Instructor Guide Ground Water Location

GROUND WATER LOCATION

Instructor Guide

For additional information please write to:
The Economic Development Institute of
The World Bank
Studies Unit
1818 "H" Street, N.W.
Washington, D.C. 20433

GENERAL INFORMATION FOR THE INSTRUCTOR

Module Use and Content

The "Ground Water Location" module may be used as an independent instructional unit, or in conjunction with the other modules in EDI's two-week seminar on "Water Supply and Sanitation." The module includes the following presentation materials:

- An Instructor Guide
- A Participant Manual
- A slide/tape program

Time Required

The module is divided into three parts and requires approximately three hours to complete.

Participant Manual and Instructor Guide

The Participant Manual contains all the information and instructions required to complete the module activities.

The Instructor Guide is organized so that Instructor Notes appear on the left-hand pages, opposite the Participant Manual pages printed on the right. (The Participant Manual pages in the Instructor Guide are identical to those in the actual Participant Manual.) The Instructor Notes include suggested time requirements, steps for conducting the module activities, discussion guidelines and suggestions on presentation. The time requirements are approximate, but following the suggested times will ensure that the module does not require more than three hours to complete.

The Instructor Guide and Participant Manual both contain reference copies of the visuals and the narrative text from the slide/tape program.

Slide/Tape Program

Most of the instructional content for this module is presented in the slide/tape program, "Ground Water Location." The slide/tape program includes 80 35mm slides which are synchronized with the narration on one accompanying audiocassette.

The slides are inserted in a carousel tray that most projectors will accommodate. The narration on the audiocassette is pulsed with audible tones. These tones are cues that the slide projector should be advanced immediately to the next slide.

Equipment and Materials

Presentation of the module by an instructor to a group of participants requires the equipment and materials listed below:

For the instructor:

- One copy of the Instructor Guide
- A flipchart easel, pad and markers, or chalkboard and chalk
- One copy of the slide/tape program (slides and audiocassettes)
- One slide projector and white projection screen
- One audiocassette player

For the participants:

- A copy of the Participant Manual for each participant
- Paper and pencils for each participant

Instructor Preparation

The "Ground Water Location" module is not a self-instructional program. It requires an instructor who is knowledgeable about ground water location methods and applications.

Instructor preparation involves a review of the Instructor Guide to become familiar with the topics, the sequence of activities and the content of the presentations. It is also useful to preview the slide/tape program in order to become familiar with the content and the synchronization of the slides with the audiocassette. If possible, the program should be previewed on the equipment that will be used during the actual presentation.

Equipment and Facilities Preparation

Preparation of the audiocassette for play requires rewinding it completely to the beginning. When the cassette is loaded into the player, Side 1 should show at the top.

Preparation of the carousel tray of slides for viewing requires four steps. First, it is important to ensure that all of the slides are inserted into the tray in sequential order, with the printed numbers showing at the top right corner, along the outer edge of the carousel tray. Second, the black plastic lock ring must be turned in the direction of the arrow marked "Lock" until the ring is secured on the tray. Third, the tray is placed in operating position by lowering it onto the projector and turning it clockwise until the tray drops down securely. Fourth, the projector must be advanced so the first slide, the title slide, appears on the screen.

Operation of the slide projector and audiocassette player should be checked prior to the presentation. At that time, it is advisable to arrange for power cords required to operate the projector and the cassette player, extension cords and extra projector bulbs. It is also useful to determine who should be contacted if assistance is needed from an engineer or audiovisual specialist.

It is important to check that each participant will be able to see and hear the slide/tape program easily. To view the slides clearly, overhead and back lighting should be kept to a minimum.

INSTRUCTOR NOTES

Overview

The "Ground Water Location" module is a general overview of a variety of methods for locating ground water supplies. The module is divided into three parts that describe existing field data sources, aerial methods and geophysical methods for ground water location. Each part includes a discussion of the slide/tape program and at least one discussion or application activity in the participants' manual.

Most of the activities are conducted best in small groups of five to seven participants. If the participants are not divided into small groups, you may want to do so before proceeding with the module.

Introduction

Time required: 15 minutes

1. Refer the participants to the Introduction on page 1 in their manuals. Review the purpose of the module and the topic outline with them.

2. Ask the participants to describe briefly their past experience with ground water location methods. Then ask them to describe their objectives in learning about ground water location methods and how they intend to use the information. Knowing about their previous experience and their objectives will help you relate the content of the module to their specific needs.

3. Tell the participants that they will not have to take extensive notes during the slide/tape program. Their manuals include copies of the visuals and the narration from the slide/tape program as well as summaries of all major concepts presented.

4. Introduce the slide/tape program. Turn on the equipment and make sure the title slide is projected before you turn on the cassette player. When you turn on the cassette player, the music at the start of the program will begin. When you hear the first signal tone, advance the slide projector immediately to the next slide. Continue advancing the slides at the sound of the tone until the narrator announces the end of the slide/tape program and you see a corresponding message projected on the screen.

   The slide/tape program is approximately twenty-five minutes in length when shown continuously. You can choose to stop the slide/tape program at the end of the first and second parts and conduct activities in the participants' manual. Or, you can show the entire slide/tape program and then conduct all of the activities.

Introduction

The "Ground Water Location" module has been designed for project analysts and managers who require an overview of the variety of methods of locating ground water supplies.

The module includes a discussion of the topics that are listed below.

PART I — Overview of the module

EXISTING FIELD DATA

Published Information

- Geologic Reports and Maps
- Water Resource Reports
- Topographic Maps

Local Consultants and Drillers

Observation of Surface Features

- Streams
- Springs
- Vegetation

PART II — **AERIAL METHODS**

Satellite Imagery

Aerial Photography

PART III — **GEOPHYSICAL METHODS**

Surface Methods

- Electrical Resistivity Surveys
- Seismic Surveys

Borehole Methods

- Resistivity Logs
- Spontaneous Potential Logs
- Gamma Ray Logs
- Caliper Logs

INSTRUCTOR NOTES

PART I: EXISTING FIELD DATA

Review and Discussion Time required: 35 minutes

1. After the participants have viewed the first part of the slide/tape program, ask them if they have any questions about the content.

2. Review the summary information on pages 2, 3 and 4 with the participants. Then ask the participants to discuss the questions on page 4 with the members of their group and to summarize their discussion for the other groups of participants.

3. Distribute any examples you have of published reports, files, maps or records that illustrate the types of existing field data that are available on the participants' regions or countries. Cite the sources of existing field data in the participants' region or country and how the data can be made available to them.

PART I: EXISTING FIELD DATA

Review and Discussion

The first consideration in any attempt to locate an aquifer is to review existing field data. Existing field data may be obtained from published information, local consultants or drillers, and observation of surface features.

Published Information

Ground water location reports and studies are available from government agencies, consultants, local and international organizations and libraries. Three types of published information are geologic reports, water resource reports and topographic maps.

Geologic Reports and Maps

Geologic reports and maps provide information on the different kinds of unconsolidated and consolidated deposits and rocks in an area. Knowing the types of deposits and rocks can help to infer the availability of water.

Unconsolidated deposits are an uncemented mixture of clay, silt, sand, and gravel-sized particles which overlie consolidated rocks. Unconsolidated deposits may contain a significant amount of water where they are composed of larger-grained particles and are sufficiently thick.

The availability of water depends upon the porosity, or the amount of void space between particles, the thickness of the overlying deposits and the permeability, that is, how easy it is for water to move through the ground. Permeability is influenced by the grain size and amount of other openings in the rock. The larger the grain size and the more fractured the rock, the higher the yield of the aquifer is likely to be.

Consolidated granular rocks, such as sandstone, can serve as aquifers if the voids in the rock are not filled with significant amounts of cementing agent. The voids can serve to store and transmit water. Fractures may also increase the yield of the aquifer.

Non-granular rocks, such as limestone, granite or basalt, may serve as aquifers. In these rocks, water occurs only in interconnected fractures and openings within the rock. If the rock does not have a significant amount of openings, it will not yield much water.

Fine-grained rocks, such as shale and fine-grained deposits with large amounts of silts and clays, are not productive aquifers.

Review and Discussion
(continued)

Review and Discussion
(continued)

Maps, often included in geologic reports, use different colors or symbols to indicate the location of different rock types. The reports may also include geologic cross-sections where colors or symbols indicate the rock type, depth and thickness.

Water Resource Reports

Water resource reports describe the water content, the size, the expected yield and current production levels of aquifers. The reports often contain maps that show the expected yield of aquifers in the area.

Topographic Maps

Topographic maps show surface information such as springs or rivers and display a series of lines that represent elevation changes in an area. The closer the lines on the map, the steeper the land. Conversely, if the lines are drawn far apart, they represent flatter land.

The water table typically is deeper under hills and shallower under valleys. Topographic maps can be useful when choosing locations for wells in hilly areas because they provide a basis for estimating where the depth to water probably will be the shallowest.

Local Consultants and Drillers

Local consultants or drillers who have conducted studies in an area may have files or personal knowledge which can be useful in locating ground water.

Drillers' logs from existing wells may contain useful information on the depth to certain rock, well yield, and water quality.

Observation of Surface Features

A third source of data on the presence of ground water is obtained from observation of surface features, including streams, springs, and vegetation.

Streams

Streamflows provide information about the presence of ground water.

Streams that flow only immediately after a rain indicate that surface runoff of precipitation is the source of the water. In this case, the

Review and Discussion
(continued)

4. After your review and the participants' discussion, show the second part of the slide/tape program on aerial methods, if you have not already done so.

5. When you are ready to proceed to a review and discussion of aerial methods, ask the participants to turn to page 5.

ground water table is lower than the stream bottom and ground water is not close to the surface.

If streams flow except during dry periods of the year, the flow is the result of both precipitation and ground water. Ground water may be available, but, during dry periods, it will occur only at greater depths.

Streams that flow all year can indicate significant amounts of ground water. The streamflow during dry periods in this case will come almost entirely from ground water.

Springs

Springs are areas where the water table intersects the ground's surface. Springs may be a reliable source of ground water, and may indicate the water table depth in nearby areas. However, it is important to check whether the springs dry up during dry periods of the year.

Vegetation

All vegetation needs some water to survive. The locations of certain types of trees and plants indicate where water is more abundant or closer to the surface.

Discussion Questions

Discuss the following questions with the members of your group. Then summarize your responses for the other groups of participants.

- Describe any knowledge or experience you have gained in the use of existing field data to locate ground water supplies.

- What information did the data provide and how was the information applied?

- What sources of existing field data have you employed? Which agencies or organizations make existing field data available in your region or country?

INSTRUCTOR NOTES

PART II: AERIAL METHODS

Review and Discussion of Satellite Imagery

Time required: 35 minutes

1. Review the summary information on pages 5 through 10 with the participants.

2. Then ask the participants to discuss the questions on page 10 with the members of their group and to summarize their discussion for the other groups of participants.

3. Distribute examples of satellite imagery photographs and interpretative reports. Explain how the information was applied in locating ground water supplies. Describe any other methods that were used to supplement the information from satellite imagery.

4. Cite any local, regional or international sources that can provide satellite imagery information on the participants' regions or countries.

PART II: AERIAL METHODS

Two common aerial methods of locating ground water are the use of satellite imagery and aerial photographs.

Review and Discussion of Satellite Imagery

Surface features that are indicators of subsurface conditions are often identified more readily by photographing the surface of the earth with black and white or various color bands through satellite imagery. For example, ice cover on streams, geologic structures, types of vegetation, streamflow and other surface features that are photographed through satellite imagery can all be used to infer the presence of ground water.

Method

Satellite imagery involves remote sensing, that is, the use of reflected and emitted energy to measure the physical properties of distant objects and their surroundings. The information is often photographed on color infrared film. The film displays the landscape in colors that are different from the way the landscape appears to the human eye. For example, surface bodies of water may appear black and healthy vegetation may appear bright red.

Advantages and Uses

The knowledge gained from satellite imagery typically is used in conjunction with other data to confirm or expand information about a specific area.

Satellite imagery offers the greatest economic benefits when used at the beginning of a project, prior to field work. The advantages of early use of satellite imagery include: 1) reduction of the need for field surveys in some areas; 2) direction of attention to areas where detailed field studies are needed; and 3) a basis for organizing field work.

In addition, many broad, regional features can be seen easily on satellite imagery but would be difficult or impossible to see on the ground or on low-altitude aerial photographs. The synoptic view that satellite imagery provides and the sharpness of boundaries that appear gradational on the ground are the two main advantages of satellite imagery over aerial photographs.

Review and Discussion of Satellite Imagery
(continued)

Review and Discussion of Satellite Imagery
(continued)

Some present and potential applications of satellite imagery include the following:

- To make preliminary surveys of probable ground water occurrence, to determine the types of aquifers in an area and to estimate probable well yields.
- To delineate alluvial aquifers, using vegetation patterns and land forms.
- To estimate future streamflows and aquifer pumpage from the water equivalent of winter snowpack.
- To predict water use and to estimate changes in the pumpage of ground water for irrigation.
- To locate springs, seeps and shallow water table aquifers by the presence of plants that absorb water from the water table or other permanent ground water supply.
- To locate and identify recharge centers.
- To study the hydrologic significance of regional land forms and geologic structures.
- To map faults and joints that may be locations of ground water abundance in hard rock areas.
- To map circular features that may affect the quantity of ground water that is available in nearby areas.

Limitations

Limits to the types and amounts of information that can be obtained by satellite imagery are determined by surface cover and near-surface characteristics. In heavily vegetated regions, for example, satellite imagery provides mainly structural information; however, the presence of ground water can be inferred from landforms, drainage and vegetation patterns.

Two other limits to the use of satellite imagery are data acquisition and the need for interpretation and inference. Repetitive data from satellite imagery are rarely identical because of differences in atmospheric conditions. The accuracy of results depends upon the knowledge, skills and experience of the interpreter of the data.

Review and Discussion of Satellite Imagery
(continued)

Review and Discussion of Satellite Imagery
(continued)

The diagrams below are part of the interpretation reports of satellite images taken of the Zagros Mountains in Iran by NASA's Landsat. These interpretations have been made by reviewing the imagery and by reviewing other applicable data on the geology, land use and vegetation of the area. Figure 1 is an image interpretation. Figures 2 and 3 are geologic interpretations.

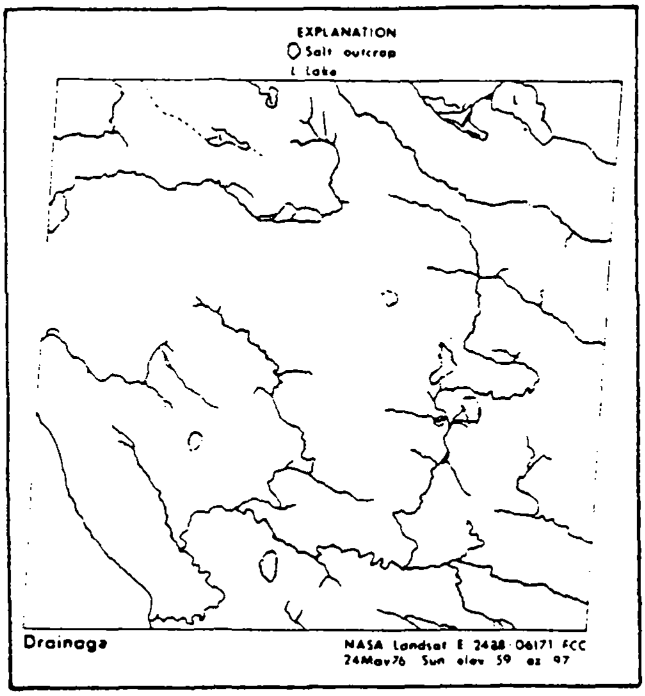


Figure 1

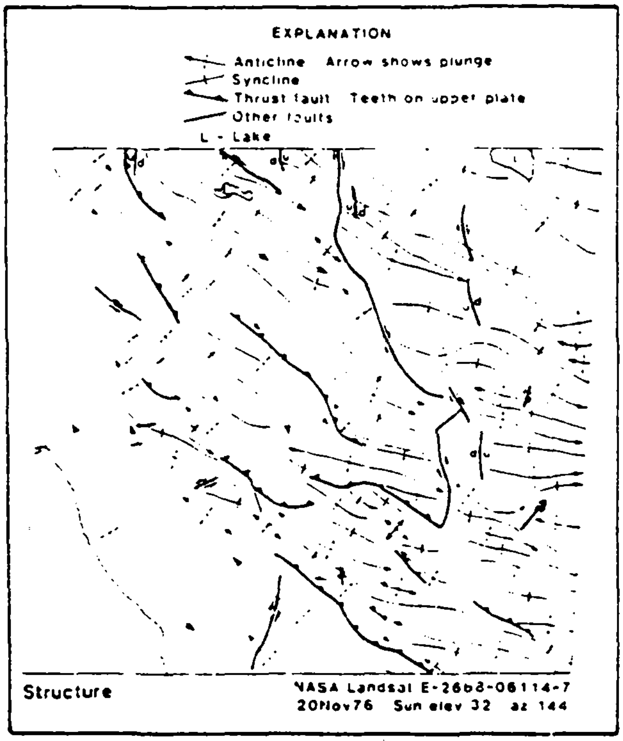


Figure 2

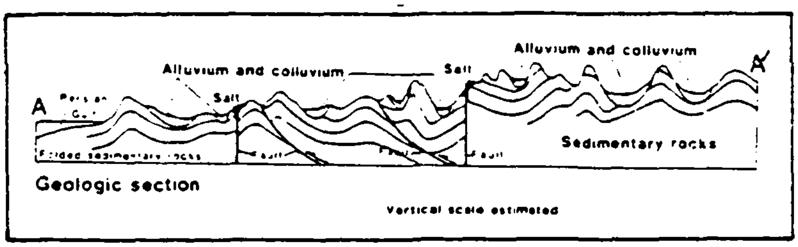


Figure 3

Review and Discussion of Satellite Imagery
(continued)

Figures 4 and 5 are ground water interpretations.

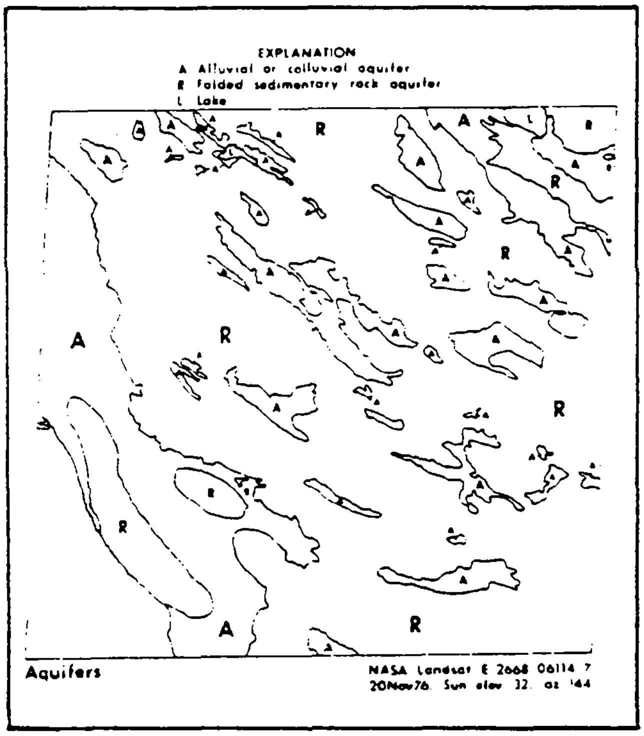


Figure 4

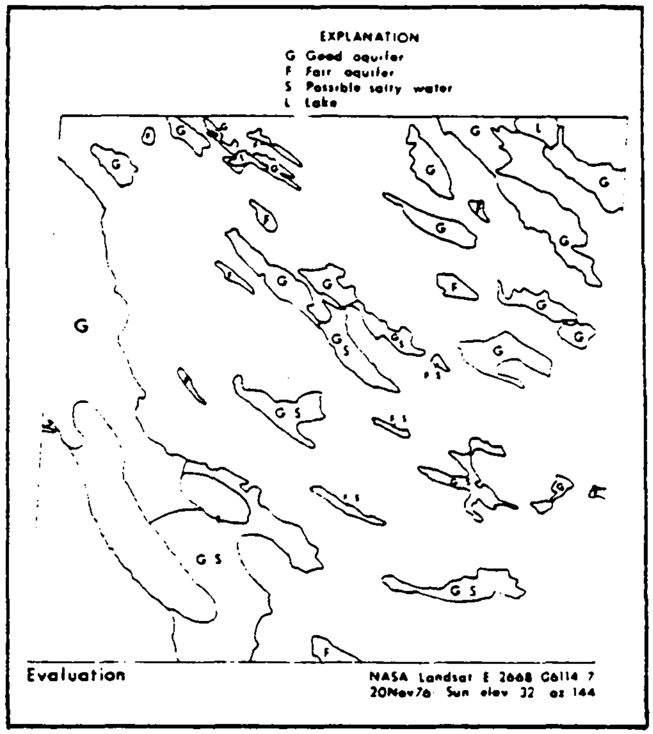


Figure 5

Springs and Seeps

Satellite imagery can often produce faster and cheaper inventories of springs and seeps than ground survey techniques. Only spring locations, however, can be determined. Water discharge rates must be measured or estimated on the ground.

Review and Discussion of Satellite Imagery
(coninued)

Review and Discussion of Satellite Imagery
(continued)

In arid regions, the presence of springs and seeps is indicated by snowmelt, soil moisture and vegetation patterns.

Snowmelt patterns show the combined results of heat sources. If everything else is equal, snow melts first in areas where ground water is at, or near, the surface.

Soils are darker where they have a high moisture content and different types or densities of vegetation may occur in these areas. In arid regions, color infrared photographs generally can detect the areas that indicate springs and seeps by the presence of vegetation.

Vegetation may also begin an earlier growth in areas where ground water is present. Early greening of vegetation is obvious in color infrared photographs on which the pink to red or reddish-brown hues of living vegetation are unique.

Streambanks and shoreline springs represent a special situation. The normal difference in temperature between land and water surfaces results in high contrast on satellite images. This change commonly obscures springs and seeps along a bank or shore. In this situation, good results have been obtained, however, by selecting a time to record images when the land and the surface water temperatures are nearly the same.

The water from underwater springs which discharge at the bottom of a lake or stream must rise to the surface to be detectable on satellite imagery because of water color or turbidity patterns.

Hydrologic Interpretation

Ground water interpretation of satellite imagery is based on inferring aquifer characteristics and water quality, including the following:

- Primary and secondary porosity and permeability characteristics of the materials;
- Aquifer boundaries;
- Estimated depth to the water table, saturated thickness, and estimated width;
- Relationship between topography and hydrology;
- Location of recharge and discharge areas;
- Relationship between ground and surface waters;

Review and Discussion of Satellite Imagery
(continued)

5. After your review and the participants' discussion, ask the participants to turn to page 11.

Review and Discussion of Satellite Imagery
(continued)

- Estimated well yields based on previous experience with similar aquifers;
- Ground water quality and whether it is fresh or saline.

The results of these interpretations can provide information on aquifer limits, ground water occurrence, and ground water quality.

Data Selection

One of the most important things that has been learned since repetitive satellite imagery has become available is that the time of year is a critical consideration for obtaining maximum information from the images. The best time depends upon the local conditions, weather patterns, and the interpretation objectives.

In summary, satellite imagery produces valuable information but is only part of the total information required for ground water location. It is important to supplement satellite imagery with topographic, hydrologic and geologic reports.

Discussion Questions

Discuss the following questions with the members of your group. Then summarize the discussion for the other groups of participants.

- What knowledge or experience have you gained in the use of satellite imagery to locate ground water?

- How has information from satellite imagery been used in your country or area to locate or confirm sources of ground water?

- Where is information from satellite imagery available in your country or area? What organizations or agencies can supply information from satellite imagery?

INSTRUCTOR NOTES

Review and Discussion of Aerial Photography

Time required: 35 minutes

1. Review the summary information on pages 11 through 14 with the participants.

2. Then ask the participants to discuss the questions on page 14 with the members of their group and to summarize their discussion for the other groups of participants.

3. Distribute examples of aerial photographs and accompanying interpretative reports. Explain how the information was applied to locate ground water. Describe any other methods that were used to supplement the information from aerial photographs.

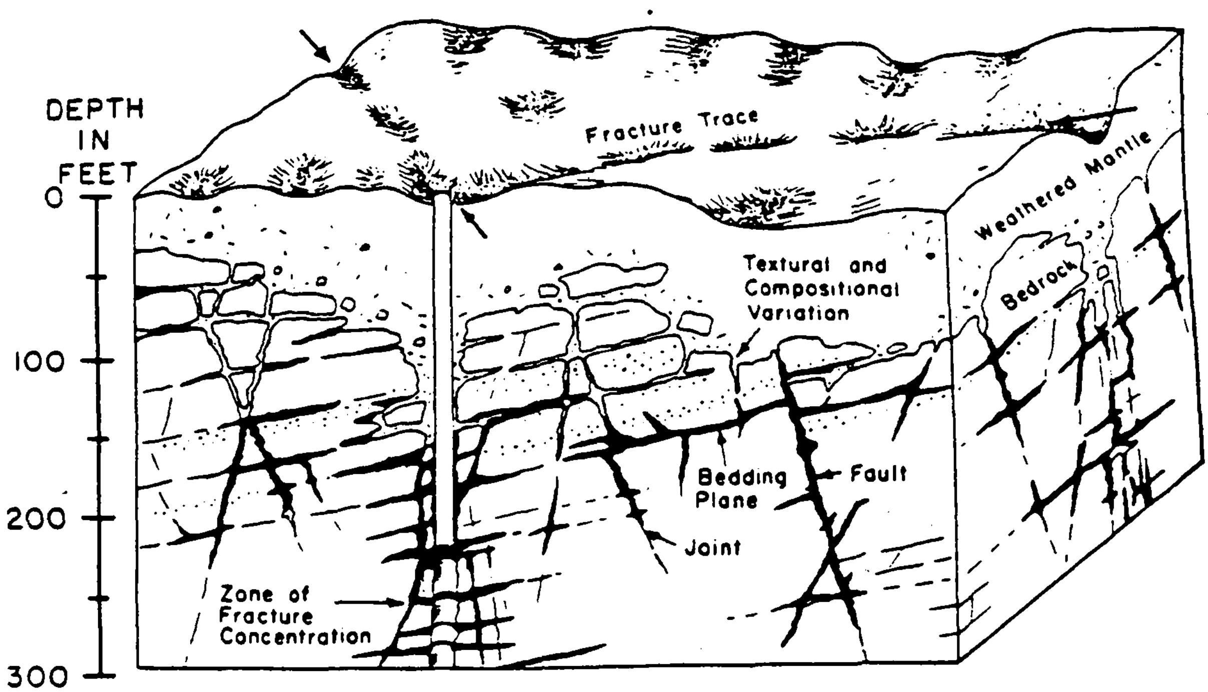
4. Cite any local, regional or international sources that can provide aerial photographs and related reports on the participants' regions or countries.

Review and Discussion of Aerial Photography

In addition to satellite imagery, a second aerial method is to take black and white photographs to locate fractures and fault zones. The method is called fracture trace analysis.

Fracture Zones

Ground water in hard rocks, such as limestone, granite and basalt, occurs in fractures. Fractures typically occur in zones, as shown in the diagram below.



SCHEMATIC DRAWING of water flow in and near fracture zone.

Zones of fractured rock containing significant quantities of ground water are indicated by subtle traces best detected on aerial photographs.

Concentrations of fracture zones facilitate deep weathering and formulation of undrained depressions. Over fractures, rocks are deeply

Review and Discussion of
Aerial Photography
(continued)

decomposed and the debris is removed in the rainy seasons. The existence of water in these areas during the dry season promotes higher and denser vegetation along water-bearing fractures which are usually located in a deep and straight valleys. These features can be seen on aerial photographs and used to infer the presence of ground water.

The most productive wells are located in fracture zones where the fractures intersect. Once the fracture intersections are identified, the intersection can be marked for drilling.

Fracture Trace Analysis

Fracture traces show up on aerial photographs as dark or light narrow lines in the soil and in the alignment of vegetation. The lines often denote continuous zones that can be as much as a mile long and fifty feet wide.

Fracture traces have been mapped in all types of terrain. Fracture trace analysis has the potential to be applied throughout the world wherever appropriate strata are found. Specifically, fracture traces may be used to select locations for wells where bedrock aquifers are not overlain by thick unconsolidated deposits.

So far, fracture trace analysis has had excellent success in the field. Some wells located by this method yield millions of gallons of water per day on a sustained basis. Others, located in rock types that traditionally have very low water yields, have produced more water than has ever been obtained from these rocks before. The fracture trace method has not proved to be successful in locating wells in uncemented soil and unconsolidated deposits, but the method can increase the probability of obtaining high yields from wells in other types of rock that seem unpromising.

Advantages and Uses

The advantage of selecting locations for wells by the aerial photography method are primarily economic, particularly when compared to the cost of drilling a well. Fracture trace location of water well sites consistently results in yields up to 50 times higher than the average for a given rock type in a given area. Use of the method also reduces the chances of drilling an unproductive well.

The fracture trace method, besides locating prime well sites, helps to characterize the subsurface "lay of the land" by documenting its

Review and Discussion of Aerial Photography
(continued)

physical conditions. Foreknowledge of the presence of highly fractured and decomposed rock can help keep tunnels, mines or building excavations from being flooded by ground water or being damaged due to poor foundation conditions.

Limitations

Where surface features have been greatly altered by natural or man-made events, the fracture-trace method cannot be applied.

In glaciated areas, or areas with very deep unconsolidated deposits, the technique is difficult to apply. And, in areas that have been subjected to extensive development, the surface signs of fracture traces may have been obliterated. For example, fracture traces, including lines of vegetation, changes in soil tone, surface sags and offset valley alignments can be wiped out by a bulldozer. For this reason, urban areas are almost impossible to prospect using aerial photography.

Hydrological Significance

In highly cemented or dense rock, such as limestone, significant amounts of water typically are obtained only from fractures or solution cavities. Even though well yields are typically increased more spectacularly in these types of rocks, well yields can still be improved in other rock types. The chart below lists the extent to which well yields have been improved by locating wells in fracture zones identified by fracture trace analysis.

Rock Type	Average Yield (gallons per minute)	Yield from Fractures (gallons per minute)
Metamorphic	-	100 - 200
Tightly Cemented Sandstone	20 - 30	100 - 200
Sedimentary Sandstone and Siltstones	100 - 400	500
Limestone, Dolomites and Marble	1 - 20	500 - 3000

<u>Review and Discussion of Aerial Photography</u>
(continued)

5. After your review and the participants' discussion, show the third part of the slide/tape program, if you have not already done so.

6. When you are ready to proceed to a review and discussion of geophysical methods, ask the participants to turn to page 15.

Review and Discussion of Aerial Photography
(continued)

To locate the water, the hydrologist must accurately locate and map the zones of fracture concentration, paying particular attention to the specific locations where these fractures in the rock intersect. By drilling precisely at the intersection point, the chances of obtaining a good supply of water are greatly increased.

Discussion Questions

- What knowledge or experience have you gained in the use of aerial photography to locate ground water?

- How has the information from aerial photography been used in your country or area to locate or confirm sources of ground water?

- Where are aerial photographs and related information on your country or area available? What organizations or agencies can provide them?

INSTRUCTOR NOTES

PART III: GEOPHYSICAL METHODS

Review and Discussion of Surface Methods

Time required: 35 minutes

1. Review the summary information on pages 15 through 20 with the participants.

2. Then ask the participants to discuss the questions on page 20 with the members of their group and to summarize their discussion for the other groups of participants.

3. Distribute examples of information obtained through electrical resistivity surveys and seismic surveys. Explain how the information was applied to locate ground water. Describe any other methods that were used to supplement the information from the surveys.

4. Cite any local, regional or international sources of electrical resistivity and seismic surveys of the participants' regions or countries.

PART III: GEOPHYSICAL METHODS

The two types of geophysical methods of locating ground water are surface and borehole methods. Surface methods are conducted on the surface of the land. Borehole methods are conducted below the earth's surface in a well or test hole.

Successful use of geophysical methods depends upon a skilled technician who understands the principles involved and can interpret the results. Geophysical surveys should be used as a supplement to other investigative methods. Nevertheless, in many cases, geophysical methods offer a faster and more economical means of exploration than is possible through drilling.

Review and Discussion of Surface Methods

Surface methods measure the distance and depth to a geologic boundary. The boundary can be detected because the rocks on each side of the boundary have different physical or electrical characteristics. These characteristics are related to the ability of the rocks to hold and transmit water.

The two surface geophysical techniques that are commonly used in ground water location are electrical resistivity surveys and seismic surveys. Both techniques can be performed with portable equipment. Typically, these surveys can be run along profiles thousands of feet long in a single day.

Electrical Resistivity Surveys

Earth materials have certain characteristics of resistance to the flow of electrical current which are dependent upon the nature of the materials themselves. These materials, which include both surface deposits and bedrock, conduct electrical current in amounts which depend upon properties, such as porosity, permeability and the amount and chemical quality of the water contained in pore spaces. In general, the greater the porosity and permeability, and the more saline the water, the less resistance there will be.

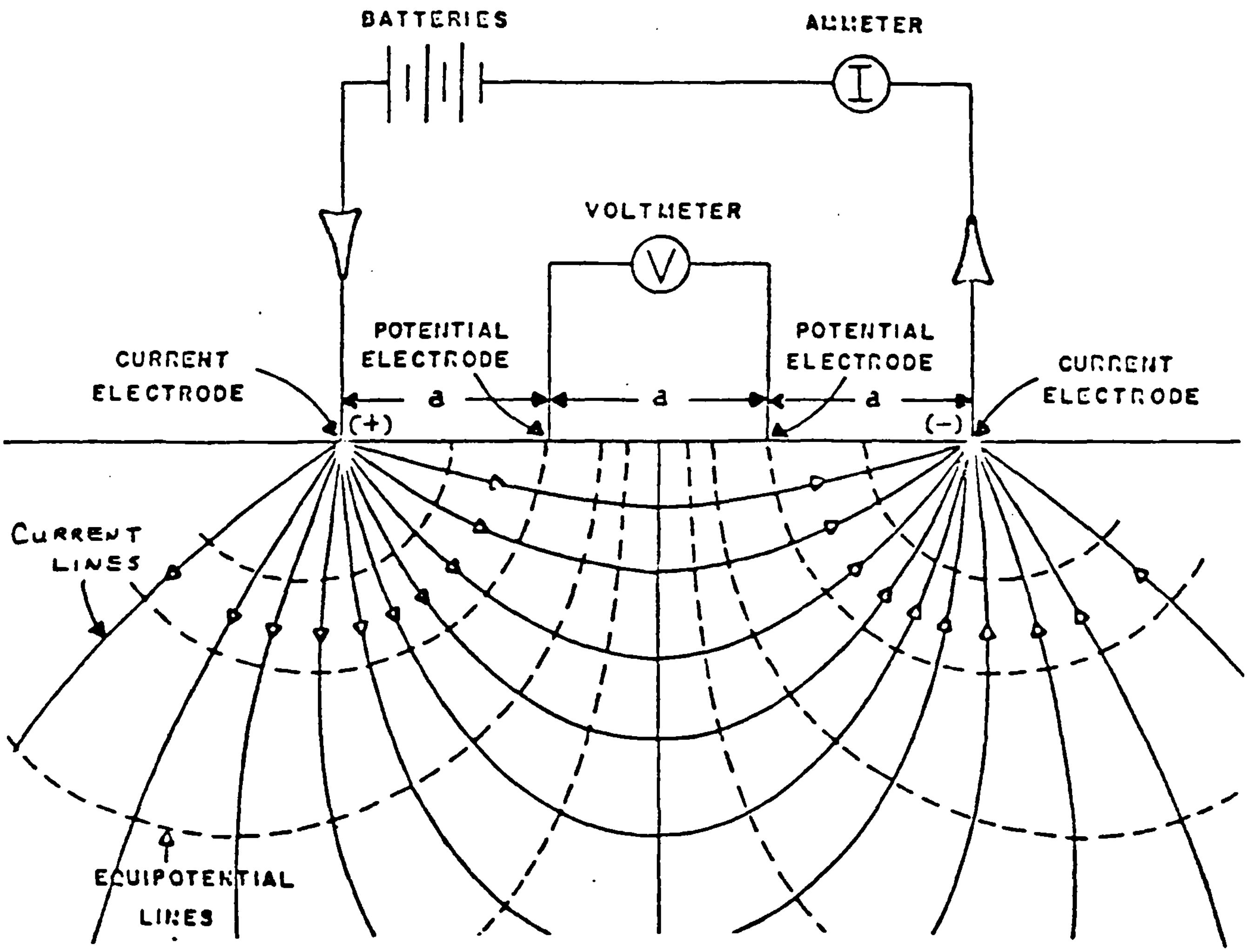
Method

In electrical resistivity surveys, four small electrodes, or electrical probes, are placed in the ground along a straight line. Using a battery as a power source, electrical current is injected into the ground. The current travels through the earth and the amount of resistance of the rock layers is measured by the drop in voltage at the two potential electrodes. Resistivity readings are affected by physical properties, such as the amount and quality of water.

Review and Discussion of Surface Methods
(continued)

Electrical resistivity surveys, therefore, may furnish information on both the subsurface geology and the water quality.

Variations in spacing arrangements of the electrodes are common, but the popular Wenner array uses a constant spacing between electrodes. As the diagram below shows, the four electrodes are placed in a straight line and at a constant distance apart. The outer two electrodes act as current electrodes. The inner two act as potential electrodes.



Review and Discussion of Surface Methods
(continued)

Review and Discussion of Surface Methods
(continued)

Current is applied to the outer electrodes. Since the earth material in the subsurface offers some resistance to the current flow, a voltage drop between the inner electrodes can be measured. This allows the determination of the apparent resistivity of the earth materials.

Resistivities

Clay-rich materials, such as fine-grained sediment or shale bedrock, have low resistances to the flow of electrical current. Coarse-grained materials, such as sand and gravels, have medium resistivities. Unweathered limestone and sandstone have higher resistivities.

Applications

Electrical resistivity surveys are useful in mapping buried stream channels. In addition to knowing the extent of a buried channel, it is also important to know its depth, which electrical resistivity surveys also can be used to evaluate. Once the extent and depth of the buried channel have been determined, the most promising site for a well can be selected.

Electrical resistivity surveys can also be used in coastal areas where salt water encroaches under the land, or in areas where salt water occurs underground. The surveys can indicate where the salt water and fresh water meet. The results of the surveys can help to determine a well depth that will avoid the salt water.

A third application of electrical resistivity surveys is to determine the depth to the water table. This application is limited to simple geologic areas, such as areas where the water table is not overlain or underlain by several layers of varying resistivities.

Review and Discussion of Surface Methods
(continued)

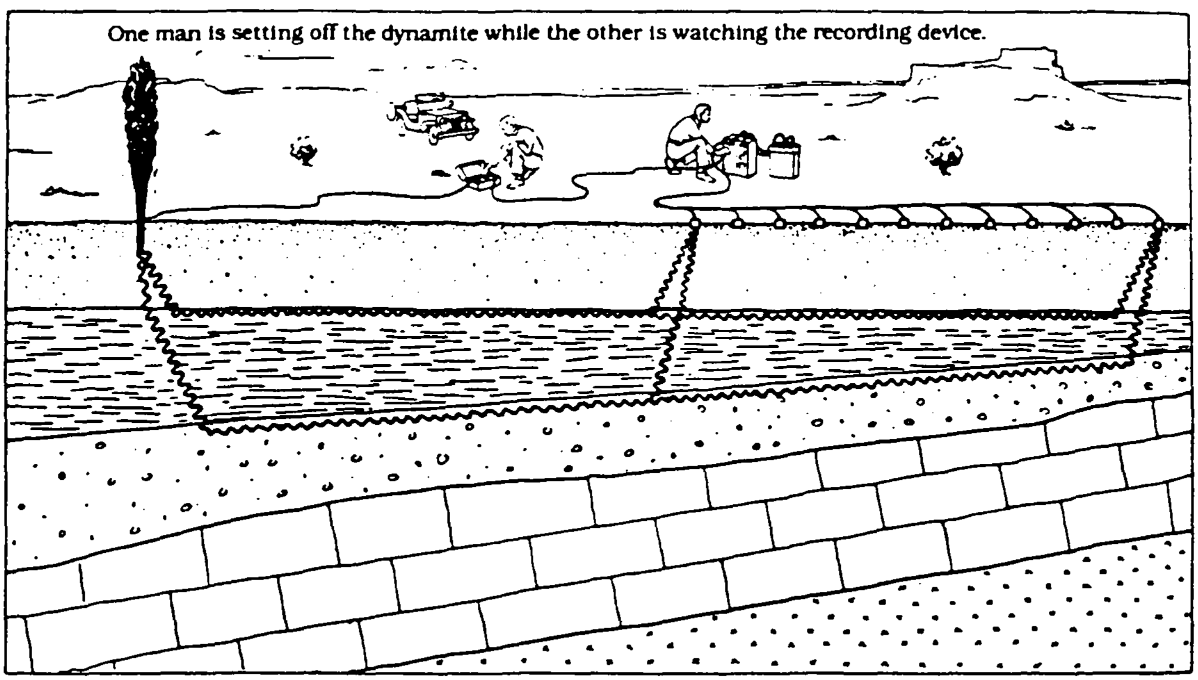
Seismic Surveys

Sending a shock wave into the earth can give a picture of the subsurface structure when the echo is recorded. The seismic method of surveying is based on the fact that the velocity of shock waves is different in different earth materials.

Method

Seismic surveys require the introduction of a shock wave into the earth, created either by a small explosion or by the impact of a heavy hammer. The shock wave reflects and refracts through different geologic layers. The waves are detected by geophones, which are simply electrical coils on a solid magnet core buried in the ground. The time it takes for the passage of the shock wave through the earth is recorded and interpreted to show types, depth and the thickness of individual rock layers.

The diagram below illustrates a typical set-up for a seismic survey.



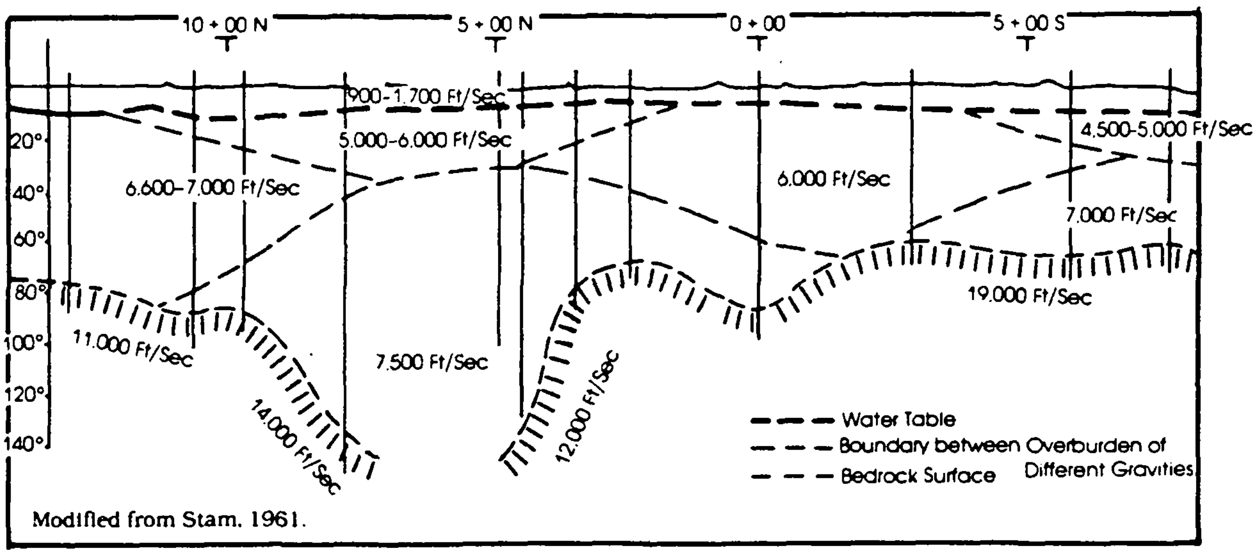
Review and Discussion of Surface Methods
(continued)

Review and Discussion of Surface Methods
(continued)

Seismic surveys help to define the subsurface geology, but unlike electrical resistivity surveys, they do not provide information about water quality.

Velocities

The velocity is generally higher in bedrock than it is in unconsolidated surface deposits. Porous layers tend to have lower velocities than more dense, less porous layers. By precise timing and mathematical analysis, it is possible to locate and to profile the depth to earth materials which may be suitable aquifers, as shown in the example below of a subsurface cross-section.



Earth materials can be divided into three groups of velocity.

Till and unconsolidated clay have low velocities of 1,000 to 3,000 feet per second.

Gravel and dense sand have medium velocities of 3,000 to 6,000 feet per second.

Consolidated or crystalline rock has a high velocity of 6,000 to 20,000 feet per second.

Review and Discussion of Surface Methods
(continued)

Review and Discussion of Surface Methods
(continued)

Applications

Seismic surveys are best suited to providing rapid, overall pictures of a terrain, then to be compared to other data. Seismic surveys are not accurate enough to pinpoint thin zones. Thin zones are layers that are too long, or too much like an overlying layer to make any significant echo that can be heard over other signals.

Seismic surveys are most commonly used to determine the thickness of unconsolidated deposits which overlie consolidated, non-water bearing bedrock. Because the shock waves travel at different velocities in the bedrock and in unconsolidated deposits, the surveys helps to indicate the depth to bedrock. Once the depth to bedrock has been determined, a well site can be located accordingly.

Seismic surveys can also be used in unconsolidated or semi-consolidated rock to determine the depth to the water table. This is possible because the velocity of shock waves is higher in saturated sediments and the water table acts as a reflector.

Another application of seismic surveys is to identify permeability differences within unconsolidated deposits. Once these differences are identified, a well site can be located in the area with the highest permeability.

Discussion Questions

- What experience or knowledge have you gained in the use of electrical resistivity surveys or seismic surveys to locate or confirm ground water?

- How was the information obtained through electrical resistivity or seismic surveys applied or used to supplement other data?

- Which organizations or agencies conduct electrical resistivity and seismic surveys and interpret the results?

INSTRUCTOR NOTES

Review and Discussion of Borehole Methods

Time required: 35 minutes

1. Review the summary information on pages 21 through 31 with the participants.

2. Then ask the participants to discuss the questions on page 31 with the members of their group and to summarize their discussion for the other groups of participants.

3. Distribute examples of information obtained through the four logging methods. Explain how the information was applied to locate ground water. Describe the methods that were used to supplement the information from the logs.

4. Cite any local, regional or international sources of logging information in the participants' regions or countries.

Review and Discussion of Borehole Methods

After using a combination of existing field data, aerial methods or surface geophysical methods, the results of the investigation must be verified. Results are verified by drilling a test hole or a well. After a test hole is drilled, it is necessary to further assess the water-bearing characteristics of the rocks. Borehole logging is used to identify water-producing zones in either a test hole or well in order to maximize the production.

Exploratory drill holes or wells are the only means of direct access to the subsurface. Drilling is an expensive means of access and sampling of the rocks and fluids penetrated are the only ways information can be derived from these holes.

Logging

Borehole logging is performed by slowly raising or lowering a sensor, or sonde, in the hole to gather information about the adjacent rocks. The information is transmitted to the surface as electrical impulses and is processed in a recorder. The processed information is displayed as a log.

Several factors are common to nearly all logs. The finished log is a chart that shows depth in addition to the properties being measured. Lines are drawn on the chart to give a graphic measurement of the property, indicating an increase one way or the other. Information about the borehole depth, size and location are also noted on the chart.

Valid logs, correctly interpreted, can be used to reduce future drilling costs by guiding the location, drilling and construction of test holes and wells.

Uses

Logs can provide continuous objective records with values that are consistent from well to well and from time to time, if the equipment is properly calibrated and standardized. In contrast to logs, samples of rock or fluid almost never provide continuous data.

Logs also permit time-lapse measurements to observe changes in a dynamic system. Changes in both fluid and rock characteristics and well construction caused by pumping or injection can be determined by periodic logging.

The graphic presentation of logs allows rapid visual interpretation and comparison at the borehole or well site.

Review and Discussion of Borehole Methods
(continued)

Types of Logs

The four types of geophysical logs that are commonly used in hydrogeologic investigations are resistivity logs, spontaneous potential logs, gamma ray logs and caliper logs.

Resistivity Logs

Resistivity logs are a specific type of electric log. They measure the apparent resistance of an electric current passing through earth materials. The measurement is made in apparent ohms of resistance per square meter of material in the earth and is typically displayed on a log.

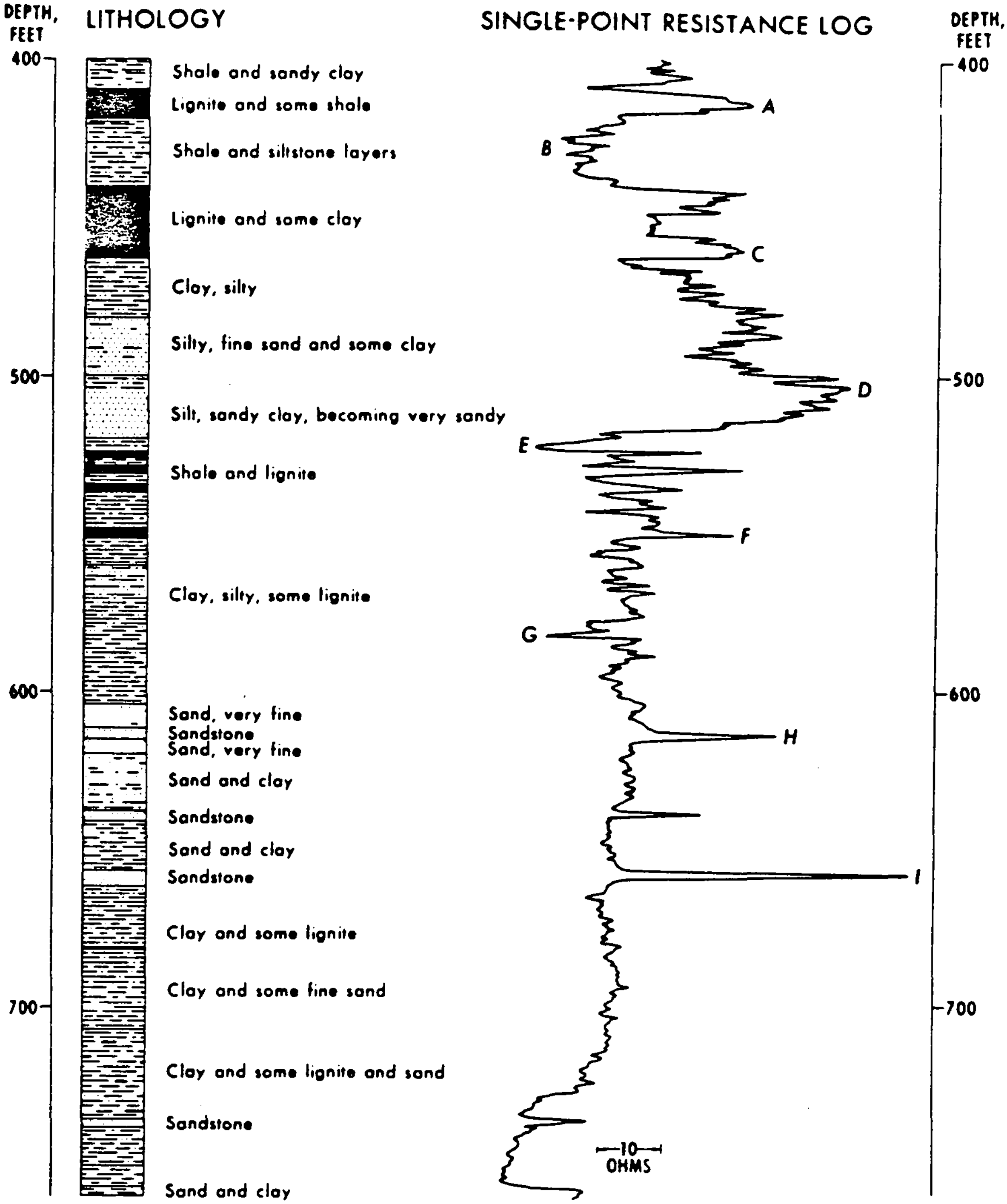
Use

The most common use of resistivity logs is to infer the permeability of a particular stratum, thereby projecting expected water yield. The top and bottom of the stratum can also be determined by varying the electrode spacing. In addition, electrical resistivity logs are helpful in determining water quality by delineating zones of high mineral content.

Method

Measurements of electrical resistance are made by a sonde which contains prespaced electrodes at specified intervals. The principle is similar to surface electrical resistivity in that resistance of flow to an electrical current is measured for the adjacent rock material. These measurements are then interpreted to determine the desired characteristics. The spacing of electrodes within the sonde are usually one of two types: short normal where the electrodes are spaced 640cm (16 inches) or long normal where they are spaced 190cm (64 inches) apart. A single point resistivity long may also be used. In this case, the voltage drop is measured between the electrode in the borehole and the one at the surface.

Review and Discussion of Borehole Methods
(continued)


DEPTH, FEET
LITHOLOGY
SINGLE-POINT RESISTANCE LOG
DEPTH, FEET
400
500
600
700
Shale and sandy clay
Lignite and some shale
Shale and siltstone layers
Lignite and some clay
Clay, silty
Silty, fine sand and some clay
Silt, sandy clay, becoming very sandy
Shale and lignite
Clay, silty, some lignite
Sand, very fine
Sandstone
Sand, very fine
Sand and clay
Sandstone
Sand and clay
Sandstone
Clay and some lignite
Clay and some fine sand
Clay and some lignite and sand
Sandstone
Sand and clay
A
B
C
D
E
F
G
H
I
10
OHMS

Review and Discussion of Borehole Methods
(continued)

Spontaneous Potential Logs

Spontaneous potential logs are another type of electrical log. They measure the very small natural electric currents found in a borehole. More specifically, they measure the electrical differences between the borehole fluid and the water in the rock.

The spontaneous potential phenomenon occurs because of several factors including the reaction of fluid in the formation with the fluid in the borehole, temperature, porosity, permeability and chemical content.

Use

This technique is most often used to determine the presence of salt water and assess water quality. It is also used to determine the top and bottom of strata.

Method

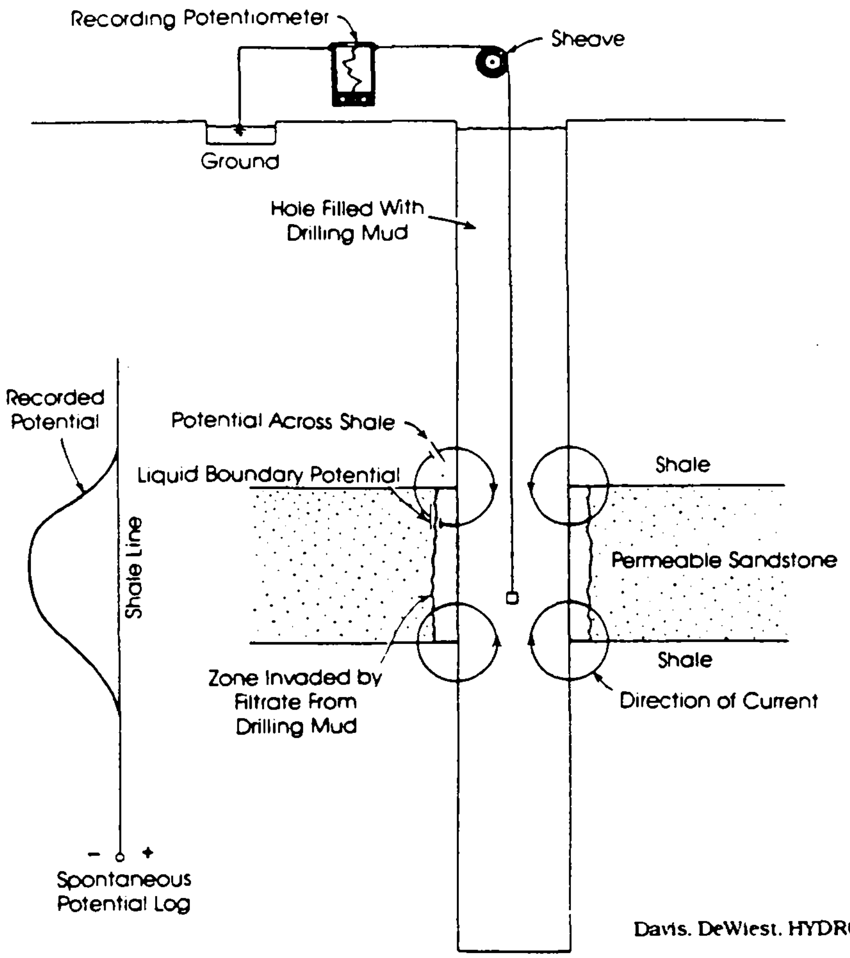
In its simplest form, a spontaneous potential logging device consists of a movable lead electrode which traverses the borehole on an insulated wire; a lead ground electrode; and a device for measuring potential.

The log measurements are in millivolts (1/1000th of a volt). However, spontaneous potential is a relative measurement which should only be compared to other readings taken in the same borehole.

Because the log is a measure of natural potentials, it can only be run in open, uncased holes that are filled with conducting fluid, such as water or mud.

The diagram in the next page illustrates a spontaneous potential log.

Review and Discussion of Borehole Methods
(continued)

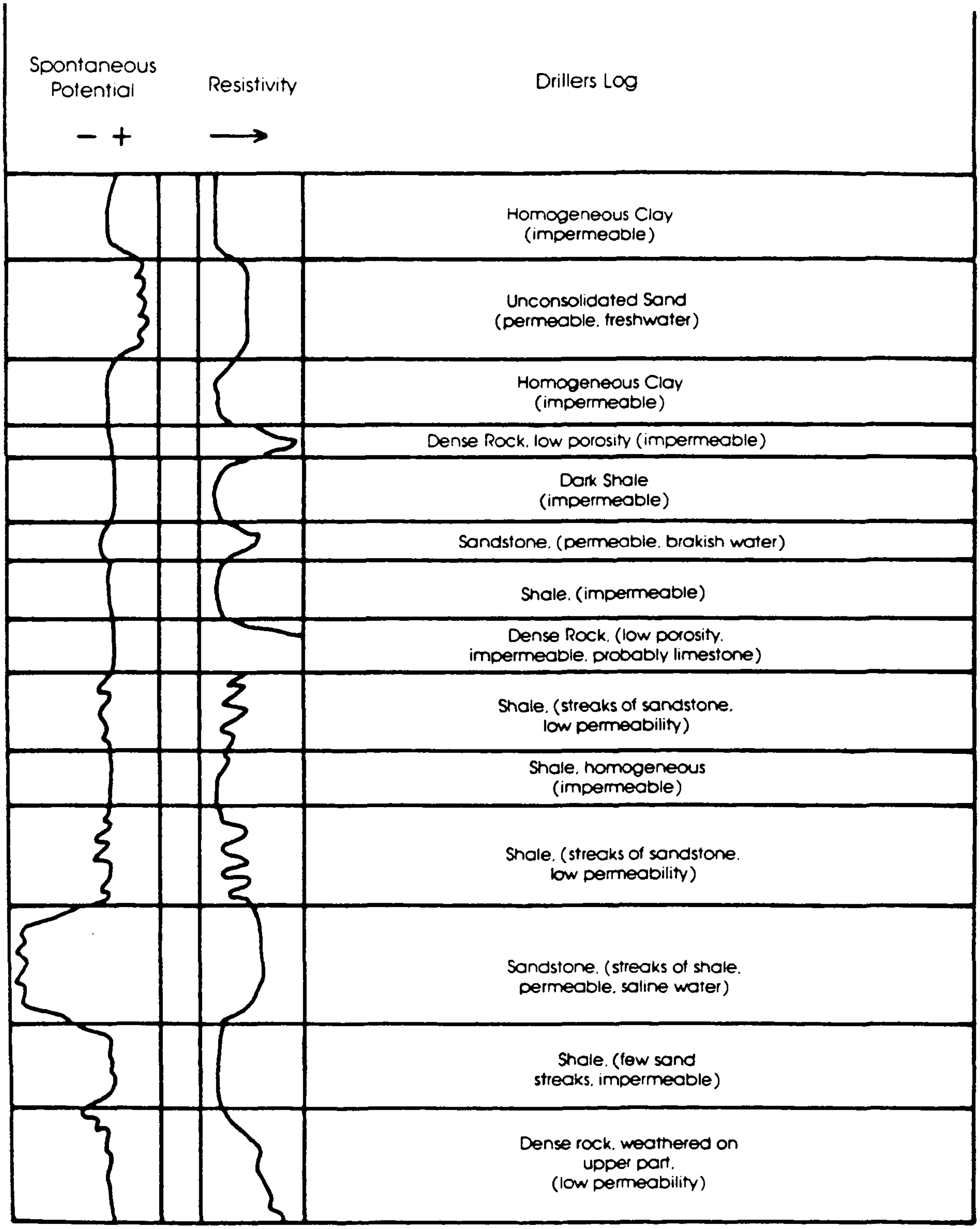


Davis. DeWiest. HYDROGEOLOGY

Review and Discussion of Borehole Methods
(continued)

Review and Discussion of Borehole Methods
(continued)

To facilitate comparison of both electric logs, a resistivity and spontaneous potential log are shown together in the diagram below.



Review and Discussion of Borehole Methods
(continued)

Gamma-Ray Logs

Gamma-ray logs comprise a third type of log. Virtually all rocks contain radioactive elements. When these elements decay, they emit a type of energy called gamma-rays. Gamma-ray logs are used to measure these emissions.

The most common sources of gamma radiation are uranium, thorium, and an isotope of potassium. Clays and shales normally contain higher concentrations of radioactive materials than clean sands and gravels.

A gamma-ray recording device measures the radiation intensity, or the number of particles that strike the probe per unit of measurement in milliroentgens per hour.

Uses

An advantage of the gamma-ray log is that it can be made in a cased well. Of the more common types of logs, only the gamma-ray (and other nuclear) logs can be made in a cased well.

Gamma logs can provide information on the depth and sequence of beds penetrated by a well. They are especially useful for correlating sediments and tracing them laterally.

Gamma logs have also been used as a basis for selecting the most favorable interval for screening sand and gravel wells and for judging the effectiveness of well development.

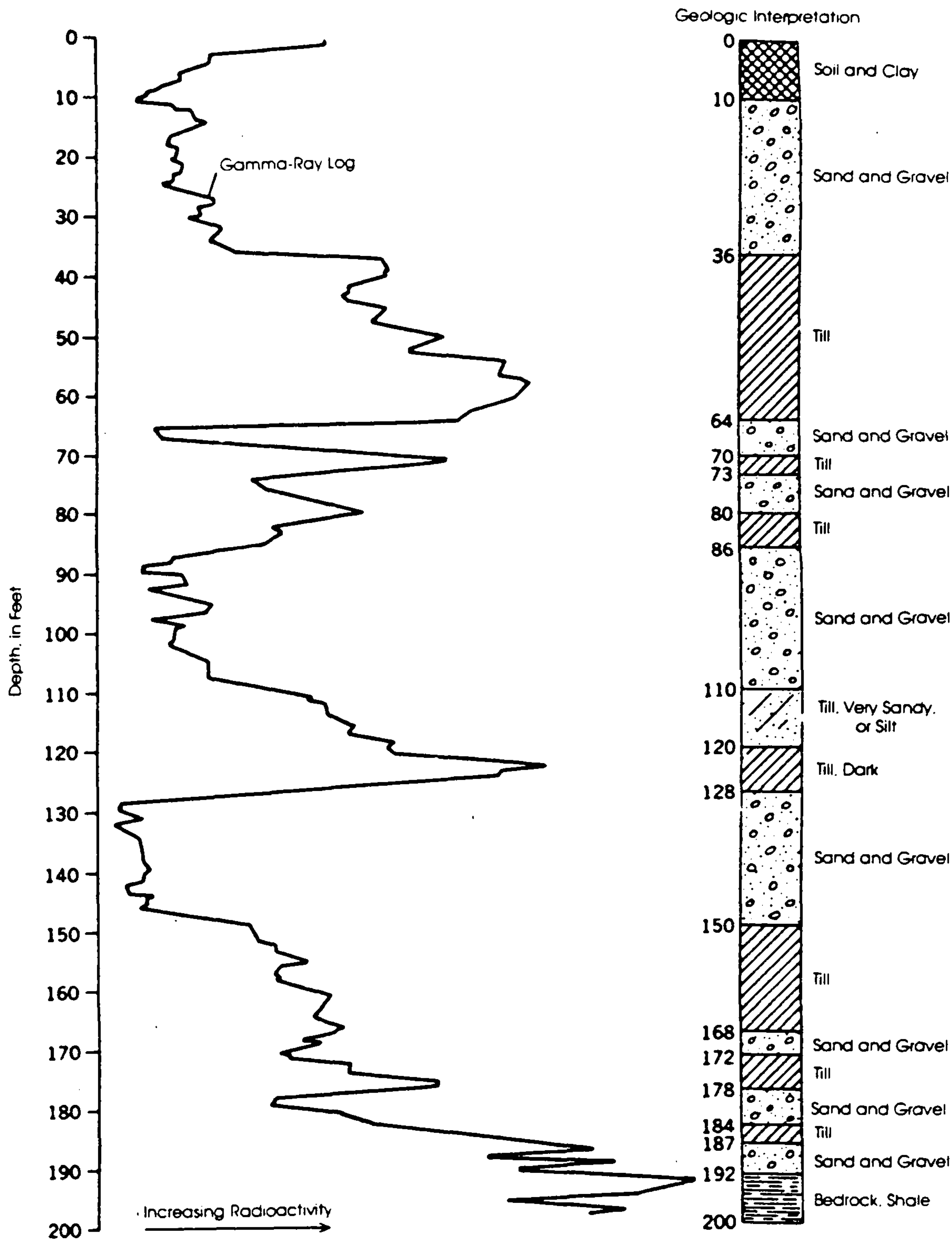
In general, a gamma log, by revealing subtle differences in unconsolidated sediments, can be highly useful in correctly interpreting drillers' logs.

Method

Gamma radiation is commonly detected by a scintillator, a device containing a sensitized instrument (usually a specially treated sodium iodine crystal) that emits light when struck by gamma radiation. The light emitted by the detector is coupled to a photomultiplier and converted into electrical pulses. The frequency is a measure of the radiation intensity. The detector is contained in a water-tight probe which is lowered into the borehole on the end of a cable.

The diagram on the next page is an example of a gamma-ray log.

Review and Discussion of Borehole Methods
(continued)


Geologic Interpretation
Gamma-Ray Log
Depth, in Feet
Increasing Radioactivity
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
0
Soil and Clay
10
Sand and Gravel
36
Till
64
Sand and Gravel
70
Till
73
Sand and Gravel
80
Till
86
Sand and Gravel
110
Till, Very Sandy, or Silt
120
Till, Dark
128
Sand and Gravel
150
Till
168
Sand and Gravel
172
Till
178
Sand and Gravel
184
Till
187
Sand and Gravel
192
Bedrock, Shale
200

Review and Discussion of Borehole Methods
(continued)

Review and Discussion of Borehole Methods
(continued)

Caliper Logs

Caliper logs are used to measure the size of the borehole. Expanding "feeler" arms record variations in borehole size which helps to determine rock type, bedding planes and fracture zones.

Use

Continuous logging of the average diameter of boreholes is one of the most useful and simplest borehole methods.

Caliper logs are primarily used to evaluate the environment in which other logs are made in order to correct them for hole-diameter effects and to provide information on rock types.

The location of fractures in igneous and metamorphic rocks, bedding planes in sandstone, and of solution openings in limestone, are important uses of caliper logs.

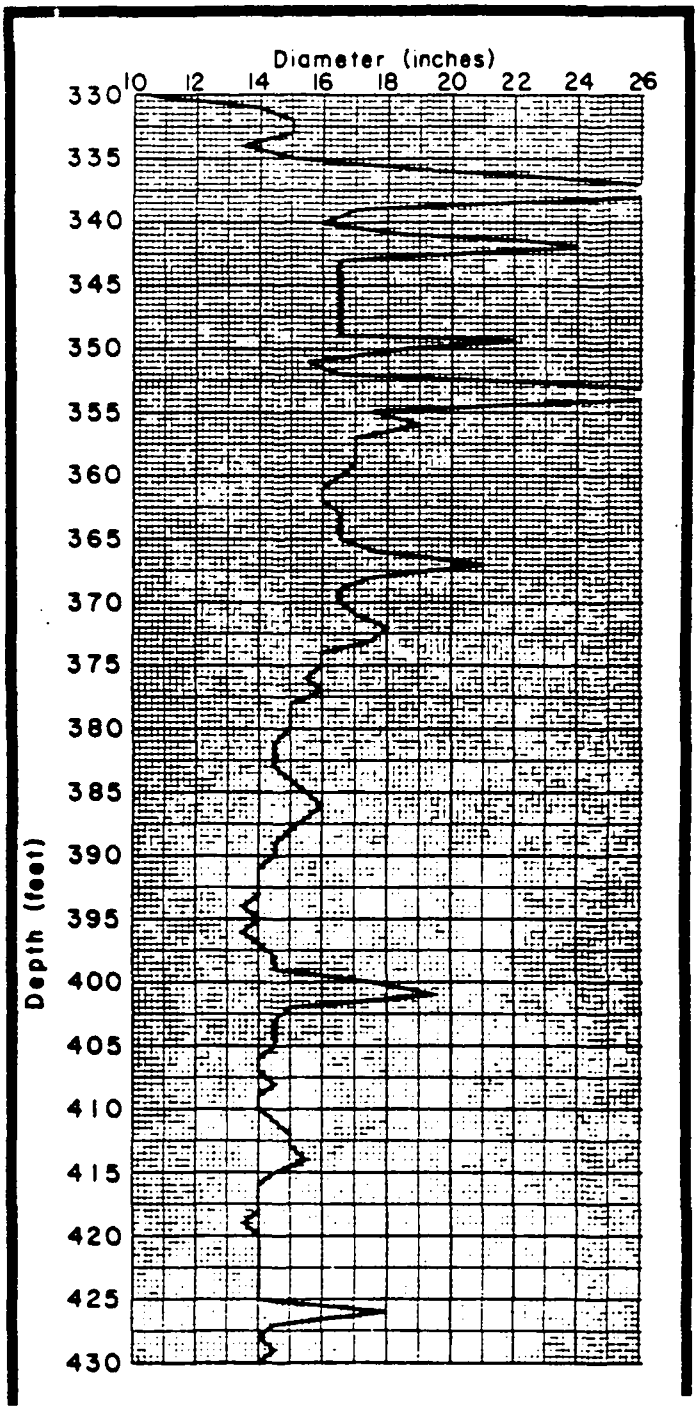
Method

A caliper log involves the use of sondes that consist of one to four pads (or feelers) which follow the wall of the hole. The graphic record for the log is calibrated in inches and reports the average hole diameter.

Two basic measuring systems are used in caliper tools: arms or feelers that are hinged at the upper end and maintained against the hole wall by springs, or, bow springs fastened at both ends.

An example of a caliper log of a municipal water well is shown on the next page.

Review and Discussion of Borehole Methods
(continued)


Diameter (inches)
10 12 14 16 18 20 22 24 26
330
335
340
345
350
355
360
365
370
375
380
385
390
395
400
405
410
415
420
425
430
Depth (feet)

<u>Review and Discussion of Borehole Methods</u>
(continued)

Review and Discussion of Borehole Methods
(continued)

Because it is difficult to determine the exact water-bearing zones using only one log, frequently a "suite," or series, of logs will be run in the borehole and the results compared. When this is done, it is much easier to determine the depth of various productive formations and more accurate in identifying water-bearing zones.

Discussion Questions

Discuss the following questions with the members of your group. Then summarize your discussion for the other groups of participants.

- What knowledge or experience have you gained in the use of logs to locate or confirm sources of ground water?

- What information did the logs provide? How was that information used with any other ground location methods?

- What local, regional or international sources can provide logging assistance in your region or country?

Comparison of Location Methods

Time required: 20 minutes

1. Present the charts on the next two pages as an aid in comparing the procedures, personnel requirements, area coverage rates and results of a variety of ground water location methods.

2. Provide any additional information that you may have on the suitability and cost effectiveness of the various methods in relation to the participants' regions or country and the types of ground water projects they are likely to undertake.

Comparison of Location Methods

Table 1.--A COMPARISON OF REGIONAL EXPLORATION METHODS FOR GROUND WATER

Method	Procedures	Personnel Requirement	Area Coverage Rate	Results
Interpret satellite images or mosaic.	Analyze tones, textures, shapes, patterns, location and association.	One scientist, in office.	3,000 to 34,000 km^2/day	Interpretation of lithology, (composition of rock) structure, and ground-water occurrence based on landforms drainage patterns, land use, soil tones, and vegetation types and patterns.
Geologic reconnaissance.	Examine lithologies, orientations, and fracture patterns.	One scientist, in field.	250 km^2/day	Generalized geologic map and section showing lithology, stratigraphy, and structure.
Hydrologic reconnaissance	Inventory largest wells and springs. Examine rock types, orientations, and fracture patterns.	One scientist, in field	100 km^2/day	Generalized hydrologic map showing aquifers, aquitards, and areas of recharge and discharge.

Comparison of Location Methods
(continued)

3. When you have completed your review of the two charts, summarize the module and assist the participants to plan how they can apply the information to their ground water location projects.

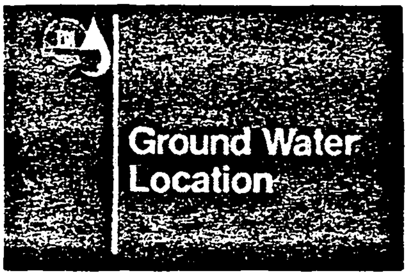
Table 2.--A COMPARISON OF LOCAL EXPLORATION METHODS FOR GROUND WATER

Method	Procedures	Personnel Requirement	Area Coverage Rate	Results
Interpret aerial photographs.	Analyze tones, textures shapes, patterns, location, and association	One scientist, in office.	100 to 500 km^2/day	Interpretation of lithology, (the composition of rock) occurrence based on landforms, drainage patterns, land use, soil tones, and vegetation types and patterns.
Detailed hydrologic mapping.	Inventory all wells and springs. Determine nature of ground-water occurrence. Determine aquifer characteristics.	One scientist, in field.	10 km^2/day	Information on ground-water occurrence, well yields, and water quality. Description or model of targets for test drilling.
Detailed geologic mapping.	Examine lithologies orientations and fracture patterns. Trace contacts.	One scientist, in field.	2.5 km^2/day	Detailed geologic map and sections, showing lithology and structure based on rock outcrops, soils, and vegetation.
Electrical prospecting.	Measure Earth's electrical potential and resistivity.	One scientist and two to four helpers	2.5 to 12 km^2/day	Interpretation of vertical stratigraphy, lateral changers in lithology, and structure (including locations of rock fractures).
Shallow test drilling.	Soil auger or jetting rig.	One scientist, one driller, and two helpers.	0.5 to 5 km^2/day	Lithology, porosity, and permeability of unconsolidated materials.
Deep test drilling.	Cable-tool or rotary rig and geophysical logs.	One scientist, one driller, and two helpers.	0.1 to 1 km^2/day	Lithology, porosity, and permeability of subsurface materials. Well yield and aquifer characteristics.

"GROUND WATER LOCATION"

SLIDE/TAPE PROGRAM VISUALS AND NARRATION

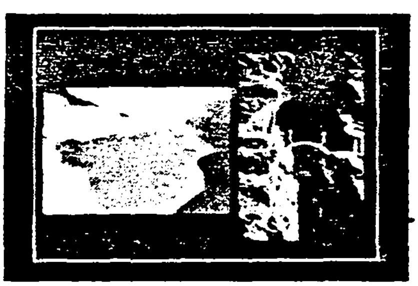
GROUND WATER LOCATION - PART I

1. 

TITLE SLIDE: Ground Water Location Part I.

2. 

NARRATOR:
Throughout the world each day more than 2 trillion gallons of water, or 8,000 million cubic meters, are used by man for drinking, hygiene, agriculture and industry.

3. 

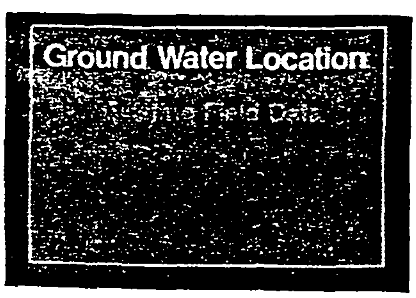
Of this water, slightly more than half comes from surface waters such as rivers or reservoirs.

4. 

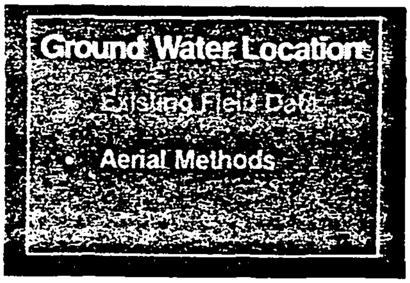
And slightly less than half comes from ground water which is stored in vast quantities underneath the earth's surface.

5. 

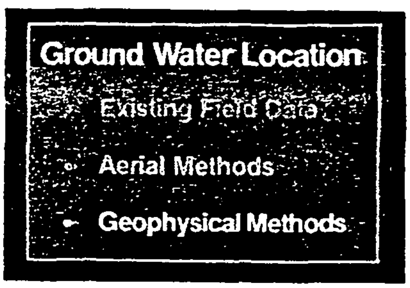
In order to satisfy growing water demand, ground water will have to provide increasingly more of the world's water. For this reason, it is essential to understand where it occurs and how to locate it. Ground water occurs almost everywhere beneath the earth's surface, but certain techniques may make it easier to locate an adequate supply.

6. 

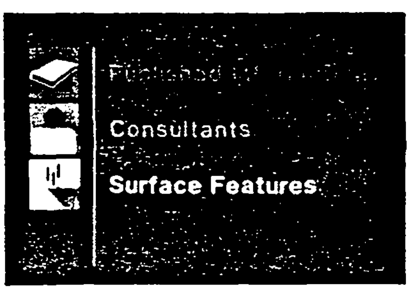
In this program, we will look at three ways to locate ground water. In the first part of the program, we will examine ways to interpret existing field data from reports, maps and observations.

7. 

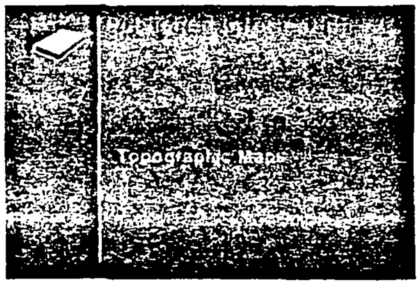
In the second part of the program, we will discuss aerial methods for locating ground water using photographs taken high above the earth's surface.

8. 

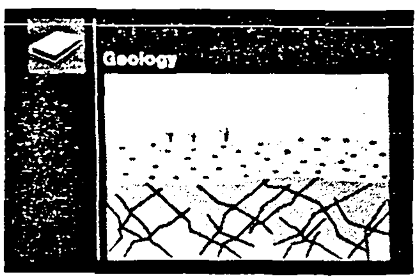
In the third part of the program we will talk about the uses of geophysical methods for finding and evaluating the ground water supply.

9. 

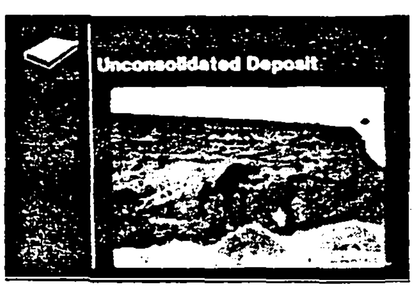
Now let us review the first method of locating ground water by using existing field data. Existing field data may be obtained from published information by speaking with local consultants or by observing features on the land surface. We will now discuss each of these sources in more detail.

10. 

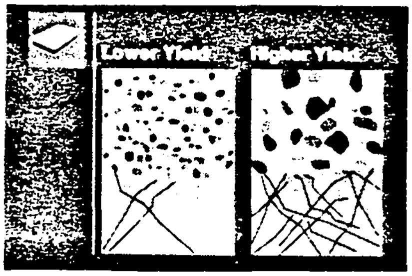
Some types of field data exist in published form. We will review three types of published information: geologic reports, water resource reports and topographic maps. These materials are available from a wide variety of sources including government agencies, consultants, local organizations, libraries and international agencies.

11. 

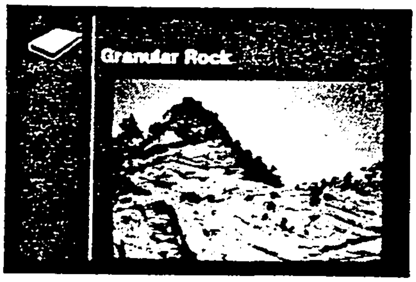
Geologic reports contain information on the different kinds of unconsolidated deposits and rocks which make up the underground environment. By knowing the types of deposits and rocks, we can sometimes infer the availability of ground water. To illustrate this, let's review some types of deposits and rocks and the water content that they indicate.

12. 

First let us discuss unconsolidated deposits. They are an uncemented mixture of clay, silt, sand and gravel-sized particles which overlie consolidated rocks. Where these deposits contain larger-grained particles, and are sufficiently thick, they may contain significant amounts of water.

13. 

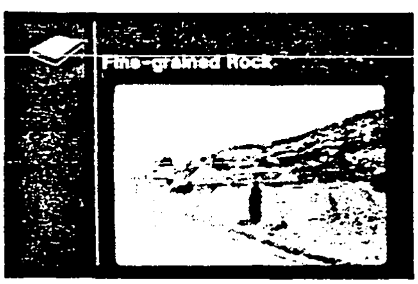
However, the amount of water which can actually be withdrawn from the ground depends on the thickness of the overlying deposits and the permeability. Permeability is a measure of how easy or difficult it is to withdraw water from the ground. Permeability is influenced by two factors: the grain size and amount of other openings in the rock. As we will see next, the larger the grain size and the more fractured the rock, the higher the yield of the aquifer.

14. 

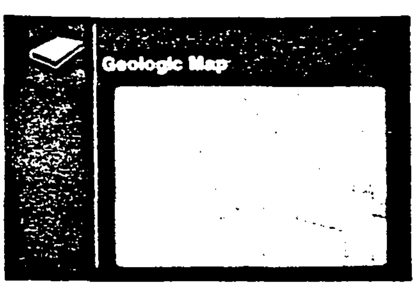
In addition to unconsolidated deposits, consolidated granular rocks, such as sandstone, may also serve as aquifers. This is the case where the voids within the rock are <u>not</u> filled with significant amounts of the cementing agent which hold the rock together. These interconnected voids serve to store and transmit water. Fractures or cracks in the rock may also increase the yield of the aquifer.

15. 

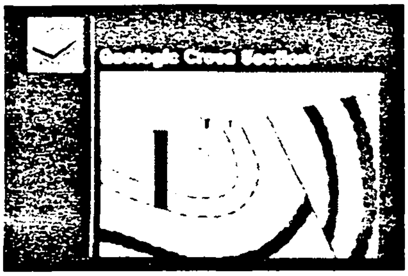
Non-granular rocks such as limestone, granite or basalt may also serve as important aquifers. However, because these rocks are non-porous, water occurs only in interconnected fractures and openings within the rock. If the rock does not have a significant amount of openings, it will not yield appreciable amounts of water.

16. 

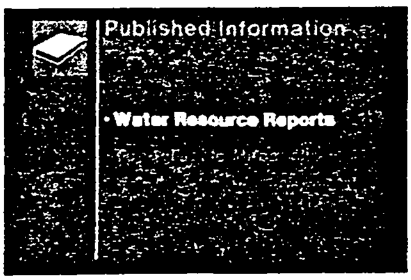
Fine grained rocks, such as shale, or fine grained deposits containing large amounts of silts and clays do not serve as productive aquifers.

17. 

Geologic reports display information in a variety of ways. For example, a geologic map can provide a quick overview of the geology of an area. The different rock types which intersect the surface of the earth are indicated by different colors or symbols.

18. 

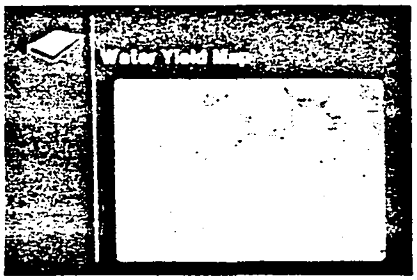
In addition to geologic maps, geologic cross sections may be prepared. These cross sections also use colors or symbols to indicate rock type, depth and thickness. Cross sections are helpful in determining the depth necessary for a well to intercept a potential aquifer.

19. 

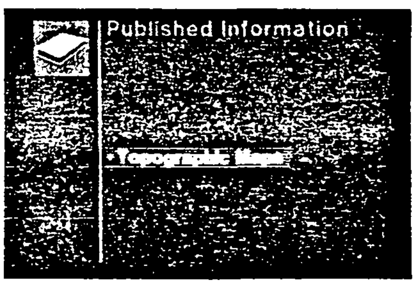
A second type of published data is the water resource report. This kind of report contains information on the availability of ground water in a given area.

20. 

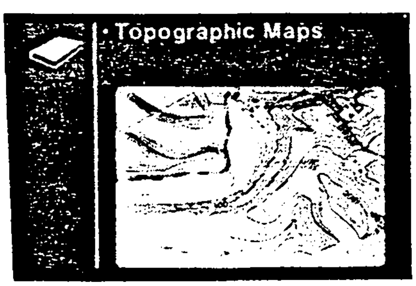
Water resource reports are similar to geologic reports except that they emphasize the water content of the rock. These reports commonly contain information on the size of an aquifer, its expected yield and its current production.

21. 

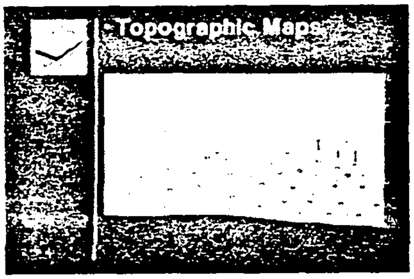
In addition to the text, water resource reports may also include maps that show the anticipated yield of rocks in the area.

22. 

A third type of published data includes topographic maps that may also provide valuable information on possible locations of ground water.

23. 

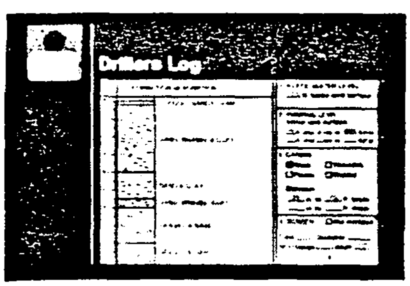
Topographic maps like this one, use a series of lines superimposed on the map to show elevation changes in the area. Each line represents a different elevation. Where the lines are closer together, the slope of the land is steeper; where the lines are farther apart, the land is flatter.

24. 

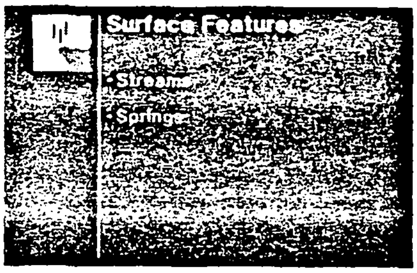
The water table commonly follows the surface of the ground, but is deeper under hills and shallower under valleys. Topographic maps may be useful when choosing locations for wells in hilly areas by indicating where the depth to water will be the shallowest.

25. 

In addition to the three types of published information we reviewed, there are also other sources of data. For example, local drillers or consultants who have already conducted studies in the area may have files or personal knowledge which may aid in ground water location.

26. 

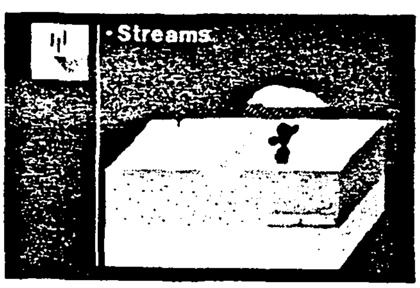
Consultant's files may contain driller's logs from existing wells. Good logs should contain information on the depth to certain types of rock, well yield and water quality.

27. 

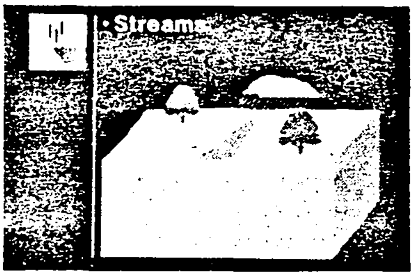
In addition to documented information, simple observation of surface features such as streams, springs and vegetation may provide clues to the presence of ground water.

28. 

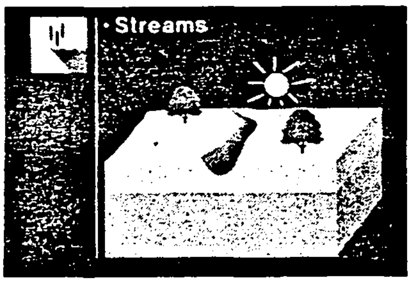
First, let us discuss streams. There are three different types of streamflow: streams that flow only immediately after a rain, streams that dry up during dry periods of the year and streams that flow all year around. Each type of streamflow has different implications for the presence of ground water.

29. 

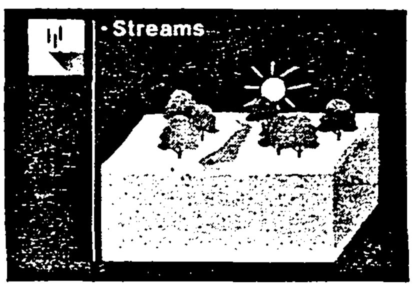
First, when streams flow only immediately after a rain, it is clear that the streamflow results entirely from precipitation and not from ground water. In this case, the ground water table is below the stream bottom. Therefore, it may be inferred that ground water does not occur close to the ground surface.

30. 

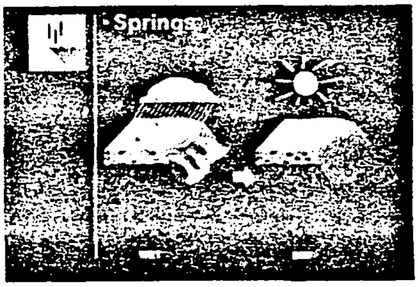
Second, when streams normally flow except during dry periods of the year, the flow in the stream is derived from both precipitation and ground water.

31. 

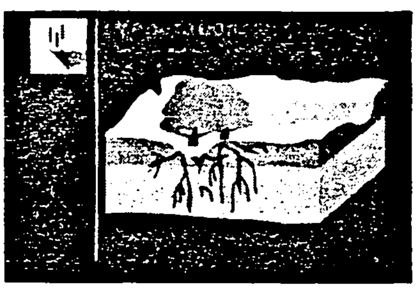
During these dry periods, the water table is lowered below the stream bottom causing the stream to dry up. This indicates that ground water may be available, but only at greater depths during drier periods.

32. 

Third, where streams flow all year round, the stream flow during dry periods consists almost entirely of ground water. These areas may provide a significant source of ground water.

33. 

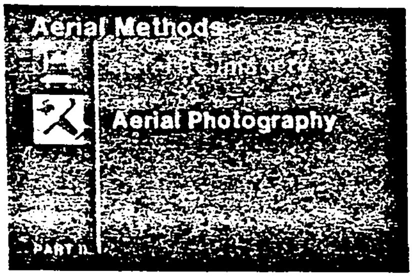
In addition to streams, springs can also be an indicator of ground water. Springs are areas where the water table intersects the surface of the ground. They may indicate reliable sources of ground water. However, if the spring dries up during dry times of the year, the spring may not be a reliable indicator of adequate ground water supplies.

34. 

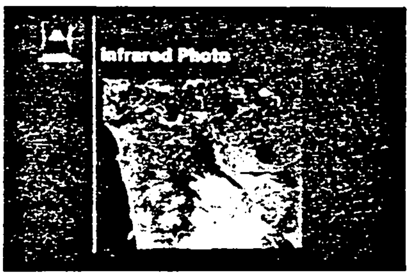
Another surface feature to observe is vegetation. All vegetation needs water to survive. However, certain types of trees and plants tend to grow where water is closer to the surface or more abundant. The presence of these plants can also be an indicator of ground water.

35. 

We have just discussed the analysis of field data and the observation of topography and vegetation to help locate ground water. These techniques are often adequate for locating domestic supplies. However, high-capacity wells or large-scale well field development may require more sophisticated location methods.

36. 

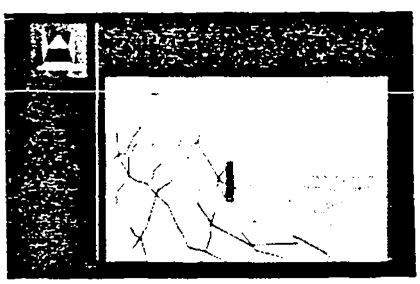
Part II of this program will review two aerial methods for locating ground water: satellite imagery and aerial photographs. Aerial methods allow some surface features which imply the presence of ground water to be seen more clearly from above the earth's surface. Both methods are used to estimate ground water availability, discern water quality and speculate on well yields.

37. 

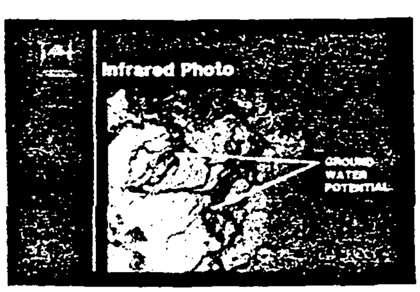
Satellite imagery is frequently produced as color infrared imagery in photographs such as this one. Color infrared film displays the landscape in colors which are different than they normally appear to the naked eye. For example, surface bodies of water may appear black, and healthy vegetation appear bright red. These photographs make it easier to distinguish features that may indicate the presence of ground water. Next we will examine some of these features in a series of photographs and discuss their implications for locating ground water.

38. 

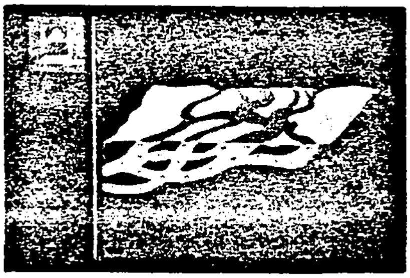
This photograph was taken along the coast of Jamaica. It shows the presence of circular turbidity plumes which usually indicate an area where surface water flows into the sea. However, since there are no rivers in this area, turbidity plumes imply the presence of ground water in the form of submarine springs.

39. 

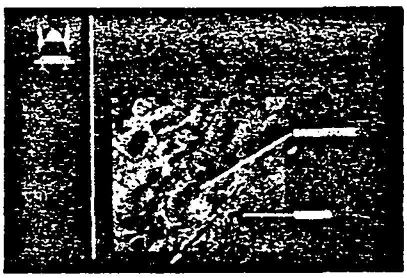
Even though rainfall is abundant in the mountains of Jamaica ground water is hard to locate. This is because the water infiltrates into the ground, flows into cracks in the limestone and is discharged into the sea through submarine springs. By locating wells in the vicinity of these springs, ground water can be intercepted before it mixes with the salt water.

40. 

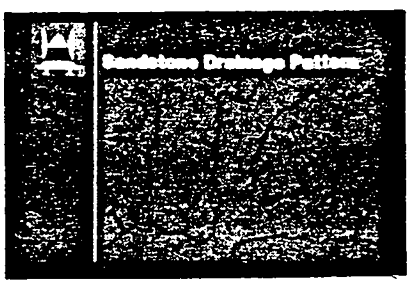
This is a photograph of the Columbia River Basin in the Northwestern United States. It shows a stream at the top and bottom of the picture and lighter colored areas in the middle. These lighter areas are former glacial meltwater tributaries which may indicate sources of ground water.

41. 

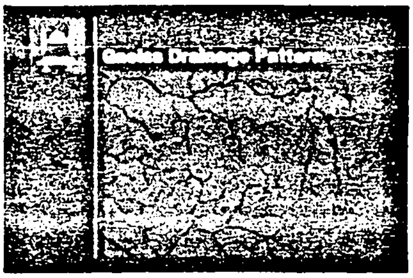
Glacial meltwater tributaries form at the edge of a melting glacier. When the glacier retreats, the meltwater streams dry up, leaving the coarse sand and gravel behind. When saturated, these deposits frequently serve as large sources of ground water.

42. 

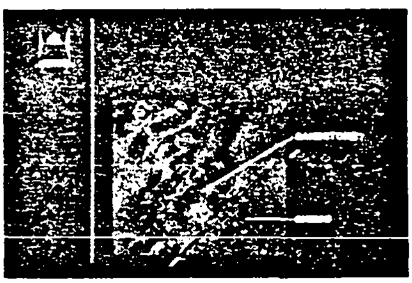
This photograph, taken in West Africa, is a good example of how satellite imagery helps identify rock types. The diagonal line across the photo indicates the boundary between two different rock types. The left side of the photograph is sandstone and the right side is gneiss. The other dark lines have been drawn in to show surface drainage patterns.

43. 

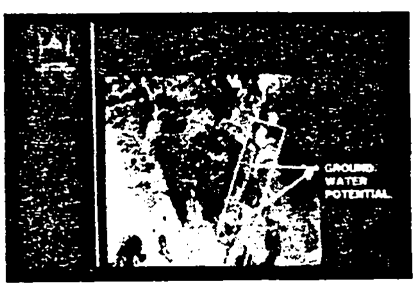
Surface drainage patterns are influenced largely by the permeability of the terrain. Thus, drainage patterns are used to determine rock type. The drainage pattern for sandstone is frequently rectangular and widely spaced because it follows joints and fractures within the sandstone.

44. 

Conversely, gneiss is a fairly impermeable rock that exhibits drainage patterns which are more branching. The larger number of tributaries per surface area is also characteristic of gneissic terrain.

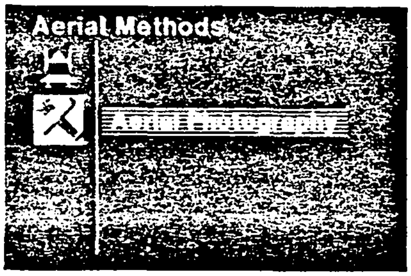
45. 

Once these drainage patterns have been identified, the rock type can be inferred and a generalization about ground water availability can be made.

46. 

In this photograph of Los Alamos, New Mexico, the pattern of vegetation allows us to infer the presence of ground water. The area in the center of the photograph is a mountainous wooded area. The outlined area to the right is a valley with sparse patches of vegetation along tributaries and springs. The presence of vegetation in these areas indicates likely sources of ground water.

47.

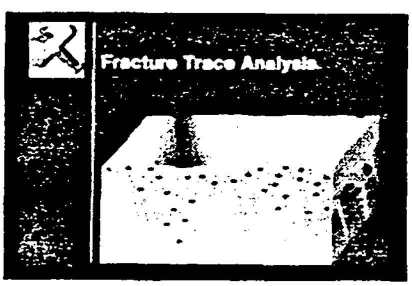


In addition to satellite imagery, a second aerial method uses aerial photographs. Black and white aerial photographs are commonly used to locate fractures and fault zones.

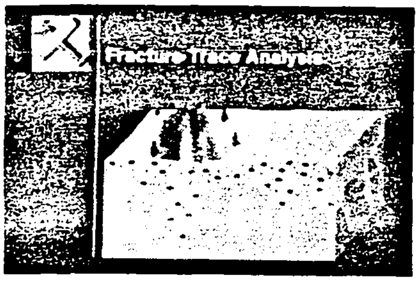
48.

This technique, called fracture trace analysis, is used to locate ground water in hard rocks such as limestone, granite and basalt where the water occurs in fractures. Fractures typically occur in zones. These zones may range in width from only a few feet to more than 200 feet and may be more than a thousand feet long.

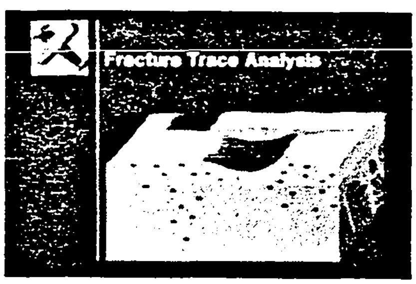
49.



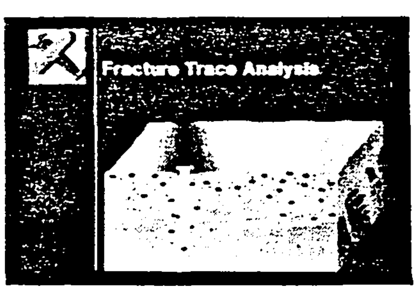
The presence of fracture zones may be betrayed by surface features such as shallow linear depressions. . .

50. 

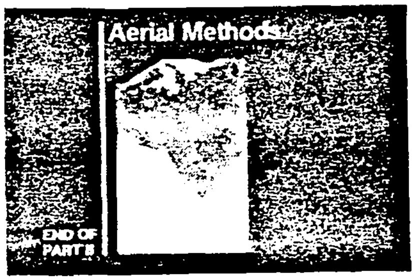
By areas of taller or more lush vegetation. . .

51. 

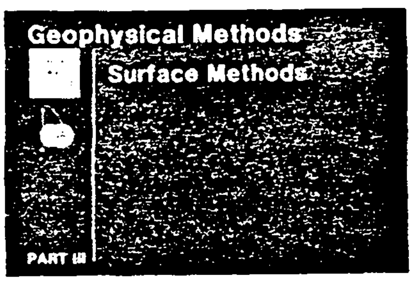
and by abrupt changes in the alignment of valleys.

52. 

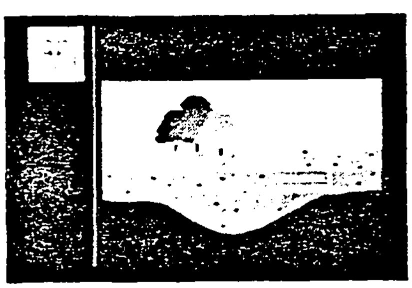
These surface features help identify where these fractures intersect. Wells located in these intersecting zones will have the greatest yield. Fracture trace analysis cannot be used in urban areas where man-made projects obscure the natural terrain.

53. 

We have discussed how aerial methods may be used in ground water location. Let us now turn our attention to another way to locate ground water, geophysical methods.

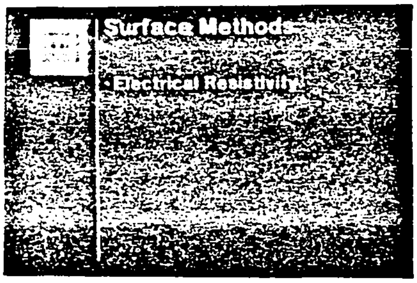
54. 

There are two types of geophysical methods: Surface methods which are conducted on the land surface and borehole methods which are conducted below the earth's surface in a well or test hole.

55. 

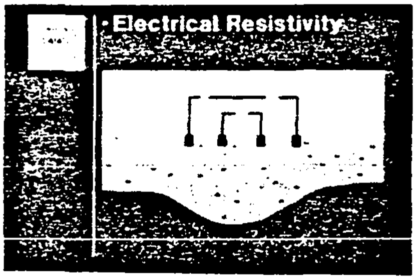
Surface geophysical methods measure the distance and depth to a geologic boundary. The boundary can be detected because the rocks on each side of the boundary have different physical or electrical characteristics. These characteristics are related to the ability of the rocks to hold and transmit water.

56.



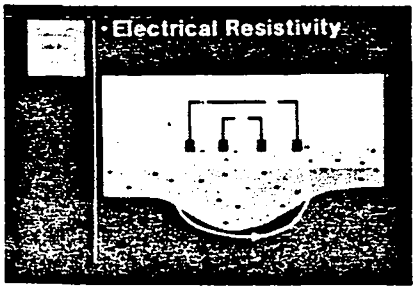
Two surface geophysical techniques are frequently used in ground water investigations--electrical resistivity and seismic surveys.

57.

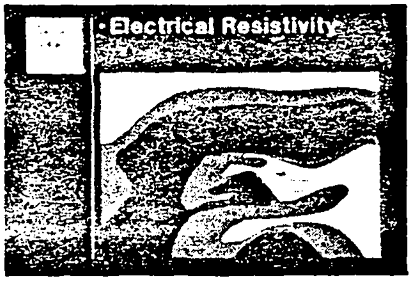


In electrical resistivity surveys, four small electrical probes are placed in the ground along a straight line. Using a battery as a power source, electrical current is injected into the ground.

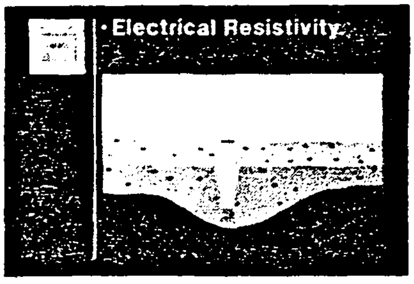
58.



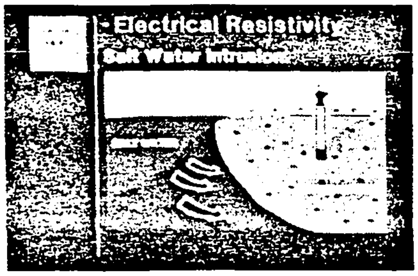
The current travels through the earth and the amount of resistance of the rock layers is measured by the drop in voltage at the two potential electrodes. Resistivity readings are also affected by other physical properties such as amount and quality of water.

59. 

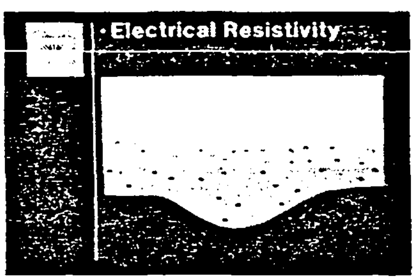
Electrical resistivity surveys are useful in mapping buried stream channels. Maps like this one display different resistivities which indicate the extent of the channel. The resistivities shown by the brown area inside the 250 contour indicate gravel deposits in a buried valley. The resistivities represented by the rust area inside the 200 contour indicate the presence of gravelly clay.

60. 

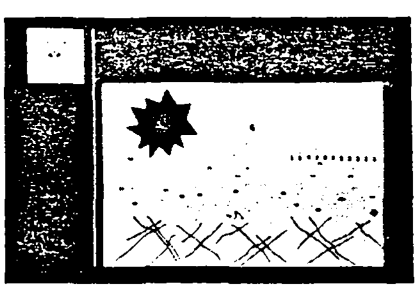
In addition to knowing the extent of a buried channel, it is also important to know its depth. Electrical resistivity surveys can also be used to evaluate the depth of the buried channel. Once the extent and depth of the buried channel have been determined, the most promising site for a well can then be selected.

61. 

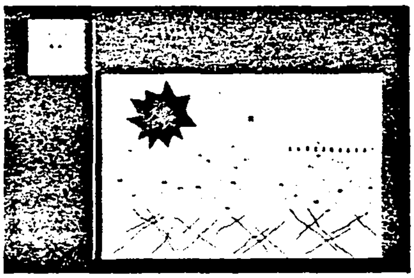
Electrical resistivity surveys may also be used in coastal areas where salt water encroaches under the land or in areas where salt water naturally occurs underground. Electrical resistivity surveys can indicate where the salt water and fresh water meet. The survey results can help to determine a well depth that will avoid the salt water.

62. 

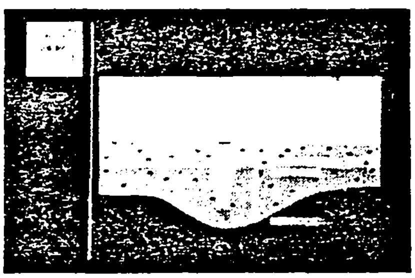
Another application of electrical resistivity surveys is to determine the depth to the water table. This application is typically limited to simple geologic areas such as this where the water table is not overlain or underlain by several layers of varying resistivities.

63. 

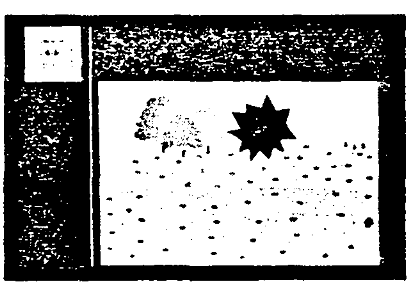
The second surface geophysical method that we will discuss is the seismic survey. Seismic surveys begin by applying a physical shock to the surface of the earth through a small explosion or heavy hammer.

64. 

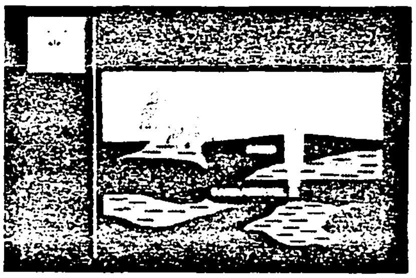
The shock wave is reflected and refracted by different geologic layers. The time it takes to return to the surface is recorded by geophones. This procedure is repeated at various locations.

65. 

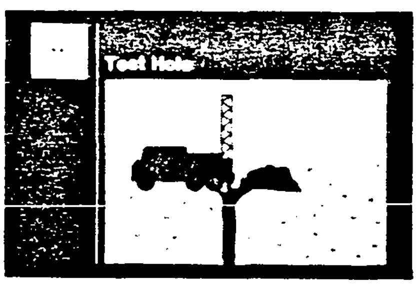
Seismic surveys are most commonly used to determine the thickness of unconsolidated deposits which overlie consolidated non-water bearing bedrock. Because the shock waves travel at different velocities in the bedrock and in unconsolidated deposits, the survey helps to indicate the depth to bedrock. Once the depth has been determined, the well can be located accordingly.

66. 

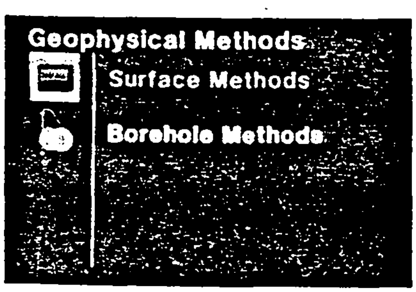
Seismic surveys may also be used in either unconsolidated or semi consolidated rock to determine the depth to the water table. This is possible because the velocity of shock waves is higher in saturated sediments and the water table acts as a reflector.

67. 

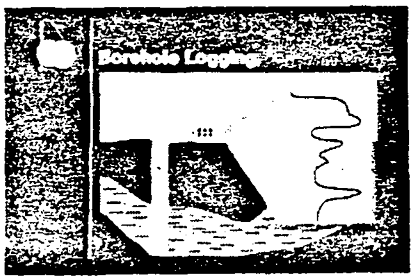
Another application of seismic methods is to identify permeability differences within unconsolidated deposits. Once these differences are identified the well can be located in the area with the highest permeability.

68. 

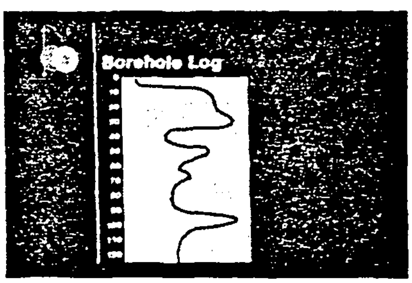
After using any or a combination of existing field data, aerial methods or surface geophysical methods, the result of the investigation must be verified. Results are verified by drilling a test hole or a well. It is especially important to drill test holes when undertaking large-scale well projects. This is done in order to confirm that water is available before investing the full cost for one or many wells.

69. 

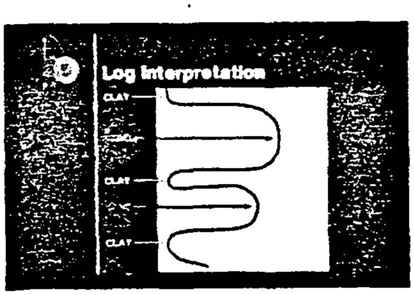
Often after a test hole is drilled, it is necessary to further assess the water-bearing characteristics of the rocks. Borehole logging is used to identify water-producing zones in either a test hole or well in order to maximize the production.

70. 

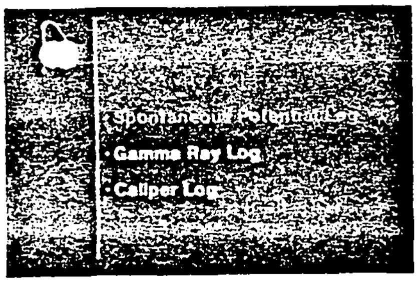
Borehole logging is performed by slowly raising or lowering a sensor or sonde in the hole to gather information about the adjacent rocks. The information is transmitted to the surface as electrical impulses and processed in a recorder. The processed information is displayed as a log.

71. 

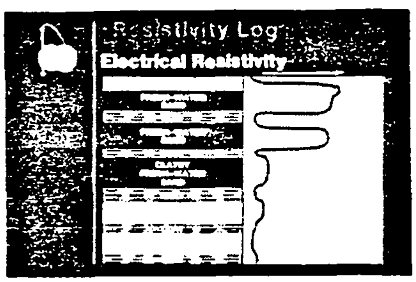
A log is a vertical trace on graph paper which corresponds to the depth below the surface. The shape of the trace depends on the type of log and the characteristics of the rock.

72. 

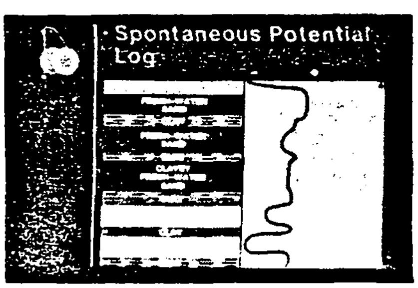
A log is interpreted by studying the shape of the curve. For example, in one type of log, when clay is encountered below the surface, the trace of the log shifts toward the left side of the chart. Similarly, when sand is encountered, the trace moves toward the middle of the chart. By knowing the response of the log, it is possible to infer rock type at specific depths.

73. 

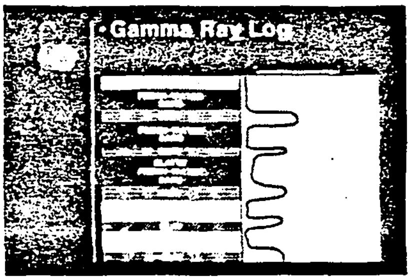
There are four types of geophysical logs which are commonly used in hydrogeologic investigations: resistivity, spontaneous potential, gamma ray and caliper logs.

74. 

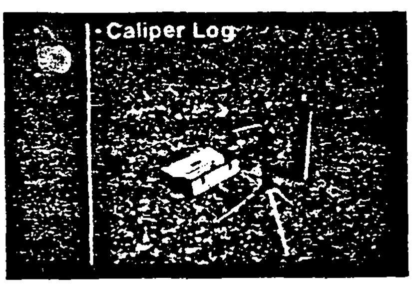
Resistivity logs measure the apparent electrical resistivity of rocks that are adjacent to the borehole. In general, clays have low resistivities which plot toward the left. Sands have medium resistivities which plot in the middle of the chart.

75. 

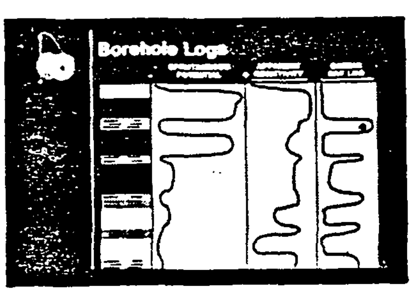
Spontaneous potential logs are a second type of electrical log. They measure the electrical differences between the borehole fluid and the water in the rock. This technique is most often used to determine the presence of salt water. In this log, the clean sandstones and clays have a positive potential and plot in the middle of the chart. The salt water formations have a negative potential and plot toward the left of the chart.

76. 

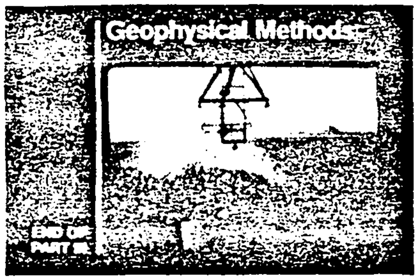
Gamma ray logs comprise a third type of logging technique. Virtually all rocks contain radioactive elements. When these elements decay, they emit energy, or gamma rays. Gamma ray logs are used to measure these emissions. In general clays have high natural gamma counts and plot toward the middle of the chart. Sandstones have low counts and plot toward the left of the chart.

77. 

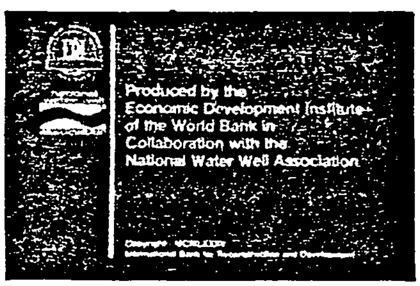
Caliper logs, the fourth type, are used to measure the size of the borehole. Expanding "feeler arms" record variations in borehole size which helps to determine rock type. For example, drilling to fractured limestone may produce a larger hole and clays may swell to make the hole smaller.

78. 

Because it is difficult to determine the exact water-bearing zones using only one log, frequently a "suite" or series of logs will be run in the borehole and the results compared. When this is done, it is much easier to determine the depths of the various productive formations.

79. 

In summary, ground water location methods range from the intuitively obvious to sophisticated scientific techniques. Regardless of the level of sophistication, when practiced by trained individuals, the results can be the location of an adequate supply of ground water which will serve the community's needs for many years.

80. 

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