

A TECHNIQUE FOR EVALUATING
THE HYDRAULIC CONDUCTIVITY OF SAPROLITE

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The work upon which this publication is based was supported in part by funds provided by the Office of Water Resources and Technology, US Department of Interior, Washington, DC, through the Water Resources Research Institute of The University of North Carolina as authorized by the Water Research and Development Act of 1978. Partial support was also provided by the Department of Marine, Earth and Atmospheric Sciences, North Carolina State University.

Project No. A-115-NC

Agreement No. 14-34-0001-1135

April 1981

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ABSTRACT

A commercially available flow meter was adapted to use as a field instrument for determination of saprolite hydraulic conductivity. Experiments with artificial standards composed of Portland cement and sand mixed in various ratios demonstrated the potential use of the instrument. The mixes served as standards relating the air permeability measured by the instrument to the hydraulic conductivity of the samples. Heat shrinkable plastic was used to encase both the standard samples as well as field samples for hydraulic conductivity determinations.

Two hundred fifty saprolite cores were analyzed. The saprolites studied were developed on a variety of rock types. Average hydraulic conductivities determined from the air permeameter measurements on dry samples fell in the 10^{-3} cm/sec range. Sandy saprolite had hydraulic conductivities in the 10^{-2} cm/sec range, and for some relatively pure clay samples hydraulic conductivity was 10^{-6} to 10^{-7} cm/sec.

It is believed that the air permeameter can be a useful, cost-effective instrument for systematic study of hydraulic conductivity of saprolite. It also can be an effective tool for reconnaissance determinations of hydraulic conductivity at proposed waste disposal sites. Its particular usefulness arises from the rapidity of the hydraulic conductivity determinations and therefore the ability to make a large number of determinations in a short period of time.

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INTRODUCTION

The increased emphasis on stringent controls of burial sites for solid and hazardous waste and the great need in North Carolina for a rapid, cost-effective evaluation of potential waste disposal sites in general requires a quick, reasonably accurate method for determining the hydraulic conductivity of the saprolite developed on the crystalline rocks of the Piedmont Province. Knowledge of the hydraulic conductivity of the saprolite is also important for an improved understanding of recharge to the groundwater contained in the underlying crystalline rocks. This report describes the results of a technique developed to provide a rapid evaluation of the saprolite hydraulic conductivity.

Experiments were run on laboratory-fabricated samples to establish the relationship between the air permeability and the saturated hydraulic conductivity and to derive an understanding of the use of the instrument. Delays in obtaining materials and learning the best technique for certain aspects of the investigation limited field experimentation with the instrument. However, it is felt that the measurements made on the field samples demonstrate the potential capabilities of the instrument and provide clues to the variability of saprolite hydraulic conductivity.

Objectives

Three objectives were outlined for the study.

- (1) Development of improved techniques for determination of hydraulic conductivity of saprolite and other near-surface materials.
- (2) Compilation of sufficient test data from the first objective to establish hydraulic conductivity ranges of saprolite derived from a variety of rock types and geomorphic settings.

- (3) Development of a strategy for preliminary evaluation of possible waste disposal sites utilizing the instruments and techniques developed in the investigation.

The investigation has demonstrated that the instrument can be constructed relatively inexpensively, that it can be used for rapid determinations of hydraulic conductivity in a variety of materials, and that it can be adapted to a field-oriented program of hydraulic conductivity determinations. It should be of particular use where three-dimensional permeability measurements need to be made. Measurements can be made on surfaces cut at almost any angle into the saprolite. Although there has been no attempt to make such a study, it appears that the instrument may be useful in studying the effect of partial saturation on the movement of water through saprolite.

Experimentation with the instrument in field situations has provided some knowledge of the permeability variations of saprolite by rock type. However, it appears from the limited experimentation that one has to consider the permeability more in terms of site-specific criteria than in terms of rock types per se. It is recognized, of course, that root holes, fractures, and cracks play an important role in the movement of water from the surface through the saprolite. However, use of the instrument does provide insight to the permeabilities of the material between the larger openings. Close observation of the saprolite also discloses that water does migrate through the saprolite between the larger openings.

PROCEDURE

The air permeameter developed during the course of this investigation is based upon a design described by Bradley, et al. (1972). The instrument consists of a borosilicate glass metering tube (Fisher Catalogue 11-164) with a steel or sapphire ball, a sleeve-type serum cup (rubber stopper) to ensure a seal between the flow meter and the sample being tested, and a double-acting rubber bulb (e.g., Fisher Catalogue No. 14-070) to draw air into the flow meter. A Spectronics pipette filler (Fisher Catalogue No. 13-681-50) provides a smoother airflow, making reading of the ball height in the flow meter somewhat easier than with the double-acting rubber bulb. A small hole approximating the inside diameter of the flow meter was made in the rubber serum cup with a heated nail of appropriate diameter.

Small pieces of sponge impede movement of dust or grit into the flow meter. Pieces cut from a standard general utility sponge with small openings were placed as filters in the upper portion of the serum cup, lower flow meter opening, and between the flow meter and the rubber bulb. A piece of "fine-grained" sponge designed as a "wash cloth" was placed within the rubber serum cup external to the coarser sponge. Both sponges were obtained from a local supermarket.

Checks were made on the effects of the "fine-grained" sponge on the air flow through the permeameters. In all cases the flow meter ball hit the top of the flow meter, both with and without the sponge in the permeameter. It did so when tested in open air and against highly permeable materials, including the more permeable standard cores.

Although there was some effect from the "fine-grained" sponge on the movement of the flow meter ball for samples of lower hydraulic conductivity, it was inconsequential within the range of permeabilities measured.

The "fine-grained" sponge proved essential in controlling the entrance of dust into the permeameters. If this sponge became damp in the field, it was easily replaced, dried out, and cleaned for later use without affecting the characteristics of the permeameter. Replacement of one piece of "fine-grained" sponge by another cut from the same large piece did not significantly affect the air permeameter characteristics.

Flow meters of three different sizes were tested during the course of the investigation: one-sixteenth inch, one-eighth inch, and one-quarter inch diameters. Glass, sapphire, and steel balls were tested. The most useful combination of size and ball type was the one-eighth inch diameter flow meter with a steel ball and the one-quarter inch diameter flow meter with a sapphire ball. The one-sixteenth inch diameter permeameter was too sensitive for use except on those materials which had an overall hydraulic conductivity in the range of 10^{-7} cm/sec. Figure 1 illustrates construction of the air permeameter.

Standards

Various mixtures of Portland cement and sand (commercial washed, fine-grained "play" sand obtained from a local building supply house) were utilized in making the hydraulic conductivity standards. The cement and sand were mixed in the proportions shown in Table 1, mixed

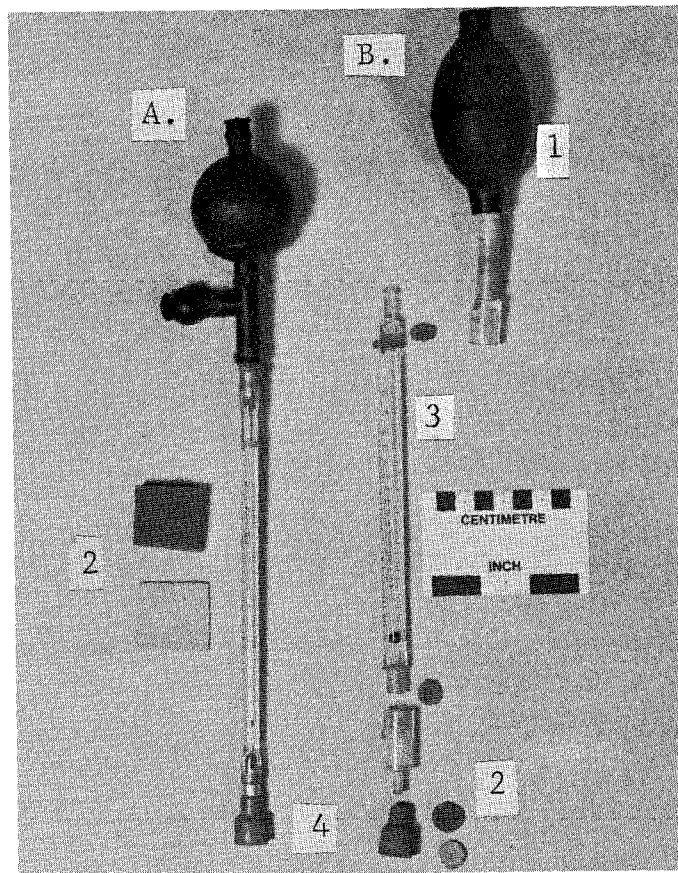


Figure 1. Construction of air permeameter

A. Assembled permeameter

B. Parts of permeameter

- (1) Bulb
- (2) Sponges
- (3) Flow meter tube
- (4) Rubber serum cup

with water, and placed in a paper one-half gallon milk carton which had been cut to be about five inches tall. Each mix was allowed to set for about an hour and then cored with a two-inch diameter juice can. The can was cut along its length so that it would spring open to release the core. During the coring operation the can was held in its original circular cross-section with a radiator clamp.

TABLE 1

STANDARD CEMENT-SAND MIXES - BY VOLUME

Cement:Sand

1:1
1:2.5
1:5.0
1:7.5
1:10

The sand-cement core was allowed to air-dry for several days after being removed from the coring device. When it appeared that the core was dry, it was placed in a section of heat-shrinkable plastic (Insulfab's Insulgrip HS101 polyolefin heat-shrink tubing, two-inch inside diameter) and placed in a drying oven at a temperature of approximately 140° for 10 minutes. Experiments at higher temperatures and longer times were undertaken, but it was found that the plastic split at the higher temperatures, and longer times did not improve the seal. Buss et al. (1978) describe use of heat shrinkable plastic in permeameters.

Repeated attempts to obtain a perfect seal of the plastic against the edges at either end of the core demonstrated that such

sealing would generally be impossible. Consequently, a double-sealing technique was developed. Heat-shrinkable plastic was cut to a length approximately one-quarter inch longer than the core. The core with the plastic was then placed in the oven on a three-quarter inch diameter stand (PVC pipe collar), and the plastic shrank against the core. After the core had cooled, a small bead of silicon cement was placed between the plastic and the core to seal the plastic to the outer rim of the core.

Following cooling to room temperature, a second piece of heat-shrinkable plastic was then placed around the core; this second piece was cut about two inches longer than the core. Again the core and plastic were placed in the oven at 140°C. The plastic shrank against the first plastic, and it also shrank over the end of the core down to a minimum diameter of about three-quarters of an inch. Thus the core was surrounded by the initial layer of plastic which had been sealed to it at either end by the silicon cement over which was a second piece of plastic which had shrank against the first, providing a seal at the edges. The second piece of plastic also provided nipples extending above and below the core and into which rubber stoppers of the permeameter could be inserted.

A piece of aluminum screen wire was placed at either end of the core prior to its insertion into the second piece of heat-shrinkable plastic. The purpose of the screen was to reduce any erosion that might occur on the core as the water from the permeameter moved into the core and flowed out the lower end when the core was in the permeameter. Figure 2 illustrates

both a standard core and a field core prepared for insertion into a permeameter.

Repeated experiments with the sand-cement cores and the heat-shrinkable plastic demonstrated that once the edges of the core had been sealed to the first piece of heat-shrinkable plastic with the silicon cement the water moved through the core rather than over the outer edges or down the outer surfaces of the core. In cases where there was an incomplete seal around the core, the plastic was removed from the core and the sealing procedure repeated.

Hydraulic Conductivity

Hydraulic conductivity measurements utilized the falling head concept as expressed in the equation

$$K = 2.3 \frac{aL}{A(t_1 - t_0)} \log_{10} \frac{h_0}{h_1},$$

where h_0 = Initial head above core at time = t_0

h_1 = Head above core at time t_1

t_0 = Time when water level in standpipe is at h_0

t_1 = Time when water in standpipe is at h_1

K = Hydraulic conductivity

a = Cross-sectional area of standpipe

L = Length of core

A = Cross-sectional area of core.

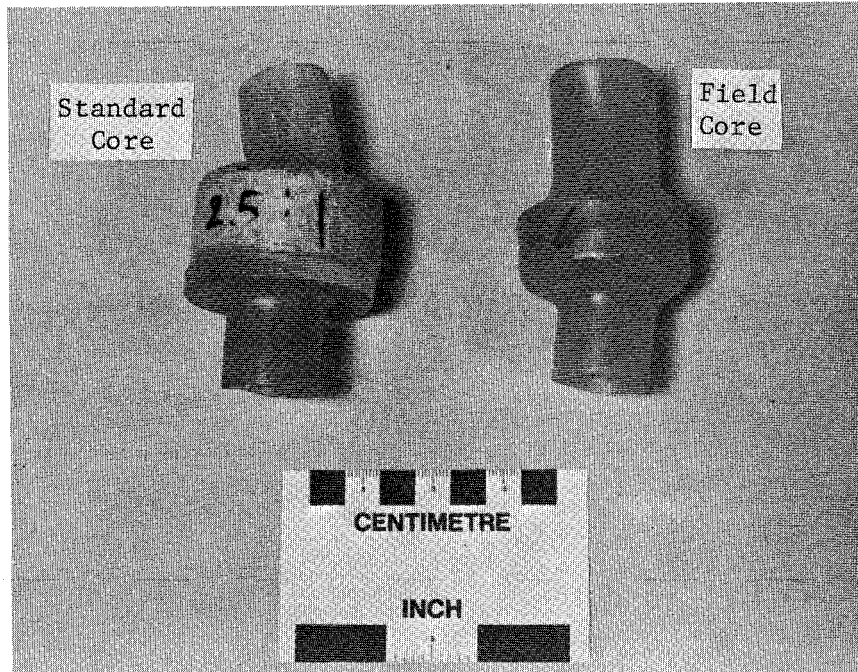


Figure 2. Cores prepared for insertion into permeameter for hydraulic conductivity measurements.

Precautions against evaporation were taken by placing a plastic cover over the receiving vessel as well as over the standpipe above the core. The individual cores were saturated and back-flushed for complete saturation and removal of air prior to commencement of the hydraulic conductivity measurements. De-aerated water was used in the measurements. Figure 3 shows several of the permeameters used in the experiment. Figure 4 shows diagrammatically the construction of an individual permeameter. The hydraulic conductivity of each standard core was determined five times, and the average value was taken as the permeability for the standard.

Air Permeability

After the hydraulic conductivity of the standard cores had been determined, they were removed from permeameters, allowed to dry, and measurements of their air permeability made. The air permeameter's rubber bulb was evacuated, and the release valve of the pipette-filler was then squeezed after the sponge inside the rubber serum cup was pressed against the core. The outer part of the cup sealed the permeameter to the core so that the only air entering the permeameter came from within the area encircled by the inside surface of the cup.

The height to which the ball rose in the flow meter and held steadily as the bulb was filled with air was noted as the "air permeability." The top of the ball was used to mark the height of its rise. Both types of rubber bulbs used caused a small sudden perturbation at the end of their expansion which in turn caused the flow meter ball to give a

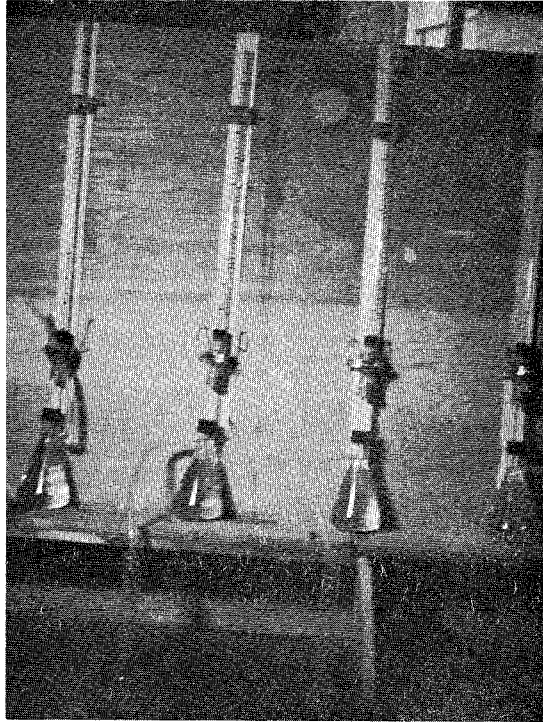


Figure 3. Several permeameters used in hydraulic conductivity determinations.

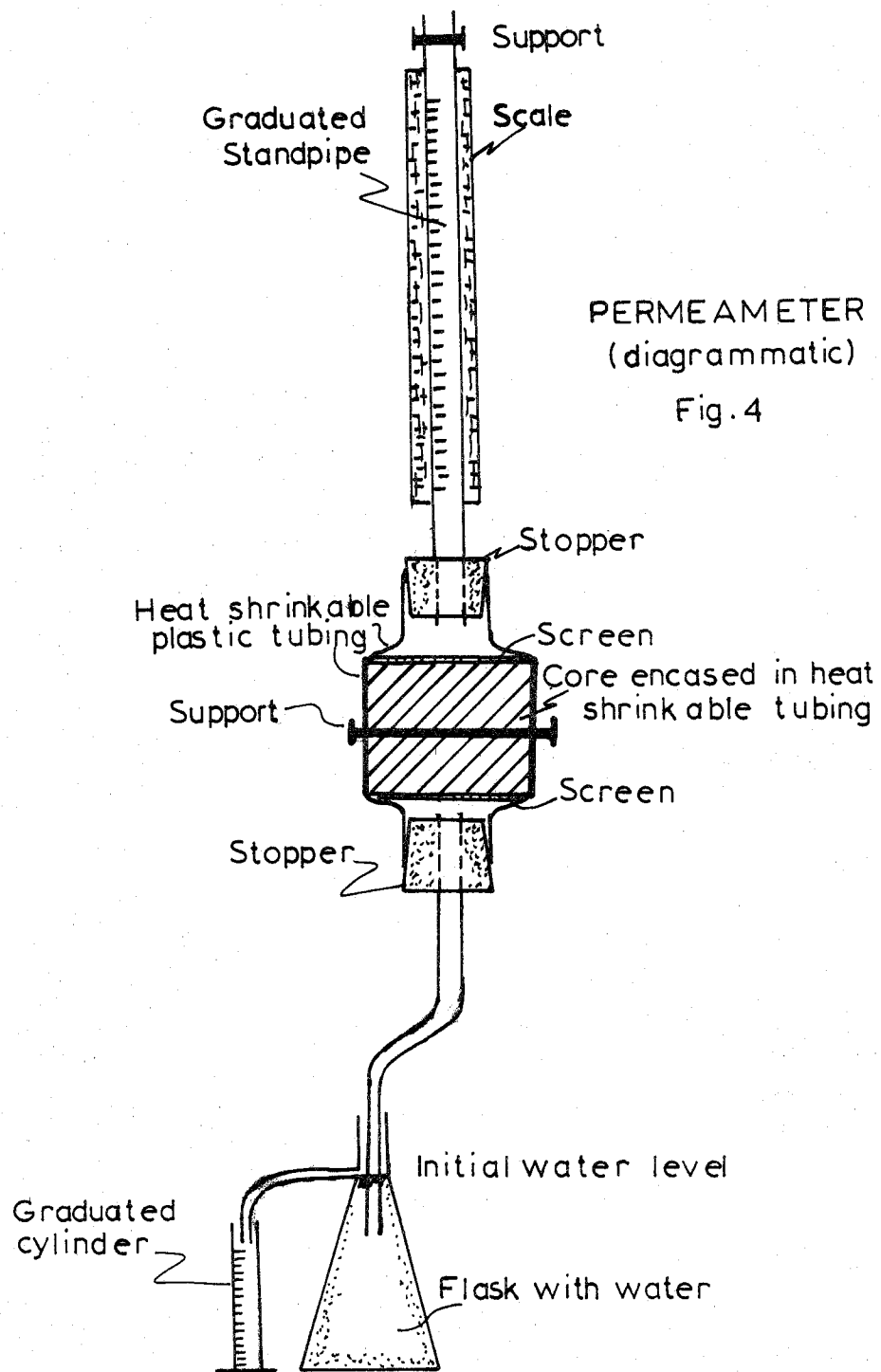


Figure 4: Construction of falling head permeameter for hydraulic conductivity measurements.

sudden jump. The maximum height immediately prior to this jump was the one used in the permeability determination. Experiments utilizing materials of various permeabilities but with smooth surfaces indicated that air flowed from the core through the "fine-grained" sponge into the flow meter and that the rubber serum cup would form a satisfactory seal.

Replicate measurements of the air permeability were made in the following fashion. Five air permeability measurements were made on each core followed by five measurements on another core. This procedure was repeated for all the standard cores. The procedure was repeated four times so that a total of twenty air permeability measurements were made on each core. The cores were initially placed on raised perforated plexiglass stands so that air could flow the length of the core. Several tests with and without the stands demonstrated that they were not required.

A standard working curve was constructed from the air permeability and hydraulic conductivity measurements. Typical curves are illustrated in Fig. 5. Figure 5A also has plotted on it the field sample values. The air permeameter used for this curve was subsequently broken. Figure 5B is a standard working curve used for the bulk of the hydraulic conductivity determinations made during the investigation. Air permeability values, hydraulic conductivity values, and standard deviations of the air permeability values for the several cores are indicated in Table 2.

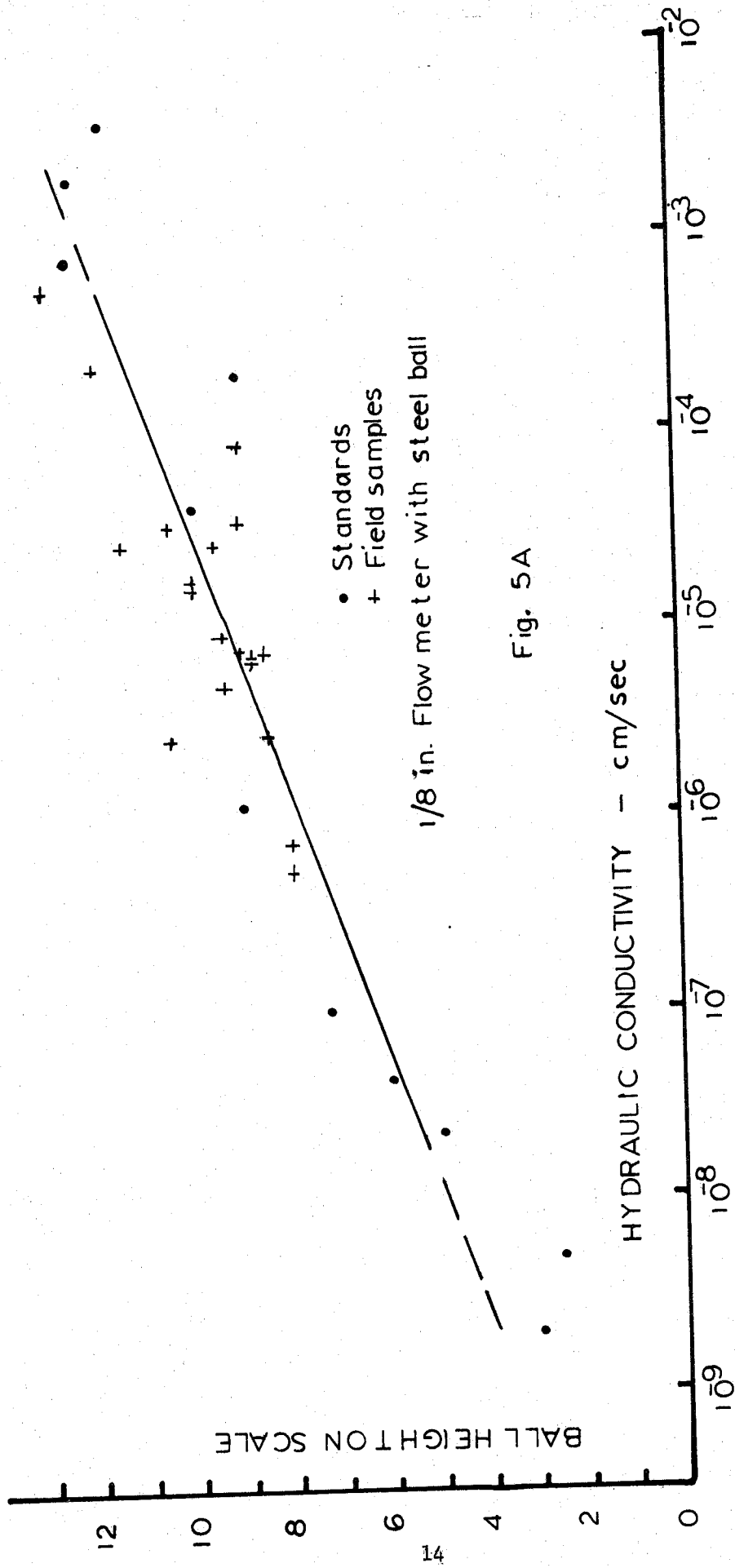


Fig. 5A

Figure 5A. Standard working curve. Shows points for standard cores and field samples.

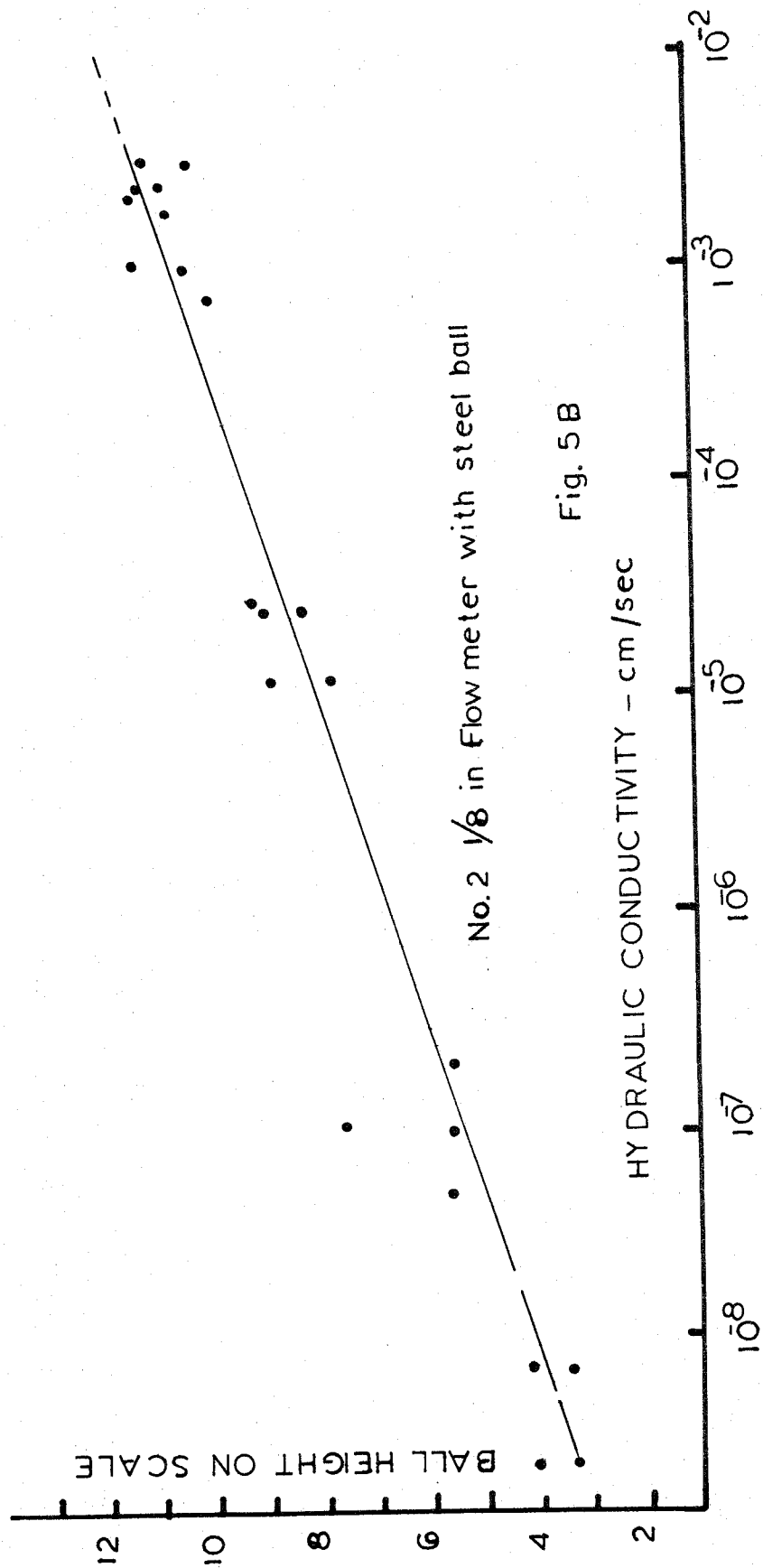


Fig. 5 B

Figure 5B. Standard working curve.

TABLE 2

Air and Water Permeability Values - One-eighth inch Permeameter with Steel Ball

Standard	Hydraulic Conductivity (5 measurements) (cm/sec)	Air Permeability (20 measurements) (Units on flow meter scale)	Air Permeameter Standard Deviation (percent)
10A-1	2.45×10^{-3}	10.8	±0.8
7.5A-1	7.28×10^{-4}	9.0	±4.4
5C-1	3.9×10^{-5}	7.9	±4.7
2.5C-1	9.7×10^{-8}	5.6	±3.5
1C-1	2.5×10^{-9}	3.3	±1.2

Precision of the technique is a concern in potential use of the air permeameter. Two standard cores were used to investigate this question. One core was composed of a 10:1 sand to cement mix, and the mix of the other was 1:1.

Twenty measurements were made on each of five spots on each core with the one-eighth inch air permeameter. The average ball height and standard deviation of the measurements on each of the five locations was then determined. The average percent standard deviation was $\pm 4\%$ for the 10:1 mix and $\pm 9\%$ for the 1:1 mix.

Periodic checking of the air permeameter against the sand-cement standards was also undertaken to determine if slight changes in the bulb had altered the permeameter and to ascertain whether or not changes in the sponges inserted in the instrument for filtering out of dust had altered the characteristics of the air permeameter. The permeameter was cleaned as necessary by disassembling it and blowing "Dust Off"TM (from Falcon Safety Products, obtainable in most photographic stores) into the flow meter tube and on the sponges. During the course of the study the characteristics of the permeameter did not seem to change significantly.

Effect of Core Length

Cores were prepared for each standard mix ranging in length from approximately 1 cm to 6 cm. All of the cores for one mix were prepared from the same batch. Thus for the experiment evaluating effects of variations in core length on a 2.5:1 mix the cores of different length were prepared from the same 2.5:1 sand-cement batch. Mixing differences and volume measurement differences for another batch of ostensibly the same sand-cement ratio could give cores with air permeability characteristics slightly different from another batch of similar ratio.

After the cores had air-dried, they were tested for air permeability with the permeameters. In addition to the cores constructed specifically for this part of the investigation, cores from other parts of the experiment were similarly evaluated.

Table 3 shows the results of several tests. As may be seen from the table, there was no significant variation in the air permeability values obtained from the several cores. The variations fall within the standard deviations determined in the study of measurement precision. Absence of a core length effect held true for both the one-eighth inch and the one-quarter inch permeameters. The one-sixteenth inch diameter permeameter consistently went off scale on those cores used to examine the effect of core length on the air permeability measurements.

It may be concluded from this experiment that the length of the core does not play a significant role in the permeability determinations made with the air permeameter. Thus a core or fragment of the saprolite approximately two inches in diameter and approximately one-half inch thick can be used to make the permeability determinations.

Effect of Moisture Content

A question which arises in the potential use of the air permeameter is that concerned with the effect of moisture content upon the air permeability. To address the question, samples were prepared using the several standard sand-cement ratios. The cores were of approximately equal length. Individual cores were weighed after they had dried, and then they were saturated by soaking for 24 hours. After soaking, the cores were allowed to drain until excess water had drained away so that they could then be described as being at "field capacity." They were then weighed to determine the "saturated weight." Subsequent to their

TABLE 3

Evaluation of Core Length Effect

<u>Mix</u>	<u>Length</u> (cm)	<u>Air Permeameter</u>		
		<u>1/4-inch</u>	<u>1/8-inch</u>	<u>1/16-inch</u>
7.5:1	6.6	6.7	11.1	off scale
	5.3	5.7	11.6	
	4.3	5.9	11.0	
	3.3	5.7	11.2	
	1.9	6.0	11.9	
5:1	6.0	5.4		off scale
	4.0	5.5		
	1.5	5.1		
	1.2	5.3		
5:1	1.4	4.6	12.4	
	1.0	4.6	11.5	
3:1	5.0	3.4	off scale	off scale
	3.7	3.6		
	3.2	3.8		
	1.9	3.8		
1:1	1.2	1.2	3.1	7.2
	0.5	1.2	2.6	7.3

weighing the saturated cores were dried for one hour in an oven at a temperature of 110°C, removed from the oven, cooled to room temperature, and weighed again. The air permeability for each core was then ascertained. The cores were returned to the oven to be dried for another hour with the cooling, weighing, and air permeability measurements then being repeated. The cycle was repeated until the weight of the individual core stabilized at, or very near, the initial dry weight. Usually a total of five hours drying time sufficed to bring the cores to this point.

The percentage moisture saturation by weight was calculated following each individual drying cycle as follows:

$$\text{Percent Saturation} = 1 - \frac{(S-P)}{(S-D)} \times 100$$

where S = Saturated weight

P = Partial saturated weight

D = Dry weight

The methodology of the experiment was carried out in the fashion described to reproduce as closely as possible what might be found in the field. A set of standard cores was utilized in the experiment. It is recognized that possibly some error was introduced through absorption of moisture from the air during air cooling to room temperature. However, it is felt that the error introduced was not significant.

The weight percent moisture was plotted as a function of drying time and also as a plot of the air permeability expressed as ball height in the permeameter. Table 4 provides typical results from this experiment, and Fig. 6 is a typical curve for the drying time vs percent saturation.

DRYING TIME CURVES

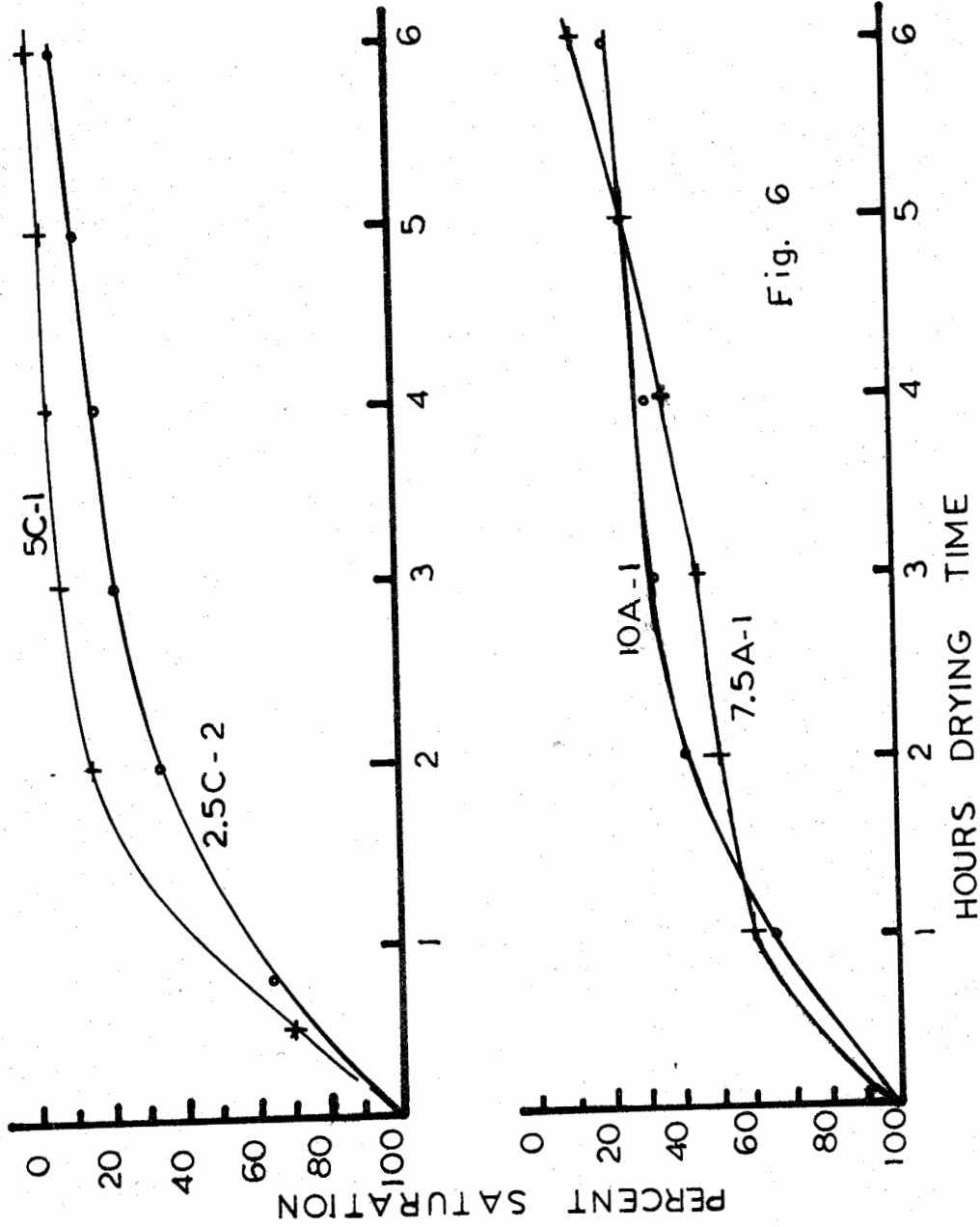


Fig. 6

Figure 6. Percent saturation as a function of drying time.

Figure 7 illustrates the relationship between air permeability and moisture content.

Table 4B lists the hydraulic conductivities of standard cores at 10 percent and 20 percent saturation. Air permeability measurements were carried out at these moisture contents on the standard cores used in preparing figures 5B and 7. The error in hydraulic conductivity determinations introduced because of the presence of moisture are also summarized in the table.

Although the percentage error introduced by the presence of water in the cores is apparently large, the order of magnitude of the hydraulic conductivity for each core is correct. It appears that variances in hydraulic conductivity associated with retained moisture of less than about 10 percent will not generally cause order-of-magnitude errors in hydraulic conductivity determinations.

FIELD SAMPLES

Part of the investigation was to collect "undisturbed" samples of saprolite and to use the heat-shrinkable plastic to encase the cores for laboratory permeability measurements. Approximately 100 attempts were made to follow this procedure but only 18 were successful. In addition to the usual difficulties associated with obtaining an undisturbed sample, the cores cracked when heated to shrink the plastic against them. Cores in which successful water permeability measurements were made were also analyzed for air permeability. Figure 5A includes a plot of air permeability as a function of hydraulic conductivity for the 18 samples. The results from this part of the investigation seem to confirm that the air permeability can be used to determine the water permeability as suggested by the work done on the sand-cement standards.

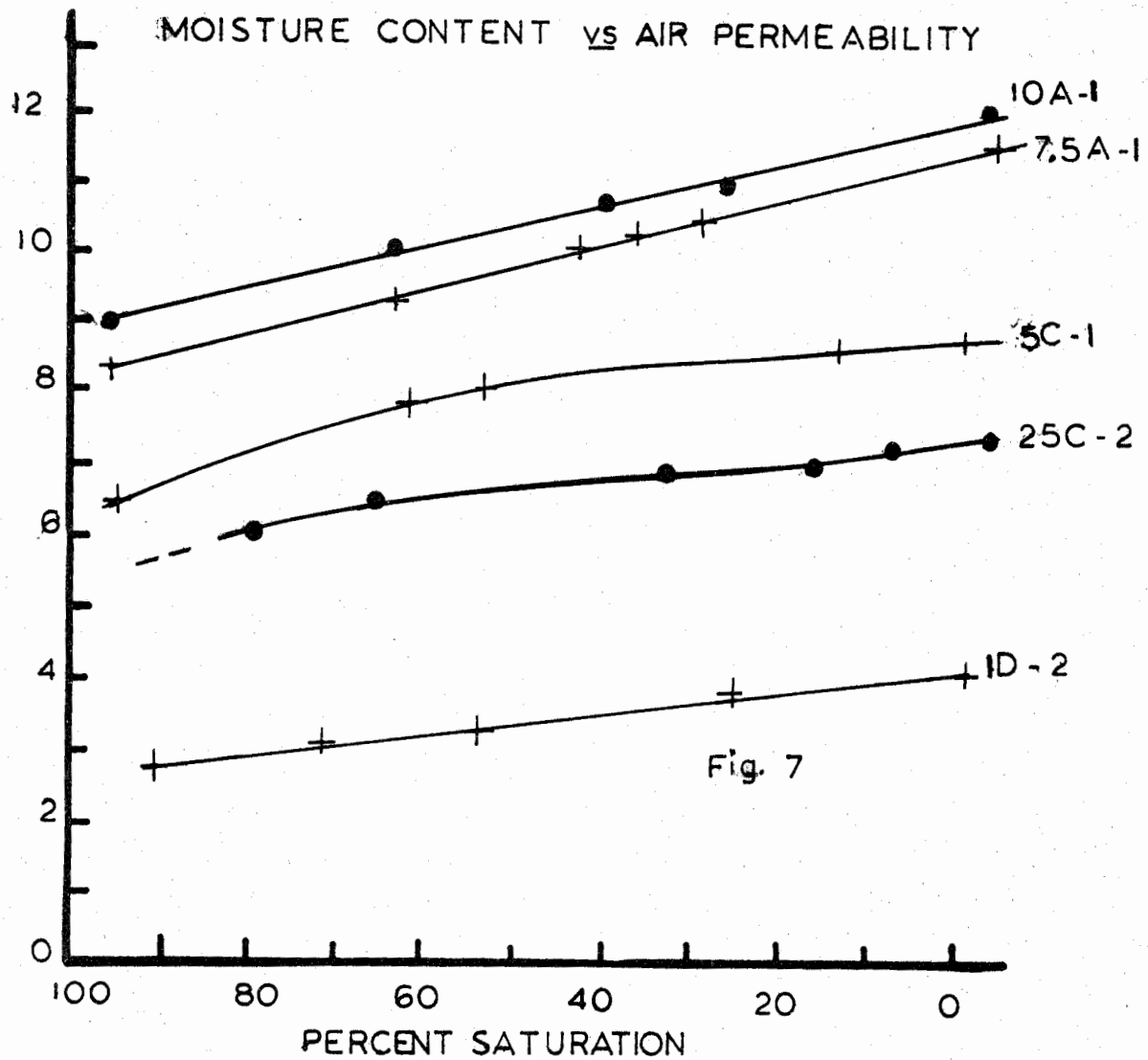


Figure 7. Air permeability and moisture content.

TABLE 4

Effect of Moisture on Air Permeability

A. Moisture Content and Air Permeability

Sample No. 2.5C-2 (2.5:1 mix)

<u>Drying Time</u> <u>(Hours)</u>	<u>Moisture</u> <u>Content</u>	<u>Flow Meter</u> <u>Ball Height</u>
1	77	6.2
2	33	6.8
3	21	7.0
4	18	7.0
5	12	7.2
6	0	7.3

Sample No. 7.5A-2 (7.5:1 mix)

1	97	7.4
2	64	9.0
3	42	10.2
4	36	10.3
5	29	10.5

TABLE 4: (continued)

B. Hydraulic Conductivity of Partially Saturated Samples

<u>Sample No.</u>	<u>Dry</u>	<u>10% Saturation</u>		<u>20% Saturation</u>	
	<u>Hyd. Cond.</u> (cm/sec)	<u>Hyd. Cond.</u> (cm/sec)	<u>%Difference</u>	<u>Hyd. Cond.</u> (cm/sec)	<u>%Difference</u>
2.5C-2	4.7×10^{-7}	3.0×10^{-7}	36%	2.3×10^{-7}	50%
5C-2	2.4×10^{-6}	2.3×10^{-6}	4%	1.5×10^{-6}	38%
7.5A-1	7.35×10^{-4}	2.4×10^{-4}	67%	1.9×10^{-4}	74%
10A-1	2.5×10^{-3}	2.0×10^{-3}	20%	1.6×10^{-3}	36%

Samples for study of the permeability distribution within saprolite were collected with a two-inch diameter, six-inch long piece of stainless steel tubing. The tubing was cut lengthwise once, and the gap created closed with a radiator clamp during sampling. Figure 8 illustrates one of these sampling devices. The core was removed from the tube by releasing the clamp and allowing the core to slide from the coring device. When the core did not slide freely, it was pushed out of the core gently, or the core was shaken gently to aid the outward movement of the core.

Cores approximately two inches long were collected. The corer was driven into the saprolite by laying a one-half inch thick steel plate across the top of the corer (Fig. 8) and hitting it several times with a small hammer. Some smearing and disturbance of the core occurred adjacent to the walls of the corer. However, so far as could be ascertained, inner portions of the core were undisturbed. Any apparent compaction or smearing of the upper surface of the core associated with discharge of the core from the corer was eliminated by splitting off from the upper portion of the core a layer about one-quarter of an inch thick with a putty knife. This technique usually provided a relatively smooth, flat surface on which the air permeameter could be used.

A sampling area approximately one-foot square was utilized in the field. From this area five cores were collected. To eliminate the effects of smearing associated with clearing the sample area, a short one-quarter to one-half inch long core was first removed from each core site. Then a two-inch long core was collected. This arrangement provided a relatively undisturbed surface on which to test the air permeability. In some cases more than one sample area was utilized per saprolite outcrop.

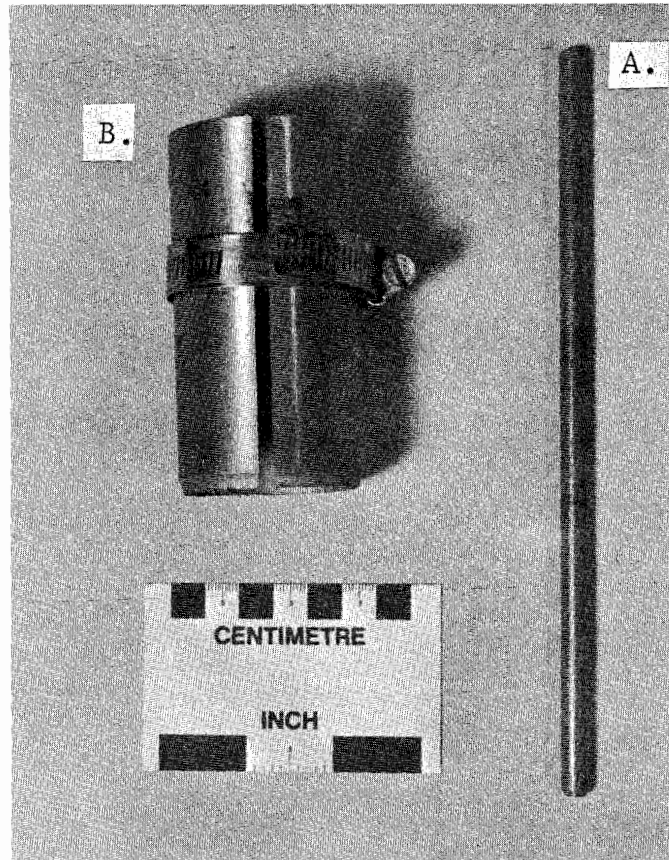


Figure 8. Coring Device

- A. Handle for pulling
- B. Stainless steel corer

Following collection of the cores, the field air permeability at the ambient moisture content was measured in the bottom of the core holes. Five measurements per core hole were made. The cores were returned to the laboratory where the air permeability of the core at the ambient field moisture content was made within two hours of the core collection. The values of these measurements compared favorably with those made in the bottom of the core holes in the field.

The cores were allowed to dry for a minimum of 48 hours in the laboratory at room temperature, between 20°C and 24°C. The air permeability of each dry core was then measured, and the hydraulic conductivity was subsequently obtained from the air permeability -hydraulic conductivity working curves. Five measurements were made across the upper surface of each core.

Table 5 shows the air permeability of a series of ten samples at ambient field moisture content and the air permeability after the cores had dried. From these and similar data it was concluded that the saprolite samples need to dry for a minimum of 24 hours at room temperature and preferably for 48 hours before an accurate permeability determination can be made. Later in the investigation only the air-dried air permeabilities were determined and taken as indicative of the saturated permeabilities of the saprolite.

Of those cores broken during removal from the coring device, the larger fragments were utilized in the permeability measurements. This approach seemed justified based upon the experiments conducted to determine the effect of core length upon the air permeability measurements. Some samples were collected by cutting the saprolite out with a trowel in a square cross-section, which provided a solid mass approximately two inches on the side and two to three inches long. Although samples collected in this

TABLE 5

Comparison of Air Permeability at Field Moisture Content and DryAverage Air Permeameter Ball Height-1/8-inch Steel Ball

Sample	Parent Rock Type (J.M. Parker, III, 1979)	Wet Sample	Indicated Hydraulic Conductivity	Dry Sample	Difference in Ball Height Units	Hydraulic Conductivity from Standard Curve cm/Sec
1	Felsic Gneiss	9.1	3.1×10^{-5}	11.2	2.1	1.3×10^{-3}
18	Felsic Gneiss	8.5	1.2×10^{-5}	10.0	1.5	1.8×10^{-4}
22	Felspathic Gneiss	9.0	3×10^{-5}	10.6	1.6	4.5×10^{-4}
51	Amphibolite	9.1	3.1×10^{-5}	11.3	2.1	1.8×10^{-3}
55	Metavolcanic	11.4	2.0×10^{-3}	11.5	0.1	2.4×10^{-3}

fashion appeared to be appropriate and adequate for the investigation, to maintain uniformity of sample collecting procedures, the coring device was used in most instances.

Results of Field Investigation

Collections were made from saprolite derived from a variety of rock types in Wake County (Parker, 1979). Air permeability determinations were made on the dried samples as well as directly on saprolite in the field where dried surfaces were available in the summer.

Cores were collected at various angles to relict foliation within the saprolite where the foliation could be recognized. However, insufficient sampling of this type was undertaken to allow formulation of any significant conclusions. It was noted in two or three instances that air permeabilities parallel to foliation were greater than those perpendicular to the foliation, a not unexpected result. The field and laboratory measurements on dried saprolite were the same. The bulk of the air permeability determinations and therefore the hydraulic conductivity determinations were made in the fall months when it was necessary to allow the core to dry in the laboratory.

Approximately 250 samples were collected and analyzed with either the one-eighth inch or one-quarter inch permeameter. Table 6 summarizes the results of this portion of the study.

As one would anticipate from the variety of weathering products to be derived from the several rock types, a range of hydraulic conductivity is found associated with each rock type. The hydraulic conductivities recorded in Table 6 are those associated with the more clay-rich portions

TABLE 6

Saprolite Hydraulic Conductivity Summary

<u>Rock Type</u>	<u>Number of Localities</u>	<u>Average Hydraulic Conductivity (cm/sec)</u>
Felsic Gneiss and Schist	10	3.2×10^{-3}
Amphibolite	1	1.1×10^{-3}
Metavolcanics and Metasediments	6	2.7×10^{-3}
Mica Gneiss and Schist	4	2×10^{-3}
Injected Gneiss and Schist	9	9.2×10^{-5}

of the saprolites. Where there was a high proportion silt-and sand-sized material in the saprolite, the air permeameters indicated hydraulic conductivities in the upper ranges of the 10^{-3} cm/sec interval to the 10^{-2} cm/sec range. With less silt and sand in the mixture the hydraulic conductivities fell into the 10^{-5} to 10^{-6} cm/sec range. A few measurements were made in the 10^{-7} cm/sec range in nearly pure clays.

With experience one learns to recognize relative orders of permeability on the basis of textural differences among saprolite samples. The general order is usually confirmed by checking with the air permeameter.

One locality investigated has been observed over a period of years by the author. It has been noted that water seeps from the surface of the road cut for several days and in some cases for a week or more after a period of significant rainfall. The air permeameter measurements on samples from the red silty clay saprolite derived from injected gneiss showed hydraulic conductivities in the 10^{-5} cm/sec range. The magnitude of the hydraulic conductivity at this locality fits with the observed pattern of water seepage from the outcrop.

Table 7 summarizes hydraulic conductivity by lithology of the saprolite and is presented to provide a clue to the variability in hydraulic conductivity within the saprolites investigated. The lithologic descriptions are field descriptions.

CONCLUSION AND SUMMARY

The investigation has demonstrated that an air permeameter can be constructed and utilized for field determinations of saprolite hydraulic conductivity. Obviously care must be exercised in its use. A set of

TABLE 7

Hydraulic Conductivity by Lithology of Saprolite

Clayey silt to silty clay	Felsic gneiss	2.2×10^{-3}
Sandy, silty clay to sandy silt	Felsic gneiss	7×10^{-3}
Clayey silt and sandy, clayey silt	Metavolcanic and metasediments	1.2×10^{-2}
Sandy clay	Injected gneiss	8×10^{-6}
Micaceous, silty clay	Metavolcanic and metasediments	1.8×10^{-4}
Clay	Injected gneiss and schist	6×10^{-7}

appropriate standards must be available to calibrate the instruments. Mixtures of Portland cement and fine sand appear to provide suitable standards.

The five sand-cement mixtures used in the investigation can be considered the minimal number. More hydraulic conductivity standards should be used than were used during the current investigation in order to define more closely the standard working curve. The instruments should be calibrated periodically, although only experience will disclose the frequency of this need.

If the saprolite mass is exposed to the sun and a thin layer dried by the sun, measurements can be made directly on the saprolite in the field. On the other hand, if a significant amount of moisture fills the voids of the saprolite, it is necessary to sample and allow the saprolite to dry prior to any air permeability determinations. So long as the surface over which the air permeabilities are to be determined is not smeared and the sample is of a size to permit handling (approximately two inches in diameter and one-half inch thick), the air permeability determination on a dry sample should reflect the hydraulic conductivity of the material.

Experience with sample collection and use of the air permeameters suggests that for routine field work cores could be left in the coring tubes to dry prior to air permeability measurements. On the other hand, samples can be collected by cutting them out with a trowel or knife and stored on trays or in small boxes to dry at room temperature. They can be placed in an oven and dried for several hours at 110°C. After the samples are cooled, air permeability measurements can be made.

With practice air permeability measurements on 20 to 30 samples can be made in an hour, assuming five readings per sample. Calculations and

conversion of the air permeability measurements to hydraulic conductivity values may require an additional hour.

Two keys exist for the optimal use of the air permeameter. The first is the availability of a good set of standards for conversion of the air permeabilities to hydraulic conductivity. A standard working curve must be prepared from these standards.

Determination of the hydraulic conductivities utilized an easily constructed falling head permeameter and heat-shrinkable plastic to encase the samples.

The second key to use of the permeameter is the care with which the operator seats the air permeameter against the surface of the saprolite. It is especially important for the sponge filter inside the serum cup to be held firmly against the sample and for the edges of the cup to seal out all air except that flowing through the sample surface within the cup.

The air permeameter is sufficiently sensitive to detect changes in air permeability within a single non-uniform sample. Numerous informal experiments were made to evaluate the sensitivity of the instruments. Where textural differences in a single sample implied the probable presence of differences in air permeability, the air permeameters confirmed them. Similarly, textural differences between two cores suggesting existence of air permeability and hydraulic conductivity differences were confirmed by the air permeameter.

The air permeameter has been utilized to determine the hydraulic conductivities of saprolite samples. Several rock types formed the parent material. Although this part of the study did not demonstrate a strong or

direct correlation between hydraulic conductivity of the saprolite and the parent material, it did show that variations in saprolite hydraulic conductivity can be detected using the air permeameter.

The cost (1980) of the materials for the permeameter is approximately \$50.00. Some connecting parts need to be fabricated from plexiglass or aluminum. Once these are machined, it takes about an hour to assemble and test the instrument. Careful calibration should take another one to two hours, depending upon the number of standards used. In addition, of course, it is necessary to prepare the standards and determine their hydraulic conductivity. The one-eighth inch diameter air permeameter functions best for hydraulic conductivities in the 10^{-5} to 10^{-3} cm/sec range. The one-quarter inch diameter permeameter can be best used for hydraulic conductivities in the 10^{-4} to 10^{-1} cm/sec interval, and the one-sixteenth inch diameter permeameter with a steel ball appears to be useful where hydraulic conductivities are 10^{-6} cm/sec or less.

RECOMMENDATIONS

The air permeameter can and should be used in detailed studies of saprolite hydraulic conductivity in the rocks of the Piedmont Province. It can be applied to evaluation of a wide range of potential disposal sites. Use of air permeameter in reconnaissance evaluation of potential hazardous disposal sites is feasible. Also its use in evaluation of other types of waste disposal sites, including sanitary land fills and spray irrigation sites appears justified.

The air permeameter should be applied to studies concerned with hydraulic conductivity variations within saprolite. It presents a rapid, reasonably accurate, and relatively inexpensive means of obtaining a large amount of hydraulic conductivity data in a short time. It would appear to be an appropriate instrument to be applied to a regional study of saprolite hydraulic conductivity. Information from such studies could provide improved insight to recharge to groundwater in the Piedmont Province.

In addition, additional detailed work on the effects of partial saturation on the measurements made with the air permeameter needs to be undertaken. Results from such studies could perhaps demonstrate the feasibility of assessing levels of partial saturation in saprolitic material with an air permeameter.

ACKNOWLEDGMENT

The investigation benefitted from informal discussions of techniques and methodology with a number of colleagues. The insights provided by Ralph C. Heath proved valuable. Graduate students Charlotte L. Otts and Pei Tau Tang constructed the equipment and ran most of the laboratory tests.

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