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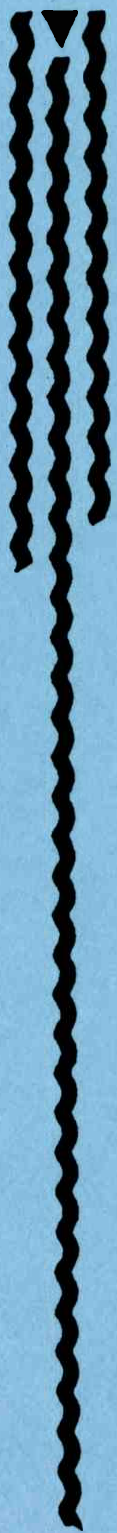

SUMMARY OF PROJECT

ASSIST IN DEVELOPING ASTM STANDARDS FOR SOIL-CORE MONITORING AND FOR PORE-LIQUID SAMPLING IN THE VADOSE ZONE

Submitted by:
The Water Resources Research Center
College of Engineering and Mines
The University of Arizona
Tucson, Arizona 85721

David W. Dorrance
L.G. Wilson

Submitted to:
The University of California
Santa Barbara, California 93106

June 30, 1989

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INTRODUCTION

The University of California at Santa Barbara (UCSB) is under contract with the United States Environmental Protection Agency (EPA) to conduct a project entitled: "Vadose Zone Equipment Specifications and Monitoring Strategies Development". An adjunct activity is to develop American Society of Testing Materials (ASTM) standards for soil-core sampling and pore-liquid sampling.

The Water Resources Research Center (WRRC) at the University of Arizona was placed under subcontract to UCSB to assist in developing the ASTM standards. The subcontract, for a period of one year, commenced on July 1, 1988. WRRC personnel involved in this project were:

Dr. L.G. Wilson, Hydrologist
David W. Dorrance, Research Assistant
Susan Maida, Research Assistant
Support personnel including secretaries and a draftsman.

This document summarizes tasks which have been performed by the WRRC.

METHODOLOGY

The project methodology, developed from briefing sessions with Dr. L.G. Everett of UCSB, was as follows:

1) Compile a list of all soil-core and pore-liquid samplers for the vadose zone.

2) Collect and review all literature pertaining to the list of sampling devices (including relevant ASTM and EPA standards).

3) Contact and visit sampling equipment manufacturers.

4) Distribute a questionnaire to vadose zone monitoring professionals to obtain information on equipment installation, operation, maintenance, durability, advantages, and limitations.

5) Prepare separate draft Standard Guides for Soil-Core and Pore-Liquid Sampling from the Vadose Zone.

6) Distribute the draft standards to members of ASTM subcommittee D18.21.02, Vadose Zone Monitoring for review.

7) Revise the standards based on reviewers' comments and assist in final preparation of the standards.

The following is a summary of work performed under these tasks.

COMPILATION OF SAMPLER INFORMATION AND LITERATURE

The list of samplers to be covered by the standards was compiled from a variety of sources including computer searches, review of recent books and journals, and consultation between Drs. Everett and Wilson. This process coincided with the collection of articles, books, catalogs and existing standards relating to these devices.

The process resulted in a file of over 30 references relating to soil-core samplers and over 144 references relating to pore-liquid samplers (see Appendix I).

MANUFACTURER CONTACTS AND VISITS

All manufacturers of the samplers to be covered by the standards were contacted. The purpose of the project was explained to them, and detailed technical information was solicited. Plant visits to Timco Mfg. Inc. and Soilmoisture Equipment Co., manufacturers of pore-liquid sampler, were planned. However, the Soilmoisture plant in Santa Barbara, California was the only site actually visited. Dr. Wilson and Mr. Dorrance met with representatives from Timco at an ASTM meeting in Orlando, Florida.

DISTRIBUTION OF QUESTIONNAIRES TO VADOSE ZONE MONITORING PROFESSIONALS

A questionnaire relating to soil-core and pore-liquid samplers was developed (see Appendix II). The questionnaire was distributed

to 766 agency and corporate members of the National Water Well Association. In addition, 100 copies were distributed by Timco Mfg. to their customers. Finally, 61 questionnaires were sent, upon request, to persons responding to announcements in Agronomy News, Ground Water Monitoring Review, and Standardization News.

Of the 927 questionnaires mailed (between October 1988 and June 1989), 80 were returned. Fifty one of the replies were sufficiently complete to allow their use. This represents a 5.5% response to the mailing.

Statistical analyses of the results (t-distribution with 95% confidence level) indicate that this sample is, for the most part, insufficient to draw reliable or meaningful conclusions. Specifically, arithmetic means of scores had coefficients of variation ranging from about 30% to over 50% with maximum errors exceeding 20%. Detailed results are on file at the WRRC.

Although the survey results could not be used, comments and documents which accompanied many of the responses were useful. This information was incorporated into the standards.

PREPARATION OF DRAFT SOIL-CORE AND PORE-LIQUID STANDARDS WITH SUBSEQUENT REVIEW BY SUBCOMMITTEE D18.21.02 MEMBERS

Draft standards were written and presented to subcommittee D18.21.02 members at the January 1989 meeting of the ASTM in Orlando, Florida. Twenty one subcommittee members and visitors were present at the meeting. Both draft standards were presented to each attendee. Subcommittee members who did not attend the January

meeting were contacted to determine if they would like to review the draft standards. This resulted in 15 additional sets being mailed out.

Three of the submitted draft soil-core and four of the submitted pore-liquid standard guides were returned with comments.

REVISION OF THE STANDARD GUIDES

Comments from reviewers were incorporated into the documents along with additional information compiled in the interim. The resulting documents: Standard Guide For Soil-Core Sampling From The Vadose Zone and Standard Guide For Pore-Liquid Sampling From The Vadose Zone are presented in Appendices III and IV respectively. Copies of these documents written in the software WordPerfect 5.0^{R} and saved on disk accompany the hard copies.

SUMMARY

The next step in the process of adopting these standards will be a vote by subcommittee D18.21.02. We anticipate questions which may result in revisions. Although the project has terminated, the primary authors are available for consultation:

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APPENDIX I

SOIL-CORE SAMPLING REFERENCES

Acker, W.L., Basic Procedures for Soil Sampling and Core Drilling, Acker Drill Co. Inc., Scranton, Pa, 1974.

Brakensiek, D.L., Osborn, H.B., and Rawls, W.L., Field Manual for Research in Agricultural Hydrology, Agriculture Handbook No. 224, Science and Education Administration, United States Dept. of Agriculture, Washington, D.C., 1979 (revised), pp. 258-275.

Bureau of Reclamation, Earth Manual, U.S. Dept. of the Interior, United States Government Printing Office, Washington, D.C., 1974.

Driscoll, F.G., Groundwater and Wells, Johnson Division, St. Paul, Minnesota, 1986 (2nd ed.).

Everett, L.G., and Wilson, L.G., Permit Guidance Manual on Unsaturated Zone Monitoring For Hazardous Waste Land Treatment Units, EPA/530-SW-86-040, 1986.

Hackett, G., "Drilling and Constructing Monitoring Wells with Hollow-Stem Augers Part 1: Drilling Considerations", Ground Water Monitoring Review, NWWA, Fall 1987, pp. 51-62.

Hvorslev, M.J., Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes, U.S. Army Corp of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, 1949.

Materials Testing Division, Catalog of Products, Soiltest Inc., Evanston, Illinois, 1983.

Riggs, C.O., "Soil Sampling in the Vadose Zone", Proceedings of the NWWA/U.S. EPA Conference on Characterization and Monitoring of the Vadose Zone, NWWA, Las Vegas, Nevada, 1983, pp. 611-622.

Sales Division, Catalog of Products, Soilmoisture Equipment Corp., Santa Barbara, California, 1988.

Sales Division, Catalog of Products, VI-COR Technologies Inc., Bellevue, Washington, 1988.

Sales Division, J.M.C. Soil Investigation Equipment, Catalog No. 6, Clements Associates Inc..

Sales Division, Catalog of Products, Diedrich Drilling Equipment, LaPorte, Indiana, 1988.

Sales Division, Catalog of Products, Little Beaver Inc., Livingston, Texas, 1988.

Sales Division, Catalog of Products, Art's Manufacturing and Supply, American Falls, Idaho, 1988.

Sales Division, Catalog of Products, Mobile Drilling Co. Inc, Indianapolis, Indiana, 1988.

Sales Division, Product Literature, Pitcher Drilling Co., Palo Alto, California, 1986.

Sales Division, Instrumentation for Soil and Rocks, Catalog of Products, Solinst, Burlington, Ontario, Canada, 1988.

Sales Division, Catalog of Products, Brainard Kilman, Stone Mountain, Georgia, 1988.

Scalf, M.R., McNabb, J.F., Dunlap, W.J., Cosby, R.L., and Fryberger, J., Manual of Groundwater Sampling Procedures, National Water Well Association, Dublin, Ohio, 1981.

Sharma, P.K., and DeDalta, S.K., "A Core Sampler for Puddled Soils", Soil Science Society of America Journal, Vol. 49, 1985, pp. 1069-1070.

Soil Survey Staff, Soil Survey Manual, U.S. Dept. of Agriculture, Superintendent of Documents, Washington, D.C., 1951.

Wilson, J.T., and McNabb, J.F., "Biological Transformation of Organic Pollutants in Groundwater", EOS-Transactions, AGU, Vol. 64, pp. 505-507.

Zapico, M.M., Vales, S., and Cherry, J.A., "A Wireline Core Barrel for Sampling Cohesionless Sand and Gravel Below the Water Table", Ground Water Monitoring Review, NWWA, Spring 1987, pp. 75-82.

PORE-LIQUID SAMPLING REFERENCES

Amoozegar-Fard, A.D., Nielsen, D.R., and Warrick, A.W., "Soil Solute Concentration Distributions for Spatially Varying Pore Water Velocities and Apparent Diffusion Coefficients" Soil Science Society of America Journal, v. 46, 1982, pp. 3-9.

Amter, S., Injection/Recovery Lysimeter Technique for Soil-Water Extraction, M.S. Thesis, Dept. of Hydrology and Water Resources, The University of Arizona, Tucson, Arizona, 1987.

Anderson, Linda Davis, "Problems Interpreting Samples Taken with Large-Volume, Falling Suction Soil-Water Samplers", Ground Water, 1986, pp. 761-

Baier, Dwight C., Aljibury, Falih K., Meyer, Jewell K., Wolfenden, Allen K., Vadose Zone Monitoring is Effective for Evaluating the Integrity of Hazardous Waste Pond Liners, Baier Agronomy, Inc., Woodland, California, November 1983, 17 pp.

Ball, John and Coley, David M., "A Comparison of Vadose Monitoring Procedures", Proceedings of the Sixth National Symposium and Exposition on Aquifer Restoration and Groundwater Monitoring, NWWA/EPA, 1986, pp. 52-61.

Barbarick, K.A., Sabey, B.R., and Klute, A., "Comparison of Various Methods of Sampling Soil Water for Determining Ionic Salts, Sodium, and Calcium Content in Soil Columns", Soil Science Society of America Journal, Vol. 43, 1979, pp. 1053-1055.

Barbee, G.C. and Brown, K.W., "Comparison Between Suction and Free-Drainage Soil Solution Samplers", Soil Science, Vol 141, February 1986, pp. 149-154.

Barcelona, M.J., Helfrich, J.A., and Garske, E.E., " Verification of Sampling Methods and Selection of Materials for Ground Water Contamination Studies", Ground-Water Contamination Field Methods, ASTM STP 963, Philadelphia, PA, 1988.

Barcelona, M.J., Gibb, J.P., and Miller, R.A., A Guide to the Selection of Materials For Monitoring Well Construction and Ground Water Sampling, Illinois State Water Survey, Champaign, Illinois, 1983.

Bell, R.G., "Porous Ceramic Soil Moisture Samplers, An Application in Lysimeter Studies on Effluent Spray Irrigation", New Zealand Journal of Experimental Agriculture, Vol 2, June 1974, pp. 173-175.

Biggar,J.W., and Nielsen, D.R., "Spatial Variability of the Leaching Characteristics of a Field Soil", Water Resources Research, v. 12, 1976, pp. 78-84.

Bond, William R. and Rouse, Jim V., "Lysimeters Allow Quicker

Monitoring of Heap Leaching and Tailing Sites", Mining Engineering, April 1985, pp. 314-319.

Bottcher, A.B., Miller, L.W., and Campbell, K.L.," Phosphorous Adsorption in Various Soil-Water Extraction Cup Materials: Effect of Acid Wash", Soil Science, v. 137, 1984, pp. 239-244.

Bouma, J., Jongerius A., and Schoondebeek, D., 1979, "Calculation of Hydraulic Conductivity of Some Saturated Clay Soils Using Micromorpho-meteric Data", Soil Science Society of America Journal, v. 43, pp. 261-265.

Brose, Richard J., Shatz, Richard W., and Regan, Thomas M., "An Alternate Method of Lysimeter and Flour Pack Placement in Deep Boreholes", Proceedings of the Sixth National Symposium and Exposition on Aquifer Restoration and Ground Water Monitoring, NWWA, 1986, pp. 88-95.

Brown, K.W., Efficiency of Soil Core and Soil Pore-Liquid Sampling Systems, U.S. EPA/600/52-86/083, Virginia, February, 1987.

Brown, K.W., Thomas, J.C., and Aurelius, M.W., "Collecting and Testing Barrel Sized Undisturbed Soil Monoliths", Soil Science Society of America Journal, Vol 49, 1985, pp. 1067-1069.

K.W. Brown and Associates, Hazardous Waste Land Treatment, U.S.EPA, Office of Research and Development, SW-874, Cincinnati, Ohio, Septmeber, 1980

Campbell, M., and Lehr, J., Water Well Technology, McGraw-Hill Book Co., New York, New York, 1973, 681 pp..

Chow, T.L., "Fritted Glass Bead Materials as Tensiometers and Tension Plates", Soil Science Society of America Journal, Vol 41, 1977, pp. 19-22.

Cole, D.W., "Alundum Tension Lysimeter", Soil Science, Vol 85, June 1958, pp. 293-296.

Cole, D., Gessell, S., and Held, E.," Tension Lysimeter Studies of Ion and Moisture Movement in Glacial Till and Coral Atoll Sites", Soil Science Society of America Proceedings, v. 25, 1968, pp. 321-325.

Creasey, Carol L. and Dreiss, Shirley J., "Soil Water Sampler: Do They Significantly Bias Concentrations in Water Samples?", Proceedings of the NWWA Conference on Characterization and Monitoring of the Vadose Zone, NWWA, 1986, pp. 173-181.

Dazzo, F., and Rothwell, D., "Evaluation of Porcelain Cup Soil Water Samplers For Bacteriological Sampling", Applied Microbiology, v.27, 1974, pp. 1172-1174.

Debyle, Norbert V., Hennes, Robert W., and Hart, George E.,

"Evaluation of Ceramic Cups for Determining Soil Solution Chemistry", Soil Science, Vol 146, July 1988, pp. 30-36.

Doanhue, Miller, and Shickluna, Soils - An Introduction to Soils and Plant Growth, 1977.

Donnan, and Schwab, in Drainage for Agriculture, Number 17 in Agronomy Series, American Society of Agronomy, Madison, Wisconsin, 1974.

Driscoll, F.G., Groundwater and Wells, Johnson Division, St. Paul, Minnesota, 1986, 1089 pp..

Duke, H., Kruse, E., and Hutchinson, G., "An Automatic Vacuum Lysimeter for Monitoring Percolation Rates", USDA Agricultural Research Service, ARS, pp. 41-165, 1970.

Dunlap, William J., Some Concepts Pertaining to Investigative Methodology for Subsurface Process Research, U.S. Environmental Protection Agency, 1977, pp. 167-172.

Eccles, L.A., and Gruenberg, P.A., "Monitoring Agricultural Waste Water Discharges For Pesticide Residues", Proceedings: Establishment of Water Quality Monitoring Programs, American Water Resources Association, 1978, pp.319-327.

England, C.B., "Comments on 'A Technique Using Porous Cups for Water Sampling at Any Depth in the Unsaturated Zone' by Warren W. Wood", Water Resources Research, Vol 10, October 1974, pp. 1049.

Environmental Monitoring Systems Laboratory, Permit Guidance Manual on Unsaturated Zone Monitoring for Hazardous Waste Land Treatment Units, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, EPA/530-SW-86-040, October 1986, 111 pp.

Everett, Lorne G., Hoylman, Edward W., Wilson, L. Graham, and McMillion, Leslie G., "Constraints and Categories of Vadose Zone Monitoring Devices", Ground Water Monitoring Review, Winter 1984, pp. 26-32.

Everett, Lorne and McMillion, Leslie G., "Operational Ranges for Suction Lysimeters", Ground Water Monitoring Review, Vol, Summer 1985, pp. 51-60.

Everett, L.G., Wilson, L.G., and Hoylman, E.W., Vadose Zone Monitoring Concepts for Hazardous Waste Sites, Noyes Data Corporation, New Jersey, 1984.

Everett, L.G., Wilson, L.G., and McMillion, L.G., "Vadose Zone Monitoring Concepts for Hazardous Waste Sites", Ground Water, Vol 20, May/June 1982, pp. 312-324.

Everett, L.G., "Monitoring in the Vadose Zone", Ground Water

Monitoring Review, Summer 1981, pp. 44-51.

Faber, W.R., and Nelson, P.V, "Evaluation of Methods for Solution from Container Root Media", Commumications in Soil Science Plant Analysis, vol. 15, number 9, 1984, pp. 1029-1040.

Fenn, D.E., Hanley, K.J., Isbister, J., Briads, O., Yare, B., and Roux, P., Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities, U.S. Environmental Protection Agency, EPA/530/SW-611, 1977.

Gambrell, R.P., Gilliam, J.W., and Weed, S.B., "Denitrification in Subsoils of the North Carolina Coastal Plain as Affected by Soil Drainage", Journal of Environmental Quality, v.4, 1975, pp. 311-316.

Gass, T.E., "Methodology for Monitoring Wells", Water Well Journal, v.38(6), 1984, pp.30-31.

Gibb, J.P., Schuller, R.M., and Griffin, R.A., Procedures for the Collection of Representative Water Quality Data from Monitoring Wells, Cooperative Groundwater Report 7, Illinois State Water Survey, 1981.

Gilliam, J.W., Skaggs, R.W., and Weed, S.B., "Drainage Control to Diminish Nitrate Loss from Agricultural Fields", Journal of Environmental Quality, v.8, 1979, pp. 137-142.

Gilliam, J.W., Daniels, R.B., and Lutz, J.F., "Nitrogen Content of Shallow Ground Water in the North Carolina Coastal Plain", Journal of Environmental Quality, v.2, 1974, pp. 147-151.

Grier, H.E., Burton, W., and Tiwari," Overland Cycling of Animal Waste", Land as a Waste Management Alternative, Ann Arbour Science, 1977, pp. 693-702

Grover, B.L., and Lamborn, R.E., "Preparation of Porous Seramic Cups to be Used for Extraction of Soil Water Having Low Solute Concentrations", Soil Science Society of America Proceedings, vol. 34, 1970, pp. 706-708.

Hackett, G., " Drilling and Constructing Monitoring Wells with Hollow Stem Augers", Ground Water Monitoring Review, Fall 1987, pp. 51-62.

Hackett, G., " Drilling and Constructing Monitoring Wells with Hollow Stem Augers", Ground Water Monitoring Review, Winter 1988, pp. 60-68.

Haines, B.L., Waide, J.B., and Todd, R.L., "Soil Solution Nutrient Concentrations Sampled with Tension and Zero-Tension Lysimeters: Report of Discrepancies", Soil Science Society of America Journal, Vol 46, 1982, pp. 658-660.

Haldorsen, Sylvi, Petsonk, Andrew M., and Tortensson, Bengt-Arne, "An Instrument for In Situ Monitoring of Water Quality and Movement in the Vadose", Proceedings of the NWWA Conference on Characterization and Monitoring of the Vadose Zone, NWWA, 1986, pp. 158-172.

Hansen, Edward A. and Harris, Alfred Ray, "Validity of Soil-Water Samples Collected with Porous Ceramic Cups", Soil Science Society of America Proceedings, Vol 39, 1975, pp. 528-536.

Hornby, W.J., Zabick, J.D. and Crawley, W., "Factors Which Affect Soil-Pore Liquid: A Comparison of Currently Available Samplers with Two New Designs", Ground Water Monitoring Review, Vol 6, Spring 1986, pp. 61-66.

Jackson, D.R., Brinkley, F.S., and Bondietti, E.A., "Extraction of Soil Water Using Cellulose-Acetate Hollow Fibers", Soil Science Society of America Journal, Vol 40, 1976, pp. 327-329.

Jacobs, T.C., and Gilliam, J.W., "Riparian Losses of Nitrate from Agricultural Drainage Waters", Journal of Environmental Quality, v.14, 1985, pp. 472-478.

Johnson, Thomas. M, and Cartwright, Keros, Monitoring of Leachate Migration in the Unsaturated Zone in the Vicinity of Sanitary Landfills, State Geological Survey Circular 514, Urbana, Illinois, 1980.

Jones, J.N., and Miller, G.D., "Adsorption of Selected Organic Contaminants onto Possible Well Casing Materials", Ground-Water Contamination Field Methods, ASTM STP 963, Philadelphia, PA, 1988.

Jordan, Carl F., "A Simple, Tension-Free Lysimeter", Soil Science, Vol 105, 1968, pp. 81-86.

Joslin, J.D., Mays, P.A., Wolfe, M.H., Kelly, J.M., Garber, R.W., Brewer, P.F., "Chemistry of Tension Lysimeter Water and Lateral Flow in Spruce and Hardwood Stands", Journal of Environmental Quality, Vol 16, 1987, pp. 152-160.

Keely, J.F., and Boateng K., "Monitoring Well Installation, Purging and Sampling Techniques", Ground Water, 1987, v.25 (3,4).

Klute, A., ed., Methods of Soil Analysis, Part I, American Society of Agronomy, Inc., Madison, Wisconsin, 1986.

Knighton, M. Dean and Streblow, Dwight E., "A More Versatile Soil Water Sampler", Soil Science Society of America Journal, Vol 45, 1981, pp. 158-159.

Law Engineering Testing Company, Lysimeter Evaluation Study, American Petroleum Institute, May 1982, 103 pp.

Levin, M.J. and Jackson, D.R., "A Comparison of In Situ Extractors

for Sampling Soil Water", Soil Science Society of America Journal, Vol 41, 1977, pp. 535-536.

Liator, M.I., " Review of Soil Solution Samplers", Water Resources Research, vol. 24, No. 5, 1988, pp. 727-733.

Linden, D.R., "Design, Installation and Use of Porous Ceramic Samplers for Monitoring Soil-Water Quality", U.S. Dep. Agric. Technical Bull., 1562, 1977.

Litaor, M. Iggy, "Review of Soil Solution Samplers", Water Resources Research, Vol 24, May 1988, pp. 727-733.

Long, F. Leslie, "A Glass Filter Soil Solution Sampler", Soil Science Society of America Journal, Vol 42, 1978, pp. 834-835.

Merry, W.M. and Palmer, C.M., "Installation and Performance of a Vadose Monitoring System", Proceedings of the NWWA Conference on Characterization and Monitoring of the Vadose Zone, NWWA, 1986, pp. 107-125.

Montgomery, B.R., Prunty, Lyle, and Bauder, J.W., "Vacuum Trough Extractors for Measuring Drainage and Nitrate Flux Through Sandy Soils", Soil Science Society of America Journal, Vol 51, 1987, pp.271-276.

Morrison, R.D., and Tsai, T.C., Modified Vacuum-Pressure Lysimeter for Vadose Zone Sampling, Calscience Research Inc., Huntington Beach, California, 1981.

Morrison, Robert D. and Szecsody, Jim E., "A Tensiometer and Pore Water Sampler for Vadose Zone Monitoring", Soil Science, Vol 144, November 1987, pp. 367-372.

Morrison, Robert and Szecsody, James, "Sleeve and Casing Lysimeters for Soil Pore Water Sampling", Soil Science, Vol 139, May 1985, pp. 446-451.

Morrison, Robert D., Ground Water Monitoring Technology, Timco MFG., Inc., Prairie DU Sac, Wisconsin, 1983.

Nagpal, N.K., "Comparison Among and Evaluation of Ceramic Porous Cup Soil Water Samplers for Nutrient Transport Studies", Canadian Journal of Soil Science, Vol 62, 1982, pp. 685-694.

Narasimhan, T.N. and Dreiss, Shirley J., "A Numerical Technique for Modeling Transient Flow of Water to a Soil Water Sampler", Soil Science, Vol 141, March 1986, pp. 230-236.

Neary, A.J. and Tomassini, F., "Preparation of Alundum/Ceramic Plate Tension Lysimeters for Soil Water Collection", Canadian Journal of Soil Science, Vol 65, February 1985, pp. 169-177.

Nielson, D., and Phillips, R.," Small Fritted Glass Bead Plates

For Determination of Moisture Retention", Soil Science Society of America Proceedings, v.22, 1958, pp.574-575.

Nightingale, H.I., Harrison, Doug, and Salo, John E., "An Evaluation Technique for Ground Water Quality Beneath Urban Runoff Retention and Percolation Basins", Ground Water Monitoring Review, Vol 5, Winter 1985, pp. 43-50.

Parizek, Richard R. and Lane, "Soil-Water Sampling Using Pan and Deep Pressure-Vacuum Lysimeters", Journal of Hydrology, Vol 11, 1970, pp. 1-21.

Patton, F.D., and Smith, H.B., "Design Considerations and the Quality of Data from Multiple-Level Groundwater Monitoring Wells", Ground-water Contamination Field Methods, ASTM, STP963, Philadelphia, PA, 1988.

Peters, Charles A. and Healy, Richard W., "The Representativeness of Pore Water Samples Collected from the Unsaturated Zone Using Pressure-Vacuum Lysimeters", Ground Water Monitoring Review, Spring 1988, pp. 96-101.

Pettyjohn, Wayne A., Dunlap, W.J., Cosby, Roger, and Keeley, Jack, W., "Sampling Ground Water for Organic Contaminants", Ground Water, Vol 19, March-April 1981, pp 180-189.

Pickens, J.F., Cherry, J.A., Coupland, R.M., Grisak, G.E., Merritt, W.F., and Risto, G.A., "A Multi-Level Device for Ground Water Sampling", Ground Water Monitoring Review, v. 1(1), 1981.

Minning, R.C., "Monitoring Well Design and Installation", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, Columbus, Ohio, 1982, pp. 194-197.

Pickens, J.F., and Grisak, G.E., "Reply to the Preceding Discussion of Vanhof et al. at a Multilevel Device for Groundwater Sampling and Pieziometric Monitoring", Ground Water, v.17(4), 1979, pp. 393-397.

Quin, B.F. and Forsythe, L.J., "All-Plastic Suction Lysimeters for the Rapid Sampling of Percolating Soil Water", New Zealand Journal of Science, Vol 19, 1976, pp. 145-148.

Ransom, M.D., and Smeck, N.E., "Water Table Characteristics and Water Chemistry of Seasonally Wet Soils of Southwestern Ohio", Soil Science Society of America Journal, v. 50, 1986, pp. 1281-1290.

Reeve, R.C. and Doering, E.J., "Sampling the Soil Solution for Salinity Appraisal", Soil Science, Vol 99, 1965, pp. 339-344.

Rhoades, J.D., and Oster, J.D.,"Methods of Soil Analysis", Agronomy, v.9, 1986, pp. 985-1006.

Richter, H.R., and Collentine, M.G., "Will My Monitoring Well Survive Down There?: Design and Installation Techniques for Hazardous Waste Studies", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, Columbus, Ohio, 1983, pp. 223-229.

Riggs, C.O., "Monitoring Well Drilling Methods", Proceedings of the Workshop on Resource Conservation Recovery Act Ground Water Monitoring Enforcement: Use of the Technical Enforcement Guidance Document and Compliance Order Guide, Philadelphia, Pennsylvania, 1987.

Riggs, C.O., and Hatheway, "Ground Water Monitoring Field Practice - An Overview", Proceedings of the ASTM Conference on Ground Water Technology, Coco Beach Florida, 1986.

Robbins, Gary A. and Gemmell, Michael M., "Factors Requiring Resolution in Installing Vadose Zone Monitoring Systems", Ground Water Monitoring Review, Summer 1985, pp. 75-80.

Sales Division, Catalog of Products, Soilmoisture Equipment Corp., Santa Barbara, California, 1988.

Sales Division, Catalog of Products, Cole-Parmer Instrument Company, 1988.

Sales Division, Catalog of Products, BAT Envitech Inc., Long Beach California, 1988.

Sales Division, Catalog of Products, Cole-Parmer Instrument Company, 1988.

Sales Division, Catalog of Products, Corning Glass Works, New York, 1988.

Sales Division, Timco Lysimeters, Timco Mfg. Inc., Prairie DU Sac, Wisconsin, 1988.

Sales Division, Catalog of Products, Mott Metallurgical Corp., Farmington, Conn., 1988.

Scalf, M.R., McNabb, J.F., Dunlap, W.J., Cosby, R.L., and Fryberger, J., Manual of Ground Water Sampling Procedures, National Water Well Association, Ohio, 1981, 93 pp..

Schilfgaarde, J.V., ed., Drainage for Agriculture, Number 17 in Agronomy Series, American Society of Agronomy, Madison, Wisconsin, 1974.

Schmidt, C., and Clements, E., Reuse of Municipal Wastewater For Groundwater Recharge, U.S. Environmental Protection Agency, 68-03-2140, 1978, Ohio, pp. 110-125.

Schneider, B.J., and Oaksford, E.T., Design and Monitoring

Capability of an Experimental Artificial-Recharge Facility at East Meadow, Long Island, New York, U.S. Geological Survey Open-File Report 84-070, 1986.

Schneider, B.J., Oliva, J., Ku, H.F.H., and Oaksford, E.T., "Monitoring the Movement and Chemical Quality of Artificial-Recharge Water in the Unsaturated Zone on Long Island, New York", Proceedings of the Characterization and Monitoring of the Vadose (Unsaturated) Zone, National Water Well Association, Las Vegas, Nevada, 1984, pp. 383-410.

Severson, R.C. and Grigal, D.F., "Soil Solution Concentrations: Effect of Extraction Time Using Porous Ceramic Cups Under Constant Tension", Water Resources Bulletin, Vol 12, December 1976, pp. 1161-1169.

Shimshi, Daniel, "Use of Ceramic Points for the Sampling of Soil Solution", Soil Science, Vol 101, 1966, pp. 98-103.

Shuford, J.W., Fritton, D.D., and Baker, D.E., "Nitrate-Nitrogen and Chloride Movement Through Undisturbed Field Soil", Journal of Environmental Quality, v.6, 1977, pp. 736-739.

Silkworth, D.R. and Grigal, D.F., "Field Comparison of Soil Solution Samplers", Soil Science Society of America Journal, Vol 45, 1981, pp. 440-442.

Smith, S.A., Small, G.S., Phillips, T.S., and Clester, M., Water Quality in the Salt River Project, A Preliminary Report, Salt River Project Water Resource Operations, Ground Water Planning Division, Pheonix, Arizona, August, 1982.

Smith, J.H., Robbins, C.W., Bondurant, J.A., and Hayden, C.W., "Treatment of Potato Processing Wastewater on Agricultural Land: Water and Organic Loading, and the Fate of Applied Plant Nutrients", Land as a Waste Management Alternative, Ann Arbour Science, 1977, pp. 769-781.

Smith, J.L., and McWhorter D.M.,"Continuous Subsurface Injection of Liquid Organic Wastes", Land as a Waste Management Alternative, Ann Arbor Science, 1977, pp. 646-656.

Smith, C.N. and Carsel, R.F., "A Stainless-Steel Soil Solution Sampler for Monitoring Pesticides in the Vadose Zone", Soil Science Society of America Journal, Vol 50, 1986, pp. 263-265.

Starr, Michael R., "Variation in the Quality of Tension Lysimeter Soil Water Samples from a Finnish Forest Soil", Soil Science, Vol 140, December 1985, pp. 453-461.

Stevenson, Craig D., "Simple Apparatus for Monitoring Land Disposal Systems by Sampling Percolating Soil Waters", Environmental Science and Technology, Vol 12, March 1978, pp.

329-331.

Suarez, D.L., "Prediction of pH Errors in Soil Water Extractors Due to Degassing", Soil Science Society of America Journal, v.51, 1987, pp. 64-68.

Tadros, V.T. and McGarity, J.W., "A Method for Collecting Soil Percolate and Soil Solution in the Field", Plant and Soil, Vol 44, June 1976, pp. 655-667.

Tanner, C.B., Bourget, S.J., and Holmes, W.E., "Moisture Tension Plates Constructed from Alundum Filter Discs", Soil Science Society of America Proceedings, Vol 18, 1954, pp. 222-223.

Taylor, T.W., and Serafini, M.C., "Screened Auger Sampling: The Technique and Two Case Studies", Ground Water Monitoring Review, Summer 1988, pp. 145-152.

Taylor, S.A., and Ashcroft, G.L., Physical Edaphology, The Physics of Irrigated and Non Irrigated Soils, W.H. Freeman and Company, San Francisco, 1972.

Thomas, G.W., and Phillips, R.E., "Consequences of Water Movement in Macropores", Journal of Environmental Quality, v.8, 1979, pp. 149-152.

Torstensson, B.A., and Petsonk, A.M., " A Hermetically Isolated Sampling Method for Ground Water Investigations", Proceeding of ASTM Symposium for Ground Water Contamination Studies and Their Standardization, ASTM, February, 1986.

Trainor, David P., The Relationship Between Two Laboratory Leaching Procedures and Leachate Quality at Foundry Waste Landfills, M.S. Thesis/Independent Report, Dept. of Civil and Environmental Engineering, The University of Wisconsin, Madison, Wisconsin, February, 1983.

Tyler, Donald D. and Thomas, Grant W., "Lysimeter Measurements of Nitrate and Chloride Losses from Soil Under Conventional and No-tillage Corn", Journal of Environmental Quality, Vol 6, 1977, pp. 63-66.

U.S. Environmental Protection Agency, RCRA Ground-Water Monitoring Technical Enforcement Guidance Document, Office of Waste Programs Enforcement, Office of Solid Waste and Emergency Response, OSWER-9950.1, 1986, 208 pp..

Van der Ploeg, R.R. and Beese, F., "Model Calculations for the Extraction of Soil Water by Ceramic Cups and Plates", Soil Science Society of America Journal, Vol 41, 1977, pp. 466-470.

Wagemann, R., and Graham, B., "Membrane and Glass Fibre Filter Contamination in Chemical Analysis of Fresh Water", Water Research, Vol 8, 1974, pp. 407-412.

Wagner, George H., "Use of Porous Ceramic Cups to Sample Soil Water Within the Profile", Soil Science, Vol 94, 1962, pp. 379-386.

Warrick, A.W. and Amoozegar-Fard, A., "Soil Water Regimes Near Porous Cup Water Samplers", Water Resources Research, Vol 13, February 1977, pp. 203-207.

Wengel, R.W. and Griffin, G.F., "Remote Soil-Water Sampling Technique", Soil Science Society of America Journal, Vol 35, 1971, pp. 661-664.

Willardson, L.S., Meek, B.D., and Huber, M.J., "A Flow Path Ground Water Sampler", Soil Science Society of America Proceedings, v.36, 1973, pp. 965-966.

Wilson, L.G., and Small, G.G., "Pollution Potential of a Sanitary Landfill Near Tucson, Hydraulic Engineering and The Environment", Proceedings 21st Annual Hydraulics Division Specialty Conference, ASCE, 1973.

Wilson, L.G., Monitoring in the Vadose Zone: A Review of Technical Elements and Methods, U.S. Environmental Protection Agency, EPA-600/7-80-134, 1980

Wilson, L.G. and Schmidt, K.D., "Monitoring Perched Water in the Vadose Zone", Establishment of Water Quality Monitoring Programs, Proceedings of a Symposium, American Water Resources Association, 1978, pp. 134-149.

Wilson, L.G., "The Fate of Pollutants in the Vadose Zone, Monitoring Methods and Case Studies", Thirteenth Biennial Conference on Ground Water, September 1981, 38 pp.

Wilson, L.G., "Monitoring in the Vadose Zone: Part II", Ground Water Monitoring Review, Winter 1982, pp. 31-42.

Wilson, L.G., "Monitoring in the Vadose Zone: Part III", Ground Water Monitoring Review, Winter 1983, pp. 155-165.

Wilson, L.G., "Methods for Sampling Fluids in the Vadose Zone", Proceedings of ASTM, 1988,

Wolff, R.G., "Weathering Woodstock Granite, near Baltimore, Maryland", American Journal of Science, v.265, 1967, pp.106-117.

Wood, A.L., Wilson, J.T., Cosby, R.L., Hornsby, A.G., and Baskin, L.B., "Apparatus and Procedure for Sampling Soil Profiles for Volatile Organic Compounds", Soil Science Society of America Journal, Vol 45, 1981, pp. 442-444.

Wood, Warren W., "A Technique Using Porous Cups for Water Sampling at Any Depth in the Unsaturated Zone", Water Resources Research, Vol 9, April 1973, pp. 486-488.

Young, Mark, "Use of Suction Lysimeters for Monitoring in the Landfill Liner Zone", Proceedings of Monitoring Hazardous Waste Sites, Geotechnical Engineering Division, American Society of Civil Engineers, Detroit, Mich., October, 1985.

Zimmermann, C.F., Price, M.T., and Montgomery, J.R., "A Comparison of Ceramic and Teflon Insitu Samplers for Nutrient Pore Water Determinations", Estuarine and Coastal Marine Science, vol. 7, 1978, pp. 93-97.

APPENDIX II

THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

COLLEGE OF ENGINEERING AND MINES

WATER RESOURCES RESEARCH CENTER
GEOLOGY BUILDING RM 318
(602) 621-7607

November 16, 1988

Dear Sir or Madam:

The American Society of Testing Materials (ASTM), Vadose Zone Section is in the process of producing standard guides for soil core and pore liquid sampling in the vadose zone. The Water Resources Research Center at the University of Arizona has been contracted to assist in this task. As part of the process we would like to obtain input from firms or agencies such as yours which are involved in this type of work.

Attached you will find two questionaires with some of the issues we are addressing. Attached to each questionaire is a list of some of the samplers which we are interested in. If you have had experience with any of these samplers or others, we ask that you complete the forms and return them by June 1 1989. If you have additional comments which are not covered by the forms, feel free to include those as well. If you would like to photocopy the forms and distribute them among your staff, the additional input would be welcomed. In addition, if you have developed any standard operating procedures which might be pertinent, those would be of use to the project.

The standard guides will discuss the sampling tools and the conditions under which they are best used. Your input will help to determine the performance of these samplers under various situations. If you have any questions, please contact David Dorrance at (602) 621-7607.

The completed questionaire may be returned to:

The University of Arizona
Water Resources Research Center
Geology Building Rm 318
Tucson, AZ 85721
ATTN: David Dorrance

Sincerely,

L.G. Wilson

L.G. Wilson, Ph.D.
Associate Director

INFORMATION SHEET

Date: _____

Name: _____
Title: _____
Firm: _____

Instructions: Please score each of the questionnaire categories from 1 to 5, where 1 = lowest score and 5 = highest score.

Do you wish to receive a copy of the results of this survey? yes _____
no _____

Comments/suggestions: _____

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QUESTIONNAIRE ON SOIL-CORE SAMPLING TECHNIQUES

Please score the following units for use under each of the following conditions. Use a score of 1 to 5, where 1 = lowest score and 5 = highest score.

Unit	Ease of Drilling									Total
1. Manually-Operated Samplers	Clay	Sand	Gravel	Consolidated Materials	Muck	Fractured Material	Wet Soils	Dry Soils	Frozen Soils	
a. Screw-type augers										
b. Post-hole augers										
c. Dutch-type augers										
d. General purpose barrel augers										
e. Mud augers										
f. Soil sampling tubes (Lord samplers)										
g. Veihmeyer tubes (aka King tubes)										
h. Thin-walled drive samplers (Shelby tubes)										
i. Ring-lined, split-barrel samplers										
j. Other (specify, including mfg name)										

Unit	Ease of Drilling									Total
2. Mechanically-Operated Samplers	Clay	Sand	Gravel	Consolidated Materials	Muck	Fractured Material	Wet Soils	Dry Soils	Frozen Soils	
a. Hand-held power augers										
b. Backhoe, trench sampling										
c. Bucket augers										
d. Solid-stem augers										
e. Thin-walled drive samplers (Shelby tubes)										
f. Split-barrel samplers										
g. Ring-lined samplers										
h. Continuous-tube samplers										
i. Piston samplers										
j. Other (please list, including name of manufacturer)										

QUESTIONNAIRE ON SOIL-CORE SAMPLING TECHNIQUES

Please score the following units for use under each of the following conditions. Use a score of 1 to 5, where 1 = lowest score and 5 = highest score.

Unit	Ease of Sample Recovery									Total
1. Manually-Operated Samplers	Clay	Sand	Gravel	Consolidated Materials	Muck	Fractured Material	Wet Soils	Dry Soils	Frozen Soils	
a. Screw-type augers										
b. Post-hole augers										
c. Dutch-type augers										
d. General purpose barrel augers										
e. Mud augers										
f. Soil sampling tubes (Lord samplers)										
g. Veihmeyer tubes (aka King tubes)										
h. Thin-walled drive samplers (Shelby tubes)										
i. Ring-lined, split-barrel samplers										
j. Other (specify, including mfg name)										

Unit 2. Mechanically-Operated Samplers	Ease of Sample Recovery									Total
	Clay	Sand	Gravel	Consolidated Materials	Muck	Fractured Material	Wet Soils	Dry Soils	Frozen Soils	
a. Hand-held power augers										
b. Backhoe, trench sampling										
c. Bucket augers										
d. Solid-stem augers										
e. Thin-walled drive samplers (Shelby tubes)										
f. Split-barrel samplers										
g. Ring-lined samplers										
h. Continuous-tube samplers										
i. Piston samplers										
j. Other (please list, including name of manufacturer)										

QUESTIONNAIRE ON SOIL-CORE SAMPLING TECHNIQUES

Please score the following units for use under each of the following conditions. Use a score of 1 to 5, where 1 = lowest score and 5 = highest score.

Unit	Maximum Sampling Depth				Total	Sampling purpose *
1. Manually-Operated Samplers	< 5 ft	5 to 10 ft	10 to 20 ft	> 20 ft		
a. Screw-type augers						
b. Post-hole augers						
c. Dutch-type augers						
d. General purpose barrel augers						
e. Mud augers						
f. Soil sampling tubes (Lord samplers)						
g. Veihmeyer tubes (aka King tubes)						
h. Thin-walled drive samplers (Shelby tubes)						
i. Ring-lined, split-barrel samplers						
j. Other (specify, including mfg name)						

* Please list the purposes of sampling, including (a) organic chemical analyses, (b) inorganic chemical analyses, (c) analyses for microorganisms, (d) gas measurement, (e) determination of lithology, (f) moisture content determination, (g) estimation of hydraulic conductivity, and (h) other.

Unit 2. Mechanically-Operated Samplers	Maximum Sampling Depth				Total	Sampling purpose *
	< 5 ft	5 to 10 ft	10 to 20 ft	> 20 ft		
a. Hand-held power augers						
b. Backhoe, trench sampling						
c. Bucket augers						
d. Solid-stem augers						
e. Thin-walled drive samplers (Shelby tubes)						
f. Split-barrel samplers						
g. Ring-lined samplers						
h. Continuous-tube samplers						
i. Piston samplers						
j. Other (please list, including name of manufacturer)						

* Please list the purposes of sampling, including (a) organic chemical analyses, (b) inorganic chemical analyses, (c) analyses for microorganisms, (d) gas measurement, (e) determination of lithology, (f) moisture content determination, (g) estimation of hydraulic conductivity, and (h) other.

QUESTIONNAIRE ON SOIL-PORE LIQUID SAMPLING

Please score the following units for use under each of the following conditions. Use a score of 1 to 5, where 1 = lowest score and 5 = highest score

Unit	Ease of Installation							Durability	Total
	Clays	Sands	Gravels	Fractured Materials	Dry Vadose Zones	Wet Vadose Zones	Frozen Vadose Zones		
1. Ceramic suction lysimeters									
a. Vacuum operated									
b. Pressure-vacuum operated									
c. High pressure-vacuum operated									
2. PTFE suction lysimeters (Specify location of porous segment, i.e. bottom, side)									
a. Vacuum operated									
b. Pressure-vacuum operated									
c. Lysimeter with transfer vessel									
3. Tensiometer/suction sampler combinations									
4. Free-drainage samplers									
a. Pan lysimeters									
b. Glass block systems									
c. Trench lysimeters									
d. Gravity lysimeter									

Unit (Continued)	Ease of Installation							Durability	Total
	Clays	Sands	Gravels	Fractured Materials	Dry Vadose Zones	Wet Vadose Zones	Frozen Vadose Zones		
5. BAT sampler									
6. Subsurface water extractor									
7. Perched ground water									
a. Piezometers									
b. Tile lines									
c. Dedicated wells									
d. Cascading water									
8. Others									
a. Cellulose acetate hollow fibers									
b. Membrane filter samplers									
c. Cellulose-nylon sponge									
d. Ceramic rods									
e. Syringe samplers									
f. Disc lysimeters									

QUESTIONNAIRE ON SOIL-PORE LIQUID SAMPLING

Please score the following units for use under each of the following conditions. Use a score of 1 to 5, where 1 = lowest score and 5 = highest score

Unit	Ease of Sampling							Adequate Sample Volume	Reliability	Plugging	Total
	Clays	Sands	Gravels	Fractured Materials	Suction 0-60 cb	Suction > 60 cb	Frozen Vadose Zones				
1. Ceramic suction lysimeters											
a. Vacuum operated											
b. Pressure-vacuum operated											
c. High pressure-vacuum operated											
2. PTFE suction lysimeters (Specify location of porous segment, i.e. bottom, side)											
a. Vacuum operated											
b. Pressure-vacuum operated											
c. Lysimeter with transfer vessel											
3. Tensiometer/suction sampler combinations											
4. Free-drainage samplers											
a. Pan lysimeters											
b. Glass block systems											
c. Trench lysimeters											
d. Gravity lysimeter											
5. BAT sampler											

QUESTIONNAIRE ON SOIL-PORE LIQUID SAMPLING

Please score the following units for use under each of the following conditions. Use a score of 1 to 5, where 1 = lowest score and 5 = highest score

Unit (Continued)	Ease of Sampling							Adequate Sample Volume	Reliability	Plugging	Total
	Clays	Sands	Gravels	Fractured Materials	Suction 0-60 cb	Suction > 60 cb	Frozen Vadose Zones				
6. Subsurface water extractor											
7. Perched ground water											
a. Piezometers											
b. Tile lines											
c. Dedicated wells											
d. Cascading water											
8. Others											
a. Cellulose acetate hollow fibers											
b. Membrane filter samplers											
c. Cellulose-nylon sponge											
d. Ceramic rods											
e. Syringe samplers											
f. Disc lysimeters											

QUESTIONNAIRE ON SOIL-PORE LIQUID SAMPLING

Please score the following units for use under each of the following conditions. Use a score of 1 to 5, where 1 = lowest score and 5 = highest score

Unit	Maximum Sampling Depth				Total
	< 10ft	10 - 20ft	20 - 50ft	> 50ft (Specify)	
1. Ceramic suction lysimeters					
a. Vacuum operated					
b. Pressure-vacuum operated					
c. High pressure-vacuum operated					
2. PTFE suction lysimeters (Specify location of porous segment, i.e. bottom, side)					
a. Vacuum operated					
b. Pressure-vacuum operated					
c. Lysimeter with transfer vessel					
3. Tensiometer/suction sampler combinations					
4. Free-drainage samplers					
a. Pan lysimeters					
b. Glass block systems					
c. Trench lysimeters					
d. Gravity lysimeter					
5. BAT sampler					

Unit (Continued)	Maximum Sampling Depth				Total
	< 10ft	10 - 20ft	20 - 50ft	> 50ft (Specify)	
6. Subsurface water extractor					
7. Perched ground water					
a. Piezometers					
b. Tile lines					
c. Dedicated wells					
d. Cascading water					
8. Others					
a. Cellulose acetate hollow fibers					
b. Membrane filter samplers					
c. Cellulose-nylon sponge					
d. Ceramic rods					
e. Syringe samplers					
f. Disc lysimeters					

Please list the purposes of sampling, including (a) organic chemical analyses, (b) inorganic chemical analyses, (c) analyses for microorganisms, (d) gas measurement, (e) determination of lithology, (f) moisture content determination (g) estimation of hydraulic conductivity, and (h) other.

Unit

1. Ceramic suction lysimeters

a. Vacuum operated	
b. Pressure-vacuum operated	
c. High pressure-vacuum operated	
2. PTFE suction lysimeters (Specify location of porous segment, i.e. bottom, side)	
a. Vacuum operated	
b. Pressure-vacuum operated	
c. Lysimeter with transfer vessel	
3. Tensiometer/suction sampler combinations	
4. Free-drainage samplers	
a. Pan lysimeters	
b. Glass block systems	
c. Trench lysimeters	
d. Gravity lysimeter	
5. BAT sampler	

Unit (Continued)

6. Subsurface water extractor	
7. Perched ground water	
a. Piezometers	
b. Tile lines	
c. Dedicated wells	
d. Cascading water	
8. Others	
a. Cellulose acetate hollow fibers	
b. Membrane filter samplers	
c. Cellulose-nylon sponge	
d. Ceramic rods	
e. Syringe samplers	
f. Disc lysimeters	

APPENDIX III

STANDARD GUIDE FOR SOIL CORE SAMPLING FROM THE VADOSE ZONE

1. Scope

1.1 This standard addresses procedures that may be used for obtaining soil samples from the vadose zone. Samples can be collected for a variety of reasons including:

1.1.1 lithologic description,

1.1.2 hydraulic conductivity testing,

1.1.3 moisture content measurement,

1.1.4 moisture release curve construction,

1.1.5 geotechnical testing,

1.1.6 soil gas analyses,

1.1.7 microorganism extraction, or

1.1.8 pore fluid and soils chemical analyses.

1.2 This standard focuses on methods which provide soil samples for chemical analyses. However, comments on how methods may be modified for other objectives are included.

1.3 This standard does not describe sampling methods for

lithified deposits and rocks (e.g., sandstone, shale, tuff, granite).

1.4 This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.5 In general, it is prudent to perform all field work with at least two people present. This increases safety and facilitates efficient data collection.

2. Referenced Documents

2.1 ASTM Standards

D 420 Recommended Practice for Investigating and Sampling Soil and Rock for Engineering Purposes

D? Hollow Stem Augers in Geoenvironmental Exploration and Subsurface Contaminant Monitoring Device Installations

D 653 Terms and Symbols Relating to Soil and Rock Mechanics

D 1452 Practice for Soil Investigation and Sampling by Auger Borings

D 1586 Penetration Test and Split-Barrel Sampling of Soils

D 1587 Thin-Walled Tube Sampling of Soils

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)

D 2607 Classification of Peats, Mosses, Humus, and Related Products

D 3550 Ring-Lined Barrel Sampling of Soils

D 4083 Description of Frozen Soils (Visual-Manual Procedure)

D 4220 Preserving and Transporting Soil Samples

D ? Glossary of Vadose Zone Monitoring Terms

3. Definitions

3.1 Except where noted, all terms and symbols in this standard are in accordance with the following documents. In order of consideration they are:

3.1.1 Glossary of Vadose Zone Monitoring Terms D?,

3.1.2 Terms and Symbols D653,

3.1.3 Compilation of ASTM Standard Definitions, 6th ed. 1986, and

3.1.4 Webster's New Collegiate Dictionary, 5th ed. 1977.

3.2 For definitions and classifications of soil related terms used, refer to Practice D2488 and Publication D653. Additional terms which require clarification are defined below.

3.2.1 cascading water--perched groundwater that enters a well casing via cracks or uncovered perforations, trickling or pouring down the inside of the casing.

3.2.2 perched groundwater--a saturated groundwater body in the vadose zone, commonly developed at the interface between regions of varying texture.

3.2.3 sludge--a water formed sedimentary deposit.

Note 1--The water-formed sedimentary deposit may include all suspended solids carried by the water and trace elements which were in solution in the water. Sludge usually does not cohere sufficiently to retain its physical shape when mechanical means are used to remove it from the surface on which it deposits, but

it may be baked in place and be adherent.

3.2.4 soil--sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter.

Note 2--Webster's, 1977 defines soil as, "the upper layer of earth that may be dug or plowed and in which plants grow." For the sake of succinctness, this more narrow definition is not used in this standard.

3.2.5 vadose zone--the hydrogeological region extending from the soil surface to the top of the principle water table.

4. Summary of Guide

4.1 Soil sampling from the vadose zone involves inserting a device into the ground which retains a sample and which is then recovered. Devices and systems for vadose zone sampling are divided into two general groups, namely: (1) samplers used in conjunction with hand operated devices; and (2) samplers used in conjunction with multipurpose or auger drill rigs. This standard discusses these groups and their associated practices.

4.2 The discussion of each device is organized into three sections describing the device, describing sampling methods, and describing limitations and advantages of its use.

5. Significance and Use

5.1 Chemical analyses of fluids, solids and gases from the vadose zone can provide information regarding contaminant transport and attenuation. This information can be used for mitigating potential problems. This standard describes devices and procedures which can be used to obtain vadose zone soil samples.

5.2 Soil sampling is useful for the reasons presented in Section 1. However, it should be recognized that the general method is destructive, and that resampling at an exact location is not possible. Therefore, if a long term monitoring program is being designed, other methods for obtaining samples should be considered (see Standard Guide for Pore Liquid Sampling from the Vadose Zone).

6. Criteria for Selecting Soil Samplers

6.1 Important criteria to consider when selecting soil sampling devices for vadose zone monitoring include:

6.1.1 capability to obtain an encased core sample, an uncased core sample, a depth specific representative sample or a sample according to requirements of the analyses,

6.1.2 sample size requirements,

6.1.3 suitability for sampling various soil types,

6.1.4 maximum sampling depth,

6.1.5 suitability for sampling soils under various moisture conditions,

6.1.6 ability to minimize cross contamination,

6.1.7 accessibility to the sampling site and general site trafficability, and

6.1.8 personnel requirements and availability.

6.2 The sampling devices described in this standard have been evaluated for these criteria. The results are summarized in Table 1.

7. Sampling with Hand Operated Devices

7.1 These devices, which have mostly been developed for agricultural purposes, include:

7.1.1 screw-type augers,

7.1.2 barrel augers,

7.1.3 tube-type samplers,

7.1.4 hand held power augers, and

7.1.5 trench sampling with backhoes and shovels.

7.2 The major advantages of using hand operated devices over drill rigs are the ease of equipment transport to locations with poor vehicle access and the lower costs of setup and decontamination. However, a major disadvantage is that these devices are limited to shallower depths than drill rigs.

7.3 Screw-Type Augers

7.3.1 Description -- The screw or ship auger is essentially a small diameter (e.g., 1.5 in. or 3.81 cm) wood auger from which the cutting side flanges and tip have been removed (1)[1](see Fig. 1(a)). According to the Soil Survey Staff (1), the spiral part of the auger should be about 7 in. (18 cm) long, with the distances between flights about the same as the diameter (e.g., 1.5 in. or 3.8 cm) of the auger. This facilitates measuring the depth of penetration of the tool. Variations on this design include the

[1] The boldface numbers in parentheses refer to the list of references at the end of this standard.

closed spiral auger and the Jamaica open spiral auger (7)(see Fig.1(b) and 1(c)). The auger is welded onto a length of tubular rod. The upper end of this rod is threaded to extension rods. As many extensions are used as are required to reach the total drilling and sampling depth. The rod and the extensions are etched in even increments (e.g.,in 6 in. or 15.24 cm increments) above the base of the auger. A wooden or metal handle fits into a tee-type coupling, screwed into the uppermost extension rod.

7.3.2 Sampling Method -- During drilling, the handle is twisted manually and the auger screws itself into the soil. The auger is advanced to its full length and then removed. Upon removal of the tool, soil from the deepest penetration is retained on the auger flights. A foot pump operated hydraulic system has been developed to advance augers up to 4.5 in. (11.43 cm) in diameter. This larger diameter allows insertion of other sampling devices if desired ([2]).

7.3.3 Comments -- Samples obtained with screw-type samplers are disturbed and are not truly core samples. Therefore, the samples are not suitable for tests requiring undisturbed samples such as hydraulic conductivity tests. In addition, soil structures are disrupted and small scale lithologic features can not be examined. Nevertheless, screw-type samplers are still suitable for

[2] This reference is manufacturer's literature, and it has not been subjected to technical review.

use in detecting contaminants. However, it is difficult to use these devices without transporting shallow contaminants downward (cross-contamination). When representative samples are desired, the borehole must be made large enough to insert a sampler and extend it to the bottom of the borehole without touching the sides of the borehole. It is suggested that a larger diameter auger be used to advance and clear the borehole than the auger-sampler which is used to obtain the sample. Screw-type augers operate more favorably in wet, cohesive soils than in dry soils. Sampling in very dry (e.g., powdery) soils may not be possible with these augers as soils will not be retained on the auger flights. In addition, if the soil contains gravel or rock fragments larger than about one tenth of the hole diameter, drilling may not be possible (3).

7.4 Barrel Augers

7.4.1 Description -- The barrel auger consists of a bit with cutting edges, a short tube or barrel within which the soil sample is retained, and two shanks. The shanks are welded to the barrel at one end and threaded at the other end. Extension rods are attached as required to reach the total sampling depth. Extensions are marked in even depth-wise increments above the base of the tool. The uppermost extension rod contains a tee-type coupling for a handle. The auger is available in carbon steel and stainless steel with hardened steel cutting edges (4,5).

7.4.2 Sampling Method -- The sampler is turned to advance the

barrel vertically into the ground. When the barrel is filled, the unit is withdrawn from the soil cavity and soil is removed from the barrel.

7.4.3 Comments -- Barrel augers generally provide larger samples than screw-type augers. The augers can penetrate up to one foot per minute in shallow clays, silts, and fine grained sands (6^2). The augers do not work well in gravelly soils, caliche, or semi-lithified deposits. Samples obtained with barrel augers are disturbed and are not core samples. Therefore, the samples are not suitable for tests requiring undisturbed samples such as hydraulic conductivity tests. Nevertheless, the samplers are still suitable for use in detecting contaminants. Because the sample is retained inside the barrel, there is less of a chance of cross contamination from shallower soils during withdrawal of the sampler. Five common barrel augers are:

7.4.3.1 post-hole augers (also called Iwan-type augers),

7.4.3.2 dutch-type augers,

7.4.3.3 regular or general purpose barrel augers,

7.4.3.4 sand augers, and

7.4.3.5 mud augers.

7.4.4 Post-Hole Augers -- The simplest and most readily available barrel auger is the post-hole auger (also called the Iwan-type auger)(7). As shown in Figure 2, the barrel part of this auger is not completely solid and the barrel is slightly tapered

toward the cutting bit. The tapered barrel together with the taper on the penetrating segment help to retain soils within the barrel. The barrel is available with a 3 in. (7.62 cm) to 12 in. (30.48 cm) diameter. There are two types of drilling systems, one has a single rod and handle, and the other has two handles. In stable, cohesive soils, the auger can be advanced up to 25 feet (7.62 m)(7).

7.4.5 Dutch-Type Augers -- The Dutch-type auger (commercially developed by Eijkelkamp) is a smaller variation of the post-hole auger design. As shown in Figure 3, the pointed bit is attached to two narrow, curved body segments, welded onto the shanks. The barrel generally has a 3 in. (7.62 cm) OD. This tool is best suited for sampling wet, clayey soils.

7.4.6 Regular or General Purpose Barrel Augers -- A version of the barrel auger commonly used by soil scientists and county agricultural agents is depicted in Figure 4(a) and 4(b). As shown, the barrel portion of this auger is completely enclosed. As with the post-hole auger, the cutting blades are arranged so that soil is loosened and forced into the barrel as the unit is rotated and pushed into the ground. Each filling of the barrel corresponds to a depth of penetration of 3 to 5 in. (7.62 to 12.70 cm) (1). The most popular barrel diameter is 3.5 in. (8.89 cm), but sizes ranging from 1.5 to 7 in. (3.81 to 17.78 cm) are available (5^2). Plastic, stainless steel, PTFE (polytetrafluoroethylene or Teflon^R) or aluminum liners can also be used (5^2). Extension rods are

available in 4 ft (1.22 m) lengths. The rods can be made from standard black pipe, from lightweight conduit or from seamless steel tubing. The extensions have evenly spaced marks to facilitate determining sample depth. The regular barrel auger is suitable for use in loam type soils.

7.4.7 Sand Augers -- For dry, sandy soils it may be necessary to use a variation of the regular barrel auger which includes a specially-formed penetrating bit to retain the sample in the barrel (see Fig. 4(c)). Sand augers with 2 in. (5.08 cm), 3 in. (7.62 cm), or 4 in. (10.16 cm) diameters are available (4^2).

7.4.8 Mud Augers -- Another variation on the regular barrel auger design is available for sampling wet, clayey soils. As shown in Figure 4(d), the barrel is designed with open sides to facilitate extraction of samples. The penetrating bits are the same as those used on the regular barrel auger (5^2). Mud augers with 2 in. (5.08 cm), 3 in. (7.62 cm), or 4 in. (10.16) diameters are available (4^2).

7.5 Tube-Type Samplers

7.5.1 Tube-type samplers differ from barrel augers in that tube-type units generally have smaller diameters and the sampler body lengths are generally greater than those of barrel augers.

7.5.2 Sampling with these units requires forcing the sampler in vertical increments into the soil. When the sampler is filled at each depth, the assembly is then pulled to the surface.

Commercial units are available with attachments which allow foot or hydraulic pressure to be applied to force the sampler into the ground, or with drop-hammers to drive the sampler into the ground (4^2). A vibratory head has also been developed to advance tube-type samplers (9^2).

7.5.3 These units are not as suitable for sampling in compacted, gravelly soils as are the barrel augers. They are preferred if an undisturbed sample is required. Commonly used varieties of the tube type samplers include:

7.5.3.1 soil sampling tubes (also called Lord samplers),

7.5.3.2 Veihmeyer tubes (also called King tubes),

7.5.3.3 thin-walled tube samplers (also called Shelby tubes),

7.5.3.4 ring-lined barrel samplers, and

7.5.3.5 piston samplers.

7.5.4 Soil Sampling Tubes

7.5.4.1 Description -- As depicted in Figure 5, the soil sampling tube consists of a hardened cutting tip, a cut-away barrel, and an uppermost threaded segment. The cut-away barrel is designed to facilitate lithologic examination and to allow for easy removal of soil samples. Generally, the tube is constructed from high strength alloy steel (10^2). The samplers are available with 6 in. (15.24 cm), 12 in. (30.48 cm), 15 in. (38.10 cm), 18 in. (45.72 cm) and 24 in. (60.96 cm) lengths (4, 5). The tubes are available with 1.13 in. (2.87 cm) or 0.88 in. (2.22 cm) OD. Two modified

versions of the tip are available for sampling in wet or in dry soils. The sampling tube is attached to extension rods (tubing) to attain the required sampling depth. A cross-handle is attached to the uppermost rod. Extension rods are manufactured from lightweight, durable metal. They are available in a variety of lengths depending on the manufacturer. Markings on the extensions and the sampler facilitate determining sample depths.

7.5.4.2 Sampling Method -- The sampler is pushed into the ground by leaning on the unit's handle. Once the sampler has reached the bottom of the sampling interval, it is twisted to break soil contact at the tip. Depending on the type of cutting edge, the tube sampler may obtain samples varying in diameter from 0.69 to 0.75 in. (1.75 to 1.91 cm).

7.5.4.3 Comments -- The soil sampling tube works best in soft, clayey, cohesive soils. If the soil contains cobbles or rock fragments larger than the cutting tip diameter, sampling may not be possible. If the soil is cohesionless, it will not be retained in the tube. With time, the cutting tip will be damaged and worn dull. Most units are designed so that this part can be replaced.

7.5.5 Veihmeyer Tubes

7.5.5.1 Description -- In contrast to the soil sampling tube, the Veihmeyer tube is a long, solid tube. As shown in Figure 6, this unit consists of a bevelled tip which is threaded into the lower end of the tube, and a drive head threaded into the upper

end of the tube. The sampler is constructed of hardened steel. The tube is generally marked in even increments (e.g. 1 ft or 0.30 m). These samplers are available in 4 ft (1.22 m) to 16 ft (4.88 m) lengths with a 0.75 in. (1.91 cm) ID.

7.5.5.2 Sampling Method -- A drop hammer is slipped onto ears on the drive head (see Fig 6). The hammer is used to drive the sampler into the ground. The sampler is then retrieved by pulling or jerking up on the hammer to force the sampler out of the soil cavity. Samples are extruded by forcing a rod through the tube.

7.5.5.3 Comments -- Prior to sampling, the inside of the tube is sometimes coated with a lubricant to facilitate extrusion. However, the types of analyses to be performed on the samples should be considered to determine if the lubricant will cause a bias. Because the Veihmeyer sampler is a solid tube and is fitted with a drop hammer, it can generally be used in harder soils than the soil sampling tube.

7.5.6 Thin-Walled Tube Samplers

7.5.6.1 Description -- Thin walled tube (Shelby Tube) samplers are readily available with 2 in. (5.08 cm), 3 in. (7.62 cm) and 5 in. (12.70 cm) OD and are commonly 30 in. (76.20 cm) long . The 3 in. (7.62 cm) OD x 30 in. (76.20 cm) long sampler is most common. During manufacturing, the advancing end of the sampler is rolled inwardly and machined to a cutting edge that has a smaller diameter than the tube ID. The cutting edge ID reduction, defined as a

"clearance ratio", is usually in the range of 0.0050 to 0.0150 or 0.50% to 1.50% (Refer to Practice D1587). The sampler tube is usually connected with set screws to a sampler head which in turn is threaded to connect with extension rods. Plastic and PTFE sealing caps for use after sampling are readily available for the 2, 3, and 5 in. (5.08, 7.62 and 12.70 cm) diameter tubes (refer to Practice D4220). Shelby tubes are commonly available in carbon steel but can be manufactured from other metal (see Fig. 7).

7.5.6.2 Sampling Method -- The shelby tube is pushed into soil by hand, with a jack-like system or with a hydraulic piston. The sample recovered is often less than the distance pushed, i.e., the recovery ratio is less than 1.0. The recovery ratio is less than 1.0 because of soil compaction during sampling and because the friction between soil and the tube ID becomes greater than the shear strength of the soil in front of the tube. Consequently, soil in front of the advancing end of the tube is displaced laterally rather than entering the tube (11). In general, shorter tubes provide less disturbed samples than longer tubes. Samples are extruded from the shelby tube with a hydraulic ram. As with all sampling devices, the portion of the sample in contact with the tube is considered contaminated. Wilson et al. (12) developed a paring device to remove this outer layer of the core during extrusion.

7.5.6.3 Comments -- Shelby tubes are best used in clays, silts

and fine grained sands. If the soils are cohesionless, they may not be retained in the tube. If firm to very hard soils are encountered, driving (hammering) the sampler may be required. However, this should be avoided as the tube may buckle under the drive stress.

7.5.7 Ring-Lined Barrel Samplers

7.5.7.1 Description -- As described in Practice D3550, the ring-lined barrel sampler consists of a one piece barrel or two split barrel halves, a drive shoe, rings, and a sampler head (see Fig. 8). The rings, which are usually brass, fit snugly inside the barrel and are designed to be directly inserted into geotechnical testing apparatuses when removed from the barrel. Most samplers are designed to hold at least two rings. The barrel is commonly 3.5 in. (8.89 cm) ID and 3.94 in. (10 cm) to 5.91 in. (15 cm) long (4^2). With these lengths, the barrel can be fitted with a variety of liners ranging in length from 2.54 in. (1 cm) to 2.36 in. (6 cm).

7.5.7.2 Sampling Method -- The ring-lined barrel sampler can be driven or pushed into soil. Once retrieved, the sampler is disassembled, and the sample filled rings are carefully removed. The rings are usually removed as one unit and placed into a capped container. Alternately, the individual soil filled rings can be capped with plastic or PTFE and then sealed with wax or adhesive tape (refer to Practice D4220).

7.5.7.3 Comments -- Because barrel samplers are more rigid than

thin walled tubes, they can be driven into hard soils and soils containing sands and gravels which might damage thin walled tubes. The sampler provides samples in rings which can be handled without further disturbance of the soil. Because of this, these devices are most often used when geotechnical or chemical analyses are to be performed.

7.5.8 Piston Samplers

7.5.8.1 Description -- Locally saturated (e.g. perched groundwater), cohesionless soils and very soft soils or sludges may not be retained in most samplers, even when fitted with retainer baskets or flap valves. Piston samplers can be used in these situations. The sampler consists of a sampling tube, extension pipe attached to the tube, an internal piston, and rods connected to the piston and running through the extension pipe (see Fig. 9). These samplers are often built, as needed, out of common PVC (for use in sludge) or steel pipe fittings. The sampling tube commonly has a 0.75 in. (1.91 cm) to 3 in. (7.62 cm) ID and is 8 in. (20.32 cm) to 9 ft (2.74 m) long (13). A variation designed for sampling peat has a cone shaped piston (7).

7.5.8.2 Sampling Method -- The sampler can be pushed into the ground with the handle or driven into the ground with a drop hammer (13). As the tube is advanced, the piston is held stationary or pulled upward with the attached rods. At the bottom of the sampling interval, the sampler is twisted to break suction which might have

developed at the tube-soil interface. The sampler is then pulled to the surface. The sample is retained because of suction which develops between the piston and the sample. Upon retrieval, the sample is extruded by using the piston to force the sample out of the tube. Sharma and De Dalta (14) described a cylindrical sampler for use in puddled soils which would flow back out of most samplers. The design includes a basal shutter which retains the sample while the sampler is withdrawn from the soil.

7.5.8.3 Comments -- Because the sampler depends on development of suction between the sample and the piston, it may not work in unsaturated, coarse, grained sands and gravels. This is due to the air filled voids which provide pathways for the suction to be relieved.

7.6 Hand Held Power Augers

7.6.1 Description -- A very simple, commercially available auger consists of a solid flight auger attached to and driven by a small air-cooled engine (see Fig. 10). Two handles on the head assembly allow two operators to guide the auger into the soil. Throttle and clutch controls are integrated into grips on the handles. Augers are available with diameters ranging from 2 in. (5.08 cm) to 16 in. (40.64 cm). The auger sections are commonly 3 ft (0.91 m) long.

7.6.2 Sampling Method -- As the auger rotates into soil, cuttings advance up the flights and are discharged at the surface.

Soil samples can be collected from the surface discharge, or from the auger flights after pulling the auger out of the ground. Alternatively, samples can be collected with other samplers (e.g. a thin-walled tubes) after auger removal.

7.6.3 Comments -- As discussed in Section 7.3, if samples are collected from surface discharge or from the flights, they are disturbed and are not suitable for some uses. In addition, if samples are collected from surface discharge, it is difficult to determine the depth from which the soil came and cross contamination concerns are amplified. The auger operates well in most soils. However, if the soil is cohesionless, it may not be retained on the flights and sampling in that fashion may not be possible. If the soil contains cobbles or boulders, drilling may not be possible. If the auger "hangs up" on an obstruction, the machine will start to rotate at the surface. In this situation, the operator should not attempt to stop rotation of the machine by grabbing the handles. An alternate design which transfers the torque to a separate engine prevents this problem ([15]). As previously stated, it is prudent to perform the field work with at least two people present.

7.7 Trench Sampling

7.7.1 Description -- Soils may be sampled from a trench or pit excavated for that purpose. Excavation is usually performed by a backhoe, and samples are collected with knives, trowels, or

shovels. Occasionally, samples are collected from the sides or the bottom of the trench or pit with hand augers or tube-type samplers.

7.7.2 Sampling Method -- Excavation is performed under the guidance of the sampling technician. Sampling is performed only after the backhoe has moved away from the trench or pit. When the trench or pit is in unstable material or is more than a few feet deep, the sampling technician should only enter the trench or pit after it has been shored up or the sidewalls have been cut back to within the angle of repose (note Occupational Safety and Health Administration regulations). In these situations, samples are more commonly collected at the surface from the bucket of the backhoe as excavation occurs.

7.7.3 Comments -- The maximum sampling depth for the trench or pit method is dictated by the reach of the backhoe, the soil type and the moisture content of the soil. Maximum depths of up to 20 ft (6.10 m) can be obtained in moist clays. Maximum depths of less than 10 ft (3.05 m) are common in dry sands. Samples collected from the backhoe bucket should be taken from the center of the material to prevent cross contamination from the bucket surface, and to prevent inclusion of materials which may have fallen to the trench bottom. However, when this is done, it is difficult to accurately estimate the depth from which the sample was obtained. Trenches are useful for obtaining lithologic information since cross sections of the vadose zone can be studied

and photographed. Trench or pit sampling is often used in areas with difficult access since backhoes are designed to travel on rough terrain. However, because the process involves excavating a much larger hole than drilling methods, chances of encountering underground utilities are increased.

8. Multipurpose and Auger Drill Rigs

8.1 Vadose zone samplers used in conjunction with drill rigs are identical to those used to sample below the water table. However, commonly used drill rigs such as cable tool and rotary units are not recommended as they generally require drilling fluids. Air rotary drilling is also undesirable for obtaining samples for pore liquid or gas extraction. In most cases, hollow-stem augers with some type of cylindrical sampler provide the greatest level of assurance that soil sampled within the vadose zone was not carried downward by the drilling or sampling process. For some situations, such as sampling firm to very hard ground, using multipurpose auger-core-rotary drill rigs will be necessary. For some geologic circumstances the use of solid stem augers will provide an adequate drilling method.

8.2 Multipurpose Auger-Core-Rotary Drill Rigs

8.2.1 Multipurpose auger-core-rotary drill rigs are generally manufactured with rotary power and vertical feed control to advance both hollow-stem augers and continuous flight (solid stem) augers to depths greater than 100 ft (30.48 m). These same drills have secondary capability for rotary and core drilling . The larger of these drills have 90 to 130 HP (67.11 to 96.94 kW) power sources and are typically mounted on 20,000 to 30,000 lb (9070 to 13605 kg) GVW trucks. The same multipurpose drill rigs are readily available in North America on both rubber-tired and track-driven all-terrain

carriers. The smaller of the multipurpose drills have 40 to 60 HP (29.83 to 44.74 kW) power sources and are typically mounted on trailers or one-ton, 4x4 trucks.

8.2.2 When equipped with augers, the sampling process is identical to that for auger drill rigs. When multipurpose auger-core-rotary drill rigs or auger drill rigs are used, the speed of drilling and sampling is much greater than with hand operated equipment. Therefore it is useful to have a larger crew to efficiently handle, log, identify, and preserve the samples.

8.3 Auger Drill Rigs

8.3.1 Auger drill rigs are similar to multipurpose auger-core-rotary drill rigs. They are manufactured specifically for efficient auger drilling but do not have the pumps and hoists that are required for efficient core or rotary drilling. The rigs can be equipped with either solid stem or hollow stem augers. There are relatively few auger drills available in comparison to multipurpose auger-core-rotary drills.

9. Auger Drilling and Sampling

9.1 Solid Stem Auger Drilling and Sampling

9.1.1 Description -- The tools used for solid-stem auger drilling include: auger sections, the drive cap, and the cutter head (see Fig. 11). Auger sections are typically 5 ft (1.52 m) long and are interchangeable for assembly in an articulated but continuously flighted column. Augers are available in diameters up to 24 in. (60.96 cm). The cutter head is attached to the lowermost or leading flight of the auger column. It is about 2 in. (5 cm) larger in diameter than the flights. Head types include fish tail or drag bits for use in cohesionless materials, and clay or stinger bits for use in more consolidated material (16).

9.1.2 Sampling Method -- As the auger column is rotated into soil, cuttings are retained on the flights. The augers are then removed from the hole and samples are taken from the retained soil. Samples obtained with solid stem augers are disturbed and are not truly core samples. Therefore, the samples are not suitable for analyses requiring undisturbed samples such as hydraulic conductivity tests. This sampling method can provide an adequately clean borehole in some clayey and silty soils. However, when using the method in caving or squeezing ground, the quality and the origin of the recovered samples are questionable because of cross contamination. Therefore, when representative samples are desired, the borehole should be made large enough to insert a smaller

diameter auger or another sampler (e.g. a thin walled tube) and extend it to the bottom of the borehole without touching the sides of the borehole (see Fig. 11).

9.1.3 Comments -- Typical drilling depths with solid stem augers range from 50 ft (15.24 m) to 120 ft (36.58 m). The greater drilling depths are attained in firm, silty and clayey soils. However, the depth to which the hole will remain open for sampling once the auger column has been removed is usually less than the maximum drilling depth. If cascading water or cohesionless soils are encountered, it can be expected that the hole will cave at that depth. The sample depth measurement, as taken from its location on an auger, is not accurate. This is because soil moves up the flights in an uneven fashion as the auger column is advanced. As with hollow-stem augers, solid stem augers are often painted by the driller or manufacturer. It is prudent to remove this paint before drilling. The majority of the paint can be removed by drilling through sandy soils or by sand blasting. As with all sampling devices, decontamination (e.g. steam cleaning) should be performed between holes when chemical analyses are to be performed on the samples. This is especially important with the solid stem auger as it doubles as the drilling and sampling tool.

9.2 Bucket Auger Drilling and Sampling

9.2.1 Description -- The bucket auger is a large diameter cylindrical bucket with auger-type cutting blades on the bottom.

The bucket can have a diameter ranging from 12 in. (30.48 cm) up to 6 ft (1.83 m) with lengths varying from 24 in. (60.96 cm) to 48 in. (121.92 cm) (17). The bottom is hinged to allow cuttings to be emptied out (see Fig. 12).

9.2.2 Sampling Method -- The bucket is rotated to depth in the vadose zone until the bucket is full. Therefore, depending on the bucket length, sampling intervals can range from 24 in. (60.96 cm) to 48 in. (121.92 cm).Sampling consists of extracting small diameter core samples from the interior of the bucket after lowering the full bucket to the ground (see Section 7). This approach minimizes problems with cross contamination of samples.

9.2.3 Comments -- The bucket auger is best suited for sampling from relatively stable clays as the caving problems discussed in Section 9.1.3 are amplified by the larger hole diameter. Boulders can impede drilling and may have to be individually removed from the hole before sampling can continue (15^2). Generally, boulders up to 1/3 of 1/4 the bucket diameter can be picked up by the bucket. Common sampling depths are less than 50 ft (15.24 m) but holes up to 250 ft (76.20 m) deep have been drilled (16,17).

9.3 Hollow Stem Auger Drilling and Sampling

9.3.1 Description -- Outer components of the hollow stem auger system include: hollow auger sections, the hollow auger head and the drive cap. Inner components include: the pilot assembly, the center rod column and the rod-to-cap adaptor (see Fig. 13).The

auger head contains replaceable carbide teeth that pulverize the formation during flight column rotation. The cutting diameter is somewhat greater than the flighting diameter because of the protruding teeth. Auger sections are typically 5 ft (1.52 m) long and are interchangeable for assembly in an articulated but continuously flighted column. Drilling progresses in 5 ft (1.52 m) or shorter increments and sampling can be accomplished at any depth within that increment. On completion of a 5 ft (1.52 m) increment, another 5 ft (1.52 m) section of hollow-stem auger and center rod is added. Hollow-stem augers are readily available with 2.25 in. (5.72 cm) ID, 2.75 in. (6.99 cm) ID, 3.25 in. (8.26 cm) ID, 3.75 in. (9.53 cm) ID, 4.25 in. (10.80 cm) ID, 6.25 in. (15.88 cm) ID, and 8.25 in. (20.96 cm)ID.

9.3.2 Sampling Method -- The auger column and pilot assembly are rotated to the top of the desired sampling interval. Sampling is accomplished by removing the pilot assembly and center rod and inserting the sampler through the hollow axis of the auger column (see Fig. 14). The sampler may be lowered to the sampling depth by attaching it to center rods or by using a wireline assembly (12). When the sampler is attached to center rods, a sample is collected by pushing or driving the sampler into undisturbed soil with the rig hydraulic system or with a drop hammer. When a wireline is used, the sampler is locked into place ahead of the lower-most auger and advanced into the sampling interval by rotating the auger

column (19[2]). Hollow stem augers with 6.25 in. (15.88 cm) ID allow the use of 5 in. (12.70 cm) OD shelby tubes and 4.5 in. (11.43 cm) OD split barrel samplers (see Section 9.4).

9.3.3 Comments -- The purpose of the center head assembly is to prevent soils from entering the auger column as it is advanced (20). Driscoll (17) suggests that the assembly may be omitted when drilling through hard, silty and clayey soils as these materials will usually form a 2 in. (5.08 cm) to 4 in. (10.16 cm) long plug at the auger opening. However, Hackett (20) recommends that the pilot assembly be used when detailed samples are required. When perched water is encountered, "heaving sands" which move up into the auger column upon pilot assembly removal during sampling, may be a concern. Various one way plugs which allow sampling, but which prevent sand from moving into the auger column are described in Hackett (20). The important capability of being able to obtain samples that are not contaminated from shallow sources in the hole is enhanced by using the hollow-stem auger method. However, because the sections are hollow, decontamination between holes to prevent cross contamination is more difficult. High pressure steam cleaners are usually necessary to remove caked on soils and contaminants. Hollow stem augers may advance rapidly through unconsolidated materials. Riggs and Hatheway (19[2]) report that the maximum drilling depth, in feet, with 3.25 in. (8.26 cm) to 4.25 in. (10.80 cm) diameter augers can be estimated by multiplying the available

horsepower at the drill spindle by 1.5. This estimate does not take into account large cobbles and boulders which slow down or impede drilling. It is generally recognized that the maximum drilling depth of hollow-stem augers in unconsolidated materials is 150 ft (45.72 m) (8).

9.4 Sampling Devices

9.4.1 Sampling devices used in conjunction with hollow stem augers and occasionally in holes advanced by solid stem augers include:

9.4.1.1 thin walled tube samplers (also called Shelby tubes),

9.4.1.2 split barrel drive samplers (also called Split Spoons),

9.4.1.3 ring-lined barrel samplers,

9.4.1.4 continuous sample tube systems, and

9.4.1.5 piston samplers.

9.4.2 These samplers are either pushed or driven in sequence with an increment of drilling or advanced simultaneously with the advance of a hollow stem auger column.

9.4.3 Thin Walled Tube Samplers

9.4.3.1 Description -- The thin walled tube sampler consists of a tube connected to a head with screws. The head is threaded to connect with standard drill rods. The head contains a ball check valve. Thin walled tube (Shelby Tube) samplers are readily available with 2 in. (5.08 cm), 3 in. (7.62 cm) and 5 in. (12.70

cm) OD and are commonly 30 in. (76.20 cm) long. The 3 in. (7.62 cm) OD x 30 in. (76.20 cm) long sampler is most common. During manufacturing, the advancing end of the sampler is rolled inwardly and machined to a cutting edge that has a smaller diameter than the tube ID. The cutting edge ID reduction, defined as a "clearance ratio", is usually in the range of 0.0050 to 0.0150 or 0.50% to 1.50% (Refer to Practice D1587). PTFE or plastic sealing caps and other sealing devices for use after sampling are readily available for the 2, 3, and 5 in. (5.08, 7.62 and 12.70 cm) diameter tubes (refer to Practice D4220). Shelby tubes are commonly available in carbon steel but can be manufactured from other metal (see Fig. 7).

9.4.3.2 Sampling Methods -- When a shelby tube is pushed into soil, the length of the sample recovered is often less than the distance pushed, i.e., the recovery ratio is less than 1.0 (see Section 7.5.6.2). In addition, a portion of the sample frequently remains in the borehole after retrieval of the sampler. This is due to suction which develops at the sampler-soil interface. This suction may be broken by twisting the sampler prior to retrieval or by advancing the auger column below the base of the sampler before retrieval (21). Samples are extruded from the shelby tube with a hydraulic ram. As with all sampling devices, the portion of the sample in contact with the tube is considered contaminated. Wilson et al. (12) developed a paring device to remove this outer layer of the core during extrusion.

9.4.3.3 Comments -- The ball check valve was originally intended to provide a vent for drilling fluids when pushing the tube into soil, and also to prevent the column of fluid within the drill stem from forcing the sample out of the tube during retrieval. Since drilling fluids are not used when sampling in the vadose zone, these considerations are not important. However, the valve does provide a vent for air displaced as the sampler is pushed into soil. Shelby tubes are best used in clays, silts and fine grained sands. They can be pushed with the hydraulic system of most drill rigs in fine grained sands that are loose to moderately consolidated or in clays and silts that are soft to firm. If the soils are cohesionless, they may not be retained in the tube. If consolidated or hard soils are encountered, driving the sampler may be required. However, some tubes may buckle under the drive stress. A spring loaded barrel has been developed to protect the shelby tube from buckling when sampling these soils (22^2).

9.4.4 Split-Barrel Drive Samplers

9.4.4.1 Description -- The split barrel drive sampler consists of two split-barrel halves, a drive shoe and a sampler head containing a ball check valve, all of which are threaded together (see Fig. 15). The most common size has a 2 in. (5.08 cm) OD and a 1.5 in. (3.81 cm) ID split barrel with a 1.375 in. (3.49 cm) ID drive shoe. This sampler is used extensively in geotechnical

exploration (Refer to Method D1586). When fitted with a 16 gage liner for encased cores, the sampler has a 1.375 in. (3.49 cm) ID throughout. A 3 in. (7.62 cm) OD x 2.5 in. (6.35 cm) ID split-barrel sampler with a 2.375 in. (6.03 cm) ID drive shoe is also available (18^2). Other split-barrel samplers in the size range of 2.5 in. (6.35 cm) OD to 4.5 in. (11.43 cm) OD are manufactured but are less common. A plastic or metal retainer basket, or a flap valve is often fitted into the drive shoe to prevent samples from falling out during retrieval.

9.4.4.2 Sampling Method -- As described in Method D1586 the sampler is threaded onto drilling rods and is lowered to the bottom of the boring. The sampler is then driven into the soil with blows from a drop hammer attached to the drill rig. The hammer usually weighs 140-lb. and is operated by the driller. The sampler is extracted from the soil by upward blows with the drop hammer.

9.4.4.3 Comments -- Split barrel drive samplers can be used in all soil types if the larger grain sizes can enter through the opening of the drive shoe. Because the sampler can be fitted with a retainer basket, it is typically used in place of thin walled tubes when cohesionless soils are to be sampled.

9.4.5. Ring-Lined Barrel Samplers

9.4.5.1 Description -- As described in Practice D3550, the ring-lined barrel sampler consists of a one piece barrel or two split barrel halves, a drive shoe, rings, a waste barrel and a

sampler head containing a ball check valve (see Fig. 16). The rings fit snugly inside the barrel and are designed to be directly inserted into geotechnical testing apparatuses when removed from the barrel. Most samplers are designed to hold at least six rings. The waste barrel provides a space above the rings into which disturbed soil, originally at the bottom of the hole, can move. The samplers are commonly available with 2 in. (5.08 cm), 3 in. (7.62 cm), and 4 in. (10.16 cm) OD.

9.4.5.2 Sampling Method -- The ring-lined barrel sampler can be driven or pushed into soil. It is important to insert the sampler deep enough to allow all disturbed soil to move through the rings and into the waste barrel. Once retrieved, the sampler is disassembled, and the sample filled rings are carefully removed. The rings are usually removed as one unit and placed into a capped container. Alternately, the individual soil filled rings can be capped with plastic or PTFE and even sealed with wax or adhesive tape (refer to Practice D4220).

9.4.5.3 Comments -- Because ring lined barrel samplers are more rigid than thin walled tubes, they can be driven into soils containing sands and gravels which might damage thin walled tubes. The sampler provides samples in rings which can be handled without further disturbance of the soil. Because of this, these devices are most often used when geotechnical or chemical analyses are to be performed.

9.4.6 Continuous Sample Tube System

9.4.6.1 Description -- Continuous sample tube systems which fit within a hollow stem auger column are readily available in North America. The barrel is typically 5 ft (1.52 m) long, and fits within the lead auger of the hollow auger column. The sampler is prevented from rotating as the auger column is turned (21). For many conditions the sampler provides continuous, 5 ft (1.52 m) samples (see Fig. 17). The assembly can be split- or solid-barrel and can be used with or without liners of various metallic and non-metallic materials (21). Two clear, plastic,30 in. (76.20 cm) long liners are often used. The sampler may also be fitted with a plastic or metal retainer basket, or a flap valve to prevent cohesionless soils from falling out of the sampler during retrieval (21).

9.4.6.2 Sampling Method -- The sampler is locked in place inside the auger column with its open end protruding a short distance beyond the end of the column. While advancing the column, soil enters the non-rotating sampling barrel. After a 5 ft (1.52 m) advance, the sampler is withdrawn, and the liner (if used) is removed and capped.

9.4.6.3 Comments -- The continuous sample tube system replaces the pilot head assembly in the hollow stem auger column. Because of this, sampling speed is greatly increased since the pilot assembly does not have to be removed before taking a sample. The

continuous sample tube system is best used in clays, silts and in fine grained sands. It can be used to sample soils that are much more consolidated or harder than can be sampled with shelby tubes.

9.4.7 Piston Samplers

9.4.7.1 Description -- Locally saturated (e.g. perched groundwater), cohesionless soils and very soft soils or sludges may not be retained in most samplers, even when they have been fitted with retainer baskets or flap valves. Piston samplers are often used under these conditions. The sampler consists of a sampling tube, an internal piston, and a drive head. The piston fits snugly inside the tube. The piston is attached to a rod assembly or a cable which leads to the surface. Tubes made of steel are available in 5.5 in. (13,97 cm), 30 in. (76.20 cm) and 5 ft (1.5 m) lengths with 0.75 in. (1.91 cm), 2 in. (5.08 cm), 3 in. (7.62 cm), 4 in. (10.16 cm), and 5 in. (12.70 cm) ID (18,23). When equipped with a hardened steel drive shoe, the tube can be fitted with an aluminum liner, a clear PVC liner, or a liner of some other material (see Fig. 18) (24). A version of the sampler designed for peat sampling has a cone shaped piston (7).

9.4.7.2 Sampling Method -- Prior to sampling, the piston is placed at the base of the tube. The sampler is then attached to drill rods and lowered down the borehole or hollow stem auger column to the bottom of the hole (top of the sampling interval). The sampler is then pushed or driven into the sampling interval.

As the tube moves downward, the piston remains stationary and in contact with the top of the soil sample. When the sampler is withdrawn, soil is retained because of suction which develops between the piston and the soil. This suction is stronger than the suction at the bottom of the sampler which would tend to extract soil from the sampler. Even so, it is often useful to twist the sampler with the drill rods prior to retrieval to ensure that the sample will not be pulled out of the sampler.

9.4.7.3 Comments -- Average recovery ratios greater than 0.9 can be attained with this sampling tool (24). However, because the sampler depends on development of suction between the sample and the piston, it may not work in unsaturated, coarse grained sands and gravels. This is due to the air filled voids which provide pathways for suction to be relieved. Samples collected with piston samplers are relatively undisturbed. Zapico et al. (24) described techniques for extracting fluid samples directly from liners, and for converting liners into permeameters.

Table 1 Criteria for selecting soil sampling equipment (from EPA/530-SW-86-040, 1986)

Type of Sampler	Obtains Core Sample		Most Suitable Core Types		Operation in Stoney Soils		Most Suitable Soil Moisture Conditions			Access to Sample Sites During Poor Soil Conditions		Relative Sample Size		Labor Req'mts	
A. Drill Rig Samplers	Yes	No	Coh.	Coh'less	Fav.	Unfav.	Wet	Dry	Inter.	Yes	No	Sm.	Lg.	Sngl.	2/More
1. Multipurpose Drill Rig	◆		◆	◆	◆		◆	◆	◆	◆		◆	◆		
2. Split-barrel Drive Sampler	◆		◆		◆			◆			◆		◆		◆
3. Thin-Walled Tube Sampler	◆		◆			◆			◆	◆			◆		◆
4. Piston Sampler	◆		◆			◆	◆			◆			◆		◆
5. Continuous Sample Tube system	◆		◆		◆		◆	◆	◆	◆		◆	◆		◆
6. Hand-Held Power Auger		◆			◆				◆	◆			◆		◆
B. Hand Operated Samplers															
1. Screw-Type Auger		◆				◆	◆			◆		◆		◆	
2. Barrel Auger															
a. Post-Hole Auger		◆	◆		◆		◆			◆			◆	◆	
b. Dutch Auger		◆	◆		◆		◆								
c. Regular Barrel Auger		◆	◆		◆				◆	◆		◆		◆	
d. Sand Auger		◆		◆	◆				◆	◆			◆	◆	
e. Mud Auger		◆	◆		◆		◆			◆			◆	◆	
3. Tube-Type Sampler															
a. Soil Sampling Tube															
(1) Wet Tip	◆					◆	◆			◆				◆	
(2) Dry Tip	◆					◆	◆			◆		◆		◆	
b. Veihmeyer Tube	◆								◆			◆		◆	

(a) Ship Auger

(b) Closed Auger

(c) Jamaica Open Spiral Auger

Fig. 1 Screw type augers (after Acker)

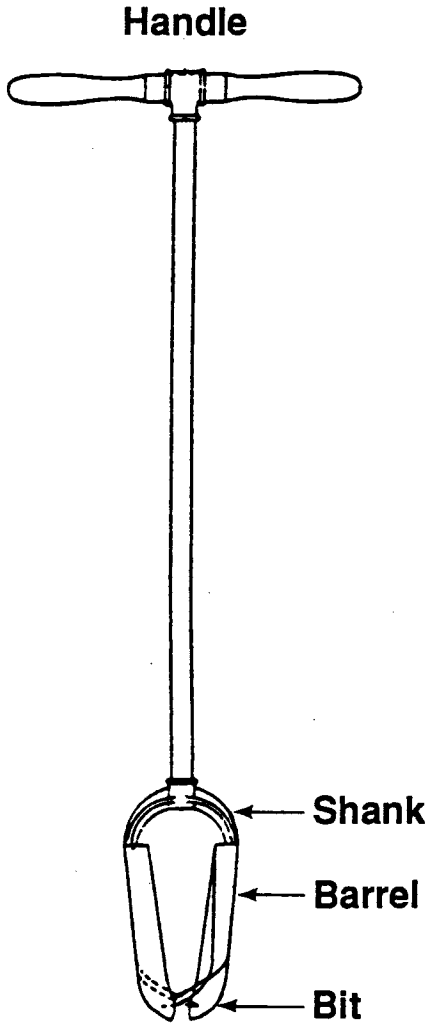


Fig. 2 Post-hole type barrel auger

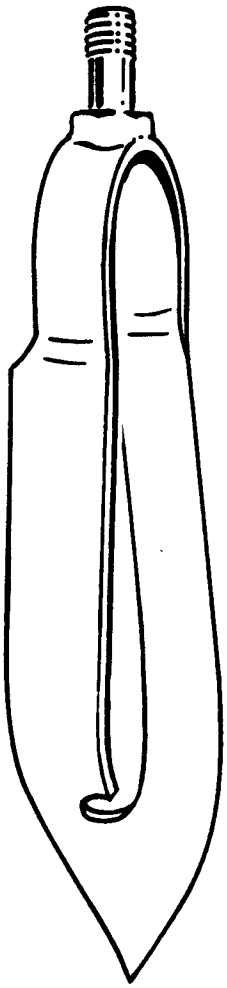
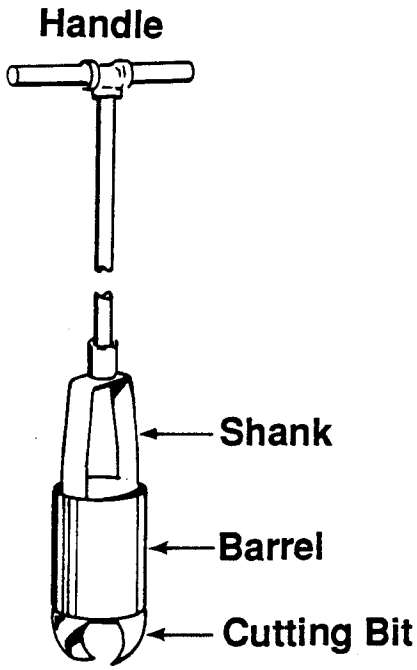
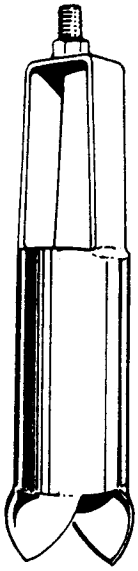


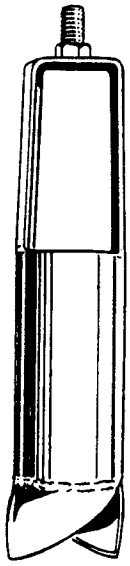
Fig. 3 Dutch type auger (after Art's manufacturing)



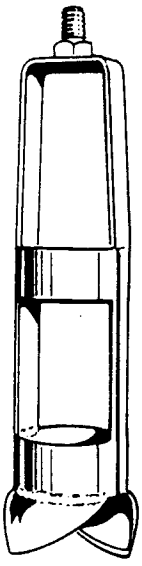
(a) Regular Barrel Auger



(b) Regular Barrel Auger



(c) Sand Auger



(d) Mud Auger

Fig. 4 Barrel auger variations (after Art's manufacturing)

and soil moisture

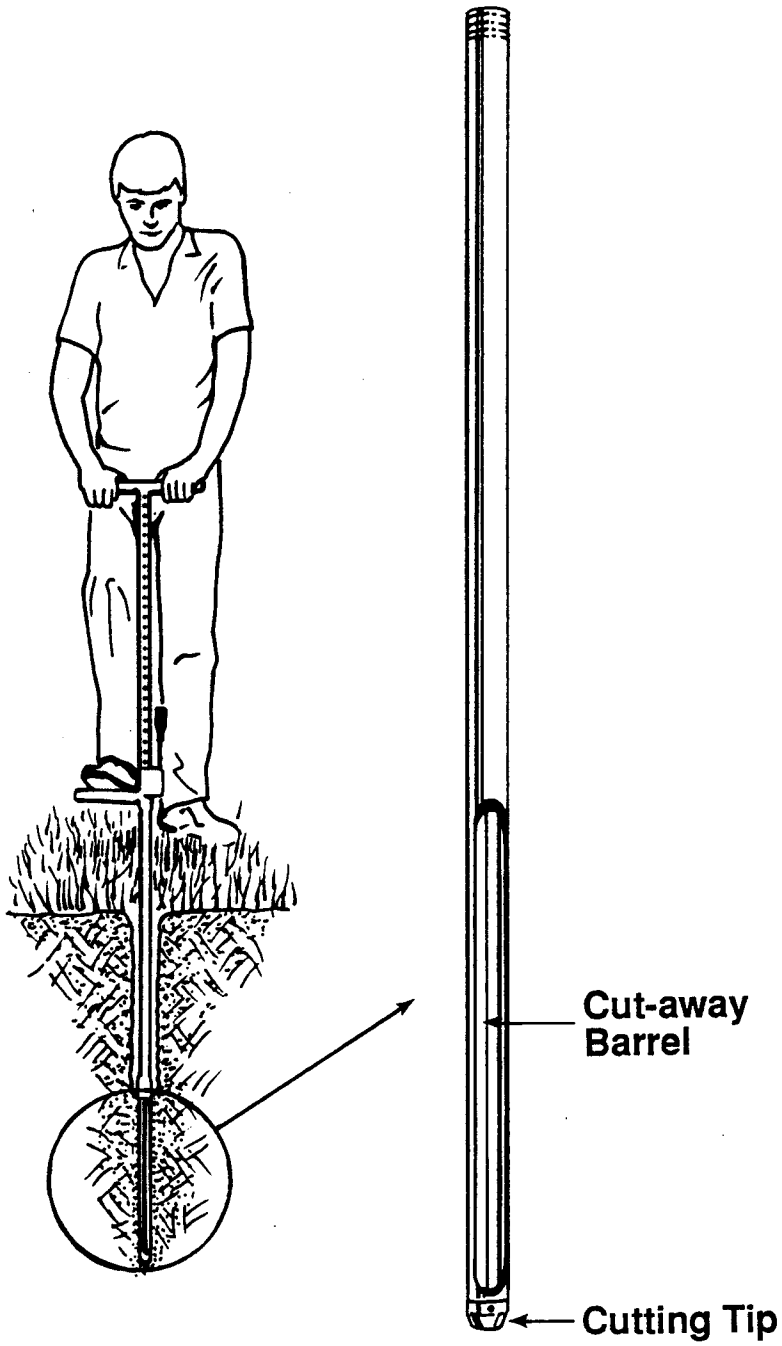


Fig. 5 Soil sampling tube (after ~~Soilmoisture Equipment Corp.~~ Clements)

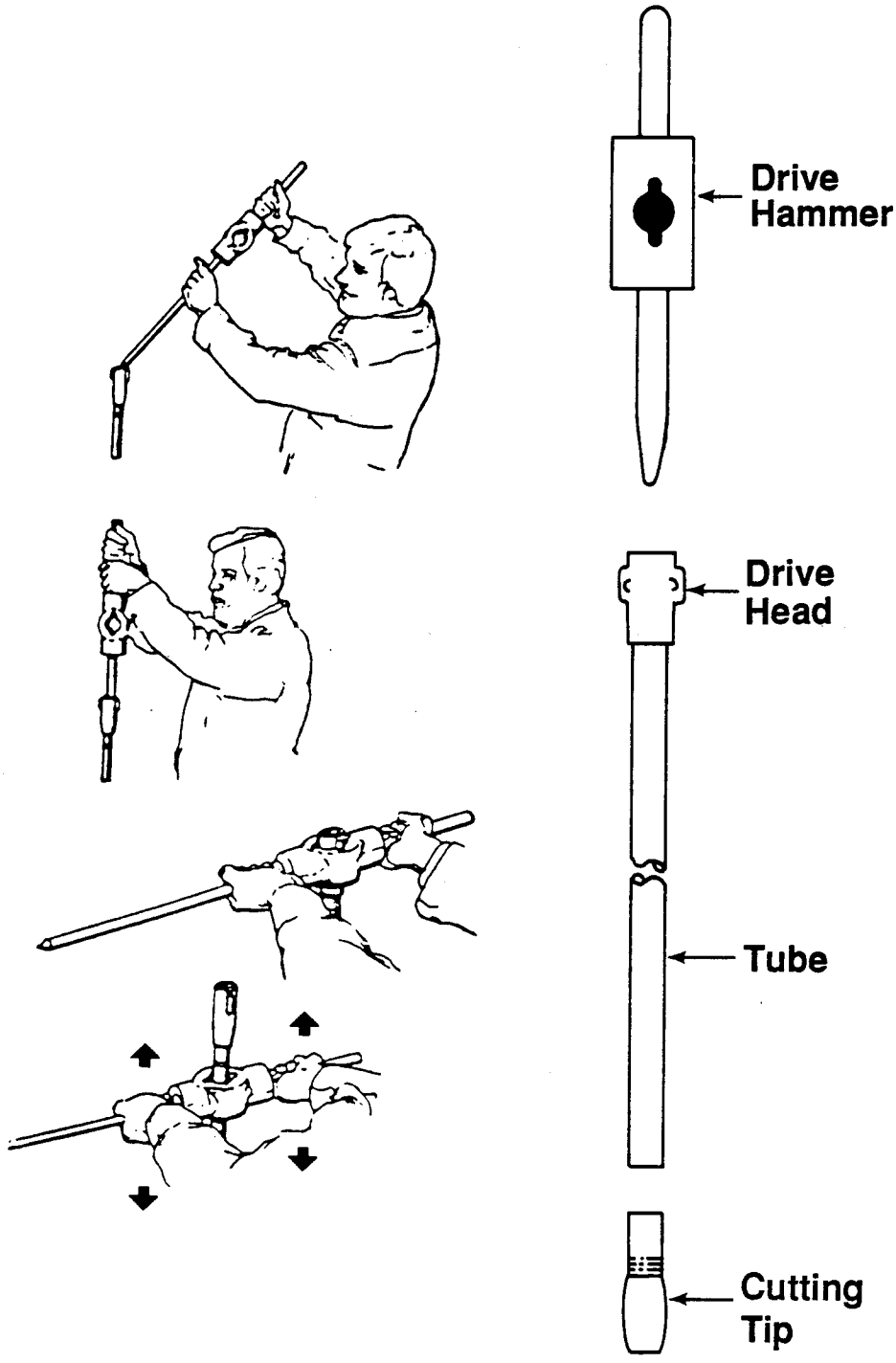


Fig. 6 Veihmeyer tube (after Soilmoisture Equipment Corp.)

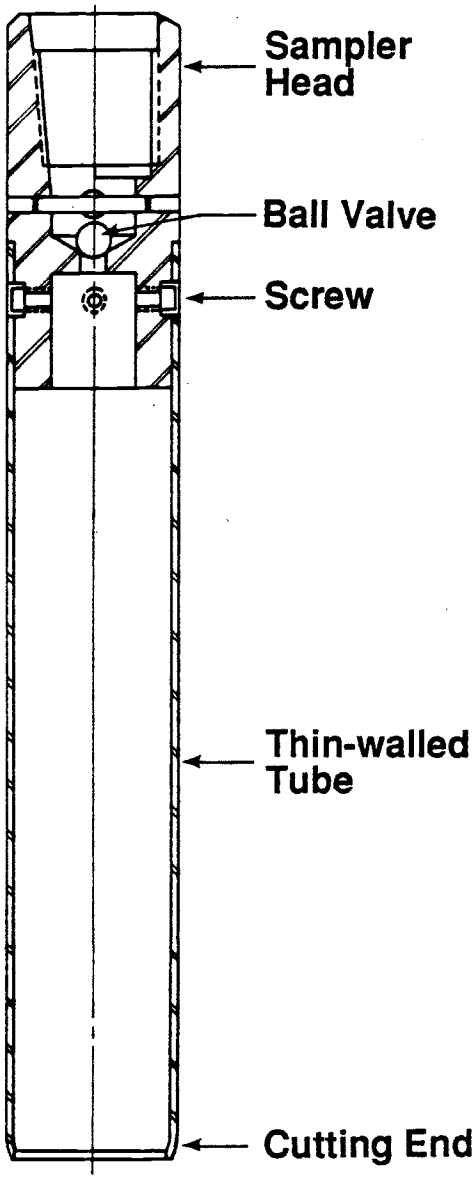


Fig. 7 Thin-walled tube sampler (after Mobile Drill Co., Inc.)

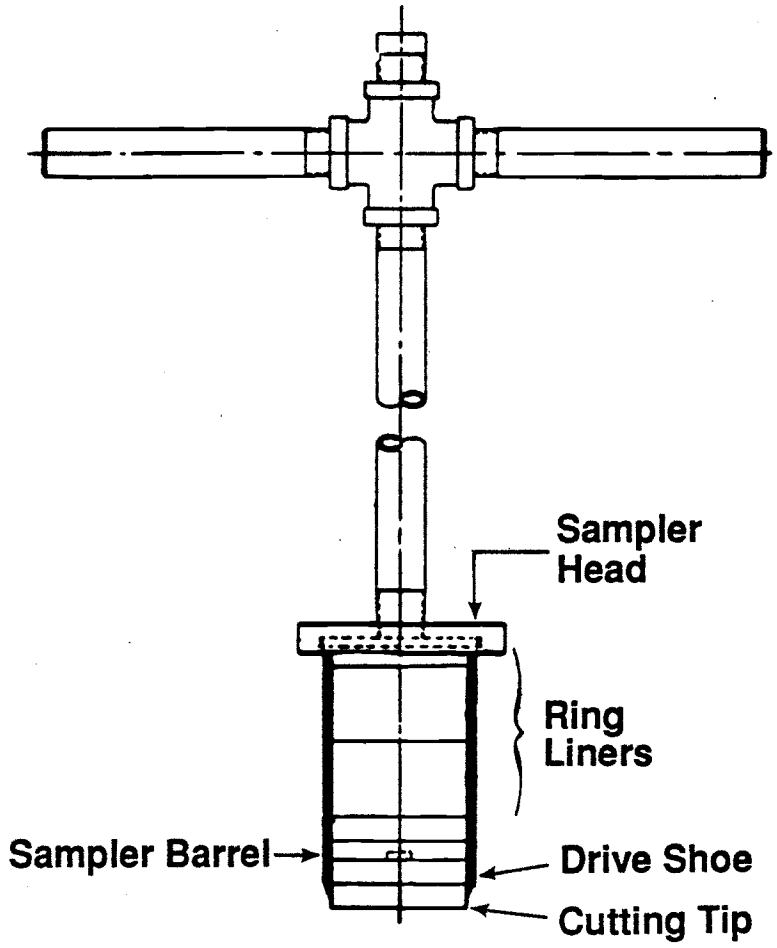


Fig 8 Hand operated ring-lined barrel sampler (after Soilmoisture Equipment Corp.)

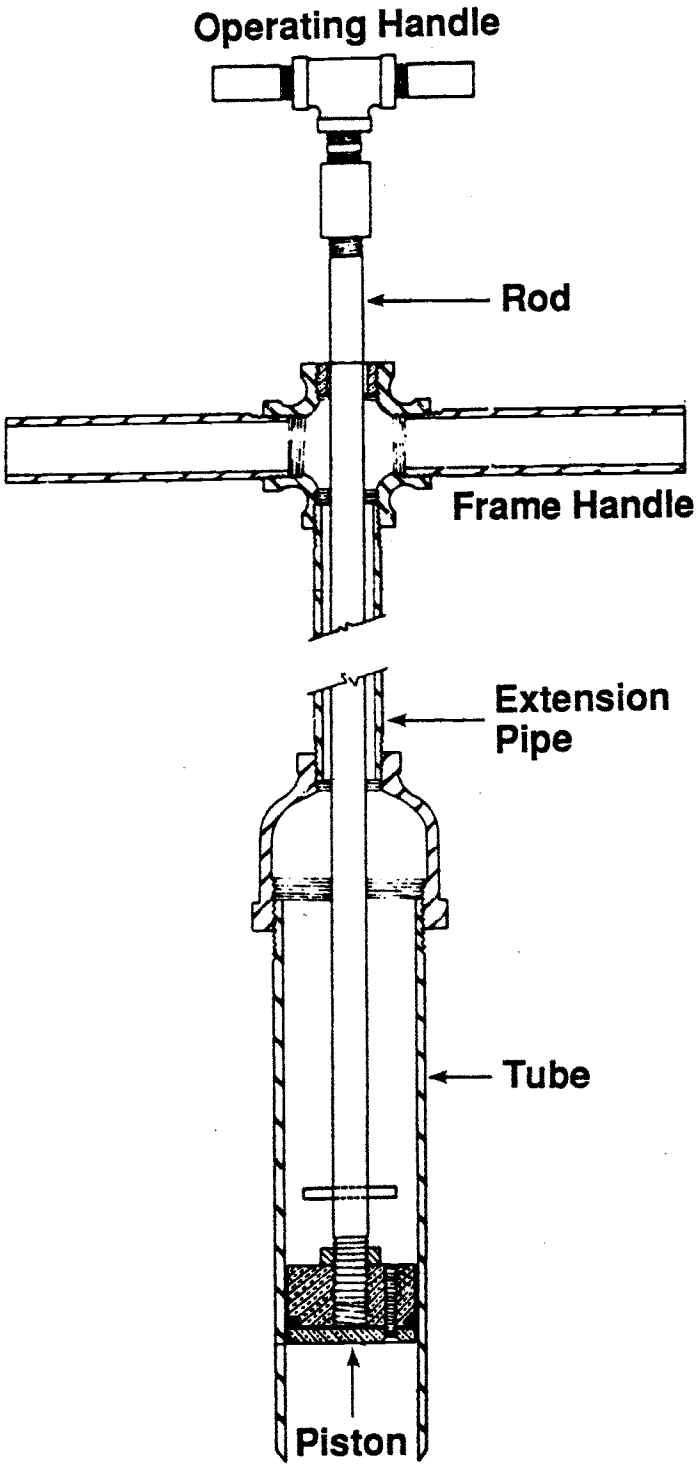


Fig. 9 Hand operated piston sampler (after Brakensiek et al.)

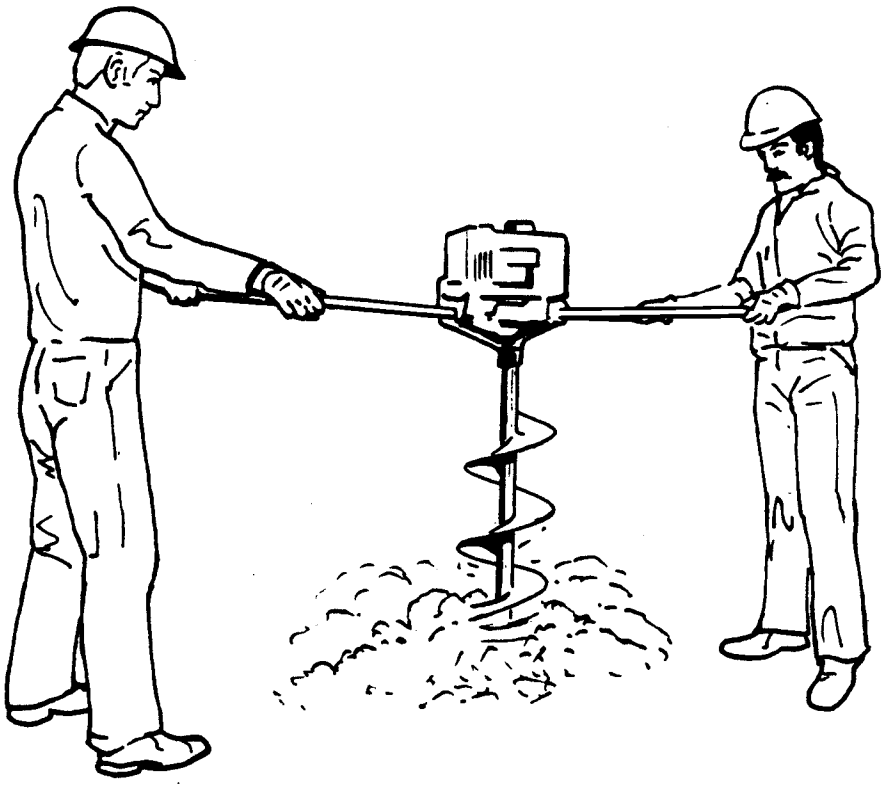


Fig. 10 Hand held power auger

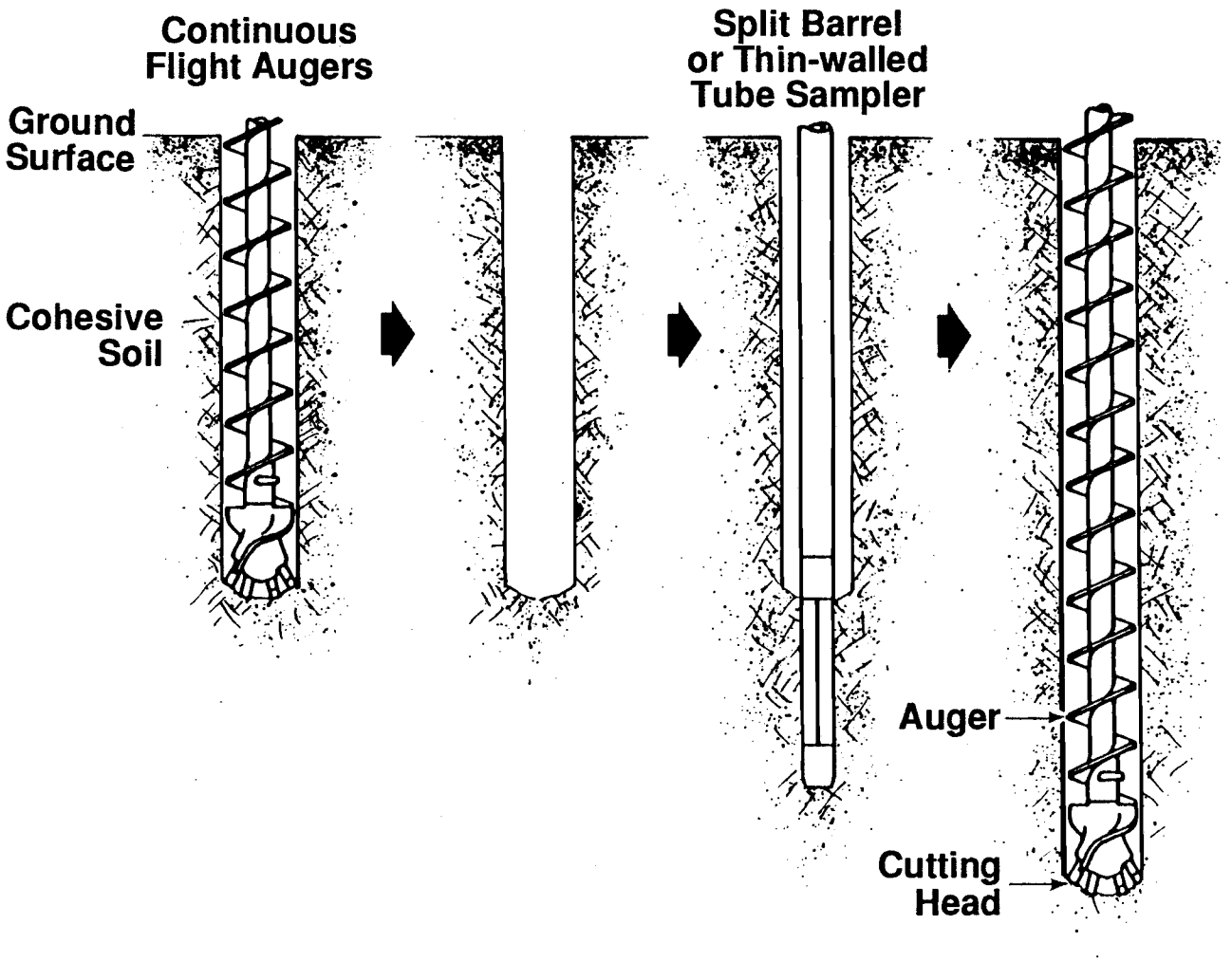


Fig. 11 Solid stem auger sampling (after Central Mine Equipment Co.)

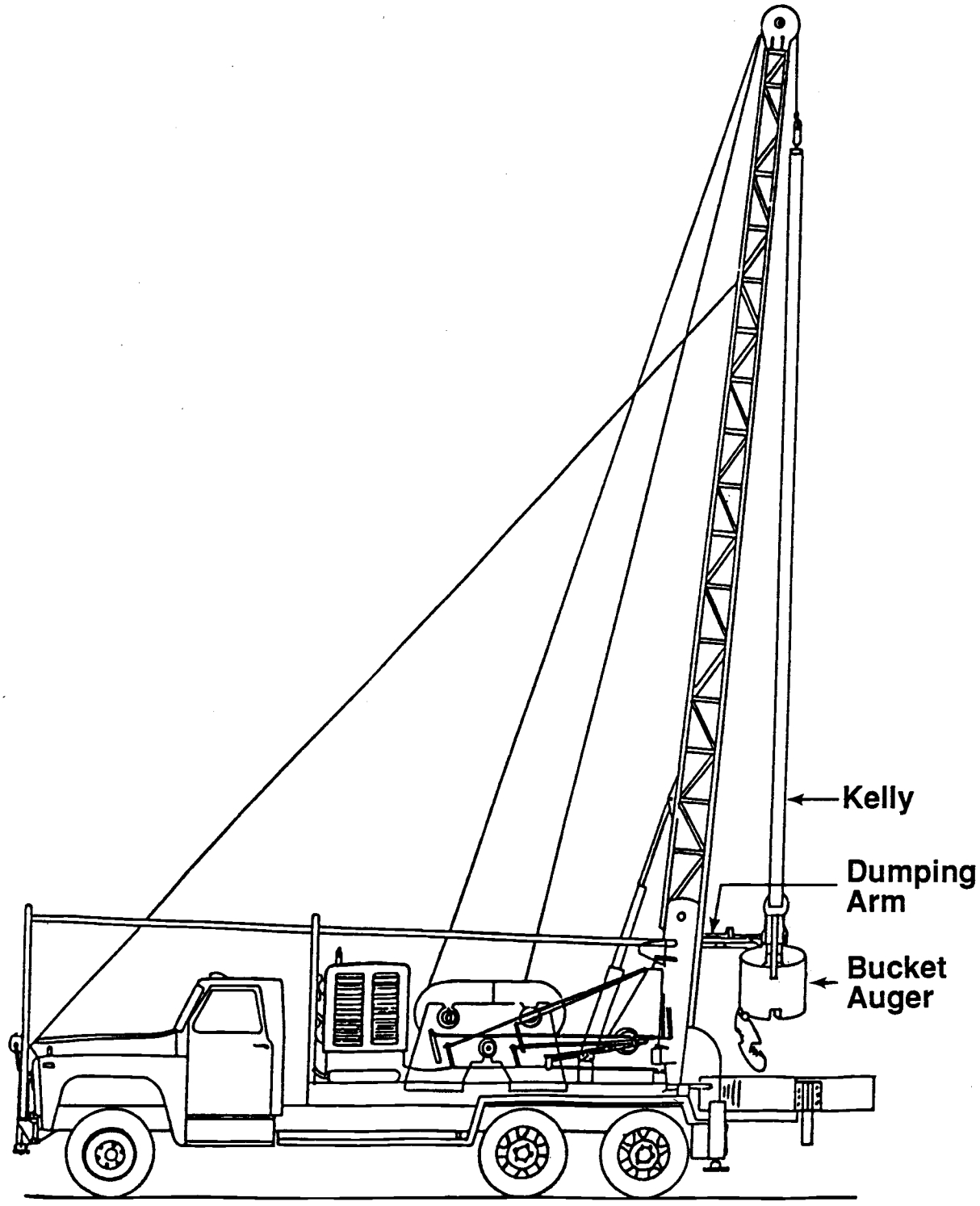


Fig. 12 Bucket auger and drilling rig (after Calweld Drilling Co.)

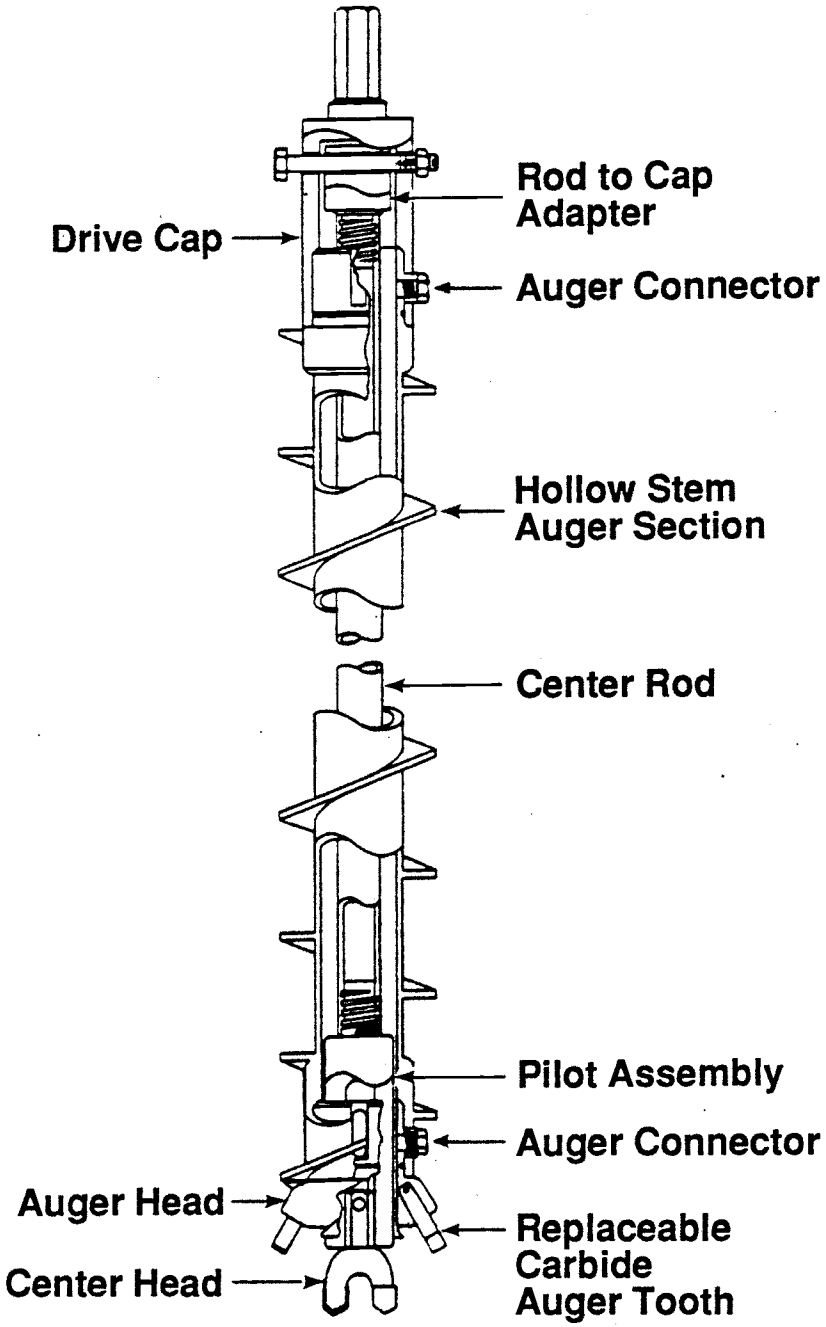


Fig. 13 Hollow stem auger components (after Central Mine Equipment Co.)

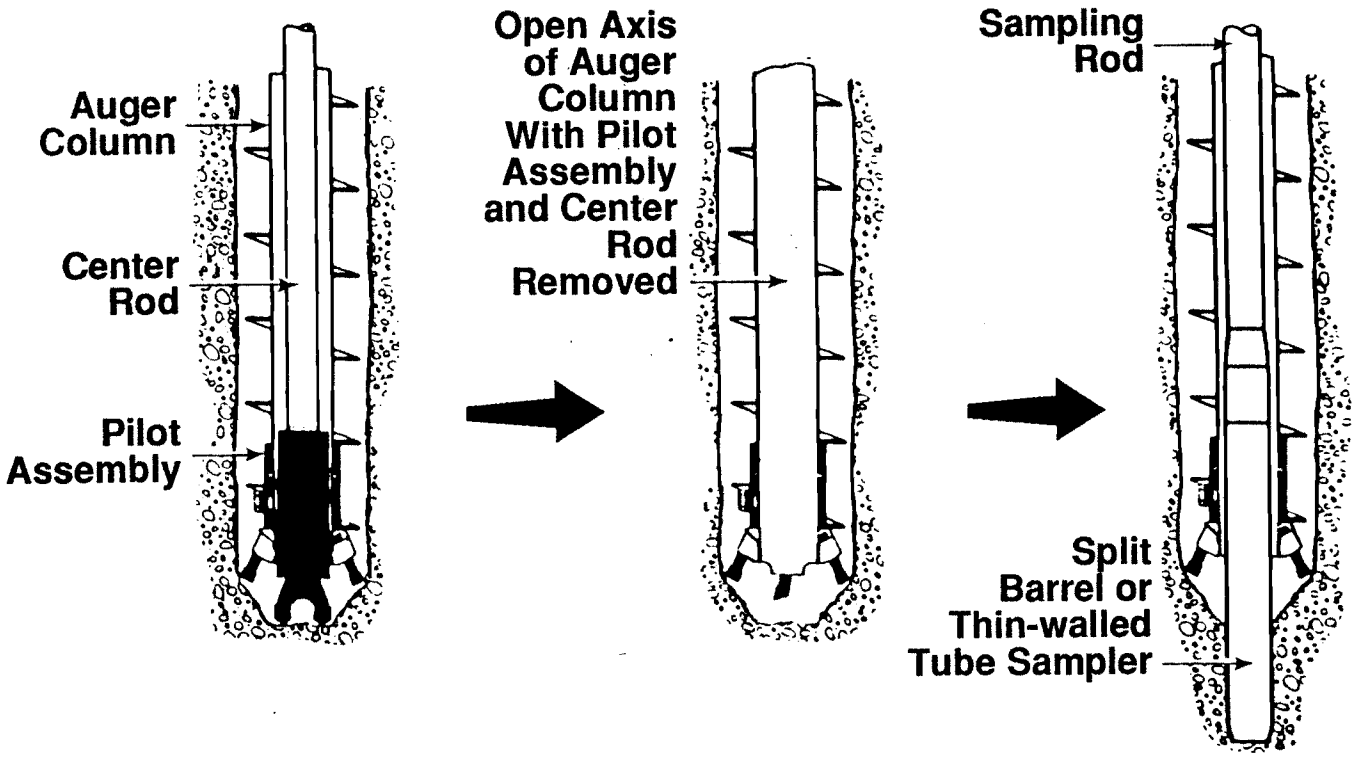


Fig. 14 Hollow stem auger sampling (after Hackett)

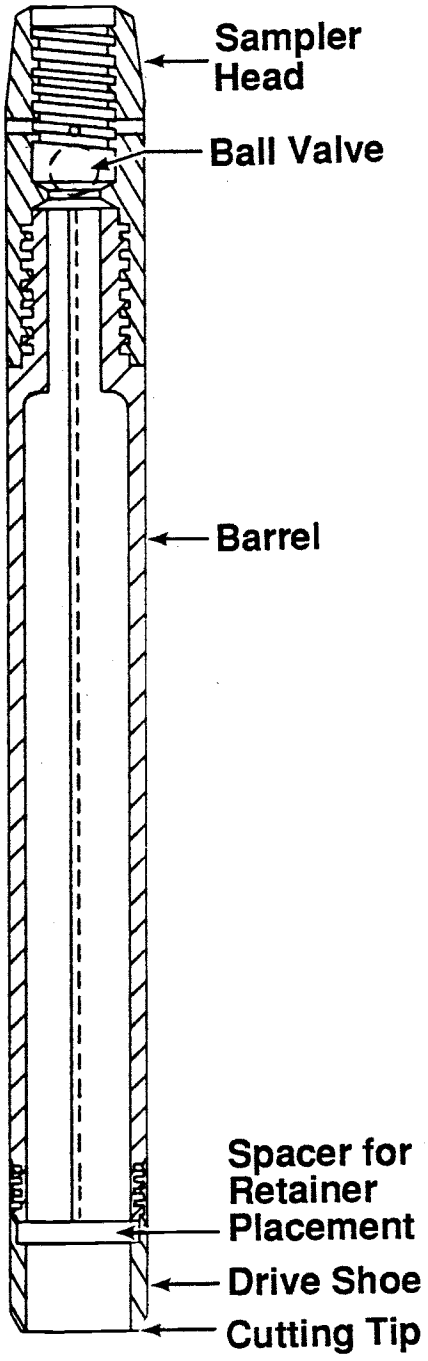


Fig. 15 Split barrel drive sampler (after Diedrich Drilling Equipment, Inc.)

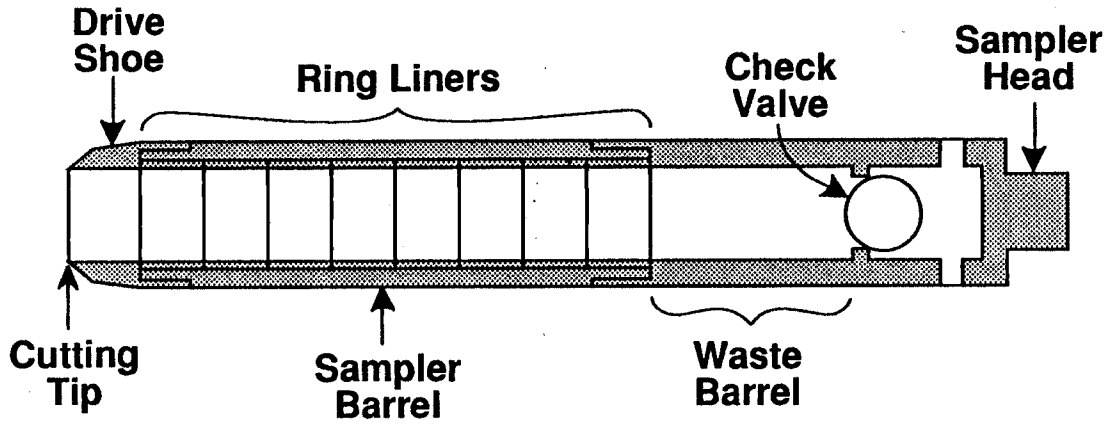


Fig. 16 Ring lined barrel sampler

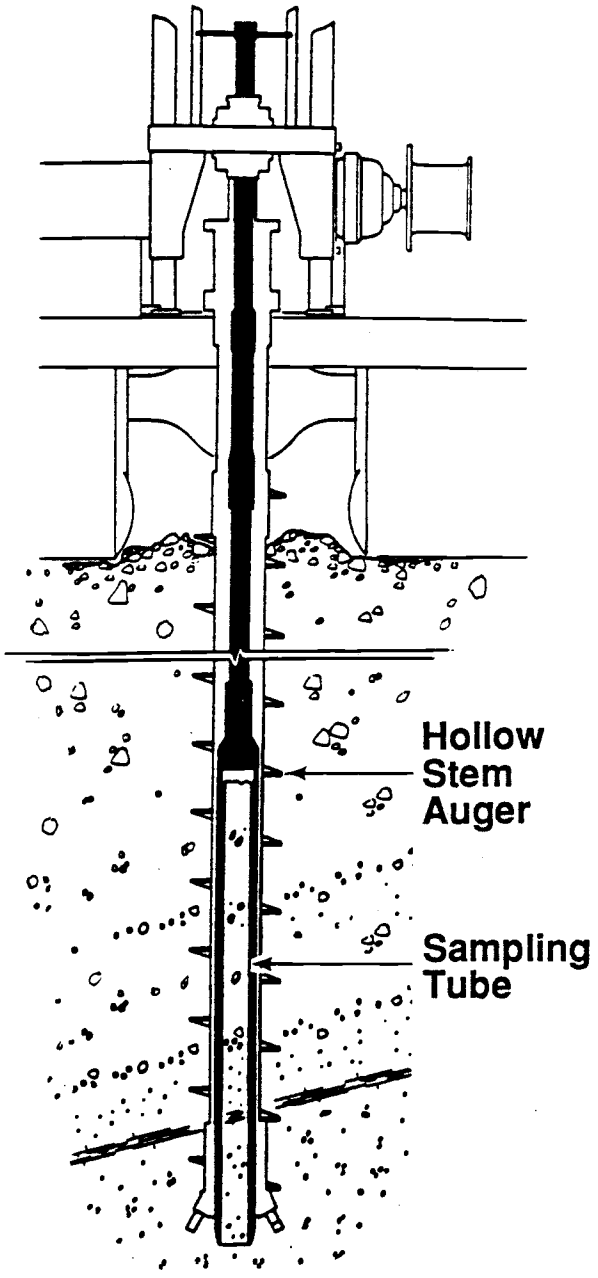


Fig. 17 Continuous sample tube system (courtesy Central Mine Equipment Co.)

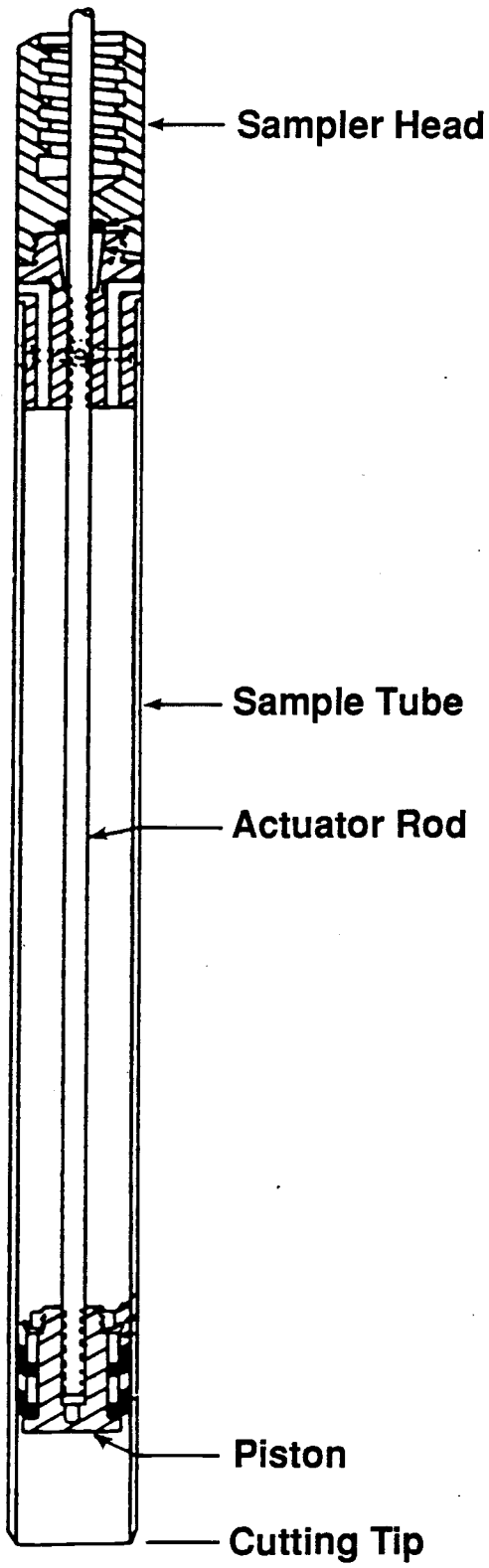


Fig. 18 Piston sampler (after Diedrich Drilling Equipment, Inc.)

References

(1) Soil Survey Staff, Soil Survey Manual, U.S. Dept. of Agriculture, Superintendent of Documents, Washington, D.C., 1951.

(2) Materials Testing Division, Catalog of Products, Soiltest Inc., Evanston, Illinois, 1983.

(3) Bureau of Reclamation, Earth Manual, U.S. Dept. of the Interior, United States Government Printing Office, Washington, D.C., 1974.

(4) Sales Division, Catalog of Products, Soilmoisture Equipment Corp., Santa Barbara, California, 1988.

(5) Sales Division, Catalog of Products, Art's Manufacturing and Supply, American Falls, Idaho, 1988.

(6) Sales Division, Catalog of Products, Brainard Kilman, Stone Mountain, Georgia, 1988.

(7) Acker, W.L., Basic Procedures for Soil Sampling and Core Drilling, Acker Drill Co. Inc., Scranton, Pa, 1974.

(8) Everett, L.G., and Wilson, L.G., Permit Guidance Manual on Unsaturated Zone Monitoring For Hazardous Waste Land Treatment Units, EPA/530-SW-86-040, 1986.

(9) Sales Division, Catalog of Products, VI-COR Technologies Inc., Bellevue, Washington, 1988.

(10) Sales Division, J.M.C. Soil Investigation Equipment, Catalog No. 6, Clements Associates Inc..

(11) Hvorslev, M.J., Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes, U.S. Army Corp of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, 1949.

(12) Wilson, J.T., and McNabb, J.F., "Biological Transformation of Organic Pollutants in Groundwater", EOS-Transactions, AGU, Vol. 64, pp. 505-507.

(13) Brakensiek, D.L., Osborn, H.B., and Rawls, W.L., Field Manual for Research in Agricultural Hydrology, Agriculture Handbook No. 224, Science and Education Administration, United States Dept. of Agriculture, Washington, D.C., 1979 (revised), pp. 258-275.

(14) Sharma, P.K., and DeDalta, S.K., "A Core Sampler for Puddled Soils", Soil Science Society of America Journal, Vol. 49, 1985, pp. 1069-1070.

(15) Sales Division, Catalog of Products, Little Beaver Inc., Livingston, Texas, 1988.

(16) Scalf, M.R., McNabb, J.F., Dunlap, W.J., Cosby, R.L., and Fryberger, J., Manual of Groundwater Sampling Procedures, National Water Well Association, Dublin, Ohio, 1981.

(17) Driscoll, F.G., Groundwater and Wells, Johnson Division, St. Paul, Minnesota, 1986 (2nd ed.).

(18) Sales Division, Catalog of Products, Diedrich Drilling Equipment, LaPorte, Indiana, 1988.

(19) Sales Division, Catalog of Products, Mobile Drilling Co. Inc, Indianapolis, Indiana, 1988.

(20) Hackett, G., "Drilling and Constructing Monitoring Wells with Hollow-Stem Augers Part 1: Drilling Considerations", Ground Water Monitoring Review, NWWA, Fall 1987, pp. 51-62.

(21) Riggs, C.O., "Soil Sampling in the Vadose Zone", Proceedings of the NWWA/U.S. EPA Conference on Characterization and Monitoring of the Vadose Zone, NWWA, Las Vegas, Nevada, 1983, pp. 611-622.

(22) Sales Division, Product Literature, Pitcher Drilling Co., Palo Alto, California, 1986.

(23) Sales Division, Instrumentation for Soil and Rocks, Catalog of Products, Solinst, Burlington, Ontario, Canada, 1988.

(24) Zapico, M.M., Vales, S., and Cherry, J.A., "A Wireline Core Barrel for Sampling Cohesionless Sand and Gravel Below the Water Table", Ground Water Monitoring Review, NWWA, Spring 1987, pp. 75-82.

APPENDIX IV

Draft: 2B
Date : June 23,1989

STANDARD GUIDE FOR PORE-LIQUID SAMPLING FROM THE VADOSE ZONE

1. Scope

1.1 This guide discusses equipment and procedures which may be used for sampling pore-liquid from the vadose zone. The guide is limited to in-situ techniques and does not include soil core collection and extraction methods for obtaining samples.

1.2 The term "pore-liquid" is applicable to any liquid from aqueous pore-liquid to oil. However, all of the samplers described in this standard were designed, and are used to sample aqueous pore-liquids only. The abilities of these samplers to collect other pore-liquids may be quite different than those described.

1.3 Some of the samplers described in this standard are not currently commercially available. These samplers are presented because they may have been available in the past, and may be encountered at sites with established vadose zone monitoring programs. In addition, some of these designs are particularly

suited to specific situations. If needed, these samplers could be fabricated.

1.4 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards

D? Standard Guide for Tensiometers--Theory, Construction and Use

D? Standard Guide for Soil-gas Monitoring in the Vadose Zone

D? Standard Guide for Soil-Core Monitoring in the Vadose Zone

D? Standard Guide for Unsaturated Hydraulic Conductivity Measurement

D? Standard Guide for the Use of Casing Advancement Drilling Methods in Geoenvironmental Exploration and Subsurface Contaminant Monitoring Device Installations

D? Glossary of Vadose Zone Monitoring Terms

D? Monitoring Well Design and Construction

D? Ground Water Sampling and Field Analysis

D? Surface and Borehole Geophysics

3. Definitions

3.1 Where reasonable, precise terms and names have been used within this guide. However, certain terms and names with varying definitions are ubiquitous within the literature and industry of vadose zone monitoring. For purposes of recognition, these terms and names have been included in the guide with their most common usage. In these instances, the common definitions have been included in Appendix X1, Glossary. Examples of such terms are soil, lysimeter, vacuum and pore-liquid tension.

3.2 Appendix X1 is a compilation of those terms used in this guide. More comprehensive compilations, which were used as sources for Appendix X1, are (in decreasing order of their usage):

3.2.1 Glossary of Vadose Zone Monitoring Terms D pending,

3.2.2 Terms and Symbols D653,

3.2.3 Compilation of ASTM Standard Definitions, 6th ed. 1986,

3.2.4 Glossary of Soil Science Terms, Soil Science Society of America, 1987 ed. and,

3.2.5 Webster's New Collegiate Dictionary, 5th ed. 1977.

4. Summary of Guide

4.1 Pores in the vadose zone can be saturated or unsaturated. Some samplers are designed to extract liquids from unsaturated pores; others are designed to obtain samples from saturated pores (e.g. perched ground water) or saturated macropores (e.g. fissures, cracks and burrows). This standard addresses these categories. The sampler types discussed are :

4.1.1 Suction Samplers (unsaturated sampling)(Section 7),

4.1.2 Free Drainage Samplers (saturated sampling)(Section 8),

4.1.3 Perched Ground Water Samplers (saturated sampling)(Section 9) and

4.1.4 Experimental Absorption Samplers (unsaturated sampling)(Section 10).

4.2 Most samplers designed for sampling liquid from unsaturated pores may also be used to sample from saturated pores. This is useful in areas where the water table fluctuates, so that both saturated and unsaturated conditions occur at different times. However, samplers designed for sampling from saturated pores cannot be used in unsaturated conditions. This is because the liquid in unsaturated pores is held at less than atmospheric pressures (see Appendix X1, Richard's Outflow Principle).

4.3 The discussion of each sampler is divided into specific topics which include:

4.3.1 Operating Principles,

4.3.2 Description,

4.3.3 Installation,

4.3.4 Operation, and

4.3.5 Limitations.

5. Significance and Use

5.1 Sampling from the vadose zone may be an important component of some ground water monitoring strategies. It can provide information regarding contaminant transport and attenuation in the vadose zone. This information can be used for mitigating potential problems prior to degradation of a ground water resource (1)[1].

5.2 The choice of appropriate sampling devices for a particular location is dependant on various criteria. Specific guidelines for designing vadose zone monitoring programs have been discussed by Morrison (1), Wilson (2), Wilson (3), Everett (4), Wilson (5), Everett et al (6), Wilson (7), Everett et al (8), Everett et al (9), Robbins et al (10), Merry and Palmer (11), U.S. EPA (12), Ball (13) and Wilson (14). In general, it is prudent to combine various unsaturated and free drainage samplers into a program, so that the different flow regimes may be monitored.

5.3 This guide does not attempt to present details of installation and use of the equipment discussed. However, an effort has been made to present those references in which the specific techniques may be found.

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[1] The boldface numbers in parentheses refer to the list of references at the end of this standard.

6. Criteria for Selecting Pore-Liquid Samplers

6.1 Decisions on the types of samplers to use in a monitoring program should be based on consideration of a variety of criteria which include:

6.1.1 Required Sampling Depths,

6.1.2 Required Sample Volumes,

6.1.3 Soil Characteristics,

6.1.4 Chemistry and Biology of the Liquids to be Sampled,

6.1.5 Moisture Flow Regimes,

6.1.6 Required Durability of the Samplers,

6.1.7 Required Reliability of the Samplers,

6.1.8 Climate,

6.1.9 Installation Requirements of the Samplers,

6.1.10 Operational Requirements of the Samplers,

6.1.11 Commercial Availability and

6.1.12 Costs.

6.2 Some of these criteria are discussed in this standard. However, the ability to balance many of these factors against one another can only be obtained through field experience.

7. Suction Samplers

7.1 Table 1 presents the various types of suction samplers. The range of operating depths is the major criterion by which suction samplers are differentiated. Accordirgly, the categories of suction samplers are:

7.1.1 Vacuum Lysimeters -- These samplers are operational at depths less than about 7.5 m.

7.1.2 Pressure-Vacuum Lysimeters -- These samplers are operational at depths less than about 15 m.

7.1.3 High Pressure-Vacuum Lysimeters (also known as pressure-vacuum lysimeters with transfer vessels) -- These samplers are normally operational down to about 46 m, although installations as deep as 91 m have been reported (15).

7.1.4 Suction Lysimeters with Low Bubbling Pressures (samplers with PTFE porous sections) -- These samplers are available in numerous designs which can be used to maximum depths varying from about 7.5 to 46 m.

NOTE 1 -- The samplers of Sections 7.1.1, 7.1.2, 7.1.3, and 7.1.4 are referred to collectively as suction lysimeters. Within this standard, lysimeter is defined as a device used to collect percolating water for analyses (16).

7.1.5 Filter Tip Samplers -- These samplers theoretically have no maximum sampling depth.

7.1.6 Experimental Suction Samplers -- The samplers have limited field applications at the present time. They include cellulose-acetate hollow-fiber samplers, membrane filter samplers,

and vacuum plate samplers. They are generally limited to depths less than about 7.5 m.

7.2 Operating Principles

7.2.1 General

7.2.1.1 Suction lysimeters consist of a hollow, porous section attached to a sample vessel or a body tube. Samples are obtained by applying suction to the sampler and collecting pore-liquid in the body tube. Samples are retrieved by a variety of methods.

7.2.1.2 Unsaturated portions of the vadose zone consist of interconnecting soil particles, interconnecting air spaces, and interconnecting liquid films. Liquid films in the soil provide hydraulic contact between the saturated porous section of the sampler and the soil (see Figure 1). When suction greater than the soil pore-liquid tension is applied to the sampler, a pressure potential gradient towards the sampler is created. If the meniscuses of the liquid in the porous segment are able to withstand the applied suction (depending on the maximum pore sizes), liquid moves into the sampler. The ability of the meniscuses to withstand a suction decreases with increasing pore size and also with increasing hydrophobicity of the porous segment (see Section 7.6). If the maximum pore sizes are too large, the meniscuses are not able to withstand the applied suction. As a result, they break down, hydraulic contact is lost, and only air enters the sampler. As described in Section 7.6, the maximum pore

sizes of ceramic porous segments are small enough to allow meniscuses to withstand the entire range of sampling suctions. The maximum pore sizes of presently available polytetrafluoroethylene (PTFE or Teflon^{R}) porous segments are larger, and only a very limited range of sampling suction can be applied before meniscuses break down and sampling ends (see Section 7.6.1.3). Therefore, samplers made with PTFE porous segments may be used only for sampling soils with low pore-liquid tensions (12,17).

7.2.1.3 The ability of a sampler to withstand applied suctions is determined by its bubbling pressure. The bubbling pressure is measured by saturating the porous segment, immersing it in water, and pressurizing the inside of the porous segment with air. The pressure at which air starts bubbling through the porous segment into the surrounding water is the bubbling pressure. The magnitude of the bubbling pressure is equal to the magnitude of the maximum suction which can be applied to the sampler before air entry occurs (air entry value). Because the bubbling pressure is a direct measure of how a sampler will perform, it is more useful than measurement of pore size distributions.

7.2.1.4 As soil pore-liquid tensions increase (low pore-liquid contents), pressure gradients towards the sampler decrease. Also, the soil hydraulic conductivity decreases exponentially. These result in lower flow rates into the sampler. At pore-liquid tensions above about 60 cbar (for coarse grained soils) to 80 cbar

(for fine grained soils), the flow rates are effectively zero and samples cannot be collected.

7.2.2 Suction Lysimeters

7.2.2.1 Vacuum lysimeters directly transfer samples to the surface via a suction line. Because the maximum suction lift of water is about 7.5 m, these samplers cannot be operated below this depth. In reality, suction lifts of even 7.5 m may be difficult to attain.

7.2.2.2 Pressure-vacuum lysimeters first collect pore-liquid in the body tube by application of suction. The sample is then retrieved by pressurizing the sampler with one line; this pushes the sample up to the surface in a second line.

7.2.2.3 High pressure-vacuum lysimeters operate in the same manner as pressure-vacuum lysimeters. However, they include a transfer vessel or a chamber between the sampler and the surface. This prevents sample loss through the porous section during pressurization, and prevents possible cup damage due to overpressurization.

7.2.2.4 Suction lysimeters with low bubbling pressures are available in each of the three previous designs. The only difference between these samplers and the three previous designs is that these porous sections are made with PTFE. The low bubbling pressure (and hence large pore size) of PTFE constrains these samplers to soils which are nearly saturated (see Section 7.2.1.2

and Section 7.6.1.3).

7.2.3 Filter Tip Samplers

7.2.3.1 Samples are collected from a filter tip sampler by lowering an evacuated sample vial down an access tube to a permanently emplaced porous tip. The vial is connected to the porous tip and sample flows through the porous section and into the vial. Once full, the vial is retrieved.

7.2.4 Experimental Suction Samplers

7.2.4.1 Experimental suction samplers generally operate on the same principle as vacuum lysimeters with different combinations of porous materials to enhance hydraulic contact. The samplers are generally fragile and difficult to install. As with vacuum lysimeters, they are generally limited to depths of less than about 7.5 m.

7.3 Description

7.3.1 Vacuum Lysimeters

7.3.1.1 Vacuum lysimeters generally consist of a porous cup mounted on the end of a tube, similar to a tensiometer. The cup is attached to the tube with adhesives (18[2]) or with "V" shaped flush threading sealed with an "O" ring (19[2]). A stopper is inserted into the upper end of the body tube and fastened in the same manner as the porous cup or, in the case of rubber stoppers, inserted tightly

[2] This reference is manufacturer's literature, and it has not been subjected to technical review.

(12). To recover samples, a suction line is inserted through the stopper to the base of the sampler. The suction line extends to the surface and connects to a sample bottle and suction source in series. Body tubes up to 1.8 m long have been reported (15)(see Figure 2).

7.3.1.2 Harris and Hansen (20) described a vacuum lysimeter with a 6 mm by 65 mm ceramic porous cup designed for intensive sampling in small areas.

7.3.1.3 A variety of materials have been used for the porous segment including nylon mesh (21), fritted glass (22), sintered glass (23), Alundum (manufacturer name), stainless steel (24^2), and ceramics (1.2 to 3.0 um max pore size)(18^2). The sampler body tube has been made with PVC, ABS, acrylic, stainless steel (25) and PTFE (18^2,19^2). Ceramic porous segments are attached with epoxy adhesives or with flush threading. The stopper is typically made of rubber (12), neoprene, or PTFE. The outlet lines are commonly PTFE, rubber, polyethylene, polypropylene, Tygon (manufacturer name), nylon, and historically, copper. Fittings and valves are available in brass or stainless steel.

7.3.2 Pressure-Vacuum Lysimeters

7.3.2.1 These samplers were developed by Parizek and Lane (26) for sampling deep moving pollutants in the vadose zone. The porous segment is usually a porous cup at the bottom of a body tube. The porous cup is attached with epoxy adhesives (18^2) or with "V"

shaped flush threading sealed with an "O" ring (19[2]). Two lines are forced through a two-hole stopper sealed into the upper end of the body tube. The discharge line extends to the base of the sampler and the pressure-vacuum line terminates a short distance below the stopper. At the surface, the discharge line connects to a sample bottle and the pressure-vacuum line connects to a pressure-vacuum pump. Body tubes are commonly available with 2.2 and 4.8 cm diameters and in a variety of lengths (see Figure 3). The sampler and its components have been made out of the same materials used for vacuum lysimeters.

7.3.2.2 These samplers can retrieve samples from depths below 7.5 m because pressure is used for retrieval. However, during pressurization some of the sample is forced back out of the cup. At depths over about 15 m, the volume of sample lost in this fashion may be significant. In addition, at depths over about 15 m, pressures required to bring the sample to the surface may be high enough to damage the cup or to reduce its hydraulic contact with the soil (27,28). Rapid pressurization causes similar problems. Morrison and Tsai (29) developed a tube lysimeter with the porous section located midway up the body tube instead of at the bottom (see Figure 4). This design mitigates the problem of sample being forced back through the cup. However, it does not prevent problems with porous segment damage due to overpressurization or rapid pressurization. The sleeve lysimeter

(which is no longer available) was a modification to this design for use with a monitoring well (1)(see Figure 5). Another modification is the casing lysimeter which consists of several tube lysimeters threaded into one unit (see Figure 6). This arrangement allows precise spacing between units (30).

7.3.2.3 Nightingale et al (31) described a design which allows incoming samples to flow into a portion of the sampler not in contact with the basal, porous ceramic cup (see Figure 7). The ceramic cup is wedged into the body tube without adhesives or threading. The sampler was used to sample the vadose zone, the capillary fringe and the fluctuating water table in a recharge area. Knighton and Streblow (32) reported a sampler with the porous cup upon the top of a chamber. This design was used with cup diameters ranging from 7.6 to 12.7 cm (see Figure 8). These designs also allow pressurization for sample retrieval without significant liquid loss. However, because the porous cups are open to the rest of the samplers, possible damage due to overpressurization or rapid pressurization are still a problem.

7.3.3 <u>High Pressure-Vacuum Lysimeters (Lysimeters with a Transfer Vessel)</u>

7.3.3.1 High pressure-vacuum lysimeters overcome the problems of fluid loss and overpressurization through the use of an attached chamber or a connected transfer vessel (see Figure 9).
The porous segment is usually a porous cup at the bottom of the

body tube. The cup is attached with epoxy adhesives (18^2) or with "V" shaped flush threading sealed with an "O" ring (19^2). In the attached chamber design, the body tube is separated into two chambers connected by a one-way check valve. A pressure-vacuum line and a discharge line enter through a two-hole plug at the top of the body tube. The pressure-vacuum line terminates below the plug. The discharge line extends to the bottom of the upper chamber. The transfer vessel design is similar. However, the vessel and body tube are separate components connected by a suction line. Body tube diameters range from 2.7 to 8.9 cm OD. Total sampler lengths commonly range from 15.2 to 182.9 cm. The samplers and their components have been made out of the same materials as vacuum lysimeters.

7.3.4 Suction Lysimeters with Low Bubbling Pressures (samplers with PTFE porous sections)

7.3.4.1 Designs are available in each of the three categories described in Sections 7.3.1, 7.3.2, and 7.3.3. The only difference between this group of samplers and the previous three samplers is that PTFE (15 to 30 um maximum pore size - calculated from bubbling pressures) is used for the porous sections of this group of samplers (19^2). The porous PTFE is attached with "V" shaped flush threading sealed with an "O" ring.

7.3.5 Filter Tip Samplers

7.3.5.1 Filter tip samplers consist of two components: a

permanently installed filter tip, and a retrievable glass sample vial. The filter tip includes a pointed end to help with installation, a porous section, a nozzle, and a septum. The tip is threaded onto extension pipes which extend to the surface. The sample vial includes a second septum. When in use, the vial is seated in an adaptor which includes a disposable hypodermic needle to penetrate both the septa, allowing sample to flow from the porous segment into the vial (see Figure 10). Extension pipes vary from 2.5 to 5.1 cm ID. Vial volumes range from 35 to 500 mL. (32).

7.3.5.2 The body of the filter tip is made of thermoplastic, stainless steel, or brass. The attached porous section is available in high density polyethylene, sintered ceramic, or sintered stainless steel. The septum is made of natural rubber, nitrile rubber, or fluororubber (32).

7.3.6 Experimental Suction samplers

7.3.6.1 Cellulose-acetate, hollow-fiber samplers were described by Jackson et al. (33) and Morrison (3). A sampler consists of a bundle of these flexible, hollow fibers (<2.8 um max pore size) pinched shut at one end and attached to a suction line at the other end. The suction line leads to the surface and attaches to a sample bottle and source of suction in the same manner as a vacuum lysimeter (see Figure 11). The fibers, which are analogous to the porous sections of vacuum lysimeters, have outside diameters of up to 250 um (33). Levin and Jackson (34) described similar fibers

made from a noncellulosic polymer solution (max pore size <2.8 um). Those fibers have dense inner layers surrounded by open celled, spongy layers with diameters ranging from 50 to 250 um.

7.3.6.2 Membrane filter samplers were described by Morrison (1), Everett and Wilson (6), U.S. EPA (12) and Stevenson (35). A sampler consists of a membrane filter of polycarbonate, cellulose acetate (<2.8 um max pore size), cellulose nitrate or PTFE (2 to 5 um max pore size); mounted in a "swinnex" type filter holder (35,36,37[2]). The filter rests on a glass fiber prefilter. The prefilter rests on a glass fiber "wick" which in turn sits on a glass fiber collector. The collector is in contact with the soil and extends the sampling area of the small diameter filter (see Figure 12 and Section 7.5.1.6). A suction line leads from the filter holder to the surface. At the surface, the suction line is attached to a sample bottle and suction source in a manner similar to vacuum lysimeters.

7.3.6.3 A vacuum plate sampler consists of a flat porous disk fitted with a nonporous backing attached to a suction line which leads to the surface (see Figure 13). Plates are available in diameters ranging from 4.3 to 25.4 cm and custom designs are easily arranged (1,18[2]). Plates are available in Alundum, porous stainless steel (24[2]), ceramic (1.2 to 3.0 um max pore size) or fritted glass (4 to 5.5 um max pore size) (38[2],6,39,40,41,42,43,44). The non permeable backing can be a fiberglass resin, glass, plastic or

butyl rubber.

7.3.7 Comments

7.3.7.1 When some ceramic cups are glued to the inner wall of the body tube in a suction lysimeter, an inner lip is formed (45). As the discharge line is pushed through the stopper at the top of the sampler, it may catch on this lip and the operator may conclude that the line has reached the bottom of the ceramic cup (see Figure 14). As a result, an 80 mL error can occur in sampling rate determinations. This 80 mL of fluid accumulates in the cup, is not removed during sampling, and will cause cross contamination between sampling events. Soilmoisture (18[2]) suggested that the line can be kept from catching by cutting its tip at an angle. In all-PTFE suction lysimeters, the discharge line is a rigid PTFE tube extending to the bottom of the cup. This results in a zero accumulation of fluid. Samplers with PTFE porous segments and PVC body tubes have a discharge line that does not extend all the way to the bottom. This results in a 34 mL accumulation of fluid (12). Filter tip samplers develop an 8 mL accumulation of fluid. Haldorsen et al. (46) suggested collecting and discarding an initial sample to purge this accumulated fluid.

7.3.7.2 Because samplers are often handled roughly during installation, durability and ruggedness are important. It has been shown that PTFE has a higher impact strength than ceramics which need to be installed with care (19[2]). It has also been found that

PTFE threads and ceramic threads (when used) are susceptible to leakage, and must be securely sealed with pipe threading tape (45).

7.3.7.3 As described above, porous sections can be made from various materials. These materials have physical and chemical limitations which must be considered when designing a monitoring program. Physical limitations are described in Section 7.6.1. Chemical limitations are described in Section 7.6.2.

7.4 Installation Methods

7.4.1 Pre-Installation

7.4.1.1 As demonstrated by Neary and Tomassini (47), new samplers may be contaminated with dust during manufacturing. In order to reduce chemical interferences from substances on the porous sections, U.S. EPA (12) recommended preparation of ceramic units prior to installation following procedures originally developed by Wolff (48), modified by Wood (49) and recommended by Neary and Tomassini (47). The process involves passing hydrochloric acid (HCL) (e.g. 8 N) through the porous sections. This is followed by flushing with distilled water until the specific conductance of the outflowing water is within 2 percent of the inflowing water. Debyle et al (50) found (in agreement with 49 and 51) that flushing with HCL strips cations off of the ceramic. This results in an initial adsorption of cations from pore-liquid onto the ceramic surface. This continues until the cation exchange capacity (CEC) of the ceramic has been satisfied. The effect is not reduced by

distilled water flushing after the acid flushing. Therefore, they suggested that the sampler also be flushed, prior to installation, with a solution similar in composition to the expected soil solution. Alternately, the first sample after installation could be discarded (see Section 7.5.2.1). Bottcher et al (52) attributed increased adsorption of PO_4 to the acid leaching process. Therefore, they recommended a thorough flushing with a PO_4 solution of approximately the same concentration as that found in the soil solution, rather than the acid leaching procedure, when sampling for PO_4. Peters and Healy (53) used H_2SO_4 rather than HCL.

7.4.1.2 Hydrochloric acid may corrode valves within pressure-vacuum and high pressure-vacuum lysimeters. Therefore, the porous segment flushing for these designs should be performed prior to attachment if possible. The maximum suction which can be applied is one atmosphere, therefore the flushing process will be slow if suction is used to draw HCL through the porous segment. The flushing can be performed more rapidly if the porous segment is filled with HCL and pressurized to force the acid out of the porous segment since more than one atmosphere of pressure can be applied. However, care must be taken to prevent overpressurization which might damage the porous section.

7.4.1.3 Corning Laboratories (38[2]) recommended washing fritted glass with hot HCL followed by a distilled water rinse. Cleaning procedures for Alundum have not been reported, although an acid and

water rinse procedure similar to that for ceramic would appear to be appropriate (1). Timco (19[2]) described cleaning procedures for PTFE. The method includes passing 0.5 L of distilled water through the material or rinsing with HCL followed by a distilled water rinse.

7.4.1.4 Stevenson (35) recommended treating cellulose-acetate hollow-fibers with silver nitrate and sodium chloride to prevent biofilm growths. Morrison (1) suggested rinsing membrane filters with distilled water.

7.4.1.5 The porous section and fittings of individual samplers may have defects which could cause air entry during sampling. Therefore, prior to taking samplers to the field, each unit should be checked for its bubbling pressure, pressure tested and vacuum tested for leaks. Procedures for these tests are given in U.S. EPA (12) and Timco (19[2]). Washers or "O" rings are used to seal the plugs at the tops of body tubes. However, the accesses for pressure-vacuum and discharge lines passing through these plugs are not sealed. These accesses may leak, and should also be sealed. In the past, lubricants have been used when cutting threads into body tubes, porous segments and fittings. In addition, lubricants have been used in various pressure-vacuum pumps. The user should contact the manufacturer to determine if these lubricants are still used. If present, these lubricants should be removed.

7.4.1.6 After cleaning and testing, samplers should be bagged

to prevent contamination during transport to the field. Compatibility of bag material and analytical parameters should be considered. Upon arrival at the installation location, and immediately prior to installation, the porous section should be placed in distilled water for about 30 minutes to ensure saturation of the porous section (1). Timco (19[2]) indicated that applying a suction of about 50 cbar to a submerged PTFE sampler for about an hour would ensure saturation. Finally, immediately prior to installation, the sampler and associated lines should be assembled and inspected for defects (e.g. crimped lines).

7.4.2 Suction Lysimeter and Filter Tip Sampler Installation

7.4.2.1 Suction lysimeter installation procedures have been described by U.S. EPA (12), Soilmoisture (18[2]), Timco (19[2]), Linden (54), and Rhoades and Oster (55). Filter tip sampler installation procedures were described by Torstensson and Petsonk (32).

7.4.2.2 The goals of installation are to ensure good hydraulic contact between the porous segment and the surrounding soil, and to minimize leakage of liquid along the outside of the sampler. U.S. EPA (12) recommended a silica flour/bentonite clay method to achieve these goals for suction lysimeters. A silica flour layer placed around the porous segment increases hydraulic contact with the surrounding soil. Screened native backfill is placed above the silica flour, and a bentonite plug above the body tube prevents liquid leakage down the installation hole and along the body tube

(see Figures 15 and 16). Klute (56) indicated that a screened native soil slurry could be used in place of silica flour for shallow installations.

7.4.2.3 Samplers may be installed in the sidewall of an excavation or, for deeper applications, in a borehole preferably advanced with a hollow stem auger (12). U.S. EPA (12) suggested that suction lysimeters should be installed at an angle of 30 to 45 degrees from vertical whenever possible. This ensures that an undisturbed column of soil is retained above the porous cup. Accordingly, pore liquid samples will reflect flow through pore sequences which have not been disturbed by sampler installation. This angular placement also improves the sampler's ability to collect macropore flow. When installed in the sidewall of a trench, the angled emplacement is simple (see Figure 15). However, when installed in a borehole, angular emplacement entails angled drilling. Where soils permit, filter tip samplers can be installed by pushing the filter tip into the ground by applying a static load to the extension pipe (32).

7.4.2.4 When suction lysimeters are installed in a borehole advanced by a drill rig, the hole is usually advanced 15 to 20 cm below the desired location of the porous section. Morrison and Szecsody (30) found that the radius of sampling influence is maximized if the borehole diameter is only slightly larger than that of the sampler and if silica flour pack is used. U.S. EPA (12)

recommended that the hole have a diameter at least 5 cm larger than the sampler. Timco (19[2]) recommended that the hole have a diameter at least 8 cm greater than that of the sampler to facilitate installation of the silica flour.

7.4.2.5 Suction lysimeters are preferably lowered into place attached to risers. These protect the lines and ensure exact placement at the desired depth. Centralizers are often used to center the sampler in the hole. Suction lysimeters float in the silica flour which is installed as a slurry. Therefore, the samplers should be installed full of distilled water or held in place by rigid risers.

7.4.2.6 The silica flour slurry (e.g. 200 mesh - 75 um mesh opening, silica to distilled water ratio of 0.45 kg to 150 mL) is usually installed using the tremie method (side discharge). Alternately, Brose et al (57) described a method for freezing the silica slurry around the sampler prior to placement. The sampler and frozen pack are then lowered to the sampling location in the borehole. They cited advantages of this technique as including assurance of proper sampler placement in the flour pack and elimination of pack contamination by soils which slough down the borehole. U.S. EPA (12) recommended filling the borehole to about 30 cm above the suction lysimeter body with the silica. In addition, it was recommended that the powdered bentonite plug placed on top of the silica be about 15 cm thick. The bentonite is

also sometimes installed as a slurry, being allowed to hydrate before emplacement. Mixing the bentonite with fine sand at a 1 to 9 ratio, respectively, reduces the potential for shrinking and swelling inherent with pure bentonite (1). The excavated soil should be backfilled above the bentonite in the order in which it was withdrawn. An effort to compact the soil to its original bulk density should be made. When more than one suction lysimeter is installed in one borehole, these procedures are repeated at the various desired sampling depths (see Figure 17). Care must be taken with these installations to ensure that lines from lower samplers does not interfere with the hydraulic contact of shallower samplers.

7.4.2.7 U.S. EPA (12) recommended removal of the water within the sampler and silica slurry after installation. Litaor (58) recommended installation of samplers a year before sampling is to begin, in order to allow them to equilibrate with the surrounding soil. The lines at the surface should be labeled, clamped and housed in locked containers such as valve boxes or casing (1). Methods for cutting and splicing tubing may be found in Timco (19^2). The user should be careful when using clamps and tubing provided by different manufacturers, inappropriate clamps may damage tubing.

7.4.3 Experimental Suction Sampler Installation

7.4.3.1 Cellulose-acetate hollow-fiber sampler installation

procedures were described by Everett et al (9). Membrane filter sampler installation procedures were described by Stevenson (35), Everett et al (9), and Morrison (1). Vacuum plate sampler installation procedures were described by Everett et al (9) and Morrison (1).

7.4.3.2 Cellulose-acetate hollow-fiber samplers have been used almost exclusively in laboratory studies (34). Because the samplers operate on the same principles as vacuum lysimeters, the goals and concerns of installation are similar. Good hydraulic contact between the hollow-fiber and the soil is critical. However, the fibers are too thin and fragile to be pushed into place. Therefore, the fibers must be placed in a predrilled hole (vertical or horizontal). Silkworth and Grigal (59) installed these samplers within a length of perforated, protective PVC tubing filled with soil slurry.

7.4.3.3 Membrane filter samplers are placed in a hole dug to the top of the selected sampling depth. First, sheets of the glass fiber "collectors" are placed at the bottom of the hole. These develop the necessary hydraulic contact between the sampler and the soil. In addition, the "collectors" extend the area of sampling as they cover a larger area than the filter holder alone. Second, two or three smaller glass fiber "wick" discs that fit within the filter holder are placed on the "collectors." Third, the filter holder fitted with a glass fiber prefilter and the membrane filter

is placed on top of the "wick" disks. The suction line leads to the surface. Finally, the hole is backfilled (1,9).

7.4.3.4 Vacuum plate lysimeters are normally installed on the ceiling of a cavity cut into the side of a trench. In order to obtain the necessary contact between the porous plate and the soil, pneumatic bladders, inner tubes, or similar devices are placed beneath the sampler and are used to force it against the cavity ceiling (1). The cavity ceiling is not a smooth surface. Therefore, a layer of silica flour between the plate and the soil is sometimes used to enhance hydraulic contact.

7.4.4 Maintenance

7.4.4.1 The major causes of sampler failure are line damage and leaks (caused by freezing, installation, rodents, etc.), connection leaks, and clogging of the porous material.

7.4.4.2 The possibility of line and connection leaks is minimized by rigorously sealing and pressure testing all connections and lines before installation. A common precaution to assist in repairing surface damage to lines is to store excess line below the surface (within the riser pipe when used) below the surface when backfilling the borehole. In the event of severed lines, an excavation to this buried length allows restoration of an operational system (1). Lines should be clamped shut when not in use to prevent foreign objects or insects from entering them. The lines should be protected from weather, sunlight exposure, and

vandalism with a locked housing. The use of riser pipe around the sampler lines prevents punctures by backfill materials and prevents rodents from damaging the lines.

7.4.4.3 When shallow samplers are used, the ground surface above the sampler should be maintained in a fairly representative state. Large line housings and excessive traffic around the sampler (causing compaction of the soil) will reduce the amount of infiltration in that area. This will affect the representativeness of the pore-liquid samples. Methods to avoid these effects include angled installations, and remote operation of sampler lines.

7.4.4.4 Porous sections may clog as a function of soil composition, type of porous section material, biofilm growth, suction application and pore-liquid content (1,17,20,50). However, porous section clogging appears to be less severe than once thought (12,17). Soils and the 200 mesh silica flour filter out fine materials before they reach the porous section (60,61,62). Clogging can be further reduced by periodically filling the sampler with distilled water and allowing it to drain out of the sampler. Debyle et al (50) suggested removing shallow samplers on a seasonal basis for flushing with HCL and distilled water. This process restores samplers to their original operational and chemical states. However, reinstallation at the same location and depth does not guarantee resumption of sampling from the same soil volume.

7.4.4.5 Often no sample is retrieved during a sampling attempt.

This could be due to sampler failure or high pore-liquid tensions. Because of this, it is prudent to install a tensiometer near the sampler at a similar depth. The tensiometer, which measures pore-liquid tensions, allows the operator to determine if failure to obtain a sample is due to high pore-liquid tensions or due to sampler damage. The tensiometer can also be used to gage the effect of sampling on local pore-liquid flow regimes.

7.4.4.6 If a tensiometer is not available to measure pore-liquid tensions, the lysimeter can be tested to help determine reasons for failure to recover a sample. The sampler is tested by applying a suction of 80 cbar, and monitoring the decay of suction with time. Figure 18 depicts the various types of suction decay which might be found in a suction lysimeter with a 200 cbar bubbling pressure ceramic section. An almost instantaneous decay of suction is associated with lysimeter leakage. A suction decay over a period of minutes is associated with pore-liquid tensions greater than 200 cbar. Under these conditons, the porous section is desaturated and air enters the sampler. A suction decay over a period of hours reflects normal sample collection. This suggests that failure to retrieve a sample is related to damage of the sample retrieval system (e.g. discharge line damage). When suction does not decay, or does so over a period of days, the pressure-vacuum line may be clogged or pore-liquid tensions may be greater than 60 cbar (but less than 200 cbar) causing liquid inflow rates

which are too low for sample collection.

7.4.4.7 Morrison and Szecsody (63) described devices which could be used as tensiometers and then converted to pressure-vacuum lysimeters. However, they found that gases entering the devices prevented accurate measurement of pore-liquid tensions. Baier et al (64) described methods for converting tensiometers to pressure-vacuum lysimeters. It would also appear reasonable to convert suction lysimeters to tensiometers. However, Taylor and Ashcroft (65) found that the volume of water drawn from a converted lysimeter into the surrounding soil would significantly affect natural pore-liquid tensions. In addition, they found that the larger porous section of a lysimeter would cause more diffusion of dissolved air into the device, and that the time constant for measurement would be significantly increased over that of a tensiometer. Filter tip samplers can be converted to tensiometers with pressure transducers (32).

7.4.4.8 Operational lifetimes of suction samplers are dependant on installation, subsurface conditions, maintenance, and sampling frequency. Some samplers have been reported to be operational for as long as 25 years (64).

7.4.5 Comments

7.4.5.1 Vacuum lysimeters and experimental samplers use suction to retrieve samples. Therefore, the maximum sampling depth is limited by the maximum suction lift of water (about 7.5 m)(12). In

practice, these samplers are generally used to about 2 m below the surface (12). They are primarily used to monitor near-surface movement of pollutants such as those from land disposal facilities and those from irrigation return flow.

7.4.5.2 Pressure-vacuum lysimeters are generally not used at depths below about 15 m. At greater depths, sample loss and overpressurization problems are considered significant enough to warrant the use of high pressure-vacuum lysimeters - which do not have these limitations. High pressure-vacuum lysimeters are not preferred at the shallower depths because they are more expensive. In addition, high pressure-vacuum units have more moving parts than pressure-vacuum units, and as a result, the possibility of failure for the former is higher.

7.4.5.3 As discussed in Section 7.6, two problems with suction samplers are that they may not sample from macropores (under unsaturated conditions - unless the macropores are directly intercepted) and that their results cannot be used in quantitative mass balance studies. Hornby et al (66) described an installation which could be used to surmount these problems. A barrel-sized casing (e.g., 57 cm outside diameter by 85.7 cm high) is placed in a support device and gently pushed into the soil with a backhoe. As the casing is pushed, soil is excavated around it to help with insertion. The process results in an encased monolith of undisturbed soil. The monolith is then rotated and lifted,

pressure-vacuum lysimeters are placed in its base, and the bottom is sealed. Subsequently the assembly is placed back into the ground at the monitoring site (see Figure 19). All fluid draining through the monolith is collected by the samplers. Inasmuch as the boundaries of the system are sealed, the flux of liquid through the system requires maintaining a vertical hydraulic gradient by applying continual suction to the samplers.

7.5 Operation

7.5.1 Methods

7.5.1.1 Vacuum Lysimeters -- Sampling methods are described by the U.S. EPA (12), by Soilmoisture (18[2]) and by Timco (19[2]). To collect a sample, suction is applied to the sampler, and the suction line is clamped shut. After sample has collected in the body tube, it is retrieved through a discharge line extending to the base of the porous cup. In shallow installations, with the body tube extending above the soil surface, the discharge line is sometimes inserted and removed as needed. For deeper installations, the discharge line is permanently installed. At the surface, the line is connected to a sample collection flask. Suction is applied to the flask, and liquid is pulled from the sampler, up the discharge line, and into the collection flask. Cole (42) constructed an array of samplers which was attached to a vacuum tank connected to an electric power source. This system allowed remote operation at a constant suction. Wengel and Griffen (67)

described methods by which samplers can be connected to a central control board and operated remotely. Brown et al (68) employed a solar panel to power a similar setup. Chow (44) described a sampler which shuts off automatically when the desired sample volume has been collected.

7.5.1.2 Pressure-Vacuum Lysimeters -- Sampling methods are described in U.S. EPA (12), by Soilmoisture (18[2]) and by Timco (19[2]). To sample, suction is applied to the system via the pressure-vacuum line. The discharge line to the sample bottle is clamped shut during this time. When sufficient time has been allowed for the unit to fill with pore-liquid, suction is released and the clamp on the discharge line is opened. Gas pressure (e.g. air or nitrogen - see Section 7.6.2) is then applied through the pressure-vacuum line. This forces the sample through the discharge line and into the collection flask at the surface (12). A variety of systems have been developed by which the pressure, suction and sample volume can be controlled remotely or manually (44,49,67,69).

7.5.1.3 High Pressure-Vacuum Lysimeters (Lysimeters with a Transfer Vessel) -- Sampling methods may be found in U.S. EPA (12), in Soilmoisture (18[2]) and in Timco (19[2]). When suction is applied to the system, it extends to the porous section through an open, one-way check valve at the bottom of the transfer vessel or chamber. A second one-way check valve in the discharge line is closed during this time. As soil solution enters the sampler it is

pulled by the suction into the transfer vessel or chamber through a line attached to the open valve at its base. The sample is brought to the surface by releasing the suction and applying pressure (e.g. air or nitrogen) through the pressure-vacuum line. This shuts the one-way valve to the porous segment and opens the one-way valve in the discharge line. The sample is then pushed to the surface (12). A variety of systems have been developed to control pressure, suction and sample volume remotely or manually (44,49,67,69).

7.5.1.4 Suction Lysimeters with Low Bubbling Pressures (samplers with PTFE porous sections) -- Sampling methods for this group of samplers are identical to those for the three designs described in Sections 7.5.1.1, 7.5.1.2 and 7.5.1.3. The only difference is that maximum sampling suctions for these units are much lower (see Section 7.6.1.3).

7.5.1.5 Filter Tip Samplers -- Sampling methods may be found in Torstensson and Petsonk (32). Samples are collected by first evacuating the sample vial. The vial is then inserted in the sampling adaptor which contains a two way hypodermic needle. The adaptor is then lowered down the extension pipe. When the adaptor connects with the nozzle of the filter tip, the needle penetrates the septa in the vial and in the filter tip. Sample then flows through the porous segment and into the sample vial due to the negative pressure in the vial. As sample is collected, the negative

pressure in the vial falls towards that of the pore-liquid tension. When these negative pressures are equal, sampling ends and the sample vial is retrieved. The standard sample volume is about 35 mL. However, by connecting several vials in series, sample volumes of up to 500 mL can be obtained.

7.5.1.6 Experimental Suction Samplers -- Cellulose-acetate hollow-fiber samplers, membrane filter samplers, and vacuum plate samplers are operated using the same general technique as for vacuum lysimeters. Jackson et al (33) sampled from soil columns using cellulose-acetate hollow-fiber samplers subjected to a constant suction of 81 cbar. At this suction, they were able to extract samples for chemical analyses from silty loams with moisture contents ranging from 20 to 50 percent. Silkworth and Grigal (59) compared the performance of these samplers to suction lysimeters. They found that cellulose-acetate hollow-fiber samplers fail more often than suction lysimeters. In membrane filter samplers, the "collectors" provide hydraulic contact between the soil and the samplers. Liquid is drawn by capillarity into the "collectors." When suction is applied, liquid flows through the "wick," the prefilter, and finally the membrane filter. The prefilter reduces clogging of the membrane filter by fine soil materials (9). Stevenson (35) recommended using a suction of between 50 and 60 cbar when sampling with membrane filter samplers. A variety of constant suction methods for sampling with vacuum

plates are described by Morrison (1). An advantage of the larger plates is that they have large contact areas with the soil. Therefore, larger sample volumes can be collected in shorter times than with vacuum lysimeters which have porous sections with smaller surface areas.

7.5.2 Comments

7.5.2.1 Nagpal (70) recommended several consecutive extractions of liquids during a sampling event and use of only the last one for chemical analyses. The purpose of this is to flush out cross contaminants from previous sampling periods, and to ensure that any porous segment/soil solution interactions have reached equilibrium. Debyle et al (50) also suggested discarding the first one or two sample volumes when sampling dilute solutions with newly flushed (HCL method) and installed samplers. The purpose of this is to allow cation exchange between the porous segment and the pore-liquid (caused by the HCL flushing) to equilibrate.

7.5.2.2 Factors which affect the volume and source of a pore-liquid sample include the amount of suction applied, the schedule of suction application, the pore-liquid content, the distribution of pore-liquid, the soil grain size distribution, the soil structure, the porous section design, and the porous section age.

7.5.2.3 Samples collected with lower suctions (about 10 cbar or less) tend to come from liquids migrating through soil macropores (1). Samples collected with higher suctions (greater

than about 10 cbar) also include fluids held at higher tensions in micropores. The sampler may disrupt normal flow patterns due to the applied suctions. The effects may extend several meters from the sampler although the area nearest the sampler is most disturbed (71,72,73). This disturbance causes samples to be averages of the affected flow area rather than point samples (1). Warrick and Amoozegar-Fard (72) developed an approximate analytical equation which can be used to estimate the maximum radius of influence on the flow regime by a suction sampler. Narasimhan and Driess (74) developed a numerical technique to simulate the effects of suction samplers on the pore-liquid regime.

7.5.2.4 Sampling with falling suction produces samples with compositions which are "averages" of the liquids held at the range of tensions applied. Because suctions and therefore inflow rates decrease with time, these "averages" are weighted towards those portions of the samples obtained in early times. Samples collected over prolonged periods (due to slow inflow rates) are "averages" of the liquids fluxing past the sampling region during those times.

7.5.2.5 During wet periods, samplers affect a small volume of soil and pull liquids from a sequence of pores which may include macropores. During dry periods samplers affect a larger volume of soil, draw from micropores because the macropores have been drained, and collect less liquid (75,76). The net result of this

is that sampled soil solutions are "averaged" over different volumes and derived from different pores as a function of the soil moisture content and distribution.

7.5.2.6 Soil textures and pore-liquid tensions control the amount of liquid which can be removed by a sampler and its radius of influence. The slope on the pore-liquid release curve for a sand is greater than that for a clay at low pore-liquid tensions (see Figure 20). This indicates that there will be a larger quantity of pore-liquid released from a sand than from a clay for an equal change of pore-liquid tension at these low tensions. At higher tensions, the slope of a clay pore-liquid release curve is greater than that for a sand (see Figure 20). This indicates that more pore-liquid will be released from a clay than from a sand for an equal change in pore-liquid tension at the higher tensions. A consequence of this is that suction samplers may not obtain samples from coarse grained soils at higher pore-liquid tensions. Morrison and Szecsody (30) found that (under the conditions of their study) radii of influence for suction lysimeters ranged from 10 cm in coarse soils up to 92 cm in fine grained soils.

7.5.2.7 Hansen and Harris (20), demonstrated that intake rates may vary substantially due to variability in the ceramic sections from one manufacturer's batch to another. As discussed in Section 7.4, the intake rate of a sampler is also a function of the degree of clogging. As discussed in Section 7.6, the range of pore-liquid

tensions over which a sampler can operate is a direct function of the maximum pore size of the porous section and the surrounding silica flour pack. Finally, Morrison and Szecsody (30) found that the radius of influence of a sampler increases with the diameter of the porous section.

7.5.2.8 Because of these factors the following recommendations have been made for sampling with suction lysimeters. Hansen and Harris (20), suggested using uniform initial suctions, short sampling intervals, and uniform sampling times for different sampling events and locations to increase the uniformity of samples. Debyle et al (50) also recommended sampling with uniform suctions that do not significantly exceed the tension at which the percolating soil solution is being held. U.S. EPA (12) suggested sampling after infiltration events such as rain storms, spring melts or irrigations as these periods of high pore-liquid content are accompanied by higher pore-liquid flow rates and contaminant transport. For sampling these events, it is useful to install samplers at interfaces between coarse and fine materials to take advantage of any liquid perching which might occur. Silkworth and Grigal (59) recommended using samplers with large diameter ceramic porous sections (as opposed to small diameter ceramic samplers, or hollow cellulose fiber samplers) since they showed less of a tendency to alter the pore-liquid, they had lower failure rates, and they collected larger sample volumes. These recommendations

were reinforced by van der Ploeg and Beese (73) who concluded that samplers with large cross sectional area porous sections used with low extraction rates (suctions approaching those of the pore-liquid tensions) reduce the effects of sampling on compositions of samples. Finally, U.S. EPA (12) recommended that porous section material types be carefully chosen based on pore-liquid tensions expected in the sampling area. Operational ranges of various porous section types are discussed in Section 7.6 and are presented in Table 1.

7.6 Limitations

7.6.1 Physical Limitations

7.6.1.1 The most severe constraint on the operation of suction samplers involves soil around the porous sections becoming so dry (and pore-liquid tensions so high) that samples cannot be collected. The limiting factors in these conditions will be the porous segment or the soil hydraulic properties. For porous segments with bubbling pressures less than 60 cbar (e.g. PTFE), the porous segment will be the limiting factor because the high suctions required to move liquids into the samplers will cause meniscuses in the porous segments to break down and air to enter. Soil hydraulic properties will be the limiting factors for porous segments with bubbling pressures greater than 60 cbar (e.g. ceramics) because unsaturated hydraulic conductivity of the soil and pressures gradients across the porous segments will be so low

(due to high pore-liquid tensions) that flow into the samplers will be negligible.

7.6.1.2 The maximum suction that the saturated porous section of a sampler can withstand before air enters is a function of the pore configuration and size, and its hydrophilicity/hydrophobicity (see Appendix X1 and 65). The following variation of the capillary rise equation combines these factors:

$$P_b = \frac{-2 \quad \cos}{r}$$

where: P_b: bubbling pressure (gage),

: surface tension between pore-liquid and air,

: contact angle between the liquid and the material of the porous segment, and

r: maximum pore radius of the pore segment.

This equation shows that the bubbling pressure decreases with increasing contact angle and with increasing maximum pore radius. The maximum sampling suction which can be applied is 100 cbar (1 atmosphere). For a hydrophilic material (which has an acute contact angle) the maximum pore size which will allow the application of 100 cbar of suction is 2.8 um. For a hydrophobic material (which has an obtuse contact angle) a smaller pore size will be required (65). The maximum pore sizes of presently available ceramics (which are hydrophilic) used for suction lysimeters and filter tip samplers vary from 1.2 to 3 um (as measured by the bubbling

pressures)(18[2],45,77[2]). The maximum pore sizes of cellulose-acetate hollow-fibers and membrane filters range from less than 2.8 um and 0.4 to 5.0 um respectively (1,35,36). These pore sizes result in maximum sampling suctions near 100 cbar. Therefore, these materials will not allow air to enter during sampling, and the limiting factors will be the soil hydraulic properties. The combination of soil limiting effects result in negligible sampling rates when pore-liquid tensions are above 60 cbar (for coarse grained soils) to 80 cbar (for finer grained soils) (45). At tensions above these levels, inflow rates are too low to allow sampling.

7.6.1.3 The maximum pore sizes of presently available porous PTFE segments for suction lysimeters range from about 15 to 30 um (calculated from bubbling pressures)(19[2]). These pore sizes allow maximum sampling suctions of about 10 to 21 cbar (19). The hydrophobicity of PTFE will further reduce the magnitude of the maximum sampling suction. Applied suctions of greater than 10 to 21 cbar (or less) will cause air to enter, and sampling to cease. Because a suction greater than 10 to 21 cbar cannot be applied to these samplers, pore-liquids held at tensions greater than 10-21 cbar cannot be sampled with these devices. Because of this, PTFE will be the limiting factor when it is used for the porous segment. A consequence of the small suction range available to PTFE porous sections is that only very moist soils approaching saturation may be sampled (17).

7.6.1.4 The silica flour pack, which has smaller pore sizes than PTFE, can act as an extension of the porous segment, and may extend the range of suctions which can be applied to the sampler. Everett and McMillion (45) found that the pack extended the suction range of earlier, larger pore size PTFE (70 to 90 um) from less than 4 cbar to 7 cbar. Timco (19[2]) suggested that the operational range of the presently available PTFE samplers (15-30 um) can be extended from 10-21 cbar to between 61-71 cbar when "properly" installed within a silica flour pack (this has not been verified in peer reviewed literature). For this to be true, the silica flour pack must be able to remain saturated over the range of applied suctions. However, the results of Everett and McMillion (45) suggest that the bubbling pressure of the silica flour pack is only 7 cbar. Trainor (27) found that even if these samplers are "properly" installed, air may still enter if applied suctions exceed pore-liquid tensions by more than 30 percent. Pore-liquid tensions are not always known, and technicians may not carefully control applied suctions. In addition, pressurization of pressure-vacuum lysimeters for sample retrieval appears to damage the silica flour pack (27,28). Thus, dependency on the silica flour pack to provide the needed suction range is an extremely limited option. Because of this, suction lysimeters with PTFE porous sections are limited to near saturated sampling and have been classified separately (see Figure 20).

7.6.1.5 Samples can be collected (using ceramic porous sections) from clays with high pore-liquid tensions (approaching 60 to 80 cbar). However, because liquid inflow rates are low at higher tensions, the amount of time required to collect sufficient sample volumes may exceed the maximum allowable holding time for many chemical analyses. Law (76) pointed out that when soils have liquid contents which allow little or no sample collection (high pore-liquid tensions), there is little or no liquid movement in the soil. Consequently, there will be little or no contaminant migration. If samples of pore-liquids held at tensions above 60 to 80 cbar are desired, soil core sampling with subsequent laboratory liquid extraction may be used (76). However, Law (76) ,and Brown (78) concluded that results from the two sampling methods are not comparable. Liquid from soil core samples will include constituents which are held at tensions greater than 60 to 80 cbar and which would not be picked up by suction samplers. Because of this and because samples removed from soil cores may include some of the constituents from the soil itself (e.g. cations preferentially adsorbed in electrical double layers) or sorbed organics, Law (76) concluded that soil cores are more conservative estimators of cation contaminant presence in soil. Brown (78) concluded that organic contaminant concentrations derived from soil cores and pore-liquid samplers are not comparable because of preferential sorption of some compounds. Amter (79) developed an alternative to

extraction of samples from soil cores. The method, involves injecting a chemically blank fluid through an existing lysimeter. After a time, the fluid (now containing dilute pore-liquid) is recovered through the sampler and analyzed. The results, although qualitative, were shown to correlate well with known relative pore-liquid constituent concentrations.

7.6.1.6 Suction samplers may not intercept macropores because of the small size of their porous sections. Because of this, they may miss the majority of flow at high moisture contents in structured soils (81). The ability to intercept this flow can be enhanced by installing the samplers in large diameter silica flour packs. However, this involves drilling larger holes. Because suction samplers only sample when suction is applied, they may miss infiltration events unless a constant suction is applied. Therefore, under conditions of high moisture content in structured soils, free drainage samplers are recommended (see Section 8) (81). Pore-liquid composition changes with time. Because suction samplers sample over an extended period (especially in drier soils), the resulting sample should be considered an average of the total flux past the sampler during the sampling interval.

7.6.1.7 A major factor limiting the operation of shallow suction samplers in cold climates is that pore-liquid may freeze near the porous segments. In addition, liquid may freeze within porous segments and lines, preventing sample retrieval and perhaps

fracturing the sampler during ice expansion. Because of this, lines should be emptied before the onset of cold weather. Additionally, some soils tend to heave during freezing and thawing. Consequently, the samplers may be displaced in the soil profile, resulting in a break of hydraulic contact (12).

7.6.2 Chemical Limitations

7.6.2.1 The inherent heterogeneities of unsaturated pore-liquid movement and chemistry limit the degree to which samples collected with suction samplers can be considered representative. This is because the small cross sectional areas of suction samplers may not adequately integrate for spatial variability in liquid movement rates and chemistry (51,82,83). Biggar and Nielsen (84) suggested that results of analyses from suction lysimeter samples are good for qualitative comparisons, but that they cannot be used for quantitative analysis unless the variabilities of the parameters involved are established. Law (76) came to similar conclusions, stating that results from suction lysimeter sampling could not be used for quantitative mass balance studies.

7.6.2.2 Well structured soils have two distinct flow regions including macropores (e.g., cracks, burrows, and root traces) and micropores. Under saturated conditions, liquids move more rapidly through macropores than through micropores. Because of this, the movement of liquid-borne pollutants into the finer pores may be limited. Consequently, pore-liquids in macropores may have

different chemistries than those in micropores (85). This is enhanced by the fact that oxygen content in macropores can change in a matter of hours during an infiltration event, whereas micropores may remain suboxic regardless of flow conditions (75). In addition, micropores are less susceptible to leaching than macropores (1,86,87,88). Because of these differences, sample chemistry can vary widely from location to location and from time to time depending on the amount of liquid drawn from these two flow systems.

7.6.2.3 Suction samplers may affect pore-liquid chemistry as it is being sampled. The major sampler related factors which can affect the sample chemistry are the porous segment material and sample storage time. The degree of chemical interaction may also be affected by the amount of porous section clogging (1). Clogging slows the rate of flow through the porous section so that contact time and chances for chemical interaction are increased (50). In addition, the types of adhesives used to attach porous segments (e.g. epoxy) may alter the pore-liquid chemistry.

7.6.2.4 Interactions between porous materials and liquid can include sorption, desorption, cation exchange, precipitation (e.g. ferric precipitation), and screening (20). These interactions can also occur with all other parts of the samplers which the samples contact. However, the much higher surface area of pores within porous segments makes them the most critical element chemically.

Table 2 presents the results of a literature review for porous section/pore-liquid interactions. An attempt has been made to document the pertinent features of the listed studies. However, the reader should refer to the original papers to determine if experimental techniques are applicable to the situation of interest. The absence of entries for a constituent relative to a material does not infer absence of interactions. Although studies for membrane filter interactions have been performed, the results have not been included in Table 2. This is because membrane filters are made from a variety of materials which have differing chemical characteristics (36).

7.6.2.5 Suarez (89) showed that the pH of a sample may be affected by 0.28 to 0.44 pH units due to CO_2 degassing during sampling. He reduced this error by reducing the gas-liquid ratio in the sampler, and by flushing several sampler volumes of soil solution through the sampler before collecting a sample. Alternately, Suarez (89) developed a model by which pH values could be corrected. He noted that multichamber samplers had minimal pH errors and that pH corrections due to CO_2 degassing were not necessary. Peters and Healy (53) found that there was no significant change in pH due to CO_2 degassing during long sampling times, although they recognized that pH changes could occur when the solution is originally more acidic than that which they tested. Ransom and Smeck (90) and Anderson (75) suggested purging the

sampler with N_2 to preserve the subsurface redox states when sampling for redox dependant ions. Filter tip samplers do not use a purging gas, therefore, pore-liquid redox states are preserved in the samples.

7.6.2.6 Nightingale et al (31) indicated that normal suction sampling techniques are not suitable for sampling volatile organic compounds due to potential loss. Wood et al (91) devised a body tube connected to a purging chamber which is in turn connected to a trap packed with resin. Compounds which volatilize during sampling are captured in the trap. Pettyjohn et al (92) described a suitable system for sampling highly volatile organics. However, the reported system was limited to a maximum sampling depth of 6 m and a small sample volume (5 to 10 mL). Torstensson and Petsonk (32) described methods which can be used to collect samples with filter tip samplers which result in no head space in the sample vial and consequently no loss of volatile compounds.

7.6.2.7 A newly forming consensus is that the effects of suction samplers (when properly pre-treated) on sample chemistry of non-dilute solutions are generally less significant than the inherent uncertainties of sampling discussed in Sections 7.6.2.1 and 7.6.2.2 (17,53,93).

7.6.3 Microbial Limitations -- Viruses or bacteria are sometimes monitored in areas where there are livestock lots, leach fields, septic tanks, or sewage sludge spreading plots. However,

it has been found that although porous ceramics will allow viruses to pass, they will screen out bacteria (e.g., Escherichia coli and Fecal coliform)(12,26,94,95).

Draft: 2B
Date : June 23,1989

8. Free Drainage Samplers

8.1 Free drainage samplers are classified differently by various authors, depending on the installation methods. Many free drainage samplers are installed in the side walls of trenches and are referred to as trench lysimeters. However, free drainage samplers are also installed in the walls of vertical caissons. The principle behind each of the samplers is essentially the same. However, the materials and construction differ. The general types of free drainage samplers include:

8.1.1 Pan Lysimeters,

8.1.2 Glass Block Lysimeters,

8.1.3 Trough Lysimeters,

8.1.4 Vacuum Trough Lysimeters,

8.1.5 Caisson Lysimeters,

8.1.6 Wicking Soil Pore-Liquid Samplers and

8.1.7 Sand Filled Funnel samplers.

8.2 Operating Principles

8.2.1 A free drainage sampler consists of some sort of collection chamber which is placed at depth in the soil. Pore-liquid in excess of field capacity is free to drain through soil (usually through macropores) under the influence of gravity. This gravity drainage creates a slightly positive pressure at the soil-sampler interface causing fluid to drip into the sampler. Hence, these samplers collect liquid from those portions of the vadose

zone which are intermittently saturated due to events such as rainfall, flooding, or irrigation. Some free drainage samplers apply a small suction in order to break the initial surface tension at the soil-sampler interface. Samples are retrieved either by accessing the samplers at depth or by drawing samples to the surface through a suction line.

8.2.2 As described in Section 4.2, suction samplers can also be used to sample free drainage flow. However, the small area of those samplers compared to the spacing of macropores limits their usefulness for this application. As described in Section 7.4.5.3, Hornby et al (66) developed an installation which includes pressure-vacuum lysimeters within an encased monolith. This enhances collection of macropore flow with these samplers.

8.3 Description

8.3.1 Pan Lysimeters

8.3.1.1 A pan lysimeter generally consists of a galvanized, metal pan of varying dimensions. A copper tube is soldered to a raised edge of the pan. Plastic or Tygon tubing connects the copper tube to a collection vessel. Any liquid that accumulates on the pan drains through the tubing into the vessel (see Figure 21)(26).

8.3.2 Glass Block Lysimeters

8.3.2.1 Barbee and Brown (81) developed free drainage samplers made from hollow glass bricks. These glass bricks, which are

produced for ornamental masonry work, have dimensions of 30 by 30 by 10 cm and have a capacity of 5.5 L. To build a sampler, nine holes, 0.47 cm in diameter, are drilled along the perimeter of one of the square surfaces of a brick. Nylon tubing is inserted into one of the holes to allow for sample removal. The collecting surface is fitted with a fiberglass sheet to improve contact with the soil. Pore-liquid collection is enhanced by a raised lip along the edge of the surface (see Figure 22).

8.3.3 Trough Lysimeters

8.3.3.1 Trough lysimeters, also known as Ebermayer lysimeters, rely on a trough or pail to collect pore-liquid. In order for the edges of the sampler to maintain a firm contact with the soil, a fiberglass screen is suspended inside the trough. The screen is lined with glass wool and covered with soil until the soil is even with the top of the trough (96).

8.3.3.2 Morrison (1) reported a trough lysimeter in which two parallel metal rods are inside the trough, in contact with the bottom side of the screen, and bent toward the collection tube. Liquid that enters the trough migrates along these rods towards the collection tube in response to capillary forces (see Figure 23). A modification of this design consists of a metal trough with a length of perforated PVC pipe mounted inside. The trough is filled with graded gravel so that coarse material is immediately adjacent to the PVC pipe and fine sand is at the edges and the top

of the trough. The pipe is capped at one end while the other end is connected to a sample container via a drainage tube (1).

8.3.4 Vacuum Trough Lysimeters

8.3.4.1 Montgomery et al (97) described a vacuum trough lysimeter consisting of a metal trough equipped with two independent strings of ceramic pipe, each 13 mm in diameter. The design, otherwise similar to trough lysimeters, allowed extraction of samples under applied suctions of up to 50 cbar. The ceramic pipes act as a vacuum system, and samples are extracted through a suction line.

8.3.5 Caisson Lysimeters

8.3.5.1 A caisson lysimeter consists of collector pipes, radiating from a vertical chamber (1). A design used by Schmidt and Clements (98) consists of a nearly horizontal, half-screened PVC casing (see Figure 24). Schneider et al (99) designed a similar system consisting of: (1) a 15.2 cm diameter stainless steel tube extending diagonally upward through the caisson wall into the native soil, (2) a screened plate assembly within the tube to retain the soil, (3) a purging system that can be used to redevelop the sampler when it becomes clogged, (4) an airtight cap that prevents exchange between the air in the caisson and the soil air.

8.3.6 Wicking Soil Pore-Liquid Samplers

8.3.6.1 Hornby et al (66) described a wicking sampler, alleged to combine the attributes of free drainage samplers and pressure-

vacuum lysimeters. The sampler collects both free drainage liquid and liquid held at tensions to about 4 cbar. A hanging "Hurculon" fibrous column acts as a wick to exert a tension on the soil pores in contact with a geotextile fiber which serves as a plate covering a 30.5 by 30.5 by 1.3 cm pan. The terminus of the fibrous column is sealed into the cap of a tubular sample collector. The collection tube also contains an inlet pressure-vacuum line and a sample collection tube. Materials for the sample collector depend on the constituents being sampled. Glass and PTFE were recommended materials when sampling for organics (see Figure 25)(66).

8.3.7 Sand Filled Funnel Samplers

8.3.7.1 K.W. Brown and Associates (100) discussed a sand-filled funnel for collecting freely draining liquid. The funnel is filled with clean sand and inserted into the sidewall of a trench. The funnel is connected through tubing to a collection bottle. Application of suction to a separate collection tube pulls the sample to land surface (see Figure 26).

8.3.8 Comments

8.3.8.1 The dimensions of the free drainage samplers discussed are purposely left vague. Because the samplers collect fluid flowing primarily through macropores, the dimensions are often dictated on a site-by-site basis by the configurations and spacings of the macropores.

8.4 Installation Methods

8.4.1 Installation

8.4.1.1 Free drainage samplers are commonly installed into the side walls of trenches or caissons. The trenches can be dug either by hand or with backhoes. But they should be stabilized with timbers and siding if deeper than 1.5 m, in order to allow safe access (26)(see Occupational Health and Safety Administration Regulations). All wood used in the construction of permanent trenches should be treated with preservatives to protect it against degradation due to semi-saturated conditions. This may pose a problem when monitoring for organics. Any spaces between the bare trench side walls and the siding are filled with soil and pea-gravel to allow for free drainage. The excavations should be covered to provide positive surface drainage away from the area. Some free drainage samplers require only temporary excavations for installation. After the samplers have been installed, the excavations are backfilled with native soil.

8.4.1.2 Caissons for housing free drainage samplers are constructed with corrugated culverts or concrete drainage pipes. Schneider and Oaksford (101) installed caissons by excavating soil from within a concrete pipe using a crane operated shovel and manual labor. Each concrete pipe section, weighing 222.5 kN (25 tons), was set in place with a crane. As excavation inside the pipe progressed, the pipe advanced downward under its own weight.

8.4.1.3 Pan Lysimeters -- A pan lysimeter can often be pushed

or driven directly into the side wall of a trench. However, if the soil is resistant, an opening for the sampler can be created by hammering a sheet metal blade into the soil profile with a sledge hammer. The pan is placed in the side wall so that it slopes gently toward the trench. Any voids above or below the pan are filled with soil (26). The end of the copper tubing is allowed to project through the trench siding and is connected to plastic tubing and a sample bottle (see Figure 27).

8.4.1.4 Glass Block Lysimeters -- A glass block lysimeter is installed in a cavity which is excavated in the side of a trench. Barbee and Brown (81) used a wooden model of the sampler in order to achieve the correct cavity size during excavation. They used a small knife to score the ceiling of the cavity in order to expose any pores which may have been smeared shut during excavation. Care should be taken to keep the ceiling of the cavity smooth and level so that liquids will not run off the upper surface of the glass block. Jordan (96) found that the edges of the sampler had to be in contact with the soil for the entire perimeter of the sampler in order to prevent liquid from running out through any spaces between the soil and the sampler. Level blocks are important so that the majority of the collected sample can be retrieved. However, the inside glass surface is uneven and has "low spots" where residual sample collects between sampling cycles. The glass block is pushed to the end of the cavity and wedges are used to

hold its collecting surface firmly against the ceiling of the tunnel. Both the cavity and trench are partially backfilled. Barbee and Brown (81) recommend pressing a sheet of aluminum foil against the wall of the trench, extending below the top of the brick, before final backfilling in order to minimize any lateral migration of liquid from the disturbed portion of the soil profile to the undisturbed portion (see Figure 28). It should be noted that aluminum foil is often coated with oil.

8.4.1.5 Trough Lysimeters -- Trough lysimeters are installed in the same manner as glass block lysimeters (see Figure 28).

8.4.1.6 Vacuum Trough Lysimeters -- The vacuum trough lysimeter described by Montgomery et al (97) is housed in a box-like structure, with four walls and a floor, but no ceiling. The floor of the structure and the lower portions of the walls are made of steel. The upper portions of the walls are composed of fiberglass coated plywood. A slotted, plastic drain pipe is set 20 mm above the floor of the structure and is surrounded by gravel. The soil profile surrounding the trough lysimeter is reconstructed incrementally in an attempt to recreate natural conditions. The structure is filled with soil in increments of 0.5 m or less. After each increment is added, liquid is piped slowly into the structure through the drain pipe and allowed to drain back out for 24 hours before the next increment is added. This working of the soil particles by liquid is believed to produce bulk densities that

are fairly representative of the undisturbed conditions. However, soil macropores are not reproduced.

8.4.1.7 Caisson Lysimeters -- Lateral collectors or free drainage samplers are installed in cavities augered by hand or by power-driven equipment through holes in the caisson walls (see Figure 24).

8.4.1.8 Wicking Soil Pore-Liquid Samplers -- These units are installed by the trench and cavity method similar to that for glass block lysimeters (66). A backhoe excavates the trench to the desired depth. A cavity is then dug into the wall of the trench to the dimensions of the sampler. The roof of the cavity is sometimes scarified (depending on the soil type) to remove smearing caused during excavation. The sampler is then forced tightly into place to ensure good contact with the roof of the cavity. The cavity is large enough to accommodate the sampler, the hanging wick and the collection tube. The pressure-vacuum line and the sample collection line are extended to the surface. During backfilling of the tunnel and trench, the bulk density of the fill should be equal to or greater than the native soil.

8.4.1.8 Sand Filled Funnel Samplers -- The installation procedure for these samplers is similar to that used for glass block lysimeters (see Figure 26).

8.4.2 Maintenance

8.4.2.1 Where samplers are accessed through permanent trenches

and caissons, the sampling station must be protected against flooding due to excessive infiltration. Parizek and Lane (26) drilled a floor drain about 27 m through underlying soil into the unsaturated bedrock. This allowed drainage of excess liquid from the floor of the sampling trench, and also decreased the chances of contamination of soil surrounding the structure. Alternately, a sump pump can be used if a drain is not feasible. Parizek and Lane (26) also found that stratified soils intensified lateral flow of pore-liquid, thus aggravating any flooding problems. They concluded that flooding may be a problem in humid areas where more than about 5 cm of liquid per week is applied to the land surface.

8.4.2.2 The ground surface above the sampler should be maintained in a fairly representative state. Large housings and excessive traffic around the sampler (causing compaction of the soil) will reduce the amount of infiltration in that area. This will affect the representativeness of the pore-liquid samples.

8.4.3 Comments

8.4.3.1 A significant advantage of samplers installed in the sidewalls of trenches is that in sufficiently cohesive soils, installation produces no disturbance in the overlying soil. In cohesionless, sandy soils, stable cavities may not be possible. As a result, backfilling of the fallen material may be required. This disturbs the soil profile and macropores are not preserved (97).

8.5 Operation

8.5.1 Methods

8.5.1.1 Since pore-liquid flows into free drainage samplers under the influence of gravity, sampling is a relatively simple procedure. Liquid accumulates in the collection device and then drains through tubing into a sample bottle. The sample can be retrieved either through access to the sampling trench or by pulling it to the surface by a suction pump. The wicking pore-liquid sampler allows the application of a slight suction (4 cbar) to improve sampling. However, this design also has a tendancy to clog.

8.5.1.2 Jordan (96) found that surface tension develops in trough lysimeters at the soil-air interface and prevents some of the liquid from entering the collector. Cole (41) addressed this problem by inserting an aluminum oxide disc between the soil and the collection surface, and then applying suction to break the surface tension and draw liquid out of the soil. The problem with this approach is that it requires the soil adjacent to the aluminum oxide disc to be free of roots, cracks, and channels (96). The two parallel rods included in the trough lysimeter design overcome this problem. If one end of the metal rod touches the fiberglass screen, then the surface film of liquid surrounds the rod and the liquid moves down the rod toward the sample container. Two rods, barely touching, facilitate this migration by allowing the liquid

to move in response to the capillary forces between them (96).

8.5.2 Comments

8.5.2.1 Under near saturated conditions with macropore flow, free drainage samplers tend to collect larger and more consistent samples than suction samplers. Since free drainage samplers are continuous samplers, they need to be emptied after each infiltration event in order to ensure sample integrity, to prevent sample container overflows, and to prevent cross contamination between hydrologic events. (12).

8.6 Advantages and Limitations

8.6.1 Physical Advantages and Limitations

8.6.1.1 A major advantage of free drainage samplers is that they are essentially passive, thus they do not alter pore-liquid flow paths. The major disadvantage of free drainage samplers is that samples can only be obtained when soil moisture conditions are in excess of field capacity. Such saturated conditions usually require constant application of surface liquid, as in the case of agricultural irrigation or at land treatment sites. Under drier conditions, free drainage samplers fail to yield any liquid and suction samplers are required.

8.6.2 Chemical Advantages and Limitations

8.6.2.1 There are both advantages and disadvantages to using free drainage samplers to collect pore-liquid for chemical analysis. A major advantage is that the samplers do not distort

natural flow patterns as do suction samplers. Because samples are collected over known areas, quantitative mass balance estimates are possible. Because the samplers are continuous collectors, infiltration events can be sampled without having to go to the field. The major limitation of free drainage samplers is that they cannot sample pore-liquids held at tensions greater than the field capacity.

8.6.2.2 Free drainage samplers tend to collect pore-liquids which drain rapidly through macropores. Since the residence time of this liquid is less than that of liquid moving under tension, the major ion chemistry appears more dilute than the fluid sampled from unsaturated pores with suction samplers. In some cases, this decrease in residence time in combination with other factors can result in an actual change in the chemical signature rather than just an overall dilution. This is because insufficient time may be available for reactions to occur with soil components that act as chemical sources or sinks (102). However, free drainage samplers have large cross-sectional areas and they are cumulative collectors. As a result, they collect samples which average soil heterogeneities and therefore give a more representative picture than suction samplers of chemical movement through wet soil, particularly through well-structured soils (81). In addition, the samplers use suction only to retrieve samples. As a result there is less potential for loss of volatile compounds than with suction

samplers (12).

8.6.3 Microbial Advantages and Limitations

8.6.3.1 Since free drainage samplers do not have the minute openings that porous ceramic suction samplers have, they do not screen out colloidal-sized particles and soil bacteria. Consequently, they yield more representative values for suspended solids or BOD measurements (26).

Draft: 2B
Date : June 23,1989

9. Perched Ground Water Samplers

9.1 Perched water occurs where varying permeability layers in the vadose zone retard downward movement of liquid. Over time, liquid collects above lower permeability layers and moisture contents rise until the soil becomes saturated with liquid (9,103). Once soil becomes saturated, wells and other devices normally installed below the water table can be used to collect samples. Separate guides are available for ground water sampling, therefore, the topics are covered briefly, with reference to appropriate documents.

9.2 Sampling perched liquid is attractive because the perching layer collects liquid over a large area. This integration allows samples to be more representative of areal conditions than suction samples (103). This also allows the sampler to potentially detect contaminants which may not be moving downward immediately adjacent to the sampler. In addition, larger sample volumes can be collected than those which can be obtained by suction samplers. Everett et al (6) and Everett et al (9) discussed the incorporation of perched ground water sampling into monitoring programs. There are a variety of systems which can be used. These include:

9.2.1 Point Samplers,

9.2.2 Wells,

9.2.3 Cascading water samplers and

9.2.4 Drainage samplers.

9.3 Operating Principles

9.3.1 Point Samplers

9.3.1.1 Point samplers are open ended pipes or tubes, such as piezometers or wells with short screened intervals, installed for the purpose of collecting samples from a discrete location in saturated material. Samples are collected by bringing liquid which flows freely into the device to the surface by one of a variety of methods.

9.3.2 Wells

9.3.2.1 A monitoring well is similar to a point sampler except the screened interval is longer. Therefore, samples are averaged over the screened length (104). Samples are collected by bringing liquid which flows freely into the well to the surface by one of a variety of methods.

9.3.3 Cascading Water Samplers

9.3.3.1 Cascading water occurs when a well is screened across a perched layer and the underlying water table or when water leaks through casing joints at the perched layer. Because the water table is lower than the perched layer, water flows into the well in the portion open to the perched layer, and cascades downward to the water table. This situation is common in some areas where the practice has been to install water wells with large screened intervals (105). Samples are collected by capturing liquid flowing

into the well from the perched layer before it cascades down to the water table.

9.3.4 Drainage Samplers

9.3.4.1 Shallow perched systems may spread contamination, cause problems with structures, or interfere with agriculture. Therefore, drainage systems are sometimes installed. These systems usually funnel liquid via gravity flow to a ditch or sump from which it is pumped out. This outflow can be sampled. Typical drainage systems include tile lines or manifold collectors. Depending on the design of the system, it may be possible to sample outflows which drain different areas.

9.4 Description

9.4.1 Point Samplers

9.4.1.1 Point samplers can be installed in separate boreholes or clustered together in one borehole at different depths. Figure 29 presents different configurations which have been used. Piezometers, which are often used as point samplers, are similar to wells, in that they consist of a small diameter casing open at one end or connected to a short screened interval (106). Reeve (107), Patton and Smith (108) and Morrison (1) discussed different designs.

9.4.1.2 Point samplers can be made from a variety of materials including steel, PVC, PTFE, ABS, fiberglass, and additional materials for joints, seals and other components (106,107).

9.4.2 Wells

9.4.2.1 Monitoring wells (as depth averaged samplers) are normally installed with one well in each borehole. Components of a well generally include a bottom plug, a length of screen, a length of blank casing, a cap, and a protective cover. Different monitoring well designs are presented in Figures 30, 31 and 32. Authors who described methods for designing and installing monitoring wells include U.S. EPA (109), Driscoll (110), Gass (111), Keely (112), Minning (113), Richter and Collentine (114), Riggs (115), Riggs and Hatheway (116), Scalf et al (117), Morrison (1), Everett et al (9), Campbell and Lehr (118). Hackett (119,120) summarized methods for designing and installing monitoring wells with hollow stem augers. Screened hollow stem augers can also be used as temporary wells for sampling (Taylor and Serafini, 121).

9.4.2.2 Monitoring wells can be made from a variety of materials including steel, PVC, PTFE, ABS, fiberglass, and additional materials for joints, seals and other components. Details are provided by Barcelona et al (122), U.S. EPA (109), Morrison (1) and many of the references listed above.

9.4.3 Cascading Water Samplers

9.4.3.1 Cascading water is most often seen in production wells in areas with extensive ground water pumpage. Samplers simply consist of a bucket or bailer lowered to a point below the inflow of cascading water. Wilson and Schmidt (103) described methods for

developing cascading water samplers (see Figure 33).

9.4.3.2 Cascading wells differ from other wells only by the way in which water flows into them. Otherwise, the materials used for these wells are identical to those used for other types of wells. Bailers or buckets used to collect samples are also available in steel, PVC, PTFE, acrylic and other materials.

9.4.4 Drainage Samplers

9.4.4.1 Drainage systems consist of conduits installed within the perched zone at sufficient slopes for water to flow to a central ditch or drain. The conduits can be tile drains, half perforated pipes, synthetic sheeting, or even layers of gravel and sand. Schilfgaarde ed.(123), contains numerous papers on the design and construction of drainage systems. Donnan and Schwab (124) described sampling from agricultural drainage systems. Gilliam et al (125), Gambrell et al (126), Eccles and Gruenberg (127) and Gilliam et al (128) described sampling from tile drains. Gilliam et al (125) and Jacobs and Gilliam (129) described sampling from drainage ditches. Wilson and Small (130) described a lateral drain sampler installed beneath a new sanitary landfill. A perforated pipe collected liquid which was funneled to a sump via a drain line. In most of these systems, a thin layer of high permeability sand or gravel is installed around the drain to promote flow into the collector, and to sieve out fine materials.

9.4.4.2 Because drainage systems often require large quantities

of materials, less exotic, cheaper materials such as baked clay tiles and PVC are often used.

9.4.5 Comments

9.4.5.1 As with all samplers, potential chemical interaction between the sampler material and the constituents of interest should be considered. Because these samplers are usually installed for other purposes, incompatibility of materials with monitoring objectives is often a problem. Everett et al (9), Dunlap (131), and U.S. EPA (109) discussed this topic.

9.5 Installation Methods

9.5.1 Point Samplers

9.5.1.1 Reeve (107), Patton and Smith (108), and Morrison (1) discussed procedures for installing and maintaining point samplers.

9.5.2 Wells

9.5.2.1 Most of the references listed in Section 9.4.2.1 describe methods for installing monitoring wells.

9.5.3 Cascading Water Samplers

9.5.3.1 Wilson and Schmidt (103) discussed methods for installing cascading water samplers.

9.5.4 Drainage Samplers

9.5.4.1 Schilfgaarde ed.(123) contains articles which discussed installation of agricultural drainage systems. Associated hazards and costs often prohibit the installation of these systems

at existing landfills. As a result, inclusion of these systems, as leachate collectors, in new landfills is more common. Everett et al (9) discussed methods for installing drainage sampling systems at hazardous waste sites.

9.6 Operation

9.6.1 Point Samplers

9.6.1.1 Point samplers usually have diameters which are too small to allow the use of submersible pumps. As a result, suction methods are usually required (1). Sampling techniques are described in Pickens et al (106), Reeve (107), Patton and Smith (108) and Morrison (1).

9.6.2 Wells

9.6.2.1 Samples may be retrieved from wells in the same manner as from piezometers. However, because wells are designed for sampling or pumpage, diameters are usually large enough to accommodate most pumps. Samples can be brought to the surface by a variety of systems including bailers, suction pumps (e.g. peristaltic pumps), air lift pumps, piston pumps, submersible pumps and swabbing. Each of these methods have advantages and disadvantages relating to considerations such as depth to water, required sample volume, sampling speed, alteration of the sample chemistry, equipment requirements, manpower requirements, and cost. These considerations were discussed by Everett et al (9), Fenn et al (132), Gibb et al (133), U.S. EPA (109), Dunlap et al

(131),Driscoll (110), and Anderson (75). Sampling methods were described in most of the references of Section 9.4.2.1. As described in Section 9.3.2, samples from wells are averaged over the screened interval. However, samples from discrete depths alorg the screened interval can also be obtained using packer-pump setups such as those described by Fenn et al (132).

9.6.3 Cascading Water Samplers

9.6.3.1 Wilson and Schmidt (103) described techniques for sampling from cascading wells. A bailer or bucket is decontaminated and then lowered to a position in the well below the cascading water but above the water table. When the sampler is full, it is pulled back to the surface. Alternately, as shown in Figure 33, the chemistry of the water table immediately around a well which has been shut down will be dominated by the cascading water. Therefore, a sample can also be collected from the water table during the initial stages of pumping.

9.6.3.2 Cascading wells are usually production wells in which drawdown has lowered the water table sufficiently to cause cascading. Because of this, there is usually a pump installed in the well which will prevent access for sampling. However, the pumps are periodically removed for maintenance. Therefore, it should be possible to coordinate sampling with pump maintenance personnel.

9.6.4 Drainage Samplers

9.6.4.1 Samples may be collected where tile lines or drainage

pipes discharge to ditches or sumps (125,126,127,128,129,130). Willardson et al (134) described a "flow-path ground water sampler" which allows collection of water following different flowpaths along a tile drainage system.

9.7 Limitations

9.7.1 Perched water systems can be difficult to find and delineate. Surface and borehole geophysical methods (e.g neutron logging) and video logging of existing wells are often used. Also, perched systems tend to be ephemeral. Therefore, suctions samplers are sometimes required as backups.

9.7.2 Point Samplers

9.7.2.1 The major problem with point sampling systems is that their diameters are often too small to allow adequate development after installation or to allow sampling by any method other than suction. Because the maximum suction lift of water is about 7.5 m, this is the maximum sampling depth for many of the small diameters systems. Systems such as those depicted in Figure 29 require tight contact with the surrounding material to prevent side leakage of liquid. Depending on the material, this tight contact may not be achievable (9).

9.7.3 Wells

9.7.3.1 Wells provide samples which are averaged over the screened interval. As a result, when contaminants are detected, packer-pump arrangements must be used if zonation of the

contaminants is to be delineated. When separate phases of water-immiscible fluid (e.g oil) are found floating in the well, it is difficult to obtain samples of the underlying water without contamination from the overlying fluid. As with all samplers, care should be taken to ensure that materials used to construct a well are compatible with the chemical analyses to be performed.

9.7.4 Cascading Water Samplers

9.7.4.1 Cascading water may enter a well from several distinct perched systems (103). As a result, the sample may be a mixture of water from several depths. Cascading water is most often sampled from pre-existing wells used for other purposes. As a result, materials used in the well construction may alter those chemical constituents of interest. Wells used for irrigation and water supply often have lubricant oils from the pump floating in them. With fluctuating water levels, these oils become smeared along the casing, and may even move out into the surrounding soils. Therefore, traces of these oils may appear in samples.

9.7.5 Drainage Samplers

9.7.5.1 Because of the limitations of excavation equipment, drainage samplers are limited to shallow depths. In addition, the systems are difficult to install in rocky or steep terrains. In areas which experience freeze-thaw cycles, they may be damaged by soil heaving (9). Drainage systems are often susceptible to clogging over time as fine particles and chemically precipitated

material accumulate on the drain openings. Collected samples may or may not be representative of average conditions, depending on the distribution of soil types and contaminants in the drained area. If the area of contamination is small compared to the drained area, dilution may prevent the detection of contaminants. In addition, pollutants which are heavier than water may move below the drain if it is not located at the bottom of the perched zone. As with all samplers, there is the possibility of chemical interaction between the sampling system and the chemical constituents of interest. In the case of drainage sampling systems, this effect is amplified as contaminants may have to travel considerable distances through drains before being sampled. In addition, normally non-aerated solutions may be aerated and chemically altered as they travel through drains.

10. Experimental Absorption Samplers

10.1 Operating Principles

10.1.1 Absorbent samplers depend on the ability of the material to absorb pore-liquid (1). Samples are collected by placing the sampler in contact with soil. Liquid is allowed to absorb into the sampler material over time. The sampler is then removed, and the sample liquid is extracted for analyses.

10.2 Description

10.2.1 Two designs have been described. The first design includes a cellulose-nylon sponge (0.5 by 4.8 by 30 cm) seated in a galvanized iron trough. The trough is pressed against a soil surface with a series of lever hinges (135).

10.2.2 The second absorbent sampler design consists of tapered ceramic rods which are driven into soil (136).
The rods are made from unglazed ceramic similar to that used as the porous segments of suction samplers.

10.3 Installation

10.3.1 Pre-installation

10.3.1.1 Sponge samplers are prepared by soaking them for 24 hours in a 1 to 5 percent NaOH solution containing a washing powder Tadros and McGarity (135). Sponges are then pressed dry using rollers, stored in a moisture tight container, and taken to the field.

10.3.1.2 Ceramic rod samplers are weighed, boiled in distilled

water, oven dried and stored in a desiccator. The rods are weighed again and then taken to the field.

10.3.2 Installation

10.3.2.1 A sponge is placed in the sampling trough. The trough is then placed in a horizontal cavity cut into the side of a trench. The trough is then pressed against the cavity ceiling with the lever hinges.

10.3.2.2 A ceramic rod sampler is installed by simply driving it into the soil.

10.3.3 Maintenance

10.3.3.1 The only field maintenance required for sponge samplers is the preservation of the sampling trench if future sampling is desired at that location.

10.3.3.2 There is no field maintenance for ceramic rod samplers as they are completely removed to retrieve the samples.

10.3.4 Comments

10.3.4.1 Theoretically, there is no maximum installation depth for sponge samplers. However, because access trenches are required for operation, installations are restricted to shallow depths dictated by excavation equipment and safety considerations.

10.3.4.2 Ceramic rod samplers will have maximum installation depths if pushed or driven from the surface. This maximum depth will generally decrease with increasing soil grain size. However, deeper installations can be achieved by drilling to the top of the

interval to be sampled, lowering a rod down the hole and pushing or driving the rod into the sampling interval (136).

10.4 Operation

10.4.1 Methods

10.4.1.1 Sponge samplers are pressed against the soil until a sufficient volume of liquid for planned analyses has been absorbed. The sampler is then removed and the sponge is placed in a moisture proof container. The sample is extracted from the sponge with rollers.

10.4.1.2 Ceramic rod samplers are pushed or driven into the soil and left in place for a period of time. The rods are then withdrawn, and weighed. The rods are leached by boiling in a known volume of distilled water. This solution is then analyzed. The concentrations of constituents in the original pore-liquid are estimated by using the ratio of the volume of absorbed water to the volume of the boiling water.

10.4.2 Comments

10.4.2.1 The amount of liquid which can be sampled is dependant on time, soil type, moisture content, absorbency of the sampler material, volume of the absorbent material, and surface area of the absorbent material in contact with the soil. Generally, sponge samplers function only at higher moisture contents approaching saturation (1). Shimshi (136) used ceramic rod samplers to sample from a sandy loam with moisture contents varying from 7

to 20 percent.

10.5 Limitations

10.5.1 Physically, absorbent methods are limited to soils approaching saturation. Sampling requires removal of the absorbent material. Because of this, repeat sampling at the same location is difficult. Although the sampler may be placed back at its original location, identical hydraulic contact with the soil cannot be guaranteed.

10.5.2 Chemically, as with other samplers, there are problems with absorption, desorption, precipitation, cation exchange and screening of various pore-liquid components as a function of the sampler materials. Tadros and McGarity (135) discussed these concerns in relation to sponge samplers. Shimshi (136) provided a good discussion of the limitations of sampling for nitrate with ceramic rod samplers. Specifically, he found that at lower moisture contents, sampled solutions became less representative due to vapor transfer and chromatographic separation. However, he suggested that these effects could be reduced by increasing the length of the rod insertion period.

Draft: 2B
Date : June 23,1989

TABLE 1

SUCTION SAMPLER SUMMARY

SAMPLER TYPE	POROUS SECTION MATERIAL	MAX. PORE SIZE(um)	AIR ENTRY VALUE(cbar)	OPERATIONAL SUCTION RANGE(cbar)	MAX. OPERATIONAL DEPTH(m)
Vacuum Lysimeters	Ceramic	1.2-3.0	>100	<60-80	<7.5
	PTFE	15-30	10-21	<10-21	<7.5
	Stainless Steel	NA	49-5	49-5	<7.5
Pressure-Vacuum Lysimeters	Ceramic	1.2-3.0	>100	<60-80	<15
	PTFE	15-30	10-21	<10-21	<15
High Pressure-Vacuum Lysimeters	Ceramic	1.2-3.0	>100	<60-80	<91
	PTFE	15-30	10-21	<10-21	<91
Filter Tip Samplers	Polyethylene	NA	NA	NA	none
	Ceramic	NA	NA	NA	none
	Stainless Steel	NA	NA	NA	none
Cellulose-Acetate Hollow-Fiber Samplers	cellulose acetate	<2.8	>100	<60-80	<7.5
	non cellulosic polymer	<2.8	>100	<60-80	<7.5
Membrane Filter Samplers	cellulose acetate	<2.8	>100	<60-80	<7.5
	PTFE	2-5	NA	NA	<7.5
Vacuum Plate Samplers	alundum	NA	NA	NA	<7.5
	ceramic	1.2-3.0	>100	<60-80	<7.5
	fritted glass	4-5.5	NA	NA	<7.5
	stainless steel	NA	49-5	49-5	<7.5

NA: not available

	Material Absorbs Species	Material Desorbs Species	Material Screens Species	No Significant Interaction	No Interaction
Al		C(2)		C(16)	
		A(14)		A(14)	
Alkalinity				SF(11)	
Ca		C(1,2,18) CAF(18) A(14)		C(3,6,10,11,25) PTFE(3) A(3) FG(18,22) CAF(10)	PTFE(13)
C		FG(22)			
CO_3		C(2)			
HCO_3		C(2)			
Cd	C(11)			C(3) PTFE(3) A(3)	
Cl				C(11,25) SF(11)	PTFE(13)
Cr	C(19)	C(3) PTFE(3) A(3)			
Cu	C(11)	C(3) PTFE(3)		A(3)	
Fe	C(11)	PTFE(3)		C(3,25)	PTFE(13)
		A(3)		A(14)	
H				SF(11)	
K	C(5,6,15)	C(18) A(14)		C(1,25) CAF(18) FG(18,22)	
Mg	C(6)	C(2,3,11,18) A(3,14) CAF(18)		C(10,25) PTFE(3) CAF(10) FG(18,22)	PTFE(13)
Mn	C(11)	A(3)		C(3) PTFE(3) A(14)	PTFE(13)
Na	C(6)	C(2,18) A(14) CAF(18) FG(18,22)		C(1,11,25)	PTFE(13)
NH_4	C(4,12)			PTFE(4)	
N		FG(22)			
NO_2				C(4,5) PTFE(4)	
NO_3			CAF(10)	C(4,8) PTFE(4)	
NO_3-N			C(10) CAF(10)		
(NO_2+NO_3)-N				C(5)	
P	C(1,5,8,15,18)			CAF(18) FG(18)	
PO_4	C(4,5,7)			PTFE(4) CAF(10)	
PO_4-P				C(10) CAF(10)	
Pb					PTFE(13)
SiO_2		C(2)			
Si				C(4) PTFE(4)	
SO_4				C(11)	
Sr		C(11)			
Zn		C(11) A(14)			PTFE(13
High MW Compounds			C(17,21) CAF(10)		
4-nitrophenol	PTFE(23)				
chlorinated hydrocarbons	PTFE(23,24)				
diethyl phthalate					PTFE(23)
napthalene	PTFE(23)				
acenaphthene	PTFE(23)				

NOTES:

C: porous ceramic
PTFE: porous PTFE
A: porous alundum
CAF: cellulose-acetate fibers
FG: fritted glass or glass fibers
SF: silica flour

- valence states are often not reported in studies.
- comparisons of materials based on this table should be made cautiously. Differing experimental techniques should be considered as a source of differing conclusions. Undocumented factors often include material age and sampling history.

EXAMPLE: Reference 18 found that there is no significant interaction of cellulose-acetate fibers with potassium in solution. The porous section was washed prior to testing and results were found to be a function of several factors.

REFERENECES	NOTES ON EXPERIMENTAL TECHNIQUE			
	Porous Section Was Washed	Results are a Function of Several Factors	Dilute Solutions were tested	Experiments were performed on nonporous materials
(1) Grover and Lamborn, 1970	■			
(2) Wolf, 1967	■			
(3) Creasey and Dreiss, 1986	■			
(4) Zimmerman et al., 1978	■			
(5) Napgal, 1982		■		
(6) Debyle et al., 1988	■	■		
(7) Bottcher et al., 1984	■			
(8) Hansen and Harris, 1975	■			
(9) Klute, 1986		■		
(10) Levin and Jackson, 1977				
(11) Peters and Healy, 1988	■			
(12) Wagner, 1962				
(13) Morrison, 1982	■			
(14) Neary and Tomassini, 1985	■	■	■	
(15) Faber and Nelson, 1984	■			
(16) Liator, 1987		■		
(17) Law, 1982				
(18) Silkworth and Grisak, 1981	■	■		
(19) Anderson, 1986		■		
(20) Barbarick et al., 1979				
(21) Brose et al., 1986				
(22) Wagman and Graham, 1974	■	■		
(23) Jones and Miller, 1988		■	■	■
(24) Barcelona et al., 1988		■	■	■
(25) Johnson and Cartwright, 1980	■	■		

Table 2
Porous Material Interactions

APPENDIX

(Nonmandatory Information)

X1. DESCRIPTIONS OF TERMS

air entry value: The applied suction at which water menisci of the porous segment of a suction sampler break down, and air enters.

bubbling pressure: The applied air pressure at which water menisci of the porous segment of a suction sampler break down, and air exits.

capillary fringe: The basal region of the vadose zone comprising sediments that are saturated, or nearly saturated, near the water table, gradually decreasing in water content with increasing elevation above the water table.

cascading water: Perched ground water that enters a well casing via cracks or uncovered perforations, trickling or pouring down the inside of the casing.

cation exchange capacity (CEC): The total capacity of a porous system to adsorb cations from a solution.

hydraulic conductivity: The proportionality factor in Darcy's equation; generally, a measure of the ease with which water moves through a porous system. More specifically, the volume of water that will move through a medium in a unit of time under a unit of hydraulic gradient through a unit area normal to the direction of flow.

hydraulic gradient: The change in total hydraulic head of water per unit distance of flow.

hydrophobicity: The property that defines a material as being water repellent. Water exhibits an obtuse contact angle with hydrophobic materials.

hydrophelicity: The property that defines a material as attracting water. Water exhibits an acute contact angle with hydrophilic materials.

lysimeter: A device to measure the quantity or rate of water movement through a block of soil, usually undisturbed or in-situ; or to collect such percolated water for analyses.

macropore: Interaggregate cavities which serve as the principal avenues for the infiltration and drainage of water and for aeration.

matric potential: The energy required to extract water from a soil against the capillary and adsorptive forces of the soil matrix.

matric suction: For isothermal soil systems, matric suction is the pressure difference across a membrane separating soil solution, in-place, from the same bulk (see soil-water pressure).

micropore: Intraaggregate capillaries responsible for the retention of water and solutes.

perched ground water: Unconfined ground water separated from an underlying body of ground water by an unsaturated zone.

percolation: The movement of water through the vadose zone, in contrast to infiltration at the land surface and recharge across a water table.

pore-liquid: Liquid which occupies an open space between solid soil particles. Within this standard, pore-liquid is limited to aqueous pore-liquid; which includes water and its solutes.

pore-liquid tension: see matric-suction or soil-water pressure.

pressure head: The head of water at a point in a porous system; negative for unsaturated systems, positive for saturated systems. Quantitatively, it is the water pressure divided by the specific weight of water.

Richard's Outflow Principle: The principle which states that pore-liquid will not generally flow into an air-filled cavity (at atmospheric pressure) in unsaturated soil.

soil: Sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter.

soil-water pressure: The pressure on the water in a soil-water system, as measured by a piezometer for a saturated soil, or by a tensiometer for an unsaturated soil.

tensiometer: A device for measuring soil-water matric potential (or tension or suction) of water in soil in-situ; a porous, permeable ceramic cup connected through a water filled tube to a pressure measuring device.

total hydraulic head: The sum of gravitational head and pressure head of water within a porous system.

total soil-water potential: the sum of the energy-related components of a soil-water system; e.g., the sum of the gravitational, matric and osmotic potentials.

tremie method: The method whereby materials are emplaced in the bottom of a borehole with a small diameter pipe.

vacuum: A degree of rarefaction below atmospheric pressure: negative pressure.

vadose zone: The hydrogeological region extending from the soil surface to the top of the principle water table; commonly referred to as the "unsaturated zone" or "zone of aeration". These alternate names are inadequate as they do not take into account locally saturated regions above the principle water table (e.g. perched water zones).

water content: The amount of water stored within a porous matrix, expressed as either a volume (volume per unit volume) or a mass (mass per unit mass) of a given solid.

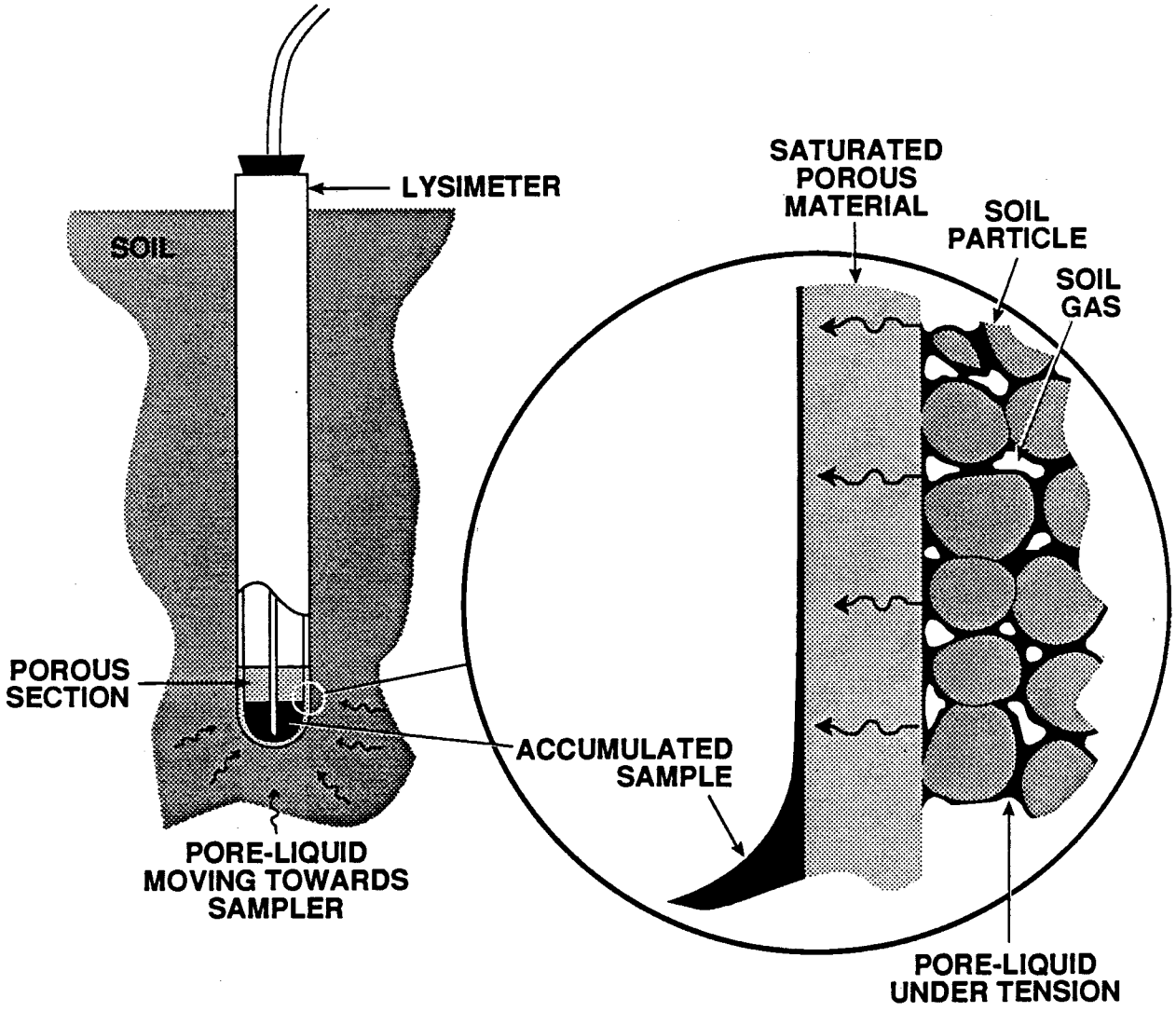


Figure 1 Porous section/soil interactions

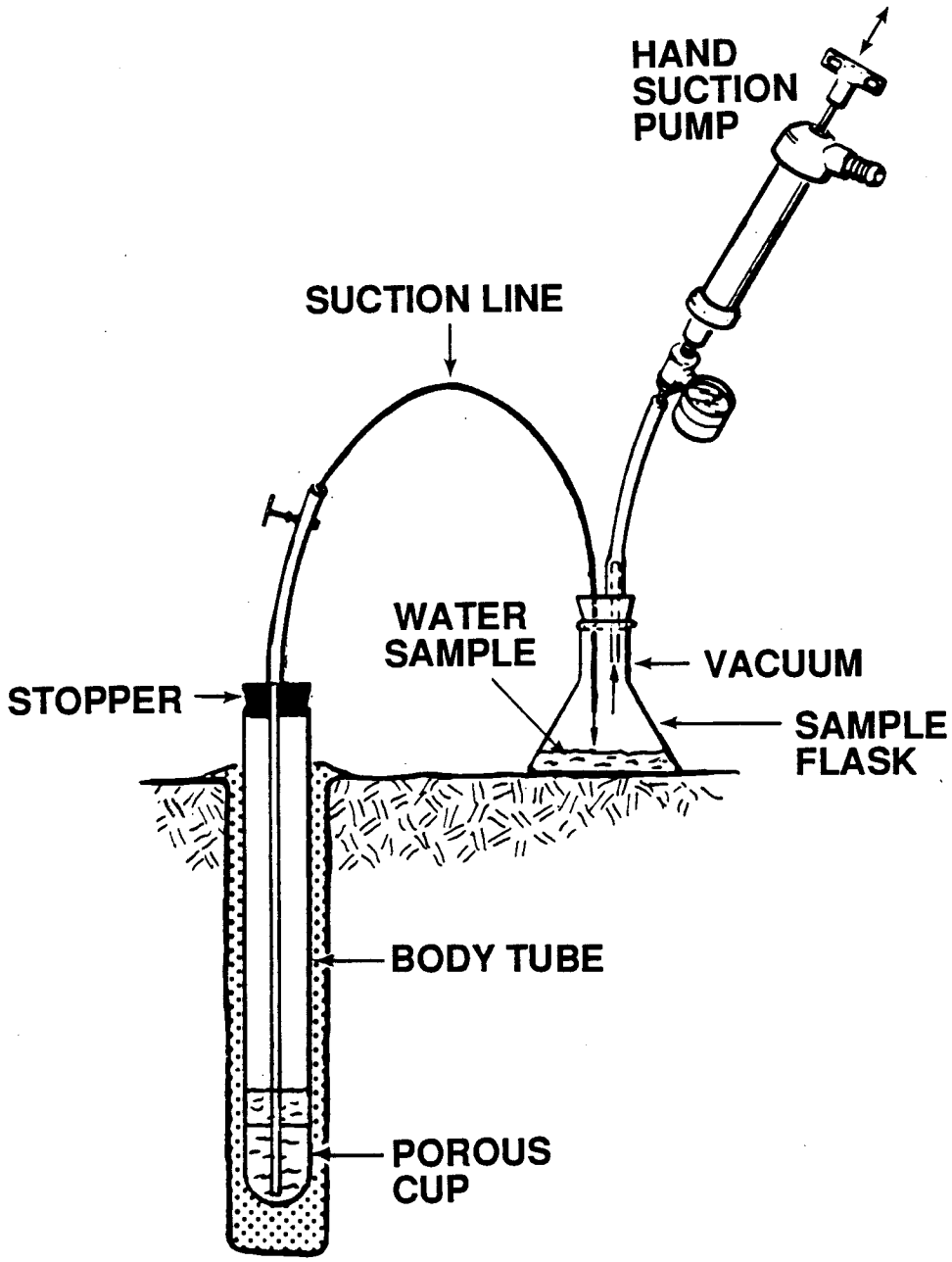


Figure 2 Vacuum lysimeter (Courtesy, Soilmoisture Equipment Corp., 1981)

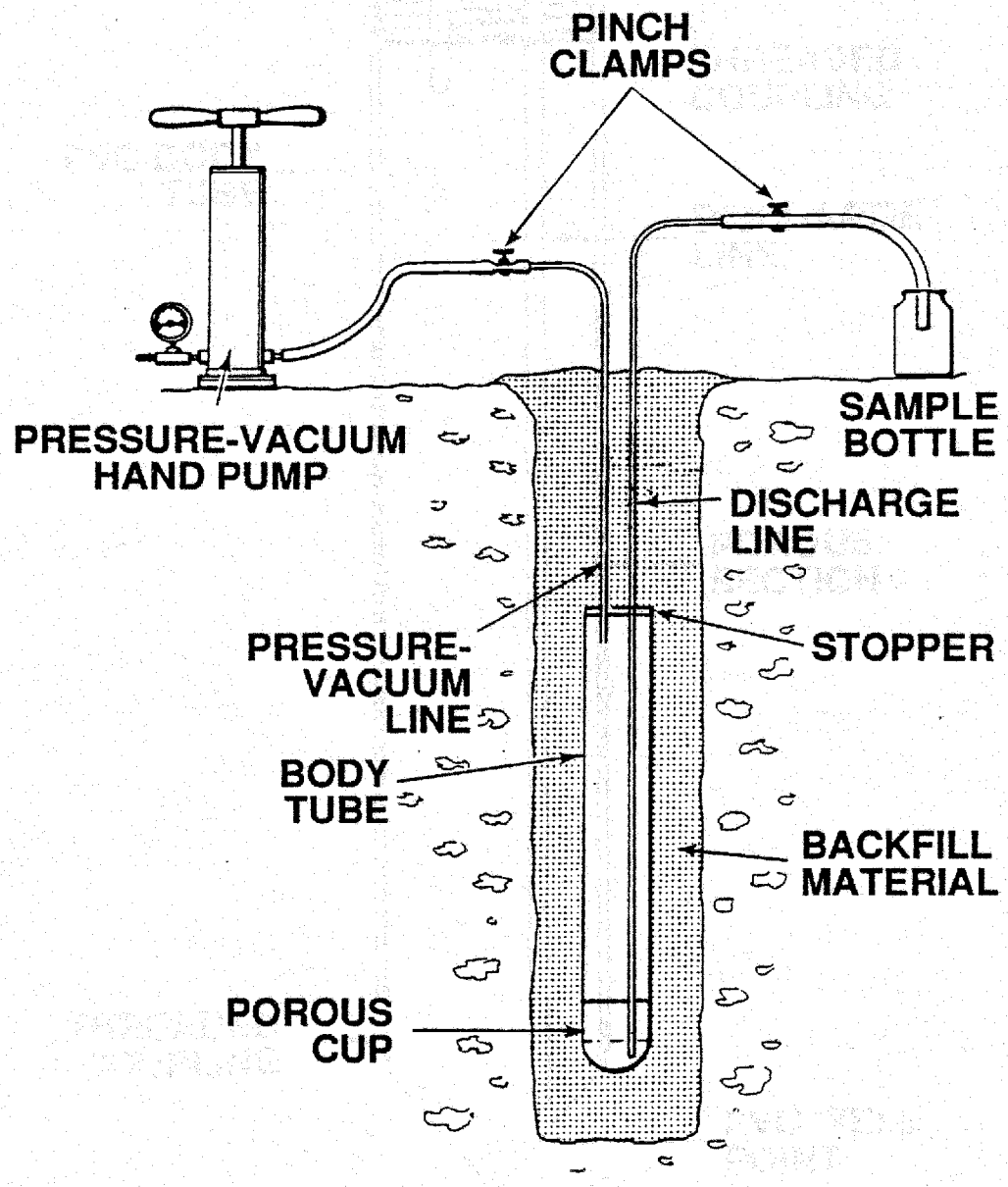


Figure 3 Pressure-vacuum lysimeter (Courtesy, Soilmoisture Equipment Corp., 1989)

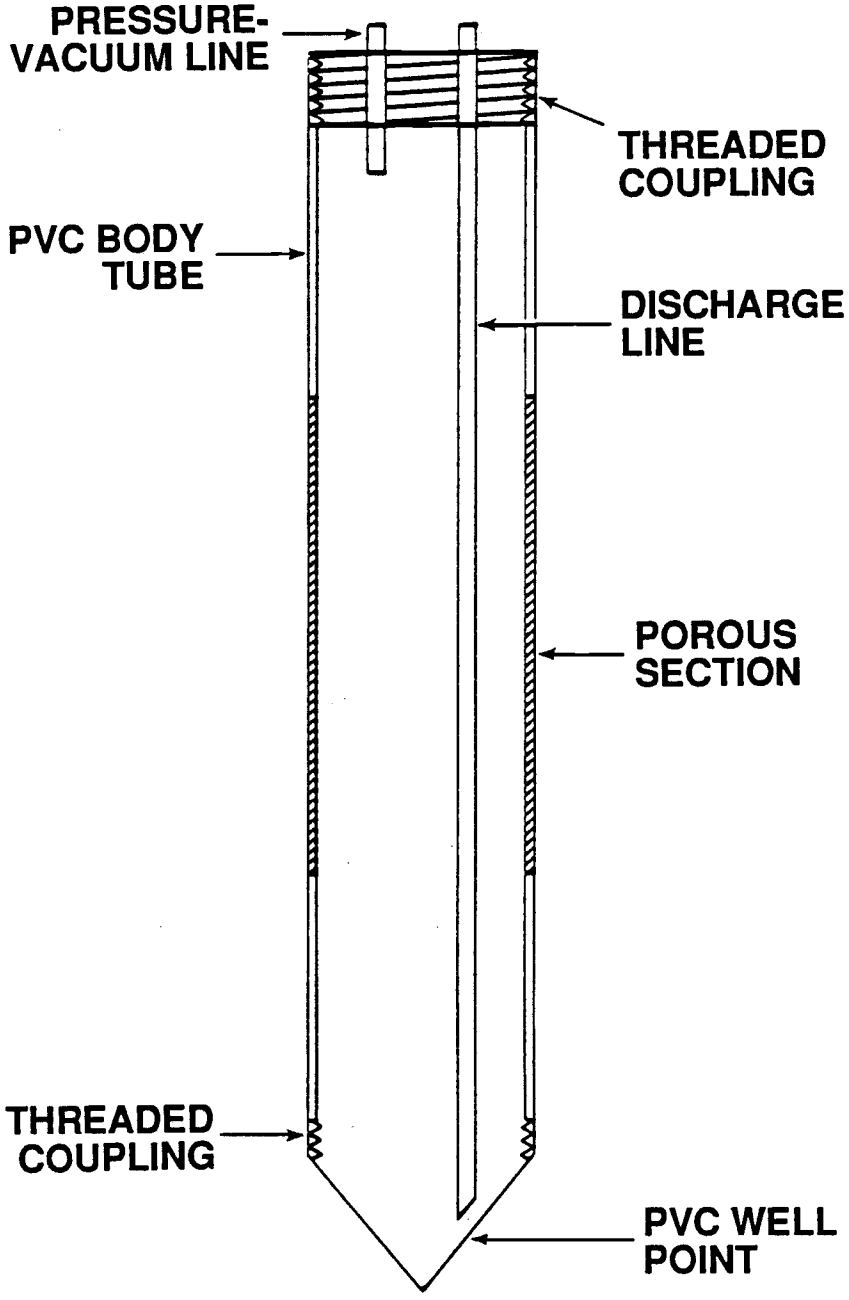


Figure 4 Tube pressure-vacuum lysimeter (Morrison and Tsai, 1981)

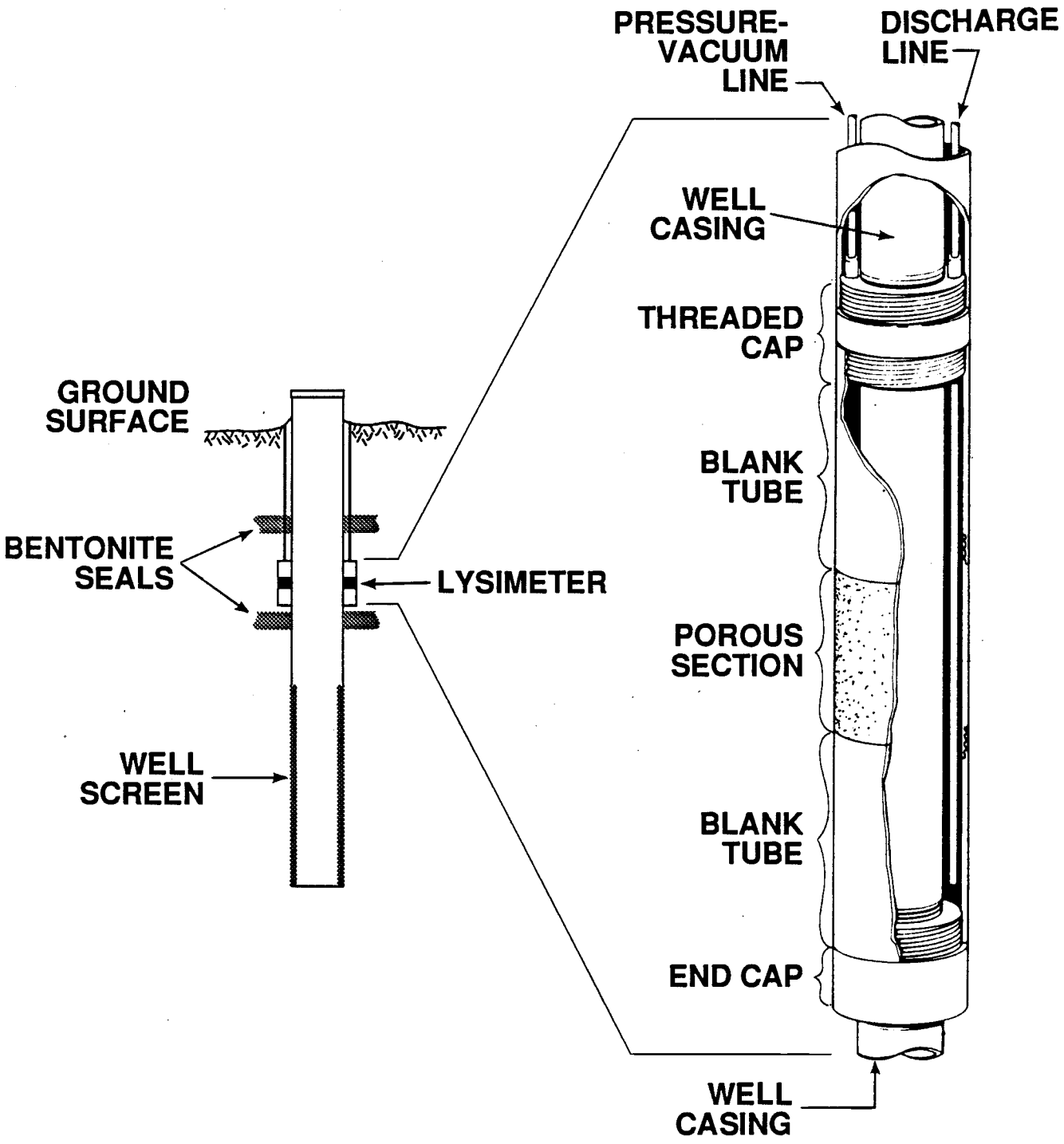


Figure 5 Sleeve lysimeter (Courtesy, Timco Mfg., Inc., 1989)

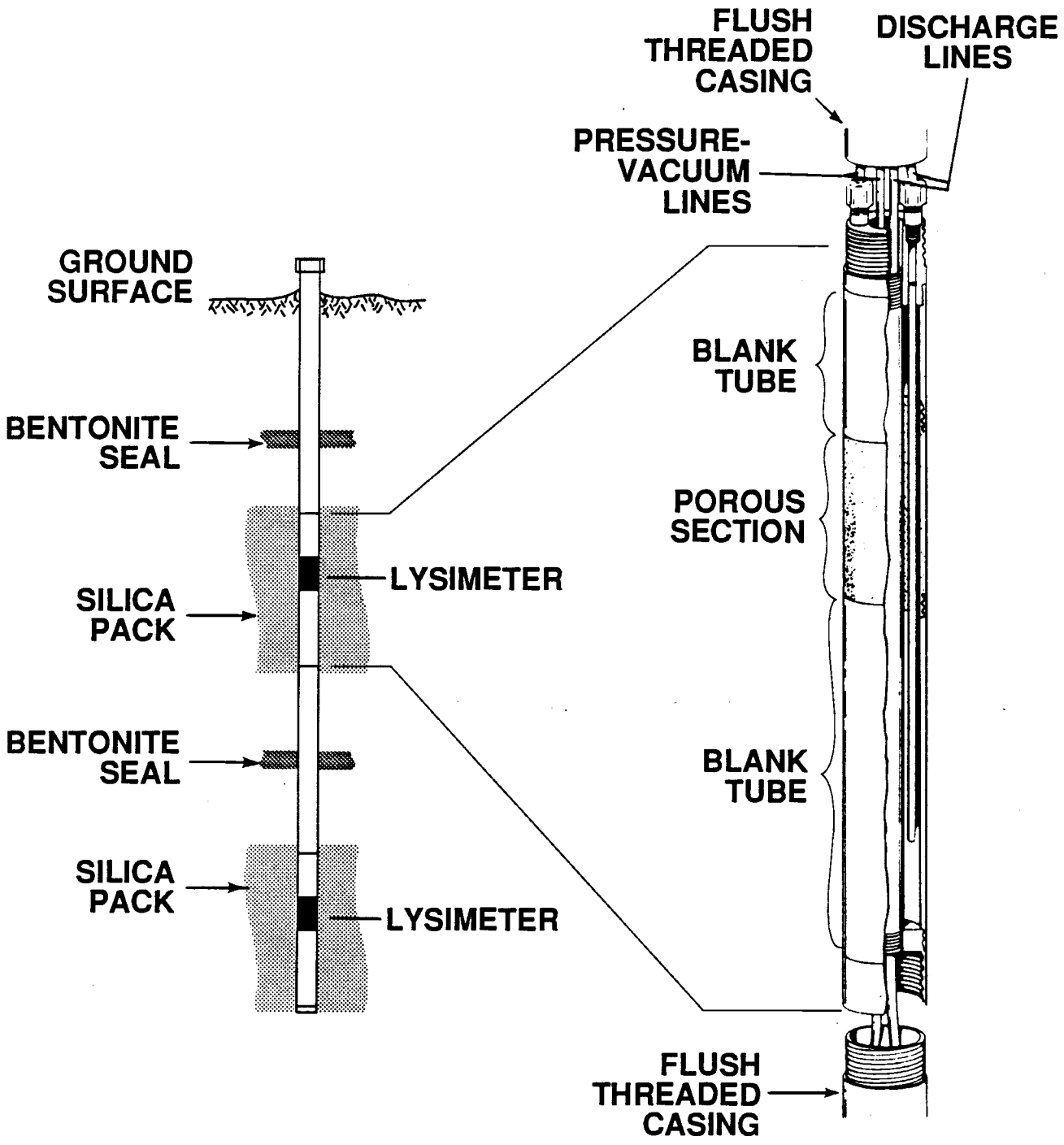


Figure 6 Casing lysimeter (Courtesy, Timco Mfg., Inc., 1989)

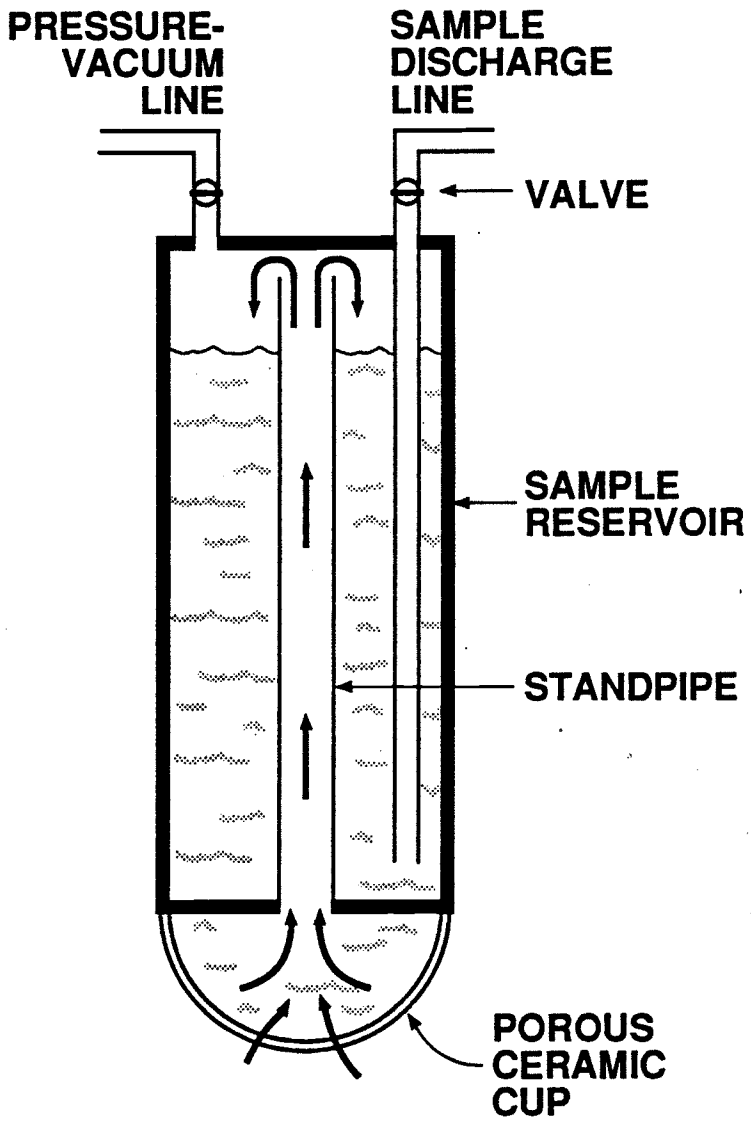


Figure 7 Modified pressure-vacuum lysimeter (Nightingale et al, 1985)

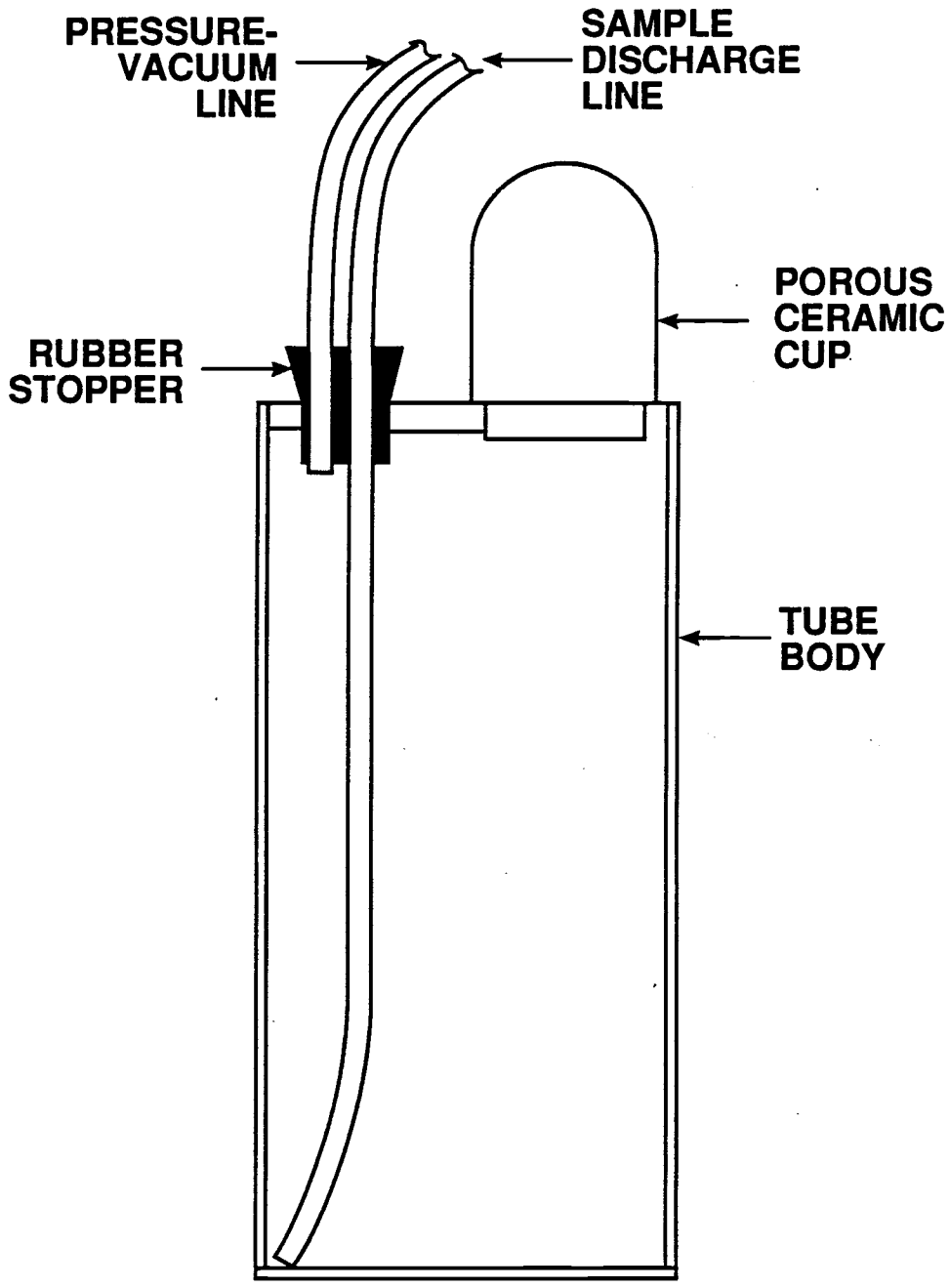


Figure 8 Knighton and Streblow-type vacuum lysimeter (Knighton and Streblow, 1981)

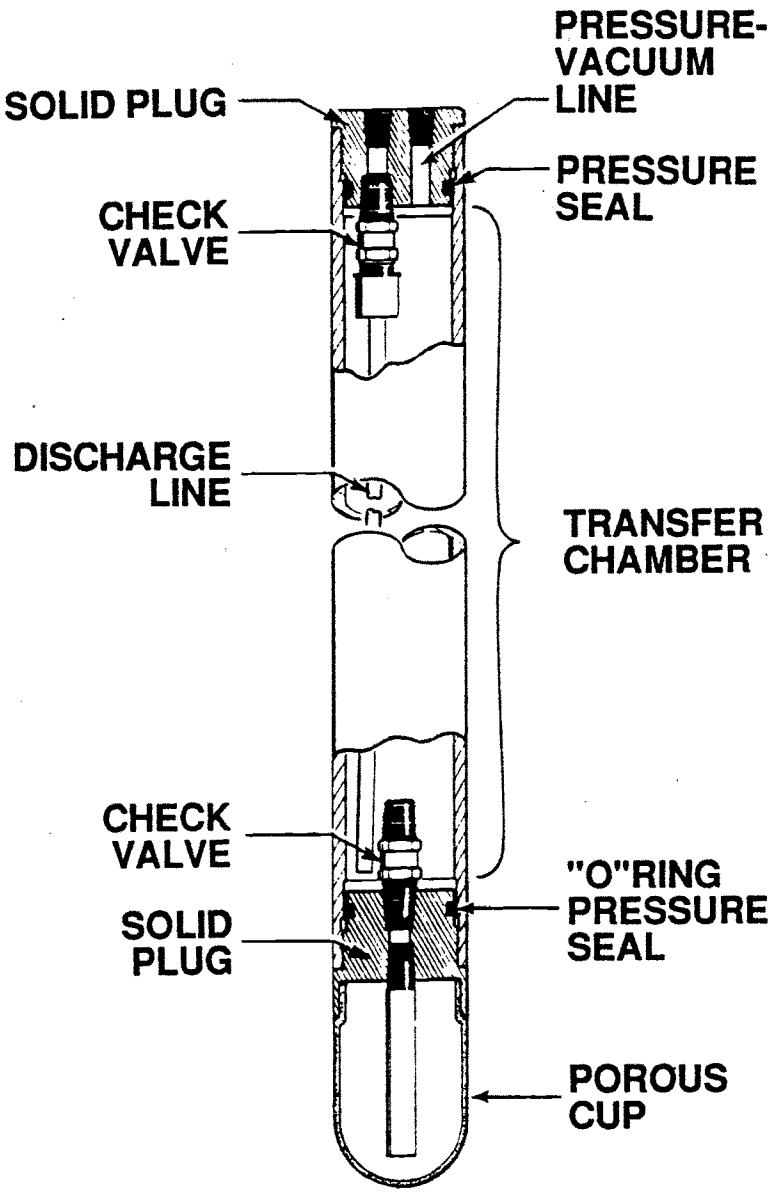


Figure 9 High pressure-vacuum lysimeter (Courtesy, Soilmoisture Equipment Corp., 1989)

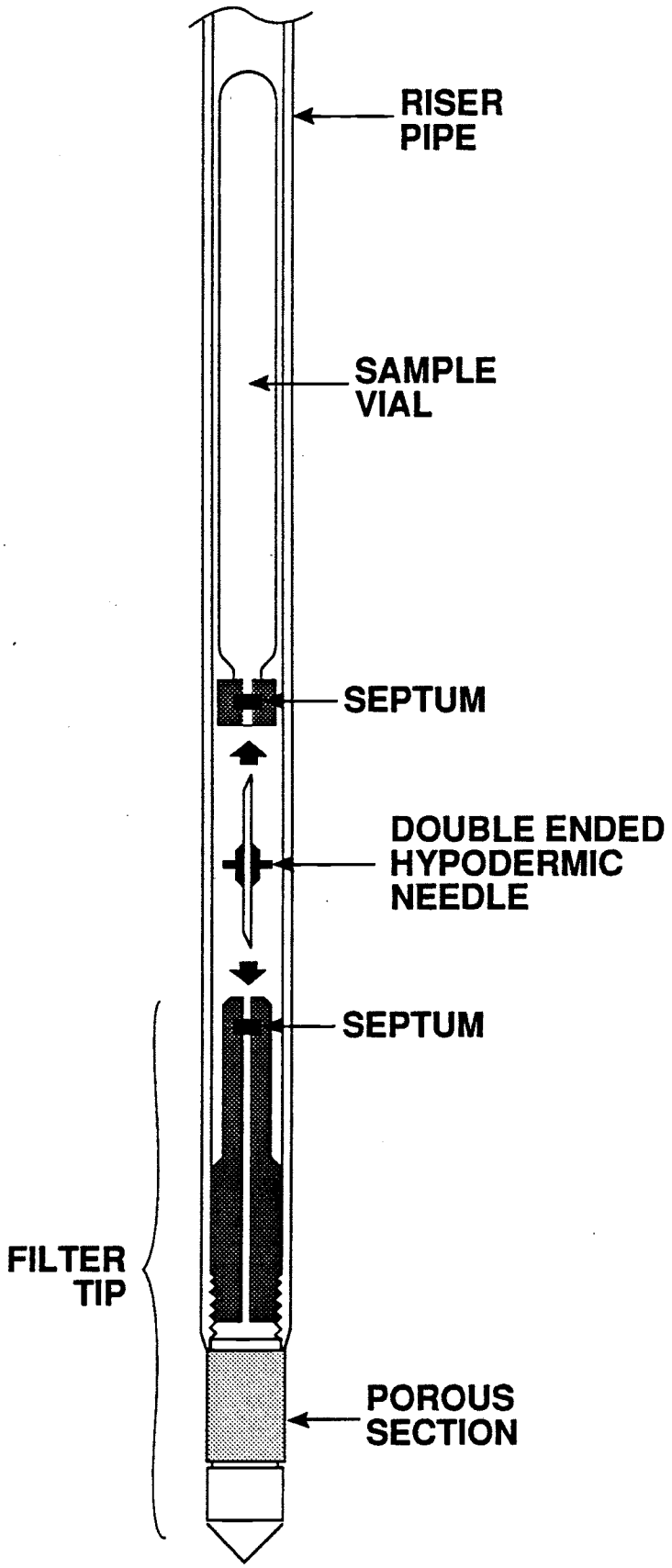


Figure 10 Filter tip sampler (BAT Envitech Inc., 1988)

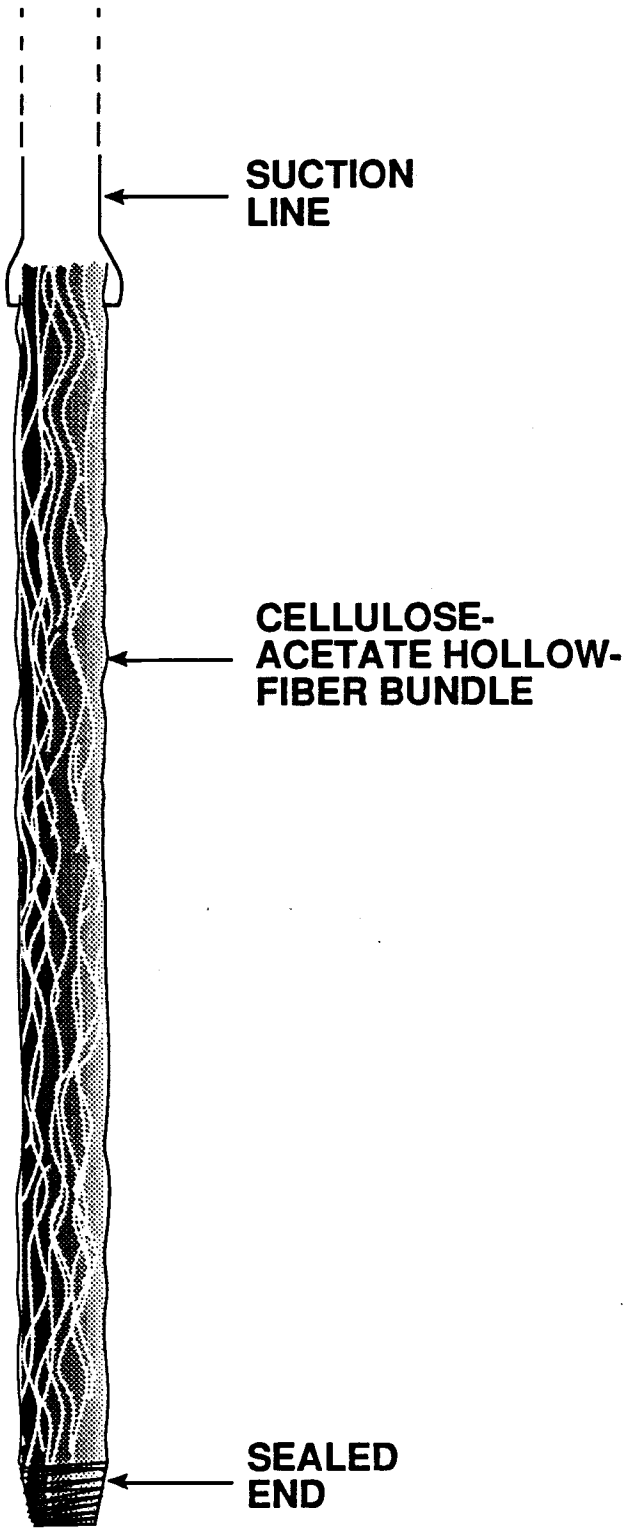
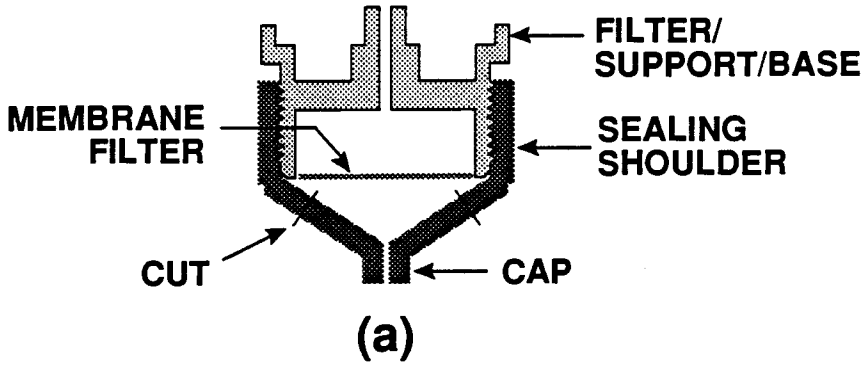


Figure 11. Cellulose-acetate hollow-fiber sampler



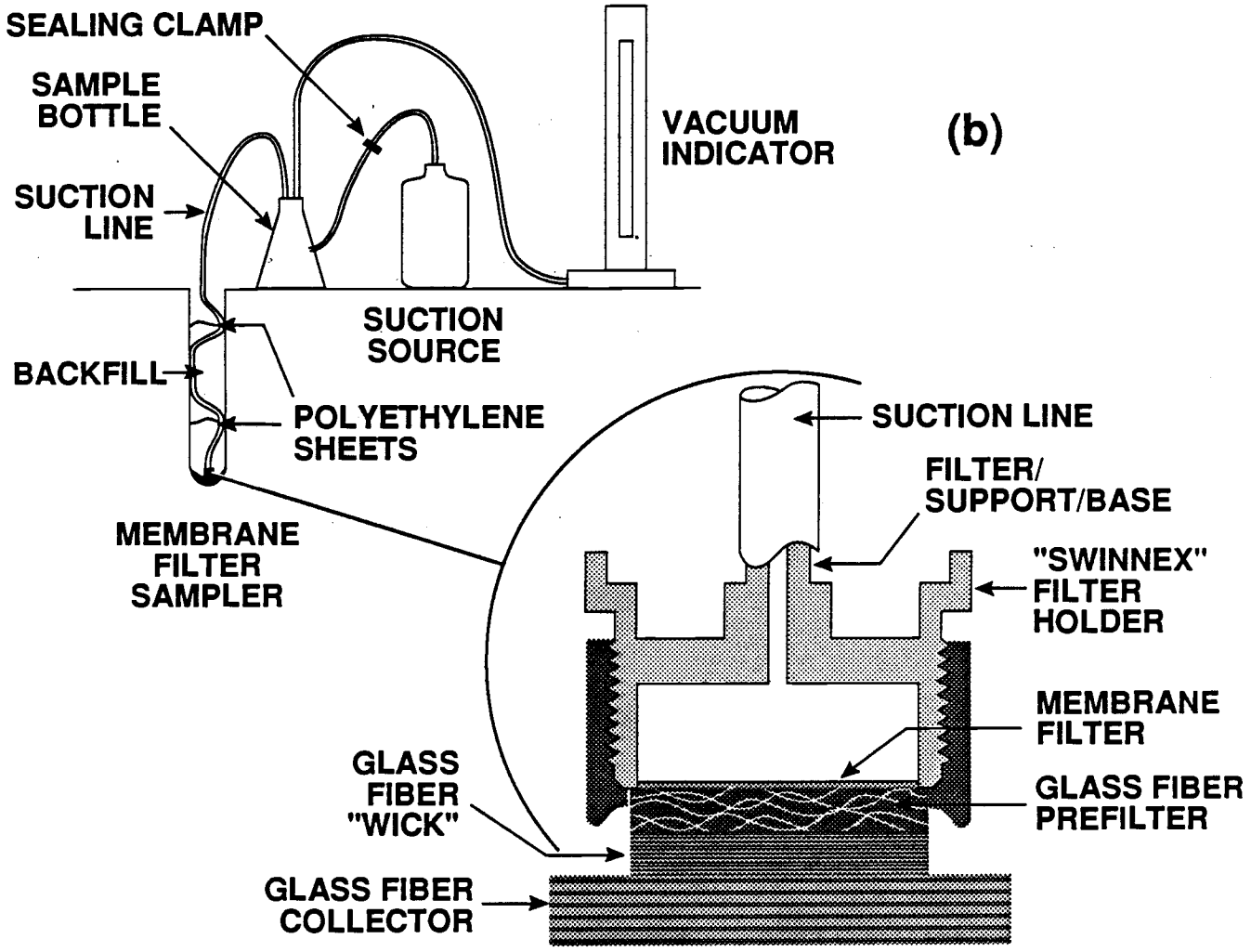


Figure 12 Membrane filter sampler (Stevenson, 1978)

a) Preparation of filter sampler

b) Installation of filter sampler

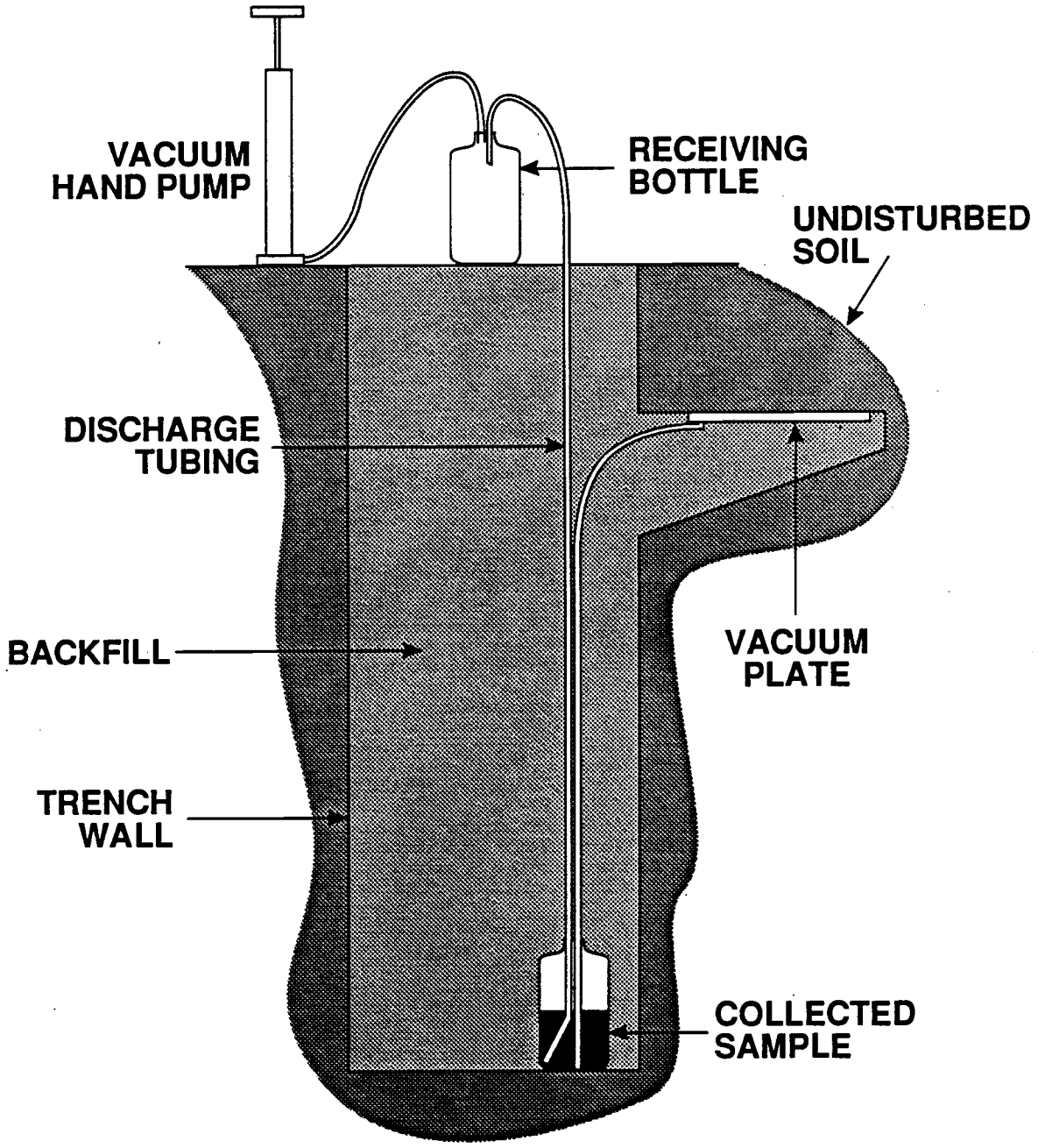


FIGURE 13 Vacuum plate sampler installation (after Cole, 1958)

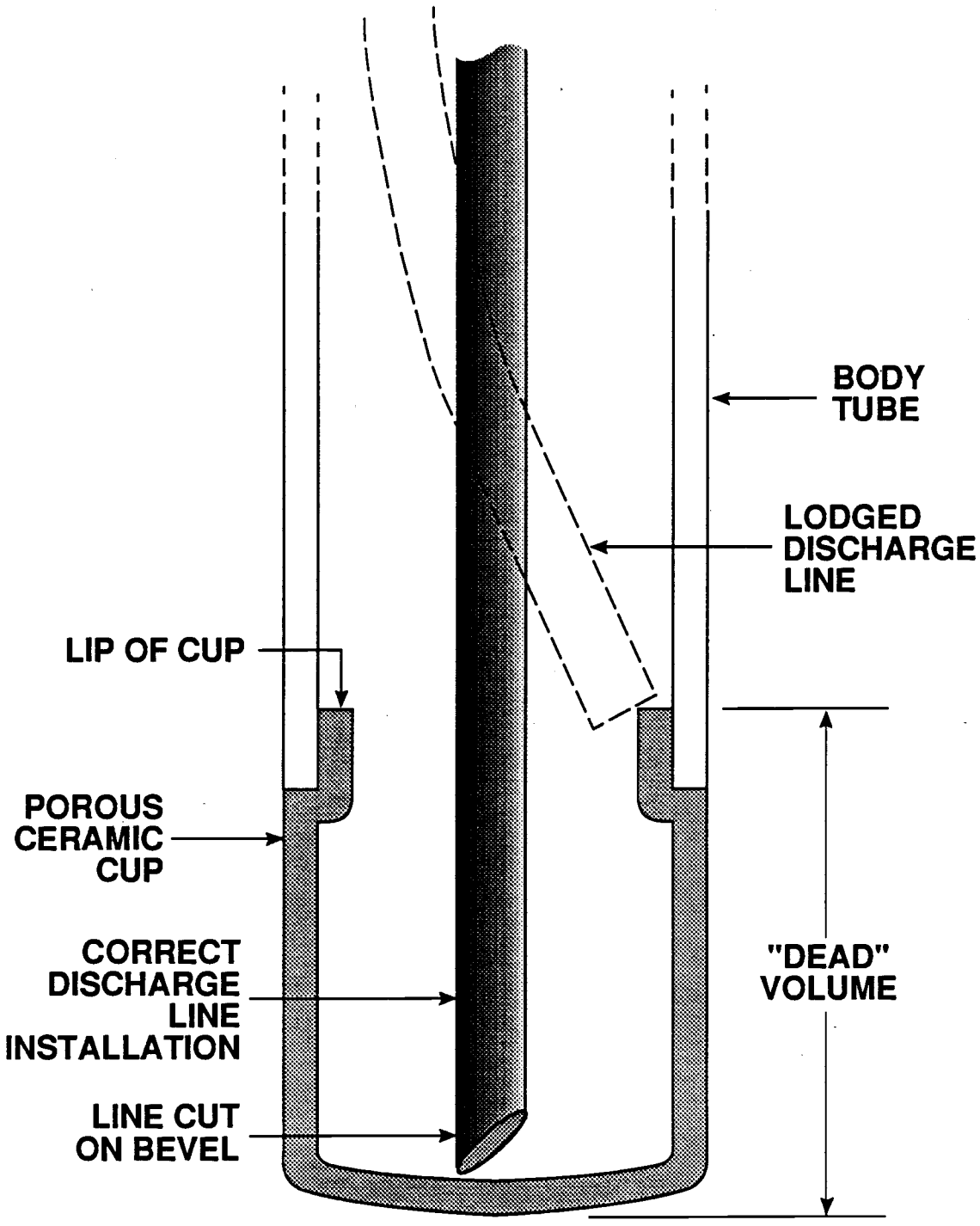


Figure 14 Location of potential dead volume in suction lysimeter (Everett and McMillin, 1985)

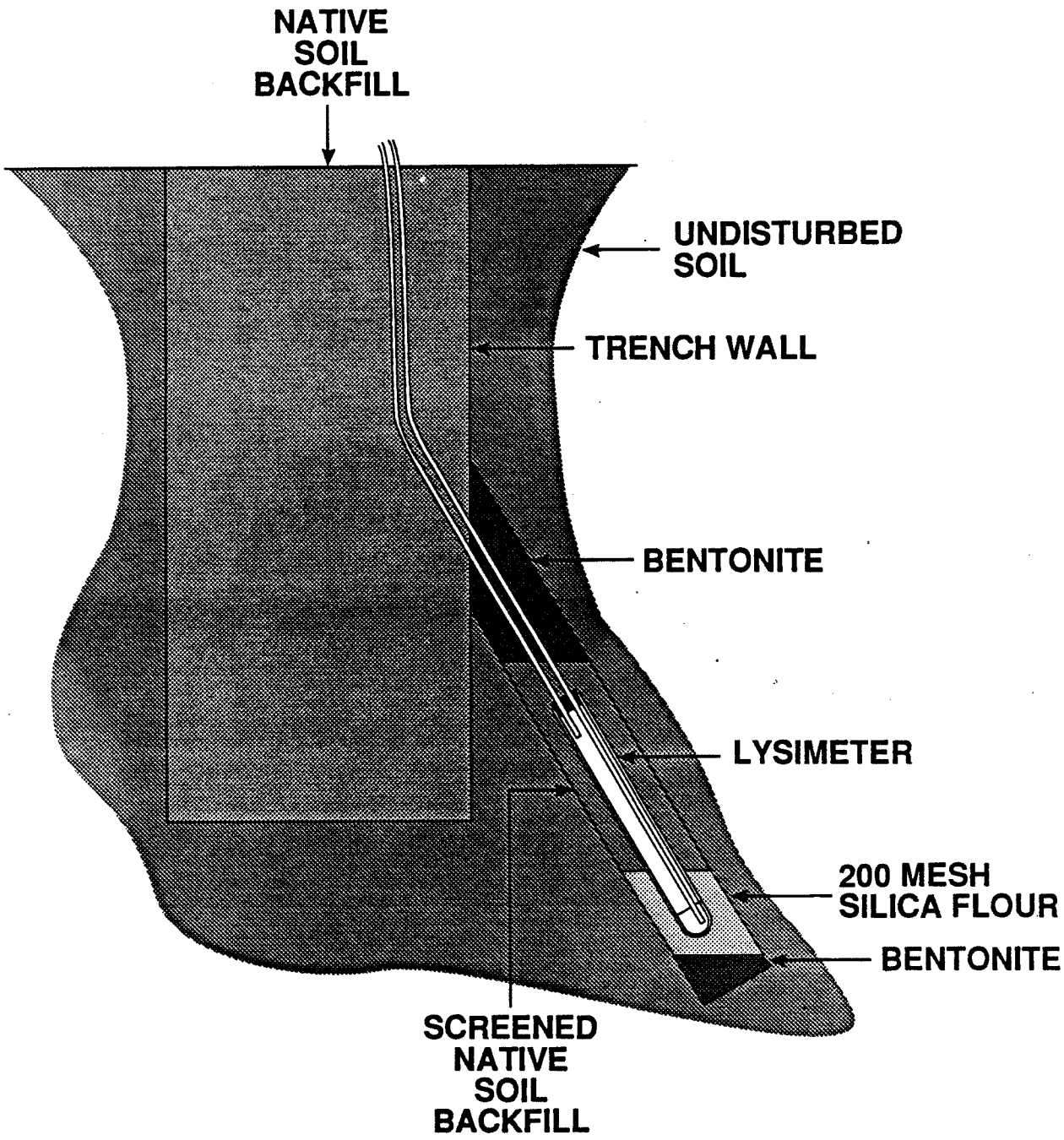


Figure 15 Pressure-vacuum lysimeter installation in the sidewall of a trench. (after EPA, 1986)

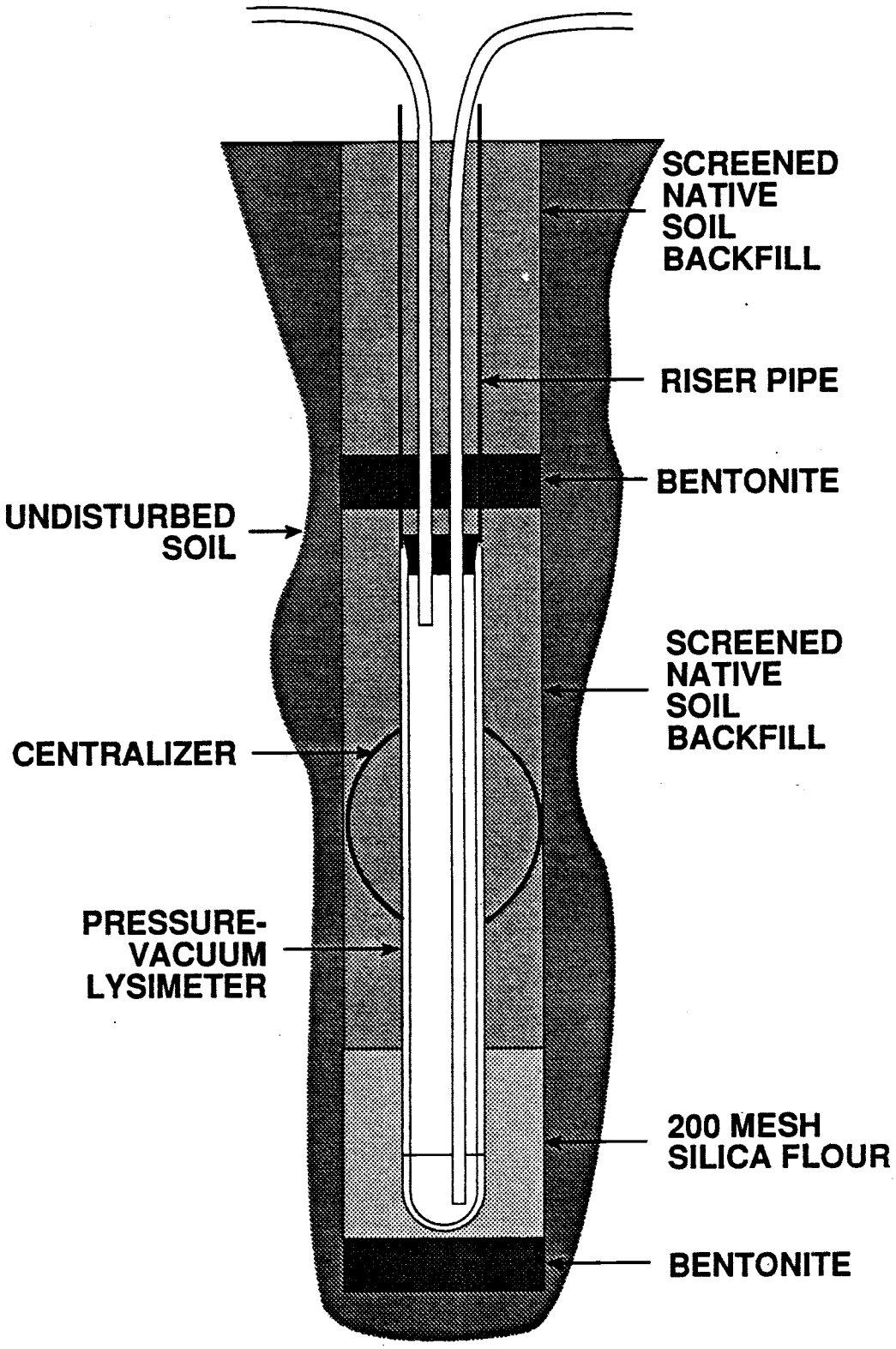


Figure 16 Pressure-vacuum lysimeter installation in a borehole

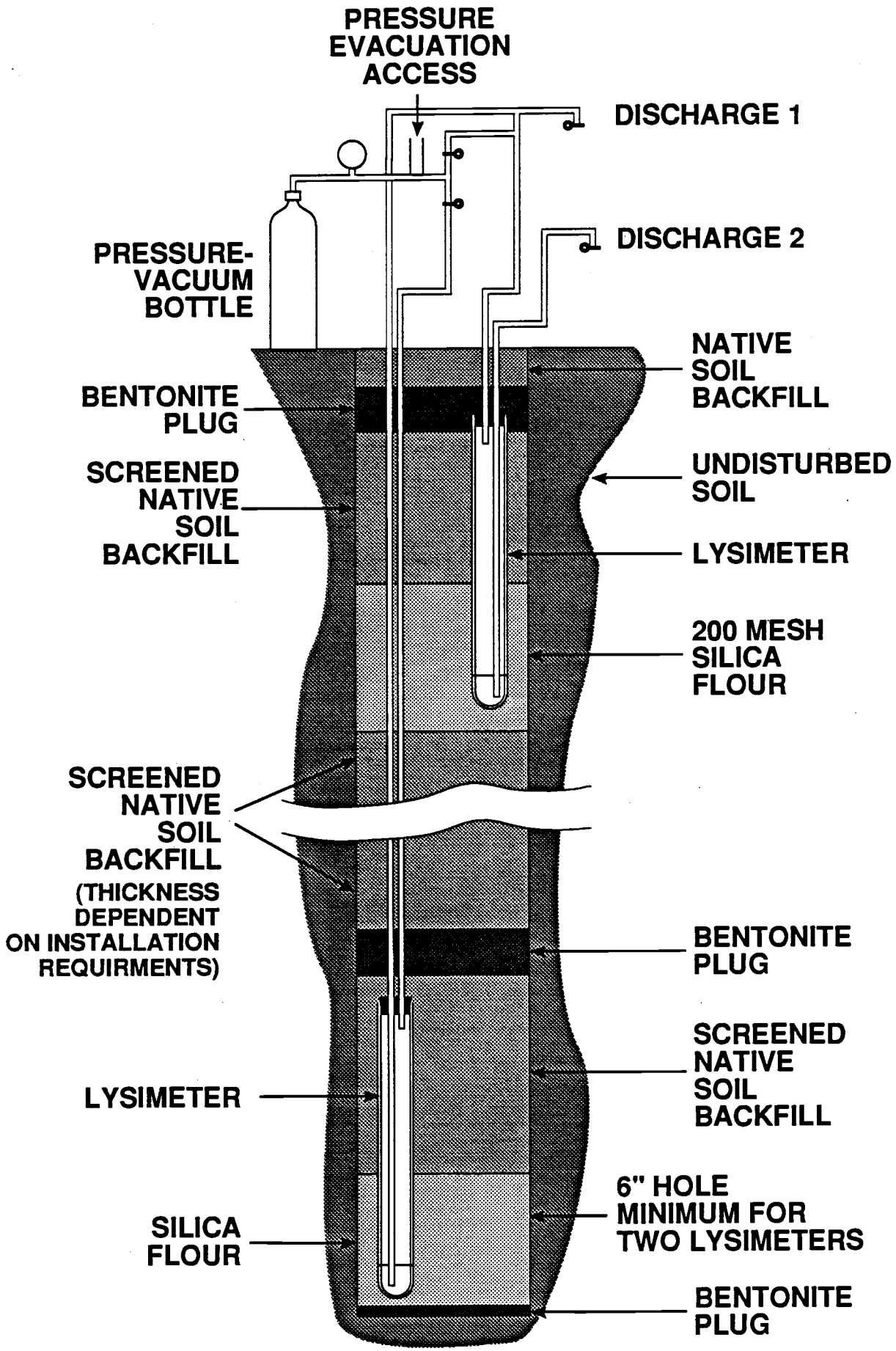


Figure 17 Multiple pressure-vacuum lysimeter installations in a borehole (after Hounslow et al, 1978)

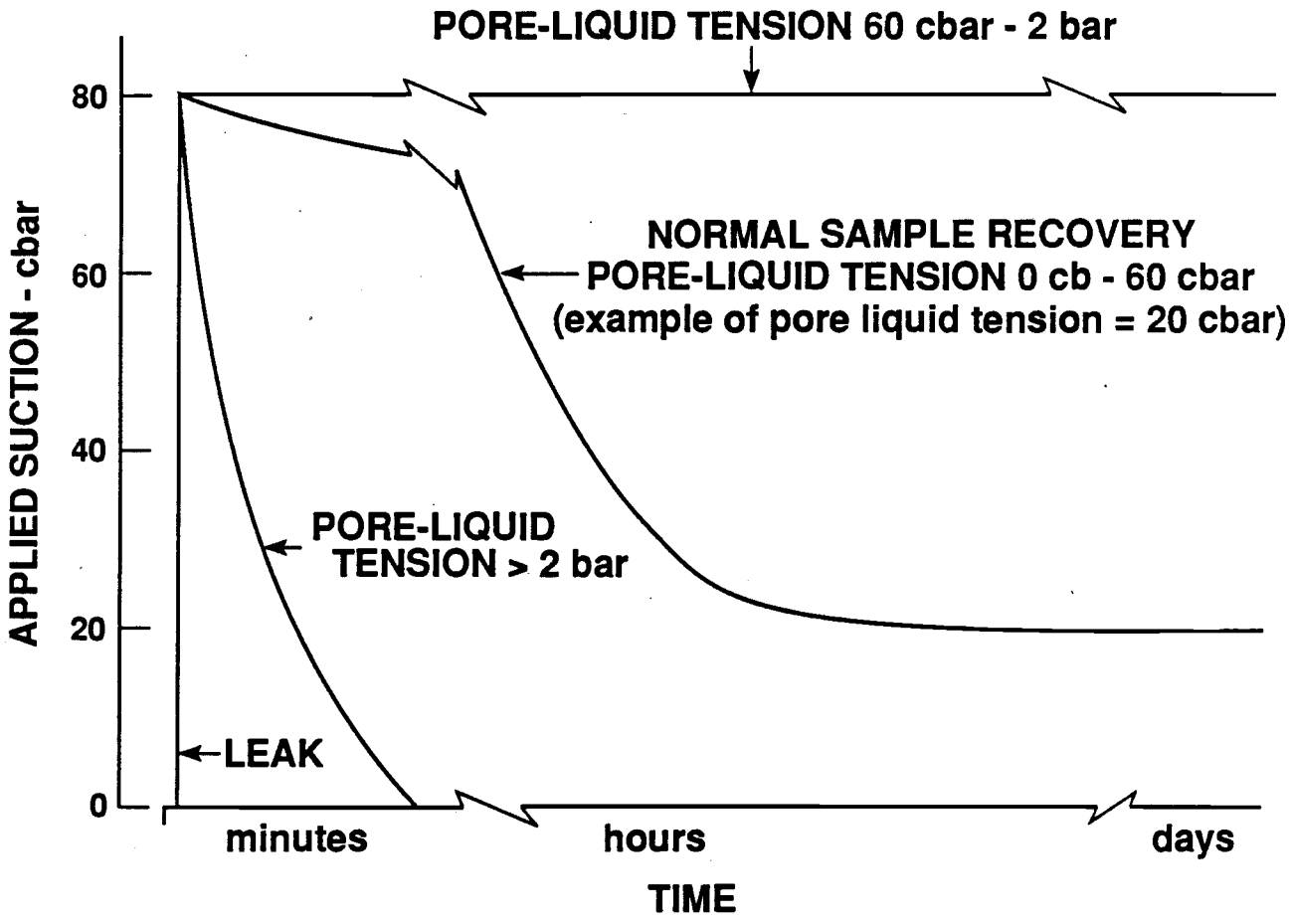


Figure 18 Decay characteristics of suction applied to a two bar (bubbling pressure) ceramic cup lysimeter in equilibrium with soils in varying ranges of pore-liquid tension. Also shown is the almost instantaneous decay associated with an appreciable leak in the instrument. (after Kaman Tempo, 1989).

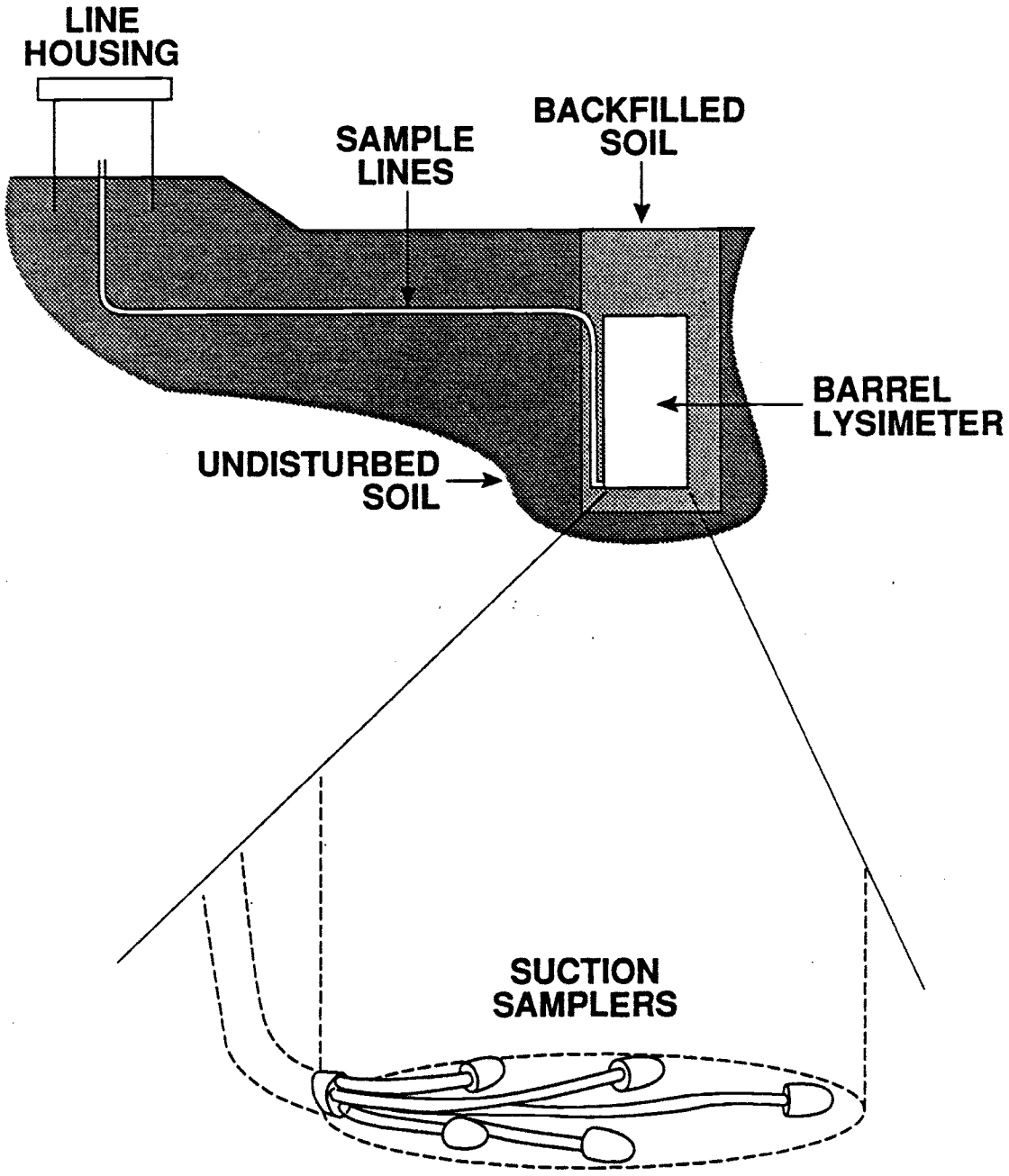


Figure 19 Barrel lysimeter (after Hornby et al,1986)

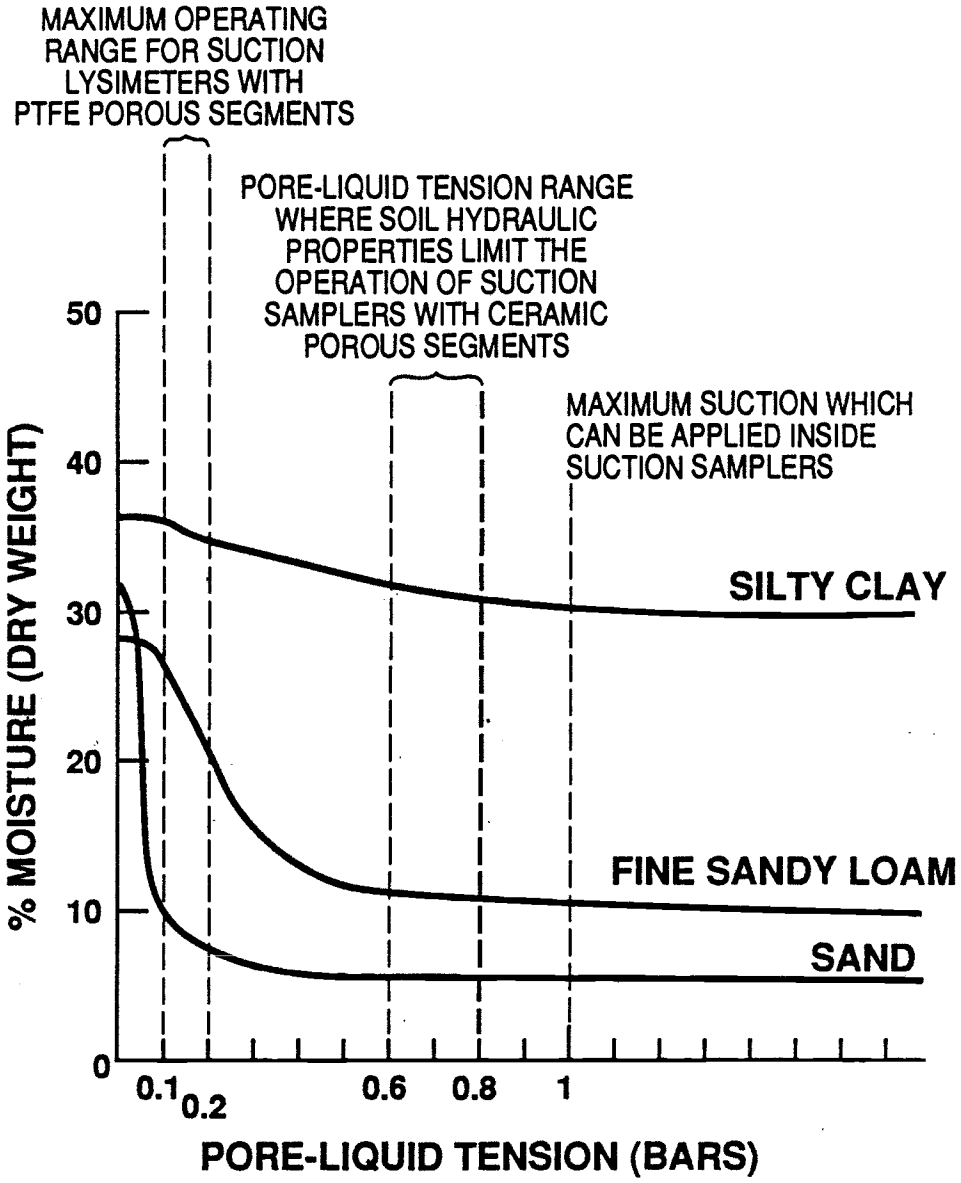


Figure 20 Water release curves for three soils, showing operating conditions for suction samplers (after Soilmoisture Equipment Corp., 1983)

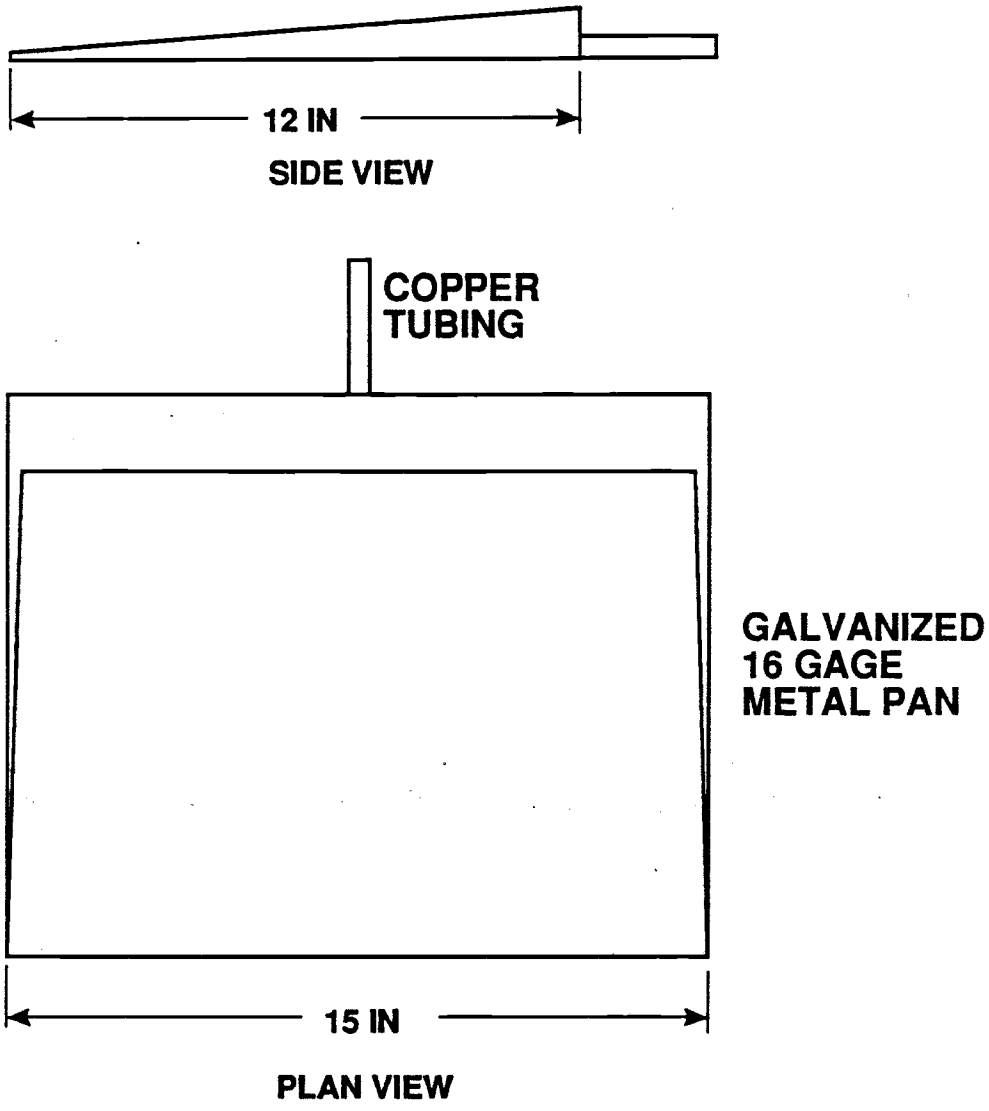


Figure 21 Example of a pan lysimeter (EPA, 1986)

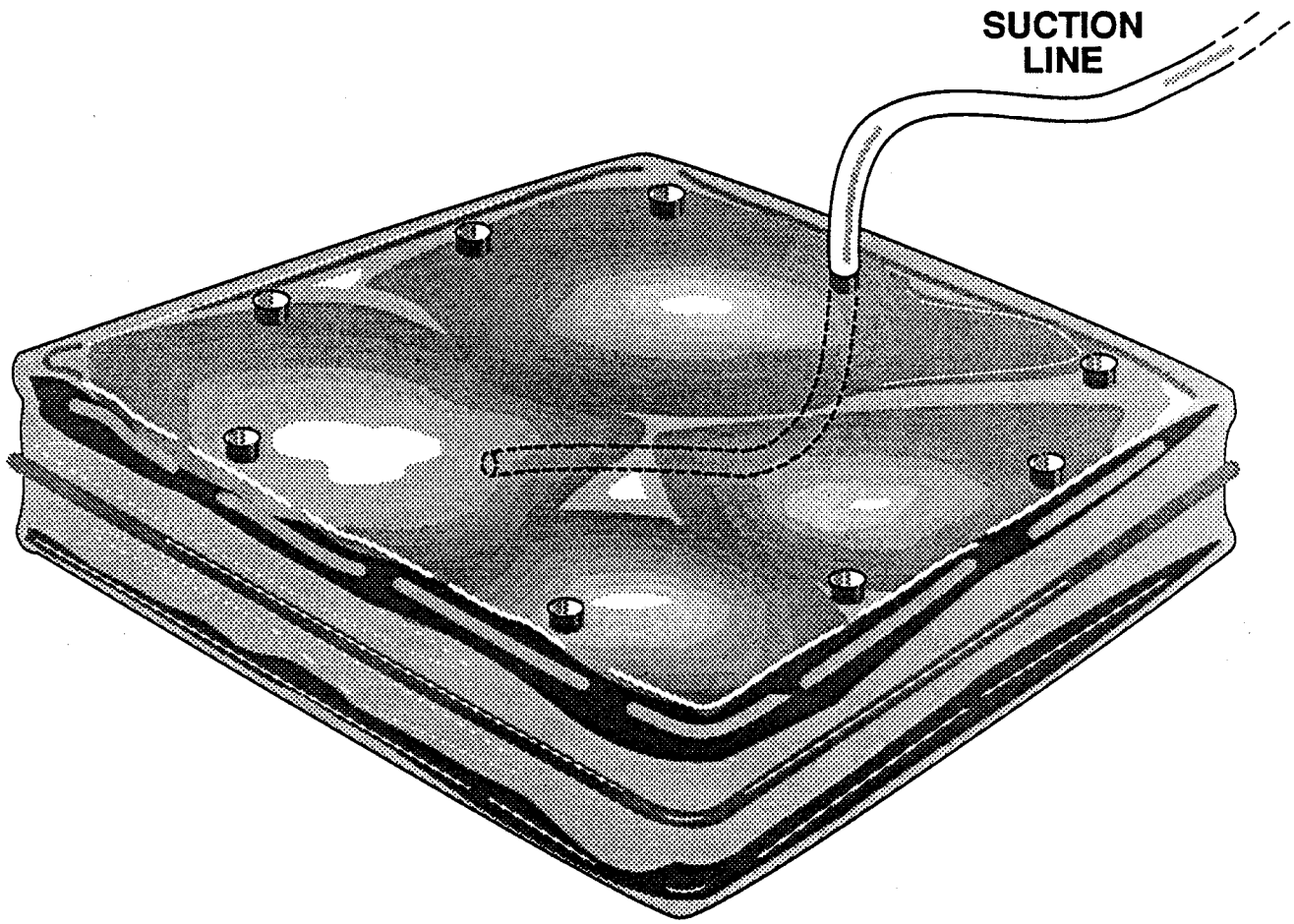


Figure 22 Glass block lysimeter (after EPA, 1986)

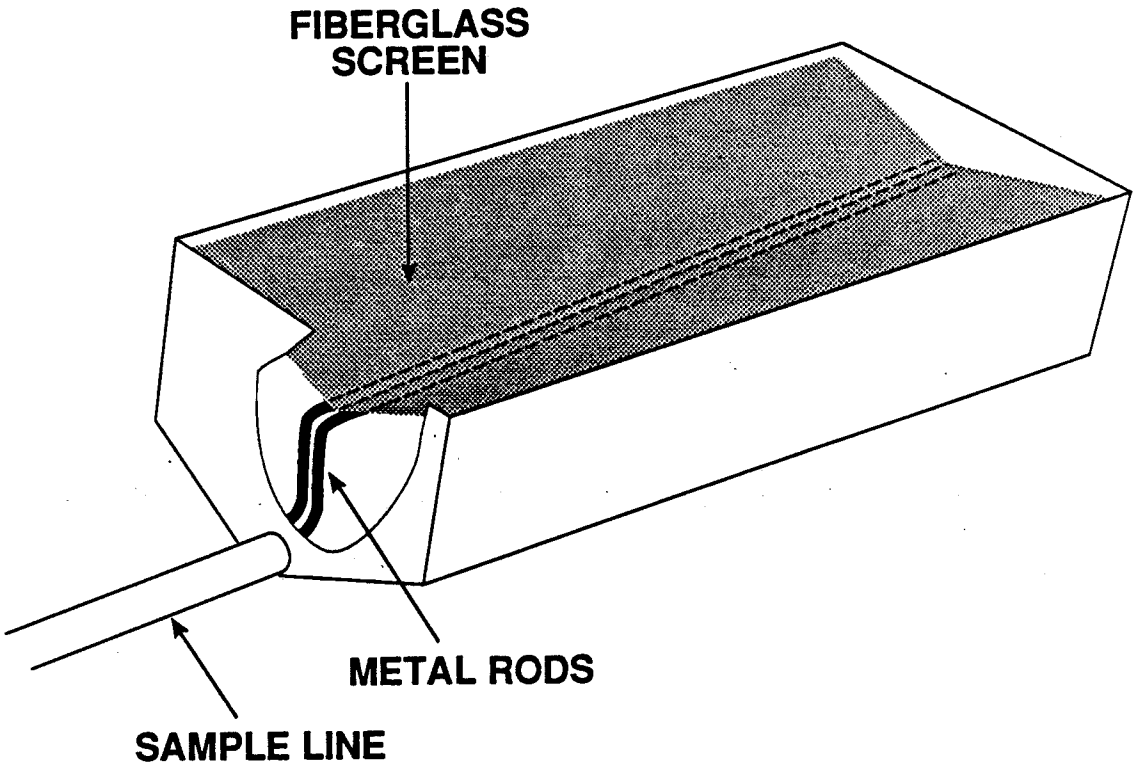


Figure 23 Trough lysimeter (after Jordan, 1968)

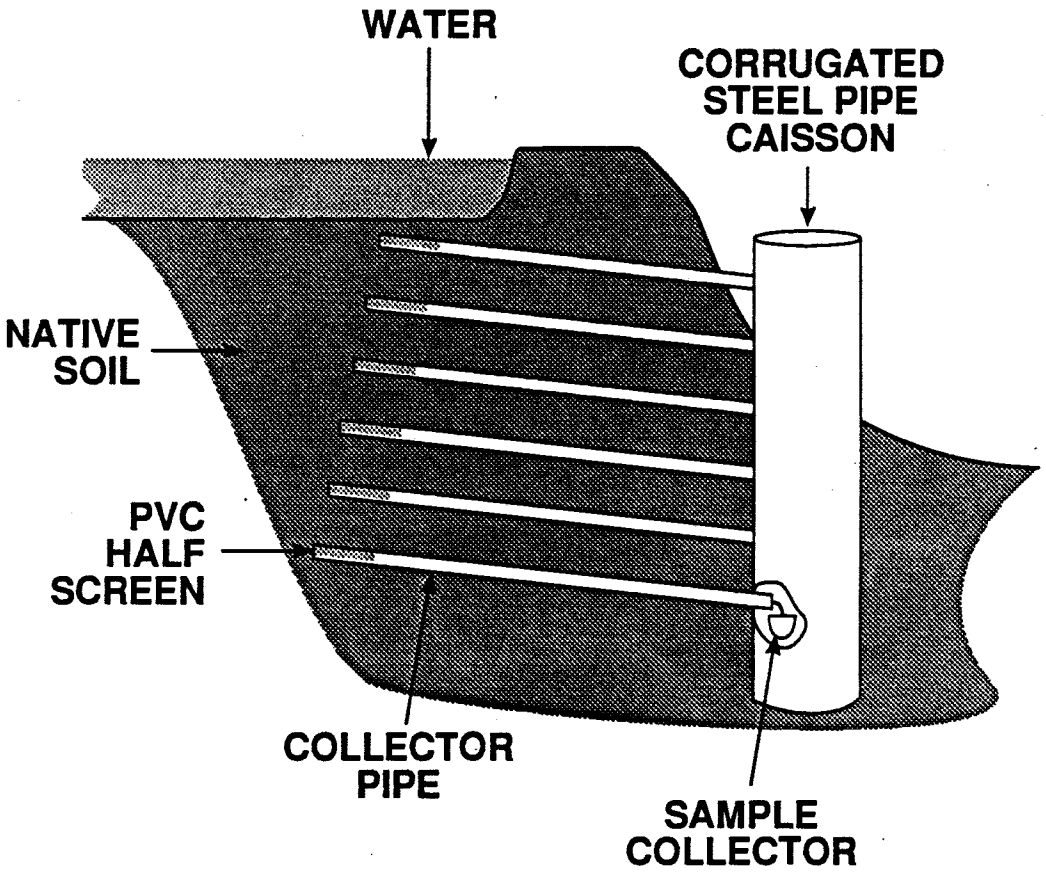


Figure 24 Example of a caisson lysimeter (Schmidt and Clements, 1978)

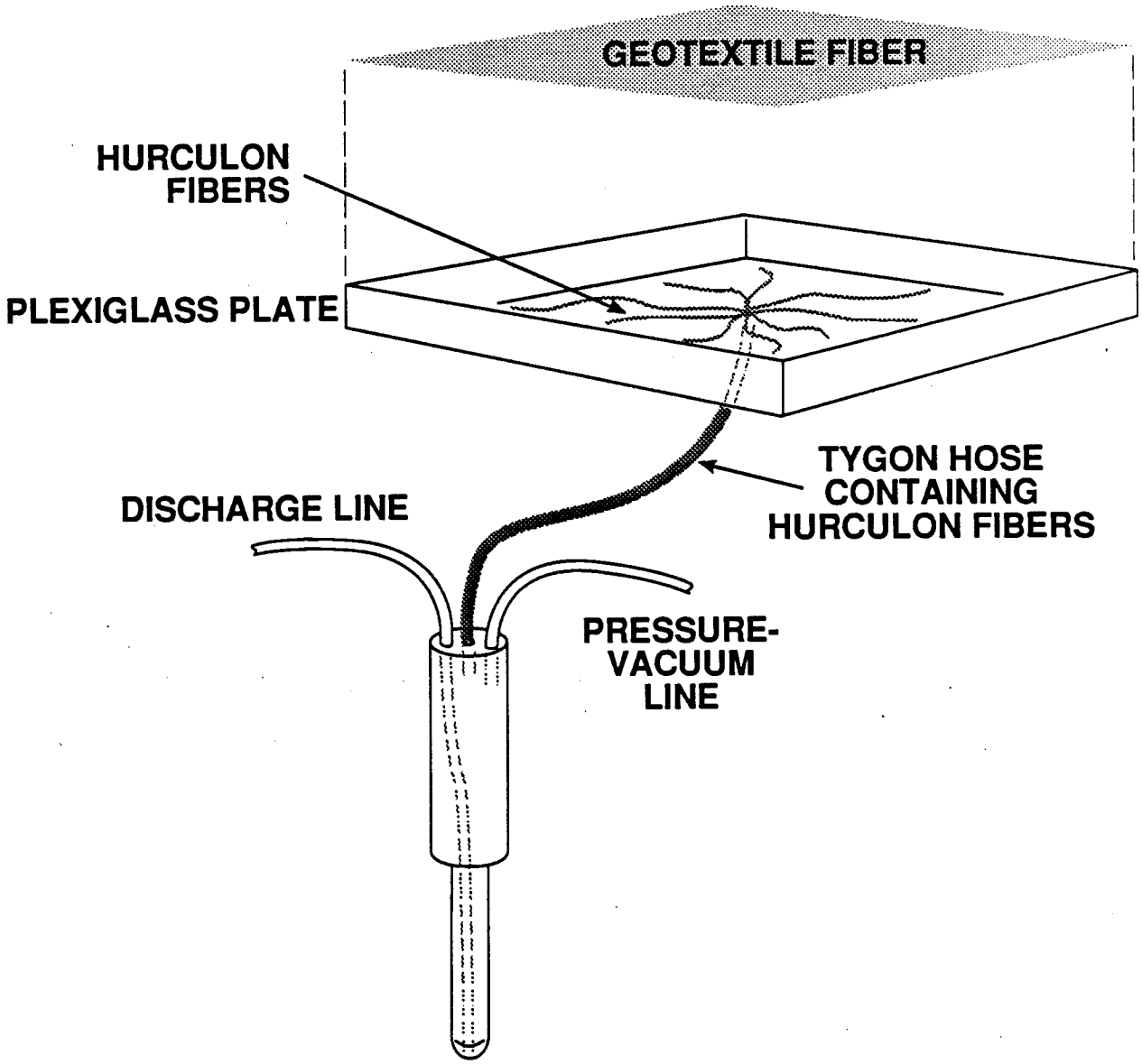


Figure 25 Wicking type soil pore-liquid sampler (Hornby et al, 1986)

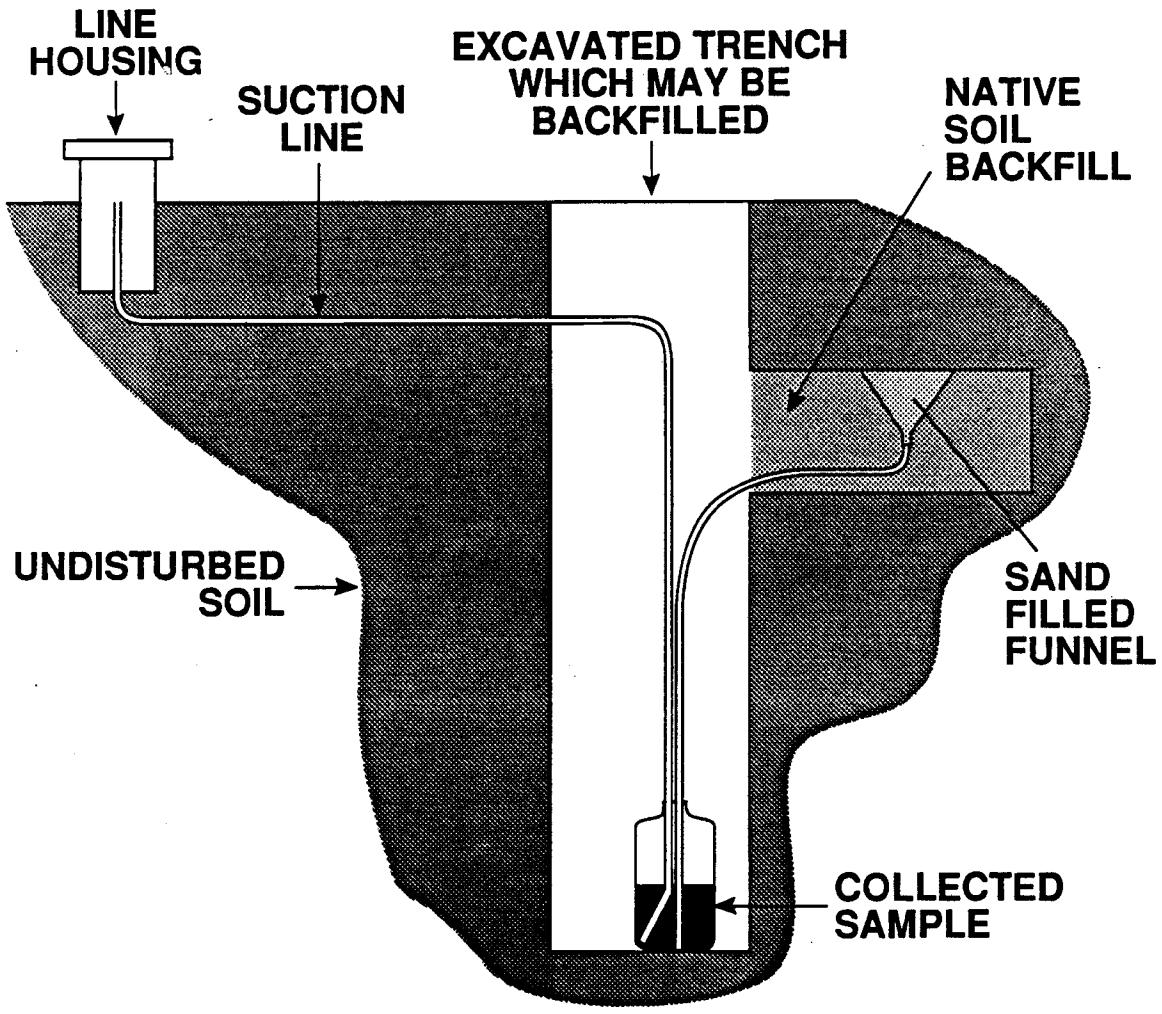


FIGURE 26 Sand filled funnel sampler installation (EPA, 1986)

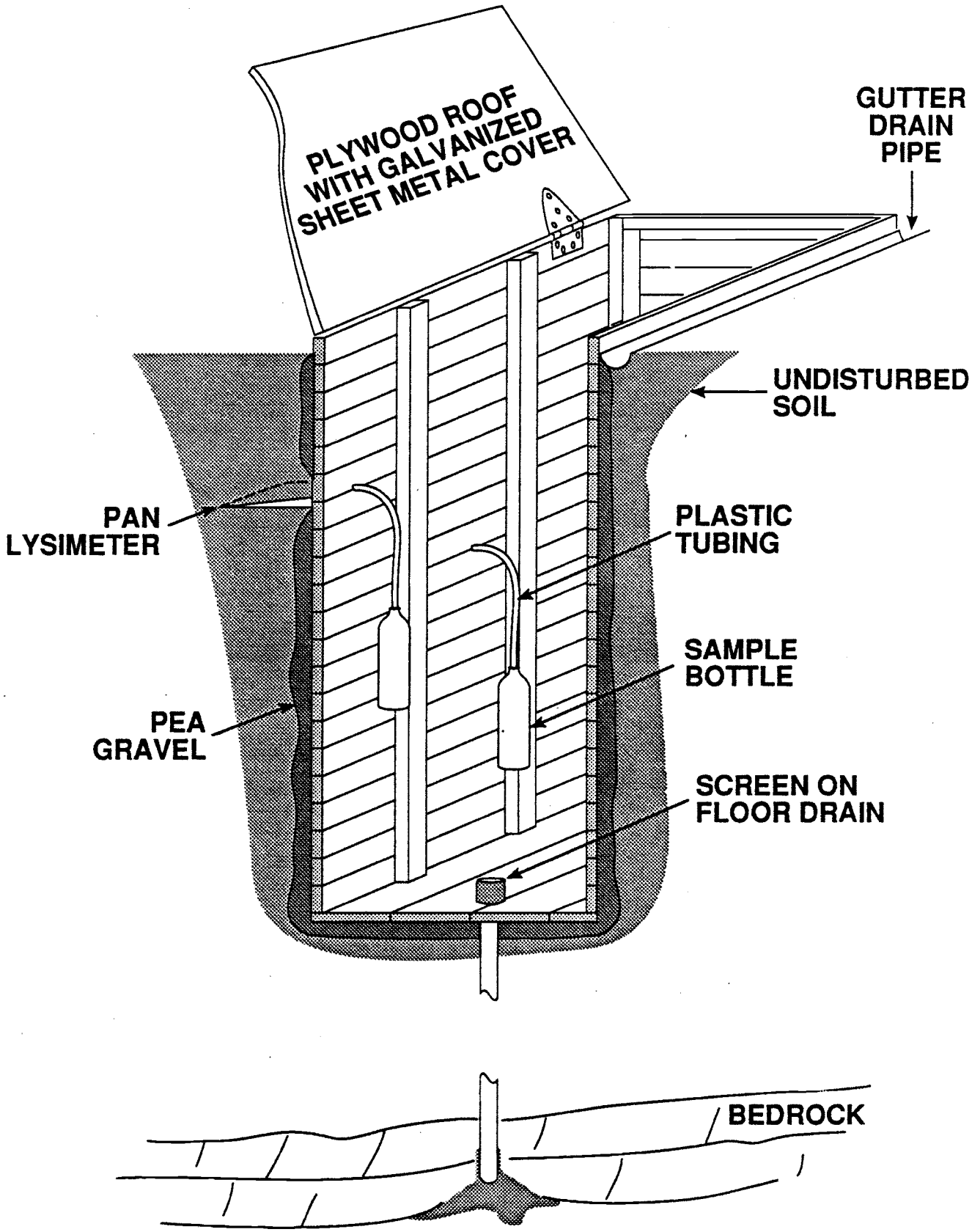


Figure 27 Example of pan lysimeter installation (after Parizek and Lane, 1970)

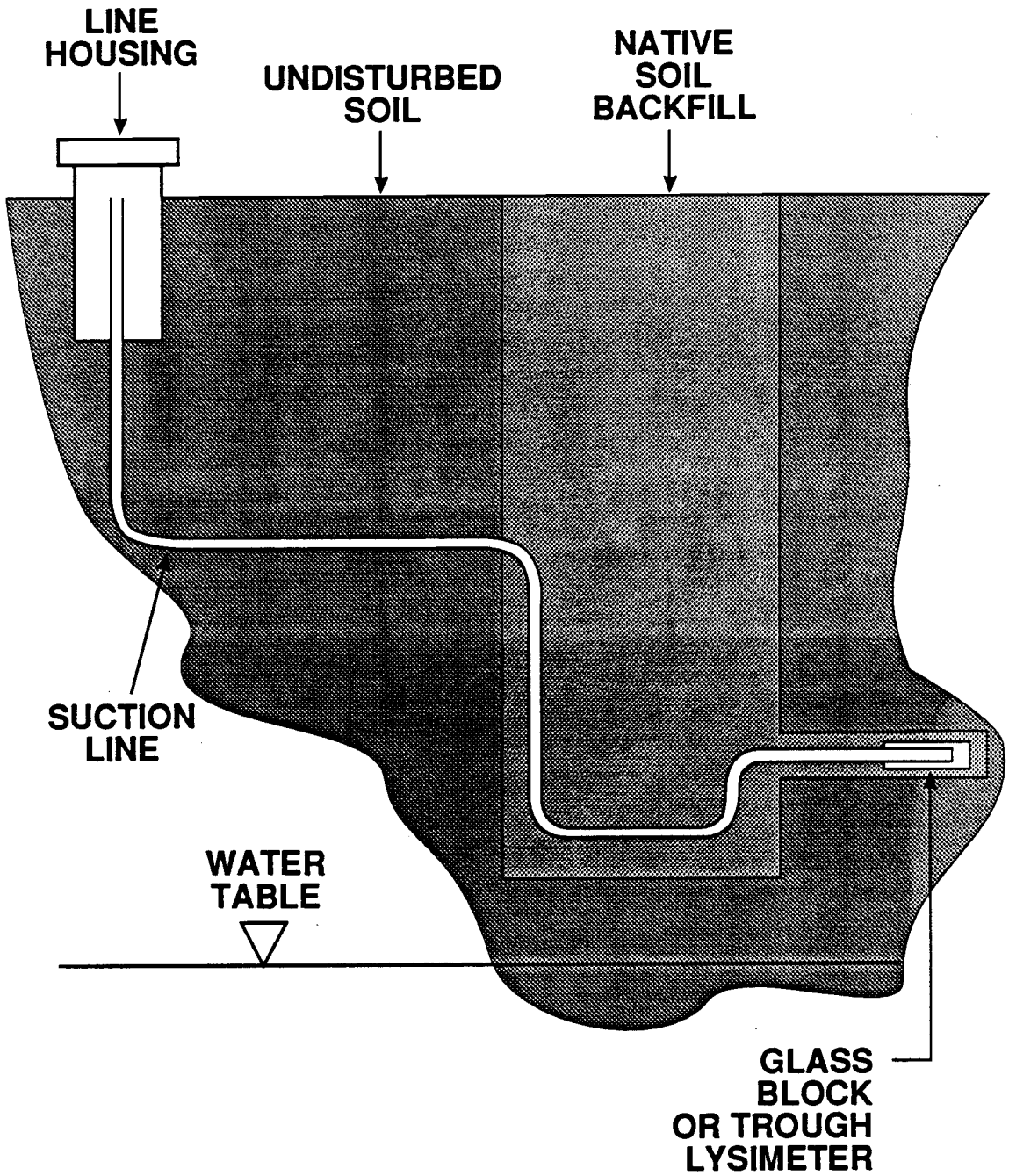


Figure 28 Example of glass block or trough lysimeter installation (EPA, 1986)

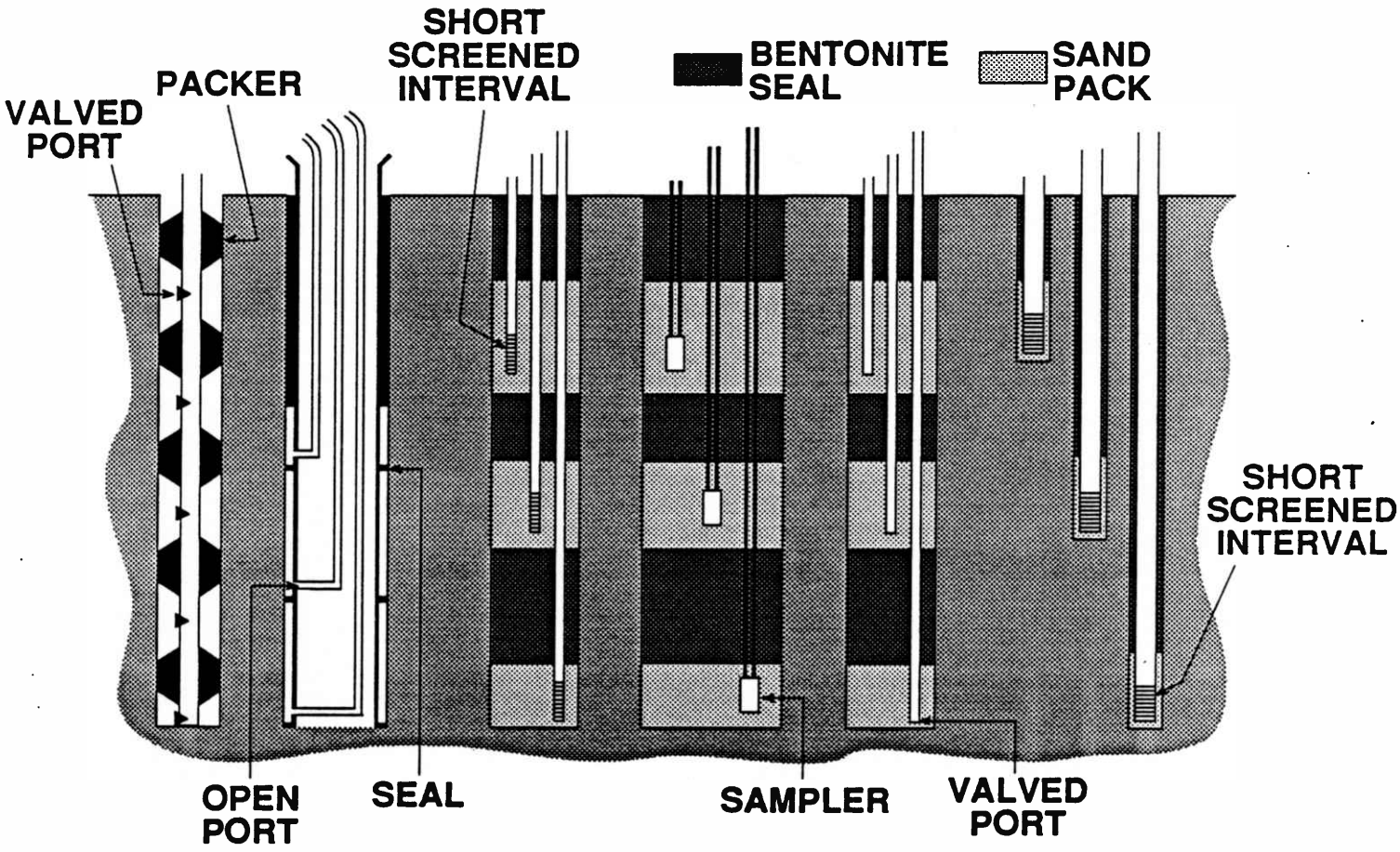


Figure 29 Examples of point sampling systems (after Patton and Smith, 1988)

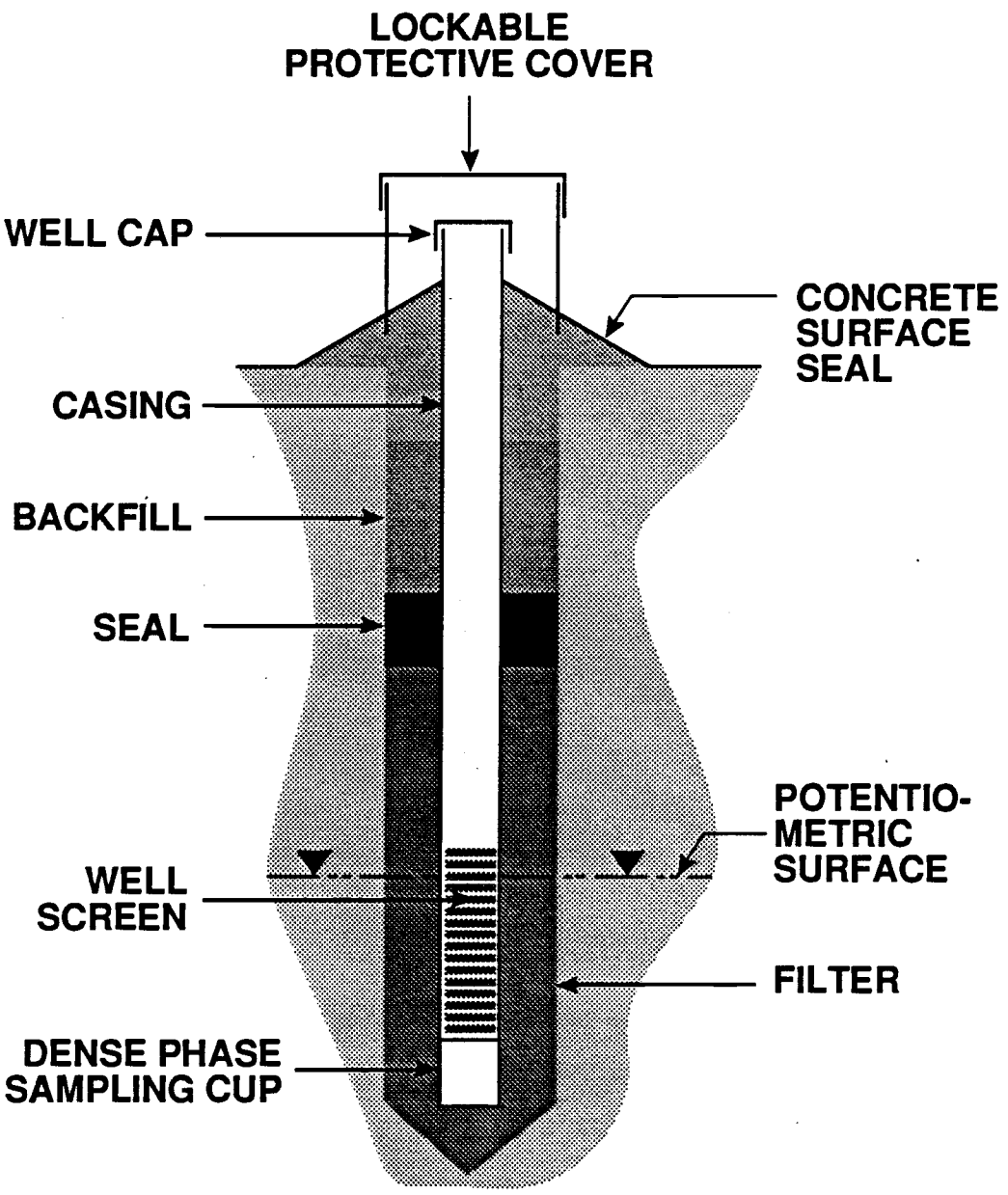


Figure 30 A monitoring well with the uppermost ground-water level intersecting the slotted well screen (after Riggs and Hatheway, 1988)

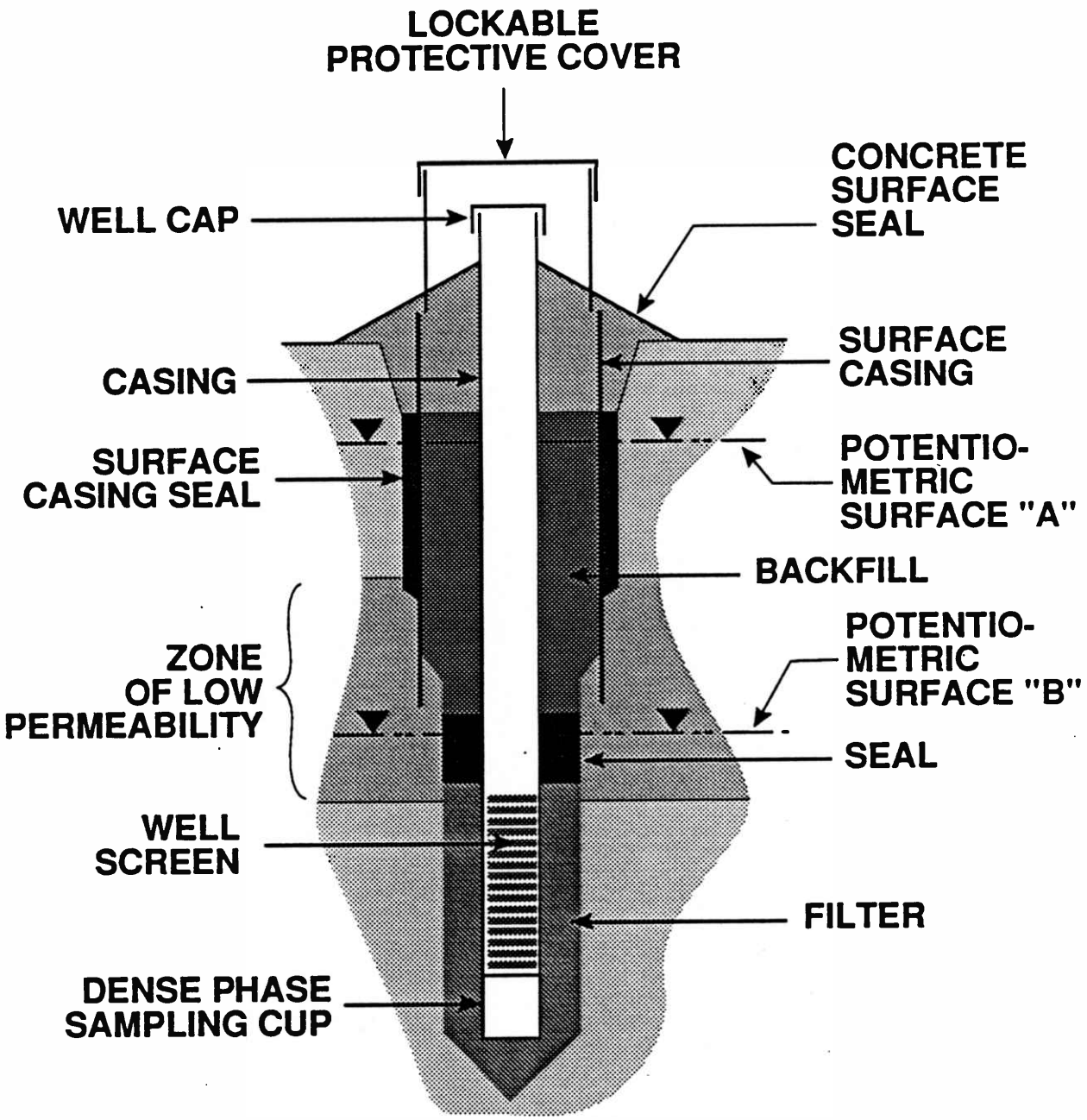


Figure 31 A monitoring well installed to sample from the lower of two ground-water zones (after Riggs and Hatheway, 1988)

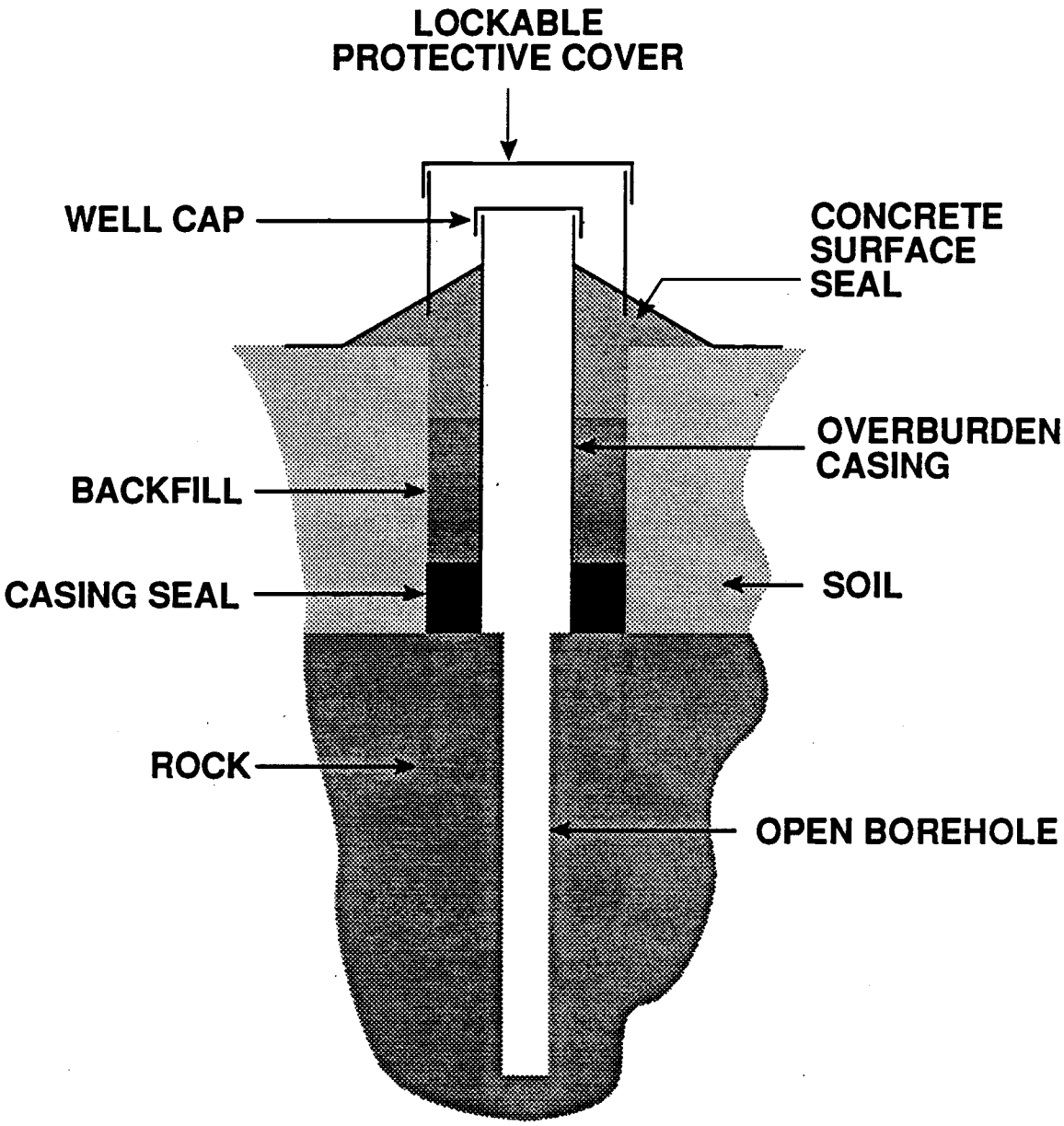


Figure 32 An open-hole ground-water monitoring well in rock (after Riggs and Hatheway, 1988)

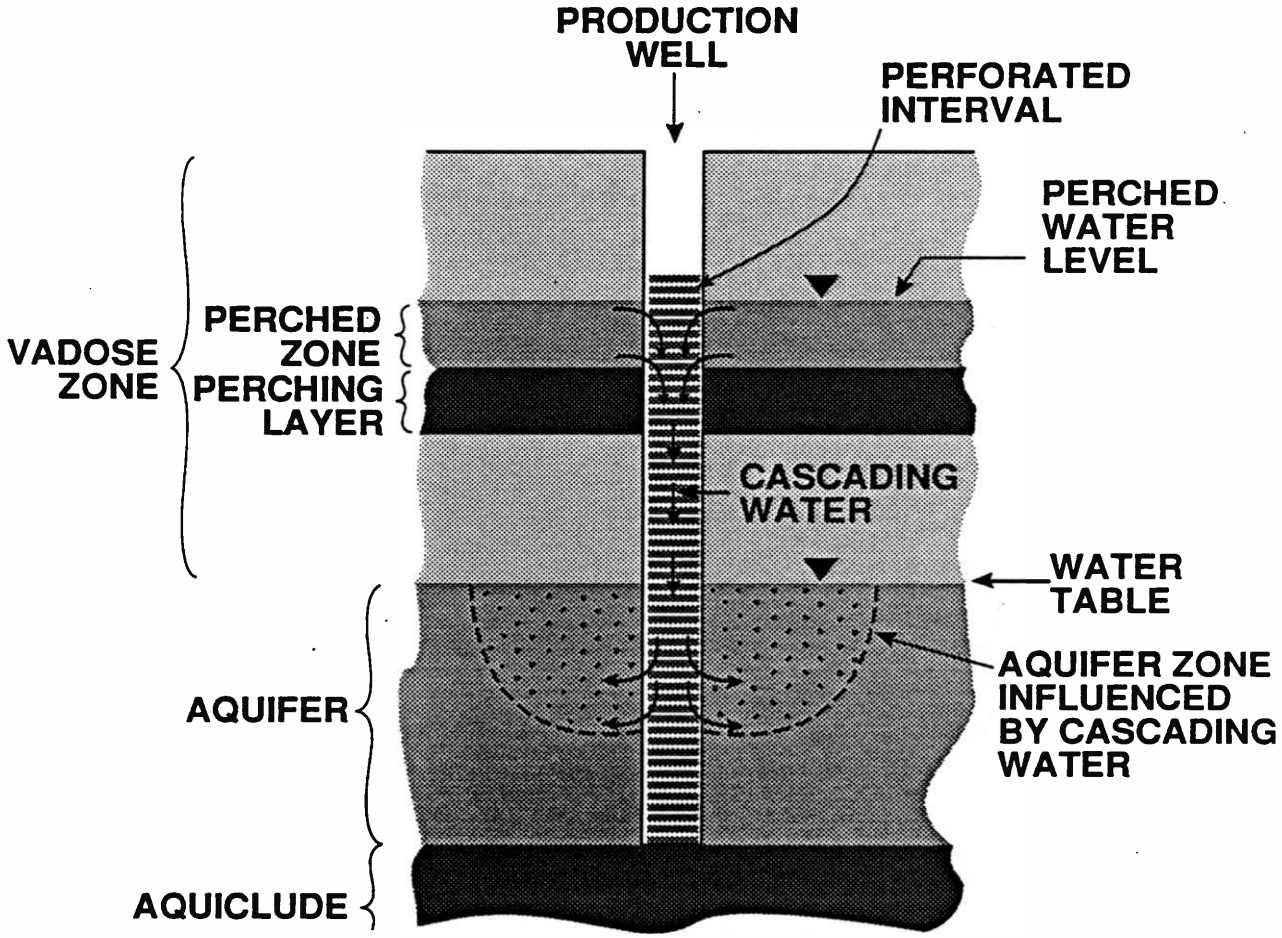


Figure 33 Conceptualized cross section of a well showing cascading water from perched zone (after Wilson and Schmidt, 1979)

References

(1) Morrison, Robert D., Ground Water Monitoring Technology, Timco MFG., Inc., Prairie DU Sac, Wisconsin, 1983.

(2) Wilson, L.G., Monitoring in the Vadose Zone: A Review of Technical Elements and Methods, U.S. Environmental Protection Agency, EPA-600/7-80-134, 1980

(3) Wilson, L.G., "The Fate of Pollutants in the Vadose Zone, Monitoring Methods and Case Studies", Thirteenth Biennial Conference on Ground Water, September 1981, 38 pp.

(4) Everett, L.G., "Monitoring in the Vadose Zone", Ground Water Monitoring Review, Summer 1981, pp. 44-51.

(5) Wilson, L.G., "Monitoring in the Vadose Zone: Part II", Ground Water Monitoring Review, Winter 1982, pp. 31-42.

(6) Everett, L.G., Wilson, L.G., and McMillion, L.G., "Vadose Zone Monitoring Concepts for Hazardous Waste Sites", Ground Water, Vol 20, May/June 1982, pp. 312-324.

(7) Wilson, L.G., "Monitoring in the Vadose Zone: Part III", Ground Water Monitoring Review, Winter 1983, pp. 155-165.

(8) Everett, Lorne G., Hoylman, Edward W., Wilson, L. Graham, and McMillion, Leslie G., "Constraints and Categories of Vadose Zone Monitoring Devices", Ground Water Monitoring Review, Winter 1984, pp. 26-32.

(9) Everett, L.G., Wilson, L.G., and Hoylman, E.W., Vadose Zone Monitoring Concepts for Hazardous Waste Sites, Noyes Data

Corporation, New Jersey, 1984.

(10) Robbins, Gary A. and Gemmell, Michael M., "Factors Requiring Resolution in Installing Vadose Zone Monitoring Systems", Ground Water Monitoring Review, Summer 1985, pp. 75-80.

(11) Merry, W.M. and Palmer, C.M., "Installation and Performance of a Vadose Monitoring System", Proceedings of the NWWA Conference on Characterization and Monitoring of the Vadose Zone, NWWA, 1986, pp. 107-125.

(12) Environmental Monitoring Systems Laboratory, Permit Guidance Manual on Unsaturated Zone Monitoring for Hazardous Waste Land Treatment Units, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, EPA/530-SW-86-040, October 1986, 111 pp.

(13) Ball, John and Coley, David M., "A Comparison of Vadose Monitoring Procedures", Proceedings of the Sixth National Symposium and Exposition on Aquifer Restoration and Groundwater Monitoring, NWWA/EPA, 1986, pp. 52-61.

(14) Wilson, L.G., "Methods for Sampling Fluids in the Vadose Zone", Proceedings of ASTM, 1988,

(15) Bond, William R. and Rouse, Jim V., "Lysimeters Allow Quicker Monitoring of Heap Leaching and Tailing Sites", Mining Engineering, April 1985, pp. 314-319.

(16) Doanhue, Miller, and Shickluna, Soils - An Introduction to Soils and Plant Growth, 1977.

(17) Johnson, Thomas. M, and Cartwright, Keros, Monitoring of Leachate Migration in the Unsaturated Zone in the Vicinity of Sanitary Landfills, State Geological Survey Circular 514, Urbana, Illinois, 1980.

(18) Sales Division, Catalog of Products, Soilmoisture Equipment Corp., Santa Barbara, California, 1988.

(19) Sales Division, Timco Lysimeters, Timco Mfg. Inc., Prairie DU Sac, Wisconsin, 1988.

(20) Hansen, Edward A. and Harris, Alfred Ray, "Validity of Soil-Water Samples Collected with Porous Ceramic Cups", Soil Science Society of America Proceedings, Vol 39, 1975, pp. 528-536.

(21) Quin, B.F. and Forsythe, L.J., "All-Plastic Suction Lysimeters for the Rapid Sampling of Percolating Soil Water", New Zealand Journal of Science, Vol 19, 1976, pp. 145-148.

(22) Long, F. Leslie, "A Glass Filter Soil Solution Sampler", Soil Science Society of America Journal, Vol 42, 1978, pp. 834-835.

(23) Starr, Michael R., "Variation in the Quality of Tension Lysimeter Soil Water Samples from a Finnish Forest Soil", Soil Science, Vol 140, December 1985, pp. 453-461.

(24) Sales Division, Catalog of Products, Mott Metallurgical Corp., Farmington, Conn., 1988.

(25) Smith, C.N. and Carsel, R.F., "A Stainless-Steel Soil Solution Sampler for Monitoring Pesticides in the Vadose Zone", Soil Science Society of America Journal, Vol 50, 1986, pp. 263-265.

(26) Parizek, Richard R. and Lane, "Soil-Water Sampling Using Pan and Deep Pressure-Vacuum Lysimeters", Journal of Hydrology, Vol 11, 1970, pp. 1-21.

(27) Trainor, David P., The Relationship Between Two Laboratory Leaching Procedures and Leachate Quality at Foundry Waste Landfills, M.S. Thesis/Independent Report, Dept. of Civil and Environmental Engineering, The University of Wisconsin, Madison, Wisconsin, February, 1983.

(28) Young, Mark, "Use of Suction Lysimeters for Monitoring in the Landfill Liner Zone", Proceedings of Monitoring Hazardous Waste Sites, Geotechnical Engineering Division, American Society of Civil Engineers, Detroit, Mich., October, 1985.

(29) Morrison, R.D., and Tsai, T.C., Modified Vacuum-Pressure Lysimeter for Vadose Zone Sampling, Calscience Research Inc., Huntington Beach, California, 1981.

(30) Morrison, Robert and Szecsody, James, "Sleeve and Casing Lysimeters for Soil Pore Water Sampling", Soil Science, Vol 139, May 1985, pp. 446-451.

(31) Nightingale, H.I., Harrison, Doug, and Salo, John E., "An Evaluation Technique for Ground Water Quality Beneath Urban Runoff Retention and Percolation Basins", Ground Water Monitoring Review, Vol 5, Winter 1985, pp. 43-50.

(32) Torstensson, B.A., and Petsonk, A.M., " A Hermetically Isolated Sampling Method for Ground Water Investigations",

Proceeding of ASTM Symposium for Ground Water Contamination Studies and Their Standardization, ASTM, February, 1986.

(32) Knighton, M. Dean and Streblow, Dwight E., "A More Versatile Soil Water Sampler", Soil Science Society of America Journal, Vol 45, 1981, pp. 158-159.

(33) Jackson, D.R., Brinkley, F.S., and Bondietti, E.A., "Extraction of Soil Water Using Cellulose-Acetate Hollow Fibers", Soil Science Society of America Journal, Vol 40, 1976, pp. 327-329.

(34) Levin, M.J. and Jackson, D.R., "A Comparison of In Situ Extractors for Sampling Soil Water", Soil Science Society of America Journal, Vol 41, 1977, pp. 535-536.

(35) Stevenson, Craig D., "Simple Apparatus for Monitoring Land Disposal Systems by Sampling Percolating Soil Waters", Environmental Science and Technology, Vol 12, March 1978, pp. 329-331.

(36) Wagemann, R., and Graham, B., "Membrane and Glass Fibre Filter Contamination in Chemical Analysis of Fresh Water", Water Research, Vol 8, 1974, pp. 407-412.

(37) Sales Division, Catalog of Products, Cole-Parmer Instrument Company, 1988.

(38) Sales Division, Catalog of Products, Corning Glass Works, New York, 1988.

(39) Duke, H., Kruse, E., and Hutchinson, G., "An Automatic Vacuum Lysimeter for Monitoring Percolation Rates", USDA Agricultural

Research Service, ARS, pp. 41-165, 1970.

(40) Tanner, C.B., Bourget, S.J., and Holmes, W.E., "Moisture Tension Plates Constructed from Alundum Filter Discs", Soil Science Society of America Proceedings, Vol 18, 1954, pp. 222-223.

(41) Cole, D.W., "Alundum Tension Lysimeter", Soil Science, Vol 85, June 1958, pp. 293-296.

(42) Cole, D., Gessell, S., and Held, E.," Tension Lysimeter Studies of Ion and Moisture Movement in Glacial Till and Coral Atoll Sites", Soil Science Society of America Proceedings, v. 25, 1968, pp. 321-325.

(43) Nielson, D., and Phillips, R.," Small Fritted Glass Bead Plates For Determination of Moisture Retention", Soil Science Society of America Proceedings, v.22, 1958, pp.574-575.

(44) Chow, T.L., "Fritted Glass Bead Materials as Tensiometers and Tension Plates", Soil Science Society of America Journal, Vol 41, 1977, pp. 19-22.

(45) Everett, Lorne and McMillion, Leslie G., "Operational Ranges for Suction Lysimeters", Ground Water Monitoring Review, Vol, Summer 1985, pp. 51-60.

(46) Haldorsen, Sylvi, Petsonk, Andrew M., and Tortensson, Bengt-Arne, "An Instrument for In Situ Monitoring of Water Quality and Movement in the Vadose", Proceedings of the NWWA Conference on Characterization and Monitoring of the Vadose Zone, NWWA, 1986, pp. 158-172.

(47) Neary, A.J. and Tomassini, F., "Preparation of Alundum/Ceramic Plate Tension Lysimeters for Soil Water Collection", Canadian Journal of Soil Science, Vol 65, February 1985, pp. 169-177.

(48) Wolff, R.G., "Weathering Woodstock Granite, near Baltimore, Maryland", American Journal of Science, v.265, 1967, pp.106-117.

(49) Wood, Warren W., "A Technique Using Porous Cups for Water Sampling at Any Depth in the Unsaturated Zone", Water Resources Research, Vol 9, April 1973, pp. 486-488.

(50) Debyle, Norbert V., Hennes, Robert W., and Hart, George E., "Evaluation of Ceramic Cups for Determining Soil Solution Chemistry", Soil Science, Vol 146, July 1988, pp. 30-36.

(51) England, C.B., "Comments on 'A Technique Using Porous Cups for Water Sampling at Any Depth in the Unsaturated Zone' by Warren W. Wood", Water Resources Research, Vol 10, October 1974, pp. 1049.

(52) Bottcher, A.B., Miller, L.W., and Campbell, K.L.," Phosphorous Adsorption in Various Soil-Water Extraction Cup Materials: Effect of Acid Wash", Soil Science, v. 137, 1984, pp. 239-244.

(53) Peters, Charles A. and Healy, Richard W., "The Representativeness of Pore Water Samples Collected from the Unsaturated Zone Using Pressure-Vacuum Lysimeters", Ground Water Monitoring Review, Spring 1988, pp. 96-101.

(54) Linden, D.R., "Design, Installation and Use of Porous Ceramic Samplers for Monitoring Soil-Water Quality", U.S. Dep. Agric. Technical Bull., 1562, 1977.

(55) Rhoades, J.D., and Oster, J.D.,"Methods of Soil Analysis", Agronomy, v.9, 1986, pp. 985-1006.

(56) Klute, A., ed., Methods of Soil Analysis, Part I, American Society of Agronomy, Inc., Madison, Wisconsin, 1986.

(57) Brose, Richard J., Shatz, Richard W., and Regan, Thomas M., "An Alternate Method of Lysimeter and Flour Pack Placement in Deep Boreholes", Proceedings of the Sixth National Symposium and Exposition on Aquifer Restoration and Ground Water Monitoring, NWWA, 1986, pp. 88-95.

(58) Litaor, M. Iggy, "Review of Soil Solution Samplers", Water Resources Research, Vol 24, May 1988, pp. 727-733.

(59) Silkworth, D.R. and Grigal, D.F., "Field Comparison of Soil Solution Samplers", Soil Science Society of America Journal, Vol 45, 1981, pp. 440-442.

(60) Smith, J.L., and McWhorter D.M.,"Continuous Subsurface Injection of Liquid Organic Wastes", Land as a Waste Management Alternative, Ann Arbor Science, 1977, pp. 646-656.

(61) Grier, H.E., Burton, W., and Tiwari," Overland Cycling of Animal Waste", Land as a Waste Management Alternative, Ann Arbour Science, 1977, pp. 693-702

(62) Smith, J.H., Robbins, C.W., Bondurant, J.A., and Hayden, C.W., "Treatment of Potato Processing Wastewater on Agricultural Land: Water and Organic Loading, and the Fate of Applied Plant Nutrients", Land as a Waste Management Alternative, Ann Arbour

Science, 1977, pp. 769-781.

(63) Morrison, Robert D. and Szecsody, Jim E., "A Tensiometer and Pore Water Sampler for Vadose Zone Monitoring", Soil Science, Vol 144, November 1987, pp. 367-372.

(64) Baier, Dwight C., Aljibury, Falih K., Meyer, Jewell K., Wolfenden, Allen K., Vadose Zone Monitoring is Effective for Evaluating the Integrity of Hazardous Waste Pond Liners, Baier Agronomy, Inc., Woodland, California, November 1983, 17 pp.

(65) Taylor, S.A., and Ashcroft, G.L., Physical Edaphology, The Physics of Irrigated and Non Irrigated Soils, W.H. Freeman and Company, San Francisco, 1972.

(66) Hornby, W.J., Zabick, J.D. and Crawley, W., "Factors Which Affect Soil-Pore Liquid: A Comparison of Currently Available Samplers with Two New Designs", Ground Water Monitoring Review, Vol 6, Spring 1986, pp. 61-66.

(67) Wengel, R.W. and Griffin, G.F., "Remote Soil-Water Sampling Technique", Soil Science Society of America Journal, Vol 35, 1971, pp. 661-664.

(68) Brown, K.W., Thomas, J.C., and Aurelius, M.W., "Collecting and Testing Barrel Sized Undisturbed Soil Monoliths", Soil Science Society of America Journal, Vol 49, 1985, pp. 1067-1069.

(69) Wagner, George H., "Use of Porous Ceramic Cups to Sample Soil Water Within the Profile", Soil Science, Vol 94, 1962, pp. 379-386.

(70) Nagpal, N.K., "Comparison Among and Evaluation of Ceramic

Porous Cup Soil Water Samplers for Nutrient Transport Studies", Canadian Journal of Soil Science, Vol 62, 1982, pp. 685-694.

(71) Bouma, J., Jongerius A., and Schoondebeek, D., 1979, "Calculation of Hydraulic Conductivity of Some Saturated Clay Soils Using Micromorpho-meteric Data", Soil Science Society of America Journal, v. 43, pp. 261-265.

(72) Warrick, A.W. and Amoozegar-Fard, A., "Soil Water Regimes Near Porous Cup Water Samplers", Water Resources Research, Vol 13, February 1977, pp. 203-207.

(73) Van der Ploeg, R.R. and Beese, F., "Model Calculations for the Extraction of Soil Water by Ceramic Cups and Plates", Soil Science Society of America Journal, Vol 41, 1977, pp. 466-470.

(74) Narasimhan, T.N. and Dreiss, Shirley J., "A Numerical Technique for Modeling Transient Flow of Water to a Soil Water Sampler", Soil Science, Vol 141, March 1986, pp. 230-236.

(75) Anderson, Linda Davis, "Problems Interpreting Samples Taken with Large-Volume, Falling Suction Soil-Water Samplers", Ground Water, 1986, pp. 761-

(76) Law Engineering Testing Company, Lysimeter Evaluation Study, American Petroleum Institute, May 1982, 103 pp.

(77) Sales Division, Catalog of Products, BAT Envitech Inc., Long Beach California, 1988.

(78) Brown, K.W., Efficiency of Soil Core and Soil Pore-Liquid Sampling Systems, U.S. EPA/600/52-86/083, Virginia, February, 1987.

(79) Amter, S., Injection/Recovery Lysimeter Technique for Soil-Water Extraction, M.S. Thesis, Dept. of Hydrology and Water Resources, The University of Arizona, Tucson, Arizona, 1987.

(80) Sales Division, Catalog of Products, Cole-Parmer Instrument Company, 1988.

(81) Barbee, G.C. and Brown, K.W., "Comparison Between Suction and Free-Drainage Soil Solution Samplers", Soil Science, Vol 141, February 1986, pp. 149-154.

(82) Amoozegar-Fard, A.D., Nielsen, D.R., and Warrick, A.W., "Soil Solute Concentration Distributions for Spatially Varying Pore Water Velocities and Apparent Diffusion Coefficients" Soil Science Society of America Journal, v. 46, 1982, pp. 3-9.

(83) Haines, B.L., Waide, J.B., and Todd, R.L., "Soil Solution Nutrient Concentrations Sampled with Tension and Zero-Tension Lysimeters: Report of Discrepancies", Soil Science Society of America Journal, Vol 46, 1982, pp. 658-660.

(84) Biggar,J.W., and Nielsen, D.R., "Spatial Variability of the Leaching Characteristics of a Field Soil", Water Resources Research, v. 12, 1976, pp. 78-84.

(85) Thomas, G.W., and Phillips, R.E., "Consequences of Water Movement in Macropores", Journal of Environmental Quality, v.8, 1979, pp. 149-152.

(86) Severson, R.C. and Grigal, D.F., "Soil Solution Concentrations: Effect of Extraction Time Using Porous Ceramic Cups

Under Constant Tension", Water Resources Bulletin, Vol 12, December 1976, pp. 1161-1169.

(87) Shuford, J.W., Fritton, D.D., and Baker, D.E., "Nitrate-Nitrogen and Chloride Movement Through Undisturbed Field Soil", Journal of Environmental Quality, v.6, 1977, pp. 736-739.

(88) Tyler, Donald D. and Thomas, Grant W., "Lysimeter Measurements of Nitrate and Chloride Losses from Soil Under Conventional and No-tillage Corn", Journal of Environmental Quality, Vol 6, 1977, pp. 63-66.

(89) Suarez, D.L., "Prediction of pH Errors in Soil Water Extractors Due to Degassing", Soil Science Society of America Journal, v.51, 1987, pp. 64-68.

(90) Ransom, M.D., and Smeck, N.E., "Water Table Characteristics and Water Chemistry of Seasonally Wet Soils of Southwestern Ohio", Soil Science Society of America Journal, v. 50, 1986, pp. 1281-1290.

(91) Wood, A.L., Wilson, J.T., Cosby, R.L., Hornsby, A.G., and Baskin, L.B., "Apparatus and Procedure for Sampling Soil Profiles for Volatile Organic Compounds", Soil Science Society of America Journal, Vol 45, 1981, pp. 442-444.

(92) Pettyjohn, Wayne A., Dunlap, W.J., Cosby, Roger, and Keeley, Jack, W., "Sampling Ground Water for Organic Contaminants", Ground Water, Vol 19, March-April 1981, pp 180-189.

(93) Creasey, Carol L. and Dreiss, Shirley J., "Soil Water Sampler:

Do They Significantly Bias Concentrations in Water Samples?", Proceedings of the NWWA Conference on Characterization and Monitoring of the Vadose Zone, NWWA, 1986, pp. 173-181.

(94) Bell, R.G., "Porous Ceramic Soil Moisture Samplers, An Application in Lysimeter Studies on Effluent Spray Irrigation", New Zealand Journal of Experimental Agriculture, Vol 2, June 1974, pp. 173-175.

(95) Dazzo, F., and Rothwell, D., "Evaluation of Porcelain Cup Soil Water Samplers For Bacteriological Sampling", Applied Microbiology, v.27, 1974, pp. 1172-1174.

(96) Jordan, Carl F., "A Simple, Tension-Free Lysimeter", Soil Science, Vol 105, 1968, pp. 81-86.

(97) Montgomery, B.R., Prunty, Lyle, and Bauder, J.W., "Vacuum Trough Extractors for Measuring Drainage and Nitrate Flux Through Sandy Soils", Soil Science Society of America Journal, Vol 51, 1987, pp.271-276.

(98) Schmidt, C., and Clements, E., Reuse of Municipal Wastewater For Groundwater Recharge, U.S. Environmental Protection Agency, 68-03-2140, 1978, Ohio, pp. 110-125.

(99) Schneider, B.J., Oliva, J., Ku, H.F.H., and Oaksford, E.T., "Monitoring the Movement and Chemical Quality of Artificial-Recharge Water in the Unsaturated Zone on Long Island, New York", Proceedings of the Characterization and Monitoring of the Vadose (Unsaturated) Zone, National Water Well Association, Las Vegas,

Nevada, 1984, pp. 383-410.

(100) K.W. Brown and Associates, Hazardous Waste Land Treatment, U.S.EPA, Office of Research and Development, SW-874, Cincinnati, Ohio, Septmeber, 1980

(101) Schneider, B.J., and Oaksford, E.T., Design and Monitoring Capability of an Experimental Artificial-Recharge Facility at East Meadow, Long Island, New York, U.S. Geological Survey Open-File Report 84-070, 1986.

(102) Joslin, J.D., Mays, P.A., Wolfe, M.H., Kelly, J.M., Garber, R.W., Brewer, P.F., "Chemistry of Tension Lysimeter Water and Lateral Flow in Spruce and Hardwood Stands", Journal of Environmental Quality, Vol 16, 1987, pp. 152-160.

(103) Wilson, L.G. and Schmidt, K.D., "Monitoring Perched Water in the Vadose Zone", Establishment of Water Quality Monitoring Programs, Proceedings of a Symposium, American Water Resources Association, 1978, pp. 134-149.

(104) Pickens, J.F., and Grisak, G.E., "Reply to the Preceding Discussion of Vanhof et al. at a Multilevel Device for Groundwater Sampling and Pieziometric Monitoring", Ground Water, v.17(4), 1979, pp. 393-397.

(105) Smith, S.A., Small, G.S., Phillips, T.S., and Clester, M., Water Quality in the Salt River Project, A Preliminary Report, Salt River Project Water Resource Operations, Ground Water Planning Division, Pheonix, Arizona, August, 1982.

(106) Pickens, J.F., Cherry, J.A., Coupland, R.M., Grisak, G.E., Merritt, W.F., and Risto, G.A., "A Multi-Level Device for Ground Water Sampling", Ground Water Monitoring Review, v. 1(1), 1981.

(107) Reeve, R.C. and Doering, E.J., "Sampling the Soil Solution for Salinity Appraisal", Soil Science, Vol 99, 1965, pp. 339-344.

(108) Patton, F.D., and Smith, H.B., "Design Considerations and the Quality of Data from Multiple-Level Groundwater Monitoring Wells", Ground-water Contamination Field Methods, ASTM, STP963, Philadelphia, PA, 1988.

(109) U.S. Environmental Protection Agency, RCRA Ground-Water Monitoring Technical Enforcement Guidance Document, Office of Waste Programs Enforcement, Office of Solid Waste and Emergency Response, OSWER-9950.1, 1986, 208 pp..

(110) Driscoll, F.G., Groundwater and Wells, Johnson Division, St. Paul, Minnesota, 1986, 1089 pp..

(111) Gass, T.E., "Methodology for Monitoring Wells", Water Well Journal, v.38(6), 1984, pp.30-31.

(112) Keely, J.F., and Boateng K., "Monitoring Well Installation, Purging and Sampling Techniques", Ground Water, 1987, v.25 (3,4).

(113) Minning, R.C., "Monitoring Well Design and Installation", Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring, Columbus, Ohio, 1982, pp. 194-197.

(114) Richter, H.R., and Collentine, M.G., "Will My Monitoring Well Survive Down There?: Design and Installation Techniques for

Hazardous Waste Studies", Proceedings of the Third National Symposium on Aquifer Restoration and Ground Water Monitoring, Columbus, Ohio, 1983, pp. 223-229.

(115) Riggs, C.O., "Monitoring Well Drilling Methods", Proceedings of the Workshop on Resource Conservation Recovery Act Ground Water Monitoring Enforcement: Use of the Technical Enforcement Guidance Document and Compliance Order Guide, Philadelphia, Pennsylvania, 1987.

(116) Riggs, C.O., and Hatheway, "Ground Water Monitoring Field Practice - An Overview", Proceedings of the ASTM Conference on Ground Water Technology, Coco Beach Florida, 1986.

(117) Scalf, M.R., McNabb, J.F., Dunlap, W.J., Cosby, R.L., and Fryberger, J., Manual of Ground Water Sampling Procedures, National Water Well Association, Ohio, 1981, 93 pp..

(118) Campbell, M., and Lehr, J., Water Well Technology, McGraw-Hill Book Co., New York, New York, 1973, 681 pp..

(119) Hackett, G., " Drilling and Constructing Monitoring Wells with Hollow Stem Augers", Ground Water Monitoring Review, Fall 1987, pp. 51-62.

(120) Hackett, G., " Drilling and Constructing Monitoring Wells with Hollow Stem Augers", Ground Water Monitoring Review, Winter 1988, pp. 60-68.

(121) Taylor, T.W., and Serafini, M.C., "Screened Auger Sampling: The Technique and Two Case Studies", Ground Water Monitoring

Review, Summer 1988, pp. 145-152.

(122) Barcelona, M.J., Gibb, J.P., and Miller, R.A., A Guide to the Selection of Materials For Monitoring Well Construction and Ground Water Sampling, Illinois State Water Survey, Champaign, Illinois, 1983.

(123) Schilfgaarde, J.V., ed., Drainage for Agriculture, Number 17 in Agronomy Series, American Society of Agronomy, Madison, Wisconsin, 1974.

(124) Donnan, and Schwab, in Drainage for Agriculture, Number 17 in Agronomy Series, American Society of Agronomy, Madison, Wisconsin, 1974.

(125) Gilliam, J.W., Daniels, R.B., and Lutz, J.F., "Nitrogen Content of Shallow Ground Water in the North Carolina Coastal Plain", Journal of Environmental Quality, v.2, 1974, pp. 147-151.

(126) Gambrell, R.P., Gilliam, J.W., and Weed, S.B., "Denitrification in Subsoils of the North Carolina Coastal Plain as Affected by Soil Drainage", Journal of Environmental Quality, v.4, 1975, pp. 311-316.

(127) Eccles, L.A., and Gruenberg, P.A., "Monitoring Agricultural Waste Water Discharges For Pesticide Residues", Proceedings: Establishment of Water Quality Monitoring Programs, American Water Resources Association, 1978, pp.319-327.

(128) Gilliam, J.W., Skaggs, R.W., and Weed, S.B., "Drainage Control to Diminish Nitrate Loss from Agricultural Fields", Journal

of Environmental Quality, v.8, 1979, pp. 137-142.

(129) Jacobs, T.C., and Gilliam, J.W., "Riparian Losses of Nitrate from Agricultural Drainage Waters", Journal of Environmental Quality, v.14, 1985, pp. 472-478.

(130) Wilson, L.G., and Small, G.G., "Pollution Potential of a Sanitary Landfill Near Tucson, Hydraulic Engineering and The Environment", Proceedings 21st Annual Hydraulics Division Specialty Conference, ASCE, 1973.

(131) Dunlap, William J., Some Concepts Pertaining to Investigative Methodology for Subsurface Process Research, U.S. Environmental Protection Agency, 1977, pp. 167-172.

(132) Fenn, D.E., Hanley, K.J., Isbister, J., Briads, O., Yare, B., and Roux, P., Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities, U.S. Environmental Protection Agency, EPA/530/SW-611, 1977.

(133) Gibb, J.P., Schuller, R.M., and Griffin, R.A., Procedures for the Collection of Representative Water Quality Data from Monitoring Wells, Cooperative Groundwater Report 7, Illinois State Water Survey, 1981.

(134) Willardson, L.S., Meek, B.D., and Huber, M.J., "A Flow Path Ground Water Sampler", Soil Science Society of America Proceedings, v.36, 1973, pp. 965-966.

(135) Tadros, V.T. and McGarity, J.W., "A Method for Collecting Soil Percolate and Soil Solution in the Field", Plant and Soil,

Vol 44, June 1976, pp. 655-667.

(136) Shimshi, Daniel, "Use of Ceramic Points for the Sampling of Soil Solution", Soil Science, Vol 101, 1966, pp. 98-103.

(137) Grover, B.L., and Lamborn, R.E., "Preparation of Porous Seramic Cups to be Used for Extraction of Soil Water Having Low Solute Concentrations", Soil Science Society of America Proceedings, vol. 34, 1970, pp. 706-708.

(138) Zimmermann, C.F., Price, M.T., and Montgomery, J.R., "A Comparison of Ceramic and Teflon Insitu Samplers for Nutrient Pore Water Determinations", Estuarine and Coastal Marine Science, vol. 7, 1978, pp. 93-97.

(139) Napgal, N.K., "Comparison Among and Evaluation of Ceramic Porous Cup Soil Water Samplers for Nutrient Transport Studies", Canadian Journal of Soil Science, vol. 62, 1982, pp. 685-694.

(140) Faber, W.R., and Nelson, P.V, "Evaluation of Methods for Solution from Container Root Media", Commumications in Soil Science Plant Analysis, vol. 15, number 9, 1984, pp. 1029-1040.

(141) Liator, M.I., " Review of Soil Solution Samplers", Water Resources Research, vol. 24, No. 5, 1988, pp. 727-733.

(142) Barbarick, K.A., Sabey, B.R., and Klute, A., "Comparison of Various Methods of Sampling Soil Water for Determining Ionic Salts, Sodium, and Calcium Content in Soil Columns", Soil Science Society of America Journal, Vol. 43, 1979, pp. 1053-1055.

(142) Wagman, R., and Graham, B., "Membrane and Glass Fibre Filter

Contamination in Chemical Analysis of Fresh Water", Water Research, Vol. 8, 1974, pp. 407-412.

(143) Jones, J.N., and Miller, G.D., "Adsorption of Selected Organic Contaminants onto Possible Well Casing Materials", Ground-Water Contamination Field Methods, ASTM STP 963, Philadelphia, PA, 1988.

(144) Barcelona, M.J., Helfrich, J.A., and Garske, E.E., " Verification of Sampling Methods and Selection of Materials for Ground Water Contamination Studies", Ground-Water Contamination Field Methods, ASTM STP 963, Philadelphia, PA, 1988.