PHASE I REVIEW: DOE STUDY PLAN FOR CHARACTERIZATION OF THE UNSATURATED-ZONE INFILTRATION (STUDY PLAN 8.3.1.2.2.1 REV. 0)

by

Rex G. Wescott

Hydrologic Transport Section
Geosciences & Systems Performance Branch
Division of High-Level Waste Management, NMSS
US Nuclear Regulatory Commission

April 19, 1991

Introduction

The purpose of the DOE "Study Plan For Characterization of the Unsaturated-Zone Infiltration" is to investigate the mechanisms, paths and quantities of infiltration at the Yucca Mountain Site. The study plan contains three activities: (1) Characterization of hydrologic properties of surficial materials (8.3.1.2.2.1.1), (2) Evaluation of natural infiltration (8.3.1.2.2.1.2), and (3) Evaluation of artificial infiltration (8.3.1.2.2.1.3). The specific objectives of these three activities are to:

1) determine present-day net-infiltration rates (fluxes) in response to natural-precipitation events;
2) determine the range of net-infiltration rates, flow velocities, and flow pathways that can be expected under simulated wetter climatic conditions; and
3) characterize the infiltration-related hydrologic properties for the surficial materials on Yucca Mountain.

The study plan was reviewed with respect to (A) DOE/NRC agreements on the content of study plans, (B) Identification of objections, (C) Closure of NRC open Items, and (D) The need for a detailed review (See review plan for NRC staff Review of DOE Study Plans, Revision I, 12/6/90).

Evaluation of Study Plans Relative to the Agreement and to the Responsible DOE Contractor's QA Program (Objectives 1 and 5)

Criterion 1- The content of the study plan under review is reasonably consistent, as appropriate for the activities, tests and analyses described, with the Agreement (NRC-DOE meeting on the level of detail for site characterization plans (SCP) and study plans May 7-8, 1986)

Staff Review: Attached (Attachment A) is an itemized checklist of the study plan content versus the agreement on content resulting from the level of detail meeting. The study plan

9104290318 910424
NMSS SUBJ
102.8 CF

contains three activities, characterization of the hydrologic properties of surficial materials, evaluation of natural infiltration, and evaluation of artificial infiltration. The study plan lists field tests and analysis methods that will be used to carry out the activities. Because of the nature of the activities, much of the information required in the Level of Detail Agreement can not be provided until prototype testing (part of the study plan) is completed. In our judgement these deficiencies do not compromise our ability to review the study plan for impacts and effectiveness.

Criterion 2 - All study plan references have been provided when the study plan was issued.

Staff Review: The study plan lists 75 references in addition to the DOE Site Characterization Plan (SCP) and the USGS Quality Assurance Program Plan for Nevada Nuclear Waste Storage investigation. Of these only 11 were listed as references for Chapter 3, Hydrology, of the SCP. Of the remainder, most appeared to be available as government reports, articles in widely circulated journals, textbooks, or ASTM standards. A few, however, were in the category of papers still in the review process, unpublished thesis, and foreign conference proceedings. These references are expected to be difficult to obtain. Attachment B is a copy of the list of references from the Study Plan with all references marked either SCP (referenced in the SCP), AA (assumed to be available), or NAA (not assumed to be available. DOE should provide copies of all references marked NAA to NRC. Copies of references marked AA may be requested later if required for future reviews or exchanges.

Criterion 3 - Open items relative to the QA program of the DOE contractor responsible for the study plan that could call into question the quality of the study plan, have been resolved.

Staff Review: [TO BE DETERMINED BY THE QA REVIEWER]

<u>Identification of Objections (Objectives 2 through 6)</u>

Criterion 1 - Potential adverse effects on repository performance:

Staff Review: Adverse effects are not expected. Activities which could affect the site are limited to the drilling of boreholes for neutron logging and use of water sprays for artificial infiltration experiments. Of the 98 neutron-access boreholes listed in the study plan, only 24 are proposed, the remainder are existing boreholes. Some of the existing boreholes extend to depths of 120 ft. The planned depth for the proposed holes is 50 ft. No holes will penetrate the repository block. In regard to the artificial infiltration experiments, the

rainfall simulation plots will only affect a small amount of surface area. According to the study plan, there will be 23 small plot rainfall simulation sites covering about 1 square meter each. There will be 15 large plot rainfall simulation plots covering about 60 square meters each. The amount of water to be used in the experiments will be less than 30 cm. over the test areas or about two years rainfall.

Criterion 2 - Potential significant and irreversible/unmitigable effects on characterization that would physically preclude obtaining information necessary for licensing.

Staff Review: None. No interference is expected between these tests and other characterization activities, nor will these tests affect any other activities.

Criterion 3 - Potential significant disruption to characterization schedules or sequencing of studies that would substantially reduce the ability of DOE to obtain information necessary for licensing.

Staff Review: Disruption of schedules is not expected. This study includes the monitoring of meteorologic and hydrologic parameters over many years and should be initiated as soon as permitted and continued through the performance confirmation period. Accordingly, the schedule for this study should be independent from other studies and not disrupt other schedules.

Criterion 4 -Inadequacies in the QA program which must be resolved before work begins.

Staff Review: [TO BE DETERMINED BY THE QA REVIEWER]

<u>Closure of NRC Open Items (Objectives 8 and 11)</u>

Staff Review: Not applicable - DOE did not propose to close any open items with this study plan in its transmittal letter.

Need for Detailed Technical Review

A study plan is a candidate for detailed technical review if it meets any of the following criteria from step 6 of part 4.2 of the Review Plan.

Criterion 1 - The study plan may be related to one or more key site related issues.

Staff Review: Determining the range of net infiltration rates, flow velocities, and flow pathways that can be expected under present day and simulated wetter conditions are key site related issues in regard to regulatory requirements such as performance assessment, groundwater travel time, EBS release rates, and waste package integrity.

Criterion 2 - The study plan pertains to some NRC open items.

Staff Review: NRC Staff Comment 13 on the DOE SCP regarding locations of stream flow, precipitation, and meteorological stations listed Study 8.3.1.2.1.2 (Characterization of Runoff and Streamflow) and Activity 8.3.1.2.1.2.1 (Surface-water Runoff Monitoring) along with Study 8.3.1.2.2.1 (Characterization of Unsaturated-Zone Infiltration) and Activity 8.3.1.2.2.1.2 (Evaluation of Natural Infiltration). The comment and recommendation are primarily concerned with the first listed study plan and activity, however. The status of Comment 13 will be discussed in the detailed technical review of Study Plan 8.3.1.2.1.2 (Characterization of the Yucca Mountain Regional Surface-water Runoff and Streamflow).

Criterion 3 - The study plan describes unique, state-of-the-art tests or analysis methods that therefore do not have a supportive scientific history of providing data usable in licensing.

Staff Review: The study plan describes a number of techniques that are relatively new investigation methods or have not been used on the scale being proposed by the study plan.

Criterion 4 - The study plan describes a study critical to the evaluation of site performance that cannot be repeated for a number of years due to its disruption of the natural baseline.

Staff Review: The natural baseline will be disrupted, possibly for a number of years, at the sites of the large plot rainfall simulation studies. At many locations, however, the large plot simulations can be moved to another location if they should need to be repeated.

Criterion 5 - The study has some other critical relationship to potential licensing concerns.

Staff Review: The staff has no licensing concerns in regard to this study plan other than those listed above.

This study plan is a candidate for a detailed technical review based on criteria 1, 3, and 4. However, many procedures will not be finalized until after the prototype testing phase. Therefore, we suggest that a detailed technical review not be conducted. As an alternative, we suggest that technical exchanges, possibly with accompanying field visits, be used to monitor the progress of the data collection program.

ATTACHMENT A

Phase I Review of Study Plan 8.3.1.2.2.1
Characterization of the Unsaturated Zone-Infiltration

Rex G. Wescott, Hydrologic Transport Section
April 15, 1991

I. Purpose and Objective

Describe the information to be obtained in the study.
Yes__X__ No_____ N/A_____

Provide the rationale for information to be obtained.
Yes__X__ No_____ N/A_____

II. Rationale for Study/Investigation

Provide rationale for tests and analysis, indicating alternatives considered and options, advantages, and limitations.
Yes__X__ No_____ N/A_____

A multiple approach strategy is being pursued with test designed to compliment one another.

Provide the rationale for the number, location, duration and timing of tests, considering uncertainty, and identify obvious alternatives.
Yes__X__ No_____ N/A_____

Describe the constraints for the study, considering:

- Potential site impacts
  Yes__X__ No_____ N/A_____

Approximately 100 neutron access boreholes will be drilled into surficial units. Planned depth for new holes is about 50 feet. Some existing holes are down to 120 ft. Less than 30cm water to be used in infiltration studies, equivalent to about two years rainfall.

- Need to simulate repository conditions
  Yes____ No_____ N/A__X___

Stated as being test dependent. It is understood that parameters determined from this study may have to be adjusted in performance assessment for climatic changes or the effects of the repository.

- Required Accuracy and precision
  Yes__X__ No_____ N/A_____

- Limits of Analytical Methods
  Yes__X__ No_____ N/A_____

- Capability of Analytical Methods
  Yes__X__ No_____ N/A_____

The limits and capabilities of each analytical method are not described explicitly in the text but are included in the discussion of most of the various methods.

- Time required vs. time available
  Yes__X__ No_____ N/A_____

- Scale of Phenomena and Parameters
  Yes__X__ No_____ N/A_____

- Interference among test
  Yes__X__ No_____ N/A_____

- Interference between tests and ES
  Yes__X___ No_____ N/A_____

III. Description of Tests and Analysis
<u>For each Type of Test</u>

- Describe general approach that will be used.
  Yes__X___ No_____ N/A_____

- Describe key parameters that will be measured in test and experimental conditions under which the test will be conducted.
  Yes__X___ No_____ N/A_____

- Indicate number of tests and locations.
  Yes__X__ No_____ N/A_____

- Summarize test methods if non-standard procedure, summarize steps of test, how it will be modified, and reference technical procedure.
  Yes_____ No__X__ N/A_____

Steps of non-standard tests will be formalized after prototype testing.

- Indicate level of QA and provide rationale for any tests not QA level.
  Yes_____ No_____ N/A_____

- Reference the applicable specific QA requirements applied to test.
  Yes_____ No____ N/A_____
  [TO BE DETERMINED BY QA REVIEWER]

- Specify tolerance, accuracy, and precision required in test.
  Yes_____ No__X__ N/A_____

The accuracy and precision of the tests can not be accurately quantified prior to the implementation of prototype testing.

- Indicate range of expected results and basis for those results.
  Yes__X___ No_____ N/A_____

- List equipment requirements, briefly describing special equipment.
  Yes_____ No__X__ N/A_____

Equipment selection and development is a major objective of the prototype testing. As such, specification of equipment to be used during site characterization cannot be completely defined until this testing is complete. For standard testing methods, equipment lists may be found in the technical procedures noted for each activity described in Section 3 of this plan.

- Describe techniques to be used for data reduction and analysis.
  Yes__X__ No_____ N/A_____

- Describe representativeness of test, indicating limitations and uncertainties that apply to use of results.
  Yes_____ No__X__ N/A_____

The representativeness of the test is discussed in general terms, limitations and uncertainties are not explicitly listed.

- Provide illustrations of test locations.
  Yes__X__ No_____ N/A_____

- Discuss relationship of test to set performance goals and confidence levels.
  Yes__X__ No_____ N/A_____

<u>For Each Type of Analysis</u>

- State purpose of analysis, indicate conditions to be evaluated and describe any uncertainty analysis.
  Yes__X__ No_____ N/A_____

- Describe methods of analysis, including analytical expressions and numerical models to be used.
  Yes__X__ No_____ N/A_____

- Reference the technical procedures document that will be followed during analysis.
  Yes__X__ No_____ N/A_____

- Indicate levels of QA applied.
  Yes_____ No_____ N/A_____
  [TO BE DETERMINED BY QA REVIEWER]

- Identify data input requirements.
  Yes__X__ No_____ N/A_____

- Describe expected output and accuracy.
  Yes_____ No__X__ N/A_____

The accuracy of the various analysis will depend, to a large part, on the accuracy of the input parameters.

- Describe representativeness of analytical approach, indicating limitations and uncertainties that apply to results.
  Yes_____ No__X__ N/A_____

The limitations and uncertainties of each analytical approach were not explicitly listed, however, representativeness of each can usually be ascertained from the discussion.

IV. Application of Results

Briefly discuss where results from study will be used for support of other studies.
Yes__X__ No_____ N/A_____

Refer to specific performance assessment analyses.
Yes__X__ No_____ N/A_____

Describe where information from study will be used in construction equipment and engineering system design and development.
Yes__X__ No_____ N/A_____

Describe where information from study will be used in planning other characterization activities.
Yes__X__ No_____ N/A_____

V. Schedules and Milestones

Provide durations of and interrelationships among principal activities associated with this study.
Yes__X__ No_____ N/A_____

List key milestones including decision points associated with study activities.
Yes__X__ No_____ N/A_____

Describe timing of study relative to other studies and other program activities.
Yes__X__ No_____ N/A_____

Provide dates for activities for the study plans: reference section 8.5 in SCP.
Yes_____ No__X__ N/A_____

Dates are expressed in terms of fiscal years after inception of the study plan.

6.0 REFERENCES

NAA Abrams, M. J., Conel, J. E., and Lang, H. R., 1984, The Joint NASA/GEOSAT Test Case Project--Final Report, Paley, H. N., editor: Tulsa, Oklahoma, American Association of Petroleum Geologists, pt. 2, v. I. Sections 1 and 2, p. 1-1 to 2-24.

AA American Society for Testing and Materials, 1984a, Density of soil and soil-aggregate material in place by nuclear methods (shallow depth): ASTM D 2922-81, Annual Book of ASTM Standards, v. 04.08, Philadelphia, Penn.

AA American Society for Testing and Materials, 1984b, Density of soil in place by the sand cone method: ASTM D 1556-82, Annual Book of ASTM Standards, v. 04.08, Philadelphia, Penn.

AA Asquith, G. and Gibson, C., 1982, Basic well log analysis for geologists: Amer. Assoc. of Petroleum Geologists, Tulsa, Okla., 216 p.

AA Benson, R. C., Glaccum, R. A., and Noel, M. R., 1982, Geophysical techniques for sensing buried wastes and waste migration: U. S. Environmental Protection Agency, Las Vegas, Nevada.

NAA Bouwer, H., 1961, A study of final infiltration rates from cylinder infiltrometers and irrigation furrows with an electrical resistance network: in Trans. Int. Congr. Soil Sci. 7th, 6:448-456.

AA Bouwer, H., 1966, Rapid field measurement of air-entry value and hydraulic conductivity as significant paramters in flow system analysis: Water Resources Research 2:729-738.

AA Brutsaert, W., 1982, Evaporation into the atmosphere; theory, history and applications: D. Reidel Publishers, Boston, Massachusetts, p. 299.

AA Campbell, G. S., 1977, Introduction to Environmental Biophysics: Springer-Verlag New York Inc., 159 p.

AA Campbell, G. S., 1985, Soil Physics with BASIC: Elsevier, New York, 150 p.

AA Chow, V. T., Maidment, D. R., and Mays, L. W., 1988, Applied Hydrology: McGraw-Hill Book Company, New York, N.Y., 572 p.

AA Clark, I., 1979, Practical Geostatistics: Applied Science Publishers, London, U. K., 126 p.

NAA Constantz, J., and Herkelrath, W. N., 1988, Field measurements of the influence of entrapped air upon ponded infiltration rates: Infiltration Principles and Practices, Proceedings International Conference Infiltration Development and Application, January 1988, Honolulu, Hawaii, p. 398-407.

SCP Czarnecki, J. B., 1985, Simulated effects of increased recharge, Yucca Mountain and vicinity, Nevada-California: U.S. Geological Survey Water- Resources Investigations Report 84-4344, 33p.

AA Dailey, W., and Ramirez, A. L., 1984, In-situ porosity distribution using geophysical tomography: Geophysical Research Letters, v. 11:614-616.

AA David, M., 1977, Geostatistical Ore Reserve Estimation: Elsevier Scientific Publishing Company, New York, N. Y., 364 p.

AA de Bruin, H. A. R., 1988, Evaporation in arid and semi-arid regions: *in* "Estimation of Natural Groundwater Recharge," edited by I. Simmers; NATO ASI Series C: Mathematical and Physical Sciences, v. 222, D. Reidel Publishing Company, Dordrecht, Holland, p. 73-88.

AA de Vries, D. A., 1963, Thermal properties of soils: *In* W. R. Van Wijk (ed.) Physics of plant environment, North-Holling Publishing Co., Amsterdam, p. 210-235.

AA Dreiss, S. J. and Anderson, L. D., 1985, Estimating vertical soil moisture flux at a land treatment site: Groundwater, 23(4):503-511.

AA Eijpe, R., and Weber, K. J., 1971, Mini-permeameters for consolidated rock and unconsolidated sand: Americam Association Petroleum Geologist, Bulletin 55:307.

NAA Firdaouss, M., Maalej, M., and Belin, B., 1983, Identification of the soil thermal diffusivity from the temperature *in situ* measurements in a semi-arid region: *In* R. W. Lewis, J. A. Johnson and W. R. Smith (eds.), Proceedings 3rd International Conference Numerical Methods in Thermal Problems, August 2-5, 1983, Seattle, Wash.

AA Flint, A. L., and Childs, S. W., 1984a, Physical properties of rock fragments and their effect on available water in skeletal soils: *In* Erosion and Productivity of Soils Containing Rock Fragments, Soil Science Society America Special Publ. No. 15, Soil Science Society of America, Madison, Wisc., p. 91-103.

AA Flint, A. L. and Childs, S. W., 1984b, Development and calibration of an irregular hole bulk density sampler: Soil Science Society of America Journal, 48:374-378.

NAA Flint, A. L. and Childs, S. W., 1987a, Modification of the Priestley-Taylor evaporation equation for soil water limited conditions: *In* 18th Conference on Agricultural and Forest Meteorology, W. Lafayette, Indiana, September, 1987, pp. 70-73.

AA Flint, A. L. and Childs, S. W., 1987b, Calculation of solar radiation in mountainous terrain: Journal Agricultural and Forest Meteorology, 40:233-249.

AA Flint, A. L. and Childs, S. W., 1987c, Detail of field measurements required to estimate soil thermal environments, Soil Science Society America Journal, 51:1326-1331.

AA Flint, A. L. and Davies, W. J., 1988, Analysis of the measurement and models of net radiation in desert terrain: Abstract, Soil Science Society of America Annual Meetings, Anaheim, California, December, 1988.

AA Flint, L. E., Flint, A. L., and Childs, S. W. 1987, Estimation of cloudy sky radiation using air temperature and modeled clear sky radiation: Abstract, Soil Science Society of America Annual Meetings, Atlanta, Georgia, December, 1987.

SCP Freeze, R. A., and Cherry, J. A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice-Hall, 604 p.

AA French, R. H., 1985, Daily, seasonal, and annual precipitation at the Nevada Test Site, Nevada: U.S. Dept. of Energy, Nevada Operations Office, #DE-AC08-85NV10384, Publ. # 45042, 40 p.

AA Fuchs, M. and Tanner, C. B., 1968, Calibration and field test of soil heat flux plates: Soil Science Society of Amer. Proceedings 32:326-328.

NAA Hammermeister, D. P., Blout, D. O., and McDaniel, J. C., 1985, Drilling and coring methods that minimize the disturbance of cuttings, core, and rock formation in the unsaturated zone, Yucca Mountain, Nevada: Proceedings of the NWWA Conference on Characterization and Monitoring of the Vadose (Unsaturated) Zone: National Water Well Association, p. 507-541.

AA Hanks, R. J. and Ashcroft, G. L., 1980, Applied Soil Physics: Springer-Verlag New York Inc., 159 p.

AA Hanks, R. J., Austin, D. D., and Ondrechen, W. T., 1971, Soil temperature estimation by a numerical method: Soil Science Society of Amer. Journal 35:665-667.

AA Hatfield, J. L., Reginato, R. J., and Idso, S. B., 1983, Comparison of long-wave radiation calculation methods over the United States: Water Resources Research, vol. 19:285-288.

AA Henley, S., 1981, Nonparametric Geostatistics: Applied Science Publishers, Halsteaad Press, John Wiley and Sons, New York, N. Y.

NAA Hevesi, J. A., Istok, J. D., and Flint, A. L., 1989a, Precipitation estimation in mountainous terrain using multivariate geostatistical analysis: 1-structural analysis: (in peer review)

NAA Hevesi, J. A., Flint, A. L., and Istok, J. D., 1989b, Precipitation estimation in mountainous terrain using multivariate geostatistical analysis: 2-applications: (in peer review)

SCP Hillel, D., 1980, Fundamentals of soil physics: Orlando, Florida, Academic Press, 120 p.

AA Horton, R., Wierenga, P. J., and Nielsen, D. R., 1983, Evaluation of methods for determining the apparent thermal diffusivity of soil near the surface: Soil Science Society of Amer. Journal 47:25-32.

AA Journel, A. G., and Huijbregts, Ch. J., 1978, Mining geostatistics: London, England, Academic Press, 600 p.

AA Keys, W. S., and MacCa[illegible] L. M., 1972, Application of bo[illegible]hole geophysics to water-resources investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 2, chap. E1, 126 p.

SCP Klavetter, E. A. and Peters, R. R., 1986, Fluid flow in a fractured rock mass: NNWSI Project Sandia Report SAND85-0855, Sandia National Labs, Albuquerque, New Mexico, 55 p.

NAA Kneiblher, C. R., 1985, Seismic refraction surveys of alluvium-filled washes, Yucca Mountain, Nevada: Reno, Nevada, University of Nevada, Reno, unpublished M.S. thesis, 112 p.

AA Kolm, K. E., 1985, Evaluation of techniques for mapping land and crops irrigated by center pivots from computer-enhanced landsat imagery in part of the James River basin near Huron, South Dakota: U.S. Geological Survey Water-Resources Inv. Report 85-4021, 24 p.

AA Kolm, K. E. and Case, H. L., 1984, The identification of irrigated crop types and estimation of acreages from Landsat imagery: Photometric Engineering and Remote Sensing, 50(10):1479-1490.

AA Libardi, P. L., Reichardt, K., Nielsen, D. R., and Biggar, J. W., 1980, Simple field methods for estimating soil hydraulic conductivity: Soil Science Society of America Journal, 44:3-7.

AA Matheron, G., 1963, Principles of geostatistics. Econ. Geol. 58:1246-1266.

SCP Montazer, P., and Wilson, W. E., 1984, Conceptual model of flow in the unsaturated zone, Yucca Mountain, Nevada: U.S. Geological Survey Water-Resources Investigation Report 84-4345, 55 p.

AA Monteith, J. L., 1964, Evaporation and environment: *In* The state and movement of water in living organisms, 19th Symposium Society Experimental Biologists, p. 205.

NAA Morineau, Y., Simandoux, P., and Dupuy, M., 1965, Etude des heterogeneities de permeabilities dans les milieux poreux. Compte Rendu de Ileme Colloque de l'Association de Recherche sur les Techniques de Forge et de Production, Rueil, May 31-June 4:273.

SCP Nichols, W. D., 1985, Geohydrology of the unsaturated zone at the burial site for low-level radioactive waste near Beatty, Nye County, Nevada: U.S. Geological Survey Open-File Report 85-198.

AA Pankratz, L. W., 1982, Reconnaissance seismic refraction studies at Calico Hills, Wahmonie, and Yucca Mountain, Southwest Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Open-File Report 82-478, 25 p.

AA Penman, J. L., 1948, Natural evaporation from open water, bare soil and grass: Proceedings Royal Society London, A193:120-145.

AA Phillips, F. M., Mattick, J. L., Duval, T. A., Elmore, D., and Kubik, P. W., 1988, Chlorine 36 and tritium from nuclear weapons fallout as tracers for long-term liquid and vapor movement in desert soils: Water Resources Research 24(11):1877-1891.

AA Priestley, C. H. B. and Taylor, R. J., 1972, On the assessment of surface heat flux and evaporation using large-scale parameters: Monthly Weather Review 100(2):81-92.

AA Ramirez, A. L. and Dailey, W. D., 1984, Preliminary evaluation of alterant geophysical tomography in welded tuff: Lawrence Livermore National Lab, UCID-20289.

NAA Reynolds, W. D., and Elrick, D. E., 1985, Measurement of field-saturated hydraulic conductivity, sorptivity and the conductivity-pressure head relationship using the "Guelph Permeameter", in Proceedings, Conference on Characterization and Monitoring of the Vadose Zone, Denver, Colorado, November 1985: National Water Well Association P. 9-33.

AA Richards, L. A., Gardner, W. R., and Ogata, G., 1956, Physical processes determining water loss from soil: Soil Science Society of Amer. Proceedings 20:310-314.

AA Sabins, F. F., 1978, Remote sensing--Principles and interpretations: San Francisco, California, W. H. Freeman and Company, 526 p.

SCP Sass, J. H., and Lackenbruch, A. H., 1982, Preliminary interpretation of thermal data from the Nevada Test Site: U.S. Geological Survey Open-File Report 92-973, 30 p.

SCP Scott, R. B., and Bonk, J., 1984, Preliminary geologic map of Yucca Mountain with geologic sections, Nye County, Nevada: U.S. Geological Survey Open-File Report 84-494, 9 p.

NAA Scotter, D. R., Clothier, B. E., and Harper, E. R., 1982, Measuring saturated hydraulic conductivity and sorptivity using twin rings: Aust. J. Soil Res. 20:295-304.

NAA Schmidt, M. R., 1988, Classification of upland soils by geomorphic and physical^Eproperties affecting infiltration at Yucca Mountain, Nevada: Golden, Colo., Colorado School of Mines, unpublished M.S. thesis, 116 p.

AA Sivapalan, M. and Wood, E. F., 1986, Spatial heterogeneity and scale in the infiltration response of catchments: In Scale Problems in Hydrology, Gupta, V. K., Rodriguez-Iturbe, I., and Wood, E. F. (editors), D. Reidel Publishing Co., Boston, Mass., p. 81-106.

AA Sjögren, B., 1984, Shallow refraction seismic: Chapman and Hall, New York, 270 p.

AA Teasdale, W. E., and Pemberton, R. R., 1984, Wireline-rotary air coring of the Bandalier Tuff: U.S. Geological Survey Water-Resources Investigations Report 84-417, 9 p.

AA Telford, W. M., Geldart, L. P., Sheriff, R. E., and Keys, D. A., 1976, Applied Geophysics: Cambridge University Press, Cambridge, U. K., 860 p.

NAA Topp, G. C. and Davis, J. L., 1982, Measurement of soil water content using time-domain reflectometry: Canadian Hydrology Symposium: 82, Assoc. Comm. on Hydrology, National Research Council of Canada, Ottawa, p. 269-287.

AA Tsang, Y. W., and Tsang, C. F., 1989, Flow channeling in a single fracture as a two-dimensional strongly heterogeneous permeable medium: Water Resources Research, 25(9), 2076-2080.

U.S. Department of Energy, 1988, Draft Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada, Washington, D.C.

U.S. Geological Survey, 1986, Quality-assurance-program plan for Nevada Nuclear Waste Storage Investigation, NNWSI-USGS-QAPP-01, R4, Preparation of technical procedures, NNWSI-USGS-QMP-5.01, R1.

SCP Walker, G. E., and Eakin, T. E., 1963, Geology and groundwater of Amargosa Desert, Nevada-California: Nevada Department of Conservation and Natural Resources Reconnaissance Report 14, 57 p.

SCP Wang, J. S. Y. and Narasimhan, T. N., 1985, Hydrologic mechanisms governing fluid flow in a partially saturated fractured porous medium: Water Resources Research 21(12):1861-1874.

AA Watson, K. K., 1966, An instantaneous profile method for determining hydraulic conductivity of unsaturated porous materials: Water Resources Research, 2:709-715.

AA Wilson, L. J., 1982, Monitoring in the vadose zone--part II: Groundwater Monitoring Review, 2(1):31-42.

SCP Winograd, I. J., and Thordarson, W., 1975, Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with special reference to the Nevada Test Site: U.S. Geological Survey Professional Paper 712-C, 126 p.