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THE USE OF GEOPHYSICAL EQUIPMENT IN HYDROGEOLOGIC INVESTIGATIONS, AND THE MEASUREMENT OF STREAM DISCHARGE

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Meeting place and time: parking lot on the northeastern side of Merrill Gymnasium, Bates College, at 8:15 a.m., Friday, October 17. *Private vehicles will be needed for transportation to the Auburn gage house.

INTRODUCTION

The use of selected geophysical equipment in hydrogeologic investigations, and the measurement of stream discharge will be presented during this two-part technical session.

The geophysics session will involve field demonstrations at Bates College by Survey (U.S. Geological Survey), MGS (Maine Geological Survey), and MDEP (Maine Department of Environmental Protection) personnel. The following geophysical techniques and equipment will be demonstrated: seismic refraction (1-channel and 12-channel seismographs); ground-penetrating radar; direct-current resistivity; and electromagnetics (terrain conductivity and resistivity). The field trip group will be split into smaller groups that will spend approximately 1 hour at each of the concurrent demonstrations of the above equipment. Principles, hydrogeologic uses, limitations, interferences, field setup, and data interpretation for each of the geophysical techniques will be discussed.

The stream-discharge-measurement session will be run concurrently with the geophysics session. It will involve a 1 1/2-hour demonstration of discharge measurements at the Survey's gaging station on the Androscoggin River at Auburn. There will be a discussion of the Survey's stream-gaging network in Maine, an explanation of the equipment in the gaging station, and a demonstration of a cable-car discharge measurement.

The following station descriptions provide summaries of information presented at the geophysics and stream-discharge measurement sessions. In addition, a list of selected references on geophysical methods and the use of integrated geophysical techniques in hydrogeologic investigations is presented at the back of this article.

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STATION DESCRIPTIONS

Station #1: Seismic-Refraction Techniques and Equipment

Multi-Channel Seismic Refraction

Demonstration by: Dorothy H. Tepper, Hydrologist
U.S. Geological Survey
Augusta, Maine

Physical property measured: The seismic-refraction method measures the time it takes a compressional sound wave to travel through the layers of the earth to detectors (geophones) placed on the land surface. The subsurface geology can be interpreted by measuring the traveltime of the sound wave and then applying the laws of physics that govern the propagation of sound through layered media.

Hydrogeologic uses: Seismic-refraction techniques can be used to determine:

- depth to water table in unconsolidated material,
- depth to and configuration of bedrock surface beneath unconsolidated material,
- depth to crystalline rocks beneath sedimentary rocks, and
- saturated thickness of aquifer material.

Limitations:

- The velocity of each successive layer must increase with depth to detect it with seismic refraction techniques.
- Layer velocities must be sufficiently different to distinguish individual layers.
- Thin layers may not be detectable even if the velocity constraints listed above are met.
- Long spreads or large distances from the shot point to the first geophone may be required, depending on the depths to the subsurface layers of interest.
- Explosives may be needed in order to obtain high-quality record.
- Different combinations of subsurface structure or layering can result in similiar time-distance plots. Because the solution is not unique, information on the hydrogeology in the area is helpful for calibration. If calibration data are unavailable, more than two shots could be fired on the line to increase data redundancy, thereby increasing the reliability of the data.
- A high-velocity layer at the land surface, such as frozen ground, will not allow distinction of layers of lower velocity beneath it. This technique, therefore, has limited applications in permafrost zones.
- Depending on the particular seismograph used, there may be no permanent record of the output (wave forms).

Interferences: Interference problems, resulting in poor-quality record, can be caused by:

- motion of nearby vehicles or heavy machinery,
- wind and associated tree-root movement,

- high humidity (can cause increased problems with electrical interferences), and
- nearby powerlines or other sources of electromagnetic fields.

Approximate cost of field equipment:

- A state-of-the-art 12-channel, signal-enhancement seismograph and accessories cost approximately $10,000 to $30,000.
- Costs for sound sources differ greatly depending on the type of source used. For example, if explosives are used, a drill may be required for making the shot holes. Training in the safe handling of explosives should be provided for personnel. Depending on the type of explosives used, the cost per shot may range from approximately $5 to $15.

Field crew required: A minimum of two people is required, but a crew of three people is preferable.

Estimated daily production:

Field:
- In an open area with deep valleys, approximately 0.5 to 0.75 miles of seismic data can be collected, using overlapping 1,100-foot spreads and multiple shot points.
- In a wooded area with shallow valleys, approximately 0.25 to 0.5 miles of seismic data can be collected using overlapping spreads and multiple shot points.

Office:
- Approximately 1 day of interpretation time should be planned for each day of field work.

Data interpretation:

- An inverse modeling program (Scott and others, 1972), which is based on the delay time method and a ray-tracing modeling technique, is commonly used. Output includes a time-distance plot, apparent velocities for each layer, depths to each layer beneath each shot point and geophone, and a subsurface profile.
- Numerous other interpretation programs (see Ballantyne and others, 1981) which use various methods and modeling techniques are available for use with hand-held calculators and microcomputers, minicomputers, and mainframes.

Selected references:

Ballantyne, E.J., D.L. Campbell, S.H. Mentemeier, and Ralphe Wiggins, (eds.), 1981, Manual of geophysical hand-calculator programs, vol. 2: Society of Exploration Geophysicists, Tulsa, Oklahoma.

Birch, F.S., 1976, A seismic ground-water survey in New Hampshire: Ground Water, v. 14, no. 2, p. 94-100.

Haeni, F.P., 1978, Computer modeling of the ground-water availability of the Pootatuck River Valley, Newtown, Connecticut: U.S. Geol. Surv. Water Resources Investigations Report 78-77, 64 p.

_____, 1986, Application of seismic refraction methods in ground-water modeling studies in New England: Geophysics, v. 51, no. 2, p. 236-249.

_____, 1986, Application of seismic refraction techniques to hydrologic studies: U.S. Geol. Surv. Open-File Report 84-746.

Mooney, H.M., 1980, Handbook of engineering physics, volume 1: seismic: Bison Instruments, Inc., Minneapolis, Minn., 193 p.

Morrissey, D.J., 1983, Hydrology of the Little Androscoggin River valley aquifer, Oxford County, Maine: U.S. Geol. Surv. Water-Resources Investigations Report 83-4018, 79 p.

Pakiser, L.C., and R.A. Black, 1957, Exploring for ancient channels with the refraction seismograph: Geophysics, v. 22, no. 1, p. 32-47.

Reynolds, R.J., and G.A. Brown, 1984, Hydrogeologic appraisal of a stratified-drift aquifer near Smyrna, Chenango County, New York: U.S. Geol. Surv. Water-Resources Investigations Report 84-4029, 53 p.

Scott, J.H., 1973, Seismic refraction modeling by computer: Geophysics, v. 38, no. 2, p. 271-284.

Scott, J.H., B.L. Tibbetts, and R.G. Burdick, 1972, Computer analysis of seismic-refraction data: U.S. Dept. of Interior, Bureau of Mines Report of Investigations RI 7595, 95 p.

_____,1977a, SIPB--A seismic-refraction inverse modeling program for batch computer systems: U.S. Geol. Surv. Open-File Report 77-366, 40 p.

_____,1977b, SIPT--A seismic-refraction inverse-modeling program for timeshare terminal computer system: U.S. Geol. Surv., Open-File Report 77-365,35 p.

Tepper, D.H., J.S. Williams, A.L. Tolman, and G.C. Prescott, Jr., 1985, Hydrogeology of significant sand and gravel aquifers in parts of Androscoggin, Cumberland, Franklin, Kennebec, Lincoln, Oxford, Sagadahoc, and Somerset Counties, Maine: Sand and gravel aquifer maps 10, 11, 16, 17, and 32: Maine Geol. Surv. Open-File Report 85-82a, 106 p.

Single-Channel Seismic Refraction

Demonstration by: Craig Neil, Research and Planning Associate
Maine Geological Survey
Augusta, Maine

Physical property measured: same as multichannel seismic refraction

Hydrogeologic uses: same as multichannel seismic refraction

Limitations: In addition to the limitations listed for multichannel seismic refraction, the following are limitations of the single-channel method:

- Because sound sources typically used for single-channel work are not high-energy and therefore do not generate strong signals, this technique generally works best where the depths to the layers of interest are within 50 to 100 feet of the land surface.

- Each spread is typically only 200 to 300 feet long, so multiple spreads will be required to profile a large area.
- Depending on the particular seismograph used, there may be no permanent record of the wave form.

Interferences: same as multichannel seismic refraction

Approximate cost of field equipment: A state-of-the-art signal enhancement single-channel seismograph with accessories costs approximately $4,500 to $5,500.

Field crew required: Two people are required.

Estimated daily production:

Field:
- In a relatively open area, approximately 10 to 15 spreads can be run (this should allow some time for preliminary data interpretation).

Office:
- Depending on the hydrogeologic complexity, each spread will take approximately 1 to 3 hours to interpret.

Data interpretation: Many programs are available for hand-held computers and micro-computers. The program that is commonly used by both the Maine Geological Survey and the Maine Department of Environmental Protection was written by Mooney (1980). Output includes calculated velocity for each layer and depth to each layer under the two geophones.

Selected references:

In addition to those listed under multichannel seismic refraction:

Heeley, R.W., and B.A. Marshall, 1985, The use of geophysical techniques in an accelerated search for ground water in the Connecticut River valley, Massachusetts: in Nielson, D.M. and M. Curl (eds.), Surface and borehole geophysical methods in ground water investigations-second national conference and exposition: National Water Well Association, Worthington, Ohio, 424 p.

Sverdrup, K.A., 1986, Shallow seismic refraction survey of near surface ground water flow: Ground Water Monitoring, v. 6, no. 1, p. 80-83.

Station #2: Ground-Penetrating Radar Techniques and Equipment

Demonstration by: David G. Johnson, Hydrologist
U.S. Geological Survey
Boston, Massachusetts

The following discussion is based largely on information from Benson and others (1982).

Physical property utilized: Radar waves are reflected from interfaces between materials having sufficiently different dielectrical properties. A continuous cross-sectional profile of shallow subsurface conditions can be produced based on variations in the return signal.

Hydrogeologic uses: Radar techniques can be used to determine the following:

- subsurface structure and stratigraphic changes
- moisture content of subsurface materials
- depth to the water table
- discontinuous clays at depth
- buried stream channels
- buried waste materials
- buried utilities
- depth to the bedrock surface
- bedrock fractures

Limitations:

- The principal limitation of radar is the depth of signal penetration, which is determined primarily from the attenuation produced from the sum of geometric scattering losses, electrical conductivity, and dielectric relaxation. Signal penetration is poor in conductive material and good in resistive material. Radar signal penetration capability is highly site-specific and can range from less than 3 feet to over 100 feet.
- Depending on the antenna (frequency) used, the resolution on the record may range from inches to several feet. High-frequency antennas (500 to 900 MHz) only provide shallow signal penetration but provide resolution of features on the scale of a few inches. In contrast, low-frequency antennas (80 to 125 MHz) can provide better signal penetration but can only provide resolution of features on the scale of a few feet or larger.
- Depth is not measured directly. It is calculated based on the velocity of radar waves in various materials and on travel time back and forth to the reflector.
- Depth calibration has to be done carefully. If conditions change, the depth calibration will be affected. In addition, the depth scale is usually nonlinear.

<u>Interferences</u>: Interference problems, resulting in poor-quality record, can be caused by:

- system noise: improper cable placement, locating antenna too close to towing vehicle
- overhead radar reflections: power lines, trees, buildings, etc. can affect lower frequency antennas that are not shielded on their top surfaces
- noise from surface factors: pieces of metal on the ground, topographic variations
- noise from subsurface features or buried debris
- external electromagnetic noise: nearby radio transmitters

<u>Approximate cost of field equipment</u>: A state-of-the-art ground-penetrating radar system and accessories cost approximately $17,000 to $50,000.

<u>Field crew required</u>: Depending on whether the antenna is towed by a vehicle or pulled by hand, two or three people will be needed. Experienced personnel are required due to the sophistication of the instrument and the technique.

<u>Estimated daily production</u>:

Field:
- For reconnaissance-level surveys, the antenna can be towed by a vehicle and data can be acquired at a rate of approximately 3 to 5 miles per hour. If more detailed surveys are required, the antenna can be hand-towed and data can be collected at a rate of approximately 0.3 to 0.5 miles per hour.

Office:
- See following discussion on "Data interpretation".

<u>Data interpretation</u>:

- Radar data are relatively straight-forward to interpret if hydrogeologic conditions are not complex and if there is a strong dielectric contrast between the features of interest and the surrounding material. As conditions become more complex, data interpretation becomes increasingly difficult and computer processing may be required.
- Graphical results can be printed in the field, allowing rapid qualitative and semi-quantitative analyses of the data, but experienced personnel are required for accurate interpretation. Radar data can be recorded on magnetic tape or other media which provides a back-up copy of the data, permits optimization of data quality, and can provide signal input to a computer or the control unit for various processing options. For example, analog- and digital-filtering techniques may be used to remove background or system noise. However, processing of data can be costly and may result in elimination of some important data.

Selected references:

Benson, R.C., R.A. Glaccum, and M.R. Noel, 1982, Geophysical Techniques for sensing buried wastes and waste migration: Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, Las Vegas, Nevada, p. 38-62.

Benson, R.C., and R.A. Glaccum, 1979, Radar surveys for geotechnical site assessment: in Geophysical methods in geotechnical engineering, specialty session, Amer. Soc. Civil Engineers, Atlanta, Georgia, p. 161-178.

Houck, R.T., 1984, Measuring moisture content profiles using ground-probing radar: in Nielson, D.M. and M. Curl (eds.), NWWA/EPA conference on surface and borehole geophysical methods in ground water investigations: Natl. Water Well Assoc., Worthington, Ohio, p. 637-653.

Olhoeft, G.R., 1984, Applications and limitations of ground penetrating radar: in Expanded abstracts, 54th annual meeting, Soc. Expl. Geophysicists, Atlanta, Georgia, p. 147-148.

Ulriksen, P.F., 1982, Application of impulse radar to civil engineering: Lund University of Technology, Lund, Sweden, 179 p.

Underwood, J.E., and J.W. Eales, 1984, Detecting a buried crystalline waste mass with ground-penetrating radar: in Nielson, D.M., and M. Curl (eds.), NWWA/EPA conference on surface and borehole geophysical methods in ground water investigations: Natl. Water Well Assoc., Worthington, Ohio, p. 654-665.

Wright, D.L., G.R. Olhoeft, and R.D. Watts, 1984, Ground-penetrating radar studies on Cape Cod: in Nielson, D.M. and M. Curl (eds.), NWWA/EPA conference on surface and borehole geophysical methods in ground water investigations: Natl. Water Well Assoc., Worthington, Ohio, p. 666-680.