DANIEL B. STEPHENS & ASSOCIATES, INC.
CONSULTANTS IN GROUND-WATER HYDROLOGY

• GROUND-WATER CONTAMINATION • UNSATURATED ZONE INVESTIGATIONS • WATER SUPPLY DEVELOPMENT •

January 5, 1988

Mr. Fred Brown
Hydrogeologist
Los Alamos National Laboratory
Group HSE-8
Los Alamos, NM 87545

Subject: Results of Testing for Hydraulic Properties of Welded Tuff

Dear Mr. Brown:

Please find enclosed the final data report on laboratory analyses for hydraulic properties of 10 cores of welded tuff. This report constitutes completion of the analyses requested.

We are continuing our own in-house research on unsaturated hydraulic conductivity using the additional cores that you provided us. I will report to you the results of the investigation when they have been completed.

We would like to point out that the porosity values we have reported are those computed from degree of saturation to water, and therefore represent the effective porosity to that fluid.

Daniel B. Stephens & Associates, Inc. cannot verify that samples are representative of the formation from which they were collected, and we do not assume any responsibility for interpretations or analyses based on this data.

We are very grateful to provide this service to Los Alamos National Laboratory. Please do not hesitate to call us if you have any questions.

Sincerely yours,

Daniel B. Stephens & Associates, Inc.

Warren B. Cox
Laboratory Manager

WBC:bdf
Enclosure

DANIEL B. STEPHENS & ASSOCIATES, INC.

CONSULTANTS IN GROUND-WATER HYDROLOGY SOCORRO, NEW MEXICO

FINAL DATA REPORT ON LABORATORY ANALYSES OF SOIL HYDRAULIC PROPERTIES OF WELDED TUFFS AT LOS ALAMOS NATIONAL LABORATORY

PREPARED FOR

LOS ALAMOS NATIONAL LABORATORY

JANUARY, 1988

Final Data Report on Laboratory Analyses

Of

Soil Hydraulic Properties

Of

Welded Tuffs

At

Los Alamos National Laboratory

Prepared For

Los Alamos National Laboratory

January, 1988

DANIEL B. STEPHENS & ASSOCIATES, INC.

LIST OF TABLES

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2. Unit Conventions

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SCOPE OF WORK

Scope of Work

Daniel B. Stephens & Associates, Inc. (DBS) was requested by Los Alamos National Laboratory of Los Alamos, New Mexico, to perform laboratory analyses for properties of soil, as outlined in written communication of September 9, 1987. The scope of work included the following laboratory tests on 10 cores:

1. Sample Preparation
2. Saturated Hydraulic Conductivity
3. Moisture Retention (main drainage curve), Hanging Column Method, 2 points
4. Moisture Retention (main drainage curve), Pressure Plate Method, 4 points
5. Initial Moisture Content, Bulk Density and Porosity
6. Unsaturated Hydraulic Conductivity

In execution of the foregoing request, DBS has performed the work as summarized below and in Table 1.

The cores of welded tuff were cut by hand to fit soil retaining rings in which all tests were performed. Descriptions of the sample characteristics are presented in Table 3. Laboratory analyses to determine the hydraulic properties of the ten samples are summarized in Tables 4-7. The sample reference numbers were taken as those marked on the outside of each individual sample bag.

Included in this data report are summary tables, graphs where presentation in this form was required, and raw laboratory data. The Principles and Methods section describes the basic principles of the analyses and methods of calculation. All calculation results are expressed in metric units according to Table 2.

Table 1. Summary of Tests Performed

Sample Number	Hydraulic Conductivity		Moisture Retention		Initial Moisture Content	Porosity	Dry Bulk Density
	Saturated	Unsaturated	Hanging Column	Pressure Plate			
7-8	X	X	X	X	X	X	X
11-12	X	X	X	X	X	X	X
16-17	X	X	X	X	X	X	X
21-22	X	X	X	X	X	X	X
25-26	X	X	X	X	X	X	X
35-36	X	X	X	X	X	X	X
42-43	X	X	X	X	X	X	X
61-62	X	X	X	X	X	X	X
75-76	X	X	X	X	X	X	X
80-81	X	X	X	X	X	X	X

Table 2. Unit Conventions

Hydraulic Conductivity: cm/sec

Moisture Content: % volume

Bulk Density: g/cc

Porosity: dimensionless (cm^3/cm^3)

Note: Unless otherwise stated, lengths are in units of centimeters, and masses are in units of grams.

SAMPLE CHARACTERISTICS

Table 3. Summary of Sample Characteristics

Sample No.	Depth (ft)	Color	Texture	Comments
7-8	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
11-12	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
16-17	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
21-22	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
25-26	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
35-36	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
42-43	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
61-62	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
75-76	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals and a small area of clay at one end
80-81	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals

SATURATED HYDRAULIC CONDUCTIVITY

Table 4. Summary of Saturated Hydraulic Conductivity Tests

Sample No.	K_s (cm/sec)
7-8	1.58E-04
11-12	2.84E-04
16-17	2.78E-04
21-22	2.00E-04
25-26	9.18E-05
35-36	2.25E-05
42-43	8.57E-05
61-62	5.15E-04
75-76	2.28E-04
80-81	4.41E-05

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 7-8
RING NUMBER: 14
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/5	0.00		19.0	0.0	70.5		
11/5	0.00	705	19.0	0.0	24.8	1.58E-04	1.61E-04
TEST # 2:							
11/5	0.00		19.0	0.0	70.5		
11/5	0.00	590	19.0	0.0	30.4	1.52E-04	1.55E-04

AVERAGE K SAT: 1.58E-04 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 11-12
RING NUMBER: 22
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/10	839:33		15.0	0.0	74.6		
11/10	845:39	423	15.0	0.0	29.4	2.35E-04	2.59E-04
TEST # 2:							
11/10	854:11		15.0	0.0	74.6		
11/10	900:20	369	15.0	0.0	28.3	2.80E-04	3.09E-04

AVERAGE K SAT: 2.84E-04 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 16-17
RING NUMBER: 2
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/5	0.00		19.0	0.0	69.8		
11/5	0.00	302	19.0	0.0	32.7	2.68E-04	2.73E-04
TEST # 2:							
11/5	0.00		19.0	0.0	69.8		
11/5	0.00	276	19.0	0.0	34.0	2.78E-04	2.83E-04

AVERAGE K SAT: 2.78E-04 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Staller
CALCULATIONS MADE BY: S. Staller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: Z1-22
RING NUMBER: F
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/5	0.00		19.0	0.0	76.1		
11/5	0.00	364	19.0	0.0	38.7	1.98E-04	2.02E-04
TEST # 2:							
11/5	0.00		19.0	0.0	76.1		
11/5	0.00	497	19.0	0.0	30.7	1.95E-04	1.99E-04

AVERAGE K SAT: 2.00E-04 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 25-26
RING NUMBER: C
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/5	0.00		19.0	0.0	76.5		
11/5	0.00	1116	19.0	0.0	29.6	9.08E-05	9.25E-05
TEST # 2:							
11/5	0.00		19.0	0.0	76.5		
11/5	0.00	736	19.0	0.0	41.3	8.94E-05	9.11E-05

AVERAGE K SAT: 9.18E-05 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 35-36
RING NUMBER: G
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/10	845:16		15.0	0.0	70.7		
11/10	941:03	3347	15.0	0.0	36.9	2.07E-05	2.29E-05
TEST # 2:							
11/10	942:22		15.0	0.0	70.7		
11/10	1110:48	5306	15.0	0.0	26.1	2.00E-05	2.21E-05

AVERAGE K SAT: 2.25E-05 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 42-43
RING NUMBER: 4
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/10	841:17		15.0	0.0	76.5		
11/10	904:42	1405	15.0	0.0	29.6	7.21E-05	7.96E-05
TEST # 2:							
11/10	905:46		15.0	0.0	76.5		
11/10	923:33	1067	15.0	0.0	33.3	8.32E-05	9.18E-05

AVERAGE K SAT: 8.57E-05 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 61-62
RING NUMBER: A4
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/10	840:53		15.0	0.0	79.8		
11/10	844:18	265	15.0	0.0	28.8	4.11E-04	4.53E-04
TEST # 2:							
11/10	855:36		15.0	0.0	79.8		
11/10	859:14	218	15.0	0.0	27.4	5.23E-04	5.78E-04

AVERAGE K SAT: 5.15E-04 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 75-76
RING NUMBER: 19
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/10	840:27		15.0	0.0	76.1		
11/10	849:03	576	15.0	0.0	26.8	1.93E-04	2.13E-04
TEST # 2:							
11/10	855:03		15.0	0.0	76.1		
11/10	903:29	506	15.0	0.0	26.8	2.20E-04	2.43E-04

AVERAGE K SAT: 2.28E-04 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 80-81
RING NUMBER: 18
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/10	840:02		15.0	0.0	74.9		
11/10	921:11	2469	15.0	0.0	27.4	4.35E-05	4.80E-05
TEST # 2:							
11/10	923:49		15.0	0.0	74.0		
11/10	1015:03	3074	15.0	0.0	25.9	3.65E-05	4.02E-05

AVERAGE K SAT: 4.41E-05 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION

Table 5. Summary of Moisture Retention Characteristics

Sample No.	Pressure Head (cm of water)	Moisture Content (cm^3/cm^3)
7-8	-0.0	51.8
	-100.0	49.4
	-195.0	49.0
	-1019.8	15.0
	-3059.4	13.9
	-5099.0	12.5
	-15297.0	8.3
11-12	-0.0	56.1
	-98.0	53.3
	-198.0	52.7
	-1019.8	37.6
	-3059.4	29.3
	-5099.0	26.1
	-15297.0	19.9
16-17	-0.0	54.9
	-101.0	53.6
	-199.0	52.9
	-1019.8	42.2
	-3059.4	29.2
	-5099.0	26.0
	-15297.0	20.4
21-22	-0.0	56.2
	-97.0	56.1
	-1019.8	28.1
	-3059.4	22.8
	-5099.0	19.5
	-15297.0	12.4
25-26	-0.0	52.0
	-98.5	51.4
	-1019.8	23.3
	-3059.4	21.3
	-5099.0	16.6
	-15297.0	10.0

Table 5. Summary of Moisture Retention Characteristics (continued)

Sample No.	Pressure Head (cm of water)	Moisture Content (% vol)
35-36	-0.0	42.8
	-205.0	41.4
	-1019.8	30.2
	-3059.4	14.2
	-5099.0	13.4
	-15297.0	9.4
42-43	-0.0	42.3
	-100.5	42.3
	-209.0	42.2
	-1019.8	33.5
	-3059.4	30.5
	-5099.0	28.9
	-15297.0	22.8
61-62	-0.0	36.4
	-95.5	34.8
	-202.0	32.6
	-1019.8	19.3
	-3059.4	11.2
	-5099.0	10.4
	-15297.0	7.9
75-76	-0.0	41.6
	-95.0	37.9
	-199.0	33.1
	-1019.8	24.0
	-3059.4	12.5
	-5099.0	11.6
	-15297.0	8.3
80-81	-0.0	34.6
	-1019.8	27.5
	-3059.4	18.3
	-5099.0	17.1
	-15297.0	10.7

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 7-8
RING NUMBER: 14
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 189.1 (g)
TARE RING: 72.1 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 82.7 (g)
SATURATED MOISTURE CONTENT: 51.8 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 34.3 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/23	1025	0.0	37.1	--	--	51.8	0.0
11/25	800	100.0	35.5	1.6	1.6	49.4	0.0
11/30	810	195.0	35.2	0.3	1.9	49.0	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 7-8
RING NUMBER: 14
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 189.1 (g)
TARE RING: 72.1 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 82.7 (g)
SATURATED MOISTURE CONTENT: 51.8 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 30.1 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 184.9 (g)
FINAL TENSION ON HANGING COLUMN: 195.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	184.9	--	--	--
12/2	735	1.0	164.7	20.2	20.2	15.0
12/6	830	3.0	164.0	0.7	20.9	13.9
12/8	840	5.0	163.1	0.9	21.8	12.5
12/13	1655	15.0	160.3	2.8	24.6	8.3

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

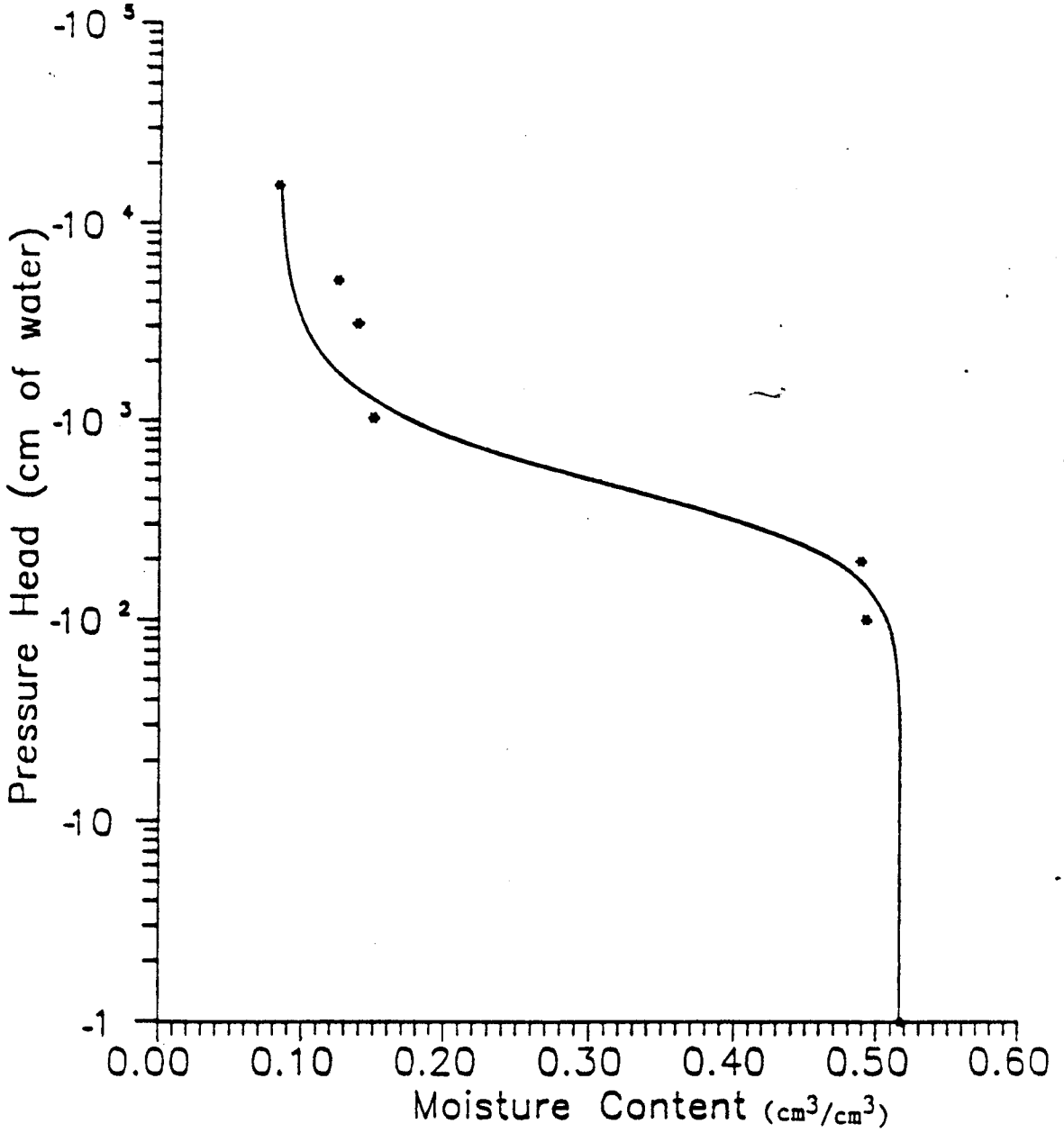


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 7-8.				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR:	PROJECT NO:	DATE:	PLOTTED BY:	CHECKED BY:	
Los Alamos	87-L-070	1/4/88	SLS	WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 11-12
RING NUMBER: 22
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 193.6 (g)
TARE RING: 73.3 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 83.2 (g)
SATURATED MOISTURE CONTENT: 56.1 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 37.1 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/23	1025	0.0	36.4	--	--	56.1	0.0
11/25	800	98.0	34.6	1.8	1.8	53.3	0.0
11/30	810	198.0	34.2	0.4	2.2	52.7	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 11-12
RING NUMBER: 22
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 193.6 (g)
TARE RING: 73.3 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 83.2 (g)
SATURATED MOISTURE CONTENT: 56.1 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 32.6 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 189.1 (g)
FINAL TENSION ON HANGING COLUMN: 198.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	189.1	--	--	--
12/2	740	1.0	181.4	7.7	7.7	37.6
12/6	830	3.0	175.9	5.5	13.2	29.3
12/8	840	5.0	173.8	2.1	15.3	26.1
12/13	1700	15.0	169.7	4.1	19.4	19.9

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

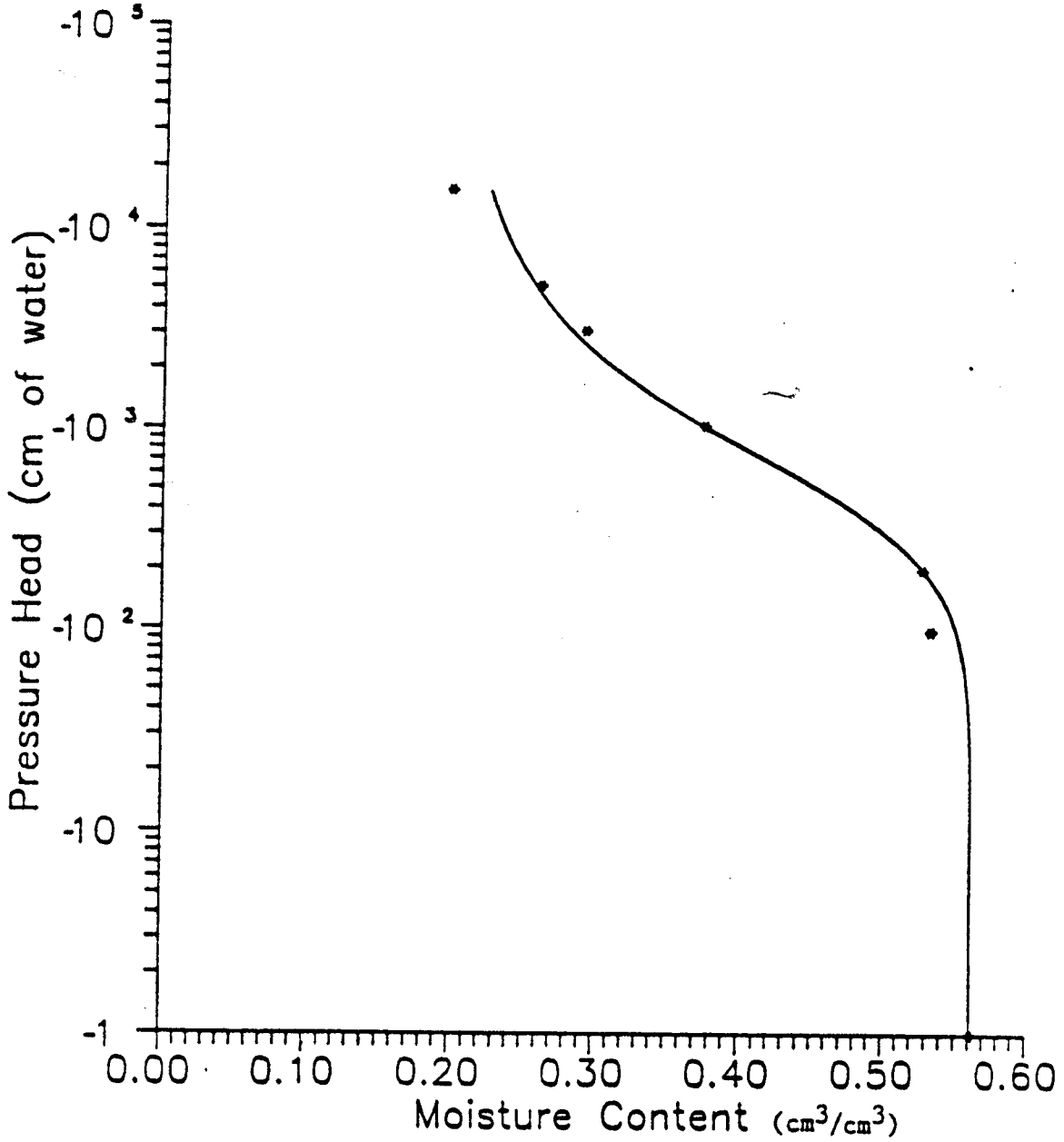


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 11-12				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 16-17
RING NUMBER: 2
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 193.6 (g)
TARE RING: 73.1 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 84.2 (g)
SATURATED MOISTURE CONTENT: 54.9 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 36.3 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/23	1025	0.0	33.7	--	--	54.9	0.0
11/25	800	101.0	32.9	0.8	0.8	53.6	0.0
11/30	810	199.0	32.4	0.5	1.3	52.9	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 16-17
RING NUMBER: 2
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 193.6 (g)
TARE RING: 73.1 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 84.2 (g)
SATURATED MOISTURE CONTENT: 54.9 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 33.4 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 190.7 (g)
FINAL TENSION ON HANGING COLUMN: 199.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	190.7	--	--	--
12/2	740	1.0	185.2	5.5	5.5	42.2
12/6	830	3.0	176.6	8.6	14.1	29.2
12/8	840	5.0	174.5	2.1	16.2	26.0
12/13	1700	15.0	170.8	3.7	19.9	20.4

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

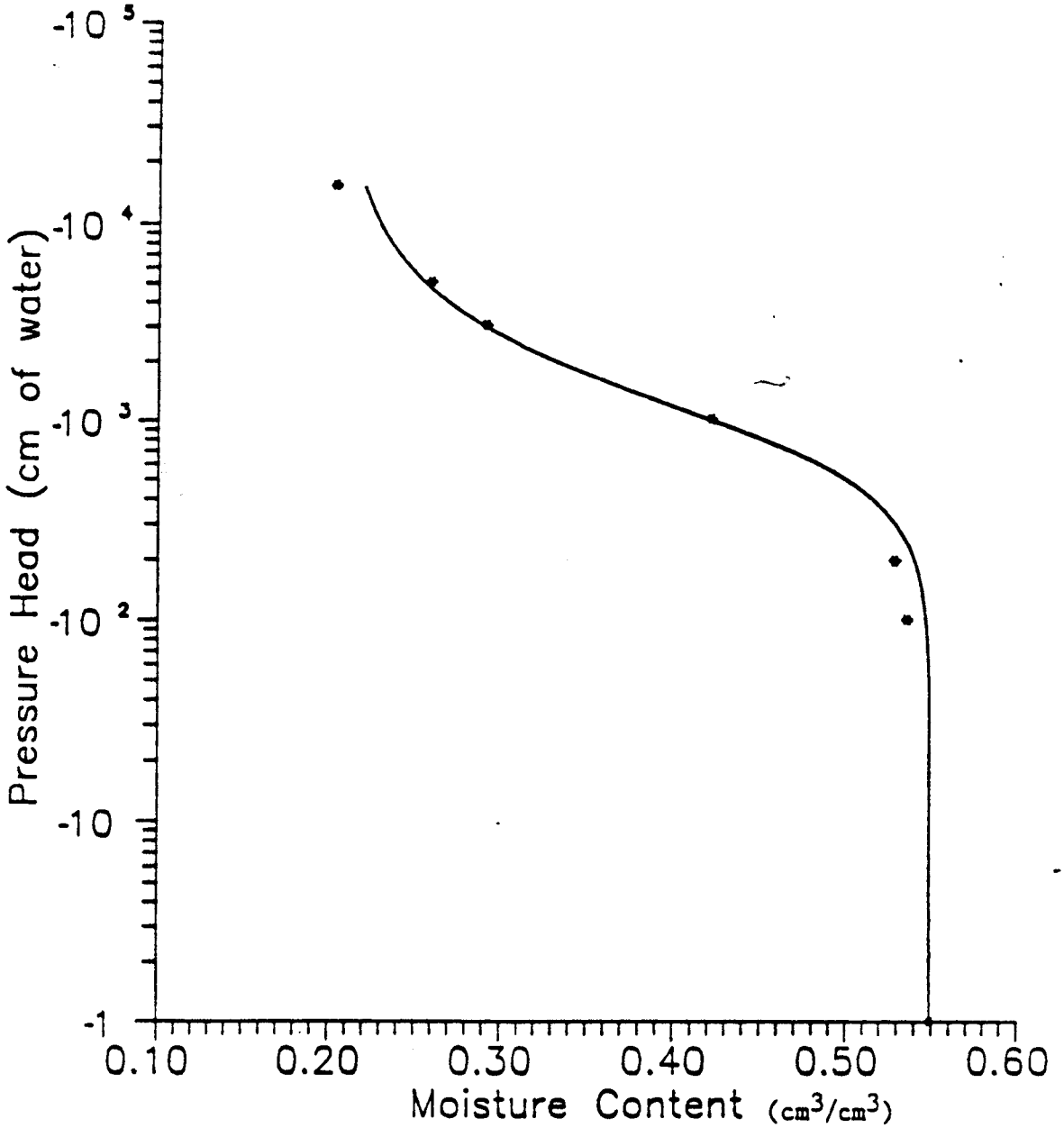


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 16-17				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 21-22
RING NUMBER: F
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 194.0 (g)
TARE RING: 73.8 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 83.0 (g)
SATURATED MOISTURE CONTENT: 56.2 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 37.2 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/23	1025	0.0	34.5	--	--	56.2	0.0
11/25	800	97.0	34.4	0.1	0.1	56.1	0.0
11/30	810	198.0	37.6	-3.2	-3.1	60.9	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME:	LOS ALAMOS
JOB NUMBER:	87-L-070
SAMPLE NUMBER:	21-22
RING NUMBER:	F
DEPTH:	unknown
SAMPLE VOLUME:	66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION (WITH CAP AND RING):	194.0 (g)
TARE RING:	73.8 (g)
TARE CAP:	0.0 (g)
DRY WEIGHT OF SAMPLE:	83.0 (g)
SATURATED MOISTURE CONTENT:	56.2 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE:	32.7 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP:	189.5 (g)
FINAL TENSION ON HANGING COLUMN:	198.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	189.5	--	--	--
12/2	740	1.0	175.4	14.1	14.1	28.1
12/6	830	3.0	171.9	3.5	17.6	22.8
12/8	840	5.0	169.7	2.2	19.8	19.5
12/13	1710	15.0	165.0	4.7	24.5	12.4

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

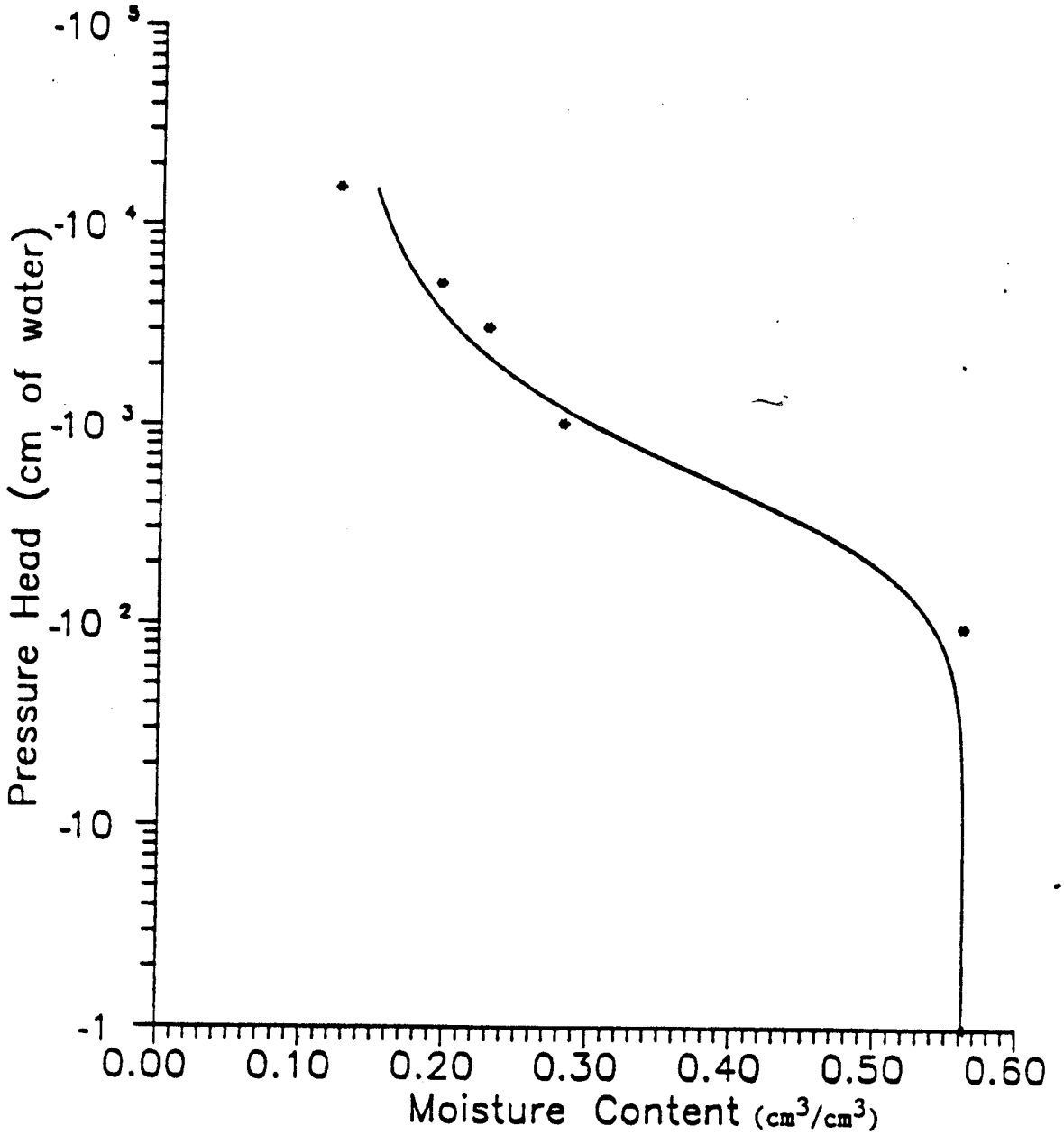


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 21-22				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 25-26
RING NUMBER: C
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 198.3 (g)
TARE RING: 72.8 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 91.1 (g)
SATURATED MOISTURE CONTENT: 52.0 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 34.4 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/23	1025	0.0	35.6	--	--	52.0	0.0
11/25	800	98.5	35.2	0.4	0.4	51.4	0.0
11/30	810	203.0	36.5	-1.3	-0.9	53.3	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 25-26
RING NUMBER: C
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 198.3 (g)
TARE RING: 72.8 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 91.1 (g)
SATURATED MOISTURE CONTENT: 52.0 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 30.9 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 194.8 (g)
FINAL TENSION ON HANGING COLUMN: 203.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	194.8	--	--	--
12/2	740	1.0	179.3	15.5	15.5	23.3
12/6	830	3.0	178.0	1.3	16.8	21.3
12/8	840	5.0	174.9	3.1	19.9	16.6
12/13	1710	15.0	170.5	4.4	24.3	10.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

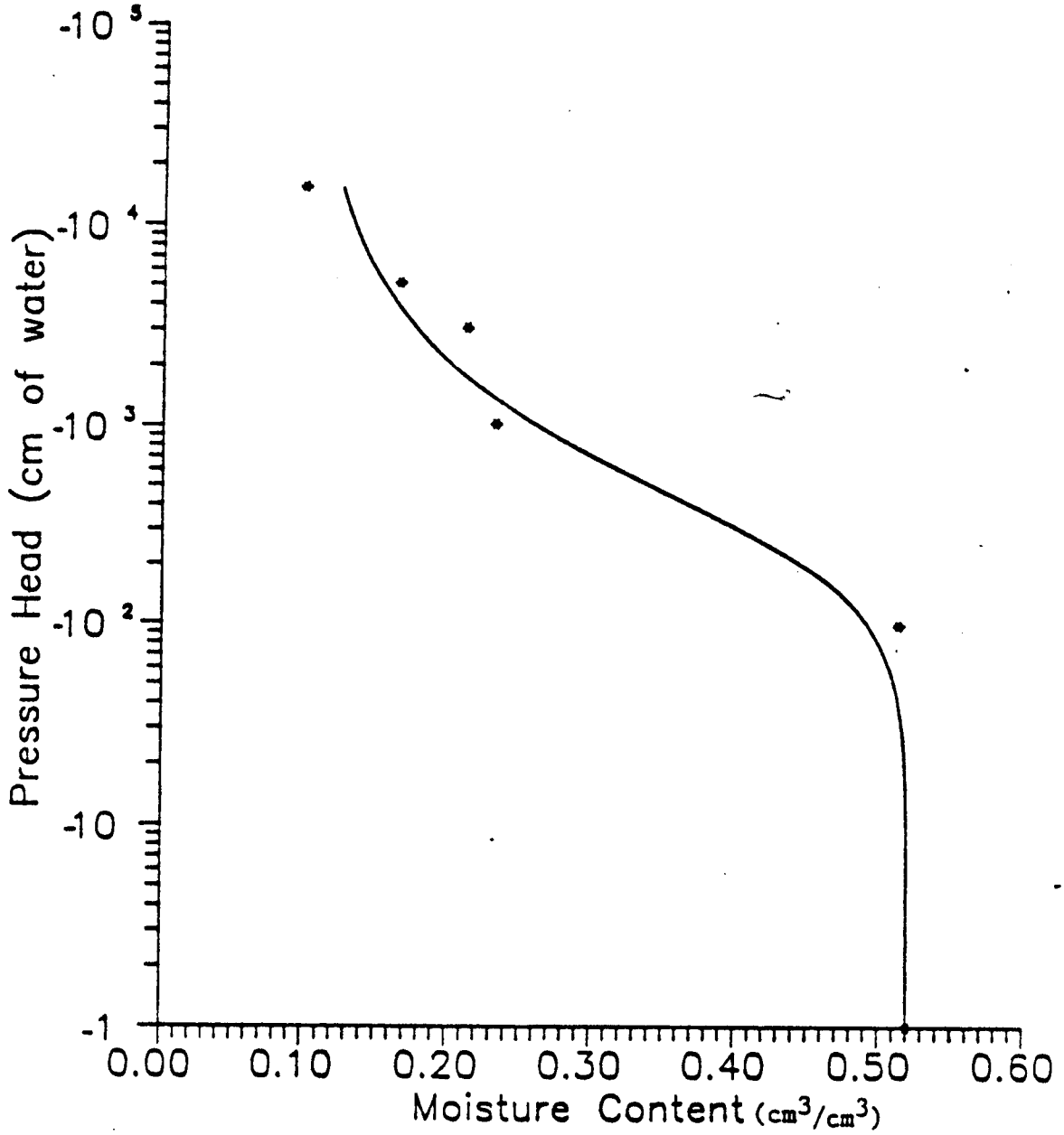


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 25-26				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 35-36
RING NUMBER: G
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 208.4 (g)
TARE RING: 73.3 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 106.8 (g)
SATURATED MOISTURE CONTENT: 42.8 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 28.3 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/24	1120	0.0	33.0	--	--	42.8	0.0
11/28	1125	96.0	32.1	0.9	0.9	41.4	0.0
11/30	810	205.0	32.1	0.0	0.9	41.4	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 35-36
RING NUMBER: G
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 208.4 (g)
TARE RING: 73.3 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 106.8 (g)
SATURATED MOISTURE CONTENT: 42.8 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 27.0 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 207.1 (g)
FINAL TENSION ON HANGING COLUMN: 205.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	207.1	--	--	--
12/2	740	1.0	200.1	7.0	7.0	30.2
12/6	830	3.0	189.5	10.6	17.6	14.2
12/8	840	5.0	189.0	0.5	18.1	13.4
12/13	1715	15.0	186.3	2.7	20.8	9.4

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

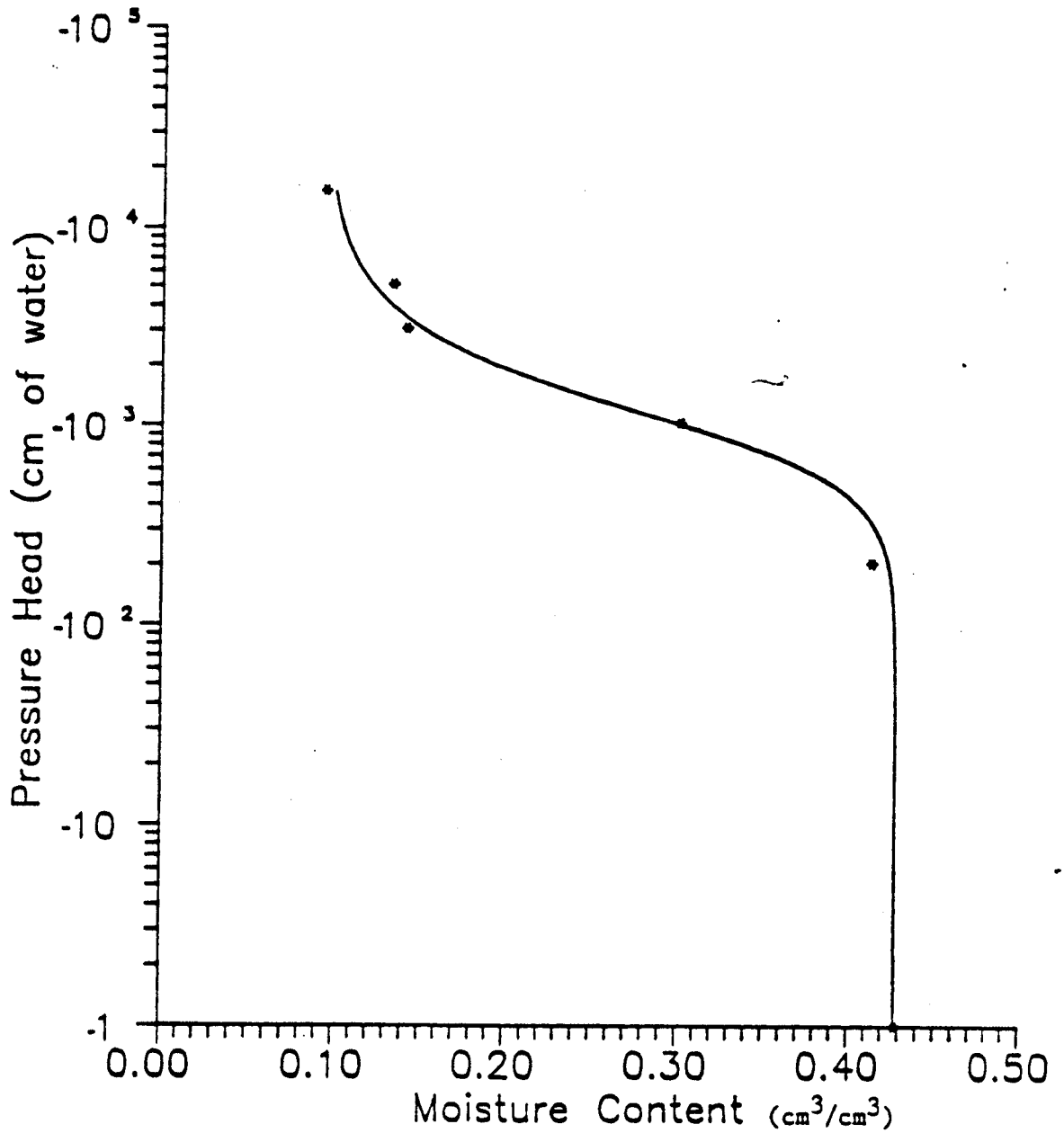


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 35-36				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 42-43
RING NUMBER: 4
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 208.0 (g)
TARE RING: 72.6 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 107.4 (g)
SATURATED MOISTURE CONTENT: 42.3 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 28.0 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/24	1120	0.0	32.7	--	--	42.3	0.0
11/28	1125	100.5	32.7	0.0	0.0	42.3	0.0
11/30	810	209.0	32.6	0.1	0.1	42.2	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 42-43
RING NUMBER: 4
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 208.0 (g)
TARE RING: 72.6 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 107.4 (g)
SATURATED MOISTURE CONTENT: 42.3 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 26.4 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 206.4 (g)
FINAL TENSION ON HANGING COLUMN: 209.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	206.4	--	--	--
12/2	740	1.0	202.2	4.2	4.2	33.5
12/6	830	3.0	200.2	2.0	6.2	30.5
12/8	840	5.0	199.1	1.1.	7.3	28.9
12/13	1720	15.0	195.1	4.0	11.3	22.8

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

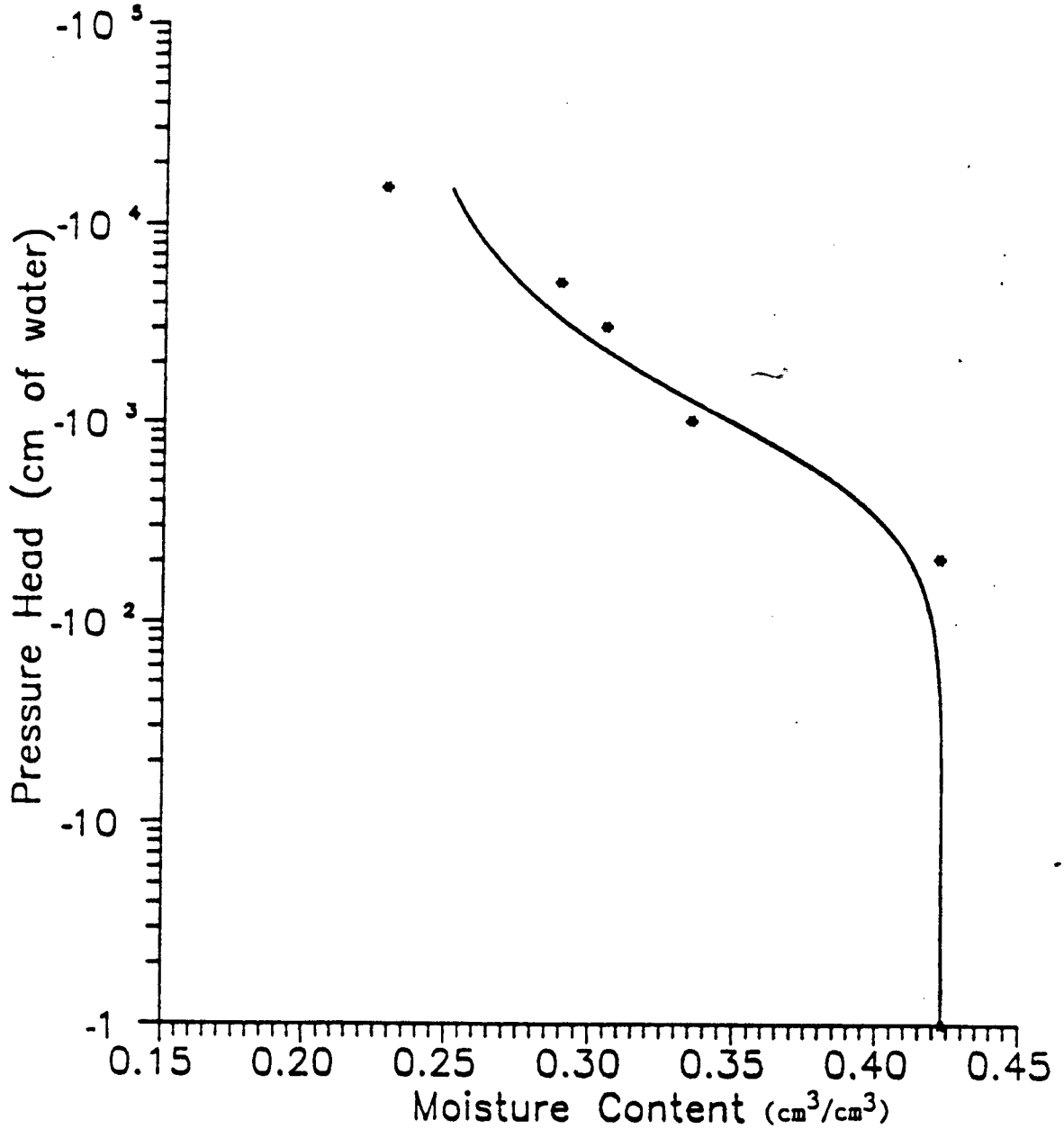


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 42-43				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 61-62
RING NUMBER: A4
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 210.1 (g)
TARE RING: 73.4 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 112.6 (g)
SATURATED MOISTURE CONTENT: 36.4 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 24.1 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/24	1120	0.0	36.1	--	--	36.4	0.0
11/28	1125	95.5	35.0	1.1	1.1	34.8	0.0
11/30	810	202.0	33.6	1.4	2.5	32.6	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 61-62
RING NUMBER: A4
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 210.1 (g)
TARE RING: 73.4 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 112.6 (g)
SATURATED MOISTURE CONTENT: 36.4 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 20.8 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 206.8 (g)
FINAL TENSION ON HANGING COLUMN: 202.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	206.8	--	--	--
12/2	740	1.0	198.8	8.0	8.0	19.3
12/6	830	3.0	193.4	5.4	13.4	11.2
12/8	840	5.0	192.9	0.5	13.9	10.4
12/13	1720	15.0	191.2	1.7	15.6	7.9

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

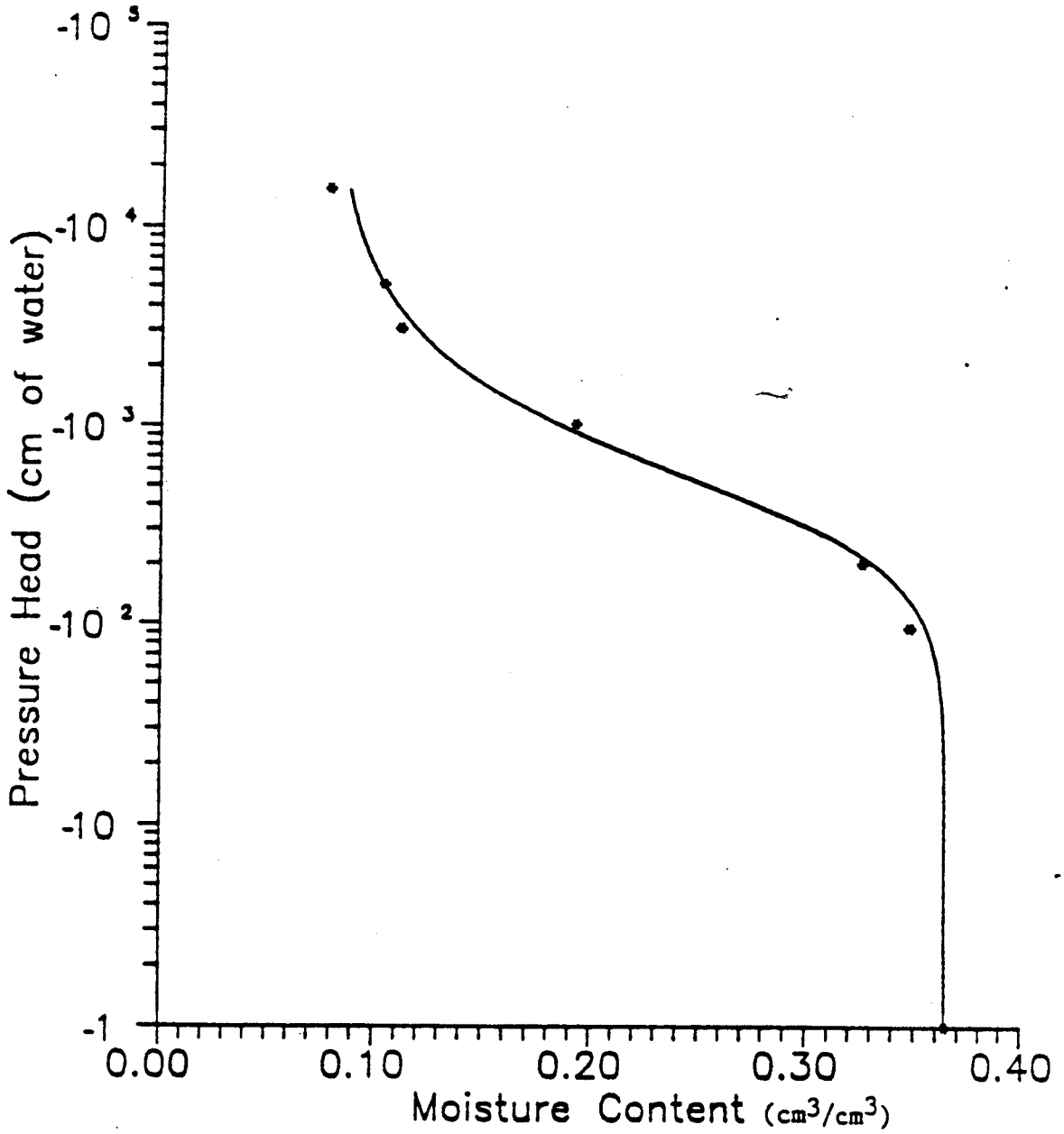


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 61-62				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 75-76
RING NUMBER: 19
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 204.5 (g)
TARE RING: 73.4 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 103.6 (g)
SATURATED MOISTURE CONTENT: 41.6 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 27.5 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/24	1120	0.0	34.4	--	--	41.6	0.0
11/28	1125	95.0	32.0	2.4	2.4	37.9	0.0
11/30	810	199.0	28.8	3.2	5.6	33.1	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Staller
CALCULATION MADE BY: S. Staller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 75-76
RING NUMBER: 19
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 204.5 (g)
TARE RING: 73.4 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 103.6 (g)
SATURATED MOISTURE CONTENT: 41.6 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 21.9 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 198.9 (g)
FINAL TENSION ON HANGING COLUMN: 199.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	198.9	--	--	--
12/2	740	1.0	192.9	6.0	6.0	24.0
12/6	830	3.0	185.3	7.6	13.6	12.5
12/8	840	5.0	184.7	0.6	14.2	11.6
12/13	1725	15.0	182.5	2.2	16.4	8.3

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

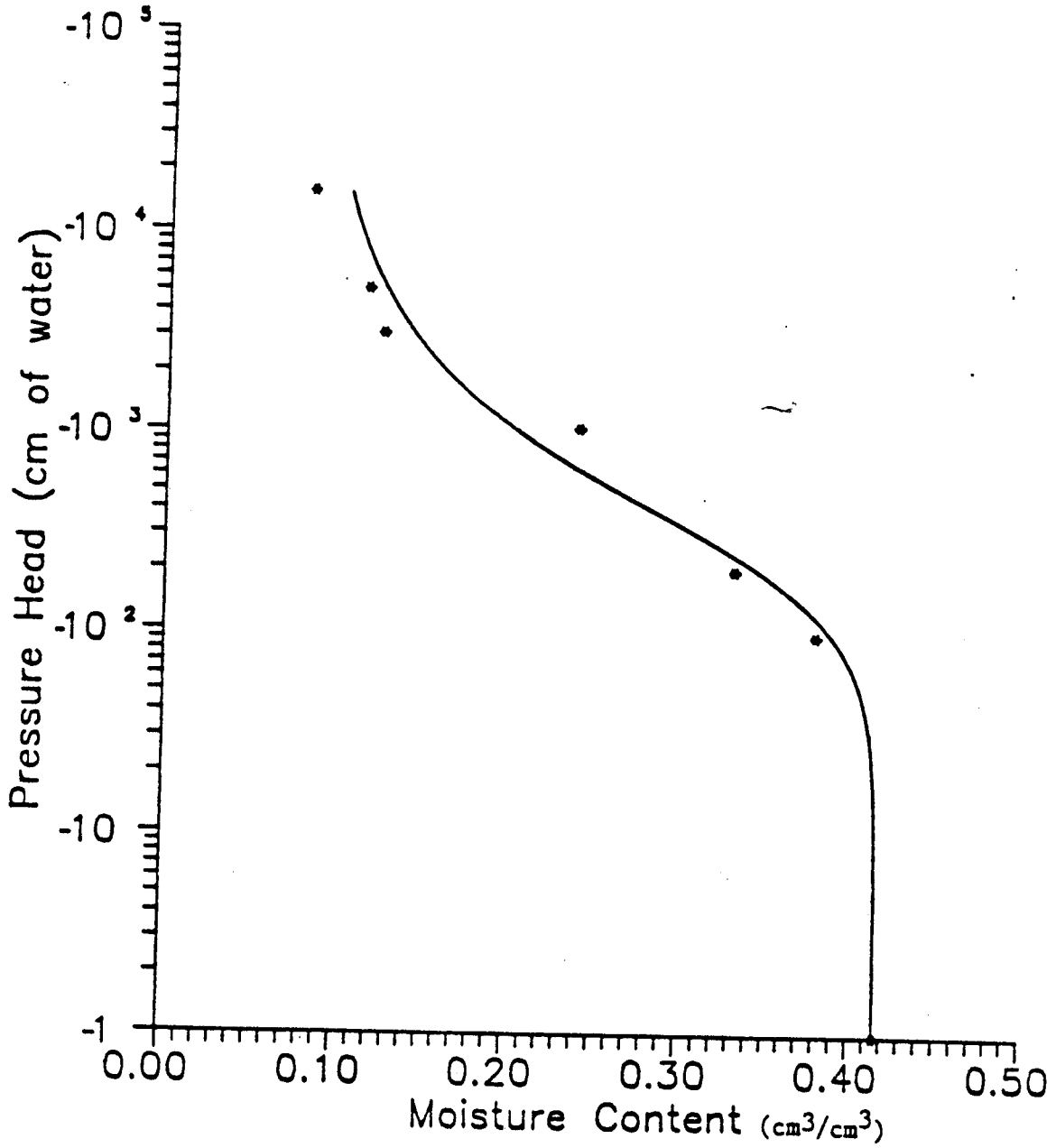


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 75-76				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 80-81
RING NUMBER: 18
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 215.1 (g)
TARE RING: 73.1 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 119.1 (g)
SATURATED MOISTURE CONTENT: 34.6 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 22.9 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/24	1120	0.0	34.0	--	--	34.6	0.0
11/28	1125	98.5	34.1	-0.1	-0.1	34.8	0.0
11/30	810	205.0	38.1	-4.0	-4.1	40.8	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME:	LOS ALAMOS
JOB NUMBER:	87-L-070
SAMPLE NUMBER:	80-81
RING NUMBER:	18
DEPTH:	unknown
SAMPLE VOLUME:	66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION (WITH CAP AND RING):	215.1 (g)
TARE RING:	73.1 (g)
TARE CAP:	0.0 (g)
DRY WEIGHT OF SAMPLE:	119.1 (g)
SATURATED MOISTURE CONTENT:	34.6 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE:	21.4 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP:	213.6 (g)
FINAL TENSION ON HANGING COLUMN:	205.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	213.6	--	--	--
12/2	740	1.0	210.4	3.2	3.2	27.5
12/6	830	3.0	204.3	6.1	9.3	18.3
12/8	840	5.0	203.5	0.8	10.1	17.1
12/13	1725	15.0	199.3	4.2	14.3	10.7

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

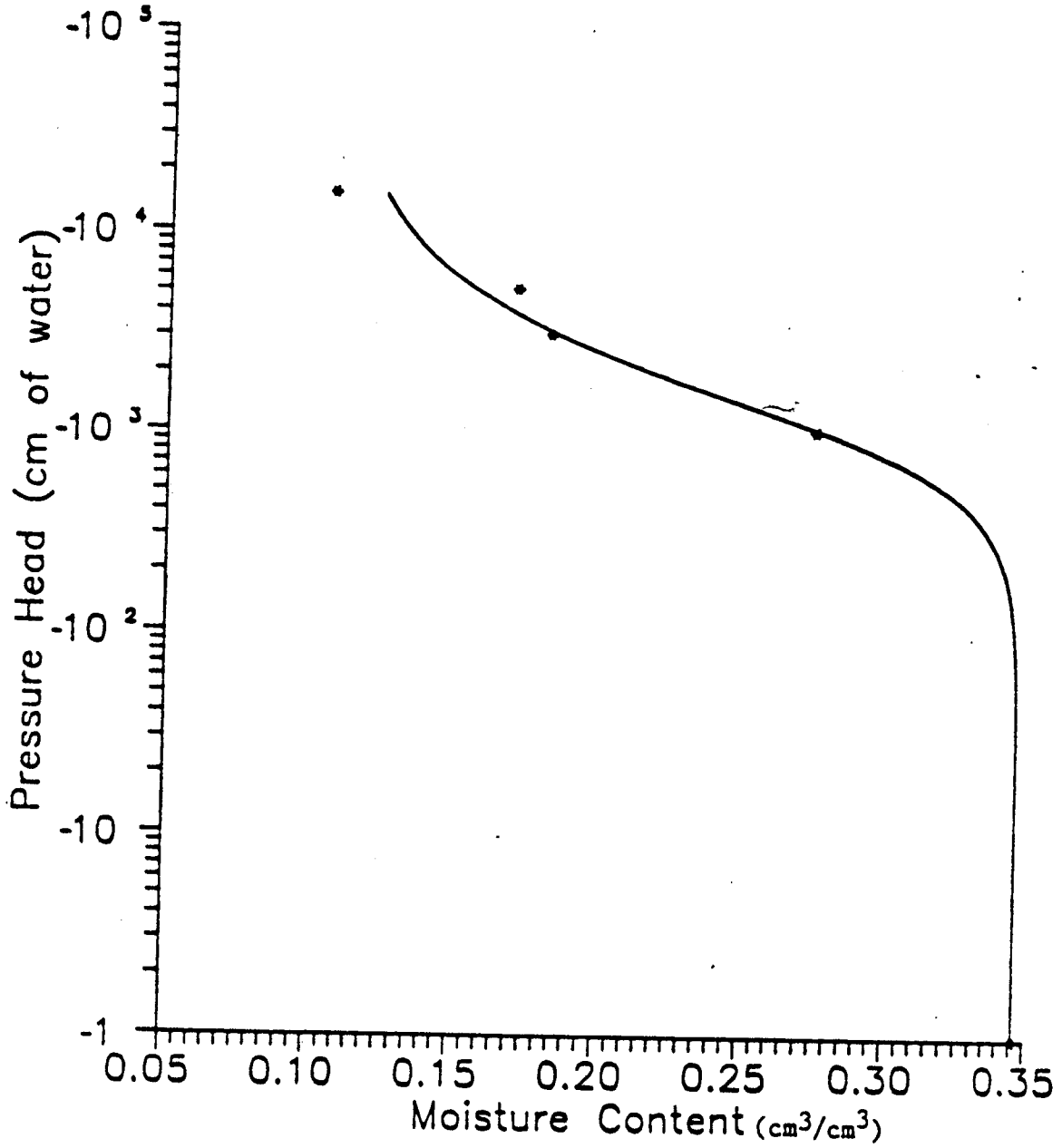


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 80-81				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

INITIAL MOISTURE CONTENT, DRY BULK DENSITY AND POROSITY

Table 6. Summary of Initial Moisture Content, Dry Bulk Density and Porosity

Sample No.	Initial Moisture Content Gravimetric (g/g)	Initial Moisture Content Volumetric (cm^3/cm^3)	Dry Bulk Density (g/cc)	Porosity* (% vol)
7-8	28.30	35.36	1.25	51.8
11-12	14.90	18.74	1.26	56.1
16-17	17.46	22.21	1.27	54.9
21-22	15.90	19.95	1.25	56.2
25-26	13.94	19.19	1.38	52.0
35-36	14.51	23.42	1.61	42.8
42-43	22.53	36.57	1.62	42.3
61-62	11.55	19.64	1.70	36.4
75-76	14.77	23.12	1.57	41.6
80-81	11.17	20.10	1.80	34.6

*Taken as saturated moisture content

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 11-12
RING NUMBER: 22
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 168.9 (g)
TARE WEIGHT, RING: 73.3 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 83.2 (g)
DRY BULK DENSITY: 1.26 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 52.56 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 18.74 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 14.90 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Staller
CALCULATIONS MADE BY: S. Staller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 16-17
RING NUMBER: 2
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 172.0 (g)
TARE WEIGHT, RING: 73.1 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 84.2 (g)
DRY BULK DENSITY: 1.27 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 51.99 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 22.21 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 17.46 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 21-22
RING NUMBER: F
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 170.0 (g)
TARE WEIGHT, RING: 73.8 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 83.0 (g)
DRY BULK DENSITY: 1.25 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 52.67 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 19.95 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 15.90 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 25-26
RING NUMBER: C
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 176.6 (g)
TARE WEIGHT, RING: 72.8 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 91.1 (g)
DRY BULK DENSITY: 1.38 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 48.05 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 19.19 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 13.94 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 35-36
RING NUMBER: G
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 195.6 (g)
TARE WEIGHT, RING: 73.3 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 106.8 (g)
DRY BULK DENSITY: 1.61 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 39.10 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 23.42 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 14.51 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 42-43
RING NUMBER: 4
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 204.2 (g)
TARE WEIGHT, RING: 72.6 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 107.4 (g)
DRY BULK DENSITY: 1.62 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 38.76 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 36.57 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 22.53 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 61-62
RING NUMBER: A4
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 199.0 (g)
TARE WEIGHT, RING: 73.4 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 112.6 (g)
DRY BULK DENSITY: 1.70 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 35.80 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 19.64 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 11.55 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 75-76
RING NUMBER: 19
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 192.3 (g)
TARE WEIGHT, RING: 73.4 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 103.6 (g)
DRY BULK DENSITY: 1.57 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 40.93 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 23.12 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 14.77 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 80-81
RING NUMBER: 18
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 205.5 (g)
TARE WEIGHT, RING: 73.1 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 119.1 (g)
DRY BULK DENSITY: 1.80 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 32.09 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 20.10 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 11.17 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

UNSATURATED HYDRAULIC PROPERTIES

Table 7. Summary of Parameters for Calculating Unsaturated Hydraulic Conductivity

Sample No.	α (cm^{-1})	N (dimensionless)	θ_r (cm^3/cm^3)	θ_s (cm^3/cm^3)	K_s (cm/sec)
7-8	0.00272	2.49734	0.083	0.518	1.58E-04
11-12	0.00231	1.73884	0.199	0.561	2.84E-04
16-17	0.00119	2.04731	0.204	0.549	2.78E-04
21-22	0.00313	1.73941	0.124	0.562	2.00E-04
25-26	0.00371	1.69308	0.100	0.520	9.18E-05
35-36	0.00108	2.44961	0.094	0.428	2.25E-05
42-43	0.00164	1.66466	0.228	0.423	8.57E-05
61-62	0.00263	1.93720	0.079	0.364	5.15E-04
75-76	0.00452	1.65070	0.083	0.416	2.28E-04
80-81	0.00098	1.96205	0.107	0.346	4.41E-05

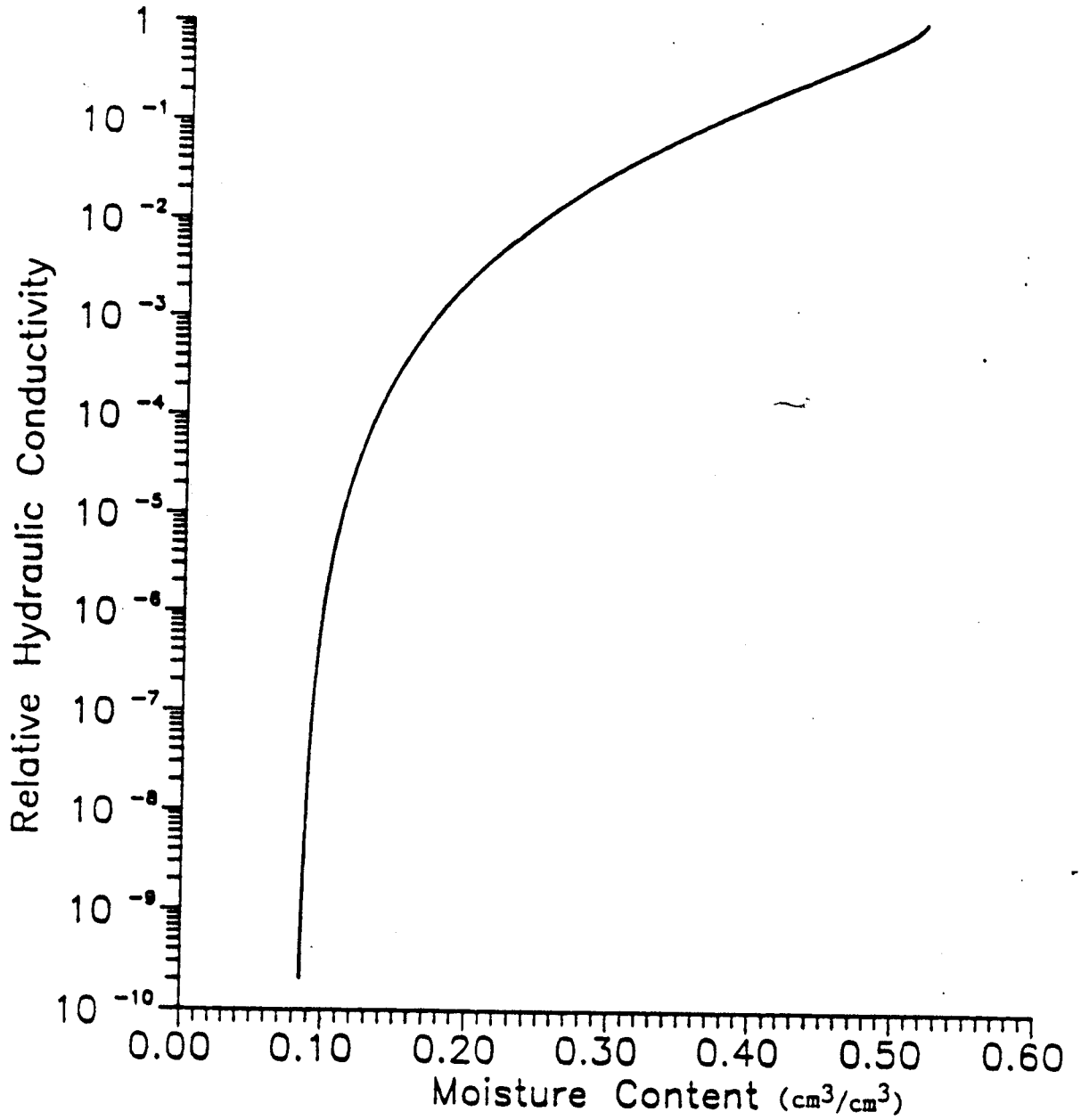


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 7-8				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

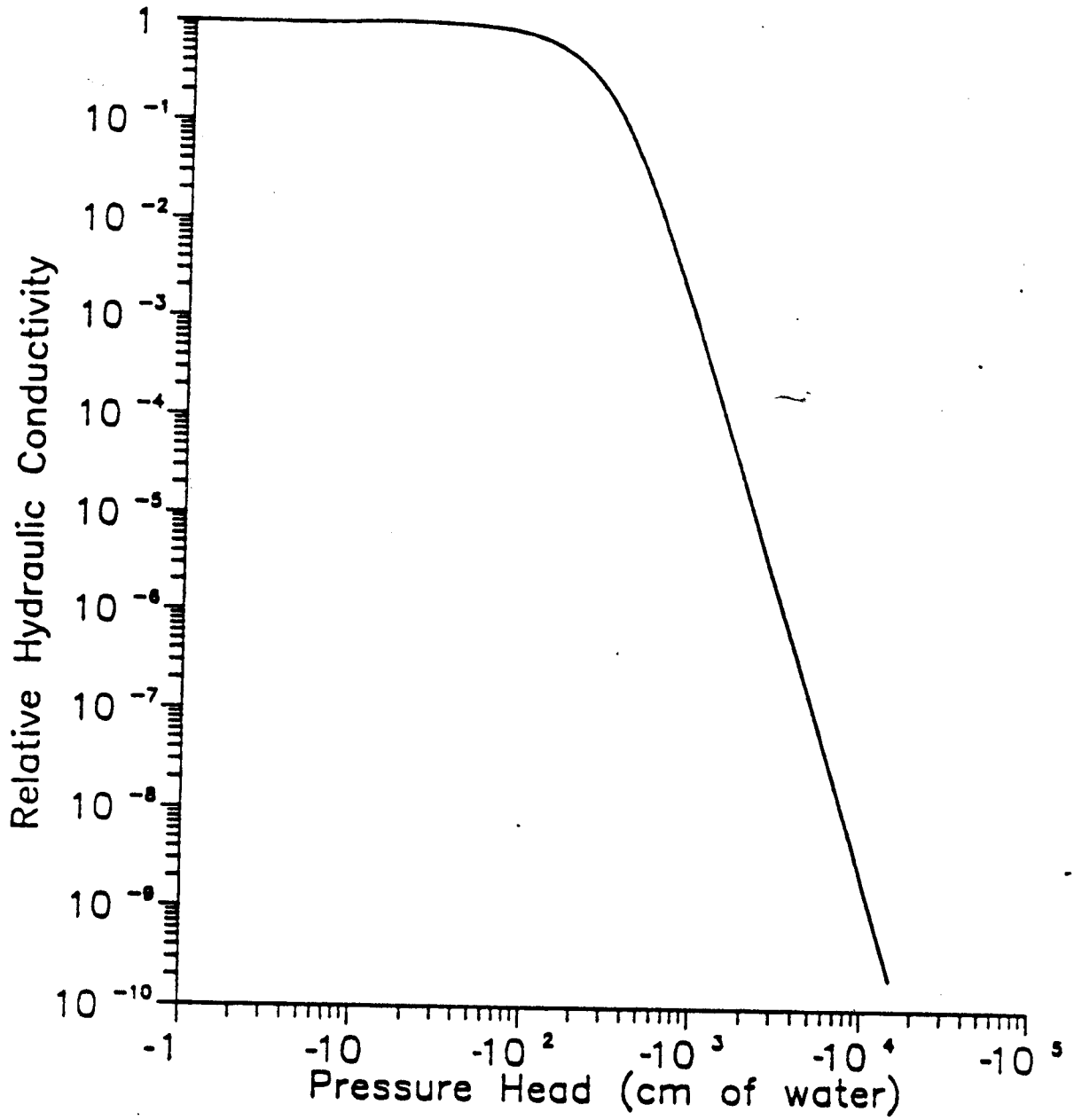


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No.7-8				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

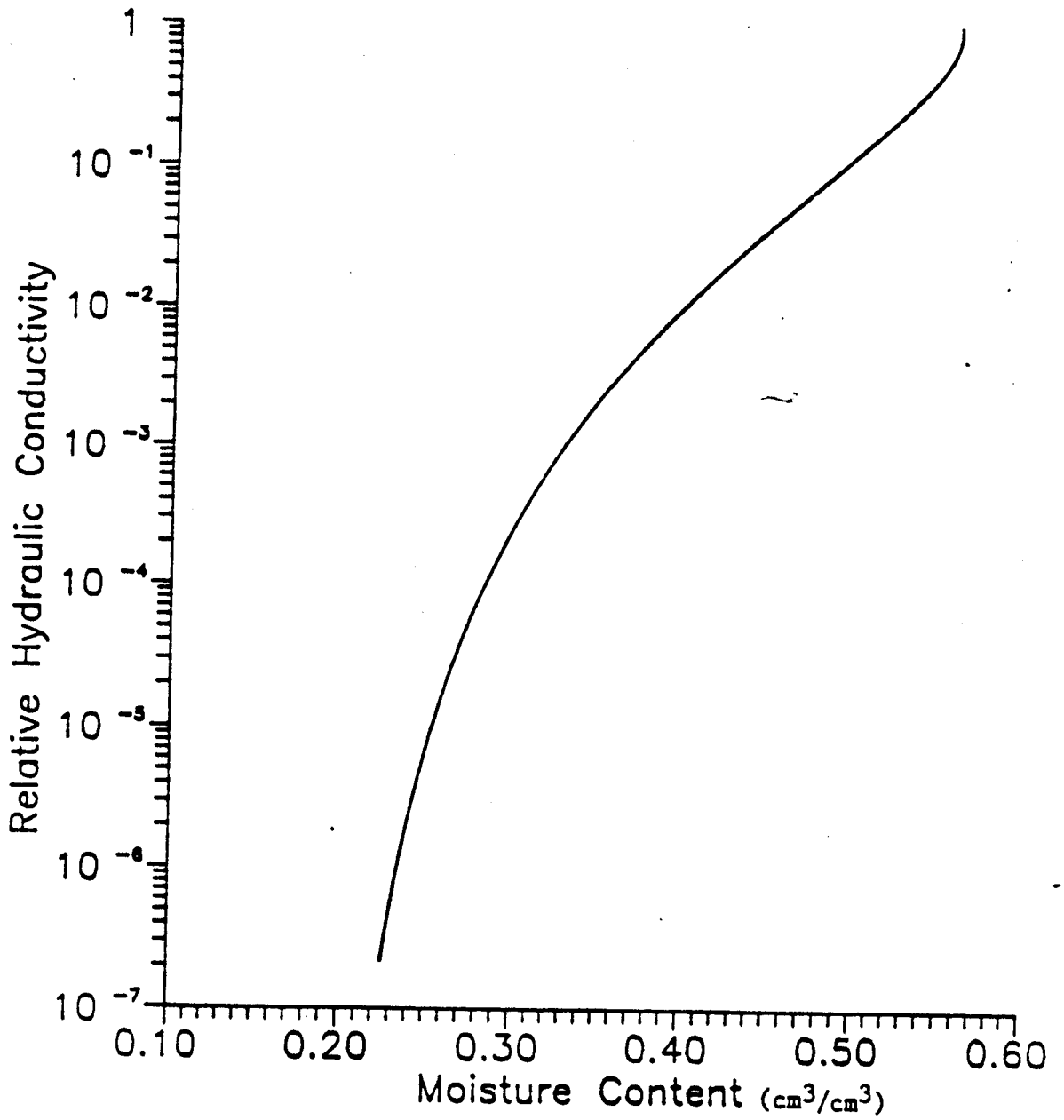


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 11-12				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

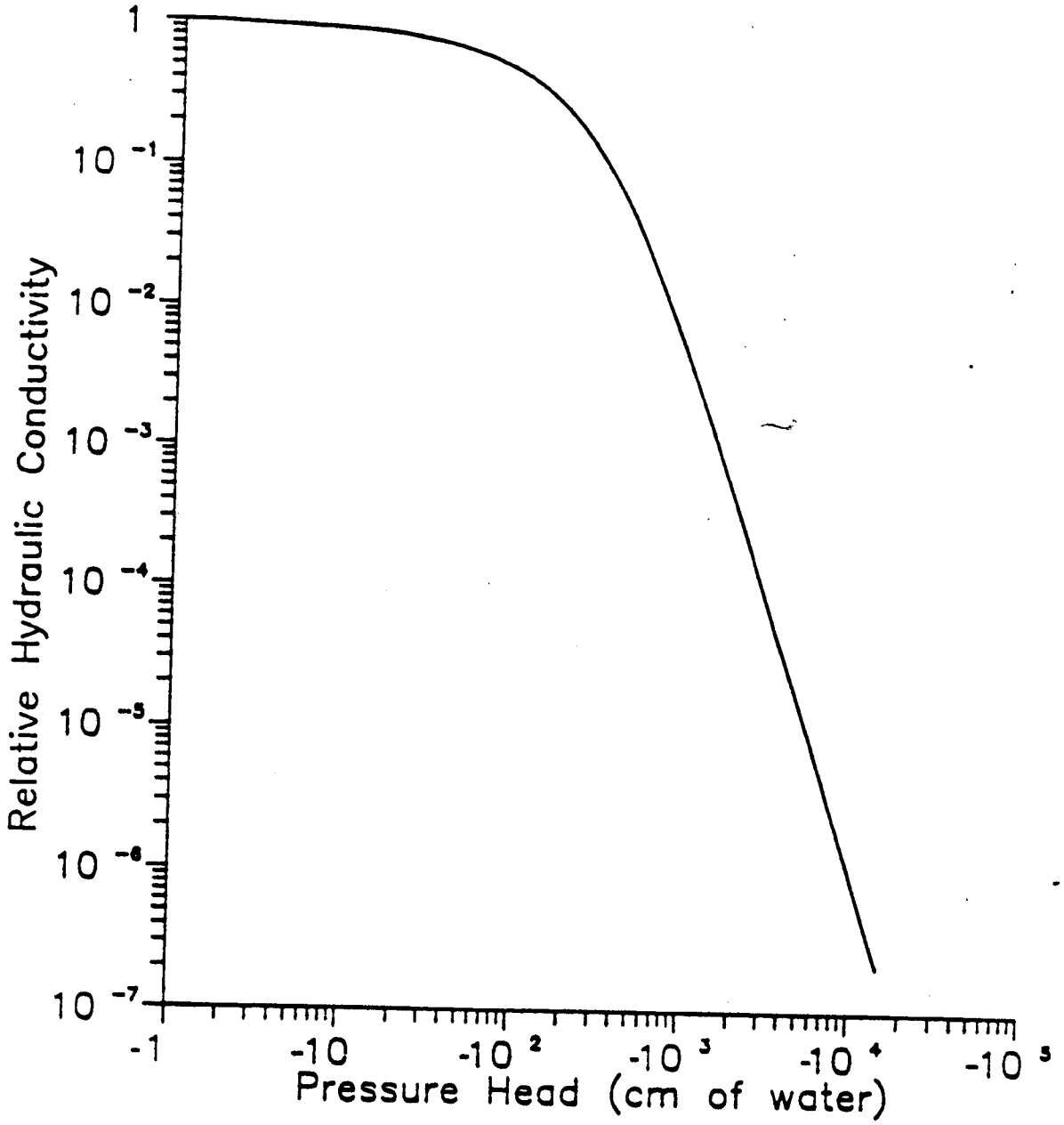


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 11-12				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

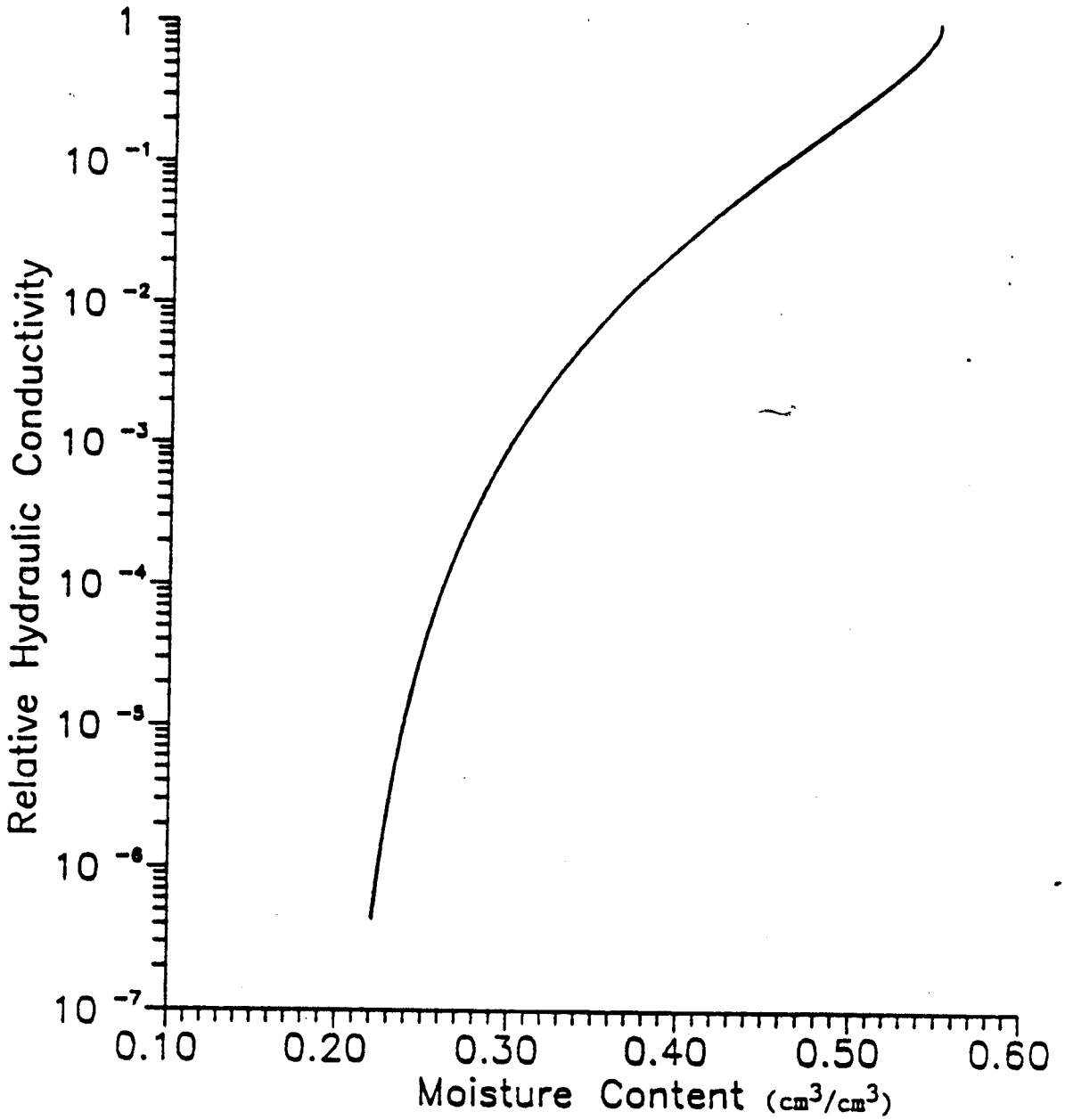


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 16-17				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

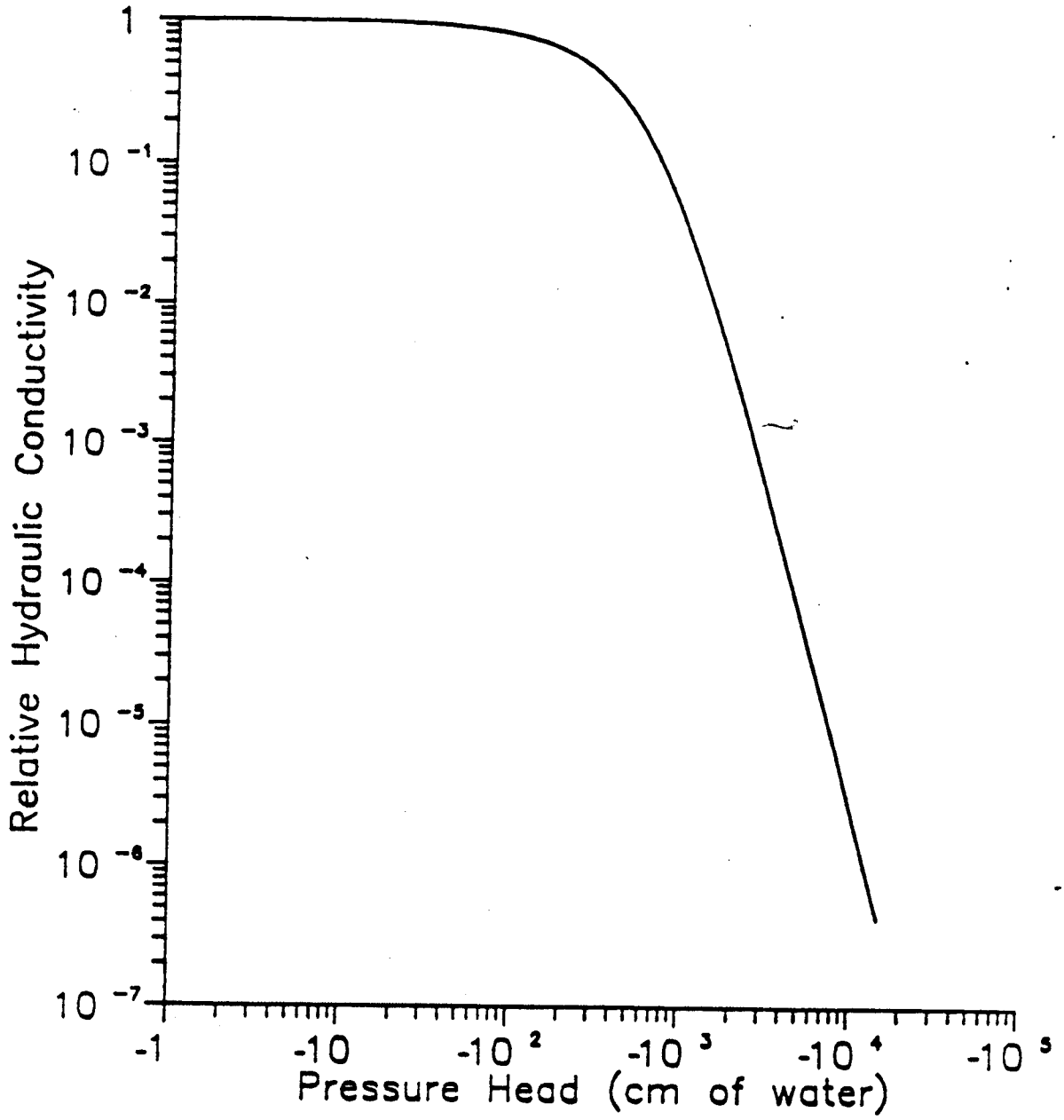


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 16-17				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

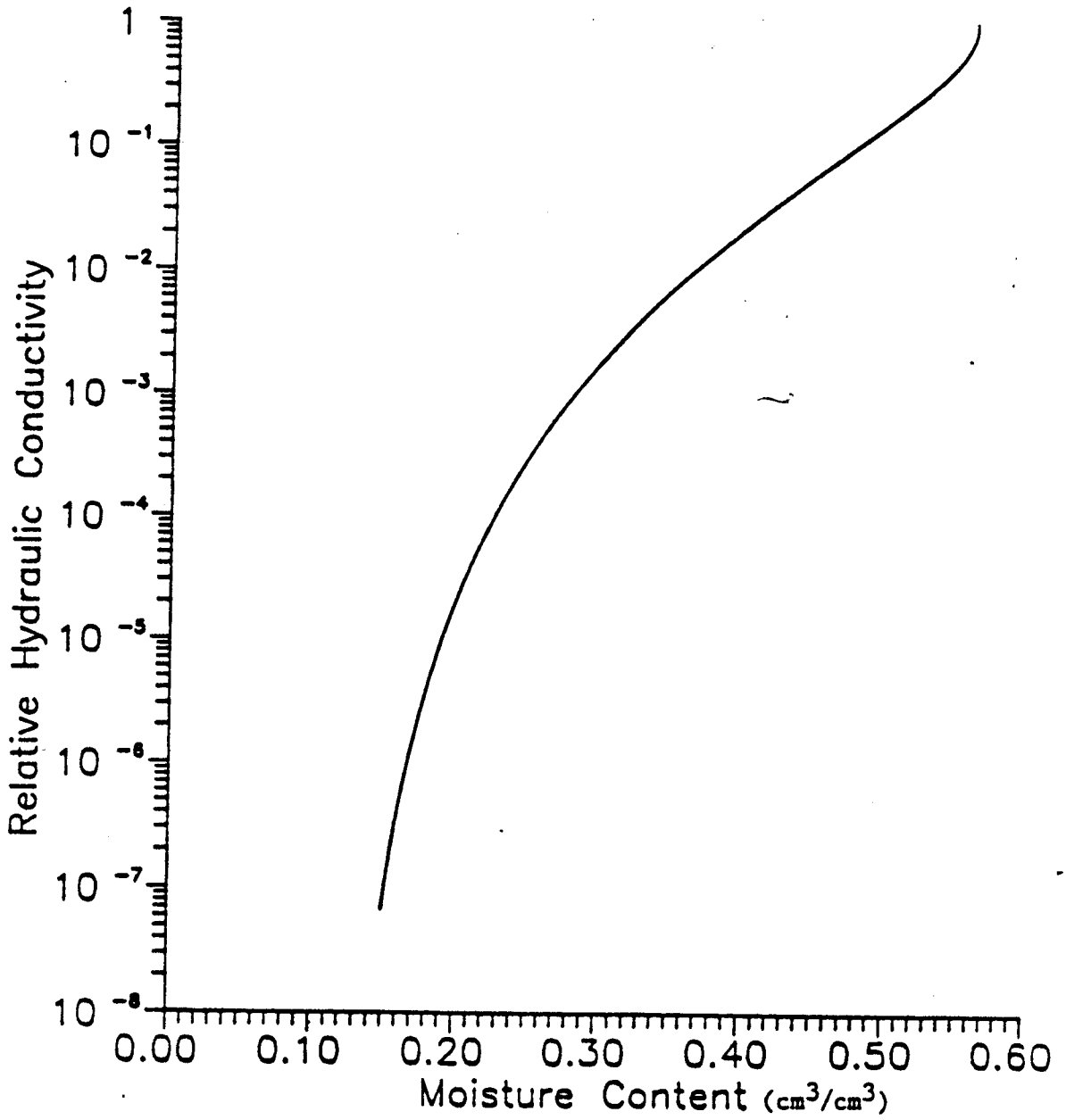


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 21-22				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

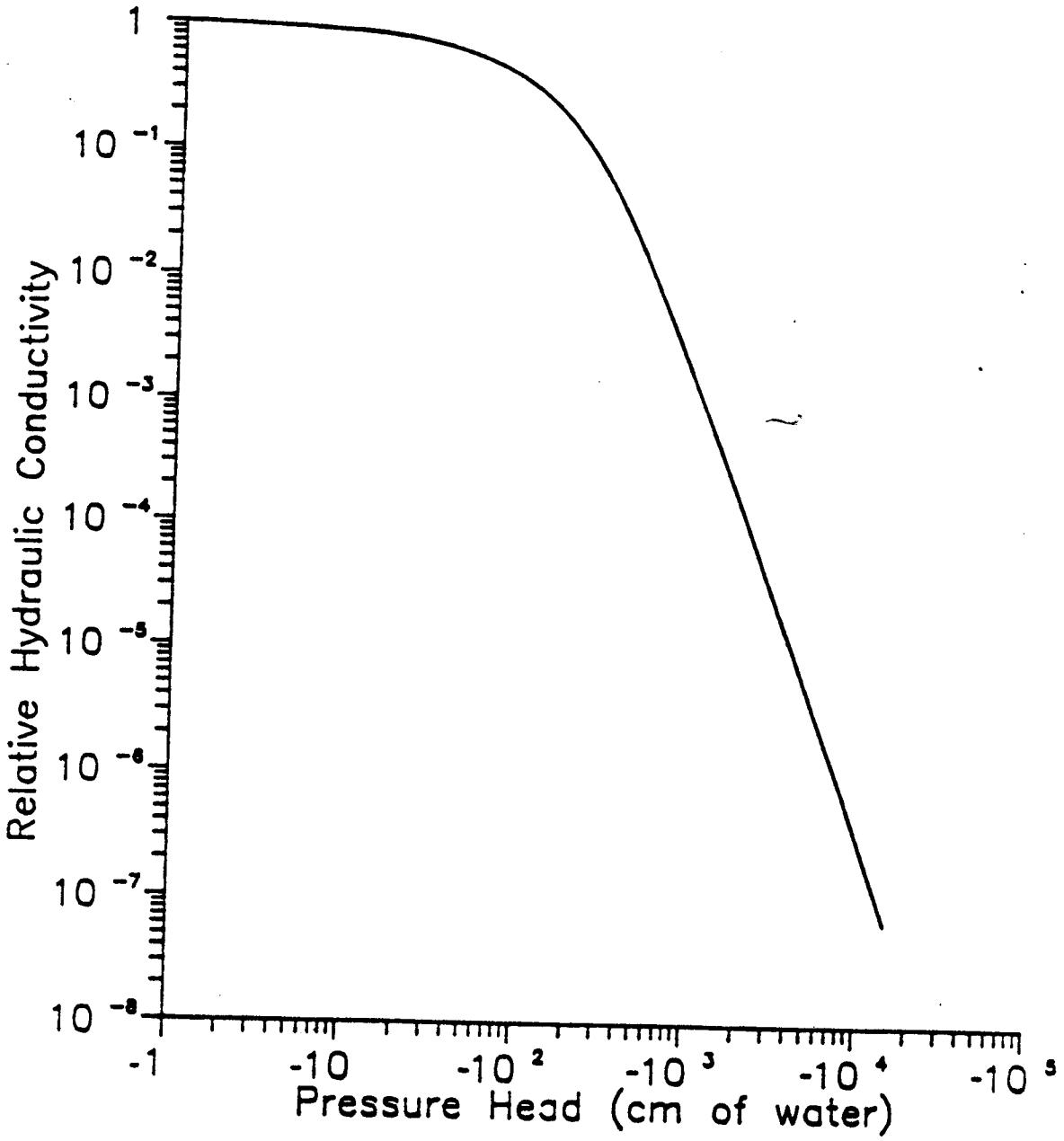


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 21-22				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

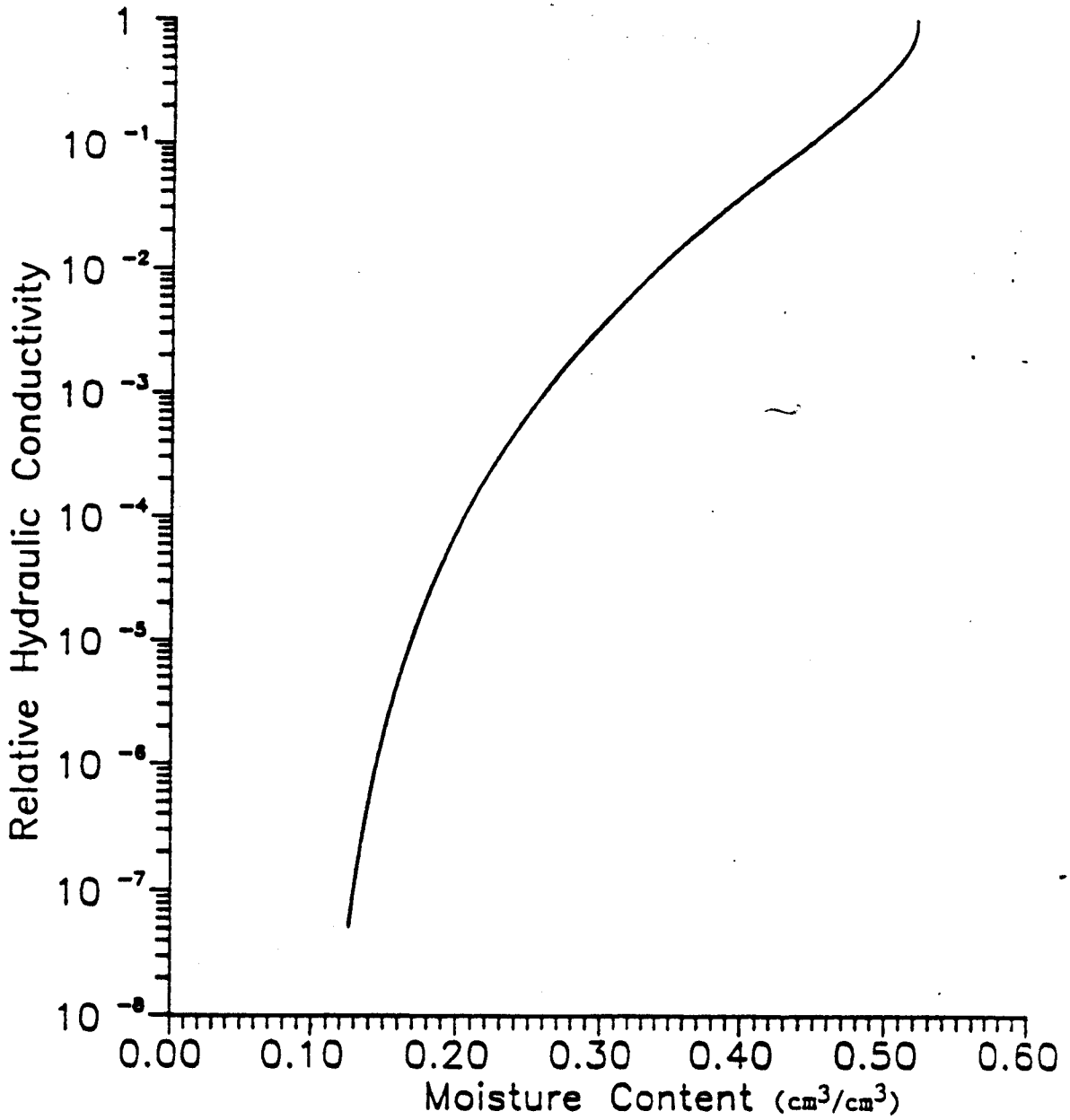


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 25-26				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

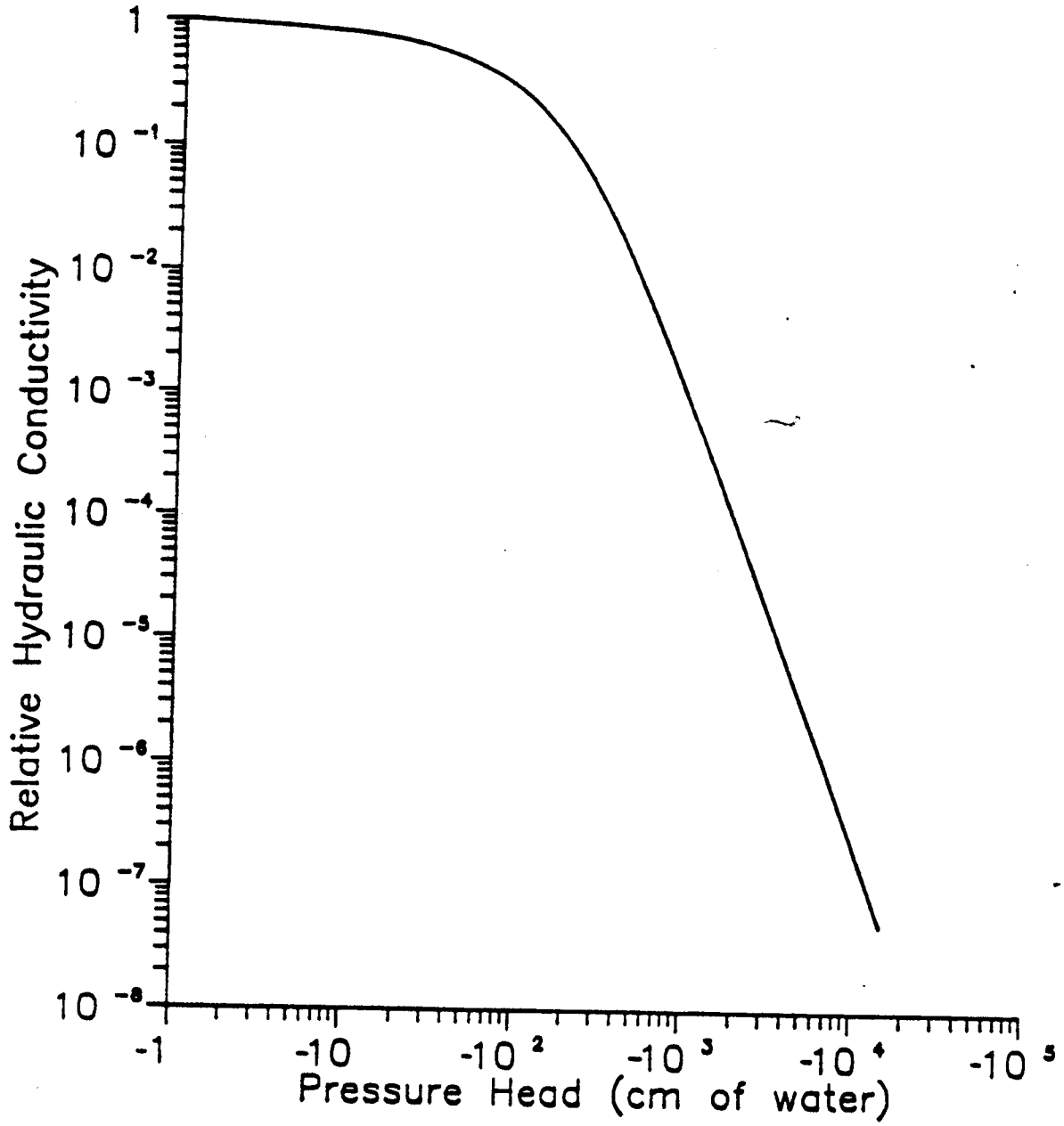


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 25-26				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

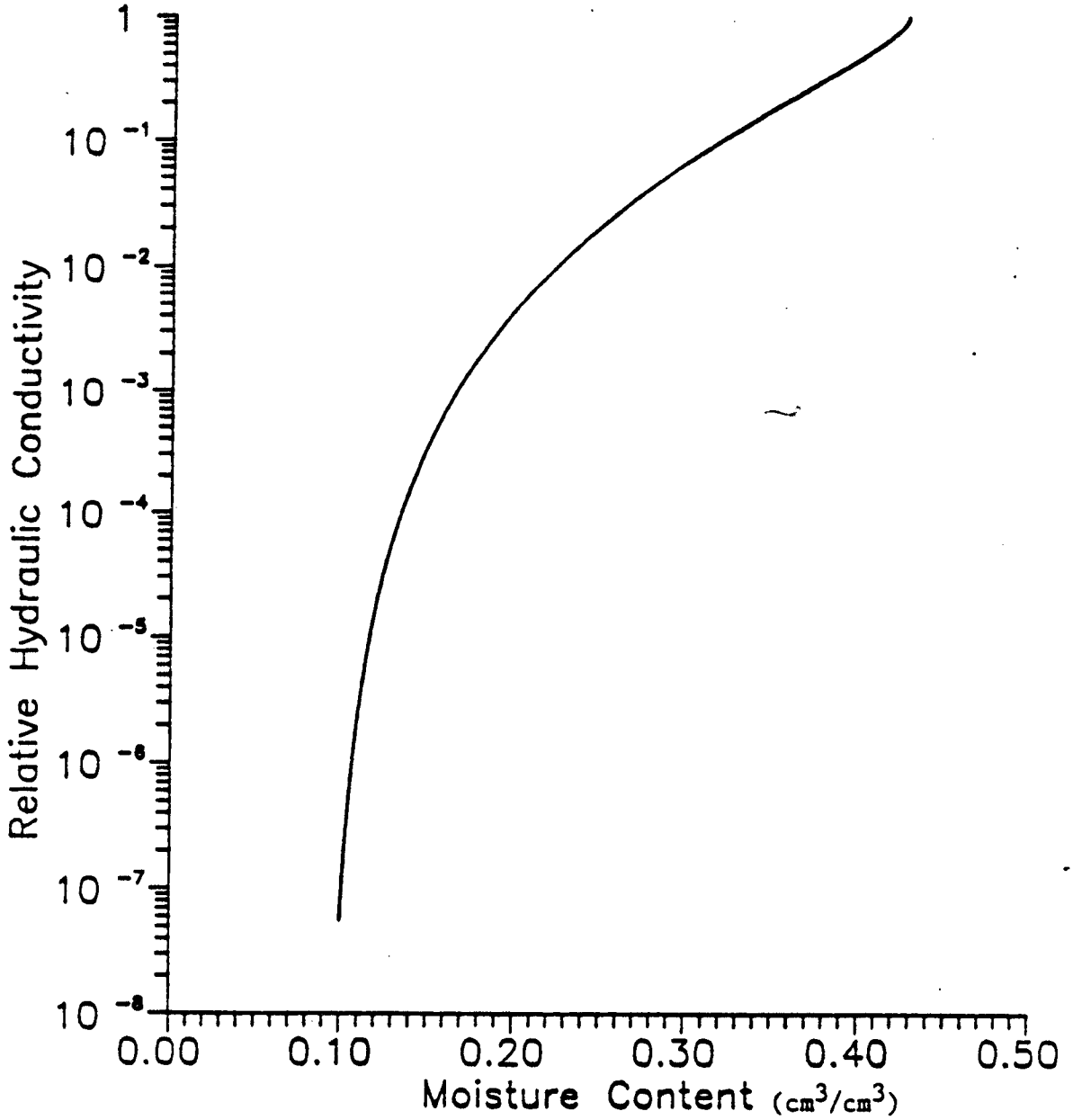


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 35-36				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

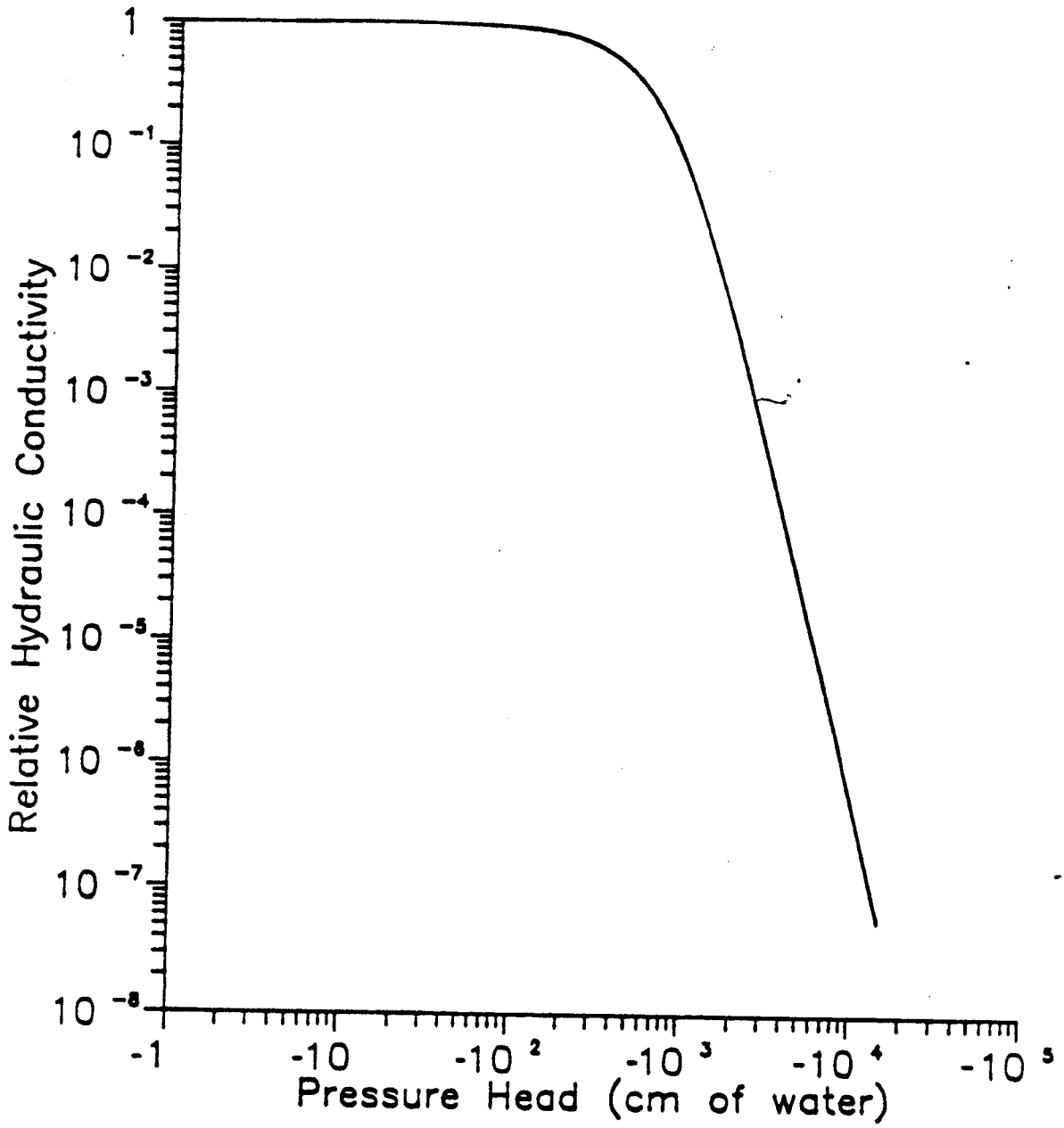


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 35-36				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

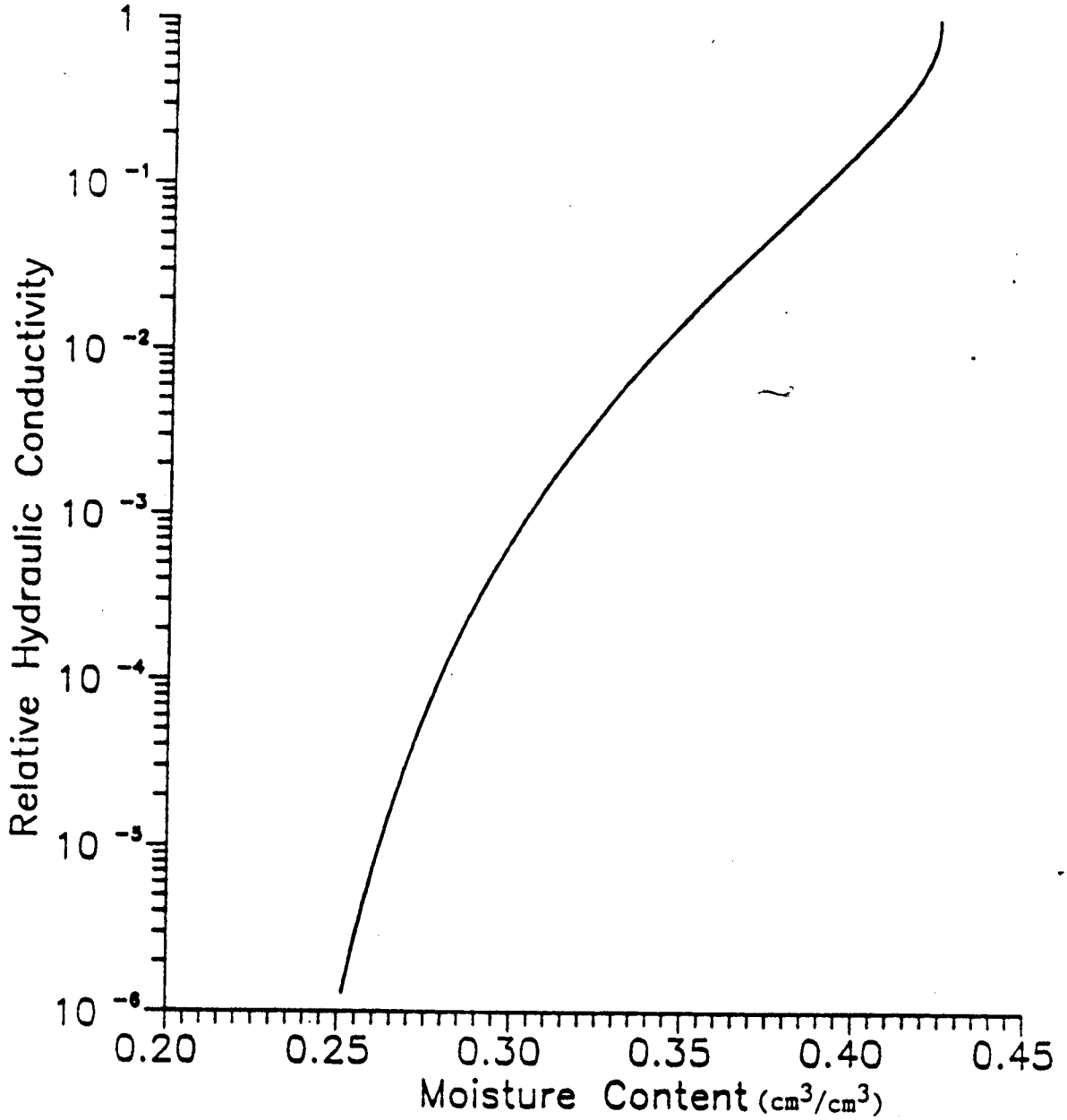


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 42-43				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

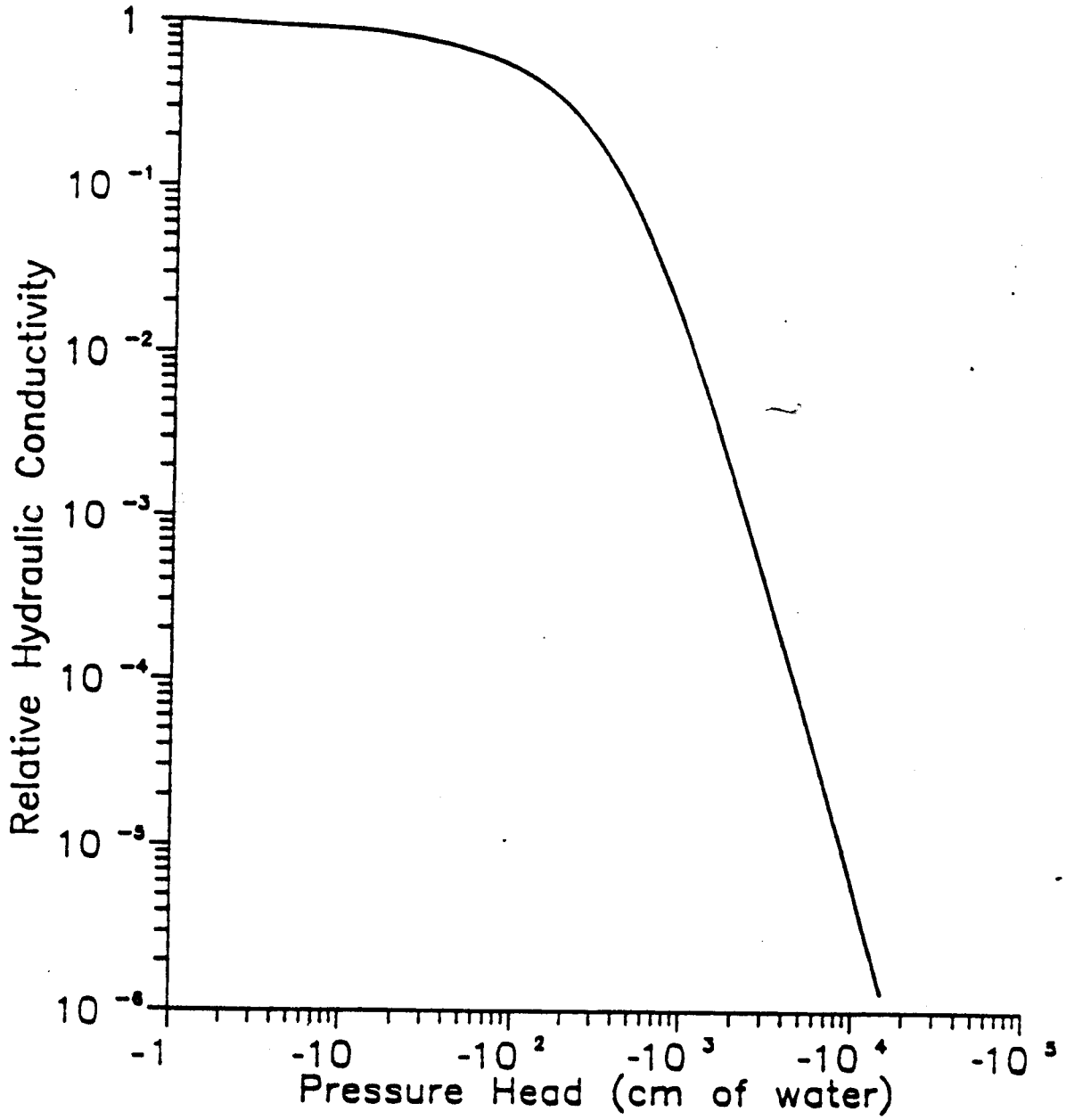


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 42-43				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

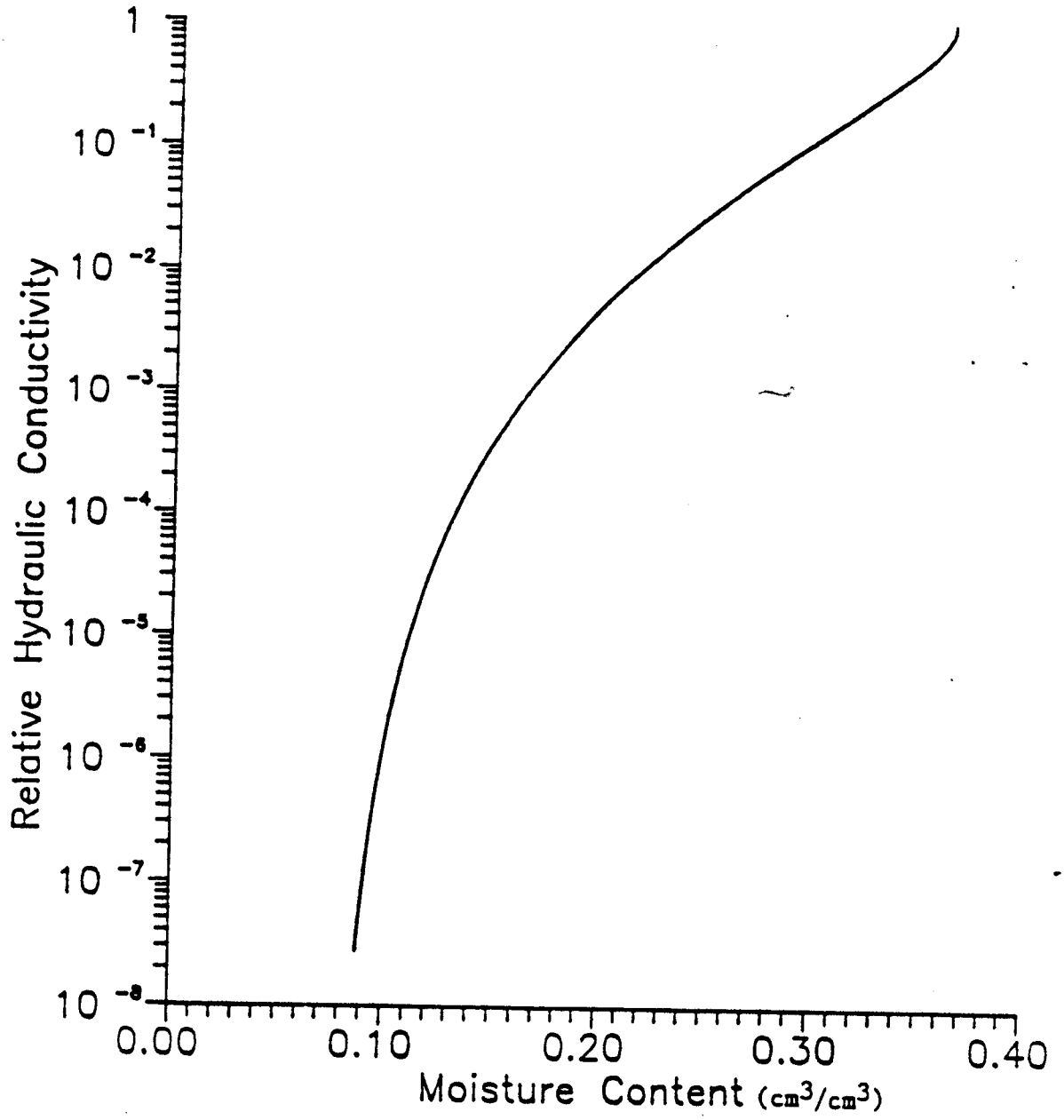


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 61-62				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

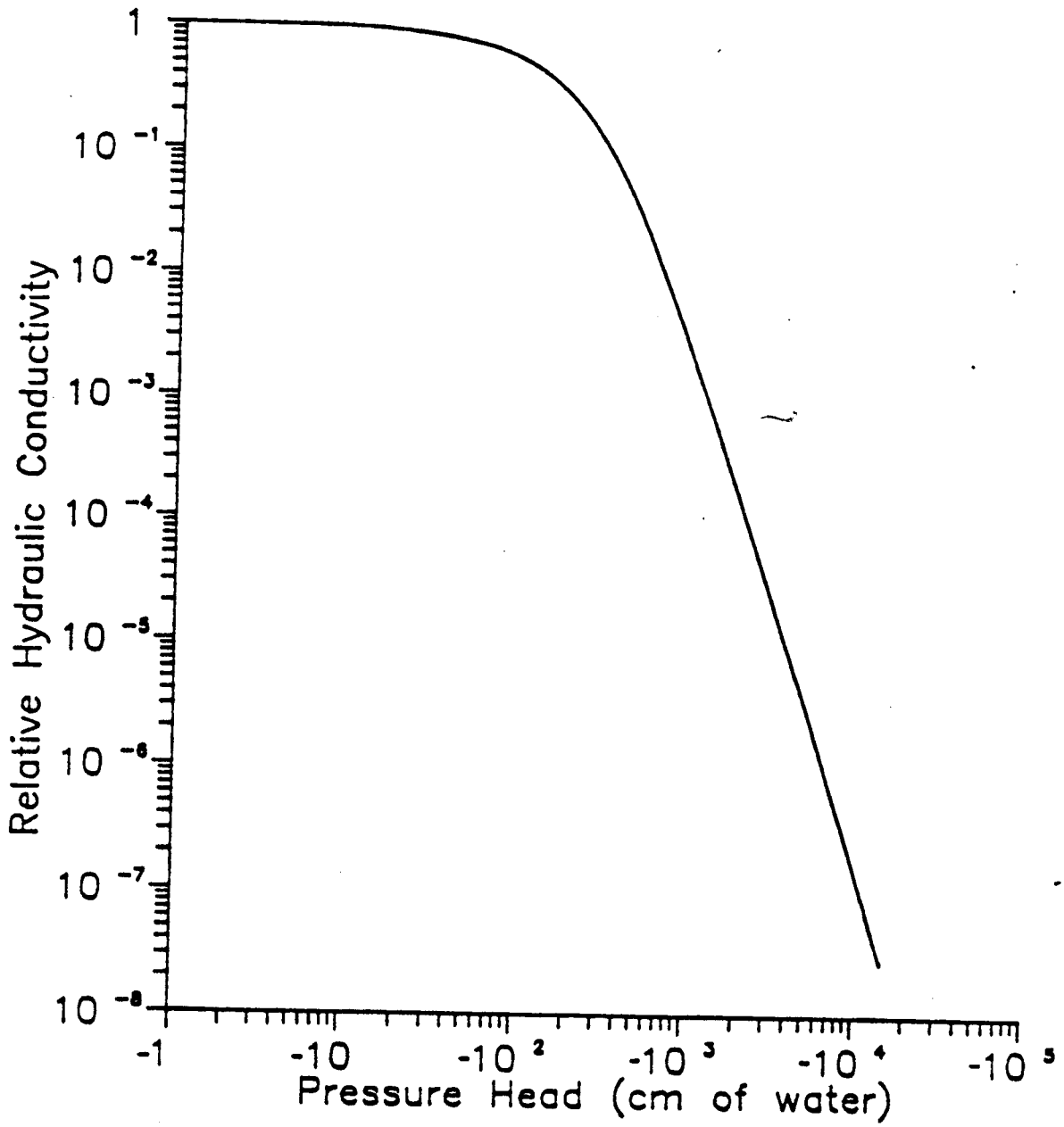


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 61-62				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

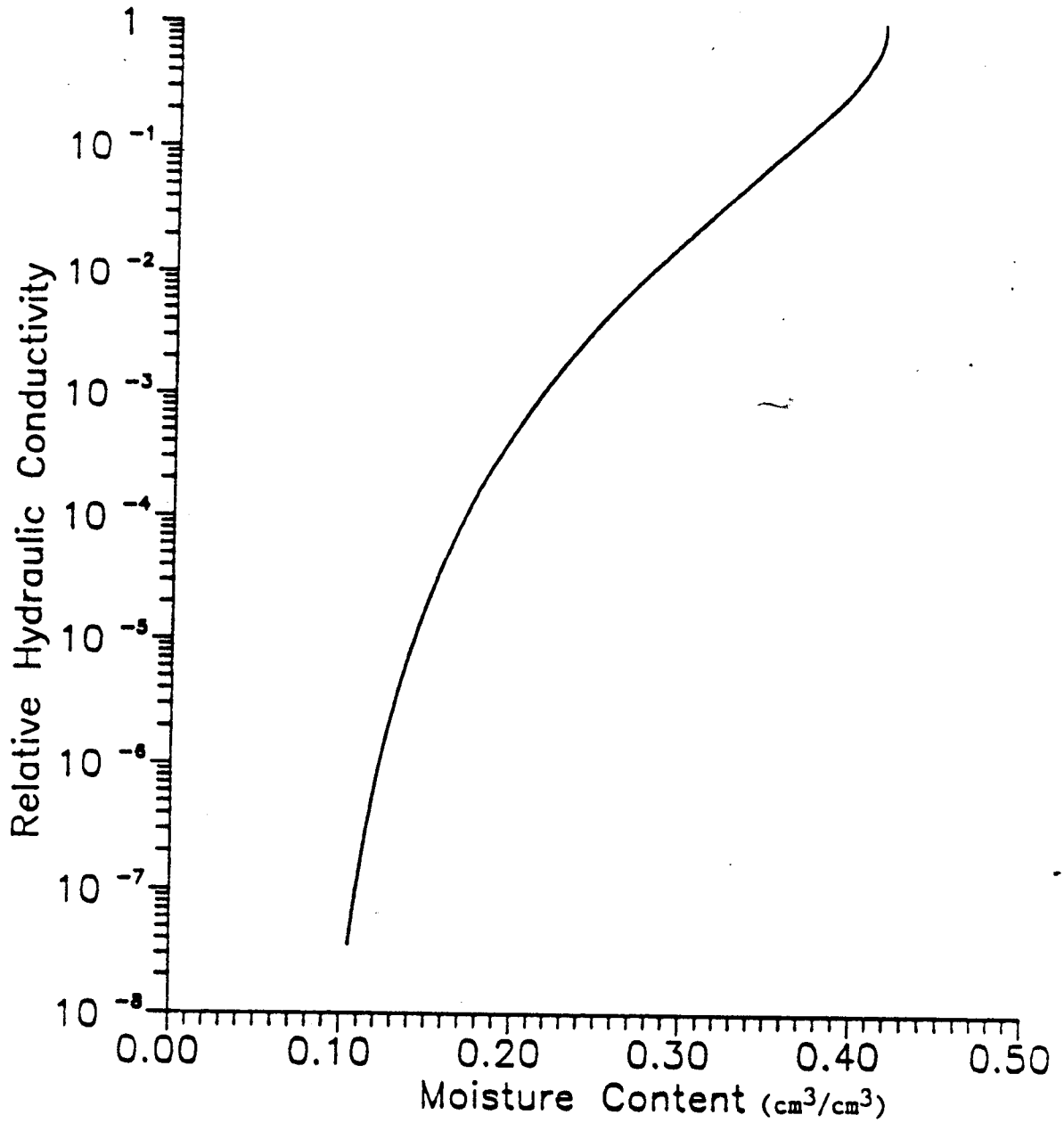


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 61-62				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

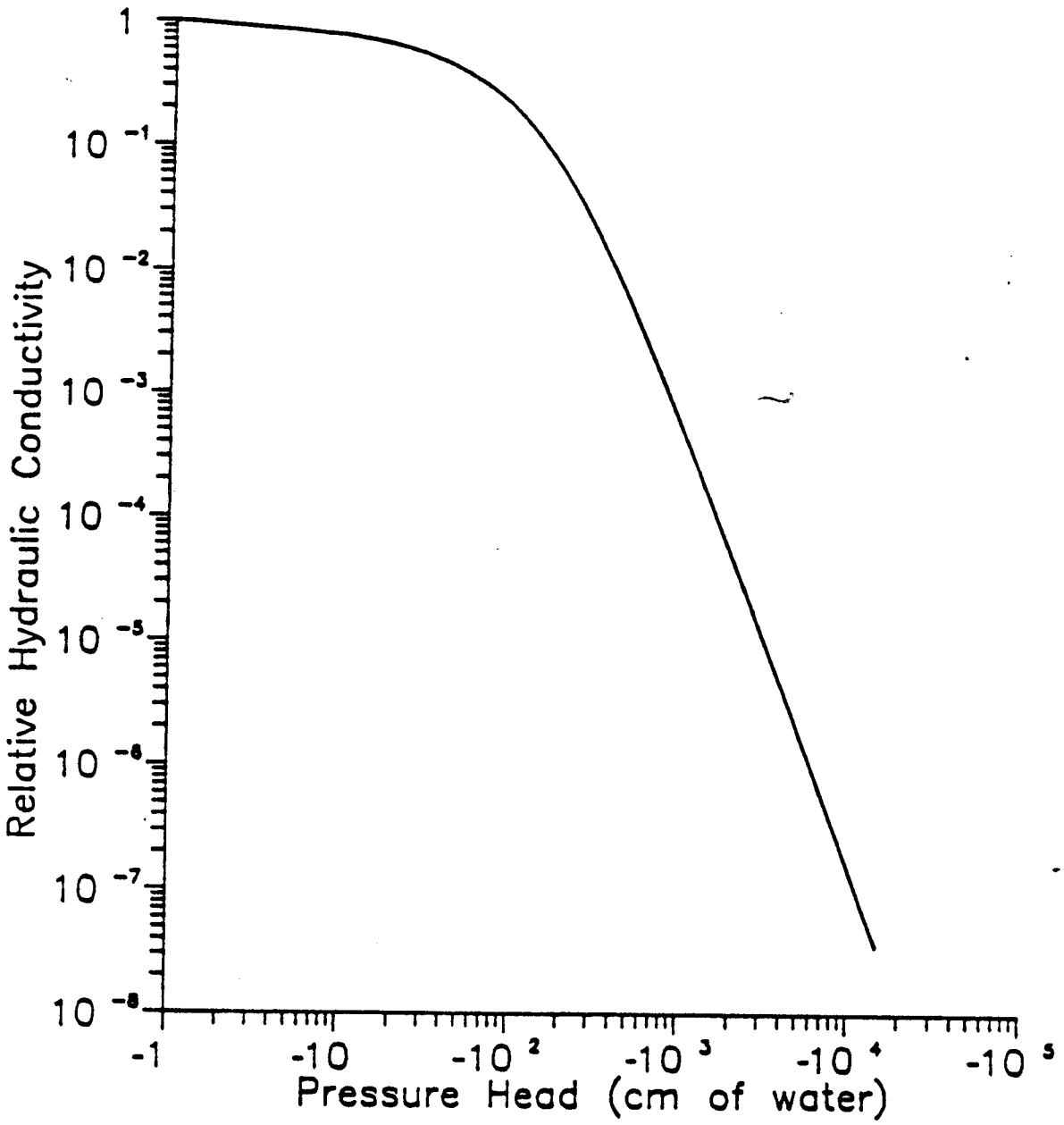


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 75-76				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

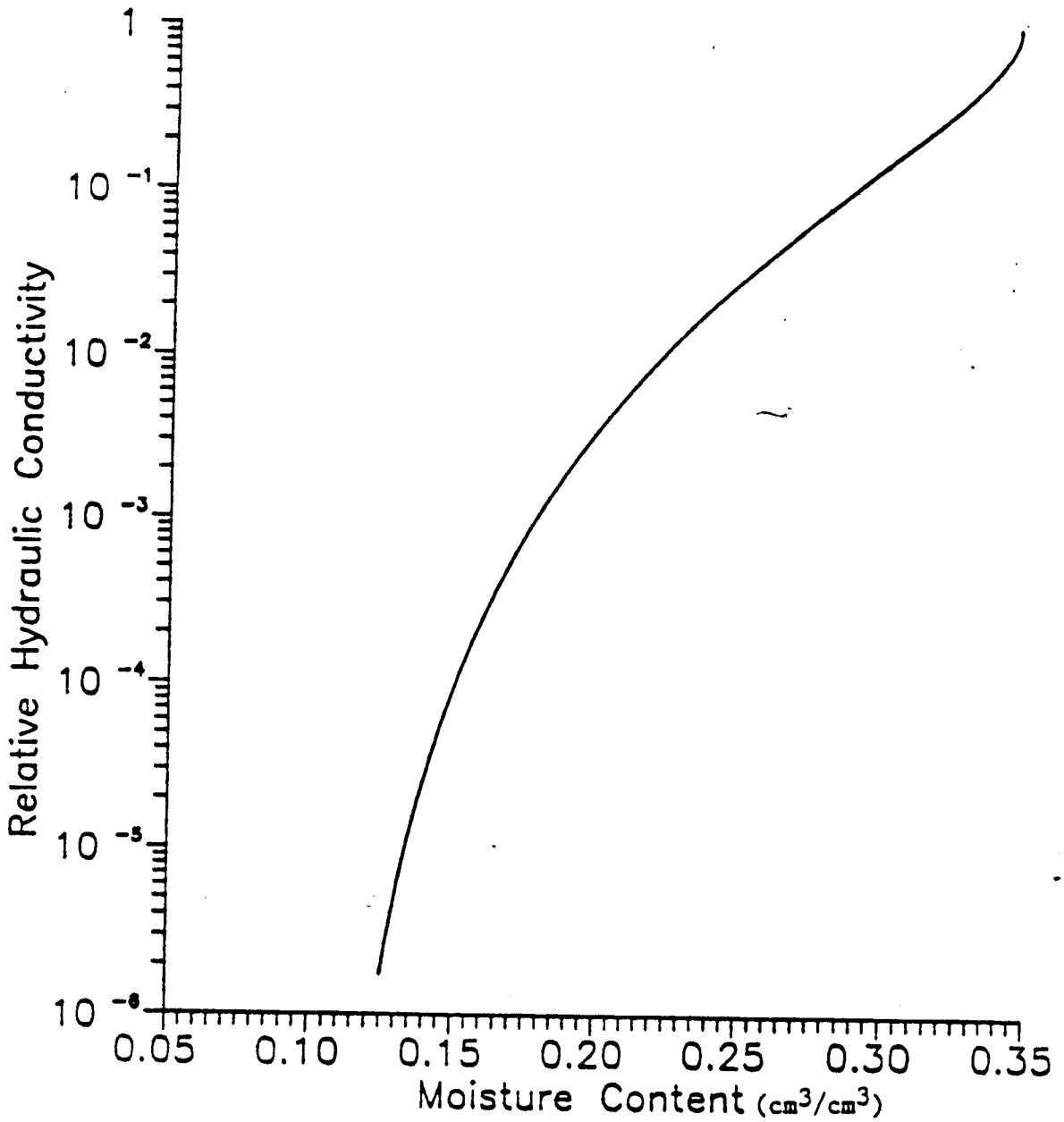


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample NO. 80-81				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

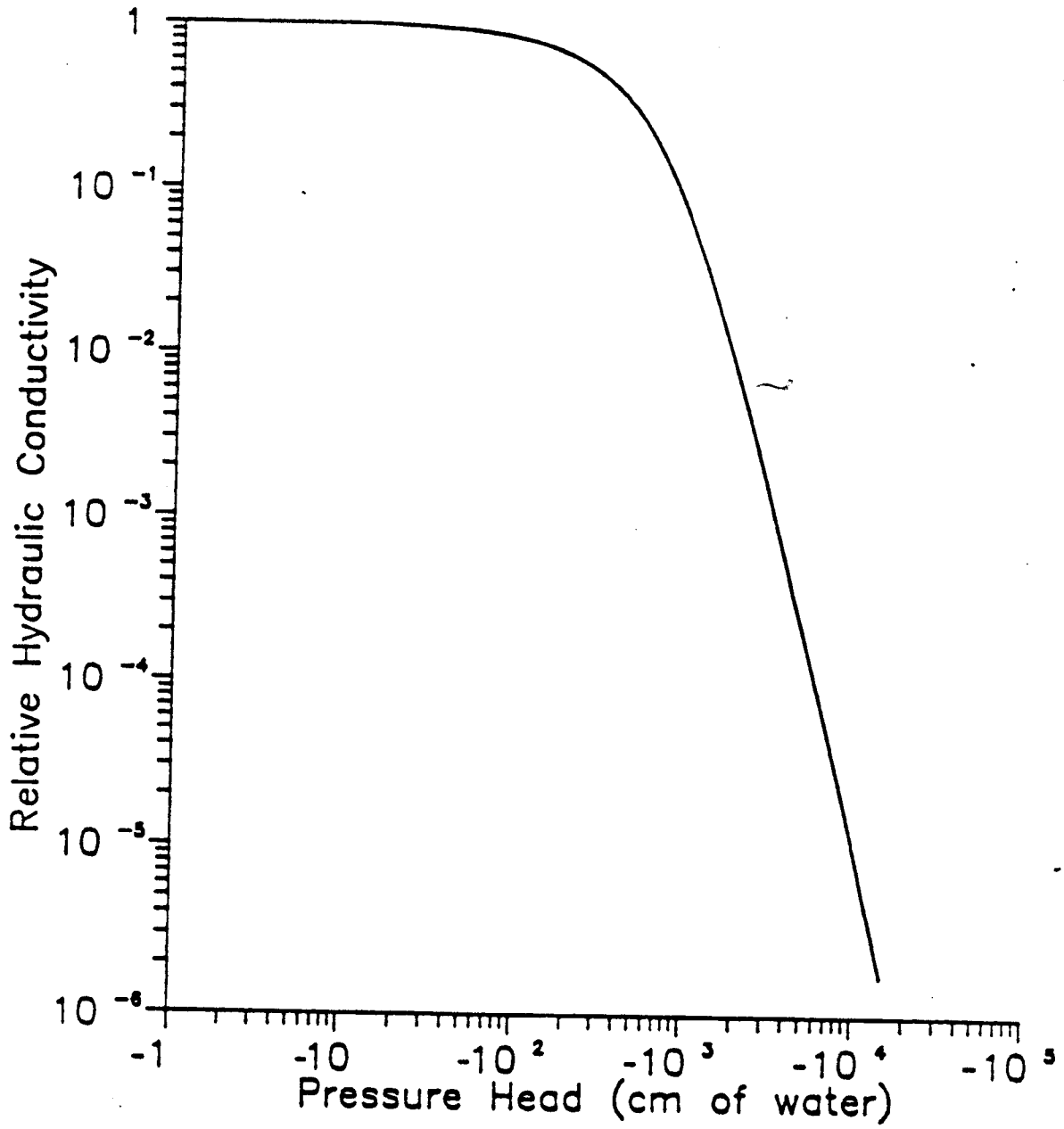


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 80-81				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

PRINCIPLES AND METHODS

SATURATED HYDRAULIC CONDUCTIVITY

Method

The saturated hydraulic conductivity of a soil sample can be measured in two types of laboratory apparatus: a constant head permeameter or a falling head permeameter.

Constant head. The hydraulic conductivity K is defined here as the ratio of q, the volume flux of water passing through a unit cross sectional area of soil per unit time, and ($\Delta h/L$) or gradient of hydraulic head in the direction of flow, corrected to 20°C:

$$K = (q/[\Delta h/L])(V_T/V_{20}) \qquad (1)$$

where $V_{20,T}$ is the kinematic viscosity at 20°C and observed temperature, T.

A soil sample of length, L, and cross-sectional area, A, is placed in a sample holder which prevents any loss of soil or change in volume and establishes laminar unidirectional flow through the sample. A constant head differential, Δh, is then set up across the sample and maintained. Periodic readings of volumetric outflow are taken until stable values for conductivity, K are obtained. Temperature of the fluid is measured with a thermometer. Figure B-1 is a diagram of the apparatus used. A constant head system is best suited to samples with conductivities greater than 10^{-4} cm/sec.

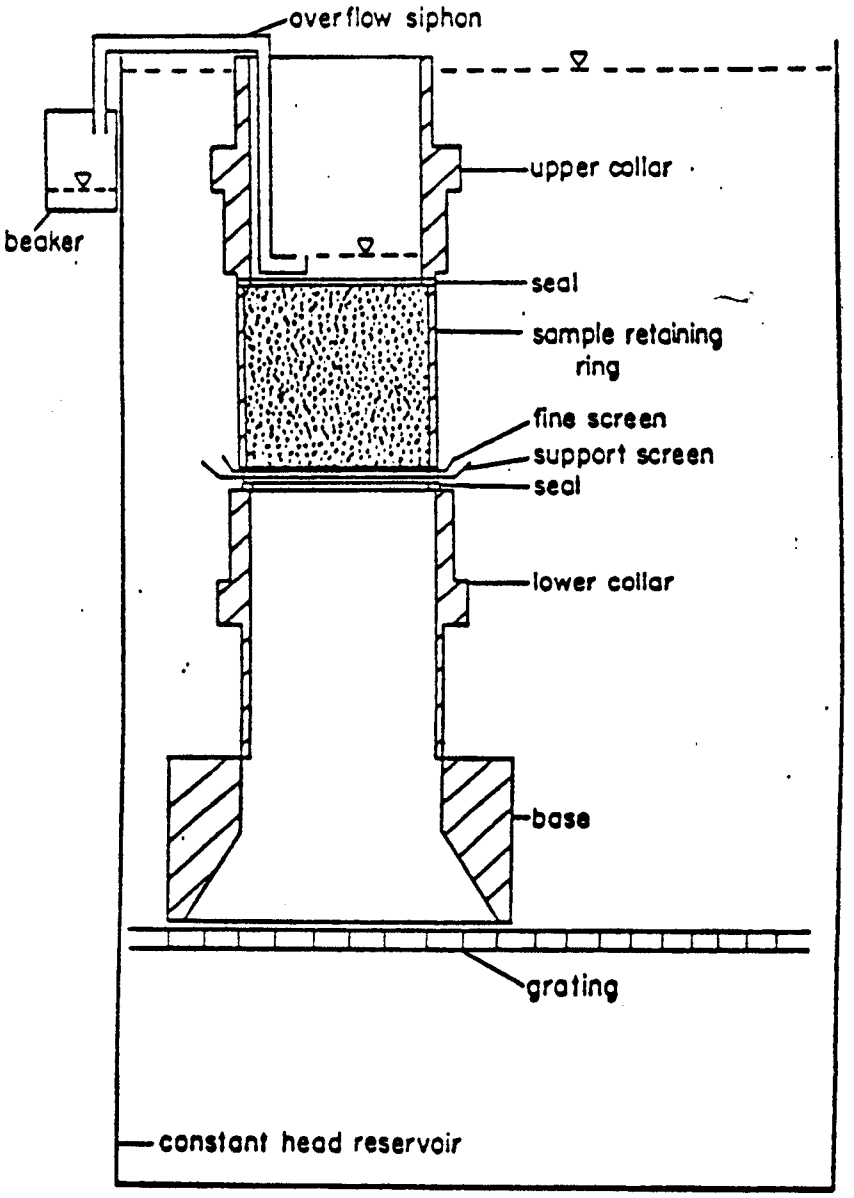


Figure B-1. Constant Head Permeameter

Falling head. A soil sample of length L and cross sectional area, A, is placed in a sample holder which has a standpipe with cross-sectional area, a. A head of H_1, is established in the standpipe above the sample, then the water level is allowed to fall to H_2 in time t. Figure B-2 is a diagram of the apparatus used. A falling head system is best suited to samples with conductivities less than 10^{-4} cm/sec. The hydraulic conductivity, is then defined as:

$$K = (a \times L/A \times t) \ \ln (H_1/H_2)(V_T/V_{20}) \qquad (2)$$

Procedures:

Constant head. Cylinders containing the soil sample are covered on both ends with loose fitting caps and placed in a shallow pan containing de-aired water. The samples are allowed to wet slowly from below for 24 hours. The samples are removed from the pan, and two screens are placed over one end; a very stiff one of coarse mesh for support and a fine one of either 80 to 100 mesh to prevent any sample from being washed out. The cylinder, with screens attached, is then clamped into the sample retainer and placed in the permeameter. The level of the water in the permeameter reservoir is then slowly raised over a period of hours. When the level in the reservoir reaches to within a few centimeters above the top of the sample, a siphon is placed in the sample retainer assembly to remove water from above

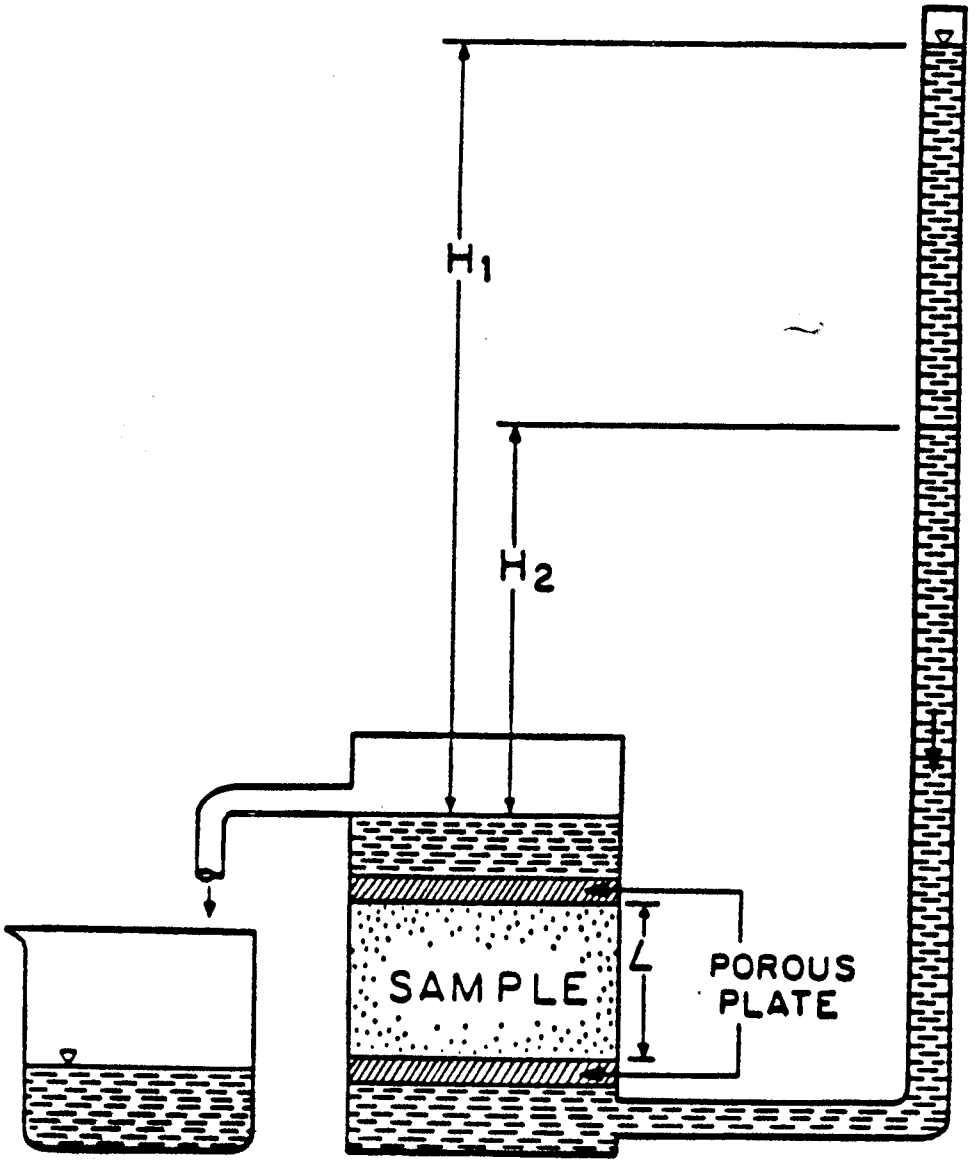


Figure B-2. Falling Head Permeameter

the sample. Water flows upward through the sample due to the hydraulic head difference across the sample. Periodic measurements of discharge and the head difference across the sample are made, and the hydraulic conductivity is calculated. A correction to 20 C is then applied for differences in kinematic viscosity. Measurement continues until the calculated hydraulic conductivity value stabilizes.

Falling head. Saturation of the sample is obtained by the same procedures described under constant head test. Screens are also attached as outlined under constant head test. The ring with screens is then placed in the falling head sample retainer and set in a constant head reservoir. Water is added to the standpipe and the difference between the water level in the standpipe and that in the constant head reservoir are recorded over time. The water level in the standpipe is allowed to fall, while the fluid level in the lower level is constant. After a period of time the difference in water levels between that in the standpipe and that in the constant head reservoir are measured and the elapsed time noted. Correction is applied for kinematic viscosity.

Calculations:

Experimental values are substituted into the appropriate equation as outlined under methods.

MOISTURE RETENTION - HANGING COLUMN

(PORE SIZE DISTRIBUTION)

Principle

Use of pore size distribution as a soil characteristic is based upon acceptance of the capillary model. This model is described by:

$$h' = 2 \cos \gamma / \rho g r \qquad (3)$$

where h' is the height to which a liquid will rise in a clean capillary tube of radius r, γ is the surface tension of the liquid, ρ is its density, and g is acceleration due to gravity. If water is extracted from an initially saturated sample of soil by a tension equal to h', the volume of water extracted is equal to the volume of pores having an effective radius greater than the radius, r. As the tension applied to the sample increases, additional water drains from progressively smaller pores.

Method

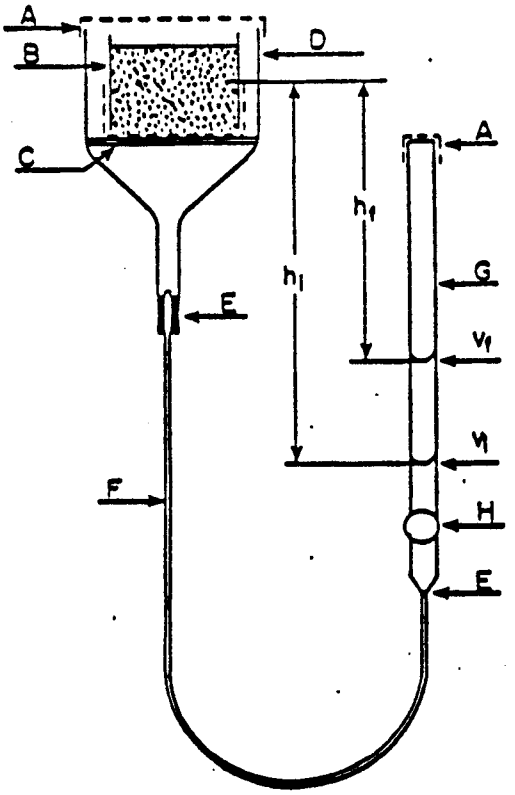
The key component of the apparatus for measuring the retention of moisture at different pressure heads or pore size distribution is a fritted glass porous plate that conducts water, but when wet the plate is impermeable to air. The fritted glass

plates have an air-entry pressure of about 300 to 400 cm of water. These plates are affixed in a glass funnel which is connected to a buret with stopcock by means of flexible tubing. A diagram of the apparatus is shown in Figure 3. A soil sample is placed on the plate and tension, h' is applied to the sample by positioning the fluid level in the buret at different levels below the center of the sample. Water flows out of the sample into the buret until equilibrium is achieved. The tension is again increased or decreased to obtain another state of equilibrium between moisture held by capillary forces in the sample and the applied tension.

Laboratory Procedure

Air is first removed from the porous plate by allowing de-aired water to pass continuously through it for 24 hours. The funnel with porous plate and the buret are supported on vertical rods by means of clamps. A saturated sample within its sample ring is then placed on the porous plate, making certain that good hydraulic contact is established between the soil particles and the plate. With the stopcock of the buret closed, the initial level of the water in the buret is recorded.

The buret is then lowered a small increment to about 10 to 15 cm below the center of the soil sample. When the stopcock is opened, the soil may begin to desaturate, and the drainage will flow into the buret. When drainage has ceased, the stopcock is



A Aluminum foil covers
B Sample in cylinder
C Fritted glass porous plate (part of D)
D Büchner funnel with porous plate
E Joints must be secure
F Flexible tubing
G Burette, least division not more than 0.1% sample volume
H Stopcock of burette
h_i cm of water suction, initial
h_f cm of water suction, final
v_i Burette reading, initial
v_f Burette reading, final

Figure B-3. Hanging Column Apparatus

closed and we record the water level in the buret and the vertical distance from the bottom of the meniscus of the water in the buret to the middle of the soil sample. The procedure is repeated in a stepwise manner until the maximum tension desired is reached. A reversal of the process is used to gather data on the wetting behavior of the sample.

Calculation

Saturated moisture content , θ_{sat} , (volume percent) is determined as follows:

$$\theta \text{ sat} = [\text{M sat} - \text{M dry}]/[V_T \times \rho_w] \times 100 \quad (\% \text{ vol}) \quad (4)$$

where M sat = mass of sample saturated, M dry = mass of sample, oven dried to a constant weight, V_T = volume of the sample, ρ_w = density of the water at temp when saturated mass was determined. The quantity [M sat - M dry]/ρ_w is the volume, in cubic centimeters, of water initially contained in the sample volume. The drainage is subtracted from the initial volume of water and then divided by the sample volume to arrive at the moisture content in percent volume at the given value of tension.

$$[V_i - V_D]/V_T \times 100 = \theta_{h'} \quad (\% \text{ vol}) \quad (5)$$

where V = volume of water initial, V_D = cumulative volume drained from sample, V_T = volume of sample, $\theta_{h'}$ = moisture content at the tension value h'. This gives then a paired set of values of tension, or pressure head, versus volumetric moisture content.

MOISTURE RETENTION - PRESSURE PLATE

Principle

The operation of the pressure plate moisture extractor requires maintaining a pressure difference between the liquid phase of the water in the soil and water on the opposite side of a porous plate which supports the soil sample. The sample and porous plate are sealed in a rigid container so that positive gas pressure applied above the plate causes flow to occur across the plate (Figure B-4). The porous ceramic plate is supported by a fine mesh screen which also provides a passage way for the extracted solution. The water beneath the plate is open to the atmosphere through the outflow tube. The illustration in Figure B-5 shows a magnified view of soil particles in contact with the plate inside the pressure plate extractor during an extraction run.

As soon as air pressure inside the chamber is raised above atmospheric pressure, the higher pressure inside the chamber forces excess water through the microscopic pores in the plate. Air, however, will not flow through the pores of the plate, because the plate remains saturated due to its high air-entry pressure. When the pressure in the chamber increases, water leaves the sample until the tension of the water

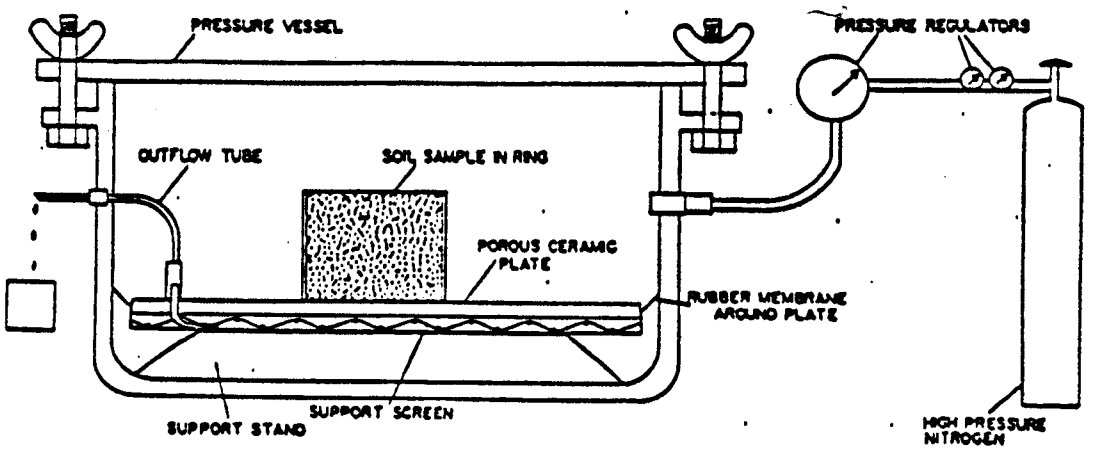


Figure B-4. Pressure Plate Extractor

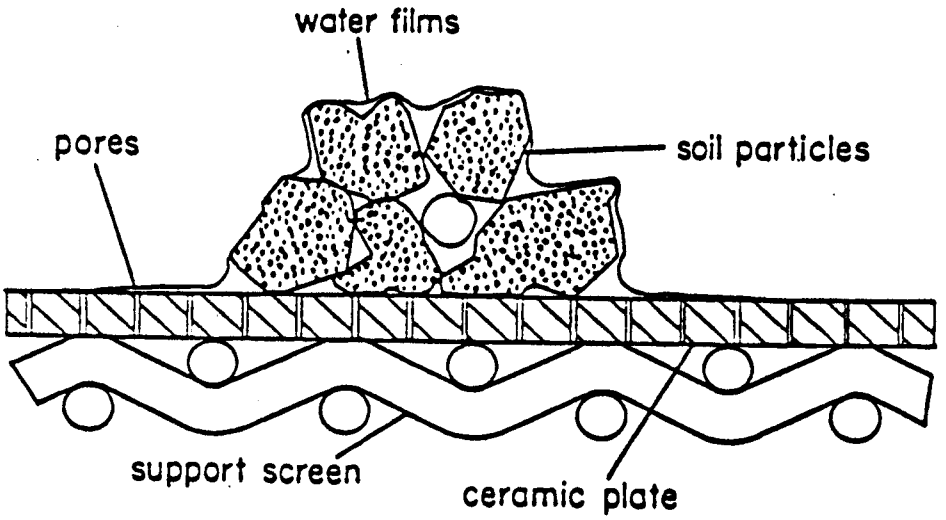


Figure B-5. Magnified View of Soil Particles

due to capillary and adsorptive forces is in equilibrium with the applied pressure.

Method

Moisture retention is obtained using a pressure plate extractor (Soil Moisture Inc., Santa Barbara, CA, Model 1500), with 1, 3 and 15 bar ceramic plates. Pressure is provided by high pressure nitrogen from cylinders.

Laboratory Procedure

The porous ceramic plate is placed is a shallow pan with deaired distilled water and allowed to stand overnight. The plate is then removed from the pan and placed in the extractor. De-aired distilled water is poured over the plate to the limit allowed by the rubber skirt, which generally just submerges the plate. The pressure plate is sealed and pressure brought to 50% of the plates maximum rated pressure. This pressure is maintained until outflow ceases. The extractor is opened and any excess water around the plate is removed.

The soil samples in their sample rings are then placed on the plate, making certain good hydraulic contact is established. The extractor is then sealed and the pressure brought to the level desired. The pressure is maintained until outflow ceases. The extractor is then opened and the samples weighed quickly on an electronic top-loading balance. Subsequently, the samples are

returned to the extractor, and the pressure is increased to the next increment.

Calculations

The decrease in mass of water in the sample during a period of applied pressure is converted to an equivalent decrease in volume of water according to:

$$V_w = \Delta m/\rho_T \qquad \text{(cc)} \qquad (6)$$

where Δm = change in mass of soil sample (g), ρ_T = density of water at temperature of experiment (g/cc), V_w = equivalent volume of water (cc).

Volumes of water calculated from equation 6 are then used to determine the moisture content at that pressure:

$$\theta_p = (V_i - \Sigma\Delta V_w)/V_T \times 100 \qquad \text{(\% vol)} \qquad (7)$$

where θ_p = moisture content at pressure p (% vol), V_i = initial volume of water in sample (cc), $\Sigma\Delta V_w$ = cumulative water volume change (cc), V_T = total volume of the sample (cc).

INITIAL MOISTURE CONTENT

Method

Core method, with oven drying.

Laboratory Procedure

The field weight of the soil sample is determined as soon as possible after the sample is removed from the packing container. The tare of the ring which holds the sample, as well as the mass of the caps for the ends of the ring, are determined. The volume of soil in the sample ring is also calculated. After all specified analyses have been performed on the sample, the sample is removed from its ring and spread in an aluminum pan. When necessary, soil aggregates are broken up by motar and pestal. Care is taken not to change the natural particle size distribution. The sample is placed in a convection oven at 110° C for at least 24 hours until dried to a constant weight.

Calculations

The initial moisture content is determined on a percent volume basis according to:

$$\theta_i = [M_i - M_f]/[V_T \times \rho] \times 100 \quad (\%vol) \qquad (8)$$

where θ_i = initial moisture content (% vol), M_i = initial mass of soil only (g), M_f = final mass of soil only (g), V_T = total

volume of sample (cc), ρ = density of pore fluid in the soil when initial mass was determined (g/cc). The density of the pore fluid initially present in the sample is assumed to be 1.0 g/cc.

BULK DENSITY

Method

Core method, with oven drying.

Laboratory Procedure

The volume of the soil sample is determined from sample geometry measurements, and the sample is dried in the oven at 110 C until no additional mass loss occurs.

Calculations

$$\rho_b = M_D/V_T \qquad (g/cc) \qquad (9)$$

where ρ_b = dry bulk density (g/cc), M_D = mass of oven dried soil sample (g), V_T = total volume of soil sample (cc).

POROSITY

Method

Calculated from bulk density and measured or assumed values of particle density.

Laboratory Procedure

Bulk density, ρ_b, is determined by oven drying, as described in the section outlining the bulk density determination. For this series of analyses particle density, ρ_s, is assumed to be 2.65 g/cc.

Calculation

$$n = [1 - (\rho_b/\rho_s)] \times 100 \qquad \text{(percent)} \qquad (10)$$

UNSATURATED HYDRAULIC CONDUCTIVITY

Method

Mualem (1976) described the theoretical basis for a procedure used to estimate unsaturated hydraulic conductivity from the soil-water release curve according to the following equations;

$$K_r = S_e^{\frac{1}{2}}\left[\int_0^{S_e} 1/h(x)dx / \int_0^1 1/h(x)\ dx\right]^2 \qquad (11)$$

where K_r = relative hydraulic conductivity, $h = h(S_e)$ is the negative pressure head, given here as a function of dimensionless moisture content:

$$S_e = \theta - \theta_r / \theta_s - \theta_r \qquad (12)$$

where subscripts s and r indicate saturated and residual values of the soil moisture (θ). The expression relating dimensionless moisture content to the pressure head, and thus the soil moisture release curve is given by:

$$S_e = [\ 1/1+(\alpha h)^n]^m \qquad m = 1 - 1/n \qquad (13)$$

where α, and n are obtained by a non-linear least squares numerical procedure applied to measured moisture retention data using the technique developed by Van Genuchten (1978).

Laboratory procedure

The data input to the computer model of Van Genuchten (1978)

consists of the saturated moisture content, residual moisture content and values of observed pressure head versus moisture content. The residual moisture content is taken to be the moisture content at -15 bars. The paired values of observed pressure head and moisture content are obtained as described under the procedures for determining moisture retention by the hanging column and pressure plate methods. Saturated moisture content is determined through gravimetric measurements and sample geometry.

References

Mualem, Y., 1976, A New Model for Predicating the Hydraulic Conductivity of Unsaturated Porous Media, Water Resources Research, vol. 12, no. 3, p. 513-522.

Van Genuchten, R., 1978, Calculating the Unsaturated Hydraulic Conductivity With a New Closed-Form Analytical Model, Research Report No. 78-WR-08, Princeton University, Department of Civil Engineering, September 1978, 65pp.