**ENVIRONMENTAL MANAGEMENT SCIENCE PROGRAM**

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# New Permeameters for in situ Characterization of Unsaturated Heterogeneous Permeability: Development, Design, Testing, and Application:

Progress Report for the Period 10/96 to 10/97

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## Introduction and Summary

During the past year, contractual difficulties have prevented significant progress on this research. This research project is a joint effort between New Mexico Institute of Mining and Technology (NMIM&T) and Sandia National Laboratories (SNL). **As** specified in the proposal, NMIM&T was to award a subcontract to SNL. Unfortunately, NMIM&T and SNL were unable to come to a satisfactory agreement on the nature of the subcontract until August, 1997, when funds were finally transferred from NMIM&T to SNL, As a result, first year progress has been less than expected.

Despite these difficulties, some progress has been made during fiscal year (FY) 1997. Our evaluation of steady-state methods for inverting permeameter data is nearing completion. As part of this effort, we developed several new approaches for estimating unsaturated hydraulic conductivity from steady-state permeameters, verified new and existing approaches for inverting steady-state data, and are preparing several manuscripts related to steady-state permeametry. Although steady-state methods for estimating unsaturated hydraulic conductivity can potentially yield accurate estimates of unsaturated hydraulic conductivity, practical implementation of these methods will violate our first design criterion, rapid measurement (presented below). Due to the large time scales associated with steady-state methods, we have chosen to focus further efforts on transient techniques. Because straightfoward analytical inversion approaches arc not an option for transient tests, numerical inversion methods will be used for transient permeametry, and we are currently evaluating several numerical codes for use in the inversion of permeameter data. We have chosen a modular approach for permeameter design to maximize final product flexibility, Individual components can then be used in several permeameter configurations. Preliminary designs of permeameter components have been completed. These designs will be finalized, fabricated, and tested during FY 1998.

## Permeameter Program Status

The primary objective of our EMSP research is to design, develop, and test new permeameters for use in spatial variability studies. In our proposal, we develop a series of permeameter design criteria. We have not modified these criteria, and we review them here. Devices or techniques for measuring the unsaturated hydraulic properties should posses the following attributes: 1) measurements should be relatively rapid, 2) the total cost per data point should be low, 3) results would accurately reflect the variation of unsaturated permeability between sampled locations. 4) the

volume sampled (measurement support) would be small, and 5) predicted parameters would be relevant to the range of soil moisture conditions encountered at DOE sites. In order to satisfy these criteria, we have employed a systematic approach for the design, construction and testing of new permeameters. Research activities are subdivided into three major tasks to be performed concurrently. In the following sections, we summarize current progress and planned research activities for each task.

***TASK 1 - Permeameter Design.***

The objectives of this task include: 1) define the parameter range of interest for rocks and sediments in the western U.S., 2) develop analytical and numerical parameter estimation methods for inverting field permeameter data, and 3) design permeameter devices consistent with promising methods for inverting permeameter data and the design criteria.

We have conducted a literature review of the hydraulic character of rocks and sediments present within basin deposits of the western U.S. with focus on saturated hydraulic conductivity and parameters that define the pressure-saturation relationship and relative permeability. We have constructed a preliminary database and are collecting additional reference materials. This information will be used for optimizing permeameter designs for relevant materials and for the development laboratory standards for permeameter testing. We are currently evaluating, developing and verifying analytical and numerical parameter estimation methods for inverting field permeameter data. During the past year, research efforts were focused on developing techniques for inverting steady-state permeameter data and verification of these techniques with numerically-generated permeameter data. We have developed and verified several methods for inverting steady-state permeameter data. These inversion techniques are ail analytical or quasi-analytical and based upon piecewise and piecewise continuous quasilinear models for steady unsaturated flow. Unsaturated hydraulicconductivities are estimated at specific tensions and are independent of any parametric unsaturated hydraulic conductivity model. This represents an advantage over numerical estimation techniques, because numerical estimation yields model-specific parameter values. These techniques were verified by inverting numerically-generated permeameter data sets and comparing estimates of unsaturated hydraulic conductivity at specific tensions against numerical input values. Inversion techniques for steady-state permeameters with buried point sources, surface *disk* sources, and geometrically-constrained, one-dimensional areal sources have been verified. Because the time-scales required to reach steady state are large, however, it is unlikely that our permeameter designs will be based upon steady-state flow. We are currently generating additional numerical data sets and preparing several manuscripts related to steady-state permeametry for submission to peer-reviewed journals.

Because no analytical approaches exist for inverting transient permeameter data, we have begun preliminary comparisons of various unsaturated flow codes and numerical parameter estimation techniques. Currently, we are evaluating the performance of several numerical flow codes.

We have completed preliminary permeameter component designs. The basic permeameter design is modular consisting of a source package and an instrument package. Development of each package is proceeding independently, allowing for flexibility in specific permeameter configuration. Preliminary designs of source components are currently being considered. These include constant and pulsed injection sources and constant potential sources. Two generic instrument package (IP) have been designed for in situ measurement of state variables within the permeameter flow domain. The first type of IP is designed for use on flat surfaces, while the second IP is designed for use down small diameter boreholes.

***TASK 2 - Permeameter Construction and Laboratory Testing***

Objectives for this task include: 1) construction of laboratory standard materials that reflect the range of unsaturated hydraulic properties found in the western U.S., 2) laboratory testing and

verification of permeameter components, 3) construction of prototype permeameters devices, and 4) evaluation of permeameter sensitivity to measurement support heterogeneity.

Because the performance of permeameter devices and components will be tested and verified in a laboratory setting, laboratory standard material that reflect the range of unsaturated hydraulic properties found in the western U.S. are required. Beginning in FY 1998, we will design and construct several laboratory standard materials, As part of this effort, we will standardize procedures for consistently mixing laboratory sands and silts to arrive at test materials with a uniform composition. We will also develop and implement techniques for uniform packing of these materials into test containers of varying shape and size (e.g., columns, thin slabs, and large boxes). Once we are assured that packing techniques are sufficient, we the hydraulic properties of the laboratory standards will be measured using standard techniques. Permeameter components consist of a source package and an instrument package containing devices for measuring state variables (e.g., tension and moisture content). In order to optimize the performance of permeameter devices, the performance of individual permeameter components must be satisfactory. We are evaluating the performance of permeameter components. We are initially using micro-tensiometer devices will be used to make in situ tension measurements, although we are investigating the feasibility of using other devices. In situ moisture content measurements with a small measurement support are critical for inverting transient permeameter data, and we are currently evaluating several different techniques for estimating in situ moisture content during permeameter infiltration, including &vices based upon electrical conductivity/resistance, time domain reflectrometry, and optical reflectance. On all permeameter components, we will measure critical performance criteria, including: response time, accuracy, precision, and measurement support, Once we have constructed prototype permeameter devices, the sensitivity of permeameter results to local-scale heterogeneity will be quantified through experiments in heterogeneous laboratory flow-ceils developed at the SFTPL. We will use techniques developed at the SFTPL for the controlled construction of heterogeneous flow-cells.

***TASK 3 - Field Testing of Permeameter Designs.***

The objectives of this task include: 1) field test permeameter designs will be conducted to evaluate their utility and confirm their performance, 2) coincident undisturbed samples will be removed and tested in the laboratory for permeameter field validation, and 3) final prototype designs will be used to conduct a small-scale study of the spatial variability of unsaturated hydraulic conductivity.

This task will be performed during the last year of funding. A field test site, however, has already been selected, and permeameter testing will be performed at a U.S. DOE EMSP project site (A Hybrid Hydrogeologic - Geophysical Inverse Technique for the Characterization, Monitoring, and Risk Assessment of Leachates in the Vadose Zone) in Socorro, New Mexico. We have already begun testing of saturated hydraulic conductivity along trenches at this site, using an air minipermeameter developed through projects of DOE's Subsurface Science Program.