associated costs. Following the collection system discussion, the alternate leachate management options are discussed.

The East Texas facilities, all operated by Laidlaw, are Pinehill Landfill (Kilgore); Greenwood Farms Landfill (Tyler); and Royal Oaks Landfill (Jacksonville). The three landfills are located within a 30-mile radius of Tyler, Texas. General information regarding the facilities is presented in Table 1.

The Texas Natural Resource Conservation Commission (TNRCC) has approved Options 1 and 2 below for the leachate collection system for all three facilities. Option 3 has been approved only for the Greenwood Farms Landfill.

- *Option 1:* A 12-inch sand or gravel collection layer (minimum 10^{-2} cm/sec permeability) overlain with a nonwoven geotextile, followed by 12 inches of protective cover (no permeability requirements);
- *Option 2:* Geonet overlain with a nonwoven geotextile followed by a 24-inch soil protective cover layer (no permeability requirements);
- *Option 3:* A 10-inch soil protective layer (no permeability requirements) overlain with 14-inch layer of tire chips.

The comparative construction costs for the leachate collection system options (not including pipe) are: Option 1, \$23,700 per acre; Option 2, \$12,600 per acre; and Option 3, \$8,500 per acre. In Option 2, TNRCC requires "chimney

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drains" along the entire length of the leachate collection pipe/trench. The chimney drains consist of sand or gravel (with a minimum 10^{-2} cm./sec. permeability) and extend vertically through the "non-spec" soil protective cover. This design allows leachate collection either through the geonet or through the chimney drains (i.e., leachate travels horizontally across non-spec protective cover then vertically through chimney drains to the leachate collection pipe/trench).

Table 1

General Facility Information

Facility	Location	Total Landfill Footprint (AC)	Constructed as of 12/1/96 (AC)	Area w/Sub D LCRS (AC)
Pinehill	Kilgore	160.0	89	11
Greenwood Farms	Tyler	122.6	58	14
Royal Oaks	Jacksonville	54.0	24	9

For Option 3, Laidlaw investigated the potential use of tire chips in the leachate collection system for several facilities in the U.S. Generally, we determined that tire chips can readily be used for the leachate collection and protective cover layer for landfill liners constructed using in-situ or recompacted layers of clay. In these designs, there is little danger of penetrating the primary liner system (clay) by the tire shreds. The size and quality of the shredded tires are also relatively unimportant, as long as they are sufficiently small enough to be handled easily for the construction application.

For composite lined sites, most states require a protective layer of sand, gravel, or other aggregate material that is 12 to 24 inches in depth above the geosynthetic liner. In addition, the lower 12 inches of aggregate material generally must have good permeability characteristics (with a minimum of 1 x 10^{-2} cm./sec.). Tire chips provide satisfactory drainage characteristics; however, wire protruding from the shredded tires historically has limited their use in composite-lined sites to that portion of the protective cover layer above the 12-inch aggregate drainage layer. For the East Texas landfills, this application of tire chips was uneconomical compared to using a geonet and non-spec protective cover, as in Option 2.

Tires roll in

In 1996, TNRCC adopted an emergency amendment to the state's solid waste rules to promote the use of shredded tires in municipal solid waste landfills (MSWLFs). The amended rules allowed a $0.625/ton rebate (for the total tons of tire chips utilized) to any MSWLF owner utilizing tire chips during the 1996 calendar year. Three criteria had to be met to obtain the rebate:

- TNRCC-approved use (i.e., leachate collection layer, liner protective cover, final cover);
- Tire chip installation and quantity certified by professional of record (i.e., PE or PG); and
- TNRCC approval of the installation report.

Several factors led Laidlaw to pursue the use of tire chips in a four-acre cell at the Greenwood Farms Landfill, including potential cost savings versus other options; TNRCC's open-minded approach to alternate uses; and potential rebate on state fees.

The chosen design differed from previous tire chip applications in a unique way. Essentially, in our design (i.e., Option 3), leachate collection is designed to occur in the first two inches of the 14-inch tire chip layer. The 2-inch tire chip layer is considered our primary leachate collection layer. Utilizing tire chips in this manner provides an economic advantage over the other options, and also allows for the beneficial use of approximately 56,000 used tires per acre-foot.

However, prior to utilizing tire chips in this application, several issues needed to be addressed. These included evaluation of leachate head on the liner; the constructability of a 10-inch-thick protective cover layer; and potential patent infringement.

Evaluation of Leachate Head on the Liner. The Hydrologic Evaluation of Landfill Performance (HELP) Model, Version 3.01, was used to confirm the adequacy of the initial 2 inches of tire chips in conveying leachate and maintaining 1 foot or less of head on the liner system. The Greenwood Farms Landfill was modeled under three scenarios: the working face with 10 feet of waste (active landfill); 40 feet of waste with intermediate cover (interim condition); and 92 feet of waste with final cover (closed landfill). The 2-inch tire chip layer was modeled with an hydraulic conductivity of 2 cm./sec. The underlying 10-inch soil protective layer was assumed saturated, which had the effect of adding 10 inches of total head to the peak daily head value.

The HELP model was run for a 30-year period with the following peak daily head (on the liner system) values: active landfill (10.426 inches); interim condition (10.042 inches); and closed landfill (10.001 inches). Additionally, we required the earthwork contractor to install the 10-inch non-spec protective cover within 0.1 feet (1.2 inches). This thickness tolerance ensured that the total head on the liner would not exceed 12 inches.

Constructability. Placement of the 10-inch "protective cover layer" directly upon the geomembrane presented several construction issues that had to be addressed in order to ensure the integrity of the underlying geomembrane liner. The protective cover specification included a maximum particle size of no greater than 3/8 inch (versus typical requirement for 1-inch maximum particle size) and a placing equipment load standard not exceeding 5 psi. Continuous third-party quality assurance/control inspectors monitored placement of the 10-inch layer to ensure no damage to the liner occurred during construction.

One option pursued by TNRCC was the use of a 14-inch layer of tire chips for leachate colleciton.

Tire-Chip Use Patent Review. Before further developing the idea of utilizing the chipped tires under Option 3 (placement of tire chips over a 10-inch protective cover), a question of potential patent infringement had to be investigated. A formal patent search yielded the finding that two patents have been issued to a single company for the use of chipped or shredded tires in landfills. These patents make some rather broad claims concerning the utilization of chipped tires in landfills and the process for producing a landfill. However, it was the opinion of our attorney that, provided we followed some specific steps regarding their use, our idea would not infringe on the existing patents. Furthermore, we have begun our own patent application process for this idea to protect our ability to continue its use.

Submitting the idea

After completing the evaluations discussed above, we submitted our design to TNRCC for review, which approved the design in August 1996. We constructed a four-acre composite lined cell using the tire chips for the leachate collection layer at the Greenwood Farms Landfill in fall 1996. A total of 2610.79 tons (7161.48 cubic yards or 250,000 used tires) of tire chips was used in construction of the 14-inch thick leachate collection layer. This quantity provided a $1,631.74 rebate on our state fees.

For temporary stormwater controls, generally the largest quantity of leachate will be generated in the first several months that a cell is open. Often, the initial leachate is nothing more than rainfall that has entered the cell in areas that have not received waste. Most states typically require this water to be managed as leachate, since this water has potentially mixed with leachate. Therefore, temporary stormwater controls that reduce the quantity of initial leachate can often be justified on a cost basis.

The temporary stormwater control that we have most often utilized is a flap that extends through the protective cover with a berm on the downgradient side of a sump. The sump is located in the leachate collection trench and extends past the trench approximately 50 feet on each side (giving an overall sump dimension of 15 feet by 100 feet). This temporary sump typically costs between $3,000 and $4,000.

When landfill operations reach the temporary sump, the flap is removed, the leachate pipe is connected, and the sump is filled with the appropriate material (e.g., drainage material in the chimney drain, protective cover outside the collection trench). Until landfill operations reach the temporary sump, collected stormwater is

Table 2

COMPARISON OF POTW LEACHATE DISPOSAL REQUIREMENTS

Parameter	Pinehill	Greenwood Farms	Royal Oaks[1]
Total Metals			
Aluminum	NA	NA	2.461/Q
Arsenic	0.3/Q	0.6/Q	0.13/Q
Barium	4.0/Q	NA	NA
Cadmium	0.2/Q	0.2/Q	0.012/Q
Chromium	5.0/Q	5.0/Q	3.71/Q
Copper	NA	NA	0.2/Q
Lead	1.5/Q	0.3/Q	0.026/Q
Manganese	3.0/Q	NA	NA
Mercury	0.01/Q	0.01/Q	0.02/Q
Molybdenum	NA	NA	0.01/Q
Nickel	3.0/Q	NA	0.536/Q
Selenium	0.2/Q	NA	NA
Silver	0.2/Q	5.0/Q	0.008/Q
Zinc	6.0/Q	NA	NA
pH	6.0-9.0/B	5-11.5/Q	NA
BOD	250/M	1500/Q	NA
COD	NL/M	1200/Q	NL/Q
Oil & Grease	100/Q	100/Q	NA
TSS	250/M	1500/Q	NA
TDS	NA	4400/Q	NA
TTO	NA	NA	NA
Chlorides	NA	500/Q	NA
Sulfides	NA	5.0/Q	NA
Phenols	NA	2.0/Q	NA
Cyanide	NA	0.3/Q	NA
DISPOSAL COST	$0.065/GAL	$0.03	$0.03[2]

All parameters in ppm, unless otherwise noted.
M — Monthly
B — Batch
Q — Quarterly
NA — Not applicable
NL — No limit

NOTES:
[1] Preliminary discharge limits pending further testing.
[2] First 100,000 gallons per month are free.

pumped out of the cell as uncontaminated water.

Testing the waters

The leachate management options for these landfills currently include off-site disposal at the local publicly owned treatment works (POTW) or liquid waste processing facility, and on-site recirculation. To date, we have not used the liquid waste processing facility due to cost and transportation factors. All three landfills have leachate disposal agreements with the local POTW. However, each POTW has slightly different acceptance criteria and disposal rates as shown in Table 2.

The testing costs required by the POTWs add $0.01 to $0.02 per gallon to the total leachate disposal cost. Also, generated leachate currently is transported to the POTWs in a 5,000-gallon tanker truck, which adds another $0.015 to $0.02 per gallon to the leachate disposal cost. Therefore, the total leachate disposal cost is between $0.055 and $0.10 per gallon.

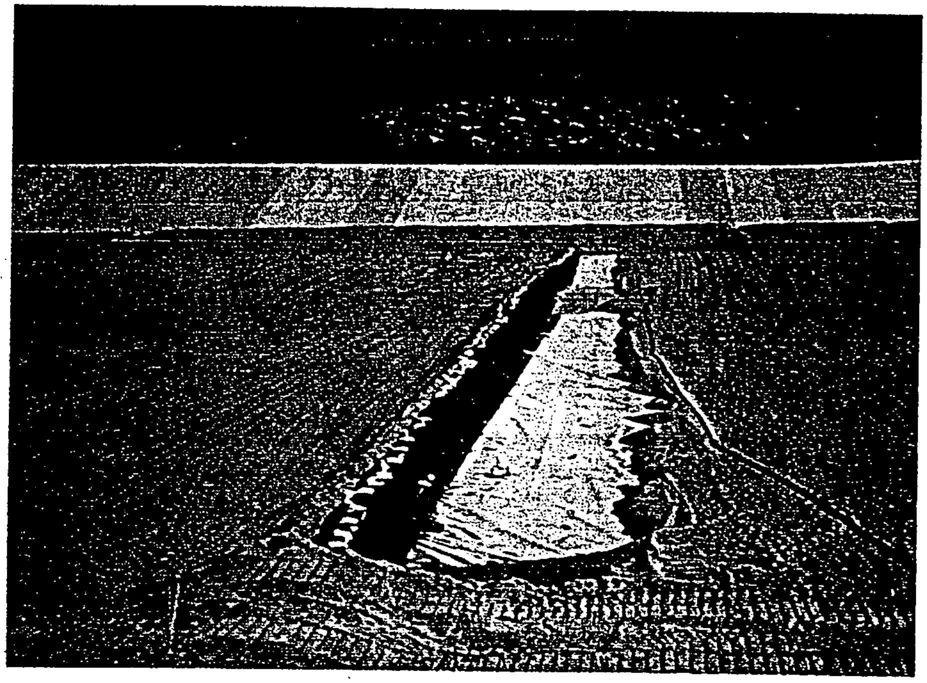
At these disposal rates, leachate management represents a large operational cost for these facilities. In fact, leachate management consumes between 2% and 3% of these landfills' revenue. Therefore, substantial savings—that is, earning—may be obtained if cheaper leachate management methods are employed. One cheaper method that has been utilized at the Pinehill and Royal Oaks landfills is leachate recirculation. This method offers several advantages to off-site disposal, in addition to being cheaper, including:

- Minimizing the potential for accidental spills during transferring to tanker trucks, and transportation to POTW;
- Increasing landfill gas production; and
- Increasing the stabilization of waste mass through settlement treatment of leachate in the waste mass.

The team also considered several leachate recirculation options, including:

- Spraying at the working face with a sprinkler system;
- Using leachate as a component of alternate daily cover (ADC), sprayed on the working face each day; and
- Discharging to leach fields/seepage pits placed in the waste.

We decided against spraying at the working face due to employee/customer health concerns, odor prob-



A temporary stormwater sump reduces the inital quantity of leachate.

lems, and the requirement for frequent relocation of the system. We used the leachate in our ADC mix at the Pinehill Landfill for a one-week test period. The ADC mix is essentially a hydromulch without the seed. Bags of paper mulch (eight to nine 40-pound bags) and a tackifier are added to a prescribed quantity of water (generally 800 gallons) in a hydroseed machine. The resulting slurry is sprayed on the working face at the close of business.

For the one-week test period, leachate was substituted for the water, thereby effecting recirculation of 800 gallons daily. This recirculation method was effective and also allowed the paper mulch to absorb the leachate. The major drawbacks of this method are potential long-term employee health concerns and the limited quantity of leachate that can be recirculated. Generally, three to five times more leachate was produced than could be recirculated with this method. Therefore, a supplemental management method would be needed.

We believe that the simplest, and perhaps most effective, recirculation method involves the reintroduction of the leachate to the in-place waste utilizing a leach field or seepage pit. Several studies indicate that the overall, in-place moisture content of waste at most landfills is well below field capacity. Additionally, studies have shown that leachate movement occurs through channeled pathways (typically 25% of the waste), which prevents uniform saturation of the waste mass. Therefore, if leachate could be more evenly distributed throughout the waste mass, then substantial leachate storage could be obtained. Table 3 presents potential storage capabilities for the three East Texas landfills for areas with a Subtitle D liner and a leachate recirculation system.

Recirculation system

The Pinehill and Royal Oaks landfills recirculated leachate throughout 1996. The Pinehill Landfill utilized seepage pits approximately 3 feet wide, 10 feet long, and 12 feet deep. The pits were constructed with a CAT 225 (Caterpillar, Peoria, Ill.) excavator and then backfilled with wood chips produced on-site. Leachate was pumped directly to the seepage pits from the collection sump.

Royal Oaks utilized a 3,000-gallon storage tank and leach field consisting of 800 feet of perforated, 4-inch diameter, schedule 80 PVC pipe spaced 15 to 20 feet apart. Leachate is pumped directly to the storage tank and then allowed to drain (via gravity) into the leach field. The leachate is typically batch-discharged to the leach field, and then the field is allowed two days of recovery time. Both recirculation methods had a positive impact on the quantity of leachate produced and disposed of at the local POTW. Table 4 compares leachate quantities collected and recirculated versus measured precipitation for the three landfills during 1996.

As seen in Table 4, the Pinehill and Royal Oaks landfills were able to recirculate approximately half of all the leachate produced. Additionally, less leachate was produced at both Royal Oaks and Pinehill on a per-acre basis. Thus, one could conclude that a portion of the additional leachate storage capacity was utilized.

In the fall of 1996, the seepage pits at the Pinehill Landfill were replaced with a leach field recirculation system consisting of the following components:

- A 22,000-gallon storage tank (frac tank) located over the intermediate covered area of waste, approximately 40 feet thick;

- A 3-inch diameter, solid, PVC Schedule 80, header pipe approximately 260 feet long;
- Fourteen lateral lines of 4-inch diameter, perforated high density polyethylene (HDPE) pipe, spaced at 20-foot intervals and each having a length of approximately 350 feet;
- A ball valve and discharge line sighting tube (to observe flow conditions).

The lateral lines were installed in shallow trenches (approximately 2-feet deep) that were excavated with a Case 980 (Case Corp.; Racine, Wis.) backhoe with a bucket width of 2 feet. The HDPE pipe was manufactured by Advanced Drainage Systems (ADS; Columbus, Ohio) and is similar to the pipe used in our leachate collection trenches. The pipe has 20-foot sections, joined by pushing the ends together and securing with a coupling.

The perforated HDPE pipe was placed in contact with the underlying waste and the trenches backfilled with wood chips. The wood chips were produced on-site from diverted wood waste. We hope that the wood chips will serve as a trickling filter to provide aerobic decomposition of organic matter in the leachate. A 12-inch soil cover layer was placed over the wood chips. The total recirculation drainage area (e.g., surface area available for recirculation) is approximately 10,000 sq. ft. Based on published permeability data for waste of 10^{-3} to 10^{-4} cm./sec., the total expected flow rate into the recirculation field is between 15 to 150 gallons per minute. Leachate is pumped directly to the storage tank at a maximum flow rate of 40 gallons per minute, where it is either stored and then recirculated, or directly recirculated.

The total installation cost for the recirculation system was $35,000, itemized by the contractor (system installation, $15,000; a 22,000-gallon storage tank, $14,000; and piping, valves, and sight tube, $6,000).

The overall grade of the recirculation area slopes at approximately 2% to the north (away from the storage tank). We did not attempt to maintain a level grade on the lateral lines during installation. Instead, we installed a ball valve to allow part of the recirculation field (four lateral lines) to be shut off if uneven loading of the field occurred due to elevation differences, and additional ball valves may be installed if necessary in the future.

Table 3

POTENTIAL LEACHATE STORAGE CAPACITY

Facility	Airspace over Subtitle D Liner/LCRS (CY)	Additional Leachate Storage Capacity (million gallons) (10%)	(30%)	(50%)
Pinehill	710,000	14.4	43.2	72
Greenwood Farms	1,130,000	22.9	68.7	114.5
Royal Oaks	725,000	14.7	44.1	73.5

Table 4

SUMMARY OF 1996 LEACHATE DATA

Facility	Total Rainfall	Leachate Produced		Leachate Recirculated		Leachate to POTW
	(in.)	(gal.)	(gal./acre)	(gal.)	(% of collected)	(gal.)
Pinehill	39.85	1,278,000	116,000	739,000	57.8%	539,000
Greenwood Farms	42.95	1,304,000	119,000	0	0%	1,304,000
Royal Oaks	30.29	804,000	89,000	365,000	45.46%	439,000
TOTAL	n/a	3,386,000	n/a	1,104,000	32.61%	2,282,000

ATTACHMENT C

GEOTEXTILE DESIGN CALCULATIONS

CLIENT HILLSBOROUGH	PROJECT SCLF	JOB NO. 0995029.23
SUBJECT WOVEN GEOTEXTILE FOR SOIL RETENTION IN LEACHATE COLLECTION TRENCH	BY Sheila / CHECKED KHS	DATE 5-1-98 / DATE 5-4-98

TASK

GIVEN PARTICLE SIZE DISTRIBUTION CURVE OF SOIL AT THE SITE, CALCULATE IF A CHOSEN WOVEN GEOTEXTILE WILL BE SUFFICIENT TO RETAIN THE SOIL WHEN USED AS A WRAP FOR CHIPPED TIRES IN AN ADDITIONAL, UPGRADED LEACHATE COLLECTION TRENCH TO BE CONSTRUCTED.

REFERENCES

- ATTACHED CHART 4-1 p. 46 AND p. 22 CALCULATION FOR C'u FROM MIRAFI SE SALES
- PRINCIPLES OF GEOTECHNICAL ENGINEERING, 3d ED., BRAJA M. DAS

METHOD

1. FROM THE THREE SAMPLES OF SOIL AT THE SITE, CHOOSE THE PARTICLE SIZE DISTRIBUTION CURVE WITH THE SMALLEST EFFECTIVE SIZE AS PER DAS.

2. FOLLOW CHART 4-1 PERFORMING CALCULATIONS NEEDED FOR DECISION MAKING USING THE CHOSEN DISTRIBUTION CURVE.

SCS ENGINEERS

CLIENT HBORO	PROJECT SCLF	JOB NO. 09950029.23
SUBJECT WOVEN GEOTEXTILE FOR SOIL RETENTION IN LEACHATE COLLECTION TRENCH	BY Sheila	DATE 5-1-98
	CHECKED KNB	DATE 5-4-93

3. CHECK INEQUALITIES ON THE CHART USING THE CHOSEN WOVEN GEOTEXTILE.

GIVEN

CHOSEN WOVEN GEOTEXTILE IS:
MIRAFI FW 401 ✓
AOS = 0.425 mm = O_{95}
(See ATTACHMENT 5)

SOLUTION

1. SMALLEST EFFECTIVE SIZE OF SAMPLES GIVEN

EFFECTIVE SIZE AS PER DAS
= d_{10} SEE ATTACH

SAMPLE 1 d_{10} = 0.14 mm

SAMPLE 2 d_{10} = 0.12 mm

SAMPLE 3 d_{10} = 0.13 mm

∴ USE SAMPLE 2 d_{10} = 0.12 mm
ATTACH 2

CLIENT H BORO	PROJECT SCLF		JOB NO. 0995029.23
SUBJECT WOVEN GEOTEXTILE FOR SOIL RETENTION IN LEACHATE COLLECTION TRENCH		BY Sheila	DATE 5-1-98
		CHECKED KAS	DATE 5-4-98

2

a. FOLLOWING CHART 4-1 (ATTACH 3)
GO TO:
LESS THAN 10% FINES AND LESS THAN 90% GRAVEL

$d_{10} > 0.075$ mm and $d_{10} < 4.8$ mm

$0.12 > 0.075$ mm and $0.12 < 4.8$ mm ✓

b. FOLLOWING CHART 4-1 DOES APPLICATION FAVOR RETENTION?

APPLICATION IS FOR SOIL RETENTION.

c. CHECK FOR STABLE OR UNSTABLE SOIL.

CALCULATING C_c ACCORDING TO THE NOTE ON THE CHART:

$$C_c = \frac{(d_{30})^2}{(d_{60})(d_{10})}$$

GET d_{30}, d_{60} FROM SAMPLE 2 PARTICLE SIZE DISTRIBUTION CURVE

$d_{30} = 0.20$ mm
$d_{60} = 0.27$ mm
$d_{10} = 0.12$ mm AS PREVIOUSLY

$$C_c = \frac{(0.20)^2}{(0.27)(0.12)} = 1.2$$

SCS ENGINEERS

CLIENT HBORO	PROJECT SCLF	JOB NO. 0995029.23
SUBJECT WOVEN GEOTEXTILE FOR SOIL RETENTION IN LEACHATE COLLECTION TRENCH	BY Sheila / DATE 5-1-98	CHECKED [illegible] / DATE 5-4-93

2c continued

IS

$1 \leq C_c \leq 3$

$1 \leq 1.2 \leq 3$ yes. ∴ STABLE SOIL

USE $C'_u \rightarrow \frac{d_{60}}{d_{30}}$ AS PER CHART 4-1

d. CHECK IF SOIL IS WIDELY GRADED OR UNIFORMLY GRADED.

$C'_u = \frac{0.27}{0.20} = 1.4$

$C'_u < 3$ ∴ UNIFORMLY GRADED

e. CHECK IS CHOSEN GEOTEXTILE WILL WORK ON VARIOUS DENSITIES OF SOIL. FROM CHART 4-1:

LOOSE $O_{95} < C'_u d'_{50}$

MEDIUM $O_{95} < 1.5\, C'_u d'_{50}$

DENSE $O_{95} < 2\, C'_u d'_{50}$

GET d'_{50} AS DESCRIBED ON p. 22 FOR DRAWING A STRAIGHT LINE APPROXIMATION THROUGH SAMPLE 2 PARTICLE SIZE DISTRIBUTION. (ATTACH 4)

SCS ENGINEERS

CLIENT HBORO	PROJECT SCLF	JOB NO. 0995029.23
SUBJECT WOVEN GEOTEXTILE FOR SOIL RETENTION IN LEACHATE COLLECTION TRENCH	BY Sheila	DATE 5-1-98
	CHECKED KNS	DATE 5-4-98

2e continued

$d'_{50} = 0.38$

LOOSE: $0.425 < (1.4)(0.38)$

$0.425 < 0.53$ OK

MEDIUM: $0.425 < (1.5)(1.4)(0.38)$

$0.425 < 0.80$ OK

DENSE: $0.425 < (2)(1.4)(0.38)$

$0.425 < 1.06$ OK

CONCLUSION

THE WOVEN GEOTEXTILE MIRAFI FW401 IS SUFFICIENT TO RETAIN THE GIVEN SOIL. ✓

PRINCIPLES OF GEOTECHNICAL ENGINEERING

ATTACHMENT 1

1.6 EFFECTIVE SIZE, UNIFORMITY COEFFICIENT, AND COEFFICIENT OF GRADATION

The particle-size distribution curves can be used for comparing different soils. Also, three basic soil parameters can be determined from these curves, and they can be used to classify granular soils. These parameters are:

1. Effective size
2. Uniformity coefficient
3. Coefficient of gradation

The diameter in the particle-size distribution curve corresponding to 10% finer is defined as the *effective size*, or D_{10}. The *uniformity coefficient* is given by the relation

$$C_u = \frac{D_{60}}{D_{10}} \tag{1.7}$$

where C_u = uniformity coefficient
D_{60} = the diameter corresponding to 60% finer in the particle-size distribution curve

The *coefficient of gradation* may be expressed as

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} \tag{1.8}$$

where C_c = coefficient of gradation
D_{30} = diameter corresponding to 30% finer

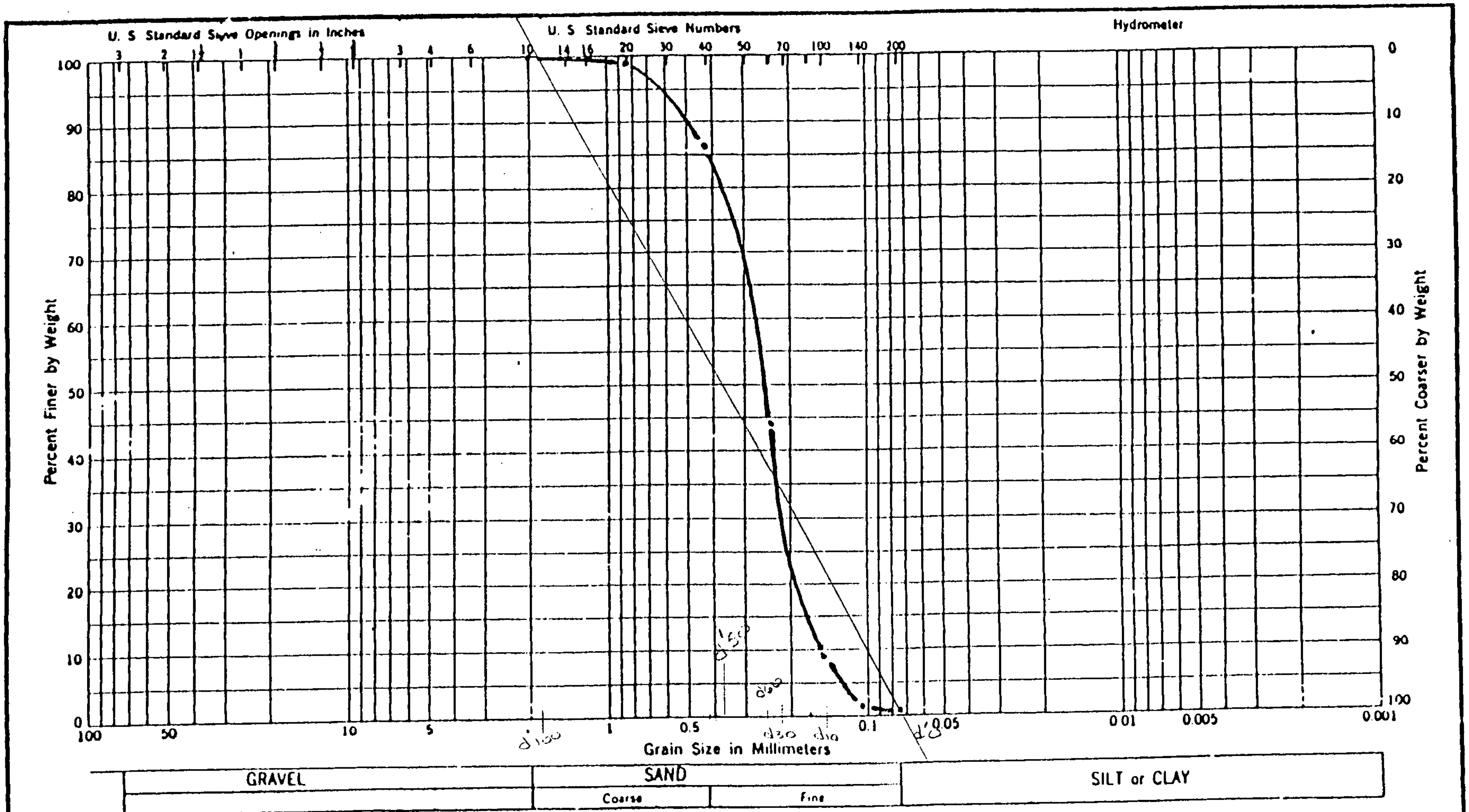
For the particle-size distribution curve of soil B shown in Figure 1.16, the values of D_{10}, D_{30}, and D_{60} are 0.096 mm, 0.16 mm, and 0.24 mm, respectively. The uniformity coefficient and coefficient of gradation are

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.24}{0.096} = 2.5$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{(0.16)^2}{0.24 \times 0.096} = 1.11$$

The particle-size distribution curve shows not only the range of particle sizes present in a soil but also the type of distribution of various size particles. This is demonstrated in Figure 1.17. Curve I represents a type of soil in which most of the soil grains are the same size. This is called *poorly graded* soil. Curve II represents a soil in

DRIGGERS ENGINEERING SERVICES, INC.
Clearwater, Florida



Number	Depth	Natural Moisture	L. L.	P. L.	P. I.	Classification
						Tailing - light brown to tan
						fine Sand (SC)

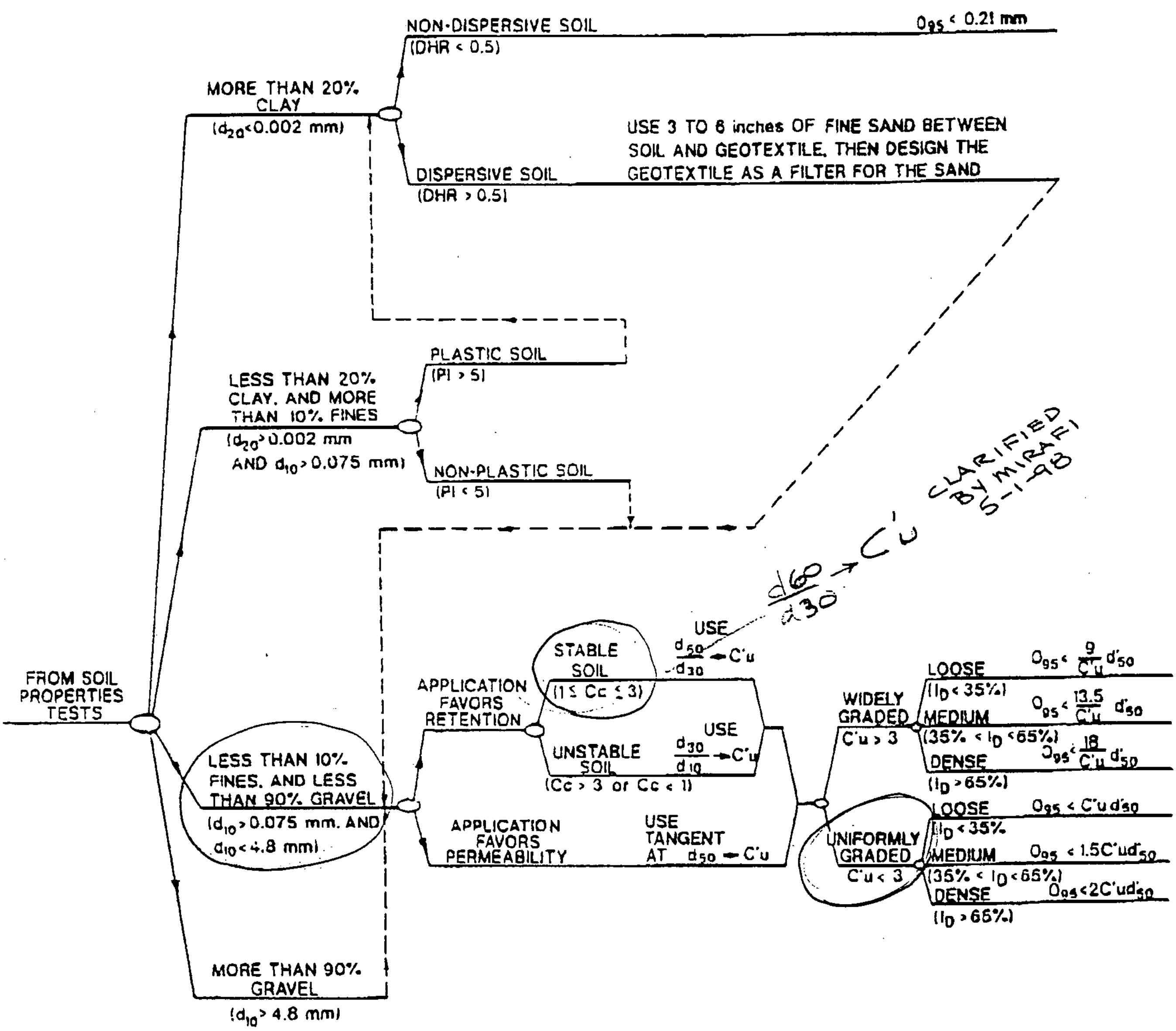
Project: Hillsborough Waste Management
Client: Indeco of Florida
Sample No. 2

d10 = 0.12

ATTACHMENT 2

ATTACHMENT 3

CHART 4-1
SOIL RETENTION CRITERIA FOR STEADY-STATE FLOW CONDITIONS



NOTES:

d_x is the particle size of which x percent is smaller

$C'_u = \sqrt{\frac{d'_{100}}{d'_0}}$ where: d'_{100} and d'_0 are the extremities of a straight line drawn through the particle-size distribution, as directed above; and d'_{50} is the midpoint of this line.

$C_c = \frac{(d_{30})^2}{d_{60} \times d_{10}}$

I_D is the relative denisty of the soil

PI is the plasticity index of the soil

DHR is the double-hydrometer ratio of the soil

Portions of this flow chart modified from Giroud (1988)

ATTACHMENT 4

$$C_u = \frac{d_{60}}{d_{10}} \quad \text{(Equation 4-1)}$$

A soil that exhibits a wide distribution of particle sizes will necessarily have a large C_u value. A soil with a uniform distribution of particle sizes will have a low C_u value. Figure 4-1A shows examples of widely-graded, uniformly-graded, and gap-graded soils along with their respective C_u values.

- Linear Coefficient of Uniformity, C'_u, is a measure of the slope of a straight line approximation of the soil particle-size distribution curve. Mathematically, the following rule is true of a straight line drawn on a semi-logarithmic particle-size distribution graph:

$$C'_u = \frac{d'_{50}}{d'_0} = \frac{d'_{60}}{d'_{10}} = \frac{d'_{70}}{d'_{20}} \ldots \frac{d'_{100}}{d'_{50}} = \sqrt{\frac{d'_{100}}{d'_0}} \quad \text{(Equation 4-2)}$$

where: d'_x is the equivalent d_x obtained from the straight line approximation of the particle-size distribution curve.

Hence, if a straight line approximation is drawn through a soil particle-size distribution, then the linear coefficient of uniformity can be calculated using Equation 4-2.

As with the conventional Coefficient of Uniformity, a widely-distributed soil will have a larger value of C'_u than a uniformly-graded soil. Figure 4-1B shows examples of widely-graded, uniformly-graded, and gap-graded soils, along with their respective C'_u values. Note that a gap-graded soil may have different values of C'_u, depending on what portion of the curve is used to draw the straight line.

The Original Geosynthetics Company

ATTACHMENT 5

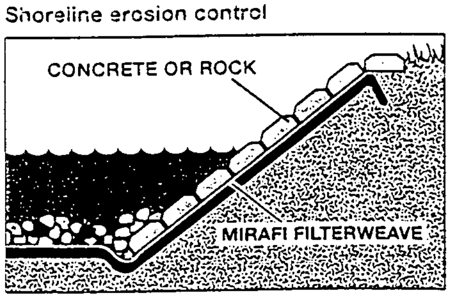
product Mirafi Filterweave Woven Geotextiles

for Erosion Control and Filtration

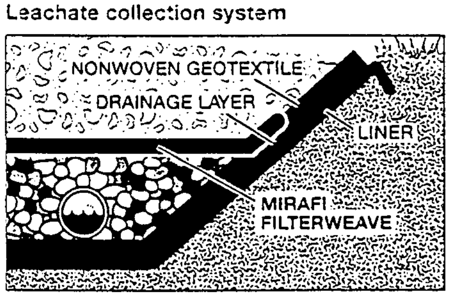
Property / Test Method	Units	FW 300	FW 400	FW 401	FW 402	FW 403	FW 500	FW 700
MECHANICAL PROPERTIES								
Wide Width Tensile Strength ASTM D 4595								
MD @ Ultimate	kN/m (lbs/in)	40 (230)	26 (150)	31 (175)	35 (200)	47 (270)	31 (180)	37 (210)
CMD @ Ultimate	kN/m (lbs/in)	39 (225)	29 (165)	19 (110)	23 (135)	39 (225)	32 (185)	24 (135)
Grab Tensile Strength ASTM D 4632								
MD @ Ultimate	kN (lbs)	1.78 (400)	1.18 (265)	1.45 (325)	1.62 (365)	1.89 (425)	1.22 (275)	1.65 (370)
CMD @ Ultimate	kN (lbs)	1.49 (335)	1.13 (255)	0.89 (200)	0.89 (200)	1.56 (350)	1.74 (390)	1.11 (250)
MD Elongation @ Ultimate	%	20	16	26	24	21	15	16
CMD Elongation @ Ultimate	%	15	15	15	10	21	30	15
Mullen Burst Strength ASTM D 3786	kPa (psi)	4990 (725)	3441 (500)	2753 (400)	3304 (480)	4783 (695)	4061 (590)	3304 (480)
Trapezoidal Tear Strength ASTM D 4533								
MD @ Ultimate	kN (lbs)	0.65 (145)	0.36 (80)	0.40 (90)	0.51 (115)	0.65 (145)	0.47 (105)	0.45 (100)
CMD @ Ultimate	kN (lbs)	0.56 (125)	0.31 (70)	0.22 (50)	0.33 (75)	0.56 (125)	0.62 (140)	0.27 (60)
Puncture Strength ASTM D 4833	kN (lbs)	0.65 (145)	0.56 (125)	0.51 (115)	0.47 (105)	0.73 (165)	0.62 (140)	0.6 (135)
UV Resistance after 500 hrs. ASTM D 4355	% Strength	90	90	90	90	90	70	90
HYDRAULIC PROPERTIES								
Apparent Opening Size (AOS) ASTM D 4751	mm (US Sieve)	0.600 (30)	0.425 (40)	0.425 (40)	0.425 (40)	0.425 (40)	0.300 (50)	0.212 (70)
Permittivity ASTM D 4491	sec^{-1}	1.50	0.95	2.14	1.36	0.96	0.50	0.28
Percent Open Area COE-02215-86	%	8	10	20	10	6	5	4-6
Flow Rate ASTM D 4491	$l/min/m^2$ ($gal/min/ft^2$)	4685 (115)	2852 (70)	5907 (145)	4074 (100)	2851 (70)	1426 (35)	733 (18)
Packaging								
Roll Width	m (ft)	3.8 (12.5)	3.7 (12)	3.7 (12)	3.8 (12.5)	3.8 (12.5)	3.7 (12)	3.7 (12)
Roll Length	m (ft)	91.5 (300)	91.5 (300)	91.5 (300)	91.5 (300)	91.5 (300)	91.5 (300)	91.5 (300)
Est. Gross Weight	kg (lbm)	99 (201)	64 (140)	67 (148)	76 (168)	99 (221)	75 (165)	76 (168)
Area	m^2 (yd^2)	348 (417)	334 (400)	334 (400)	348 (417)	348 (417)	334 (400)	334 (400)

NOTE: All Mechanical Properties and Hydraulic Properties shown are Minimum Average Roll Values (MARV).

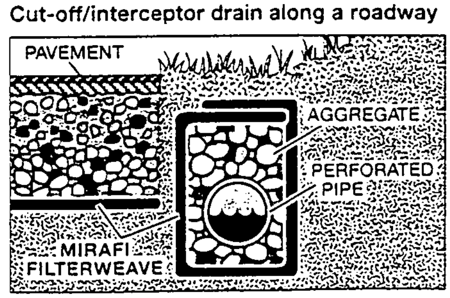
Shoreline erosion control



Leachate collection system



Cut-off/interceptor drain along a roadway



TC Mirafi

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Fax (706) 693-4400

SCS ENGINEERS

CLIENT	PROJECT	JOB NO.
HBORO	SCLF	0995029.23

SUBJECT	BY	DATE
WOVEN GEOTEXTILE PERMITTIVITY	Sheila	5-7-98
	CHECKED KAB	DATE 6-21-98

TASK

FIND IF THE CHOSEN WOVEN GEOTEXTILE WILL BE ACCEPTABLE WITH RESPECT TO PERMITTIVITY.

REFERENCES

DESIGNING WITH GEOSYNTHETICS, 3RD ED., ROBERT M. KOERNER, CHAPTER 2

SCS ENGINEERS WATER BALANCE SUMMARY REPORTS FOR RAINFALL DATA AT THE SITE (PROJ 0995029.12)

METHOD

FOLLOW KOERNER'S EXAMPLE USING OUR SITE SPECIFIC DATA FOR PERMITTIVITY.

GIVEN

- GEOTEXTILE

  MIRAFI FW 401 (SPEC SHEET ATTACHED)

CLIENT HBORO	PROJECT SCLF	JOB NO. 0995029.23
SUBJECT WOVEN GEOTEXTILE PERMITTIVITY	BY Sheila	DATE 5-7-98
	CHECKED [illegible]	DATE 6-21-98

SOLUTION

GEOTEXTILE PERMITTIVITY, Ψ_{ULT}
AS PER MFGR = 2.14 sec^{-1} (ATTACH. 1)

CHECK ADEQUATE FLOW CAPABILITY
AS PER KOERNER'S EXAMPLE

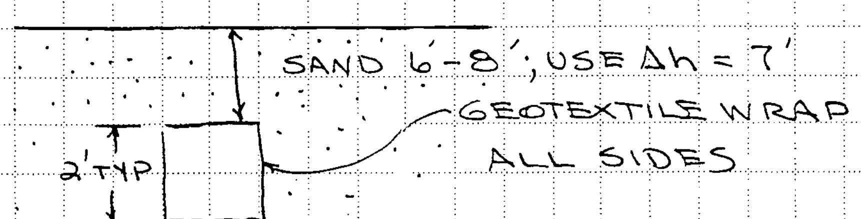
a. ESTIMATE MAXIMUM FLOW COMING
TO THE GEOTEXTILE, q, $\frac{FT^3}{SEC}$

USE RAINFALL DATA FROM WATER
BALANCE SUMMARIES
1996 = 66.30" TOTAL
1997 (JAN-SEP) = 72.3"

- USE 66" RAINFALL / YR
- CONSIDER 100% OF RAINFALL BECOMES LEACHATE

SITE SPECIFIC

AREA = 42 ac



SCS ENGINEERS

CLIENT HBORO	PROJECT SCLF		JOB NO. 0995029.23
SUBJECT WOVEN GEOTEXTILE PERMITTIVITY		BY Sheila	DATE 5-7-98
		CHECKED KAS	DATE 6-21-98

ASSUME LEACHATE WILL ENTER TRENCH THROUGH THE TOP AND SIDES ONLY

CONSIDER 1 FOOT IN LENGTH

$q, \frac{FT^3}{SEC}$ USING 100% OF YEARLY RAINFALL
= 100%(66 IN)
= 66 IN/YR

THEN

$$q, \frac{FT^3}{SEC} = \frac{66\ IN}{YR} \left| \frac{42\ AC}{} \right| \frac{FT}{12\ IN} \left| \frac{43560\ FT^2}{AC} \right| \frac{1\ YR}{365\ DAY} \left| \frac{1\ DAY}{24\ HR} \right| \frac{1\ HR}{3600\ SEC}$$

$$q = 0.32\ \frac{FT^3}{SEC}$$

b. FROM KOERNER
CALCULATE REQD PERMITTIVITY, Ψ_{REQD}

$$\Psi_{REQD} = \frac{q}{\Delta h\ A}$$

where q, FT^3/SEC = FLOW THROUGH THE GEOTEXTILE

Δh, FT = DISTANCE ABOVE GEOTEXTILE

A, FT^2 = AREA OF GEOTEXTILE THROUGH WHICH FLOW WILL PASS.

SITE SPECIFIC DATA:

Δh = 7 FT DEPTH OF SAND

A = AREA OF GEOTEXTILE
= (2' TOP + 2(2' SIDES))(1 FT LENGTH)

$A = 6\ FT^2$

SCS ENGINEERS

CLIENT H BORO	PROJECT SCLF	JOB NO. 0995029.23
SUBJECT WOVEN GEOTEXTILE PERMITTIVITY	BY Sheila	DATE 5-7-98
	CHECKED [illegible]	DATE 6-21-98

THEN

$$\psi_{REQD} = \frac{0.32\ FT^3}{SEC} \bigg| \frac{}{7\ FT} \bigg| \frac{}{6\ FT^2}$$

$$\psi_{REQD} = 0.01\ SEC^{-1}$$

c. CHECK THIS REQUIRED PERMITTIVITY AGAINST THE ALLOWABLE PERMITTIVITY OF THE GEOTEXTILE

AS PER KOERNER:

$$\psi_{ALLOW} = \psi_{ULT} \left[\frac{1}{8.25} \right]$$

ψ_{ULT}: AS PER MFGR $= 2.14\ SEC^{-1}$

8.25: AS PER KOERNER FOR ESTIMATED VALUES OF PARTIAL SAFETY FACTORS

$$\psi_{ALLOW} = \frac{2.14}{8.25}$$

$$\psi_{ALLOW} = 0.26\ SEC^{-1}$$

$$FS_{FLOW} = \frac{\psi_{ALLOW}}{\psi_{REQD}} = \frac{0.26}{0.01} = 26$$

CONCLUSION

ACCEPTABLE

Technical Data

MIRAFI®

The Original Geosynthetics Company

product **Mirafi Filterweave Woven Geotextiles**

for Erosion Control and Filtration

Property / Test Method	Units	FW 300	FW 400	FW 401	FW 402	FW 403	FW 500	FW 700
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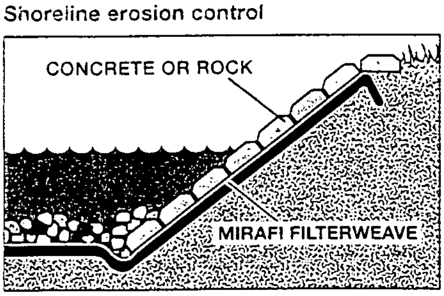
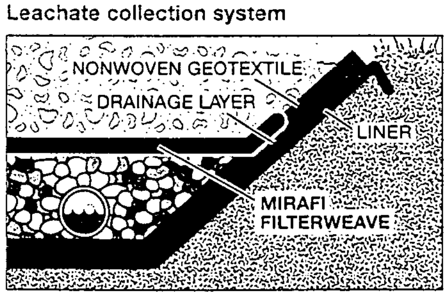
NOTE: All Mechanical Properties and Hydraulic Properties shown are Minimum Average Roll Values (MARV).

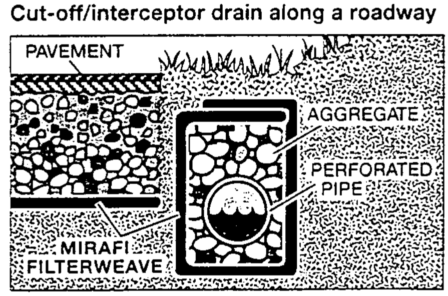
Shoreline erosion control



Leachate collection system



Cut-off/interceptor drain along a roadway



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Filtration Series

Geotextile-filter hydraulic requirements

The current state of practice for selecting the optimal geotextile for filtration conditions.

By Yves Faure and Jacek Mlynarek

Editor's note: *This article marks the fourth installment in a nine-part series on geotextile-filter design. The previous articles examined the initial steps of the filtration-design process. Upcoming series articles will discuss installation considerations and feature case histories that highlight individual filtration-design parameters.*

THE THREE PREVIOUS *GFR* FILTRATION-SERIES papers have presented the general approach to geotextile-filter design, an analysis of the influence of on-site conditions on geotextile-filter selection, and a review of soil and leachate properties that are significant in the geotextile-filter selection process. This paper presents the geotextile-hydraulic properties and design criteria for soil- and leachate-filtration applications (step 3 in the design process).

Geotextile-filter hydraulic properties

To satisfy filter criteria, i.e., to form an ideal soil-geotextile filter system, the interaction between soil particles and specific geotextile-filter properties must be determined adequately. In all types of geotextiles, the dimension of characteristic opening size (O_F) and the permeability (k) affect the formation of a stable soil/geotextile interface. The percent open area (POA) must also be taken into account with woven-geotextile filters.

Filtration Educational Series Technical Advisors

Eight of the industry's geotextile-filtration experts will help to ensure the technical credibility of this series. These advisors helped plan the series, select the authors, and review each paper.

Deron Austin
Synthetic Industries, Chattanooga, Tenn.

Jonathan Fannin
University of British Columbia, Vancouver

Andy Fourie
University of the Witwatersrand, Johannesburg

Chris Lawson
Ten Cate Nicolon Asia, Selangor, Malaysia

Barry Christopher
Christopher Consultants, Roswell, Ga.

Yves-Henri Faure
Université Joseph Fourier, Grenoble, France

Michael Heibaum
Bundesanstalt für Wasserbau (BAW), Karlsruhe, Germany

Jacek Mlynarek
SAGEOS, Saint-Hyacinthe, Quebec

In general, for a given O_F and POA, the optimal geotextile should have the highest permeability possible. This prevents geotextile-filter permeability from being reduced significantly when particles block or clog openings during filtration.

Characteristic opening size

Characteristic opening size, or filtration opening size (O_F), is defined as the approximate largest particle diameter that can pass across the geotextile. Though various techniques can be used to measure the geotextile opening size, only indirect sieving techniques currently are accepted as standard geosynthetics-engineering approaches. Depending on the method employed for its measurement, the O_F opening is called apparent opening size (AOS), filtration opening size (FOS), or characteristic opening size (O_{90}):

- AOS: Measured with ASTM D 475, "Dry sieving using glass beads by uniform fractions"
- FOS: Measured with CGSB 148.1-10, "Hydrodynamic sieving with well-graded glass beads"
- O_{90}: Measured with PR EN ISO 12956, "Wet sieving with well-graded sand particles"

Permeability

It is necessary to know the permeability values (k) of a geotextile-filter to assess its compatibility with the soil to be drained. Similar standard procedures for measuring permeability are used in different countries.

The engineering community has applied laminar-flow principles to characterize geotextile permeability. Using a test device modeled after soil permeameters with both falling- and constant-head testing techniques, geotextile permeability can be determined using laminar (Darcy) law, according to ASTM D 4491 (with no compression) or to ASTM D 5493 (under compression).

In many countries, flow rate per unit area, or index-water permeability, is recommended (e.g., the proposed European/ISO standard PR EN ISO 12040). Index-water permeability represents the flow of water through a unit surface of geotextiles when a hydraulic head is equal to 50 mm. With such high-hydraulic gradient, turbulent flow can occur in many geotextile filters. Thus, the measured water-permeability value will be lower than the actual permeability value measured for laminar-flow conditions. Such extremes rarely occur in engineering practice for typical filtration applications.

Percent open area

The percent open area (POA) is the ratio of the total woven-geotextile open area (the void spaces between adjacent filaments and yarns) to the total specimen area. For woven geotextiles, this characteristic is considered to be a design parameter (U.S. Army Corps of Engineers [COE] 1974; Federal Highway Administration [FHWA] 1995).

Soil and geotextile-filter criteria

A step-by-step design procedure for an optimal geotextile-filter has been published by the FHWA (1996). Two of these steps were introduced in previous papers of the Filtration Series:

1. Evaluation of the critical nature and site conditions of the application (Christopher 1998)
2. Evaluation of a soil or leachate sample from the site (Fourie 1998)

This paper presents only the geotextile-filter hydraulic requirements from the FHWA procedure. Other requirements (survivability and durability) included in step 3 of the FHWA procedure will be discussed in upcoming Filtration Series papers.

Hydraulic requirements

Every designer has to consider three hydraulic requirements:

1. The retention requirement: The geotextile filter performs a protection function, preventing significant particle movement from the soil.

2. The anti-clogging requirement: The geotextile filter performs a filtration function, allowing acceptable particle movement from the soil and avoiding accumulation of fines (clogging) at the soil/geotextile interface and/or within the geotextile filter.

3. The hydraulic conductivity requirements: Sufficient hydraulic conductivity is needed to permit the free flow of water out of the soil.

All three requirements must be satisfied to avoid contamination of the drain by fines washed out from the soil and an increase of pore-water pressure within adjacent soil.

Retention criteria: Nonwoven-geotextile filters

All applied retention criteria proposed for soils currently can be simplified and expressed as follows:

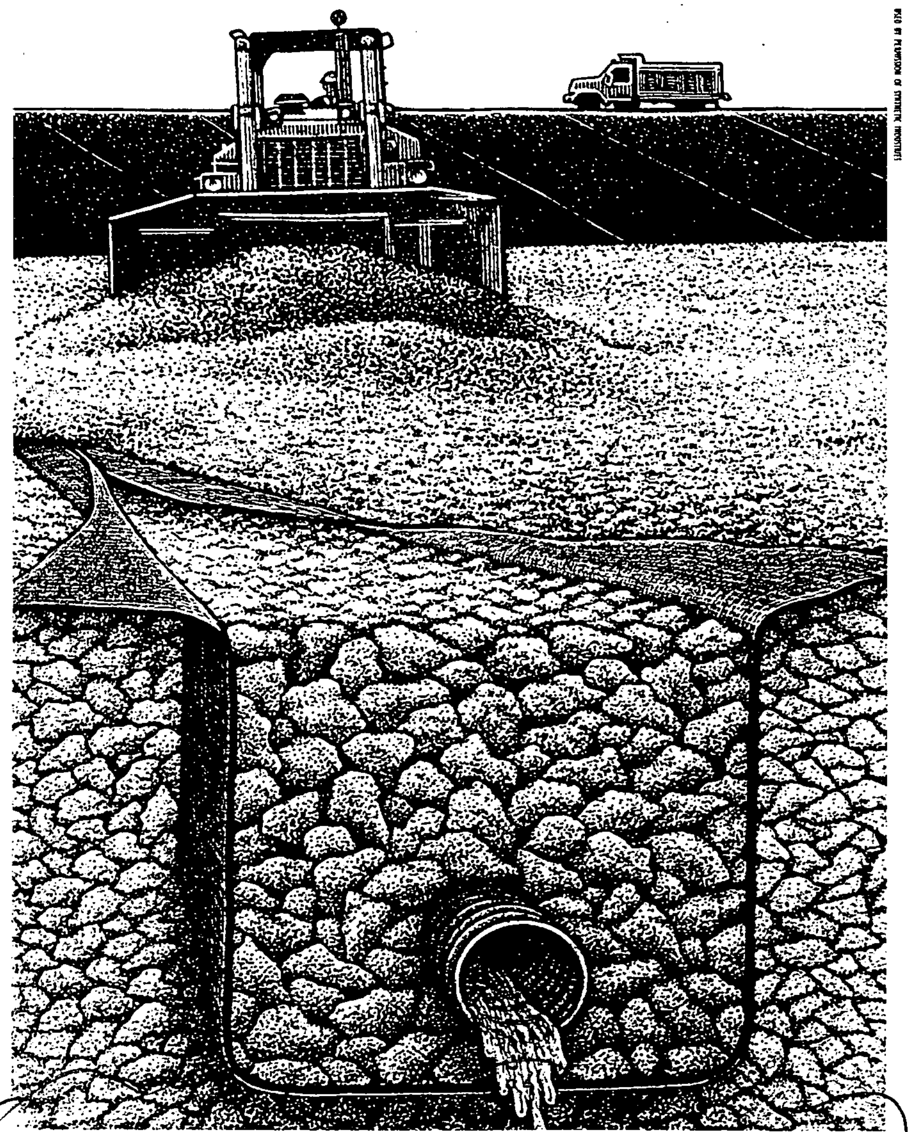

Figure 1. To minimize biological clogging in landfill leachate-collection systems, select a geotextile-filter with the largest opening size possible.

$$O_F \leq B \times d_I$$

where O_F is the specific opening size of the geotextile filter; d_I indicates particle diameter, such that I% by weight of the soil particles are smaller than d_I; and B is the dimesionless coefficient, which takes into account flow conditions, state of soil and its properties, and state of loading (unconfined and confined).

The FHWA uses AOS as the O_F and d_{85} particle dimension as d_I. Thus, the equation is written as:

$$AOS \leq B \times d_{85}$$

where, for a conservative design, B equals 1—or, for a less conservative design, where $d_{50} > 0.075$ mm:

$B = 1$	for $C_u \leq 2$ or ≥ 8
$B = 0.5\,C_u$	for $2 \leq C_u \leq 4$
$B = 8/C_u$	for $4 < C_u \leq 8$

and, for $d_{50} < 0.075$ mm:

$B = 1.8$ for nonwovens

$AOS \leq 0.3$ mm (FHWA 1995).

Recent evaluations of geotextile-filter field performance indicate that, in filter-design criteria, the d_{85} particle size should be replaced by a more precise particle dimension—the so-called indicative soil-particle size, which is the size capable of initiating the bridging process near the interface (Lafleur et al. 1993; Giroud 1996). A filter designed with this criteria will function as protection (of drains) by retaining some particles, and will prevent clogging (for filters) by accepting passage of some particles into the drain.

Lafleur et al. use FOS as the O_F (1993). They also propose that the filter-opening size must fall within a narrow range. If it is too large, erosion will take place; if it is too small, blocking or clogging can occur near the interface, resulting in decreased system-discharge capacity. O_F must therefore be approximately equal to the indicative size, d_I, of the soil particles. Lafleur et al. (1993) offer the following criteria:

- $O_F \cong d_{85}$, for linearly graded soils with self-filtering properties
- $O_F \cong d_{30}$, for concave-upward graded and all other soils with internally unstable behavior (Mlynarek and Fannin 1998)
- $O_F \cong$ the lower particle size of the gap, for the gap-graded soils.

Woven-geotextile filters

Geotextiles Used as Filters, the COE civil-works construction guide released in 1974, contains probably the oldest recognized geotextile specification in the world, and includes filter-design criteria provisions for both woven and nonwoven geotextiles. COE guidance considers retention and anti-clogging for wovens as the same criteria. For woven geotextile-filter applications where soil has $d_5 > 0.075$ mm, a criteria of POA > 10% is given. For all other soils, the POA must be greater than, or equal to, 4%.

The FHWA indicates that, for less conservative design with soils where $d_{50} >$ 0.075 mm, woven filters can be selected by using the equation: AOS < B x d_{85}, where B = 1 (1995).

Anti-clogging criteria

In order to avoid the possibility of clogging the geotextile filter, its opening size or percent open area cannot be too small. As previously mentioned, the retention criteria presented by Lafleur et al. already include an anti-clogging requirement (1993).

FHWA guidelines require the following anti-clogging criteria :

1. For less critical conditions:
   $O_F \geq 3\ d_{15}$, for soil with $C_u > 3$

Other qualifiers:
n (porosity) > 50% for nonwoven filters,
POA > 4%, for woven filters

2. For critical conditions: Select geotextile filters that meet the retention criteria and the above anti-clogging criteria, then perform a filtration test.

The FHWA guidelines are based on observation of filter-field performance and extensive laboratory testing (1995).

Austin et al. have confirmed that the POA parameter governs filtration through soil/woven-geotextile systems (1997). They found that the minimum anti-clogging criteria of POA > 4%, recommended by the FHWA and the COE, is applicable for coarse sands. However, according to their laboratory-test results, the requirement could be lowered to 1.6% for fine, poorly graded sands, and to 0.5% < POA < 8.0% for silt and silty sand.

We strongly suggest that a filtration test be performed after the geotextile filter is selected according to the previously presented retention and anti-clogging criteria. The Gradient Ratio test (ASTM D 5101), with minor corrections suggested by Fannin et al. (1994), is recommended for sandy and silty soils. For fine-grained (cohesive) soils, the ASTM-recommended hydraulic conductivity ratio test is ASTM D 5567. Experience is required to obtain reproducible data in each of these tests.

Finally, we recommend being very careful in selecting geotextile filters for wave-attack applications, or any other situation in which turbulent or two-directional flow conditions can occur—for example, in erosion-control systems. The next Filtration Series paper, by Michael Heibaum, will address this important issue.

Permeability criteria

The presence of a filter, even when very permeable, disturbs the flow in the soil located immediately upstream (Giroud 1996). The selected filter should have permeability such that the disturbance to the flow—e.g., the pore-water pressure and the flow rate—is small and acceptable. For geotextile filters, typical permeability criteria should be (after Giroud 1996):

$$k_{geotextile} > 10\ k_{soil},$$
(for a standard trench)

$$k_{geotextile} > 20\ k_{soil},$$
(for a typical dam-toe drain)

$$k_{geotextile} > 100\ k_{soil},$$
(for dam-clay cores)

It must be noted that critical applications may require the design of even higher $k_{geotextile}/k_{soil}$ ratio values, due to the high gradient that can occur in the filter vicinities.

The FHWA also established the following permittivity requirements (1995):

$\psi \geq 0.5\ s^{-1}$, for < 15% passing 0.075 mm

$\psi \geq 0.2\ s^{-1}$, for 15–50% passing 0.075 mm

$\psi \geq 0.1\ s^{-1}$, for > 50% passing 0.075 mm.

Leachate and geotextile-filter criteria

Opening size/POA criteria

Selecting a geotextile filter for a leachate-collection system is one of most challenging issues in landfill design. The U.S. Environmental Protection Agency (EPA) has recommended a 10% POA for woven-monofilament-geotextile filters used with relatively mild landfill leachates, which have low total suspended solids (TSS) and low biological oxygen demand (BOD5) values, e.g., less than 2500 mg/l (Koerner and Koerner 1995). Under these same conditions, the EPA recommends an AOS of 0.212 mm for needle-punched nonwoven-geotextile filters.

According to Mlynarek and Rollin, the geotextile-filter opening size (measured by hydrodynamic sieving procedure) in a leachate-collection system should be as large as possible to minimize the risk of biofilm development (1994). In recent, as yet unpublished research, Mlynarek found that for all leachates that do not meet the EPA recommendations, acceptable minimum properties of the filters should be: O_F > 0.500 mm (as suggested by Giroud 1996) and POA > 30%.

It also is recommended that a candidate filter be analyzed with the ASTM D 1987 filtration test.

Permeability criteria

The following global factor of safety equation should be used to assess excessive filter clogging for all types of leachates:

$$FS = k_{allow}/k_{reqd} \times DCF$$

where:

FS	=	the flow factor of safety
k_{allow}	=	the allowable permeability as per a simulated test method (ASTM D 1987)
k_{reqd}	=	the minimum required permeability as per an adequate design model

DC = the drain correction factor according to geotextile filter-specific geometric calculations.

Summary

The criteria presented in this paper are based on long-term field experience and extensive laboratory testing performed by many engineers and researchers. In designing geotextile filters, engineers must consider particle retention—a very complex phenomenon. At the same time, high filter permeability must be assured. We must advise our colleagues to, in case of any doubts, consult filtration experts.

The next step

In the next issue, Michael Heibaum will discuss methods for reducing installation and construction stresses on geotextiles in filter applications. GFR

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Independent Research On Fabric Clogging

- What really counts in long-term filtration performance?
  Woven - Nonwoven - AOS/EOS - Percent Open Area
- Which of the four most standard fabric types best resists clogging?
- What test is the best current means available to evaluate and quantify clogging potential of geotextiles?

Comparative Hydraulic Performance Evaluation of Geotechnical Fabrics, 1980
Philip D. Wood, Cecilia Hayes Shappee, T. Allan Haliburton
Haliburton Associates, Stillwater, Oklahoma, U.S.A.

Evaluation of the U.S. Army Corps of Engineers Gradient Ratio Test for Geotextile Performance - Proceedings of Second International Conference on Geotextiles, Las Vegas, Nevada, U.S.A., 1982
Haliburton, T.A.
Haliburton Associates, Stillwater, Oklahoma, U.S.A.
Wood, P.D.
McClelland Engineers, St. Louis, Missouri, U.S.A.

SYNOPSIS OF REPORTS

Introduction

The first recorded use in the U.S. of a geotechnical fabric for erosion control occurred in 1958, when the owner of Carthage Mills developed a permeable synthetic woven filter fabric to replace a graded granular filter in a waterfront structure in Florida. Since that time, Carthage Mills has provided woven monofilament geotechnical fabrics used in thousands of projects in the U.S. and abroad. Carthage Mills also pioneered the use of woven geotechnical fabrics in French drains, wrapped around perforated drainage pipe, and scour protection around bridge piers, in addition to conventional river and harbor slope protection and soil erosion control [1]. However, in recent years, various other types of geotextiles, both woven and nonwoven, have become available in the marketplace and have been offered as substitutes for Carthage Mills original monofilament products.

Until 1980, comparatively little experimentation and evaluation had been done to determine which properties of a geotextile will lead to successful long-term performance in filtration, drainage and erosion control applications. Insufficient data existed to determine whether or not the more expensive monofilament fabrics offered significant performance advantages over less expensive woven and nonwoven geotechnical fabrics in filtration/drainage. If a significant performance advantage accrues from use of monofilament fabrics, as compared to other fabrics, this advantage would more than justify any cost differential. Obviously, long-term successful performance is the main criterion desired by both the designer and the user in any fabric application.

To initiate this effort, the Erosion Control Division of Carthage Mills retained Haliburton Associates to investigate the properties that influence geotechnical fabric filtration, drainage, and erosion control behavior, and to evaluate, on a comparative basis, Carthage Mills monofilament fabrics and competitive fabrics. This series of tests was conducted on six geotextiles (four woven, two nonwoven). The test procedures proposed by Haliburton Associates for fabric evaluation were originally developed by the U.S. Army Corps of Engineers, with primary emphasis upon determining fabric performance under soil loss (piping) and fabric clogging conditions.

Background

In 1972, Calhoun developed testing equipment and procedures to evaluate woven filter fabrics for U.S. Army Corps of Engineers use in filtration, drainage, and erosion control [2]. The method used uniform Ottawa 20-30 Sand (ASTM C-190) and various specific fractions of Vicksburg silt loess in a constant-head testing apparatus. Fabrics were evaluated by measuring head loss at various points through the soil-fabric system. This was designated as the Clogging Ratio, and was used to indicate the degree of fabric clogging [2]. In 1977, the Corps modified Calhoun's procedure to specify measurement of the soil-fabric Gradient Ratio, a direct measurement of the fabric clogging potential applicable to both woven and nonwoven fabrics, and established a limiting Gradient Ratio for recommended fabric use. Gradient Ratio values exceeding 3.0 were found to signify excessive fabric clogging, and a limiting value of 3.0 was established by Corps fabric acceptance specifications [3]. Haliburton Associates carefully recreated the Corps of Engineers test equipment and procedures, to provide an independent assessment of fabric performance using the field verified test procedures of the Corps.

Methodology

The testing program was designed to evaluate the comparative hydraulic performance of geotechnical fabrics, with primary emphasis on fabric clogging potential. Six geotextiles, representing the basic types of standard geotextiles on the market, were used in the test program. Descriptions and relevant properties of the geotextiles are shown below:

Description	AOS/EOS	Percent Open Area (%)
Nonwoven heatbonded	70-100	–
Nonwoven needlepunched	70	–
Woven slit film	40	<1%
Woven monofilament	70	5%
Woven monofilament	70	20%
Woven monofilament	40	30%

In order to compare geotextile clogging resistance using Corps of Engineers criteria, four units of the Calhoun test apparatus were constructed for the test program [2]. Ottawa sand and Vicksburg silt loess test soil mixtures of 0%, 5%, 10%, 15%, 20%, 25%, 30%, 40%, 50%, 60%, 70%, and 80% silt by weight were prepared. Soil mixtures were tremmied in dry and placed to a 4 inch thickness. Each unit was slowly filled from the bottom with ordinary tap water, to minimize soil disturbance.

Water used in the testing program was first distilled and then deaired by vacuum pump. The outflow standpipe elevation remained constant for all fabrics at each silt percentage and was changed with each silt percentage. Piezometer readings were taken every 15 minutes until they stabilized and initial and final flow rate measurements were recorded.

After testing, soil samples were taken from each test unit, over intervals of 0 mm - 6 mm (0 in. - 0.25 in.), 6 mm - 25 mm (0.25 in. - 1 in.), and 50 mm - 75 mm (2 in. - 3 in.) above the geotextile, and the final silt percentage distribution determined.

Test Results and Evaluation

Geotechnical fabric clogging resistance is the most important fabric property needed for long-term field performance. The Gradient Ratio, as defined by the U.S. Army Corps of Engineers [3] was used to determine the quantitative performance of each fabric. The Corps of Engineers specification allows a maximum value of 3.0 for the Gradient Ratio. This is related to the fact that the Gradient Ratio increases rapidly with small changes in silt percentage after a value of 3.0 is reached [3]. Gradient Ratio values for each soil-geotextile combination were computed as the average of four individual tests and are plotted versus Percent Silt in Figure 1. The various geotextiles exceeded the maximum GR of 3.0 at the following silt percentages:

Geotextile	Maximum Allowable Soil Silt Percentage (GR ≤ 3.0)
Woven Slit Film	0% (Clean Sand)
Nonwoven Heatbonded	0.5%
Nonwoven Needlepunched	18.5%
Woven Monofilament - 5% Open Area	25%
Woven Monofilament - 20% Open Area	60%
Woven Monofilament - 30% Open Area	Could not clog - Maximum GR = 1.1 at 80% Silt

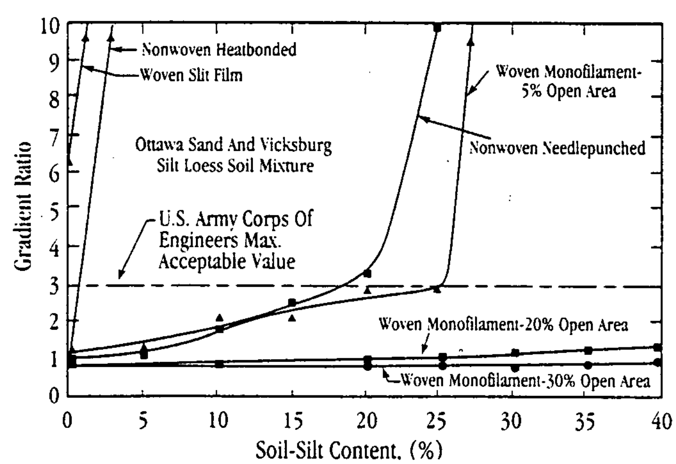

Figure 1: Gradient Ratio as a function of Soil-Silt Content for geotextiles tested.

Review of the various test data indicated that:

a. AOS/EOS values for the six tested fabrics varied from 40 to 70 and all fabrics satisfied both the original 1972 Calhoun [2] and 1977 Corps of Engineers [3] piping criteria. This was confirmed during testing, as no appreciable piping through the fabrics was noted for any fabric or soil combination.

b. The 1977 U.S. Army Corps of Engineers Gradient Ratio test is an acceptable method to evaluate and quantify the clogging potential of geotextiles. Geotextiles should definitely not be used in severe/critical design applications where soil-geotextile system Gradient Ratio exceeds 3.0.

c. Geotextile AOS/EOS was found to have no relationship to geotextile clogging behavior, but a direct relationship between percent open area and clogging behavior exists. The larger the percent open area for the fabric, the better its performance, especially at higher silt contents, substantiating Calhoun's original Corps of Engineers conclusions [2].

d. Once a GR of 3.0 was exceeded, noticeable amounts of silt were found deposited on or in all geotextiles. However, despite the gap-graded nature of the test soils, significant changes in soil-silt content were found to occur only in the 6 mm (0.25 inches) above the geotextile. For all samples and all silt percentages where silt loss occurred, loss occurred only during the initial 10 min.-15 min. of the test, with the majority of loss occurring in the first 5 min.. When the GR was $\leq$ 3.0, a slight <u>increase</u> in soil-geotextile system permeability was noted to accompany the soil loss. The Clogging Ratio changed as each test progressed, indicating the initial silt migration and, consequently, changing system permeability, but as silt migration ceased, permeability stabilized, and the Clogging Ratio became constant. This was the first indication that a "mini-graded filter" had formed in the soil immediately behind the geotextile, as originally suggested by Calhoun [2].

e. The woven slit film fabric allowed some migration of silt, but the openings in the fabric are widely scattered and the fabric had <1% open area. The 40 EOS openings allow some migration, but the flow is still restricted in areas where there are no openings. This behavior was the basis for Calhoun's original recommendation of $\geq$4% open area for any filtration/drainage use [2].

f. The nonwoven heatbonded fabric allowed little migration and the silt that did migrate was not passed through the fabric, probably because of the tight "weave" produced by heatbonding the fibers and the relative small number of actual (or equivalent) openings.

g. For the nonwoven needlepunched fabric, some small initial migration of silt occurred at 10% silt content. Flow was concentrated through the needlepunched AOS/EOS 70 holes but these openings are variable in diameter and concentrated in small areas. Although the GR of 3.0 was not exceeded until 18.5% silt, this fabric was found to cause some <u>decrease</u> in soil-fabric system permeability during testing. Such behavior is undesirable in protective filter applications. At 25% silt (GR of 10.43) a continuing increase in Clogging Ratio was noted to occur, <u>without</u> the release of silt and reduction in clogging. These data indicate that the mini-graded filter was forming <u>inside</u> the fabric.

h. The three woven monofilament geotextiles had the best clogging resistance among the six fabrics tested. Although they were initially clogged by silt migration, the silt was almost immediately lost through the fabric, causing the formation of a "mini-graded filter" in the soil and reducing fabric loading. Clogging resistance increased with increase in woven fabric percent open area, substantiating Calhoun's original Corps of Engineers conclusions [2].

i. Results of soil-fabric system permeability measurements showed that both the woven slit film and nonwoven heatbonded fabrics had, after clogging, one or more orders of magnitude less permeability than the test soils. This indicated that the fabrics constituted the least permeable part of the soil-fabric system and violate the accepted design concept that the filter fabric should be more permeable than the soil. Of the balance of the fabrics, only the woven monofilament geotextiles allowed an increase in soil-fabric system permeability for all tested silt percentages, indicating the filter (fabric) was and remained more permeable than the soil.

j. Based on test data for the woven monofilament geotextiles, the Silt Percentage which caused a GR of 3.0 is plotted versus the woven geotextile Percent Open Area in Figure 2. This Figure may be used to estimate the Minimum Woven Geotextile Percent Open Area required for acceptable clogging resistance at the various Silt Percentages noted for a given site-specific silt-soil content.

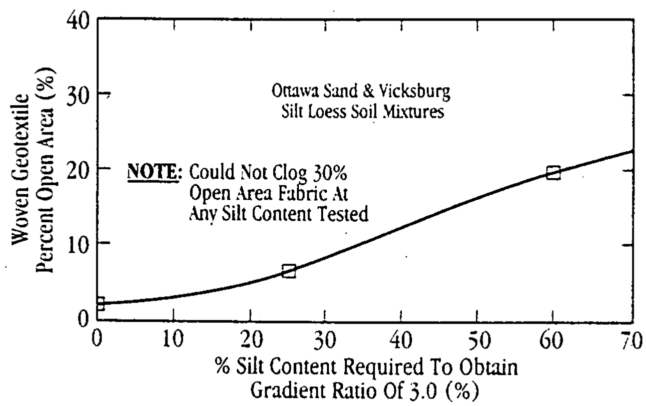

Figure 2: Woven Geotextile Percent Open Area vs. Percent Silt to develop Gradient Ratio of 3.0

Summary and Conclusions

The testing program was designed to evaluate the comparative hydraulic performance of various geotextiles under soil loss (piping) and fabric clogging conditions, with primary emphasis on clogging potential. Test equipment, procedures, sand/silt mixtures, and performance criteria developed by the U.S. Army Corps of Engineers were used for this study and lead to the following conclusions:

1. The **nonwoven heat-bonded** and the **woven slit film** fabrics both clogged at silt-soil fractions of 1/2% or less. In fact, significant clogging occurred with clean uniform sand and these fabrics are judged unsuitable for long-term filtration/drainage use with soils having any silt fraction.

2. The **needlepunched nonwoven** geotextile experienced internal clogging in the felt-like portion of the fabric. Outflow continued but was concentrated at the needlepunched holes which caused it to act more like a woven than a nonwoven. If these holes had not been present, fabric performance would have undoubtedly exceeded U.S. Army Corps of Engineers maximum allowable Gradient Ratio of 3.0 at a much lower silt-soil content.

3. Fabric **AOS/EOS** was found to have no relationship to fabric clogging behavior. The woven slit film, which had the largest AOS/EOS (40), also had the worst clogging performance and developed the largest Gradient Ratios among the tested fabrics.

4. The greater the **percent open area** of the fabric, the better the filtration performance and

resistance to clogging. This confirms original 1972 Corps of Engineers findings concerning percent open area.

5. The **woven monofilament** tested were the only fabrics that allowed the soil-fabric system permeability to increase through bridging and cake formulation in the soil immediately behind the fabric, creating a mini-graded filter.

6. All tested fabrics satisfied both the 1972 and 1977 U.S. Army Corps of Engineers AOS/EOS **piping criteria**, and minimal in-service piping was observed for all fabrics at all silt contents.

7. The 1977 U.S. Army Corps of Engineers **Gradient Ratio** test is an acceptable method to evaluate and quantify the clogging potential of geotextiles.

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The late **T. Allan Haliburton** (BSCE, MSCE, Ph.D.) held the rank of Professor of Civil Engineering at Oklahoma State University, was a Registered Professional Engineer in ten states, and was President and Managing Director of Haliburton Associates, Inc., a research and consulting firm. Dr. Haliburton was a member and held various offices in ASCE, ASEE, TRB, ASTM, and ISMFE; was the author of numerous professional papers, governmental reports and engineering reports; and enjoyed an international reputation as a researcher and practicing civil engineer, particularly in the field of soil mechanics. He was deeply involved in geotextile engineering activities starting in 1972, and conducted research for the U.S. Army Corps of Engineers, U.S. Air Force, and American Association of Railroads in geotextile usage.

BIOLOGICAL CLOGGING IN LEACHATE COLLECTION SYSTEMS

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ABSTRACT

Six municipal landfill leachates are being monitored to evaluate the degree of biological clogging of geotextile filter systems. At each site aerobic flow rate tests are conducted on a monthly basis. Four different geotextiles are used at each site. Flow rate decreases from 12% to 100% have occurred within time periods of up to 11 months. Backflushing and biocide treatments are to be performed in the next phase to see if flow is reinstituted and to what degree.

Additionally, at each site four different geotextiles are being anaerobically immersed in the respective leachates with monthly samples of each fabric withdrawn and evaluated in the laboratory. To date, this study has shown flow rate decreases from 5% to 20%. Scanning electron micrographs are presented showing the nature of microorganism buildup on the fibers which is causing the reduced flow rates. It has been observed that the biofilm is not physically attached to the fibers, thus biodegradation of the polymers should not present a problem. Separate strength tests confirm this tentative conclusion. A new field setup will be fabricated for backflushing and biocide treatment of this anaerobic phase in a similar manner as with the aerobic study.

INTRODUCTION

The entire purpose of a leachate collection system in a waste landfill is to efficiently collect the generated liquid, drain it to a down gradient sump area and rapidly remove it for proper treatment and/or disposal. Furthermore, such collection systems must be kept free flowing for the entire service life and post closure care period of the facility. Thus time frames of 30 to 100 years are often stipulated. The impact of a nonfunctioning, or clogged, system is quite serious. If a leachate collection system does clog, the accumulated liquid will either find a hole in the liner system and be forced through it by an ever increasing hydraulic head, or eventually diffuse through the liner (whatever its type) via Fickian diffusion. In either case the negative implications toward subsurface contamination are obvious.

This paper investigates the potential for, and degree of, biological clogging of leachate collection systems at six municipal landfill sites. At each facility aerobic and anaerobic test setups are operational and are ongoing. The primary focus of the measurements is on the filter system protecting the drain since both stone and geonet drainage systems use geotextile filters. The paper presents results on both aerobic and anaerobic phases of biological activity at each site. A companion paper in these Proceedings by Rios and Gealt [1] investigates biological activity in the leachate; per se, via samples taken from each site.

DETAILS OF THE STUDY AND MATERIALS USED

Within landfills and waste piles there are a number of locations where biological activity could limit, or completely restrict, the free flow of leachate. Figure 1 shows a schematic diagram of a lined waste landfill facility using geosynthetics on the side slopes and natural soils on the bottom slope. The geosynthetic system on the side slope uses a geotextile filter over a geonet drain. The natural soil system on the bottom slope uses a sand filter over a gravel drain. Note, however, that the geotextile from the side slope extends above the sand filter and continues over the entire drainage and collection system. Thus the geotextile filter is the first and primary target for potential biological clogging.

This project investigates the biological clogging activity at six municipal landfill facilities on various types of geotextile filters. The geotextiles used are listed in Table 1 with their appropriate descriptive and hydraulic properties. At least four of the fabrics listed were evaluated at each of the six sites.

The landfills where the on-site tests are being conducted are all active and consist of multiple cells with interconnected leachate collection systems. These leachate collection systems are usually gravitationally drained to a low point where an underground storage tank or surface impoundment is located. It is at this collection point where the leachate is taken to conduct the experiments. (In four of the landfills the leachate is removed for treatment and disposal. In two cases the leachate is treated and recycled through the waste on a continuous basis). The age of the facilities range from 1 to 15 years. Details of the six landfills and their leachates are presented in Table 2. Note that the leachate characteristics were measured at the approximate time of our starting of testing. These characteristics undoubtedly change over time due to fluctuations in type of waste, aging of waste, temperature, weather, etc. Also note that the variation in properties is enormous. Perhaps the best indicator of potential biological clogging is the BOD_5 values which range from 150 to 30,000. They are in approximate proportion to the amount of total solids (TS) values which range from 100 to 20,000 mg/l. The latter values are probably indicative of potential precipitate clogging. Thus one can expect that if clogging occurs it is an interrelationship between biological and precipitate clogging [2,3]. These features will be elaborated further in the test results to follow.

TABLE 1
Details of Geotextile Filters Used in This Study

Designation and Polymer Type	Type of Fabric Construction	Thickness(1) (mm)	Mass/Unit Area (g/m^2)	POA(2) (%)	AOS(3) (Sieve No.)	Permittivity(4) (sec^{-1})
W(C)-PP	woven monofilament (calendered)	0.36	200	4	70 - 100	0.14
W(N)-PP	woven-monofilament (non-calendered)	0.51	220	10	40 - 70	2.3
NW(N)-PP1	nonwoven needled	2.2	280	-	70 - 100	2.1
NW(N)-PET	nonwoven needled	1.9	240	-	70 - 100	2.0
NW(N)-PP2	nonwoven needled	2.6	260	-	70 - 100	1.8
NW(N)-PE	nonwoven needled	2.8	450	-	70 - 100	0.96
NW(HS)-PP	nonwoven heat set	0.43	140	-	≃ 100	0.65

(1) under 2.0 kPa normal pressure
(2) percent open area
(3) apparent opening size expressed as U. S. Sieve Number
(4) constant head test at 50 mm head

TABLE 2

Details of Municipal Landfill Leachates Evaluated in this Study and Approximate Leachate Characteristics

Site	Start-up	Leachate Management	Approximate Leachate Characteristics			
			pH	COD (mg/l)	TS (mg/l)	BOD_5
PA-1	Nov. 18, 1987	Continuously Removed	8.0	15,000	8,000	2,000
NY-2	Dec. 10, 1987	Recycled through Landfill	5.5	50,000	20,000	30,000
DE-3	Jan. 25, 1988	Recycled through Landfill	5.8	40,000	17,000	24,000
NJ-4	April 5, 1988	Continuously Removed	7.4	45,000	16,000	25,000
MD-5	June 6, 1988	Continuously Removed	6.8	1,000	100	150
PA-6	June 28, 1988	Continuously Removed	6.5	10,000	5,000	2,500

where

COD = chemical oxygen demand
TS = total solids
BOD_5 = biochemical oxygen demand at five days

TABLE 3
Results of Aerobic Flow Rate Tests to Date

Site Designation	Time		Aerobic Flow Rate Trends[1]						
	Startup	Elapsed Time	W(C)-PP	W(N)-PP	NW(N)-PP1	NW(N)-PET	NW(N)-PP2	NW(N)-PE	NW(HS)-PP
PA-1	11/18/87	11 mos.	-100%[3]	-30%	-12%	-12%	-15%		
NY-2	12/10/87	10 mos.	-60%		-15%	-15%	-15%[2]		
DE-3	1/25/88	9 mos.	-95%[3]	-20%	-75%	-75%		-75%	
NJ-4	4/5/88	7 mos.	-97%		-75%	-90%		-80%	
MD-5	6/6/88	5 mos.		-35%	-30%	-35%		-30%	-40%
PA-6	6/28/88	4 mos.		-25%	-15%	-25%		-25%	-25%

[1] flow rate tests within box (average of 60-45; 45-30; 30-15 cm falling head tests)
[2] fabric was NW-PP changed at Site #3 to PE
[3] test fully clogged and was restarted with higher POA fabric

TABLE 4

Results of Anaerobic Flow Rate and Strength Tests to Date (N/C indicates "no change")

(a) ANAEROBIC FLOW RATE TRENDS [1]

Site	Startup	Elapsed Time	W(C)PP	W(N)PP	NW(N)-PP1	NW(N)-PET	NW(N)-PP2	NW(N)-PE	NW(HS)-PP
PA-1	11/18/87	11 mos.	-10%		-5%	-5%	-5%		
NY-2	12/10/87	10 mos.	-15%		-10%	-10%	-10%		
DE-3	1/25/88	9 mos.	-20%		-10%	-10%		-15%	
NJ-4	4/5/88	7 mos.	-20%		-10%	-10%		-15%	
MD-5	6/6/88	5 mos.		N/C	N/C	N/C		N/C	N/C
PA-6	6/28/88	4 mos.		N/C	N/C	N/C		N/C	N/C

[1] average of 3 permittivity and 3 transmissivity values

(b) ANAEROBIC STRENGTH TRENDS [2]

Site	Startup	Elapsed Time	W(C)PP	W(N)PP	NW(N)-PP1	NW(N)-PET	NW(N)-PP2	NW(N)-PE	NW(HS)-PP
PA-1	11/18/87	11 mos.	N/C		N/C	N/C	N/C		
NY-2	12/10/87	10 mos.	N/C		N/C	N/C	N/C		
DE-3	1/25/88	9 mos.	N/C		N/C	N/C		N/C	
NJ-4	4/5/88	7 mos.	N/C		N/C	N/C		N/C	
MD-5	6/6/88	5 mos.		N/C	N/C	N/C		N/C	N/C
PA-6	6/28/88	4 mos.		N/C	N/C	N/C		N/C	N/C

[2] average of 4-1" wide tensile and 3 burst tests

There is approximate agreement of the flow rate reductions with the BOD_5 of the respective leachates. No attachment was seen of the biofilm layer to the fibers and no strength reductions were observed on the basis of numerous strip tensile and burst tests. Thus biodegradation does not appear to be a concern. This anaerobic phase of the study will be extended to evaluate backflushing and biocide treatment.

ACKNOWLEDGMENTS

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Mirafi, Inc.
Polyfelt, Inc.
The Tensar Corp.

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7. ASTM D-774 - "Test Method for Bursting Strength of Paper"

8. ASTM D-1682 - "Test Method for Breaking Load and Elongation of Textile Fabrics,"

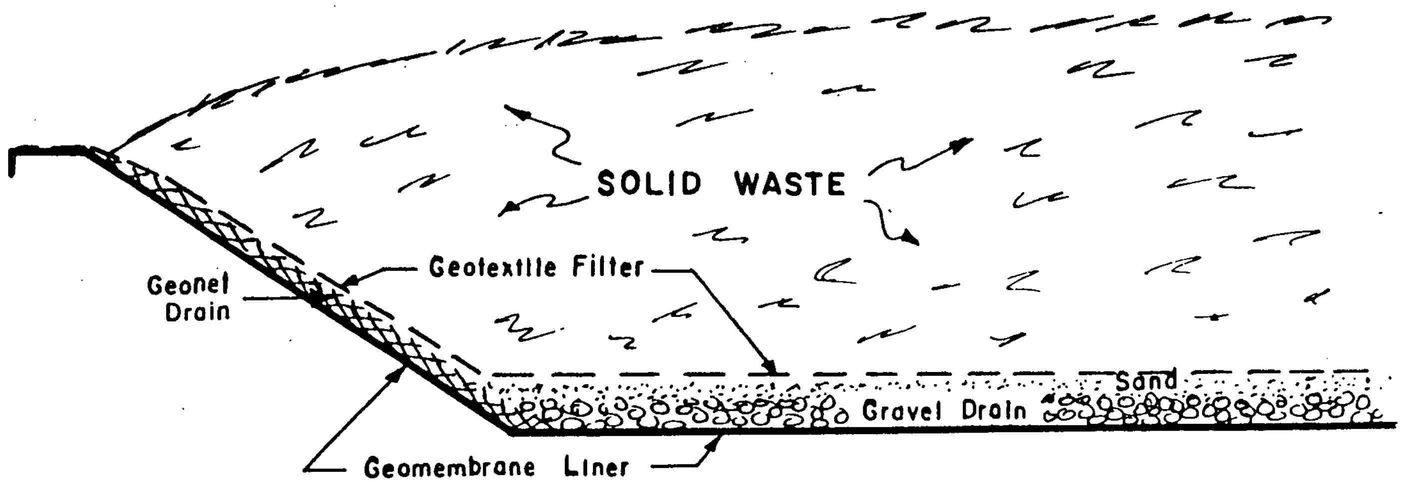

Fig. 1. - Cross Section of Synthetic and Natural Leachate Collection Systems at Bottom of a Landfill Facility

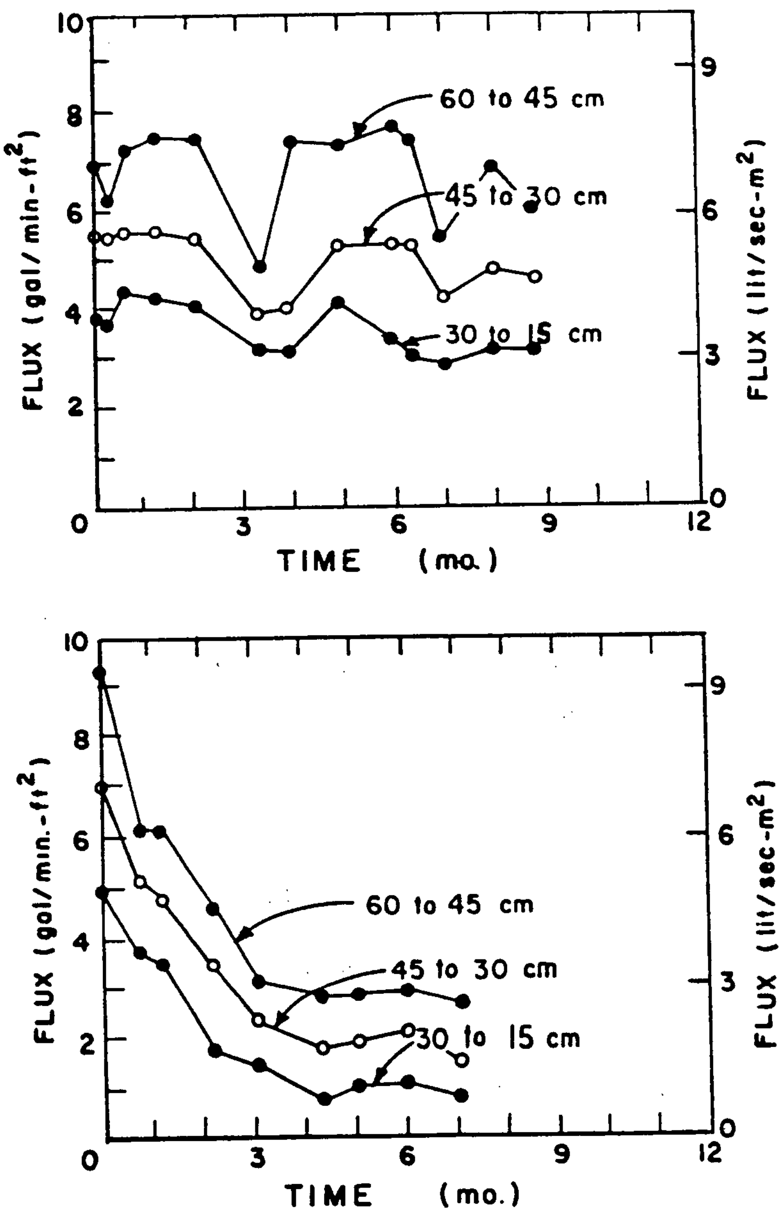

Fig. 3. - Typical Flow Rate Plots for Aerobic Test Setups Showing Nonclogged and Clogged Situations

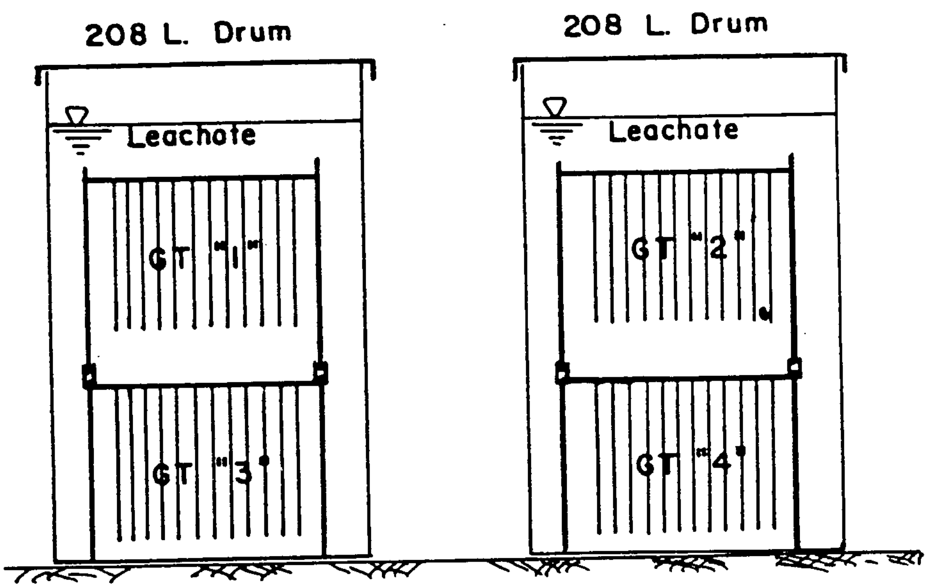

Fig. 5. - Anaerobic Incubation Drums

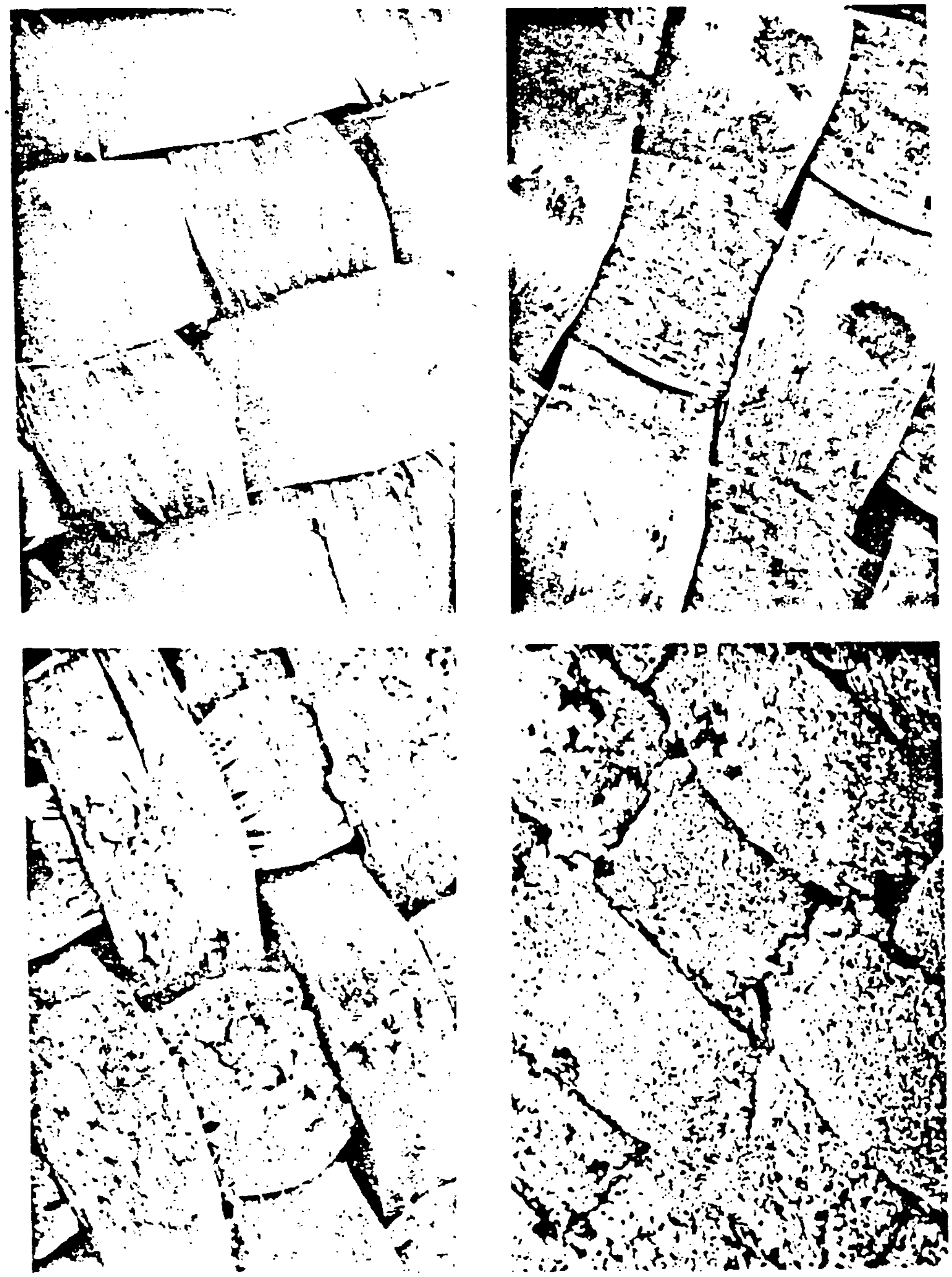

Fig. 6. - SEM's of As Received Calendered Woven Geotextile (upper left) and After 3 Months Incubation at PA-1 (upper right), NY-2 (lower left) and DE-3 (lower right); all at 30X

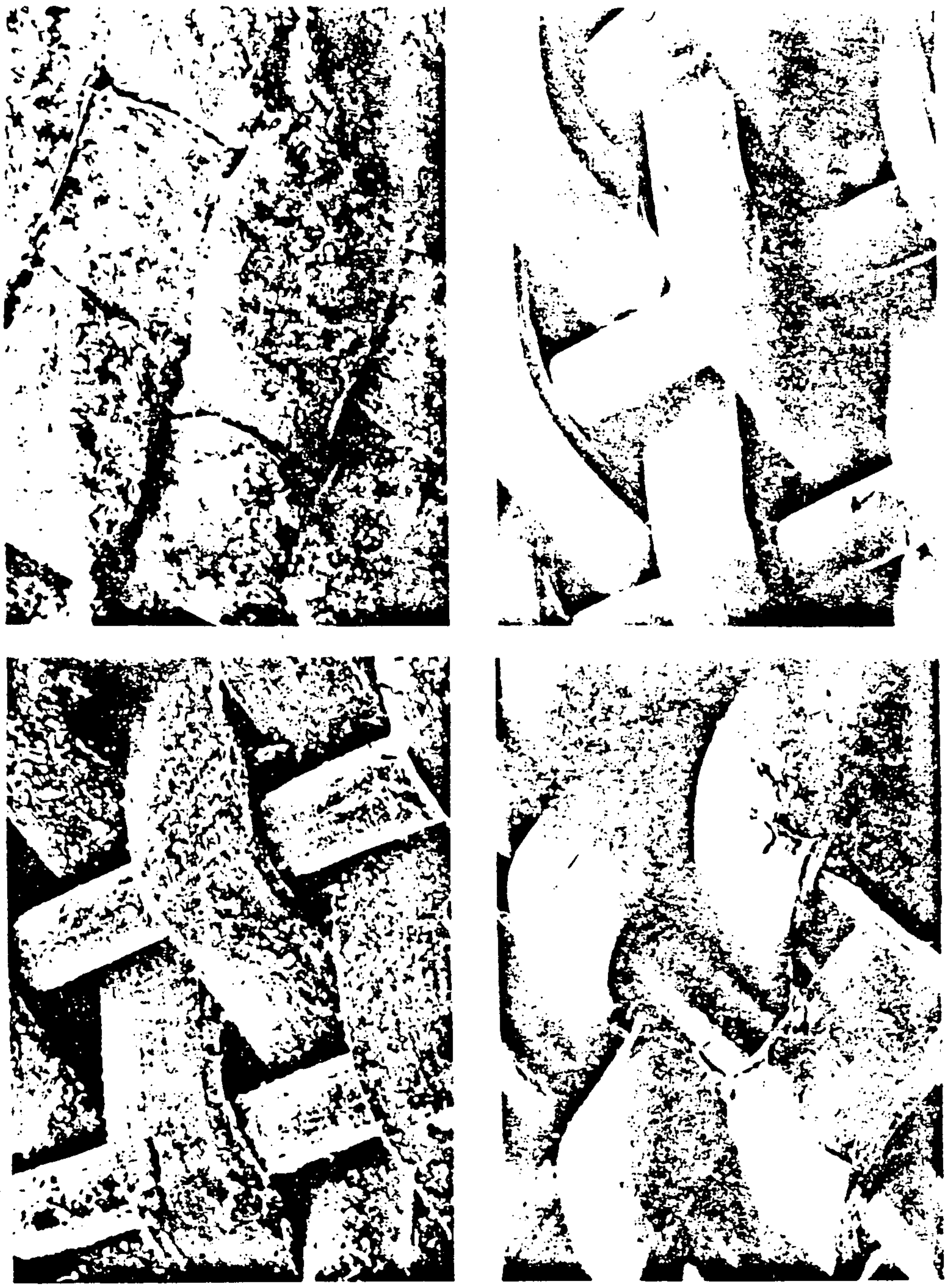

Fig. 6. (cont.) - SEM's at NJ-4 After 3 Months Incubation (upper left), As-Received Non-Calendered Woven Geotextile (upper right) and After 3 Months Incubation at MD-5 (lower left) and PA-6 (lower right); all at 30X

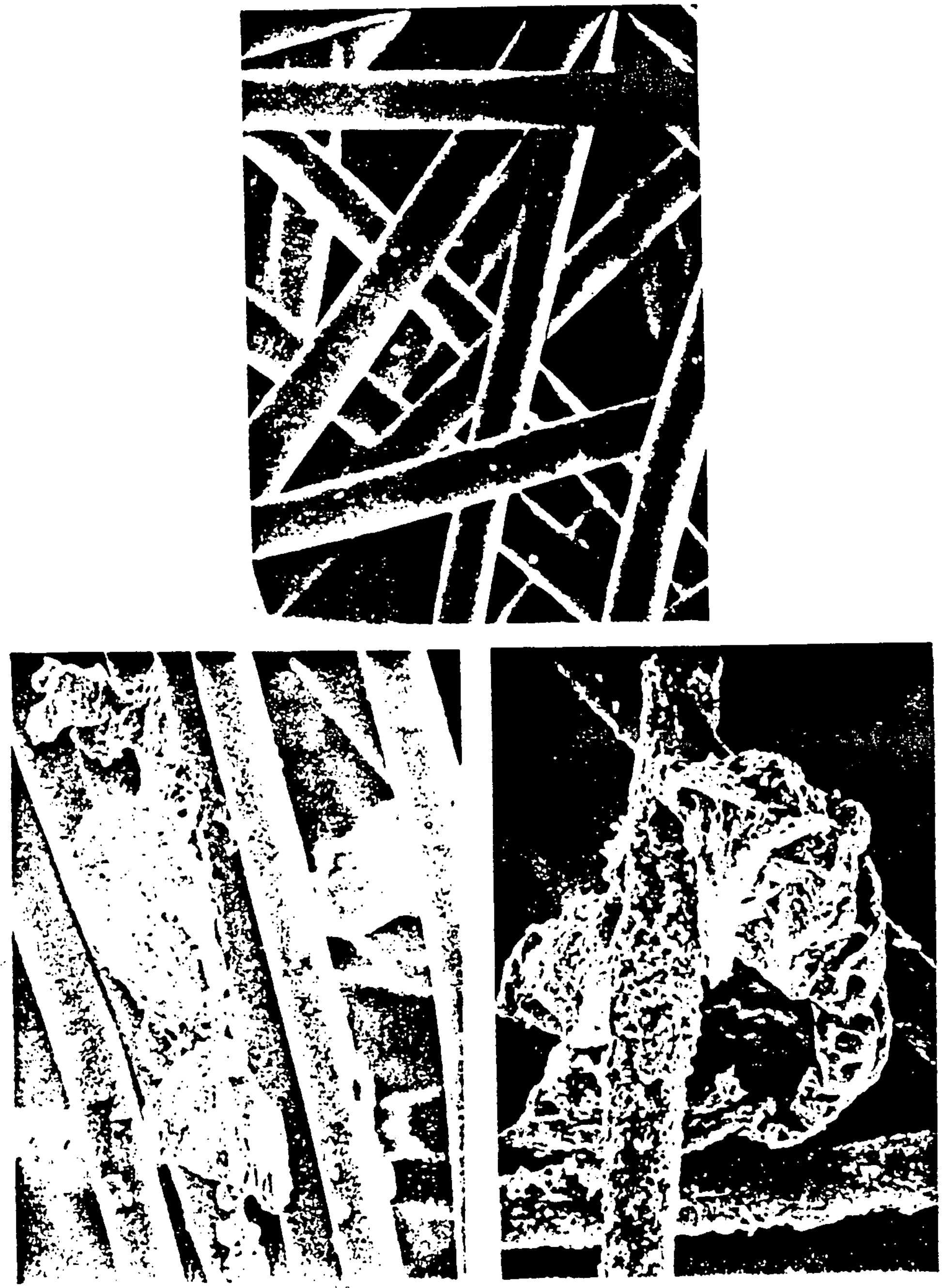

Fig. 7.- SEM's of As-Received Nonwoven Geotextile (upper) and After 3 Months Incubation at PA-1 (lower left) and NY-2 (lower right); all at 400X

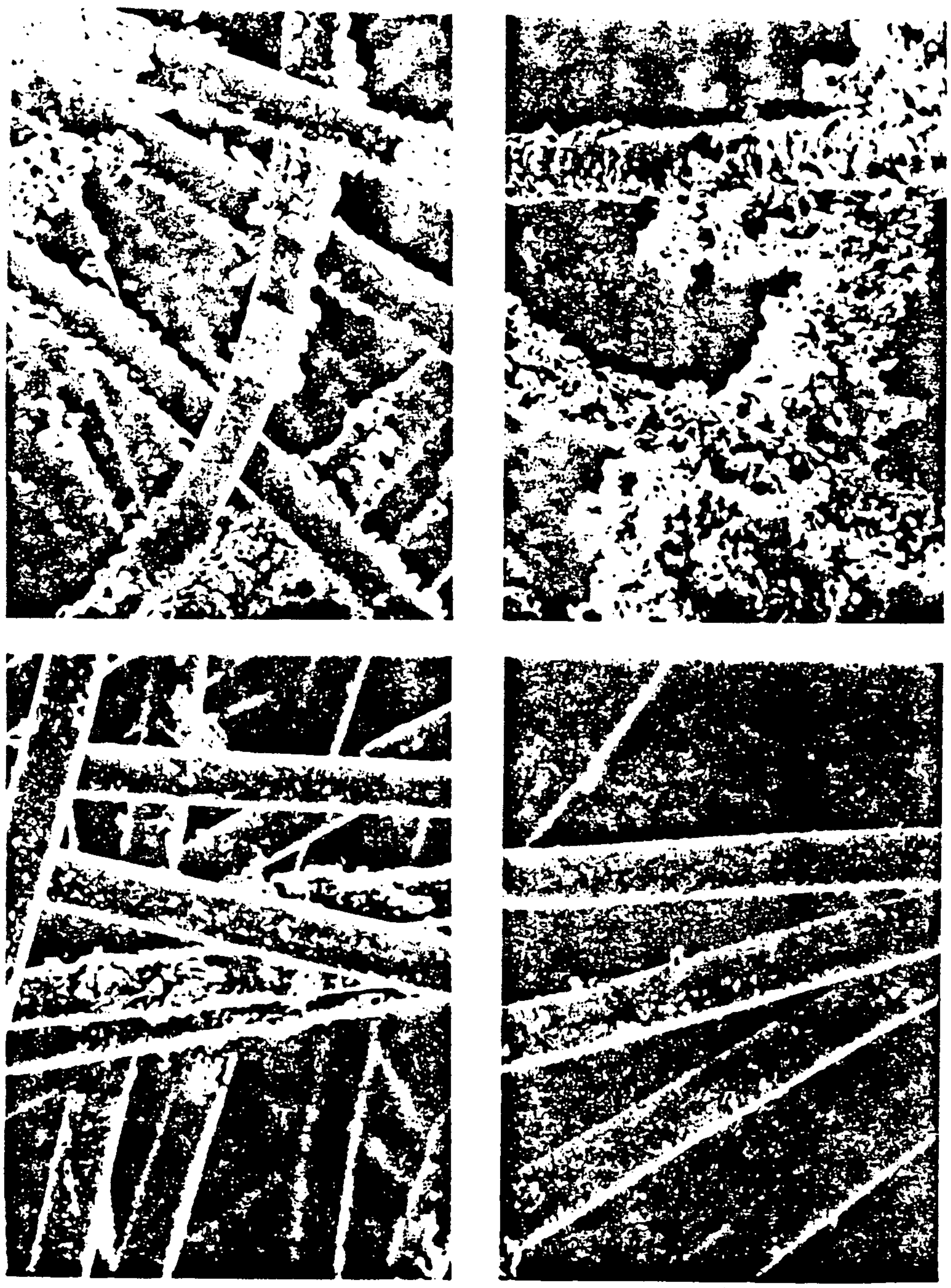

Fig. 7. (cont.) - SEM's at DE-3 (upper left), NJ-4 (upper right), MD-5 (lower left) and PA-6 (lower right) After 3 Months Incubation; all at 400X

ATTACHMENT D

CONSTRUCTION SPECIFICATIONS

SECTION 02220 - EXCAVATION, BACKFILL, FILL, AND GRADING

PART 1 - GENERAL

1.01 SCOPE OF WORK

A. The work specified in this section includes excavating, trenching, shoring, transporting, stockpiling, placing, backfilling, compacting, grading, and disposing materials required for the completion of trench improvements in Phases V and VI as shown on the Drawings and as specified herein.

B. Work shall be in accordance with the provisions of the Contract for the Continuing Construction and Operation of the Southeast County Landfill, Contract/RFP No. C-206-89, and all documents referenced therein.

1.02 DEFINITIONS

A. DRAWINGS - The drawings or plans which show the character and scope of the Work to be performed and which have been prepared or approved by the ENGINEER. The Drawings are titled "Southeast County Landfill Phase V and VI Leachate Collection and Removal System Improvements".

B. SPECIFICATIONS - Those portions of the Contract Documents consisting of written technical descriptions of material, equipment, construction systems, standards, and workmanship as applied to the Work and certain administrative details applicable thereto.

C. CONTRACT DOCUMENTS - Includes the Drawings, Specifications, and current CONTRACTOR's contract relating to operation and construction of the Southeast County Landfill (Contract No. RFP No. C-206-89 to include all documents referenced there in and all modification to agreements).

D. CONTRACTOR - Waste Management Inc. of Florida.

E. COUNTY - Hillsborough County Solid Waste Management Department.

F. ENGINEER - SCS Engineers, U.S. Highway 301 North, Suite 700, Tampa, Florida, 33619.

1.03 RESPONSIBILITIES

A. Excavation, trenching, and backfilling shall be performed by the CONTRACTOR only when the COUNTY or ENGINEER are present. A written notification shall be submitted to the ENGINEER a minimum of 24-hours prior to the CONTRACTOR performing any work. The CONTRACTOR shall be reimbursed for down-time costs incurred in the event a representative of the COUNTY or

ENGINEER is not present for pre-approved scheduled work. Conversely, the CONTRACTOR shall reimburse the COUNTY or ENGINEER for down-time costs incurred in the event pre-approved scheduled work is not performed by the CONTRACTOR (with the exception of weather delays).

B. Health and Safety:

1. The CONTRACTOR shall be responsible for initiating, maintaining, and supervising all safety precautions and programs in connection with the work. The CONTRACTOR shall take all necessary precautions for the safety of all employees on the work site and other persons who may be affected by the work.

2. The CONTRACTOR shall comply with all applicable laws, ordinances, rules, regulations, and orders of any public body having jurisdiction for the safety of persons and property or to protect them from damage, injury or loss. CONTRACTOR shall erect and maintain, as required by the conditions and progress of the work, all necessary safeguards for safety and protection.

3. The CONTRACTOR shall designate a responsible member of its organization as on-site health and safety officer whose duty shall be the prevention of accidents at the site.

1.04 SUBMITTALS

A. Health and Safety Plan: The CONTRACTOR shall submit a Health and Safety Plan for this work which includes, as a minimum:

1. The name of CONTRACTOR's on-site health and safety officer.
2. Safety procedures in the vicinity of excavations, trenches, and structures.
3. Response procedures to emergencies.

B. Excavation Plan: The CONTRACTOR shall provide a detailed construction plan for excavation, trenching, and backfilling. The Excavation Plan shall be submitted to the ENGINEER for review prior to starting construction activities, and shall, as a minimum, include the following:

1. A description of addressing safety issues in consideration of OSHA, Federal, State, and local safety requirements for excavations of this type.

2. Methods for the following activities shall be described:

   a. Excavation and slope stabilization.
   b. Stockpiling of materials.
   c. Shoring or Trench Box (if necessary).

d. Dewatering.
e. Backfilling.

3. A description of the equipment being used for excavation activities.

4. Controls for stormwater runoff and erosion control explaining how stormwater runoff will be diverted from entering into excavated areas.

5. A schedule describing the sequence of construction activities.

C. As-Built Survey: Horizontal and vertical topographic information depicting the actual grades, lengths, elevations and quantities of constructed items. Include the location and elevation of the invert of each end of an installed trench.

1. Drawings shall be plotted on sheets measuring 24 inches by 36 inches and in a scale similar to the Contract Drawings. If multiple sheets are required, each sheet must include match lines.

2. All survey information shall reference the coordinate system as depicted in the Contract Drawings, and include a north arrow and scale designation.

3. Contour intervals of 1 foot, with index contours at every fifth contour.

4. Submit to the ENGINEER computer disks containing the as-built record drawing in AutoCAD® (version 12) or at a scale of 1:1. Prior to reducing data to electronic media, CONTRACTOR shall coordinate with ENGINEER on the layering system to be used for the computer files.

5. Contour lines shall be polylines with a width of zero, and an elevation (z-coordinate) assigned according to the elevation of the contour line.

6. Submit certificate signed by registered surveyor ensuring that elevations and locations of improvements are in conformance with the Contract Documents, or if not in conformance, certify as to ENGINEER approved variances from the Contract Documents.

1.05 EXISTING SITE CONDITIONS

A. Damage to property caused directly or indirectly, in whole or in part, by the CONTRACTOR shall be restored to the original condition by the CONTRACTOR at no cost to the COUNTY, including the components of the leachate collection and removal system (LCRS).

PART 2 - PRODUCTS

2.01 CHIPPED TIRES

A. The chipped tires for use as backfill in the trenches will be provided by the COUNTY and stockpiled at the on-site tire processing facility.

PART 3 - EXECUTION

3.01 GENERAL

A. Layout all trenches and establish elevations as shown on the Drawings. Perform all other layout work required. Layout work shall be performed by a licensed land surveyor registered in the State of Florida.

B. Trenching operations shall proceed with due caution to protect the existing LCRS components, including the intersection between the chipped tire trench and the existing LCRS.

C. Slope surrounding grade away from excavations and trenches to prevent stormwater from entering into the open cuts. Maintain ditches and berms to provide drainage and control erosion at all times. Protect graded areas against the action of elements prior to acceptance of work. Re-establish grade where settlement, washouts, or erosion damage occurs. Damaged areas shall be repaired at no additional cost to the COUNTY.

D. At no time will the slopes of any excavation be steeper than 2 horizontal to 1 vertical (2:1).

E. The CONTRACTOR shall be responsible for dewatering during excavation and trenching activities. Chipped tires shall not be placed in trenches with standing water.

3.02 CHIPPED TIRE TRENCHES

A. All trenching activities shall conform to the Health and Safety Plan submitted under part 1.04(A), this Section.

B. When the trenches have reached the prescribed depths, the ENGINEER and COUNTY shall be notified to allow for inspection. If materials and conditions are not satisfactory to the ENGINEER, the ENGINEER will issue procedures to be followed to satisfactorily complete the contract within its intended scope.

C. If the bottom of any trench is beyond the limits as shown on the Drawings or as directed by the ENGINEER, it shall be backfilled at the CONTRACTOR's expense with ENGINEER approved material.

D. Trenches shall not extend into the phosphatic clay.

F. The CONTRACTOR shall not leave any open trenches overnight. All open trenches shall be backfilled with acceptable material prior to leaving the site.

G. Upon reaching prescribed depths, the geotextile shall be placed into the bottom of the trench. See Section 02940 for more information on the geotextiles. Special care shall be taken during the placement of the geotextile to protect the integrity of the trench.

H. Chipped tire stockpiles: Stockpiles within Phases V and VI shall be located a sufficient distance from the trenches to prevent impacting the integrity of trench walls. While retrieving chipped tires from stockpiles for placement into the trenches, mixing soil with the chipped tires is prohibited.

I. Place chipped tires to the depth shown in the Drawings. The chipped tires shall be placed in the trench in a manner which does not impact the integrity of the trench walls. There shall be no voids remaining between the chipped tires as determined by the COUNTY or ENGINEER.

J. Completed chipped tire trenches shall be approved by the ENGINEER prior to backfilling.

3.03 BACKFILL

A. Soils removed during trenching and excavation activities that is free from phosphatic clay may be used as backfill. Soils that contains any phosphatic clay is deemed unsuitable and shall not be used as backfill.

3.04 COMPACTION REQUIREMENTS

A. Chipped tires shall not be compacted.

B. The sand backfill material shall be placed loosely.

3.05 GRADING

A. After backfill soil is placed, surface shall be uniformly dressed to the pre-construction grades shown on the Drawings.

B. The ENGINEER reserves the right to make adjustments or revisions in lines or grades as the work progresses in order to incorporate any surplus fill materials at the end of the project while still achieving the intent of the grading plan at no additional cost to the COUNTY.

3.06 DISPOSAL OF SURPLUS OR UNSUITABLE SOILS

A. No materials shall be removed from the site or disposed of by the CONTRACTOR except as directed by the ENGINEER or COUNTY.

B. CONTRACTOR shall coordinate disposal activities with the ENGINEER. Materials shall be placed in an area of sufficient distance from excavations so as to not create a surcharge loading adjacent to any excavation, and within the limits and to the fill heights as directed by the ENGINEER or COUNTY.

3.07 CERTIFICATION OF COMPLETION

A. Upon completing the improvements, the CONTRACTOR shall certify the following to the COUNTY:

1. The chipped tire trenches have been constructed in accordance with the approved project plans and specifications.

2. No damage has occurred to the geotextile or existing LCRS during construction or backfilling operation.

- END OF SECTION -

SECTION 02940 - GEOTEXTILE

Part 1 - GENERAL

1.01 SCOPE OF WORK

A. The work specified in this section includes the manufacture, testing, and installation of geotextile for the chipped tire trenches as shown on the Drawings and as specified herein, in accordance with provisions of the Contract Documents.

1.02 SUBMITTALS

A. Submit prequalification test reports, manufacturer's data, specifications, installation instructions, roll dimensions, and geotextile approval form.

B. Copies of evaluation reports provided by manufacturers demonstrating that properties for the materials comply with specification requirements.

C. ENGINEER's approval shall be obtained prior to the use of any materials in the project.

1.03 PROTECTION AND STORAGE

A. Each roll of material shall have a manufacturer's identification label. Each roll shall be labeled to provide product identification adequate for inventory and quality control purposes. The label shall provide as a minimum the manufacturer's name, product identification, lot number, roll number, and roll dimensions. Rolls shall be labeled as per ASTM D 4873, Guide for Identification, Storage, and Handling of Geotextiles.

B. Materials shall be shipped and stored in rolls furnished at the manufacturing facility to prevent exposure of the geotextile to ultraviolet light, precipitation, moisture, mud, dirt, dust, puncture, or other damaging conditions.

C. Rolls of geotextiles should not be stacked upon one another to the extent that deformation of the core occurs and outdoor storage should not be allowed to exceed six months.

D. Rolls of geotextile shall be located a sufficient distance from the trenches to prevent impacting the integrity of trench walls.

Part 2 - PRODUCTS

2.01 GEOTEXTILE

A. Material shall be a woven monofilament geotextile equivalent to FW 401 as manufactured by TC Mirifi, or ENGINEER approved equivalent conforming to the following minimum properties:

Characteristics	Specification	Test Method
Percent Opening Area	20%	COE-02215-86
Wide Width Tensile Strength (MD)	175 lbs/in	ASTM D 4595
Wide Width Tensile Strength (CD)	110 lbs/in	ASTM D 4595
Grab Tensile Strength (MD)	325 lbs @ ultimate	ASTM D 4632
Grab Tensile Strength (CD)	200 lbs @ ultimate	ASTM D 4632
Trapezoidal Tear Strength (MD)	90 @ ultimate	ASTM D 4533
Trapezoidal Tear Strength (CD)	50 @ ultimate	ASTM D 4533

Part 3 - EXECUTION

3.01 GENERAL

A. Geotextile shall be tested during manufacturing for the compliance with the following minimum test frequencies shall be observed:

Property	Test Method	Minimum Frequency
Wide Width Tensile Strength)	ASTM D 4595	1/100,000 sf
Grab Tensile Strength	ASTM D 4632	1/100,000 sf
Trapezoidal Tear Strength	ASTM D 4533	1/100,000 sf
Percent Opening Area	COE-02215-86	1/100,000 sf

B. Geotextiles shall be installed in accordance with the manufacturer's recommendations. No equipment shall be allowed to operate on the geotextile, and any tears or damage to the geotextile shall be repaired prior to placement in the trench. The surface of the geotextile shall be kept relatively clean and free of debris during installation.

C. Geotextile shall not be placed in a trench that is excessively wet or has standing water.

D. Geotextile shall be overlapped in the trench as shown in the Drawings. Overlapped material can be sewn or pegged to maintain overlap during backfilling operations.

E. Geotextile sheets shall be joined in accordance with manufacturers recommendations.

F. The CONTRACTOR shall place all cover materials in such a manner to prevent damage to the materials, slippage of the underlying layers, and excessive tensile stresses in the materials.

3.03 REPAIRS

A. Any geotextile damaged during placement shall be replaced or repaired at the CONTRACTOR'S expense in accordance with manufacturers recommendation. The CONTRACTOR shall be responsible for the documentation of repairs describing location and type of repair. Repair documentation shall be submitted to the COUNTY or ENGINEER.

3.04 GEOTEXTILE EXPOSURE FOLLOWING PLACEMENT

A. Exposure of geotextiles to the elements between the time the geotextile is placed in the trench to the time backfilling operations are complete shall be limited to a maximum of 30 days to minimize ultraviolet damage. Any geotextile exposed to sunlight for more than 30 days shall be removed and replaced with new material at the CONTRACTOR'S expense.

- END OF SECTION -

ATTACHMENT E

HEAD OVER LINER CALCULATIONS

SCENARIO 1

BEGINNING OF FILLING SEQUENCE

MOORE'S EQUATION (as modified by Giroud and used by FDEP):

Head (T) = CL{ sqrt [4(e/k) + tan(Beta)^2] - tan(Beta)}/2cos(Beta)

Current, Open Phase (no waste):

Conversion Factor (C) =	39.37	in/m		
Impingement Rate (e) =	16.80	in/yr----->	1.35E-08	m/sec
Drainage Permeability (k) =	1.70E-03	cm/sec->	1.70E-05	m/sec
Slope TO Pipe (Beta) =	0.51	% ------->	0.29	degrees
Pipe Spacing Length (L) =	400	ft	121.95	meters

T = 123.8 inches

Source: "Final Guidance Manual", FDEP, February 10, 1995.

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                 HELP MODEL VERSION 3.05  (30 MARCH 1996)                 **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**              FOR USEPA RISK REDUCTION ENGINEERING LABORATORY             **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************
```

```
PRECIPITATION DATA FILE:     p:\help3\CURRENT.D4
TEMPERATURE DATA FILE:       p:\help3\CURRENT.D7
SOLAR RADIATION DATA FILE:   p:\help3\CURRENT.D13
EVAPOTRANSPIRATION DATA:     p:\help3\CURRENT.D11
SOIL AND DESIGN DATA FILE:   p:\help3\CURRENT.D10
OUTPUT DATA FILE:            p:\help3\CURRENT.OUT
```

```
TIME:   9:21      DATE:   4/ 3/1998
```

```
******************************************************************************

TITLE:  SCLF - Current, Open Phase (no waste)

******************************************************************************
```

```
     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.
```

```
                                  LAYER  1
                                  --------

                       TYPE 2 - LATERAL DRAINAGE LAYER
                         MATERIAL TEXTURE NUMBER   4
           THICKNESS                  =      96.00   INCHES
           POROSITY                   =       0.4370 VOL/VOL
           FIELD CAPACITY             =       0.1050 VOL/VOL
           WILTING POINT              =       0.0470 VOL/VOL
           INITIAL SOIL WATER CONTENT =       0.2594 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.170000002000E-02 CM/SEC
           SLOPE                      =       0.51   PERCENT
           DRAINAGE LENGTH            =     400.0    FEET
           SUBSURFACE INFLOW          =       0.67   INCHES/YR
```

LAYER 2

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	120.00	INCHES
POROSITY	=	0.4270	VOL/VOL
FIELD CAPACITY	=	0.4180	VOL/VOL
WILTING POINT	=	0.3670	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06	CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE # 4 WITH BARE GROUND CONDITIONS, A SURFACE SLOPE OF 1.% AND A SLOPE LENGTH OF 400. FEET.

SCS RUNOFF CURVE NUMBER	=	80.10	
FRACTION OF AREA ALLOWING RUNOFF	=	0.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	6.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	0.313	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	2.622	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	0.282	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	76.138	INCHES
TOTAL INITIAL WATER	=	76.138	INCHES
TOTAL SUBSURFACE INFLOW	=	0.67	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM TAMPA FLORIDA

STATION LATITUDE	=	27.58	DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00	
START OF GROWING SEASON (JULIAN DATE)	=	0	
END OF GROWING SEASON (JULIAN DATE)	=	367	
EVAPORATIVE ZONE DEPTH	=	6.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.50	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	74.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	72.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	76.00	%

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
2.30	3.10	4.40	2.40	2.90	7.40
8.10	8.10	6.20	2.60	2.60	2.10

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
59.80	60.80	66.20	71.60	77.10	80.90
82.20	82.20	80.90	74.50	66.70	61.30

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR TAMPA FLORIDA AND STATION LATITUDE = 27.58 DEGREES

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ANNUAL TOTALS FOR YEAR 1

	INCHES	CU. FEET	PERCENT
PRECIPITATION	39.87	144728.078	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	23.691	85998.789	59.42
SUBSURFACE INFLOW INTO LAYER 1	0.672000	2439.360	1.69
DRAINAGE COLLECTED FROM LAYER 1	5.8303	21163.914	14.62
PERC./LEAKAGE THROUGH LAYER 2	1.789707	6496.637	4.49
AVG. HEAD ON TOP OF LAYER 2	52.9093		
CHANGE IN WATER STORAGE	9.231	33508.152	23.15
SOIL WATER AT START OF YEAR	76.138	276381.562	
SOIL WATER AT END OF YEAR	85.369	309889.719	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.048	0.00

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ANNUAL TOTALS FOR YEAR 2

	INCHES	CU. FEET	PERCENT
PRECIPITATION	62.20	225785.969	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	42.982	156023.141	69.10
SUBSURFACE INFLOW INTO LAYER 1	0.672000	2439.360	1.08
DRAINAGE COLLECTED FROM LAYER 1	13.0951	47535.070	21.05
PERC./LEAKAGE THROUGH LAYER 2	2.122586	7704.986	3.41
AVG. HEAD ON TOP OF LAYER 2	85.0807		
CHANGE IN WATER STORAGE	4.673	16962.174	7.51
SOIL WATER AT START OF YEAR	85.369	309889.719	
SOIL WATER AT END OF YEAR	90.042	326851.875	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.054	0.00

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ANNUAL TOTALS FOR YEAR 3

	INCHES	CU. FEET	PERCENT
PRECIPITATION	54.14	196528.172	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	36.947	134116.516	68.24
SUBSURFACE INFLOW INTO LAYER 1	0.672000	2439.360	1.24
DRAINAGE COLLECTED FROM LAYER 1	14.7955	53707.648	27.33
PERC./LEAKAGE THROUGH LAYER 2	2.189967	7949.581	4.05
AVG. HEAD ON TOP OF LAYER 2	91.6681		
CHANGE IN WATER STORAGE	0.880	3193.808	1.63
SOIL WATER AT START OF YEAR	90.042	326851.875	

SOIL WATER AT END OF YEAR	90.922	330045.687	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.017	0.00

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ANNUAL TOTALS FOR YEAR 4

	INCHES	CU. FEET	PERCENT
PRECIPITATION	54.27	197000.094	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	38.700	140480.562	71.31
SUBSURFACE INFLOW INTO LAYER 1	0.673841	2446.043	1.24
DRAINAGE COLLECTED FROM LAYER 1	14.6459	53164.465	26.99
PERC./LEAKAGE THROUGH LAYER 2	2.189319	7947.227	4.03
AVG. HEAD ON TOP OF LAYER 2	91.0090		
CHANGE IN WATER STORAGE	-0.591	-2145.952	-1.09
SOIL WATER AT START OF YEAR	90.922	330045.687	
SOIL WATER AT END OF YEAR	90.331	327899.750	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.168	0.00

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ANNUAL TOTALS FOR YEAR 5

	INCHES	CU. FEET	PERCENT
PRECIPITATION	44.50	161535.000	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	28.661	104038.922	64.41

SUBSURFACE INFLOW INTO LAYER 1	0.672000	2439.360	1.51
DRAINAGE COLLECTED FROM LAYER 1	13.3229	48362.012	29.94
PERC./LEAKAGE THROUGH LAYER 2	2.134835	7749.450	4.80
AVG. HEAD ON TOP OF LAYER 2	86.3149		
CHANGE IN WATER STORAGE	1.053	3824.001	2.37
SOIL WATER AT START OF YEAR	90.331	327899.750	
SOIL WATER AT END OF YEAR	91.384	331723.750	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.026	0.00

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 5

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	2.24	3.20	2.68	1.31	2.33	6.14
	11.78	8.57	5.46	3.89	0.97	2.43
STD. DEVIATIONS	1.78	1.56	1.42	1.12	2.47	4.89
	2.30	2.56	3.62	0.90	0.92	1.34
RUNOFF						
TOTALS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
STD. DEVIATIONS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
EVAPOTRANSPIRATION						
TOTALS	1.159	1.759	1.829	0.901	1.439	3.774
	5.729	5.393	5.084	3.670	1.883	1.577
STD. DEVIATIONS	0.714	0.749	0.786	0.519	1.040	2.122
	1.007	1.489	0.912	1.181	1.280	0.524

SUBSURFACE INFLOW INTO LAYER 1

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

LATERAL DRAINAGE COLLECTED FROM LAYER 1

TOTALS	0.9197	0.8272	0.9261	0.8904	0.8851	0.9143
	1.1007	1.1948	1.1916	1.2203	1.1531	1.1148
STD. DEVIATIONS	0.3696	0.3328	0.3868	0.3635	0.3461	0.3474
	0.3676	0.3155	0.2783	0.2705	0.2490	0.2177

PERCOLATION/LEAKAGE THROUGH LAYER 2

TOTALS	0.1725	0.1549	0.1718	0.1661	0.1702	0.1670
	0.1790	0.1831	0.1786	0.1843	0.1773	0.1805
STD. DEVIATIONS	0.0183	0.0157	0.0179	0.0171	0.0168	0.0170
	0.0163	0.0128	0.0110	0.0106	0.0099	0.0088

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 2

AVERAGES	74.9867	75.1221	75.5004	75.2839	73.7458	76.3743
	83.6669	88.3602	90.0616	89.6874	88.5369	85.4306
STD. DEVIATIONS	19.5858	19.8013	20.4060	20.0502	19.1229	19.9578
	18.5918	14.5513	12.8984	12.0646	11.5919	10.0452

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 5

	INCHES	CU. FEET	PERCENT
PRECIPITATION	51.00 (8.833)	185115.5	100.00
RUNOFF	0.000 (0.0000)	0.00	0.000
EVAPOTRANSPIRATION	34.196 (7.8426)	124131.57	67.056
SUBSURFACE INFLOW INTO LAYER 1	0.67200	2439.360	1.31775
LATERAL DRAINAGE COLLECTED FROM LAYER 1	12.33791 (3.71682)	44786.617	24.19388
PERCOLATION/LEAKAGE THROUGH LAYER 2	2.08528 (0.16808)	7569.576	4.08911
AVERAGE HEAD ON TOP OF LAYER 2	81.396 (16.180)		
CHANGE IN WATER STORAGE	3.049 (3.9620)	11068.44	5.979

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 5

	(INCHES)	(CU. FT.)
PRECIPITATION	4.35	15790.500
RUNOFF	0.000	0.0000
DRAINAGE COLLECTED FROM LAYER 1	0.04401	159.75246
PERCOLATION/LEAKAGE THROUGH LAYER 2	0.006123	22.22551
AVERAGE HEAD ON TOP OF LAYER 2	96.000	
MAXIMUM HEAD ON TOP OF LAYER 2	115.485	
LOCATION OF MAXIMUM HEAD IN LAYER 1 (DISTANCE FROM DRAIN)	335.5 FEET	
SNOW WATER	0.00	0.0000

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4370
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.0470

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 5

LAYER	(INCHES)	(VOL/VOL)
1	40.1440	0.4182
2	51.2400	0.4270
SNOW WATER	0.000	

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SCENARIO 2

BEGINNING OF FILLING SEQUENCE USING TARP ON NON-ACTIVE AREAS

MOORE'S EQUATION (as modified by Giroud and used by FDEP):

Head (T) = CL{ sqrt [4(e/k) + tan(Beta)^2] - tan(Beta)}/2cos(Beta)

Current with Tarp (Lifts 7A - 7D):

Conversion Factor (C) =	39.37	in/m		
Impingement Rate (e) =	0.01	in/yr----->	8.05E-12	m/sec
Drainage Permeability (k) =	1.70E-03	cm/sec->	1.70E-05	m/sec
Slope TO Pipe (Beta) =	1.6	% -------->	0.92	degrees
Pipe Spacing Length (L) =	400	ft	121.95	meters

T = 0.1 inches

Source: "Final Guidance Manual", FDEP, February 10, 1995.

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                 HELP MODEL VERSION 3.05  (30 MARCH 1996)                 **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**            FOR USEPA RISK REDUCTION ENGINEERING LABORATORY               **
**                                                                          **
**                                                                          **
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PRECIPITATION DATA FILE:     P:\HELP3\TARP.D4
TEMPERATURE DATA FILE:       P:\HELP3\TARP.D7
SOLAR RADIATION DATA FILE:   P:\HELP3\TARP.D13
EVAPOTRANSPIRATION DATA:     P:\HELP3\TARP.D11
SOIL AND DESIGN DATA FILE:   P:\HELP3\TARP.D10
OUTPUT DATA FILE:            P:\HELP3\TARP.OUT


TIME:   9:22     DATE:   3/23/1998


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TITLE: SCLF - Current with Tarp (Lifts 7A-7D)

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                  LAYER  1
                                  --------

                       TYPE 2 - LATERAL DRAINAGE LAYER
                        MATERIAL TEXTURE NUMBER   1
          THICKNESS                    =        0.10   INCHES
          POROSITY                     =        0.4170 VOL/VOL
          FIELD CAPACITY               =        0.0450 VOL/VOL
          WILTING POINT                =        0.0180 VOL/VOL
          INITIAL SOIL WATER CONTENT   =        0.0180 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.999999978000E-02 CM/SEC
          SLOPE                        =        0.51   PERCENT
          DRAINAGE LENGTH              =      400.0    FEET
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LAYER 2

TYPE 4 - FLEXIBLE MEMBRANE LINER
MATERIAL TEXTURE NUMBER 36

THICKNESS	=	0.01	INCHES
POROSITY	=	0.0000	VOL/VOL
FIELD CAPACITY	=	0.0000	VOL/VOL
WILTING POINT	=	0.0000	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0000	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.399999993000E-12	CM/SEC
FML PINHOLE DENSITY	=	2.00	HOLES/ACRE
FML INSTALLATION DEFECTS	=	1.00	HOLES/ACRE
FML PLACEMENT QUALITY	=	4 - POOR	

LAYER 3

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 4

THICKNESS	=	96.00	INCHES
POROSITY	=	0.4370	VOL/VOL
FIELD CAPACITY	=	0.1050	VOL/VOL
WILTING POINT	=	0.0470	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.1111	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.170000002000E-02	CM/SEC
SLOPE	=	0.51	PERCENT
DRAINAGE LENGTH	=	400.0	FEET
SUBSURFACE INFLOW	=	0.67	INCHES/YR

LAYER 4

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	120.00	INCHES
POROSITY	=	0.4270	VOL/VOL
FIELD CAPACITY	=	0.4180	VOL/VOL
WILTING POINT	=	0.3670	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06	CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS USER-SPECIFIED.

SCS RUNOFF CURVE NUMBER	=	100.00	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES

EVAPORATIVE ZONE DEPTH	=	0.1	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	0.002	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	0.042	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	0.002	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	61.910	INCHES
TOTAL INITIAL WATER	=	61.910	INCHES
TOTAL SUBSURFACE INFLOW	=	0.67	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
TAMPA FLORIDA

STATION LATITUDE	=	27.58 DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00
START OF GROWING SEASON (JULIAN DATE)	=	0
END OF GROWING SEASON (JULIAN DATE)	=	367
EVAPORATIVE ZONE DEPTH	=	0.1 INCHES
AVERAGE ANNUAL WIND SPEED	=	7.50 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	74.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	72.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	76.00 %

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
2.30	3.10	4.40	2.40	2.90	7.40
8.10	8.10	6.20	2.60	2.60	2.10

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
59.80	60.80	66.20	71.60	77.10	80.90
82.20	82.20	80.90	74.50	66.70	61.30

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA
AND STATION LATITUDE = 27.58 DEGREES

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 5

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	2.24	3.20	2.68	1.31	2.33	6.14
	11.78	8.57	5.46	3.89	0.97	2.43
STD. DEVIATIONS	1.78	1.56	1.42	1.12	2.47	4.89
	2.30	2.56	3.62	0.90	0.92	1.34
RUNOFF						
TOTALS	2.236	3.200	2.684	1.314	2.326	6.140
	11.778	8.572	5.464	3.890	0.966	2.426
STD. DEVIATIONS	1.777	1.559	1.422	1.121	2.469	4.889
	2.301	2.556	3.624	0.901	0.917	1.345
EVAPOTRANSPIRATION						
TOTALS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
STD. DEVIATIONS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
LATERAL DRAINAGE COLLECTED FROM LAYER 1						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PERCOLATION/LEAKAGE THROUGH LAYER 2						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SUBSURFACE INFLOW INTO LAYER 3						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
LATERAL DRAINAGE COLLECTED FROM LAYER 3						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

PERCOLATION/LEAKAGE THROUGH LAYER 4

TOTALS	0.0663	0.0599	0.0669	0.0651	0.0676	0.0660
	0.0685	0.0689	0.0671	0.0699	0.0682	0.0715
STD. DEVIATIONS	0.0039	0.0040	0.0059	0.0067	0.0079	0.0086
	0.0095	0.0105	0.0111	0.0122	0.0121	0.0134

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 2

AVERAGES	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

DAILY AVERAGE HEAD ON TOP OF LAYER 4

AVERAGES	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
	0.0007	0.0007	0.0008	0.0008	0.0008	0.0008
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
	0.0001	0.0001	0.0001	0.0002	0.0001	0.0002

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 5

	INCHES		CU. FEET	PERCENT
PRECIPITATION	51.00	(8.833)	185115.5	100.00
RUNOFF	50.996	(8.8334)	185115.17	100.000
EVAPOTRANSPIRATION	0.000	(0.0000)	0.30	0.000
LATERAL DRAINAGE COLLECTED FROM LAYER 1	0.00000	(0.00000)	0.000	0.00000
PERCOLATION/LEAKAGE THROUGH LAYER 2	0.00000	(0.00000)	0.000	0.00000
AVERAGE HEAD ON TOP OF LAYER 2	0.000	(0.000)		
SUBSURFACE INFLOW INTO LAYER 3	0.00000		0.000	0.00000
LATERAL DRAINAGE COLLECTED FROM LAYER 3	0.00003	(0.00000)	0.116	0.00006
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.80600	(0.10541)	2925.795	1.58052
AVERAGE HEAD ON TOP OF LAYER 4	0.001	(0.000)		
CHANGE IN WATER STORAGE	0.539	(0.1058)	1955.48	1.056

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 5

	(INCHES)	(CU. FT.)
PRECIPITATION	4.35	15790.500
RUNOFF	4.350	15790.4961
DRAINAGE COLLECTED FROM LAYER 1	0.00000	0.00000
PERCOLATION/LEAKAGE THROUGH LAYER 2	0.000000	0.00000
AVERAGE HEAD ON TOP OF LAYER 2	0.000	
MAXIMUM HEAD ON TOP OF LAYER 2	0.000	
LOCATION OF MAXIMUM HEAD IN LAYER 1 (DISTANCE FROM DRAIN)	0.0 FEET	
DRAINAGE COLLECTED FROM LAYER 3	0.00000	0.00085
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.003402	12.34772
AVERAGE HEAD ON TOP OF LAYER 4	0.002	
MAXIMUM HEAD ON TOP OF LAYER 4	0.004	
LOCATION OF MAXIMUM HEAD IN LAYER 3 (DISTANCE FROM DRAIN)	17.1 FEET	
SNOW WATER	0.00	0.0000

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.0180
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.0180

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 5

LAYER	(INCHES)	(VOL/VOL)
1	0.0018	0.0180
2	0.0000	0.0000
3	13.3617	0.1392
4	51.2400	0.4270
SNOW WATER	0.000	

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****

SCENARIO 3

AFTER PLACEMENT OF 30 FEET WASTE

<u>MOORE'S EQUATION (as modified by Giroud and used by FDEP):</u>
Head (T) = CL{ sqrt [4(e/k) + tan(Beta)^2] - tan(Beta)}/2cos(Beta)

Current, After Lift 7 (30' waste & no additional trenches):

Conversion Factor (C) =	39.37	in/m		
Impingement Rate (e) =	1.61	in/yr----->	1.30E-09	m/sec
Drainage Permeability (k) =	1.70E-03	cm/sec->	1.70E-05	m/sec
Slope TO Pipe (Beta) =	1.6	% ------->	0.92	degrees
Pipe Spacing Length (L) =	400	ft	121.95	meters

T = 18.5 inches

Source: "Final Guidance Manual", FDEP, February 10, 1995.

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                 HELP MODEL VERSION 3.05  (30 MARCH 1996)                 **
**                 DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                   USAE WATERWAYS EXPERIMENT STATION                      **
**              FOR USEPA RISK REDUCTION ENGINEERING LABORATORY             **
**                                                                          **
**                                                                          **
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```
PRECIPITATION DATA FILE:     p:\help3\INT.D4
TEMPERATURE DATA FILE:       p:\help3\INT.D7
SOLAR RADIATION DATA FILE:   p:\help3\INT.D13
EVAPOTRANSPIRATION DATA:     p:\help3\INT.D11
SOIL AND DESIGN DATA FILE:   p:\help3\INT.D10
OUTPUT DATA FILE:            p:\help3\INT.OUT
```

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TIME:  10:23     DATE:   3/25/1998
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 *****************************************************************************

TITLE: SCLF - Current, after Lift 7 (30' waste & no additional trenches)

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.
```

```
                                  LAYER  1
                                  --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   0
           THICKNESS                  =      18.00   INCHES
           POROSITY                   =       0.4750 VOL/VOL
           FIELD CAPACITY             =       0.3780 VOL/VOL
           WILTING POINT              =       0.2650 VOL/VOL
           INITIAL SOIL WATER CONTENT =       0.3594 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.999999975000E-05 CM/SEC
```

LAYER 2

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	348.00 INCHES
POROSITY	=	0.5200 VOL/VOL
FIELD CAPACITY	=	0.2942 VOL/VOL
WILTING POINT	=	0.1400 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3004 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999975000E-04 CM/SEC

LAYER 3

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	12.00 INCHES
POROSITY	=	0.5200 VOL/VOL
FIELD CAPACITY	=	0.2942 VOL/VOL
WILTING POINT	=	0.1400 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2942 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999975000E-04 CM/SEC

LAYER 4

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 4

THICKNESS	=	96.00 INCHES
POROSITY	=	0.4370 VOL/VOL
FIELD CAPACITY	=	0.1050 VOL/VOL
WILTING POINT	=	0.0470 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.1128 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.170000002000E-02 CM/SEC
SLOPE	=	1.60 PERCENT
DRAINAGE LENGTH	=	400.0 FEET
SUBSURFACE INFLOW	=	0.67 INCHES/YR

LAYER 5

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	120.00 INCHES
POROSITY	=	0.4270 VOL/VOL
FIELD CAPACITY	=	0.4180 VOL/VOL
WILTING POINT	=	0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS USER-SPECIFIED.

SCS RUNOFF CURVE NUMBER	=	86.00	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	6.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	1.675	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	2.850	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	1.590	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	176.609	INCHES
TOTAL INITIAL WATER	=	176.609	INCHES
TOTAL SUBSURFACE INFLOW	=	0.67	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
TAMPA FLORIDA

STATION LATITUDE	=	27.58	DEGREES
MAXIMUM LEAF AREA INDEX	=	3.50	
START OF GROWING SEASON (JULIAN DATE)	=	0	
END OF GROWING SEASON (JULIAN DATE)	=	367	
EVAPORATIVE ZONE DEPTH	=	6.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.50	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	74.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	72.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	76.00	%

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
2.30	3.10	4.40	2.40	2.90	7.40
8.10	8.10	6.20	2.60	2.60	2.10

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
59.80	60.80	66.20	71.60	77.10	80.90

82.20	82.20	80.90	74.50	66.70	61.30

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA
AND STATION LATITUDE = 27.58 DEGREES

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ANNUAL TOTALS FOR YEAR 1

	INCHES	CU. FEET	PERCENT
PRECIPITATION	39.87	144728.078	100.00
RUNOFF	13.533	49123.930	33.94
EVAPOTRANSPIRATION	23.820	86468.133	59.75
SUBSURFACE INFLOW INTO LAYER 4	0.672000	2439.360	1.69
DRAINAGE COLLECTED FROM LAYER 4	0.0001	0.258	0.00
PERC./LEAKAGE THROUGH LAYER 5	0.755929	2744.021	1.90
AVG. HEAD ON TOP OF LAYER 5	0.0005		
CHANGE IN WATER STORAGE	3.105	11270.414	7.79
SOIL WATER AT START OF YEAR	176.609	641091.375	
SOIL WATER AT END OF YEAR	179.714	652361.750	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6720	-2439.309	-1.69

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ANNUAL TOTALS FOR YEAR 2

	INCHES	CU. FEET	PERCENT
PRECIPITATION	62.20	225785.969	100.00
RUNOFF	31.227	113354.984	50.20
EVAPOTRANSPIRATION	29.217	106056.359	46.97
SUBSURFACE INFLOW INTO LAYER 4	0.672000	2439.360	1.08

DRAINAGE COLLECTED FROM LAYER 4	0.0042	15.362	0.01
PERC./LEAKAGE THROUGH LAYER 5	0.846642	3073.311	1.36
AVG. HEAD ON TOP OF LAYER 5	0.0299		
CHANGE IN WATER STORAGE	2.249	8164.730	3.62
SOIL WATER AT START OF YEAR	179.714	652361.750	
SOIL WATER AT END OF YEAR	181.963	660526.500	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6720	-2439.422	-1.08

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ANNUAL TOTALS FOR YEAR 3

	INCHES	CU. FEET	PERCENT
PRECIPITATION	54.14	196528.172	100.00
RUNOFF	24.263	88073.383	44.81
EVAPOTRANSPIRATION	27.903	101288.148	51.54
SUBSURFACE INFLOW INTO LAYER 4	0.672000	2439.360	1.24
DRAINAGE COLLECTED FROM LAYER 4	0.2216	804.408	0.41
PERC./LEAKAGE THROUGH LAYER 5	1.257853	4566.006	2.32
AVG. HEAD ON TOP OF LAYER 5	1.5708		
CHANGE IN WATER STORAGE	1.839	6674.977	3.40
SOIL WATER AT START OF YEAR	181.963	660526.500	
SOIL WATER AT END OF YEAR	183.802	667201.500	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6720	-2439.390	-1.24

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ANNUAL TOTALS FOR YEAR 4

	INCHES	CU. FEET	PERCENT
PRECIPITATION	54.27	197000.094	100.00
RUNOFF	24.064	87351.805	44.34
EVAPOTRANSPIRATION	29.393	106695.922	54.16
SUBSURFACE INFLOW INTO LAYER 4	0.673841	2446.043	1.24
DRAINAGE COLLECTED FROM LAYER 4	0.7267	2637.858	1.34
PERC./LEAKAGE THROUGH LAYER 5	1.298403	4713.202	2.39
AVG. HEAD ON TOP OF LAYER 5	5.1491		
CHANGE IN WATER STORAGE	0.136	493.409	0.25
SOIL WATER AT START OF YEAR	183.802	667201.500	
SOIL WATER AT END OF YEAR	183.938	667694.875	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6738	-2446.067	-1.24

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ANNUAL TOTALS FOR YEAR 5

	INCHES	CU. FEET	PERCENT
PRECIPITATION	44.50	161535.000	100.00
RUNOFF	18.922	68685.461	42.52
EVAPOTRANSPIRATION	24.604	89313.109	55.29
SUBSURFACE INFLOW INTO LAYER 4	0.672000	2439.360	1.51
DRAINAGE COLLECTED FROM LAYER 4	1.3407	4866.784	3.01
PERC./LEAKAGE THROUGH LAYER 5	1.340162	4864.788	3.01
AVG. HEAD ON TOP OF LAYER 5	9.5272		
CHANGE IN WATER STORAGE	-0.363	-1316.385	-0.81
SOIL WATER AT START OF YEAR	183.938	667694.875	

SOIL WATER AT END OF YEAR	183.575	666378.500	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6720	-2439.394	-1.51

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 5

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	2.24	3.20	2.68	1.31	2.33	6.14
	11.78	8.57	5.46	3.89	0.97	2.43
STD. DEVIATIONS	1.78	1.56	1.42	1.12	2.47	4.89
	2.30	2.56	3.62	0.90	0.92	1.34
RUNOFF						
TOTALS	0.864	0.971	1.386	0.374	0.993	2.690
	6.130	4.029	2.395	1.512	0.269	0.791
STD. DEVIATIONS	1.100	0.867	1.074	0.693	1.748	3.726
	1.434	1.790	2.920	0.754	0.419	0.650
EVAPOTRANSPIRATION						
TOTALS	1.228	1.794	1.651	0.887	1.378	3.338
	5.161	4.005	3.129	1.957	0.857	1.603
STD. DEVIATIONS	0.568	0.691	0.611	0.467	0.820	1.606
	0.758	0.950	0.493	0.531	0.530	0.695
SUBSURFACE INFLOW INTO LAYER 4						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
TOTALS	0.0296	0.0294	0.0347	0.0344	0.0357	0.0354
	0.0384	0.0408	0.0412	0.0443	0.0444	0.0505
STD. DEVIATIONS	0.0437	0.0411	0.0472	0.0461	0.0474	0.0458
	0.0477	0.0488	0.0490	0.0531	0.0523	0.0568
PERCOLATION/LEAKAGE THROUGH LAYER 5						

TOTALS	0.0918	0.0825	0.0915	0.0886	0.0922	0.0887
	0.0918	0.0919	0.0892	0.0933	0.0973	0.1009
STD. DEVIATIONS	0.0253	0.0225	0.0251	0.0243	0.0243	0.0244
	0.0253	0.0254	0.0247	0.0242	0.0200	0.0208

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES	2.4571	2.7285	2.9022	2.9752	2.9906	3.0575
	3.2113	3.4143	3.5598	3.7037	3.8372	4.2286
STD. DEVIATIONS	3.6525	3.8127	3.9531	3.9855	3.9687	3.9609
	3.9927	4.0807	4.2353	4.4480	4.5232	4.7559

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 5

	INCHES		CU. FEET	PERCENT
PRECIPITATION	51.00	(8.833)	185115.5	100.00
RUNOFF	22.402	(6.6122)	81317.92	43.928
EVAPOTRANSPIRATION	26.987	(2.6127)	97964.33	52.921
SUBSURFACE INFLOW INTO LAYER 4	0.67200		2439.360	1.31775
LATERAL DRAINAGE COLLECTED FROM LAYER 4	0.45866	(0.57508)	1664.934	0.89940
PERCOLATION/LEAKAGE THROUGH LAYER 5	1.09980	(0.27592)	3992.266	2.15664
AVERAGE HEAD ON TOP OF LAYER 5	3.256	(4.085)		
CHANGE IN WATER STORAGE	1.393	(1.4599)	5057.43	2.732

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 5

	(INCHES)	(CU. FT.)
PRECIPITATION	4.35	15790.500
RUNOFF	3.834	13918.3779
DRAINAGE COLLECTED FROM LAYER 4	0.00416	15.09761
PERCOLATION/LEAKAGE THROUGH LAYER 5	0.003707	13.45792
AVERAGE HEAD ON TOP OF LAYER 5	10.792	
MAXIMUM HEAD ON TOP OF LAYER 5	15.567	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	111.4 FEET	
SNOW WATER	0.00	0.0000

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4593
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2650

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 5

LAYER	(INCHES)	(VOL/VOL)
1	6.1306	0.3406
2	103.3410	0.2970
3	3.5304	0.2942
4	19.3333	0.2014
5	51.2400	0.4270
SNOW WATER	0.000	

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SCENARIO 4

FINAL CLOSURE

MOORE'S EQUATION (as modified by Giroud and used by FDEP):

Head (T) = CL{ sqrt [4(e/k) + tan(Beta)^2] - tan(Beta)}/2cos(Beta)

Final Cover System:

Conversion Factor (C) =	39.37	in/m		
Impingement Rate (e) =	0.68	in/yr----->	5.52E-10	m/sec
Drainage Permeability (k) =	1.70E-03	cm/sec->	1.70E-05	m/sec
Slope TO Pipe (Beta) =	1.6	% -------->	0.92	degrees
Pipe Spacing Length (L) =	400	ft	121.95	meters

T = 8.7 inches

Source: "Final Guidance Manual", FDEP, February 10, 1995.

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**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                  HELP MODEL VERSION 3.05  (30 MARCH 1996)                **
**                   DEVELOPED BY ENVIRONMENTAL LABORATORY                  **
**                     USAE WATERWAYS EXPERIMENT STATION                    **
**              FOR USEPA RISK REDUCTION ENGINEERING LABORATORY             **
**                                                                          **
**                                                                          **
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PRECIPITATION DATA FILE:     p:\help3\FINAL.D4
TEMPERATURE DATA FILE:       p:\help3\FINAL.D7
SOLAR RADIATION DATA FILE:   p:\help3\FINAL.D13
EVAPOTRANSPIRATION DATA:     p:\help3\FINAL.D11
SOIL AND DESIGN DATA FILE:   p:\help3\FINAL.D10
OUTPUT DATA FILE:            p:\help3\FINAL.OUT


TIME:  10:31     DATE:   3/25/1998


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TITLE:  SCLF - Final Cover System (no upward gradient)

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                  LAYER  1
                                  --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER   0
          THICKNESS                    =      24.00   INCHES
          POROSITY                     =       0.4750 VOL/VOL
          FIELD CAPACITY               =       0.3780 VOL/VOL
          WILTING POINT                =       0.2650 VOL/VOL
          INITIAL SOIL WATER CONTENT   =       0.3590 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.999999975000E-05 CM/SEC


                                  LAYER  2
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LAYER 2

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 34

THICKNESS	=	0.20	INCHES
POROSITY	=	0.8500	VOL/VOL
FIELD CAPACITY	=	0.0100	VOL/VOL
WILTING POINT	=	0.0050	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0118	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	33.0000000000	CM/SEC
SLOPE	=	5.00	PERCENT
DRAINAGE LENGTH	=	800.0	FEET

LAYER 3

TYPE 4 - FLEXIBLE MEMBRANE LINER
MATERIAL TEXTURE NUMBER 36

THICKNESS	=	0.04	INCHES
POROSITY	=	0.0000	VOL/VOL
FIELD CAPACITY	=	0.0000	VOL/VOL
WILTING POINT	=	0.0000	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0000	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.399999993000E-12	CM/SEC
FML PINHOLE DENSITY	=	2.00	HOLES/ACRE
FML INSTALLATION DEFECTS	=	1.00	HOLES/ACRE
FML PLACEMENT QUALITY	=	3 - GOOD	

LAYER 4

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	1188.00	INCHES
POROSITY	=	0.5200	VOL/VOL
FIELD CAPACITY	=	0.2942	VOL/VOL
WILTING POINT	=	0.1400	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2942	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999975000E-04	CM/SEC

LAYER 5

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	12.00	INCHES
POROSITY	=	0.5200	VOL/VOL
FIELD CAPACITY	=	0.2942	VOL/VOL
WILTING POINT	=	0.1400	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2942	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999975000E-04	CM/SEC

LAYER 6

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 4

THICKNESS	=	96.00	INCHES
POROSITY	=	0.4370	VOL/VOL
FIELD CAPACITY	=	0.1050	VOL/VOL
WILTING POINT	=	0.0470	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.1050	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.170000002000E-02	CM/SEC
SLOPE	=	1.60	PERCENT
DRAINAGE LENGTH	=	400.0	FEET

LAYER 7

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	48.00	INCHES
POROSITY	=	0.4270	VOL/VOL
FIELD CAPACITY	=	0.4180	VOL/VOL
WILTING POINT	=	0.3670	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06	CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS USER-SPECIFIED.

SCS RUNOFF CURVE NUMBER	=	86.00	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	8.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	2.460	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	3.800	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.120	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	385.934	INCHES
TOTAL INITIAL WATER	=	385.934	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
TAMPA FLORIDA

STATION LATITUDE = 27.58 DEGREES

STATION LATITUDE	=	27.58 DEGREES
MAXIMUM LEAF AREA INDEX	=	3.50
START OF GROWING SEASON (JULIAN DATE)	=	0
END OF GROWING SEASON (JULIAN DATE)	=	367
EVAPORATIVE ZONE DEPTH	=	8.0 INCHES
AVERAGE ANNUAL WIND SPEED	=	7.50 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	74.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	72.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	76.00 %

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
2.30	3.10	4.40	2.40	2.90	7.40
8.10	8.10	6.20	2.60	2.60	2.10

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
59.80	60.80	66.20	71.60	77.10	80.90
82.20	82.20	80.90	74.50	66.70	61.30

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA
AND STATION LATITUDE = 27.58 DEGREES

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ANNUAL TOTALS FOR YEAR 1

	INCHES	CU. FEET	PERCENT
PRECIPITATION	39.87	144728.078	100.00
RUNOFF	13.973	50720.629	35.05
EVAPOTRANSPIRATION	24.415	88625.125	61.24
DRAINAGE COLLECTED FROM LAYER 2	1.4777	5364.172	3.71
PERC./LEAKAGE THROUGH LAYER 3	0.000103	0.372	0.00
AVG. HEAD ON TOP OF LAYER 3	0.0003		

DRAINAGE COLLECTED FROM LAYER 6	0.0000	0.000	0.00
PERC./LEAKAGE THROUGH LAYER 7	0.000103	0.372	0.00
AVG. HEAD ON TOP OF LAYER 7	0.0000		
CHANGE IN WATER STORAGE	0.005	17.835	0.01
SOIL WATER AT START OF YEAR	389.465	1413757.000	
SOIL WATER AT END OF YEAR	389.470	1413774.750	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.050	0.00

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ANNUAL TOTALS FOR YEAR 2

	INCHES	CU. FEET	PERCENT
PRECIPITATION	62.20	225785.969	100.00
RUNOFF	31.460	114199.266	50.58
EVAPOTRANSPIRATION	30.304	110003.891	48.72
DRAINAGE COLLECTED FROM LAYER 2	0.8840	3208.753	1.42
PERC./LEAKAGE THROUGH LAYER 3	0.000067	0.242	0.00
AVG. HEAD ON TOP OF LAYER 3	0.0002		
DRAINAGE COLLECTED FROM LAYER 6	0.0000	0.000	0.00
PERC./LEAKAGE THROUGH LAYER 7	0.000067	0.242	0.00
AVG. HEAD ON TOP OF LAYER 7	0.0000		
CHANGE IN WATER STORAGE	-0.448	-1626.122	-0.72
SOIL WATER AT START OF YEAR	389.470	1413774.750	
SOIL WATER AT END OF YEAR	389.022	1412148.620	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.065	0.00

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ANNUAL TOTALS FOR YEAR 3

	INCHES	CU. FEET	PERCENT
PRECIPITATION	54.14	196528.172	100.00
RUNOFF	24.453	88764.148	45.17
EVAPOTRANSPIRATION	28.844	104704.859	53.28
DRAINAGE COLLECTED FROM LAYER 2	0.7363	2672.868	1.36
PERC./LEAKAGE THROUGH LAYER 3	0.000058	0.210	0.00
AVG. HEAD ON TOP OF LAYER 3	0.0002		
DRAINAGE COLLECTED FROM LAYER 6	0.0000	0.000	0.00
PERC./LEAKAGE THROUGH LAYER 7	0.000058	0.210	0.00
AVG. HEAD ON TOP OF LAYER 7	0.0000		
CHANGE IN WATER STORAGE	0.106	386.064	0.20
SOIL WATER AT START OF YEAR	389.022	1412148.620	
SOIL WATER AT END OF YEAR	389.128	1412534.750	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.014	0.00

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ANNUAL TOTALS FOR YEAR 4

	INCHES	CU. FEET	PERCENT
PRECIPITATION	54.27	197000.094	100.00
RUNOFF	24.329	88312.828	44.83
EVAPOTRANSPIRATION	29.713	107859.687	54.75
DRAINAGE COLLECTED FROM LAYER 2	0.3317	1203.890	0.61
PERC./LEAKAGE THROUGH LAYER 3	0.000027	0.096	0.00
AVG. HEAD ON TOP OF LAYER 3	0.0001		

DRAINAGE COLLECTED FROM LAYER 6	0.0000	0.000	0.00
PERC./LEAKAGE THROUGH LAYER 7	0.000027	0.096	0.00
AVG. HEAD ON TOP OF LAYER 7	0.0000		
CHANGE IN WATER STORAGE	-0.104	-376.316	-0.19
SOIL WATER AT START OF YEAR	389.128	1412534.750	
SOIL WATER AT END OF YEAR	389.024	1412158.370	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.105	0.00

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ANNUAL TOTALS FOR YEAR 5

	INCHES	CU. FEET	PERCENT
PRECIPITATION	44.50	161535.000	100.00
RUNOFF	19.031	69081.180	42.77
EVAPOTRANSPIRATION	25.054	90944.680	56.30
DRAINAGE COLLECTED FROM LAYER 2	0.4227	1534.252	0.95
PERC./LEAKAGE THROUGH LAYER 3	0.000035	0.128	0.00
AVG. HEAD ON TOP OF LAYER 3	0.0001		
DRAINAGE COLLECTED FROM LAYER 6	0.0000	0.000	0.00
PERC./LEAKAGE THROUGH LAYER 7	0.000035	0.128	0.00
AVG. HEAD ON TOP OF LAYER 7	0.0000		
CHANGE IN WATER STORAGE	-0.007	-25.368	-0.02
SOIL WATER AT START OF YEAR	389.024	1412158.370	
SOIL WATER AT END OF YEAR	389.017	1412133.000	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.129	0.00

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 5

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	2.24	3.20	2.68	1.31	2.33	6.14
	11.78	8.57	5.46	3.89	0.97	2.43
STD. DEVIATIONS	1.78	1.56	1.42	1.12	2.47	4.89
	2.30	2.56	3.62	0.90	0.92	1.34
RUNOFF						
TOTALS	0.861	0.986	1.378	0.377	0.997	2.706
	6.221	4.060	2.437	1.547	0.260	0.819
STD. DEVIATIONS	1.095	0.876	1.066	0.693	1.756	3.726
	1.445	1.794	2.929	0.788	0.416	0.650
EVAPOTRANSPIRATION						
TOTALS	1.351	1.811	1.741	0.901	1.358	3.321
	5.223	4.088	3.270	1.950	1.093	1.560
STD. DEVIATIONS	0.598	0.745	0.705	0.470	0.812	1.599
	0.890	0.969	0.571	0.493	0.566	0.683
LATERAL DRAINAGE COLLECTED FROM LAYER 2						
TOTALS	0.0458	0.0003	0.0389	0.0265	0.0032	0.0010
	0.0671	0.0935	0.1309	0.1809	0.1157	0.0666
STD. DEVIATIONS	0.0603	0.0006	0.0860	0.0593	0.0066	0.0009
	0.1119	0.1271	0.0774	0.0814	0.1322	0.0627
PERCOLATION/LEAKAGE THROUGH LAYER 3						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
LATERAL DRAINAGE COLLECTED FROM LAYER 6						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

PERCOLATION/LEAKAGE THROUGH LAYER 7

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 3

AVERAGES	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000
	0.0002	0.0003	0.0004	0.0005	0.0003	0.0002
STD. DEVIATIONS	0.0002	0.0000	0.0002	0.0002	0.0000	0.0000
	0.0003	0.0004	0.0002	0.0002	0.0004	0.0002

DAILY AVERAGE HEAD ON TOP OF LAYER 7

AVERAGES	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 5

	INCHES		CU. FEET	PERCENT
PRECIPITATION	51.00	(8.833)	185115.5	100.00
RUNOFF	22.649	(6.5589)	82215.62	44.413
EVAPOTRANSPIRATION	27.666	(2.7357)	100427.65	54.251
LATERAL DRAINAGE COLLECTED FROM LAYER 2	0.77046	(0.45492)	2796.787	1.51083
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.00006	(0.00003)	0.210	0.00011
AVERAGE HEAD ON TOP OF LAYER 3	0.000	(0.000)		
LATERAL DRAINAGE COLLECTED FROM LAYER 6	0.00000	(0.00000)	0.000	0.00000
PERCOLATION/LEAKAGE THROUGH LAYER 7	0.00006	(0.00003)	0.210	0.00011
AVERAGE HEAD ON TOP OF LAYER 7	0.000	(0.000)		
CHANGE IN WATER STORAGE	-0.089	(0.2138)	-324.78	-0.175

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 5

	(INCHES)	(CU. FT.)
PRECIPITATION	4.35	15790.500
RUNOFF	3.835	13921.8174
DRAINAGE COLLECTED FROM LAYER 2	0.03819	138.62772
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.000002	0.00687
AVERAGE HEAD ON TOP OF LAYER 3	0.003	
MAXIMUM HEAD ON TOP OF LAYER 3	0.039	
LOCATION OF MAXIMUM HEAD IN LAYER 2 (DISTANCE FROM DRAIN)	0.0 FEET	
DRAINAGE COLLECTED FROM LAYER 6	0.00000	0.00000
PERCOLATION/LEAKAGE THROUGH LAYER 7	0.000002	0.00687
AVERAGE HEAD ON TOP OF LAYER 7	0.000	
MAXIMUM HEAD ON TOP OF LAYER 7	0.003	
LOCATION OF MAXIMUM HEAD IN LAYER 6 (DISTANCE FROM DRAIN)	0.0 FEET	
SNOW WATER	0.00	0.0000

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4627
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2650

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 5

LAYER	(INCHES)	(VOL/VOL)
1	8.1690	0.3404
2	0.0020	0.0100
3	0.0000	0.0000
4	349.5096	0.2942
5	3.5304	0.2942
6	3.7800	0.1050
7	20.4960	0.4270
SNOW WATER	0.000	

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SCENARIO 5

BEGINNING OF FILLING SEQUENCE

MOORE'S EQUATION (as modified by Giroud and used by FDEP):

Head (T) = CL{ sqrt [4(e/k) + tan(Beta)^2] - tan(Beta)}/2cos(Beta)

Current, Open Phase (no waste) w/ Additional Trenches at 200':

Conversion Factor (C) =	39.37	in/m		
Impingement Rate (e) =	24.00	in/yr----->	1.93E-08	m/sec
Drainage Permeability (k) =	1.70E-03	cm/sec->	1.70E-05	m/sec
Slope TO Pipe (Beta) =	0.51	% -------->	0.29	degrees
Pipe Spacing Length (L) =	200	ft	60.97	meters

T = 75.1 inches

Source: "Final Guidance Manual", FDEP, February 10, 1995.

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**                                                                      **
**                                                                      **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE           **
**                 HELP MODEL VERSION 3.05  (30 MARCH 1996)             **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY               **
**                    USAE WATERWAYS EXPERIMENT STATION                 **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY          **
**                                                                      **
**                                                                      **
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PRECIPITATION DATA FILE:     p:\help3\CUR_IMP.D4
TEMPERATURE DATA FILE:       P:\help3\CUR_IMP.D7
SOLAR RADIATION DATA FILE:   p:\help3\CUR_IMP.D13
EVAPOTRANSPIRATION DATA:     p:\help3\CUR_IMP.D11
SOIL AND DESIGN DATA FILE:   p:\help3\CUR_IMP.D10
OUTPUT DATA FILE:            p:\help3\CUR_IMP.OUT


TIME:  10:44     DATE:   3/30/1998


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TITLE: SCLF - Current, Open Phase (no waste) w/ Additional Trenches @ 200'

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                              LAYER  1
                              --------

                    TYPE 2 - LATERAL DRAINAGE LAYER
                      MATERIAL TEXTURE NUMBER   4
          THICKNESS                    =     96.00   INCHES
          POROSITY                     =      0.4370 VOL/VOL
          FIELD CAPACITY               =      0.1050 VOL/VOL
          WILTING POINT                =      0.0470 VOL/VOL
          INITIAL SOIL WATER CONTENT   =      0.2418 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    = 0.170000002000E-02 CM/SEC
          SLOPE                        =      0.51   PERCENT
          DRAINAGE LENGTH              =    200.0    FEET
          SUBSURFACE INFLOW            =      0.67   INCHES/YR
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LAYER 2

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	120.00 INCHES
POROSITY	=	0.4270 VOL/VOL
FIELD CAPACITY	=	0.4180 VOL/VOL
WILTING POINT	=	0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE # 4 WITH BARE GROUND CONDITIONS, A SURFACE SLOPE OF 1.% AND A SLOPE LENGTH OF 100. FEET.

SCS RUNOFF CURVE NUMBER	=	81.50	
FRACTION OF AREA ALLOWING RUNOFF	=	0.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	6.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	0.313	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	2.622	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	0.282	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	74.449	INCHES
TOTAL INITIAL WATER	=	74.449	INCHES
TOTAL SUBSURFACE INFLOW	=	0.67	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM TAMPA FLORIDA

STATION LATITUDE	=	27.58	DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00	
START OF GROWING SEASON (JULIAN DATE)	=	0	
END OF GROWING SEASON (JULIAN DATE)	=	367	
EVAPORATIVE ZONE DEPTH	=	6.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.50	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	74.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	72.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	76.00	%

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
2.30	3.10	4.40	2.40	2.90	7.40
8.10	8.10	6.20	2.60	2.60	2.10

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
59.80	60.80	66.20	71.60	77.10	80.90
82.20	82.20	80.90	74.50	66.70	61.30

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR TAMPA FLORIDA AND STATION LATITUDE = 27.58 DEGREES

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ANNUAL TOTALS FOR YEAR 1

	INCHES	CU. FEET	PERCENT
PRECIPITATION	39.87	144728.078	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	23.691	85998.789	59.42
SUBSURFACE INFLOW INTO LAYER 1	0.672000	2439.360	1.69
DRAINAGE COLLECTED FROM LAYER 1	11.7251	42562.012	29.41
PERC./LEAKAGE THROUGH LAYER 2	1.646288	5976.027	4.13
AVG. HEAD ON TOP OF LAYER 2	39.0785		
CHANGE IN WATER STORAGE	3.480	12630.667	8.73
SOIL WATER AT START OF YEAR	74.449	270249.719	
SOIL WATER AT END OF YEAR	77.928	282880.375	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.050	0.00

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ANNUAL TOTALS FOR YEAR 2

	INCHES	CU. FEET	PERCENT
PRECIPITATION	62.20	225785.969	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	29.822	108254.977	47.95
SUBSURFACE INFLOW INTO LAYER 1	0.672000	2439.360	1.08
DRAINAGE COLLECTED FROM LAYER 1	27.0729	98274.766	43.53
PERC./LEAKAGE THROUGH LAYER 2	1.883271	6836.275	3.03
AVG. HEAD ON TOP OF LAYER 2	61.9254		
CHANGE IN WATER STORAGE	4.094	14859.426	6.58
SOIL WATER AT START OF YEAR	77.928	282880.375	
SOIL WATER AT END OF YEAR	82.022	297739.812	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.125	0.00

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ANNUAL TOTALS FOR YEAR 3

	INCHES	CU. FEET	PERCENT
PRECIPITATION	54.14	196528.172	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	27.212	98779.031	50.26
SUBSURFACE INFLOW INTO LAYER 1	0.672000	2439.360	1.24
DRAINAGE COLLECTED FROM LAYER 1	26.1397	94886.977	48.28
PERC./LEAKAGE THROUGH LAYER 2	1.881631	6830.319	3.48
AVG. HEAD ON TOP OF LAYER 2	61.8731		
CHANGE IN WATER STORAGE	-0.421	-1528.748	-0.78

SOIL WATER AT START OF YEAR	82.022	297739.812	
SOIL WATER AT END OF YEAR	81.601	296211.062	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.054	0.00

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ANNUAL TOTALS FOR YEAR 4

	INCHES	CU. FEET	PERCENT
PRECIPITATION	54.27	197000.094	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	29.588	107406.227	54.52
SUBSURFACE INFLOW INTO LAYER 1	0.673841	2446.043	1.24
DRAINAGE COLLECTED FROM LAYER 1	24.1795	87771.711	44.55
PERC./LEAKAGE THROUGH LAYER 2	1.859481	6749.917	3.43
AVG. HEAD ON TOP OF LAYER 2	59.2203		
CHANGE IN WATER STORAGE	-0.684	-2481.695	-1.26
SOIL WATER AT START OF YEAR	81.601	296211.062	
SOIL WATER AT END OF YEAR	80.917	293729.375	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.028	0.00

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ANNUAL TOTALS FOR YEAR 5

	INCHES	CU. FEET	PERCENT
PRECIPITATION	44.50	161535.000	100.00

RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	24.676	89573.070	55.45
SUBSURFACE INFLOW INTO LAYER 1	0.672000	2439.360	1.51
DRAINAGE COLLECTED FROM LAYER 1	18.9802	68897.984	42.65
PERC./LEAKAGE THROUGH LAYER 2	1.781767	6467.813	4.00
AVG. HEAD ON TOP OF LAYER 2	52.1996		
CHANGE IN WATER STORAGE	-0.266	-964.496	-0.60
SOIL WATER AT START OF YEAR	80.917	293729.375	
SOIL WATER AT END OF YEAR	80.651	292764.875	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.017	0.00

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 5

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	2.24	3.20	2.68	1.31	2.33	6.14
	11.78	8.57	5.46	3.89	0.97	2.43
STD. DEVIATIONS	1.78	1.56	1.42	1.12	2.47	4.89
	2.30	2.56	3.62	0.90	0.92	1.34
RUNOFF						
TOTALS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
STD. DEVIATIONS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
EVAPOTRANSPIRATION						
TOTALS	1.160	1.726	1.646	0.757	1.418	3.495
	5.078	4.075	3.213	2.338	0.656	1.434
STD. DEVIATIONS	0.711	0.709	0.549	0.410	1.056	1.688
	0.480	0.723	0.436	0.653	0.459	0.536

SUBSURFACE INFLOW INTO LAYER 1

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

LATERAL DRAINAGE COLLECTED FROM LAYER 1

TOTALS	1.5684	1.3238	1.4609	1.3703	1.2744	1.2588
	1.8166	2.2513	2.6454	2.5254	2.1907	1.9334
STD. DEVIATIONS	0.4845	0.4318	0.5479	0.5285	0.4456	0.5472
	0.9131	0.8942	0.8454	0.7645	0.5751	0.4390

PERCOLATION/LEAKAGE THROUGH LAYER 2

TOTALS	0.1512	0.1343	0.1485	0.1429	0.1454	0.1403
	0.1528	0.1598	0.1605	0.1635	0.1552	0.1560
STD. DEVIATIONS	0.0090	0.0074	0.0092	0.0092	0.0084	0.0113
	0.0136	0.0110	0.0106	0.0099	0.0079	0.0065

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 2

AVERAGES	50.9530	49.2344	48.9569	48.0643	45.4831	44.9404
	53.9057	61.8834	68.7693	66.0934	62.4774	57.5514
STD. DEVIATIONS	9.1723	9.2999	10.5228	10.8065	9.5473	13.2873
	15.4415	12.5568	12.4188	11.2271	9.3084	7.3585

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 5

	INCHES	CU. FEET	PERCENT
PRECIPITATION	51.00 (8.833)	185115.5	100.00
RUNOFF	0.000 (0.0000)	0.00	0.000
EVAPOTRANSPIRATION	26.998 (2.7866)	98002.42	52.941
SUBSURFACE INFLOW INTO LAYER 1	0.67200	2439.360	1.31775
LATERAL DRAINAGE COLLECTED FROM LAYER 1	21.61947 (6.35593)	78478.695	42.39445
PERCOLATION/LEAKAGE THROUGH LAYER 2	1.81049 (0.10068)	6572.070	3.55025
AVERAGE HEAD ON TOP OF LAYER 2	54.859 (9.673)		
CHANGE IN WATER STORAGE	1.241 (2.3391)	4503.03	2.433

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 5

	(INCHES)	(CU. FT.)
PRECIPITATION	4.35	15790.500
RUNOFF	0.000	0.0000
DRAINAGE COLLECTED FROM LAYER 1	0.13457	488.48874
PERCOLATION/LEAKAGE THROUGH LAYER 2	0.005872	21.31548
AVERAGE HEAD ON TOP OF LAYER 2	87.156	
MAXIMUM HEAD ON TOP OF LAYER 2	106.965	
LOCATION OF MAXIMUM HEAD IN LAYER 1 (DISTANCE FROM DRAIN)	180.5 FEET	
SNOW WATER	0.00	0.0000
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4132	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.0470	

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 5

LAYER	(INCHES)	(VOL/VOL)
1	29.4115	0.3064
2	51.2400	0.4270
SNOW WATER	0.000	

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SCENARIO 6

BEGINNING OF FILLING SEQUENCE USING TARP ON NON-ACTIVE AREAS

MOORE'S EQUATION (as modified by Giroud and used by FDEP):

Head (T) = CL{ sqrt [4(e/k) + tan(Beta)^2] - tan(Beta)}/2cos(Beta)

Current with Tarp and Additional Trenches:

Conversion Factor (C) =	39.37	in/m		
Impingement Rate (e) =	0.01	in/yr----->	8.05E-12	m/sec
Drainage Permeability (k) =	1.70E-03	cm/sec->	1.70E-05	m/sec
Slope TO Pipe (Beta) =	1.6	% ------->	0.92	degrees
Pipe Spacing Length (L) =	200	ft	60.97	meters

T = 0.1 inches

Source: "Final Guidance Manual", FDEP, February 10, 1995.

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                 HELP MODEL VERSION 3.05  (30 MARCH 1996)                 **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
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PRECIPITATION DATA FILE:     p:\help3\TARP_P.D4
TEMPERATURE DATA FILE:       p:\help3\TARP_P.D7
SOLAR RADIATION DATA FILE:   p:\help3\TARP_P.D13
EVAPOTRANSPIRATION DATA:     p:\help3\TARP_P.D11
SOIL AND DESIGN DATA FILE:   p:\help3\TARP_P.D10
OUTPUT DATA FILE:            p:\help3\TARP_P.OUT


TIME:  10:45     DATE:   3/25/1998


 *****************************************************************************

TITLE: SCLF - Current with Tarp and Additional Trenches

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                  LAYER  1
                                  --------

                        TYPE 2 - LATERAL DRAINAGE LAYER
                          MATERIAL TEXTURE NUMBER   1
           THICKNESS                    =       0.10   INCHES
           POROSITY                     =       0.4170 VOL/VOL
           FIELD CAPACITY               =       0.0450 VOL/VOL
           WILTING POINT                =       0.0180 VOL/VOL
           INITIAL SOIL WATER CONTENT   =       0.0180 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.999999978000E-02 CM/SEC
           SLOPE                        =       0.51   PERCENT
           DRAINAGE LENGTH              =     100.0    FEET
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LAYER 2

TYPE 4 - FLEXIBLE MEMBRANE LINER
MATERIAL TEXTURE NUMBER 36

THICKNESS	=	0.01 INCHES
POROSITY	=	0.0000 VOL/VOL
FIELD CAPACITY	=	0.0000 VOL/VOL
WILTING POINT	=	0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.399999993000E-12 CM/SEC
FML PINHOLE DENSITY	=	2.00 HOLES/ACRE
FML INSTALLATION DEFECTS	=	1.00 HOLES/ACRE
FML PLACEMENT QUALITY	=	4 - POOR

LAYER 3

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 4

THICKNESS	=	96.00 INCHES
POROSITY	=	0.4370 VOL/VOL
FIELD CAPACITY	=	0.1050 VOL/VOL
WILTING POINT	=	0.0470 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.1111 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.170000002000E-02 CM/SEC
SLOPE	=	0.51 PERCENT
DRAINAGE LENGTH	=	200.0 FEET
SUBSURFACE INFLOW	=	0.67 INCHES/YR

LAYER 4

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	120.00 INCHES
POROSITY	=	0.4270 VOL/VOL
FIELD CAPACITY	=	0.4180 VOL/VOL
WILTING POINT	=	0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS USER-SPECIFIED.

SCS RUNOFF CURVE NUMBER	=	100.00	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	0.1	INCHES

INITIAL WATER IN EVAPORATIVE ZONE	=	0.002	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	0.042	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	0.002	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	61.910	INCHES
TOTAL INITIAL WATER	=	61.910	INCHES
TOTAL SUBSURFACE INFLOW	=	0.67	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
TAMPA FLORIDA

STATION LATITUDE	=	27.58	DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00	
START OF GROWING SEASON (JULIAN DATE)	=	0	
END OF GROWING SEASON (JULIAN DATE)	=	367	
EVAPORATIVE ZONE DEPTH	=	0.1	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.50	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	74.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	72.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	76.00	%

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
2.30	3.10	4.40	2.40	2.90	7.40
8.10	8.10	6.20	2.60	2.60	2.10

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
59.80	60.80	66.20	71.60	77.10	80.90
82.20	82.20	80.90	74.50	66.70	61.30

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA
AND STATION LATITUDE = 27.58 DEGREES

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ANNUAL TOTALS FOR YEAR 1

	INCHES	CU. FEET	PERCENT
PRECIPITATION	39.87	144728.078	100.00
RUNOFF	39.870	144727.766	100.00
EVAPOTRANSPIRATION	0.000	0.295	0.00
DRAINAGE COLLECTED FROM LAYER 1	0.0000	0.000	0.00
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
SUBSURFACE INFLOW INTO LAYER 3	0.672000	2439.360	1.69
DRAINAGE COLLECTED FROM LAYER 3	0.0001	0.438	0.00
PERC./LEAKAGE THROUGH LAYER 4	0.755547	2742.636	1.90
AVG. HEAD ON TOP OF LAYER 4	0.0007		
CHANGE IN WATER STORAGE	0.588	2135.649	1.48
SOIL WATER AT START OF YEAR	63.170	229307.031	
SOIL WATER AT END OF YEAR	63.758	231442.687	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6720	-2439.340	-1.69

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ANNUAL TOTALS FOR YEAR 2

	INCHES	CU. FEET	PERCENT
PRECIPITATION	62.20	225785.969	100.00
RUNOFF	62.200	225785.687	100.00
EVAPOTRANSPIRATION	0.000	0.295	0.00
DRAINAGE COLLECTED FROM LAYER 1	0.0000	0.000	0.00
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		

SUBSURFACE INFLOW INTO LAYER 3	0.672000	2439.360	1.08
DRAINAGE COLLECTED FROM LAYER 3	0.0001	0.439	0.00
PERC./LEAKAGE THROUGH LAYER 4	0.756397	2745.723	1.22
AVG. HEAD ON TOP OF LAYER 4	0.0007		
CHANGE IN WATER STORAGE	0.587	2132.547	0.94
SOIL WATER AT START OF YEAR	63.758	231442.687	
SOIL WATER AT END OF YEAR	64.346	233575.234	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6720	-2439.367	-1.08

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ANNUAL TOTALS FOR YEAR 3

	INCHES	CU. FEET	PERCENT
PRECIPITATION	54.14	196528.172	100.00
RUNOFF	54.140	196527.875	100.00
EVAPOTRANSPIRATION	0.000	0.314	0.00
DRAINAGE COLLECTED FROM LAYER 1	0.0000	0.000	0.00
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
SUBSURFACE INFLOW INTO LAYER 3	0.672000	2439.360	1.24
DRAINAGE COLLECTED FROM LAYER 3	0.0001	0.439	0.00
PERC./LEAKAGE THROUGH LAYER 4	0.755695	2743.172	1.40
AVG. HEAD ON TOP OF LAYER 4	0.0007		
CHANGE IN WATER STORAGE	0.588	2135.123	1.09
SOIL WATER AT START OF YEAR	64.346	233575.234	
SOIL WATER AT END OF YEAR	64.934	235710.359	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00

ANNUAL WATER BUDGET BALANCE	-0.6720	-2439.396	-1.24

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ANNUAL TOTALS FOR YEAR 4

	INCHES	CU. FEET	PERCENT
PRECIPITATION	54.27	197000.094	100.00
RUNOFF	54.270	196999.797	100.00
EVAPOTRANSPIRATION	0.000	0.317	0.00
DRAINAGE COLLECTED FROM LAYER 1	0.0000	0.000	0.00
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
SUBSURFACE INFLOW INTO LAYER 3	0.673841	2446.043	1.24
DRAINAGE COLLECTED FROM LAYER 3	0.0001	0.435	0.00
PERC./LEAKAGE THROUGH LAYER 4	0.767946	2787.645	1.42
AVG. HEAD ON TOP OF LAYER 4	0.0007		
CHANGE IN WATER STORAGE	0.580	2103.994	1.07
SOIL WATER AT START OF YEAR	64.934	235710.359	
SOIL WATER AT END OF YEAR	65.514	237814.359	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6738	-2446.056	-1.24

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ANNUAL TOTALS FOR YEAR 5

	INCHES	CU. FEET	PERCENT
PRECIPITATION	44.50	161535.000	100.00
RUNOFF	44.500	161534.719	100.00
EVAPOTRANSPIRATION	0.000	0.270	0.00

DRAINAGE COLLECTED FROM LAYER 1	0.0000	0.000	0.00
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
SUBSURFACE INFLOW INTO LAYER 3	0.672000	2439.360	1.51
DRAINAGE COLLECTED FROM LAYER 3	0.0002	0.565	0.00
PERC./LEAKAGE THROUGH LAYER 4	0.993801	3607.497	2.23
AVG. HEAD ON TOP OF LAYER 4	0.0009		
CHANGE IN WATER STORAGE	0.350	1270.688	0.79
SOIL WATER AT START OF YEAR	65.514	237814.359	
SOIL WATER AT END OF YEAR	65.864	239085.047	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6720	-2439.383	-1.51

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 5

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	2.24	3.20	2.68	1.31	2.33	6.14
	11.78	8.57	5.46	3.89	0.97	2.43
STD. DEVIATIONS	1.78	1.56	1.42	1.12	2.47	4.89
	2.30	2.56	3.62	0.90	0.92	1.34
RUNOFF						
TOTALS	2.236	3.200	2.684	1.314	2.326	6.140
	11.778	8.572	5.464	3.890	0.966	2.426
STD. DEVIATIONS	1.777	1.559	1.422	1.121	2.469	4.889
	2.301	2.556	3.624	0.901	0.917	1.345
EVAPOTRANSPIRATION						
TOTALS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000

STD. DEVIATIONS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000

LATERAL DRAINAGE COLLECTED FROM LAYER 1

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

PERCOLATION/LEAKAGE THROUGH LAYER 2

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

SUBSURFACE INFLOW INTO LAYER 3

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

LATERAL DRAINAGE COLLECTED FROM LAYER 3

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

PERCOLATION/LEAKAGE THROUGH LAYER 4

TOTALS	0.0663	0.0600	0.0668	0.0652	0.0676	0.0658
	0.0686	0.0691	0.0671	0.0696	0.0685	0.0713
STD. DEVIATIONS	0.0037	0.0043	0.0057	0.0068	0.0078	0.0083
	0.0096	0.0109	0.0110	0.0120	0.0124	0.0130

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 2

AVERAGES	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

DAILY AVERAGE HEAD ON TOP OF LAYER 4

AVERAGES	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
	0.0007	0.0008	0.0008	0.0007	0.0008	0.0008
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001

0.0001 0.0001 0.0001 0.0001 0.0001 0.0001

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 5

	INCHES		CU. FEET	PERCENT
PRECIPITATION	51.00	(8.833)	185115.5	100.00
RUNOFF	50.996	(8.8334)	185115.17	100.000
EVAPOTRANSPIRATION	0.000	(0.0000)	0.30	0.000
LATERAL DRAINAGE COLLECTED FROM LAYER 1	0.00000	(0.00000)	0.000	0.00000
PERCOLATION/LEAKAGE THROUGH LAYER 2	0.00000	(0.00000)	0.000	0.00000
AVERAGE HEAD ON TOP OF LAYER 2	0.000	(0.000)		
SUBSURFACE INFLOW INTO LAYER 3	0.67200		2439.360	1.31775
LATERAL DRAINAGE COLLECTED FROM LAYER 3	0.00013	(0.00002)	0.463	0.00025
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.80588	(0.10518)	2925.335	1.58028
AVERAGE HEAD ON TOP OF LAYER 4	0.001	(0.000)		
CHANGE IN WATER STORAGE	0.539	(0.1055)	1955.60	1.056

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 5

	(INCHES)	(CU. FT.)
PRECIPITATION	4.35	15790.500
RUNOFF	4.350	15790.4961
DRAINAGE COLLECTED FROM LAYER 1	0.00000	0.00000
PERCOLATION/LEAKAGE THROUGH LAYER 2	0.000000	0.00000
AVERAGE HEAD ON TOP OF LAYER 2	0.000	
MAXIMUM HEAD ON TOP OF LAYER 2	0.000	
LOCATION OF MAXIMUM HEAD IN LAYER 1 (DISTANCE FROM DRAIN)	0.0 FEET	
DRAINAGE COLLECTED FROM LAYER 3	0.00000	0.00346
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.003402	12.34772
AVERAGE HEAD ON TOP OF LAYER 4	0.002	
MAXIMUM HEAD ON TOP OF LAYER 4	0.004	
LOCATION OF MAXIMUM HEAD IN LAYER 3 (DISTANCE FROM DRAIN)	0.0 FEET	
SNOW WATER	0.00	0.0000
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.0180	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.0180	

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 5

LAYER	(INCHES)	(VOL/VOL)
1	0.0018	0.0180
2	0.0000	0.0000
3	13.3618	0.1392
4	51.2400	0.4270
SNOW WATER	0.000	

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SCENARIO 7

INTERMEDIATE FILLING USING INTERMEDIATE COVER OVER NON-ACTIVE AREAS (LIFTS 7C THROUGH 7E)

MOORE'S EQUATION (as modified by Girod and used by FDEP):

Head (T) = CL{ sqrt [4(e/k) + tan(Beta)^2] - tan(Beta)}/2cos(Beta)

Future Phases V & VI with Improvements

Conversion Factor (C) =	39.37	in/m		
Impingement Rate (e) =	1.53	in/yr----->	1.23E-09	m/sec
Drainage Permeability (k) =	1.70E-03	cm/sec->	1.70E-05	m/sec
Slope TO Pipe (Beta) =	1.00	% -------->	0.57	degrees
Pipe Spacing Length (L) =	200	ft	60.97	meters

T = 11.7 inches

Source: "Final Guidance Manual", FDEP, February 10, 1995.

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************
```

```
PRECIPITATION DATA FILE:     p:\help\INT.D4
TEMPERATURE DATA FILE:       p:\help\INT.D7
SOLAR RADIATION DATA FILE:   p:\help\INT.D13
EVAPOTRANSPIRATION DATA:     p:\help\INT.D11
SOIL AND DESIGN DATA FILE:   p:\help\INT.D10
OUTPUT DATA FILE:            p:\help\15int.OUT
```

TIME: 15:12   DATE: 6/22/1998

```
******************************************************************************

     TITLE:  Phases V & VI (w/ tire trenches @ 15' waste)

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NOTE: INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.

LAYER 1

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

```
THICKNESS                  =     18.00   INCHES
POROSITY                   =      0.4750 VOL/VOL
FIELD CAPACITY             =      0.3780 VOL/VOL
WILTING POINT              =      0.2650 VOL/VOL
INITIAL SOIL WATER CONTENT =      0.3881 VOL/VOL
EFFECTIVE SAT. HYD. COND.  = 0.999999975000E-05 CM/SEC
```

LAYER 2

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	168.00 INCHES
POROSITY	=	0.5200 VOL/VOL
FIELD CAPACITY	=	0.2942 VOL/VOL
WILTING POINT	=	0.1400 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3053 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999975000E-04 CM/SEC

LAYER 3

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	12.00 INCHES
POROSITY	=	0.5200 VOL/VOL
FIELD CAPACITY	=	0.2942 VOL/VOL
WILTING POINT	=	0.1400 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2951 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999975000E-04 CM/SEC

LAYER 4

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 4

THICKNESS	=	96.00 INCHES
POROSITY	=	0.4370 VOL/VOL
FIELD CAPACITY	=	0.1050 VOL/VOL
WILTING POINT	=	0.0470 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.1151 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.170000002000E-02 CM/SEC
SLOPE	=	1.00 PERCENT
DRAINAGE LENGTH	=	200.0 FEET
SUBSURFACE INFLOW	=	0.67 INCHES/YR

LAYER 5

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	120.00 INCHES
POROSITY	=	0.4270 VOL/VOL
FIELD CAPACITY	=	0.4180 VOL/VOL
WILTING POINT	=	0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS USER-SPECIFIED.

SCS RUNOFF CURVE NUMBER	=	86.00	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	6.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	1.906	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	2.850	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	1.590	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	124.106	INCHES
TOTAL INITIAL WATER	=	124.106	INCHES
TOTAL SUBSURFACE INFLOW	=	0.67	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
TAMPA FLORIDA

STATION LATITUDE	=	27.58	DEGREES
MAXIMUM LEAF AREA INDEX	=	3.50	
START OF GROWING SEASON (JULIAN DATE)	=	0	
END OF GROWING SEASON (JULIAN DATE)	=	367	
EVAPORATIVE ZONE DEPTH	=	6.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.50	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	74.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	72.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	76.00	%

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
2.30	3.10	4.40	2.40	2.90	7.40
8.10	8.10	6.20	2.60	2.60	2.10

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC

59.80	60.80	66.20	71.60	77.10	80.90
82.20	82.20	80.90	74.50	66.70	61.30

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TAMPA FLORIDA
AND STATION LATITUDE = 27.58 DEGREES

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ANNUAL TOTALS FOR YEAR 1

	INCHES	CU. FEET	PERCENT
PRECIPITATION	39.87	144728.078	100.00
RUNOFF	13.512	49047.219	33.89
EVAPOTRANSPIRATION	23.502	85311.102	58.95
SUBSURFACE INFLOW INTO LAYER 4	0.672000	2439.360	1.69
DRAINAGE COLLECTED FROM LAYER 4	0.0000	0.163	0.00
PERC./LEAKAGE THROUGH LAYER 5	0.757935	2751.305	1.90
AVG. HEAD ON TOP OF LAYER 5	0.0005		
CHANGE IN WATER STORAGE	3.443	12497.068	8.63
SOIL WATER AT START OF YEAR	124.106	450505.062	
SOIL WATER AT END OF YEAR	127.549	463002.125	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6720	-2439.411	-1.69

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ANNUAL TOTALS FOR YEAR 2

	INCHES	CU. FEET	PERCENT
PRECIPITATION	62.20	225785.969	100.00

RUNOFF	31.229	113362.070	50.21
EVAPOTRANSPIRATION	30.040	109047.000	48.30
SUBSURFACE INFLOW INTO LAYER 4	0.672000	2439.360	1.08
DRAINAGE COLLECTED FROM LAYER 4	0.0198	71.973	0.03
PERC./LEAKAGE THROUGH LAYER 5	0.992616	3603.195	1.60
AVG. HEAD ON TOP OF LAYER 5	0.2235		
CHANGE IN WATER STORAGE	1.262	4580.482	2.03
SOIL WATER AT START OF YEAR	127.549	463002.125	
SOIL WATER AT END OF YEAR	128.811	467582.625	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6720	-2439.406	-1.08

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ANNUAL TOTALS FOR YEAR 3

	INCHES	CU. FEET	PERCENT
PRECIPITATION	54.14	196528.172	100.00
RUNOFF	24.233	87965.984	44.76
EVAPOTRANSPIRATION	27.234	98859.336	50.30
SUBSURFACE INFLOW INTO LAYER 4	0.672000	2439.360	1.24
DRAINAGE COLLECTED FROM LAYER 4	0.4023	1460.278	0.74
PERC./LEAKAGE THROUGH LAYER 5	1.285818	4667.521	2.37
AVG. HEAD ON TOP OF LAYER 5	4.2675		
CHANGE IN WATER STORAGE	2.329	8453.808	4.30
SOIL WATER AT START OF YEAR	128.811	467582.625	
SOIL WATER AT END OF YEAR	131.140	476036.437	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00

SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6720	-2439.394	-1.24

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ANNUAL TOTALS FOR YEAR 4

	INCHES	CU. FEET	PERCENT
PRECIPITATION	54.27	197000.094	100.00
RUNOFF	24.079	87407.922	44.37
EVAPOTRANSPIRATION	29.686	107758.750	54.70
SUBSURFACE INFLOW INTO LAYER 4	0.673841	2446.043	1.24
DRAINAGE COLLECTED FROM LAYER 4	1.0842	3935.736	2.00
PERC./LEAKAGE THROUGH LAYER 5	1.340789	4867.062	2.47
AVG. HEAD ON TOP OF LAYER 5	9.2320		
CHANGE IN WATER STORAGE	-0.572	-2077.269	-1.05
SOIL WATER AT START OF YEAR	131.140	476036.437	
SOIL WATER AT END OF YEAR	130.567	473959.156	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6738	-2446.070	-1.24

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ANNUAL TOTALS FOR YEAR 5

	INCHES	CU. FEET	PERCENT
PRECIPITATION	44.50	161535.000	100.00
RUNOFF	18.893	68581.000	42.46

EVAPOTRANSPIRATION	24.931	90501.187	56.03
SUBSURFACE INFLOW INTO LAYER 4	0.672000	2439.360	1.51
DRAINAGE COLLECTED FROM LAYER 4	1.8150	6588.463	4.08
PERC./LEAKAGE THROUGH LAYER 5	1.374984	4991.192	3.09
AVG. HEAD ON TOP OF LAYER 5	12.8874		
CHANGE IN WATER STORAGE	-1.170	-4248.146	-2.63
SOIL WATER AT START OF YEAR	130.567	473959.156	
SOIL WATER AT END OF YEAR	129.397	469711.000	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	-0.6720	-2439.334	-1.51

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 5

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	2.23	3.21	2.68	1.31	2.33	6.14
	11.78	8.57	5.46	3.89	0.97	2.43
STD. DEVIATIONS	1.78	1.57	1.42	1.12	2.47	4.89
	2.30	2.56	3.62	0.90	0.92	1.34
RUNOFF						
TOTALS	0.857	0.976	1.400	0.377	0.996	2.684
	6.123	4.031	2.396	1.489	0.265	0.793
STD. DEVIATIONS	1.098	0.868	1.087	0.689	1.744	3.699
	1.423	1.790	2.920	0.751	0.419	0.652
EVAPOTRANSPIRATION						
TOTALS	1.228	1.913	1.637	0.887	1.371	3.346
	5.160	4.001	3.244	2.353	0.709	1.231

STD. DEVIATIONS	0.468	0.722	0.613	0.467	0.818	1.622
	0.763	0.946	0.571	0.534	0.534	0.353

SUBSURFACE INFLOW INTO LAYER 4

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

LATERAL DRAINAGE COLLECTED FROM LAYER 4

TOTALS	0.0652	0.0434	0.0539	0.0441	0.0470	0.0538
	0.0614	0.0584	0.0549	0.0572	0.0580	0.0670
STD. DEVIATIONS	0.1044	0.0571	0.0734	0.0530	0.0555	0.0663
	0.0752	0.0659	0.0602	0.0613	0.0595	0.0654

PERCOLATION/LEAKAGE THROUGH LAYER 5

TOTALS	0.0940	0.0847	0.0933	0.0913	0.1014	0.0967
	0.0939	0.0945	0.0964	0.1021	0.0993	0.1029
STD. DEVIATIONS	0.0266	0.0246	0.0268	0.0240	0.0211	0.0208
	0.0272	0.0263	0.0210	0.0216	0.0204	0.0216

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES	5.2226	4.5937	4.9403	4.6323	4.7638	5.2315
	5.5980	5.5583	5.5199	5.5938	5.8444	6.3676
STD. DEVIATIONS	7.1002	5.5015	5.8862	5.1195	5.1731	5.7404
	6.0524	5.7560	5.6548	5.6100	5.5704	5.6725

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 5

	INCHES		CU. FEET	PERCENT
PRECIPITATION	51.00	(8.833)	185115.5	100.00
RUNOFF	22.389	(6.6226)	81272.84	43.904
EVAPOTRANSPIRATION	27.079	(2.8722)	98295.48	53.100
SUBSURFACE INFLOW INTO LAYER 4	0.67200		2439.360	1.31775
LATERAL DRAINAGE COLLECTED FROM LAYER 4	0.66428	(0.77873)	2411.323	1.30260
PERCOLATION/LEAKAGE THROUGH LAYER 5	1.15043	(0.26643)	4176.055	2.25592
AVERAGE HEAD ON TOP OF LAYER 5	5.322	(5.656)		
CHANGE IN WATER STORAGE	1.058	(1.9343)	3841.19	2.075

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 5

	(INCHES)	(CU. FT.)
PRECIPITATION	4.35	15790.500
RUNOFF	3.837	13929.1367
DRAINAGE COLLECTED FROM LAYER 4	0.00998	36.24349
PERCOLATION/LEAKAGE THROUGH LAYER 5	0.003952	14.34665
AVERAGE HEAD ON TOP OF LAYER 5	19.429	
MAXIMUM HEAD ON TOP OF LAYER 5	24.141	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	141.7 FEET	
SNOW WATER	0.00	0.0000
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4638	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2650	

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 5

LAYER	(INCHES)	(VOL/VOL)
1	6.3326	0.3518
2	49.9140	0.2971
3	3.5597	0.2966
4	18.3507	0.1912
5	51.2400	0.4270
SNOW WATER	0.000	

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