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Instructor Guide Ground Water Development

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GROUND WATER DEVELOPMENT

Instructor Guide

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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 Development" module may be used as an independent instructional unit, or in conjunction with the other modules in a two-week seminar on "Water Supply and Sanitation" presented by the Economic Development Institute of the World Bank.

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 Development." The slide/tape program includes 160 35mm slides which are synchronized with the narration on the two accompanying audiocassettes.

The slides are inserted in a carousel tray that most projectors will accommodate. The narration for Parts I and II is on the first audiocassette. The narration for Part III is on the second audiocassette. Both audiocassettes are 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 audio-cassettes)
- 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 participant

Instructor Preparation

The "Ground Water Development" module is not a a self-instructional program. It requires an instructor who is knowledgeable about ground water technology 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 audiocassettes. 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 audiocassettes for play requires rewinding them completely to the beginning. When the audiocassettes are 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 number 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 the 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 Development" module includes an overview of hydrology, ground water utilization and ground water management.

The module is divided into three parts. Parts I and II are accompanied by one segment of the slide/tape program and Part III is accompanied by a second segment. Both segments are followed by discussion or application activities in the participant 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 supply projects or systems. Then ask them to describe their objectives in learning about ground water development 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 the major concepts that were presented.

4. Introduce Parts I and II of the slide tape program. Explain that Part I includes an overview of the module and a review of basic hydrology. Part II reviews the steps of ground water utilization. Parts I and II of the slide/tape program are approximately twenty minutes in length.

5. 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 Part I and you see a corresponding message projected on the screen.

Introduction

The "Ground Water Development" module has been designed for individuals who require a general orientation to the features, benefits, and use of ground water supply systems.

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

PART I — Overview of the module

GROUND WATER HYDROLOGY

The Hydrologic Cycle
Occurrence of Ground Water
Ground Water Quantity and Quality

PART II — **GROUND WATER UTILIZATION**

Step 1. Location
Step 2. Well Design
Step 3. Construction
Step 4. Development
Step 5. Testing
Step 6. Pump Selection
Step 7. Disinfection
Step 8. Operations and Maintenance

PART III — **GROUND WATER MANAGEMENT**

Step 1. Cost Comparison and Selection
Step 2. Natural Recharge
Step 3. Artificial Recharge
Step 4. Monitoring

INSTRUCTOR NOTES

PART I: GROUND WATER HYDROLOGY

Review of Hydrology Time required: 15 minutes

1. After the participants have viewed the first two parts 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. The purpose of the review is to ensure that the participants are familiar with the important terms and definitions that will recur throughout the module.

PART I: GROUND WATER HYDROLOGY

Review of Hydrology

Ground water hydrology deals with the occurrence and location of water beneath the earth's surface. Some basic terms that are important in ground water hydrology are described below.

Water Bearing Rocks

Water bearing rocks consist either of unconsolidated deposits or consolidated rocks.

- Unconsolidated deposits are underlain everywhere by consolidated rocks. Unconsolidated deposits consist of material from the disintegration of consolidated rock. The material consists of particles of rocks or minerals ranging in size from one millimeter (clay size) to several meters (boulders). Unconsolidated deposits that are important in ground water hydrology include clay, silt, sand, and gravel.

- Consolidated rocks consist of mineral particles of different sizes and shapes that have been welded by heat and pressure or by chemical reactions into a solid mass. They include sedimentary rocks that were originally unconsolidated and igneous rocks formed from a molten state. Consolidated sedimentary rocks that are important in ground water hydrology include granite and basalt.

Rock Openings

Most rocks near the earth's surface are composed of solids and voids. The solid parts are obvious, but without voids, there would be no water supply from wells and springs. There are different types of voids in rocks.

- If the voids were formed at the same time as the rock, they are termed primary openings. The pores in sand and gravel are examples of primary openings.

- If the voids were formed after the rock was formed, they are termed secondary openings. Fractures in granite and consolidated sedimentary rocks are examples of secondary openings.

Review of Hydrology
(continued)

Water Zones

Underground water occurs in two zones:

- The unsaturated zone is immediately below the land surface in most areas.
- The saturated zone is where all interconnected openings are full of water. Water in the saturated zone is the only underground water available to supply wells and springs. It is, therefore, the only water that can be correctly termed ground water.

Water Yield of Rocks

From the standpoint of ground water occurrence, all rocks that underlie the earth's surface are classified as aquifers or confining beds.

- An aquifer is a rock unit that will yield water in useable quantity to a well or spring.
- A confining bed is a rock unit with very low hydraulic conductivity that restricts the movement of ground water either in or out of adjacent aquifers. Where water completely fills an aquifer that is overlain by a confining bed, the water in the aquifer is said to be confined.

Types of Wells

Wells can be drilled into both confined and unconfined aquifers.

- Wells drilled into confined aquifers are called artesian wells.
- Wells that open into unconfined aquifers are referred to as water table wells.

Review of Hydrology
(continued)

3. After your review of the summary information on pages 2, 3 and 4, tell the participants to turn to page 5.

Porosity

Porosity is important in ground water hydrology because it influences the maximum amount of water that a rock can contain when saturated.

- Soils are the most porous of natural materials because soil particles tend to form loose clumps and because of the presence of root holes and animal burrows.
- Porosity of unconsolidated deposits depends upon the range in grain size and the shape of rock particles (but not size).
- Fine-grained materials tend to have a great range in grain size and, therefore, tend to have the largest porosities.

Permeability

Permeability determines whether the water can be removed in appreciable quantities.

Ground Water System

The ground water system comprises the aquifers and confining beds that underlie an area ground. The ground water system serves two functions. It stores water and it transmits water from recharge to discharge areas.

- Water enters ground water systems in recharge areas. Recharge occurs during and immediately following precipitation and, therefore, is intermittent.
- Water moves through recharge areas to discharge areas. Discharge is a continous process as long as groundwater heads are above the level at which discharge occurs.

INSTRUCTOR NOTES

Discussion Point on Hydrology Time required: 25 minutes

1. After you review the basic terms and definitions of ground water hydrology, ask the participants to discuss the questions on page 5 with the other members of their group.

2. After twenty minutes, stop the participants. Ask a representative of each group to summarize the group's responses. Note key points on the board or flipchart and point out the similarities and differences in their responses. There will be opportunities later in the program for you to refer back to the conditions the participants described and to relate other information on ground water to those conditions.

3. When you are ready to proceed, tell the participants to turn to page 6.

Discussion Point on Hydrology

Use the questions below to conduct a discussion with the other members of your group. Use your knowledge of hydrologic conditions and your experience with ground water systems to discuss the similarities and differences in the availability of ground water supplies in your country or region.

- Where have ground water supplies been developed in your country or region?

- What conditions prevail in the areas where ground water supplies have been developed in terms of rock composition, the types of openings that supply wells or springs, and the location of aquifers?

- What quantity and quality characterize the ground water sources currently in use?

- Are both artesian and water table wells currently in use? If one type of well is predominant, what conditions have limited the use of the other type of well?

- Where are major recharge and discharge areas located? What conditions influence the transmission of water from recharge to discharge areas?

INSTRUCTOR NOTES

PART II: GROUND WATER UTILIZATION

Review and Discussion of Step 1 Time required: 20 minutes

1. Review the summary information on page 6 with the participants.

2. Ask the participants who have experience with the location of ground water to describe the methods that were employed and the results that were obtained. If they identify a variety of methods, assist them to describe the features, benefits and advantages of the methods and the conditions in which they were most appropriate. Record major points on the board or flipchart.

3. Provide additional information on the methods of locating ground water that are appropriate to the participants' countries or regions.

4. When you are ready to proceed, ask the participants to turn to page 7.

PART II: GROUND WATER UTILIZATION

Review and Discussion of Step 1

Step 1. Location
Step 2. Well Design
Step 3. Construction
Step 4. Development
Step 5. Testing
Step 6. Pump Selection
Step 7. Disinfection
Step 8. Operations and Maintenance

The first step in ground water utilization is to locate adequate sources of supply for future well sites. Locating ground water may require investigation using some combination of the following sources of information:

- Published geological reports on rock types in an area and their water content, or reports on existing wells in the area;
- Studies of the topography and vegetation in an area to determine where water supplies are likely to be more abundant;
- Aerial photography and fracture trace analysis to detect fractures in rock that may yield the necessary amount of water;
- Electrical resistivity surveys to record the resistance of rock layers in order to infer the presence of ground water and the depth of bedrock;
- Seismic surveys to map buried channels and to determine the type of rock in the area;
- Drilling test holes to verify findings from other location methods;
- Borehole geophysical methods to identify water producing zones in either a test hole or well in order to maximize the production from a well.

INSTRUCTOR NOTES

Review and Discussion of Step 2 Time required: 20 minutes

1. Review the summary information on pages 7, 8, and 9 with the participants.

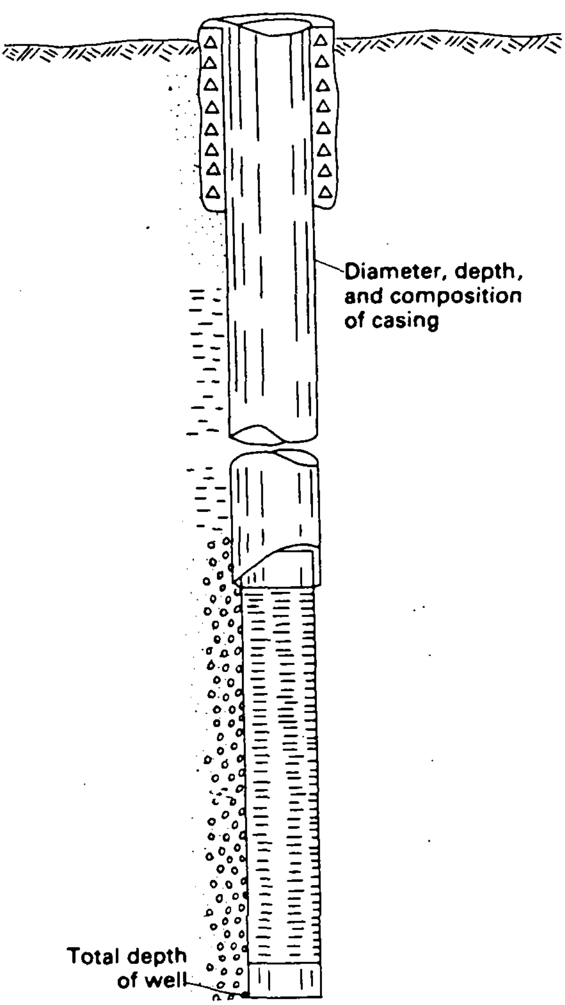
2. Ask the participants who have any knowledge of well designs to describe the wells they have seen in use, the way they were designed and the results that they have produced. Use their descriptions to reinforce the features and design specifications of wells that are described on pages 7, 8, and 9.

3. Provide any additional information on well design that is particularly relevant to the participants' countries or regions.

Review and Discussion of Step 2

Step 1. Location
Step 2. Well design
Step 3. Construction
Step 4. Development
Step 5. Testing
Step 6. Pump Selection
Step 7. Disinfection
Step 8. Operations and Maintenance

The second step in ground water utilization is to design an appropriate well. A completed design should specify the diameter, the total depth of the well, the position of the screen or open-hole sections, the method of construction, the materials to be used in construction, and the thickness and composition of a gravel pack, if one is required.



- Well diameter - The diameter is determined by the desired yield and depth to the aquifer.
  The primary effect of well diameter on yield is related to the size of the pump that can be installed, which, in turn, determines the pumping rate. Data on pumping rate, pump size and the well diameter are shown in the chart below.

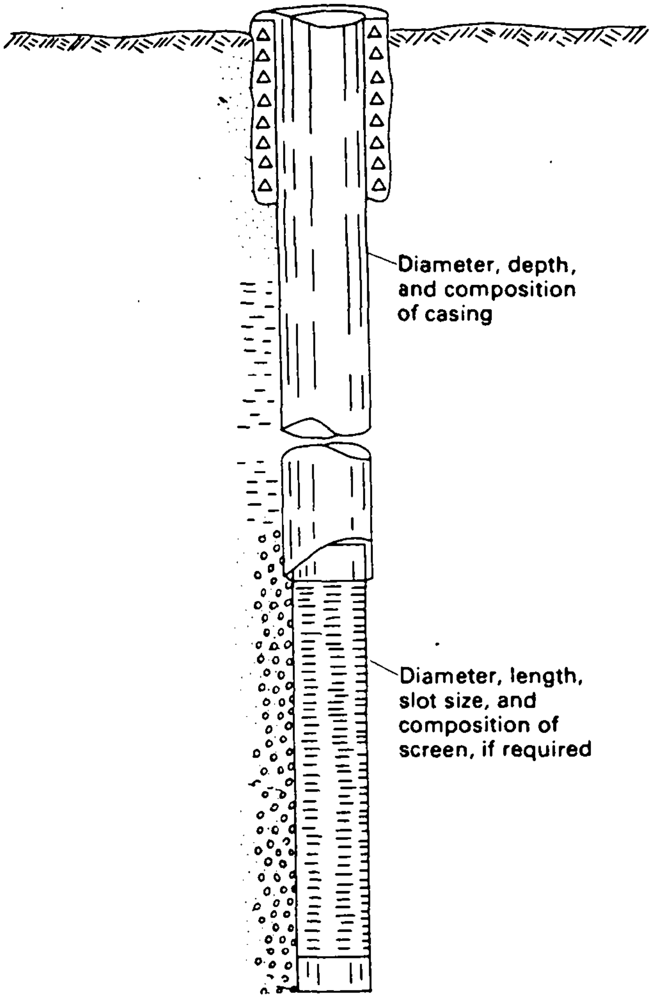
Table 1. Data on yield, pump size, and well diameter
[ID, inside diameter; OD, outside diameter]

Anticipated well yield			Nominal size of pump bowls (in.)	Optimum well diameter (in.)
In gal min^{-1}	In ft^3 min^{-1}	In m^3 min^{-1}		
Less than 100	Less than 13	Less than 0.38	4	6 ID
75-175	10-23	.28-.66	5	8 ID
150-400	20-53	.57-1.52	6	10 ID
350-650	47-87	1.33-2.46	8	12 ID
600-900	80-120	2.27-3.41	10	14 OD
850-1,300	113-173	3.22-4.93	12	16 OD
1,200-1,800	160-240	4.55-6.82	14	20 OD
1,600-3,000	213-400	6.06-11.37	16	24 OD

- Total Depth of Well - The depth depends upon the depth below the land surface to the lowest water-bearing zone to be tapped.

Review and Discussion of Step 2
(continued)

The diagram below shows the design specifications common to most wells.



- Casing - The casing prevents caving. It will extend through loose materials if the well penetrates into hard rock.

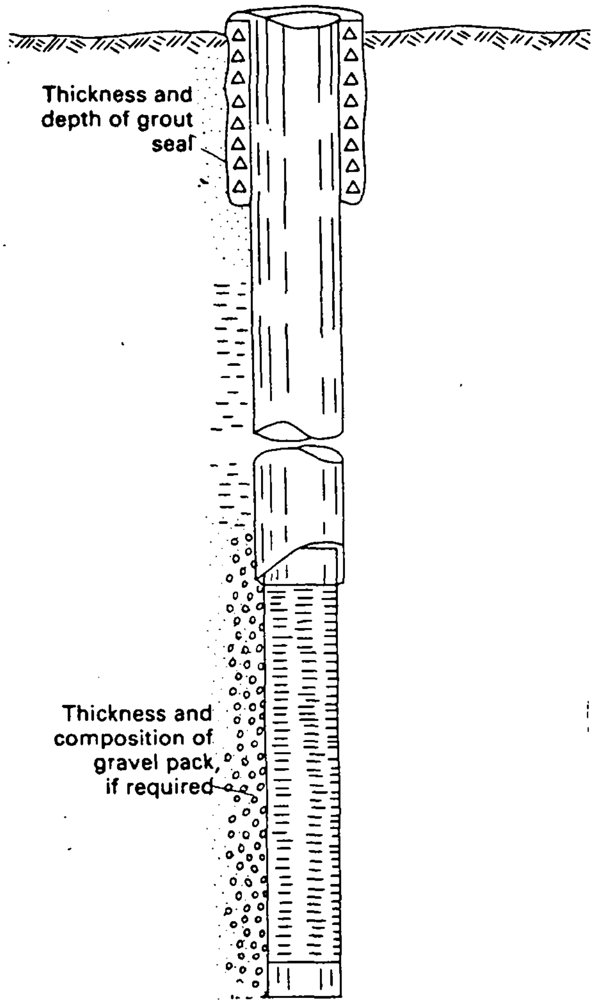
- Well Screen - The well screen diameter, length, slot size, along with pumping rate, will determine the velocity at which water passes through the screen. The entrance velocity should not normally exceed 6 feet min^{-1} (1.8 m min^{-1}). If the anticipated yield in cubic feet per minute shown on the chart on page 7 is divided by 6 feet min^{-1}, the result is the minimum open area of screen needed in square feet.

  The amount of open area per unit length of well screen depends on the diameter, slot size and the type of screen. If the open area needed in square feet is divided by the open area per linear foot, the result is the length of screen, in feet, required to provide the yield without exceeding the recommended entrance velocity.

  The position of the screen depends upon the thickness and composition of the source aquifer and whether the well has been designed to obtain the maximum possible yield.

Review and Discussion of Step 2
(continued)

4. When you are ready to proceed, ask the participants to turn to page 10.



The length of the screen depends upon the thickness of the aquifer, the desired yield, whether the aquifer is confined or unconfined and economic considerations. When an attempt is being made to obtain the maximum available yield, screens are normally installed in the lower 30 to 40 percent of unconfined aquifers and in the middle 70 to 80 percent of confined aquifers.

- Gravel Pack - If required, the gravel pack is placed around the screen.

- Grout Seal - A grout seal around the casing prevents water movement along the outside of the casing and prevents surface contamination of the aquifer. A grout seal also prevents inter-aquifer leakage.

INSTRUCTOR NOTES

Review and Discussion of Step 3 Time required: 20 minutes

1. Review the summary information on pages 10 and 11 with the participants.

2. Ask the participants who have experience with or knowledge of well construction to describe the methods that were selected, the reasons for the choice and the results that were obtained. Use their descriptions to reinforce the features and benefits of the six construction methods summarized on page 11.

3. Provide any additional information on well construction methods that is especially relevant to the participants' countries or regions.

Review and Discussion of Step 3

Step 1. Location
Step 2. Well Design
Step 3. Construction
Step 4. Development
Step 5. Testing
Step 6. Pump Selection
Step 7. Disinfection
Step 8. Operations and Maintenance

The third step in ground water utilization is to construct the well.

The objectives of well construction are to excavate a hole (usually of small diameter in comparison with the depth) to an aquifer and to provide a means for water to enter the hole, while excluding rock material.

The six commonly used construction methods are listed on the chart on the next page. The excavation of the hole is performed differently for each of the six methods.

The first four methods are limited to relatively shallow depths. They are most commonly used to construct domestic wells. The last two methods are used in the construction of municipal and industrial wells and domestic wells in consolidated rock.

Review and Discussion of Step 3
(continued)

4. When you are ready to proceed, ask the participants to turn to page 12.

Review Discussion of Step 3
(continued)

SUMMARY OF CONSTRUCTION METHODS						
CHARACTERISTICS	DUG	BORED	DRIVEN	JETTED	DRILLED CABLE TOOL	 ROTARY
Maximum practical depth in meters	15	30	15	30	300	300
Range in diameter (centimeters)	1-6	5-75	3-6	5-30	10-46	10-61
Suitable in unconsolidated materials:						
Silt	x	x	x	x	x	x
Sand	x	x	x	x	x	x
Gravel	x	x			x	x
Glacial Till	x	x			x	x
Shell and Limestone	x	x		x	x	x
Suitable in consolidated materials:						
Cemented Gravel	x			x		x
Sandstone				x		x
Limestone				x		x
Shale				x		x
Igneous and Metamorphic Rocks				x		
Excavation Means	Large hole is dug into water table by hand or power.	Auger by hand or power through loose materials into the water table.	Pointed screen (well point) is driven into the aquifer.	Water under pressure is circulated down through well point to loosen material around the screen.	Heavy drill bit and stem are raised and dropped to crush rock and material. Casing is driven as drilling proceeds. Crushed material is removed by a bailer.	Rotating bit is fixed to lower end of drill pipe and breaks up rock and loosens material as the hole is deepened. Drilling fluid is circulated to remove cuttings and to cool the bit. Casing is installed after the hole is completed.

Review and Discussion of Step 4 Time required: 20 minutes

1. Review the summary information on pages 12, 13, and 14 with the participants.

2. Ask the participants who have any experience with the development of wells to describe the methods that were used and the results that were obtained. Record major points on the board or flipchart. Use their descriptions to reinforce the information on pages 12, 13, and 14.

3. Provide any additional information on well development methods that is appropriate to the participants' countries or regions.

Review and Discussion of Step 4

Step 1.	Location
Step 2.	Well Design
Step 3.	Construction
Step 4.	**Development**
Step 5.	Testing
Step 6.	Pump Selection
Step 7.	Disinfection
Step 8.	Operations and Maintenance

The fourth step in ground water utilization is to develop the well.

Development means removing the fine materials from the aquifer and the area adjacent to the screen or the open hole. The two objectives of development are to clean out, or enlarge, passages so that water can enter the well more freely and to produce sediment-free water.

Successful development produces three benefits.

- Development corrects any damage to the water-bearing formation which occurs as a side effect of drilling.

- Development increases the porosity and permeability of the natural formation in the vicinity of the well.

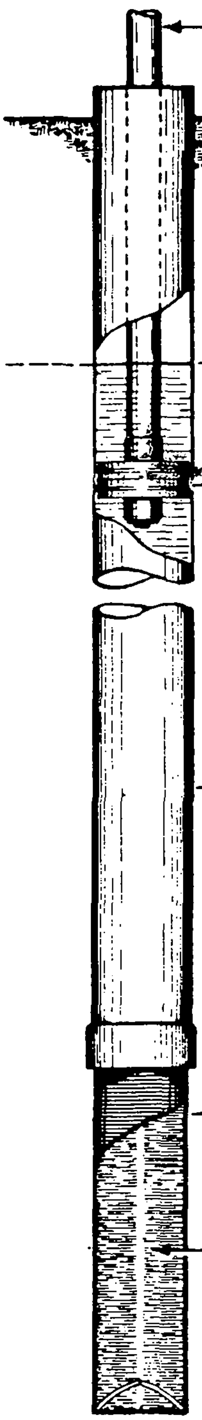
- Development stabilizes the sand formation around a screened well so that the well will yield water that is free of sand.

Three commonly used development methods are overpumping, surging and high velocity jetting.

- Overpumping - The simplest method of removing fine materials from the well is overpumping. The well is pumped at a higher rate than that at which it will be pumped in service. Over-pumping may leave some of the sand grains in the well. The method also requires high capacity pumping equipment that is not always conveniently available. Normally, this method is not successful in screened and gravel-packed wells that are drilled by the rotary method.

Review and Discussion of Step 4
(continued)

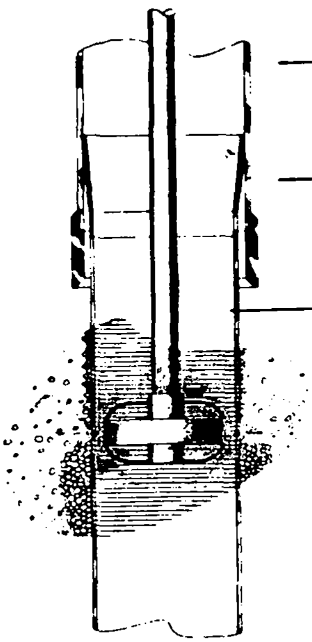
Review and Discussion of Step 4
(continued)



- Surging - Surging the water in a well involves moving a plunger up and down in the casing like a piston in a cylinder. The tool normally used is called a surge plunger or surge block. The surging movement forces water in and out of the aquifer. Then, agitated materials are removed by bailing or pumping. Surge plungers may produce unsatisfactory results if the aquifer contains many clay streaks or clay balls. Surge plungers require a sufficient flow of water in order to operate smoothly and freely.

Review and Discussion of Step 4
(continued)

4. When you are ready to proceed, ask the participants to turn to page 15.



- <u>High Velocity Jetting</u> - High velocity jetting is used with high capacity screened wells. A jetting tool directs water under high pressure to small intervals along the screen. The well is pumped to remove the dislodged materials. Every part of the well screen can be covered selectively. Complete development can be achieved if well screen openings are closely spaced and correctly shaped to direct the jet stream out into the surrounding formation.

Review and Discussion of Step 5 Time required: 20 minutes

1. Review the summary information on pages 15, 16 and 17 with the participants.

2. Ask the participants who have experience with or knowledge of testing to describe the methods that were used and the types of information that resulted. Record major points on the board or flipchart and use the descriptions to reinforce the information on pages 15, 16 and 17.

3. Provide any additional information on testing that is relevant to the participants' countries or regions.

Review and Discussion of Step 5

Step 1. Location
Step 2. Well Design
Step 3. Construction
Step 4. Development
Step 5. Testing
Step 6. Pump Selection
Step 7. Disinfection
Step 8. Operations and Maintenance

The fifth step in ground water utilization is to test the well in order to determine the amount of water that the well will provide.

Determining the yield of ground water systems (and evaluating the movement and rate of ground water pollutants) requires the following information:

- The position and thickness of aquifers and confining beds;
- The transmissivity and storage coefficient of the aquifers;
- The hydraulic characteristics of the confining beds;
- The position and nature of aquifer boundaries;
- The location and amounts of ground water withdrawals;
- The location, kinds, and amount of pollutants and pollutant practices.

Aquifer Tests

One of the most important tests in ground water development is the aquifer test. It is used to analyze the change in water levels in an aquifer, over time, that is caused by withdrawals through wells. In most cases, the study is conducted by pumping a well at a constant rate for a specified period of time. The change in water level is measured in the test wells located at different distances from the pumped well.

Among other things, effective aquifer tests require, the following:

- Determination of the pre-pumping water level (the regional trend);
- A carefully controlled and constant pumping rate; and
- Accurate water level measurements made at precisely known times during both drawdown and recovery periods.

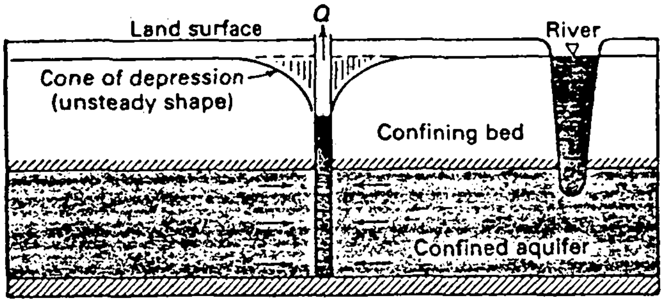
Review and Discussion of Step 5
(continued)

Drawdown is the difference between the water level at any time during the test and the position at which the water level would have been, if withdrawals had not started. At first, drawdown is rapid. As pumping continues and the cone of depression expands, drawdown decreases.

The recovery of the water level, under ideal conditions, is a mirror image of the drawdown. The change in water during the recovery period is the same as if withdrawals had continued at the same rate from the pumped well but, at the moment of pump cutoff, a recharge well had begun recharging water at the same point and at the same rate. Therefore, the recovery of the water level is the difference between the actual measured level and the projected pumping level.

Changes During an Aquifer Test

Changes occur in the cone of depression during an aquifer test. The changes that are of concern involve the shape of the cone and the rate of drawdown. As the cone of depression migrates outward from a pumping well, its shape changes. At the start of withdrawals, the entire cone has an unsteady shape (1). After a test has been underway for some time, the cone assumes a relatively steady shape (2). If withdrawals continue long enough for increases in recharge and (or) reductions in discharge to balance the rate of withdrawal, drawdowns cease, and the cone of depression is said to be in a steady state (3).



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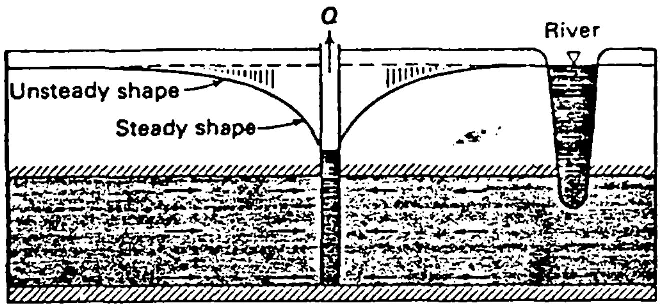

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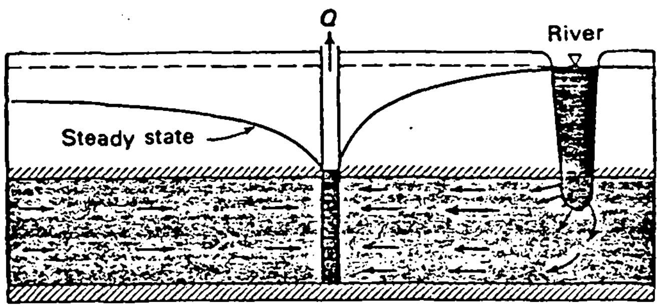

(3)

Review and Discussion of Step 5
(continued)

4. When you are ready to proceed, ask the participants to turn to page 18.

Review and Discussion of Step 5
(continued)

Pumping Tests

There are many different ways to conduct pumping tests and to analyze the results. Pumping tests may be conducted by pumping the well at one constant rate for the duration of the test or by pumping the well at different specified rates for certain time intervals. Pumping test data is analyzed using analytical methods which allow for such variable conditions as water table aquifers, confined aquifers, and leakage of water across confining beds into an aquifer. The analytical methods also permit analysis of tests conducted on both vertical wells and horizontal well and drains.

INSTRUCTOR NOTES

Review and Discussion of Step 6 Time required: 35 minutes

1. Review the publication on pages 19 through 33 with the participants.

2. Ask the participants who have experience with, or knowledge of, different types of pumps to describe the pumps that were selected and the selection criteria that were used. Record major points on the board or flipchart.

3. Provide any additional information on the types or use of pumps that will help the participants determine which pumps can be used in their countries or regions.

Review and Discussion of Step 6

Step 1. Location
Step 2. Well Design
Step 3. Construction
Step 4. Development
Step 5. Testing
Step 6. Pump Selection
Step 7. Disinfection
Step 8. Operations and Maintenance

The sixth step in ground water utilization is to select and install a proper pump, based on the diameter, depth, capacity and power requirements of the well.

The publication reproduced on pages 19 through 33 describes the features of different pump types and where they are most appropriate to use.

Review and Discussion of Step 6
(continued)

AAVIM

Planning for an Individual Water System

Developed by the . . .
AMERICAN ASSOCIATION FOR VOCATIONAL INSTRUCTIONAL MATERIALS
120 Driftmier Engineering Center
Athens, Georgia 30602

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DIRECTOR

W. Harold Parady, Executive Director, AAVIM

REVISION

J. Howard Turner, Editor and Coordinator, AAVIM

GRAPHICS

George W. Smith, Art Director, AAVIM

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Prepared initially and revised twice by **G. E. Henderson**, formerly Executive Director of AAVIM, in cooperation with **Elmer E. Jones**, Research Agricultural Engineer, Agricultural Research Service, USDA. Illustrations and design are by **George W. Smith, Jr.**, Art Director, AAVIM.

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<u>Review and Discussion of Step 6</u>
(continued)

If your pump has a capacity of 10 gallons per minute, it will supply enough water for a ¼-inch fire nozzle. At 30 pounds (psi) pressure the nozzle will produce a stream that will reach 30 feet high, or a stream that will extend horizontally about 40 feet. This is not enough water to be effective with a large fire, or a fire that is well under way, but it can be very effective in either putting out or controlling a small fire. Sometimes, it can be most effective if used in keeping another building dampened down so as to keep it from catching fire (Figure 62).

If you install a pump with as much as **25 gallons per minute,** there will be enough water for **one ⅜-inch nozzle or two ¼-inch nozzles.** With a ⅜-inch nozzle at 30 pounds (psi) pressure, you can provide a stream that will reach 40 feet high or extend horizontally about 65 feet.

If you wish more protection than that which your water pump will provide, you may need to install a reserve storage tank where 3,000 to 5,000 gallons of water can be stored continuously for use by community fire-fighting equipment. This will be discussed later under "D. What Type and Size Water Storage to Use."

RATE OF WATER YIELD

The next factor you will need to consider is whether your water source will supply water as fast as your pump will need it. This applies mostly to springs or wells. You determined the rate of yield of your water source when you measured the "Amount of Water Available," page 16.

If it is evident your water source will supply enough water to take care of your peak demand, you can use a pump of the same capacity that you determined meets your peak demand. The water can be pumped directly from the source.

If your peak demand is more than the hourly yield of your water source, you will still need the same size of pump to provide water to meet your periods of high demand, but the extra water will have to be supplied from a water storage. A **second pump** will be needed to provide water for the storage from the source. This pump will need to be sized to match the capacity of the source to supply water. This is also discussed under "D. What Type and Size Water Storage to Use."

B. Understanding Pump Types

Now that you have determined the amount of water you need to meet your peak demands, you are ready to select a pump that provides that much capacity, or more. But, before selecting a pump, you need to know how the various pumps work. In doing so, you will learn their names and gain an understanding of their limitations and capabilities. With this information it will be easier for you to work with a pump dealer in securing the type of pump that will best fit your needs.

The information is discussed under the following headings:

- — Principles involved in pumping
- — How a piston pump works
- — How a centrifugal pump works
- — How a centrifugal-jet (ejector) pump works
- — How a turbine pump works

This discussion deals only with the **water end**—pumping mechanism—of a pump. The **power end**—motor-and-drive mechanism—is determined by the manufacturer. Each pump is limited in the amount of water it will deliver and the pressures under which it will deliver the water. Consequently, each manufacturer selects a motor and drive that will be satisfactory under the range of operating conditions for which a particular pump model is designed.

PRINCIPLES INVOLVED IN PUMPING

There is a wide assortment of pumps for home and farm use. But, no matter how they are made, they do a certain amount of **pulling water by suction** and a lot of **pushing of water by pressure** (Figure 63). The

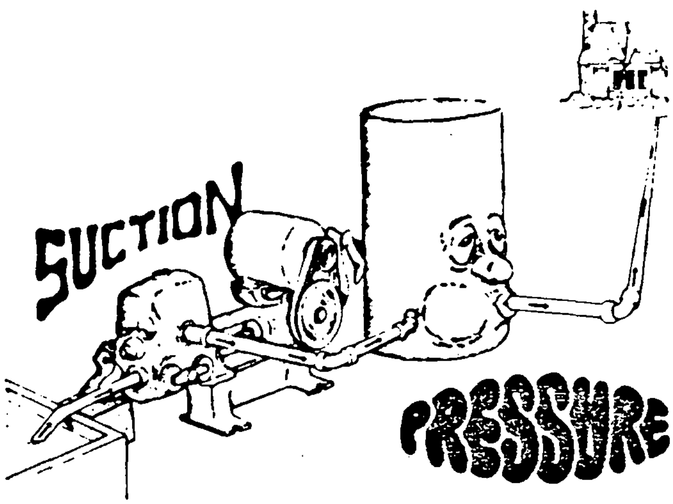

FIGURE 63.

Review and Discussion of Step 6
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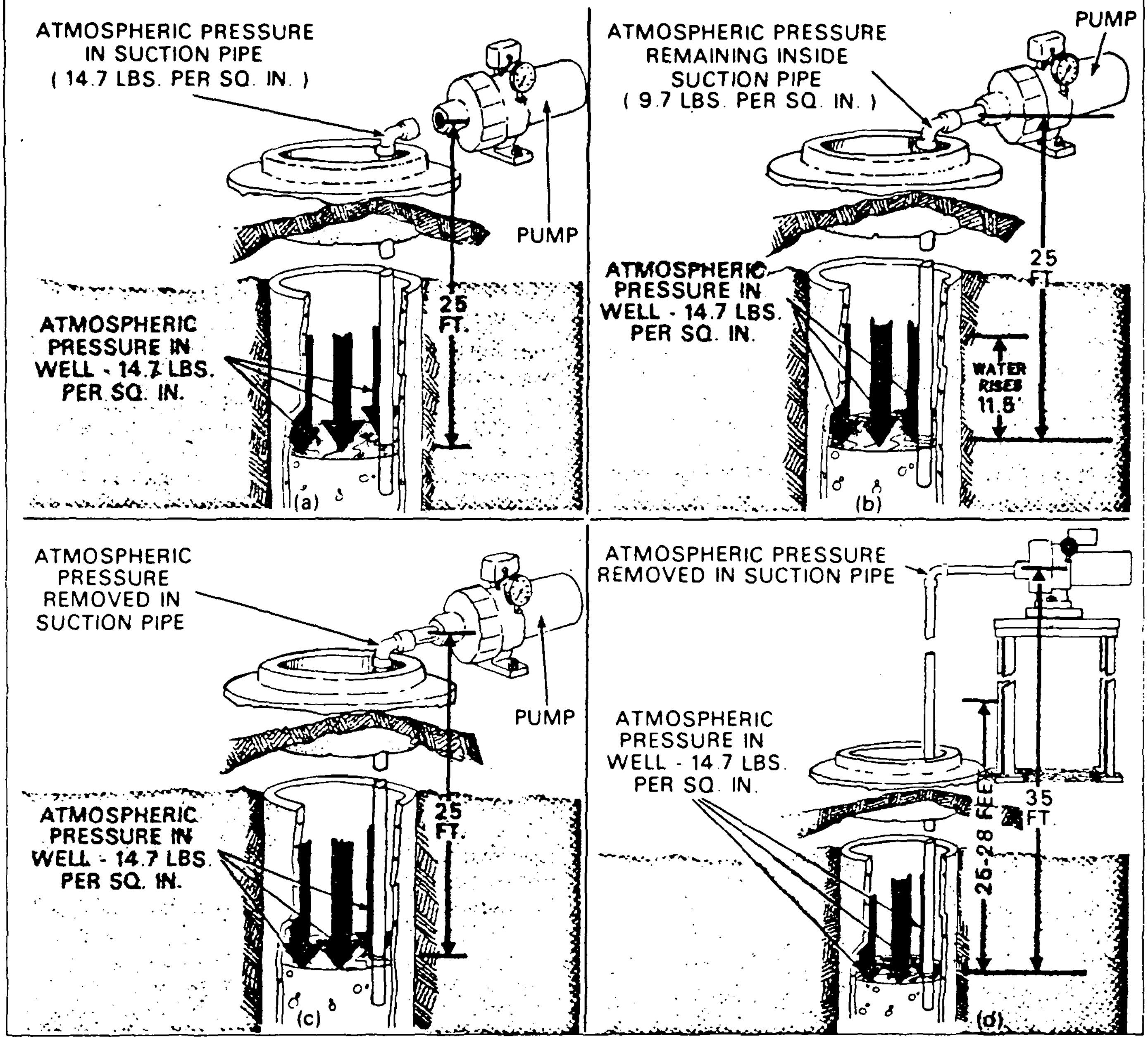

FIGURE 64. How a pump lifts water by suction. (a) With the pump suction pipe disconnected, atmospheric pressure on the water in the well and the water inside of the pipe is the same—14.7 pounds per square inch (at or near sea level). (b) When the suction pipe is connected to the pump and the pump is started, air pressure in the suction pipe is reduced (a partial vacuum develops) and the water rises from the well into the pipe. (c) As pumping action continues, all air is pumped from the suction pipe so that atmospheric pressure pushes the water into the pump. (d) If the pump is raised too high above the water source, there is not enough atmospheric pressure to push the water into the pump.

suction comes when your pump draws water into its working mechanism from your water source. Then the pump puts the water under pressure as it forces the water into the pressure tank. From the tank, it flows under pressure through your piping system.

The **height water can be lifted by suction**—from the water source to the level of the pump—**is quite limited.** Even the best suction pumps cannot lift water more than about 22 to 25 feet straight up on a clear day at sea level. Some are limited to 15 feet or less. Here is the reason why. When water is lifted by the suction, all the pump does is remove part or all of the atmospheric pressure—develop a partial or complete vacuum—in the suction pipe.

Note in Figure 64a, the pump is not connected to the suction pipe. Atmospheric pressure inside the pipe and in the well is the same—14.7 pounds per square inch (psi).

Review and Discussion of Step 6
(continued)

When the pump starts (Figure 64b), it **removes more and more air** from the suction pipe. This gradually reduces the air pressure inside the pipe while the atmospheric pressure on the outside remains the same—14.7 psi. Water from the well is pushed into the suction pipe because of this difference in pressures. As the pump continues to operate, more and more air is removed—creating more and more of a vacuum effect—until the atmospheric pressure finally forces the water up to the level of the pump (Figure 64c). *With all air removed from the suction pipe,* the pump can continue to operate and take advantage of the action of the atmospheric pressure lifting the water to its level.

If a **leak develops in the suction pipe,** air enters. The vacuum effect is destroyed, and the water level drops in the suction pipe down to the same level as that of the water source. When this happens the pump is said to "have lost its prime."

Assume the pump is moved to a height of 35 feet above the water level in the well (Figure 64d), and the pumping action started. With most pumps, the water would be lifted about 15 to 28 feet high depending on the type of pump. (If you were able to take full advantage of atmospheric pressure, you could lift the water as high as 33.9 feet, but pumps are not that efficient.) The space in the suction pipe between the 25- to 28-foot level and the 35-foot level would remain empty, except for a small amount of air and water vapor—no matter how long you pump. There is not enough vacuum for the atmospheric pressure to lift the water any higher.

The figure of **14.7 pounds (psi) is atmospheric pressure at sea level.** Atmospheric pressure becomes less and less as you rise above sea level. If you live at a high elevation, subtract 1 foot from the pump suction lift for each 1,000 feet of elevation. For example, if you live 2,000 feet above sea level, a pump that lifts water 25 feet by suction at sea level will lift it only 23 feet at the higher elevation when in proper condition.

You cannot depend on a pump lifting water by suction more than 25 feet. A piston pump, in good mechanical condition, located not more than a few hundred feet above sea level, may be able to do so. There are other types that can not. You occasionally hear of someone who claims he has a pump that is lifting water by suction as much as 30 or 35 feet. The 30-foot lift is highly improbable. The 35-foot lift is impossible—atmospheric pressure will not lift water that high.

Pumps that lift water by suction from these limited depths are called *"shallow-well" pumps.*

Pumps that lift water from greater depths are called *"deep-well" pumps.* Pumps of this type provide for lowering part, or all, of the pumping mechanism down into the well to a point where little or no suction is needed. The "no-suction" condition is when the pumping mechanism is submerged in the water (Figure 68).

HOW A PISTON PUMP WORKS

A piston pump was one of the earliest automatic pumps developed for home and farm use. Its operating principle is basically the same as the once popular hand-operated piston pump. Here is how the hand-operated pump works.

As you push down on the handle of a hand-operated piston pump (Figure 65a), water is lifted by the plunger, and it flows out of the spout. At the same time, a partial vacuum develops below the plunger. The partial vacuum causes the water in the suction pipe to force open the check valve and fill the cylinder below the plunger.

As you lift the pump handle (Figure 65b), the water below the plunger is trapped by the closed check valve in the bottom of the cylinder. At the same time, a valve in the plunger lifts and lets the water pass to the upper side of the plunger. It is then ready for discharge when the pump handle is pushed down and the plunger is raised again. This is called a *"single-acting" piston pump.* This is the simplest type of shallow-well suction-type pump.

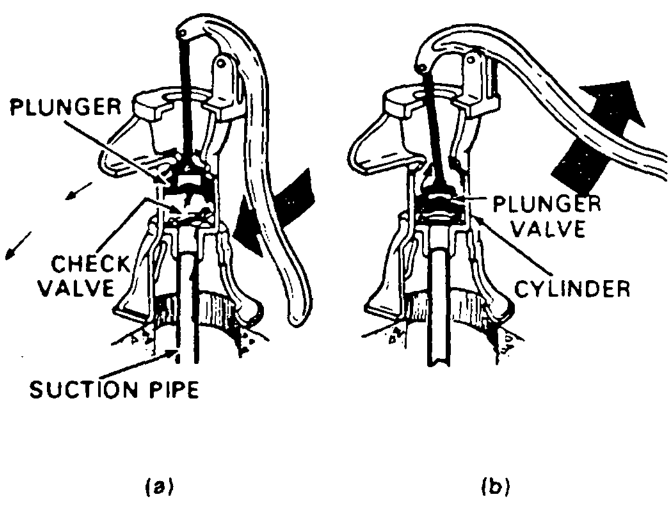

FIGURE 65. How a hand-operated piston pump works. (a) As the handle is pushed down, causing the plunger to rise, water is discharged through the pump spout. The vacuum that develops in the cylinder below the plunger is filled with water from the suction pipe which connects the pump to the water source. (b) As the pump handle is raised, the plunger lowers. This causes the check valve to seat and trap water in the cylinder. The trapped water forces the plunger valve open allowing the water to enter the cylinder area on the upper side of the plunger.

Review and Discussion of Step 6
(continued)

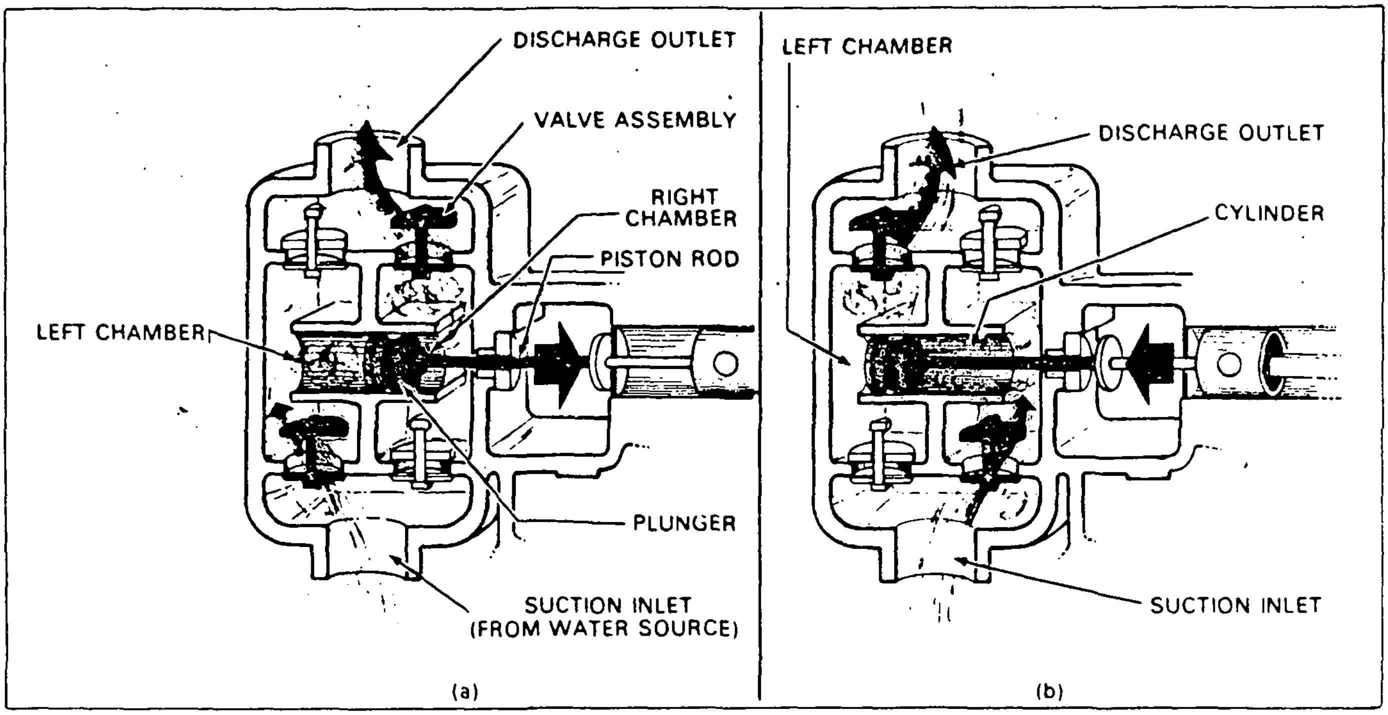

FIGURE 66. How a double-acting piston pump works. (a) Movement of the plunger to the right pulls water from well into the left chamber and forces water out of right chamber. (b) Plunger movement to left forces water out of left chamber and pulls water from the well into the right chamber.

If you purchase a motor-driven **shallow-well piston pump,** it will be one that works on the principle you just studied, but is improved by use of the **double-acting principle.** That is, it pulls water from the well on one side of the plunger at the same time it forces water out on the other side (Figure 66a). On the return stroke (Figure 66b), the action is *reversed*—the side that was pulling water into the cylinder now forces it out. The side that was forcing water out is now pulling water into the cylinder. This is the reason for calling it a "double-acting" pump. The double-acting design makes a close-coupled compact unit, one that will work at a fairly high speed.

Figure 67 shows what a double-acting shallow-well pump looks like.

If the water in your well is more than 22 to 25 feet below pump level, a **deep-well piston pump** is used. The plunger and cylinder are put down into the well to within a few feet of water level or, better yet, below water level (Figure 68). It works on exactly the same principle as the hand-operated pump (Figure 65). This type of pump works at a fairly slow speed (about 45-65 strokes per minute) because of the long sucker rod that extends from the pump head down to the cylinder to work the plunger.

All piston pumps are called *"positive acting"* because each stroke of the plunger moves a constant amount of water. Since it is positive acting, it **will pump air** from the suction line without any difficulty. A small air leak in the suction line simply slows down the amount of water delivered.

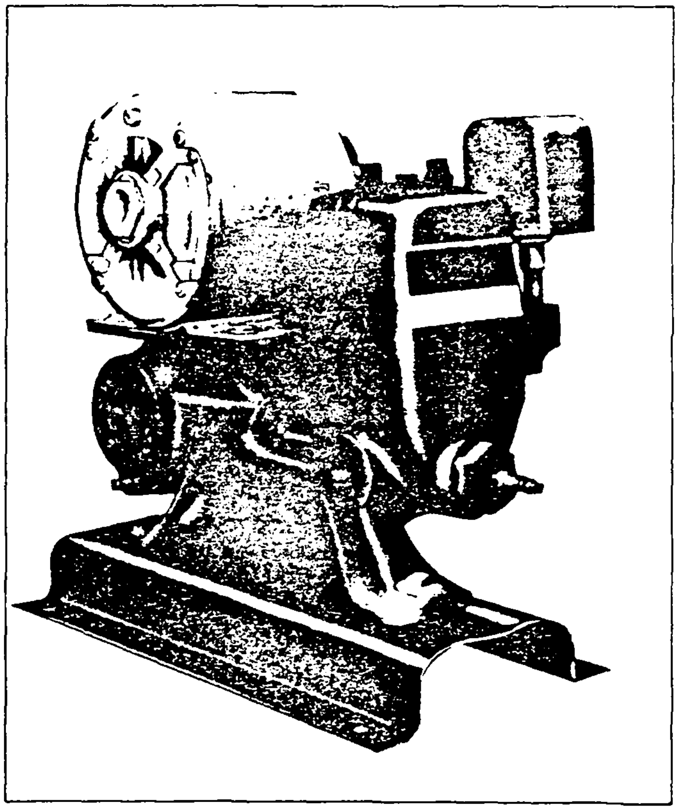

FIGURE 67. A double-acting shallow-well piston pump.

Review and Discussion of Step 6
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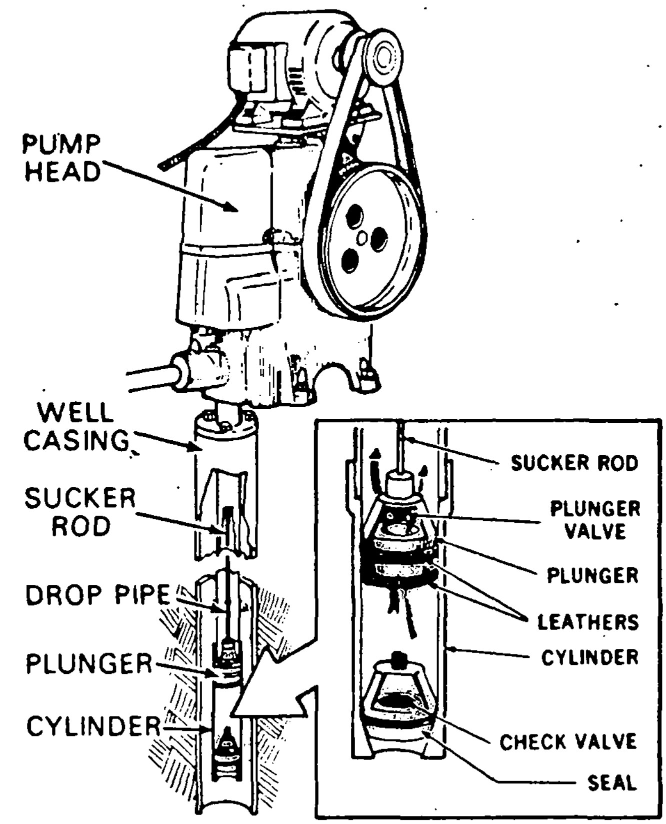

FIGURE 68. A deep-well piston pump is installed with the pumping mechanism in the well, usually below water level.

HOW A CENTRIFUGAL PUMP WORKS

A **centrifugal pump** is of very simple design. Th only moving part is an impeller wheel attached directl to the motor shaft.

To understand how an **impeller** develops pumpin action, let us examine a very simple centrifugal pump In Figure 69a, the impeller consists of a suction pip and lateral arm. It is turned by an electric motor. A long as there is air in the pipe, and in the lateral arm there can be no pumping action no matter how fast it i turned.

If the suction pipe and lateral arm are filled with wate and then started rotating, water in the lateral arm i thrown out by centrifugal force. This creates a partia vacuum which lifts more water from the bucket. In thi way, the pumping action continues as long as the as sembly spins and no air enters it.

If you add more lateral arms to the pipe, more wate is pumped (Figure 69b). These arms provide the sam action as the vanes in a centrifugal pump impelle (Figure 69c). The space between each pair of vane acts in the same way as the lateral arms.

The pumps shown in Figure 69a and b are not useable partly because the suction pipe turns with the rotatin lateral arms. **Factory-built centrifugal pumps** ar equipped with a **wearing ring** on the suction inlet nex

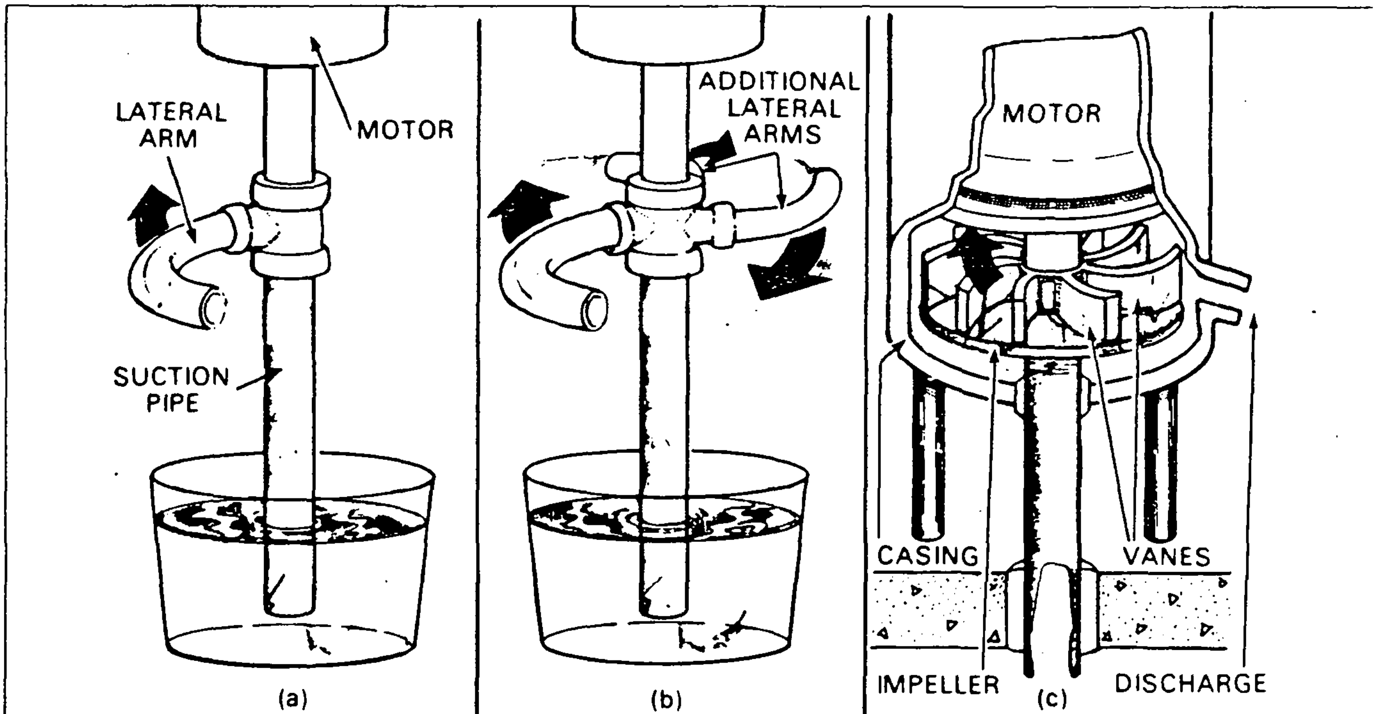

FIGURE 69. How a centrifugal pump works. (a) An L-shaped pipe, completely filled with water and rotated rapidly, will pump water out of a bucket. Water thrown out of lateral arm by centrifugal force creates a suction, causing water to rise from the bucket. (b) By adding more lateral arms, more water is pumped. (c) With a manufactured pump, the lateral arms are replaced with an impeller mounted inside of a casing. The impeller vanes are mounted with a plate on one side (as shown) or with a plate on each side. These vanes act in the same way as the lateral arms in (b).

Review and Discussion of Step 6
(continued)

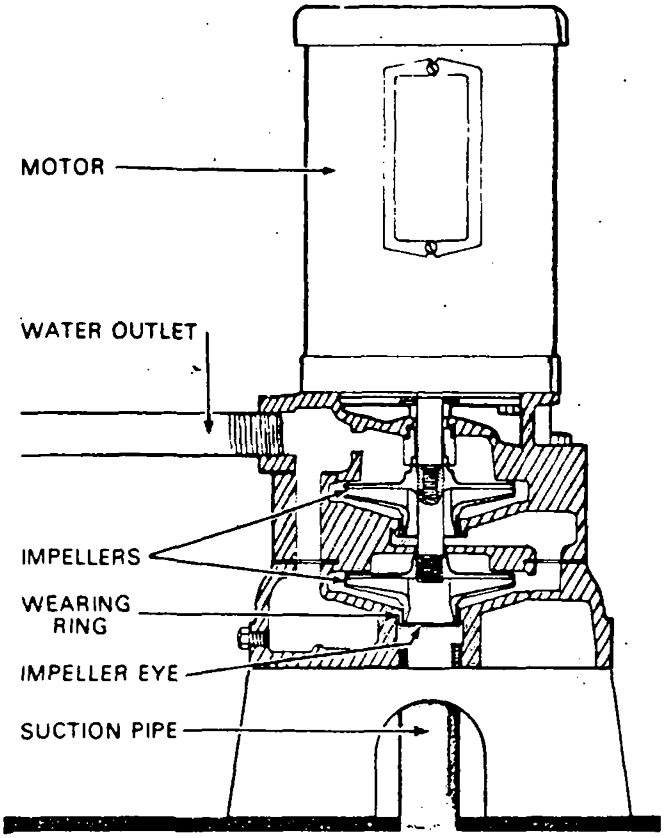

FIGURE 70. When water must be supplied at higher pressures, two or more impellers are used on a centrifugal pump.

to the impeller. The **eye** of the impeller is machined to fit very closely into the wearing ring (Figure 70). The only moving part is the impeller.

A centrifugal pump is not positive acting. As the *water level lowers* in your well, it pumps less and less water. Also, when it pumps against *increasing pressure,* it pumps less and less water. For these reasons, it is important in selecting a centrifugal pump that you get one designed to do your particular pumping job.

For higher pressures or greater lifts, two or more impellers are commonly used to meet the needs, as shown in Figure 70.

Shallow-well centrifugal pumps are seldom used if **the suction lift is more than about 15 to 18 feet.** This has limited their use for shallow-well pumping, unless they are equipped with an ejector. The combination centrifugal pump and ejector is another type of pump which will be studied under the next heading.

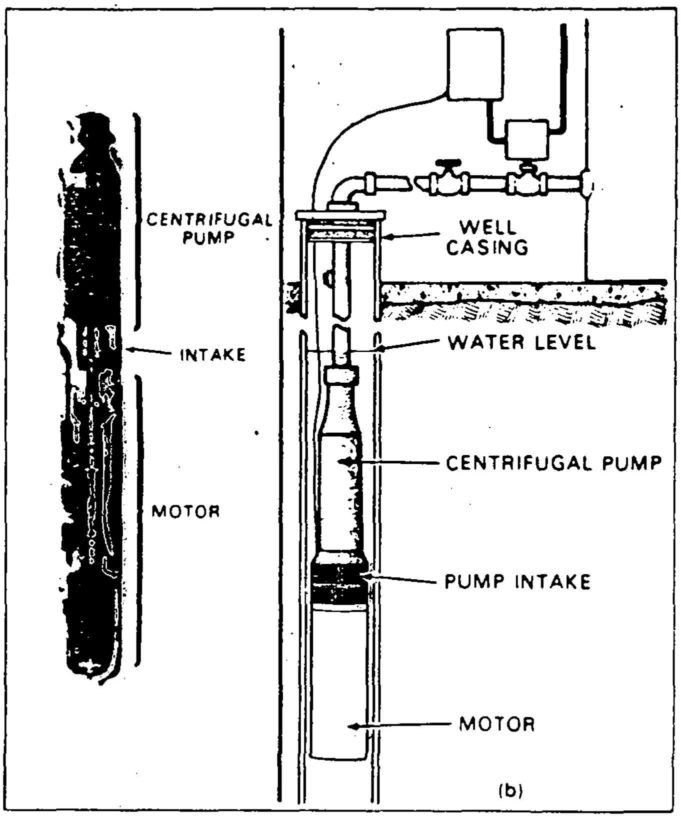

FIGURE 71. (a) Sectional view of a deep-well submersible centrifugal pump. (b) Submersible pump and motor is installed in a well below water level.

Deep-well centrifugal pumps have become quite popular. They are known as "submersible" or "submergible" pumps. Note in Figure 71a that a submersible unit consists of several impellers driven by a motor that attaches below it. Pumps with more than one impeller are sometimes called "multi-stage" pumps. The number of impellers is determined by how far the water has to be lifted and how much pressure is needed at the point of delivery. Each time water is pumped from one impeller to the next one, its pressure is increased. This is a popular pump because of positive action and having no need for freeze protection.

The motor-and-pump assembly are closely connected and built as a unit. The motor is specially designed for use under water. The whole assembly, including the motor, is let down into the well on the end of a drop pipe to a position below the water level. In this way, the pumping mechanism is always filled with water (primed) and ready to pump (Figure 71b).

Centrifugal pumps, both the shallow-well type and the deep-well type, have either **little or no ability to pump air.** When starting, the pump and suction line needs to have all of the air removed. An air leak in the suction line will cause the pump to quit pumping.

Review and Discussion of Step 6
(continued)

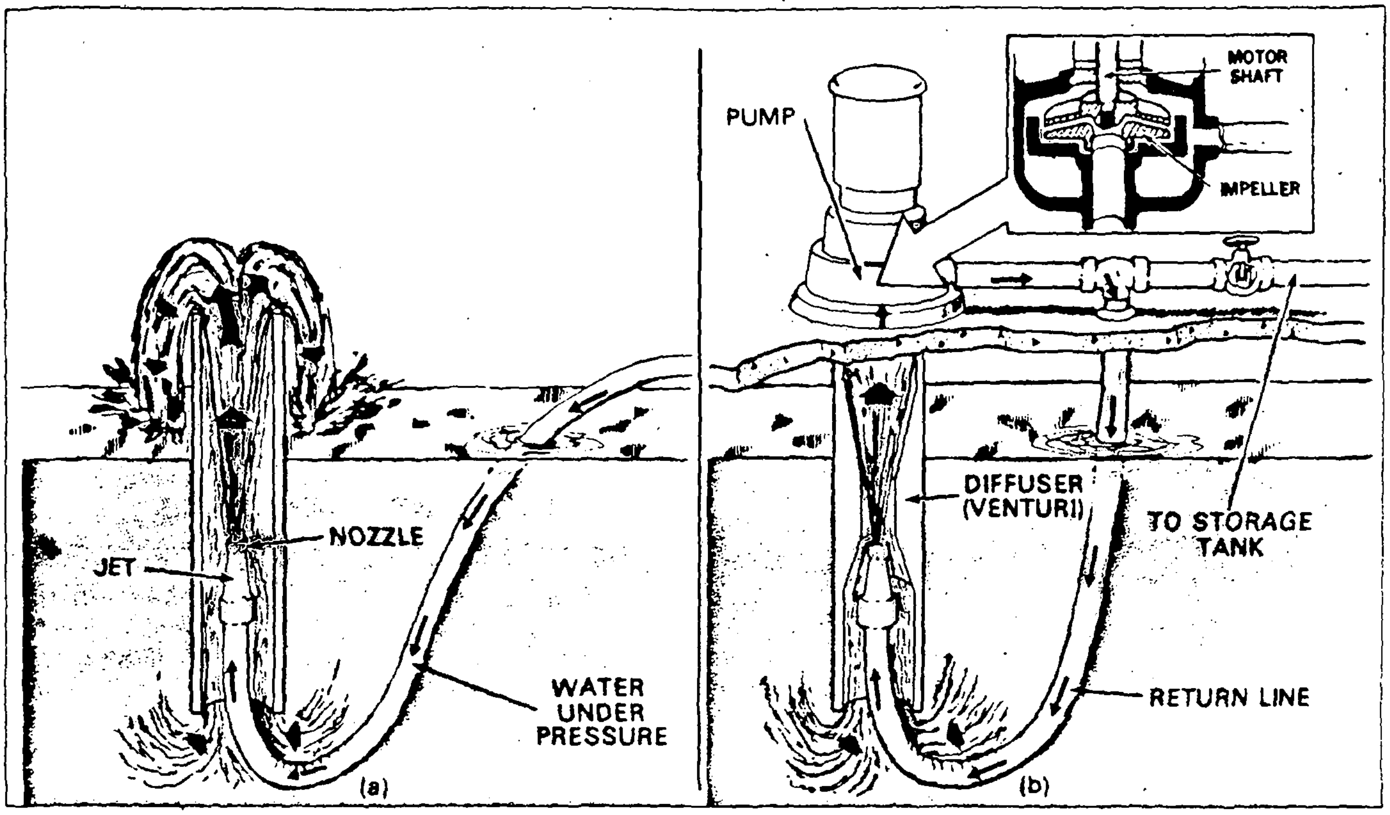

FIGURE 72. (a) How a jet provides pumping action. Water is supplied to the jet nozzle under pressure. Water surrounding the jet stream is lifted and carried up the pipe as a result of the jet action. (b) When a jet is used with a centrifugal pump, a portion of the water delivered by the pump is returned to the jet nozzle to operate it. The jet lifts water from the well to a level where the centrifugal pump can finish lifting it by suction.

HOW A CENTRIFUGAL-JET (EJECTOR) PUMP WORKS

The **addition of a jet to a centrifugal pump** makes it adaptable to many more conditions. But first you need to understand what a jet is and how it works.

A **jet** is a nozzle which receives water at high pressure (Figure 72a). As the water passes through the jet, water speed (velocity) is greatly increased, but the pressure drops. This action is the same as the squirting action you get with a hose when you start to close the nozzle. The greatly increased water speed, or squirting action, plus the low pressure around the tip of the nozzle, is what *causes suction to develop* around the jet nozzle. Air, water or loose materials around a jet nozzle are drawn into the water stream and carried along with it.

If the squirting action is confined inside a pipe (Figure 72a), the high-speed stream will suck in additional water and carry it along, thus providing pumping action.

For a jet to be efficient and effective in a combination centrifugal-jet pump, it must be used with a cone-shaped member called a "**diffuser**" or "**venturi**" (Figure 72b). In this discussion it will be called a diffuser, since it is widely known by that name in the pump industry. The diffuser changes the high-speed jet stream back to a high-pressure stream for delivery to the centrifugal pump.

The **jet and the diffuser** are simple in appearance, but they have to be well engineered and carefully matched to be efficient for various pumping conditions. Pumps of this type are usually called "jet pumps". Also, the jet-and-diffuser combinations are known as "*ejectors*." Those terms will be used in the rest of this discussion.

Review and Discussion of Step 6
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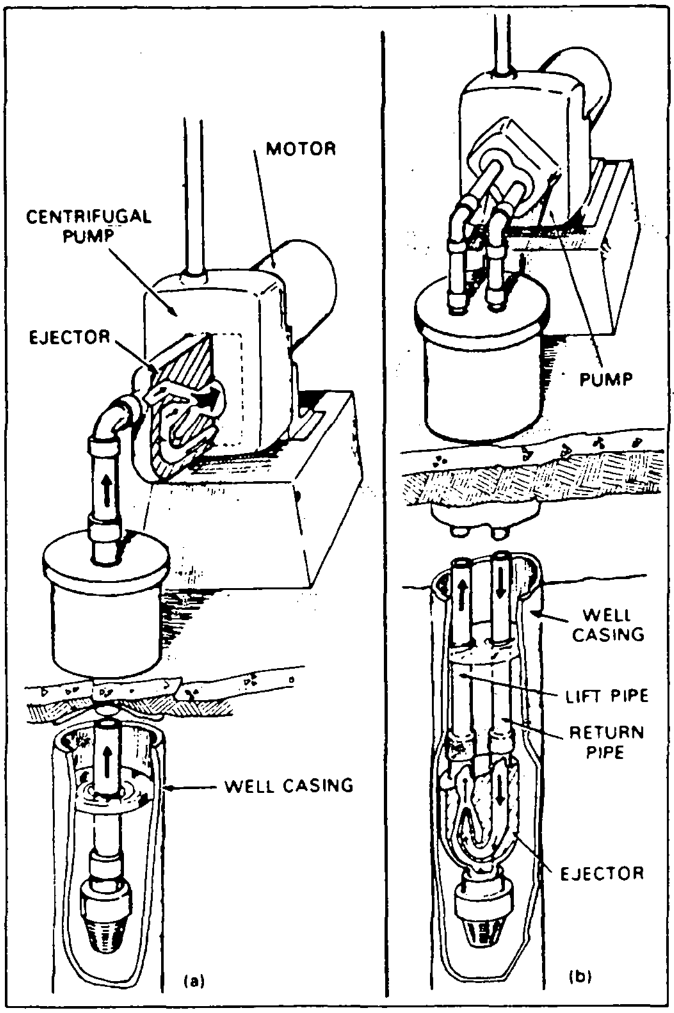

FIGURE 73. (a) With a shallow-well jet pump, the ejector is mounted close to the pump impeller. (b) With a deep-well jet pump, the ejector is usually mounted just above the water level in the well, or else submerged below water level.

With a **shallow-well jet pump,** the ejector is located next to the impeller (Figure 73a). A portion of the water from the impeller is forced through the ejector, and the rest is delivered to the pressure tank. With the ejector located on the suction side of the pump, the *suction is increased* considerably. This enables a centrifugal pump to increase its effective suction lift from about 15 feet to as much as 25 feet. But, the amount of water delivered to the storage tank becomes less as the distance from the pump down to the water increases—more water has to be returned to operate the ejector.

The difference between a **deep-well jet pump** (Figure 73b) and a shallow-well jet pump is the location of the ejector. The deep-well ejector is located in the well below water level. (The ejector design varies for different depths, but the manufacturer takes care of that problem.) The deep-well ejector works in the same way as the shallow-well ejector. Water is supplied to it under pressure from the centrifugal pump (Figure 73b). The ejector then returns the water, plus an additional supply from the well, to a level where the centrifugal pump can lift it the rest of the way by suction.

Many shallow-well jet pumps are built so the ejector may be removed from the pump casing (Figure 73a) and connected to the drop pipe in the well (Figure 73b), thus making it possible to *convert a shallow-well jet pump into a deep-well jet pump.* This will probably require a change of ejectors to work efficiently. This is of particular value when you have a water level that is gradually lowering in your water source.

Jet pumps have the same **air-handling** characteristics as the centrifugal pump that makes up the unit. In general, the pump has to be started with the pump and piping connections to the water supply completely filled with water.

HOW A TURBINE PUMP WORKS

Turbine pumps look very much like centrifugal pumps, and they operate in much the same manner. However, they are not as dependent on centrifugal force as the straight-centrifugal pump. Although there is some centrifugal action, there is also propelling or paddling action to provide a lifting effect.

Figure 74 shows how a **shallow-well turbine pump** works. It uses one impeller. The design is such that it spins the water several times as it passes from the pump inlet to the outlet. At the same time, the fins provide some pushing action. This improves its suction over that of a straight centrifugal pump. It will lift water by suction from *depths of 25 feet* or more. It can also **pump some air.**

Deep-well turbine pumps *are usually of the sub-*mersible type. They look very similar to the centrifugal-submersible pump shown in Figure 71.

FIGURE 74. How a shallow-well turbine pump works. The fins on the impeller give the incoming water a spinning action. The water spirals from the tips of the fins, into the raceway and back into the fins, several times before it reaches the outlet. Each time it is thrown from the fin tips, its pressure is increased.

Review and Discussion of Step 6
(continued)

C. What Type of Pump to Use

With the information you developed on the pump capacity you will need, and with a knowledge of how the different pumps work, you are now in position to decide on what type of pump to use. The one you select will be determined by the following factors:

- — Depth to water
- — Well size
- — Pressure range needed for adequate water service
- — Height water is lifted above pump
- — Pump location
- — Pump durability and efficiency
- — Dealer service

You will find **Tables X, XI and XII** of help in dealing with the first three factors. The tables **give ranges of pumping capacities** for the different pump types operating under the various conditions listed. You may wonder how accurate the manufacturers' data is for these pumping capacities. The national Water Systems Council (manufacturers of jet, submersible and reciprocating pumps) has a certification program to help provide this assurance. Any pump with a WSC *"Certified Performance"* sticker on it is guaranteed by the manufacturer to produce within 10 per cent of its rated capacity while new and operating under the conditions for which it is designed.

DEPTH TO WATER

If the water in your well or water source never gets **lower than 15 to 25 feet below the pump,** you can use a **shallow-well pump**—one of the types you just finished studying under "Understanding Pump Types." Compared to deep-well pumps, they cost less to buy, and connecting the pump to the water source is simple. All your plumber needs to do is run a suction pipe from your pump to the water source (Figure 73a).

You have already determined how much water you will need per hour to meet your peak demands. Now you need to know which of the **pump types** will supply that quantity of water and lift it as high as needed to reach your water-use outlets. Tables X and XI show these various pump types and the range of pumping capacities for each type at different depths. Pump manufacturers publish the capacities of their pumps when pumping from various depths, so there is no need for your dealer to guess at the capacity his pumps will deliver under your conditions.

If the water in your well or water source is **more than 25 feet below pump level,** Table XII shows the types of deep-well pumps available to you and their capacities at various depths.

If you have a **shallow well, but you have observed the water level lowering** over a period of several years, the jet pump may best fit your needs. As shown in Figure 73, some of these are designed for changing from shallow- to deep-well use when the water level lowers.

WELL SIZE

When you have found the pump type that will lift water from your water source to pump level and provide the amount of water you need, your next check is to see if it will work with **your size of well.** Note that in all three tables the different well sizes are given in the left column for the different pump types along with their capacities.

Well size is mostly a **problem for deep-well installations.** Ones less than 4 inches in diameter are the biggest problem, especially if you have need for large amounts of water. Manufacturers of piston pumps and jet pumps have tried to meet this problem with special cylinders and ejectors.

A **deep-well piston pump** can be used on a well as small as 2 inches in diameter. This can be accomplished

Review and Discussion of Step 6
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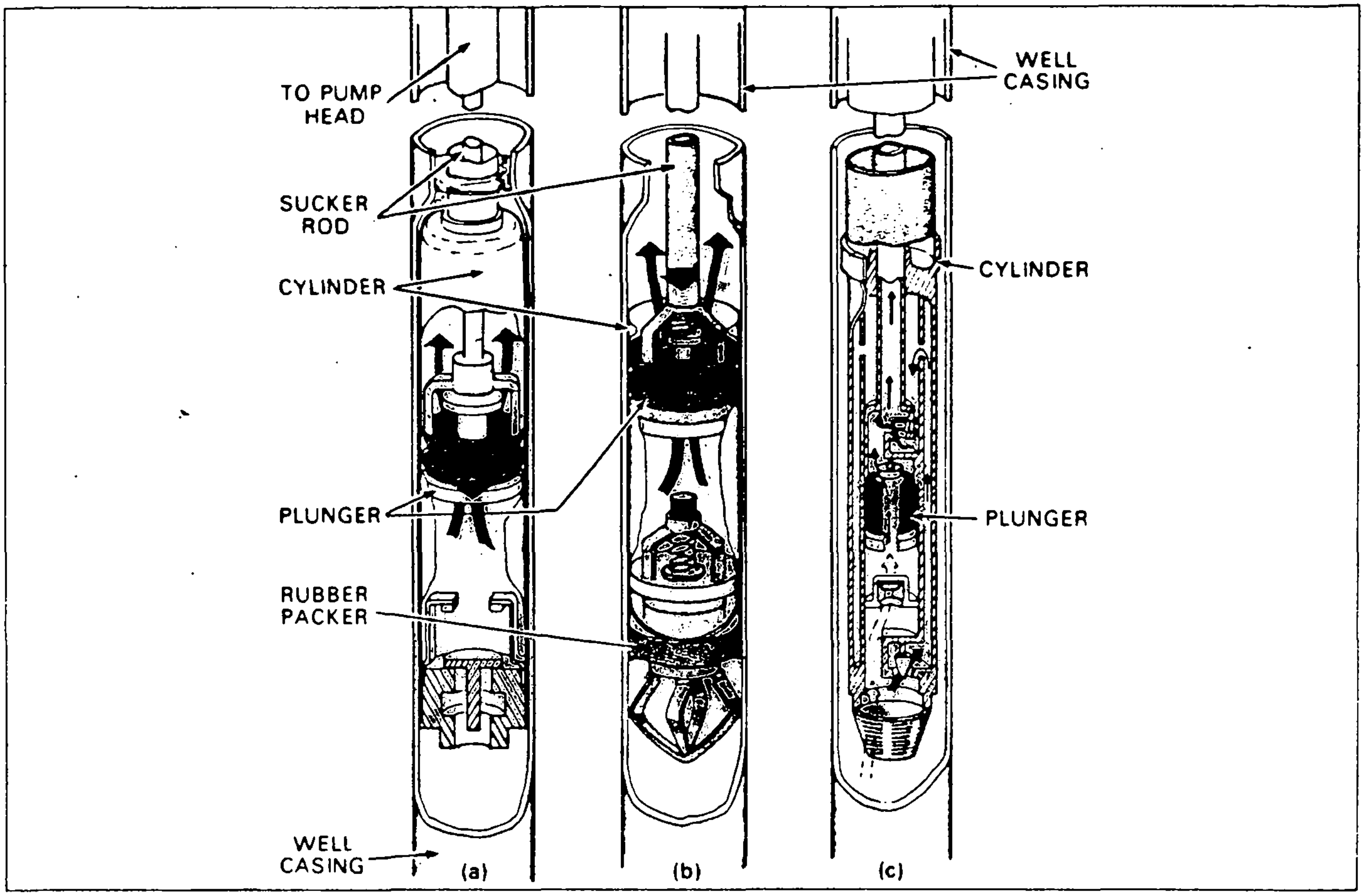


FIGURE 75. Piston-pump cylinders for extra small wells (2-4 inches in diameter). (a) Single-acting closed-type cylinder. (b) Single-acting Eureka cylinder. Packer at bottom of cylinder makes water-tight connection so well casing may be used in place of drop pipe. (c) Double-acting cylinder. Pumps water on both up and down strokes.

with a small, *closed-type single-acting cylinder* (Figure 75a), a *Eureka cylinder* (Figure 75b), or a *double-acting cylinder* (Figure 75c). The latter two will deliver more water than the former. Table XII shows the comparative pumping capacity for each of these cylinders from various depths and with various well sizes.

The **Eureka cylinder** (Figure 75b) is equipped with a water-tight rubber packer that fits against the cylinder wall. This does away with a drop pipe for connecting the cylinder to the pumping head and provides room for a larger cylinder.

A **double-acting deep-well cylinder** (Figure 75c), in the same size well as the other two, delivers more water than either of the others. It pumps water on both the up stroke and down stroke.

Any of these extra-small cylinders will probably have to be ordered as special equipment by your dealer.

Jet pumps can be used with a well size as small as 2 inches. If your well casing is in good condition, you can use it in place of one pipe. To do this requires a packer-type ejector to keep water in the upper section of the casing from passing down into the well (Figure 76). In this way, the casing acts as a return pipe. Water is forced down the casing from the pump and into the ejector. The ejector then acts in the usual manner in lifting water

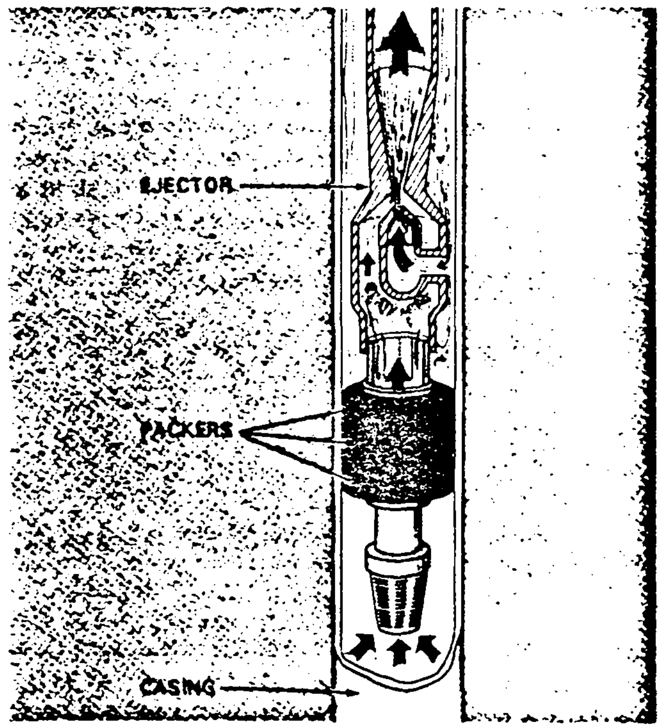
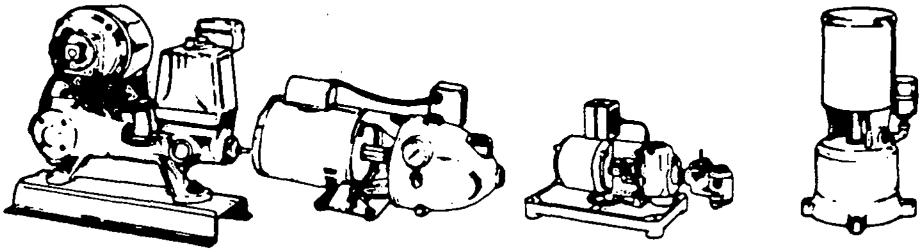


FIGURE 76. Packer-type jet used for extra-small wells (2 to 4 inches in diameter). Also used for larger wells where maximum pumping capacity is needed.

Review and Discussion of Step 6
(continued)

TABLE X. PUMP SELECTION CHART—SHALLOW WELLS, LOW PRESSURE*

For pumps lifting water from depth of 25 feet or less and delivering to faucets not more than 20 feet above level of pump. Capacities based on delivery against pounds-per-square-inch tank pressure.



Well Size	Total Lift (Distance from lowest water level to pump)	Piston Pump	Shallow-well Jet	Shallow-well Turbine	Straight Centrifugal**
		Range in Pump Capacities (gal. per hr.)			
1¼" Diameter					
	10 feet	250 — 500	400 — 1830	400 — 565	450 — 684
	15 feet	250 — 500	375 — 1650	390 — 555	350 — 672
	20 feet	250 — 500	285 — 1440	380 — 545	275 — 646
	25 feet	250 — 500	240 — 780	370 — 535	
1½" Diameter					
	10 feet	250 — 500	440 — 2800	400 — 1330	450 — 2300
	15 feet	250 — 500	360 — 2640	390 — 1310	350 — 2200
	20 feet	250 — 500	285 — 2500	380 — 1290	275 — 2050
	25 feet	250 — 500	210 — 1200	370 — 1270	200 — 1900
2" Diameter (or larger, also includes dug wells, cisterns, springs, ponds and lakes)	10 feet	250 — 500	440 — 3660	400 — 1330	450 — 3500
	15 feet	250 — 500	360 — 3540	390 — 1310	350 — 3300
	20 feet	250 — 500	285 — 3420	380 — 1290	275 — 3100
	25 feet	250 — 500	210 — 3180	370 — 1270	200 — 1900

*The range of pumping capacities in this table are not for any one pump but rather for a number of pumps, with different capacities, operating under the conditions given. All figures are taken from manufacturers' published ratings on pumps. If more pumping capacity is needed, check Table XI. Some high pressure pumps have more capacity than low-pressure pumps and can often replace them.

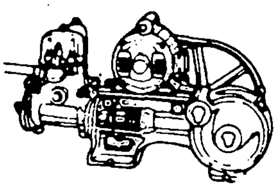
**Many manufacturers of straight centrifugal pumps recommend limiting their use to 15 feet or less.

from the well back up the center pipe to the pump. In some pumps, water flow is the reverse of that just described. Water is forced from the pump down the center pipe to the ejector. This type must be located directly over the well and normally requires more maintenance than other types.

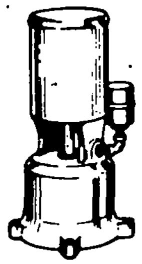
Review and Discussion of Step 6
(continued)

TABLE XI. PUMP SELECTION CHART—SHALLOW WELL, HIGH PRESSURE*

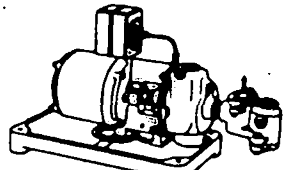
For pumps lifting water from depths of 25 feet or less and delivering to faucets higher than 20 feet above pump level.
Capacities based on **20 pounds per square inch of tank pressure at delivery level.**



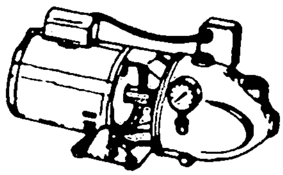
Shallow-well Piston Pumps



Centrifugal Single and Multistage Straight Centrifugal

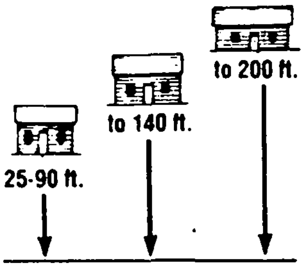


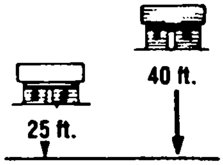
Shallow-well Turbine

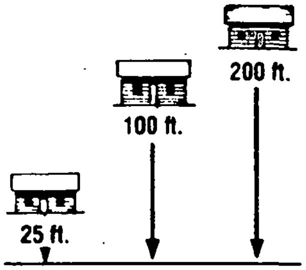


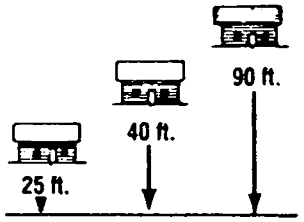
Shallow-well Jet

Height Pump to Delivery Point









Range in Pump Capacities (gal. per hr.)

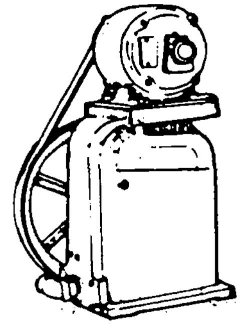
Well Size	Total Lift (Distance from lowest water level to pump)	Shallow-well Piston Pumps: 25-90 ft.	Shallow-well Piston Pumps: to 140 ft.	Shallow-well Piston Pumps: to 200 ft.	Centrifugal Single and Multistage Straight Centrifugal: 25 ft.	Centrifugal: 40 ft.	Shallow-well Turbine: 25 ft.	Shallow-well Turbine: 100 ft.	Shallow-well Turbine: 200 ft.	Shallow-well Jet: 25 ft.	Shallow-well Jet: 40 ft.	Shallow-well Jet: 90 ft.
1¼" Dia.	10 feet	260- 540	260- 580	260- 580	900-1400	900-1200	0- 227			530-1450	345-1080	345- 450
	15 feet	260- 540	260- 580	260- 580	750-1200	750-1100	0- 220			460-1270	300- 930	300- 400
	20 feet	260- 540	260- 580	260- 580	600-1000	600-1000	0- 213			370-1080	240- 750	240- 350
	25 feet	260- 540	260- 580	260- 580	450- 800	450- 300	0- 206			240- 780	200- 540	200- 300
1½" Dia.	10 feet	260-1020	260-1020	260-1020	2200-2500	1800-2100	227-1240	270-1460	285-1120	530-2610	345-1080	345- 450
	15 feet	260-1020	260-1020	260-1020	1950-2300	1450-1850	220-1220	265-1440	282-1115	460-2280	300- 930	300- 400
	20 feet	260-1020	260-1020	260-1020	1800-2100	1200-1600	213-1200	260-1425	279-1110	370-1920	240- 750	240- 350
	25 feet	260-1020	260-1020	260-1020	1600-2000	1000-1500	206-1180	255-1410	276-1105	240-1260	200- 540	200- 540
2" Dia.	10 feet	260-1680	260-1680	260-1020	2200-5600	1800-2100	227-1240	270-1460	285-1120	530-2610	345-1080	810-3350
	15 feet	260-1680	260-1680	260-1020	1950-5250	1450-1850	220-1220	265-1440	282-1115	460-2280	300- 930	600-2800
	20 feet	260-1680	260-1680	260-1020	1800-2100	1200-1600	213-1200	260-1425	279-1110	370-1920	240- 750	420-2340
	25 feet	260-1680	260-1680	260-1020	1600-2000	1000-1500	206-1180	255-1410	276-1105	240-1260	200- 540	0-1700
2½" Dia.	10 feet	260-2640	260-2640	260-1020	2200-5600	1800-2100	227-1240	270-1460	285-1120	530-2610	345-1080	810-3350
	15 feet	260-2640	260-2640	260-1020	1950-5250	1450-1850	220-1220	265-1440	282-1115	460-2280	300- 930	600-2800
	20 feet	260-2640	260-2640	260-1020	1800-2100	1200-1600	213-1200	260-1425	279-1110	370-1920	240- 750	420-2340
	25 feet	260-2640	260-2640	260-1020	1600-2000	1000-1500	206-1180	255-1410	276-1105	240-1260	200- 540	0-1700
3" Dia. (or larger, also includes dug wells, cisterns, ponds and lakes)	10 feet	260-3960	260-2640	260-2640	2200-5600	1800-2100	227-1240	270-1460	285-1120	530-2610	345-1080	810-3350
	15 feet	260-3960	260-2640	260-2640	1950-5250	1450-1850	220-1220	265-1440	252-1115	460-2280	300- 930	600-2800
	20 feet	260-3960	260-2640	260-2640	1800-2100	1200-1600	213-1200	260-1425	249-1110	370-1920	240- 750	420-2340
	25 feet	260-3960	260-2640	260-2640	1600-2000	1000-1500	206-1180	255-1410	246-1105	240-1260	200- 540	0-1700

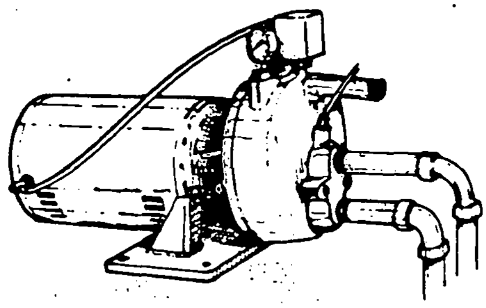
*The range of pumping capacities in this table are not those of any one pump but rather for a wide range of pumps with different capacities made by different manufacturers but operating under the conditions given. All figures are taken from manufacturers' published ratings on pumps offered for individual water supplies.

Review and Discussion of Step 6
(continued)

TABLE XII. PUMPS FOR LIFTING WATER FROM MORE THAN 25 FEET DEPTH

Water sources include driven, drilled, bored and dug wells.
Capacities based on 20 lbs. per square inch tank pressure at point of delivery.





Well Size	Total lift (Lowest water level to highest delivery point except for jets)	Piston (plunger) Pumps: Single-Acting Cylinder	Piston (plunger) Pumps: Double-Acting Cylinder	Piston (plunger) Pumps: Eureka Cylinder*	Centrifugal Jet — Height — Pump to Delivery Point: Pump and building on same level, 1-Pipe	Pump and building on same level, 2-Pipe	50 ft., 1-Pipe	50 ft., 2-Pipe	75 ft., 1-Pipe	75 ft., 2-Pipe	Centrifugal Submersible (Gals. per hour)	Deep-well Turbine (Gals. per hour)
		Range in Pump Capacities (gal. per hr.)**										
2" Diameter	30 feet	170- 225	300- 385	190- 270	310- 900	Not adaptable	270-1032	Not adaptable	250-1000	Not adaptable	Not adaptable	Not adaptable
	50 feet	170- 225	300- 385	190- 270	245- 620		220- 690		190- 790			
	70 feet	170- 225	300- 385	190- 270	180- 500		160- 546		140- 650			
	100 feet	170- 225	300- 385	190- 270	165- 350		0- 315		120- 490			
	125 feet	170- 225	300- 385	190- 270	140- 250		0- 220		110- 405			
	150 feet	170- 225	300- 385	190- 270	120- 180		0- 192		0- 360			
	200 feet	170- 225	300- 385	190- 270	100- 125		0- 100		0- 100			
	250 feet	170- 225	300- 385	190- 270								
	300 feet	170- 225	300- 385	190- 270								
	350 feet	170- 225	300- 385	190- 270								
2½" Diameter (2½" smallest well using open type cylinder)	30 feet	180- 250	300- 445	310- 465	400-1480	Not adaptable	360-1380	Not adaptable	320-1020	Not adaptable	Not adaptable	Not adaptable
	50 feet	180- 250	300- 445	310- 465	360-1270		310-1070		290- 850			
	70 feet	180- 250	300- 445	310- 465	210- 970		200- 870		170- 700			
	100 feet	180- 250	300- 445	310- 465	200- 600		180- 540		160- 430			
	125 feet	180- 250	300- 445	310- 465	180- 450		100- 400		140- 320			
	150 feet	180- 250	300- 445	310- 465	170- 400		150- 260		130- 260			
	200 feet	180- 250	300- 445	310- 465	160- 240		140- 220		120- 170			
	250 feet	180- 250	300- 445	310- 465	150- 200		130- 180		100- 140			
	300 feet	180- 250	300- 445	310- 465	140- 150		120- 130		95- 100			
	350 feet	180- 250	300- 445	310- 465								
3" Diameter	30 feet	180- 285	300- 480	465- 625	400-2250	350- 470	360-2030	0- 582	280-1800	0- 576	Not adaptable	Not adaptable
	50 feet	180- 285	300- 480	465- 625	360-1900	280- 330	330-1700	0- 384	260-1640	0- 444		
	70 feet	180- 285	300- 480	465- 625	250-1600		220-1400	0- 240	170-1120	0- 384		
	100 feet	180- 285	300- 480	465- 625	180-1200		160-1100		130- 880	0- 252		
	125 feet	180- 285	300- 480	465- 625	160- 900		140- 810		110- 650	0- 175		
	150 feet	180- 285	300- 480	465- 625	150- 750		130- 670		100- 520			
	200 feet	180- 285	300- 480	465- 625	140- 500		0- 450		0- 360			
	250 feet	180- 285	300- 480	465- 625	130- 330		0- 290		0- 230			
	300 feet	180- 285	300- 480	465- 625	120- 230		0- 210		0- 170			
	350 feet	180- 285	300- 480									
3½" Diameter	30 feet	180- 360	300- 720	Requires special cylinder	Same as for 3" well	Not adaptable	Same as for 3" well	Not adaptable	Same as for 3" well	Same as for 3" well	Not adaptable	Not adaptable
	50 feet	180- 360	300- 720									
	70 feet	180- 360	300- 720									
	100 feet	180- 360	300- 720									
	125 feet	180- 360	300- 720									
	150 feet	180- 360	300- 720									
	200 feet	180- 360	300- 720									
	250 feet	180- 360	300- 720									
	300 feet	180- 360	300- 720									
	350 feet	180- 360	300- 720									

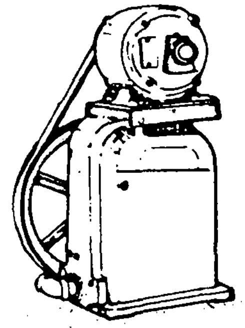
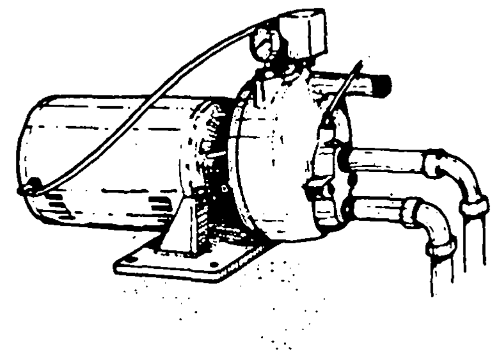
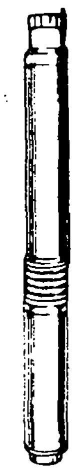
*Minimum capacity based on 6" stroke at 50 strokes per minute. Maximum based on 9" stroke at 45 strokes per minute.
**Larger units can be built to fit individual needs.

Review and Discussion of Step 6
(continued)

4. When you have concluded the review of pumps, ask the participants to turn to the next page.

TABLE XII. (CONTINUED) PUMPS FOR LIFTING WATER FROM MORE THAN 25 FEET DEPTH

Water sources include driven, drilled, bored and dug wells.
Capacities based on **20 lbs. per square inch tank pressure at point of delivery.**

Well Size	Total lift (Lowest water level to highest delivery point except for jets)	Piston (plunger) Pumps 			Centrifugal Jet  — Height — Pump to Delivery Point: Pump and building on same level		50 ft.		75 ft.		Centrifugal Submersible 	Deep-well Turbine 
		Single-Acting Cylinder	Double-Acting Cylinder	Eureka Cylinder*	1-Pipe	2-Pipe	1-Pipe	2-Pipe	1-Pipe	2-Pipe	(Gals. per hour)	(Gals. per hour)
		Range in Pump Capacities (gal. per hr.)										
4" Diameter	30 feet	180- 585	300- 720	675-1100	480-3000	400-1400	450-1700	360-1260	450-4000	320-1120	640-4000	2160-7860
	50 feet	150- 585	300- 720	675-1100	450-1900	330-1000	400-1700	290- 900	410-3350	260- 800	570-3600	1560-7560
	70 feet	180- 585	300- 720	675-1100	400-1500	200- 650	360-1500	230- 580	360-2100	210- 520	480-3350	1200-7200
	100 feet	180- 585	300- 720	675-1100	300-1100	0- 570	310-1200	210- 510	290-1530	180- 460	320-3120	120-6720
	125 feet	180- 585	300- 720	675-1100	220- 900	0- 500	270- 810	180- 450	270-1100	160- 400	160-2920	0-6300
	150 feet	180- 585	300- 720	675-1100	0- 750	0- 400	220- 670	170- 360	220- 670	150- 320	0-2640	0-5880
	200 feet	180- 585	300- 720	675-1100	0- 500	0- 300	180- 450	160- 270	180- 450	140- 240	0-2250	0-4320
	250 feet	180- 585	300- 720	675-1100	0- 330	0- 270	170- 290	150- 210	170- 290	130- 180	0-2000	0-3840
	300 feet	180- 585	300- 720	675-1100	0- 230	0- 180	160- 210	140- 160	160- 200	120- 140	0-1560	
	400 feet	180- 585	300- 720								0-1130	
	500 feet	180- 585	300- 720								0- 820	
	600 feet	180- 585	300- 720								0- 660	
	700 feet	180- 585	300- 720								0- 590	
	800 feet	180- 585	300- 720								0- 510	
	900 feet										0- 400	
	1000 feet										0- 270	
5" Diameter	30 feet	180- 825	300-1620	Not	Not	650-2950	1500-4075	650-2350	Not	1000-2000	640-4000**	2160-7860
	50 feet	180- 825	300-1620	adaptable	adaptable	540-2300	1085-3375	690-1800	adaptable	790-1600	570-3600	1560-7560
	70 feet	180- 825	300-1620			450-1800	870-2875	420-1600		595-1440	480-3350	1200-7200
	100 feet	180- 825	300-1620			300-1300	610-2060	282-1100		468-1040	320-3120	120-6720
	125 feet	180- 825	300-1620			275-1000	390-1580	250- 900		400- 800	160-2920	0-6300
	150 feet	180- 825	300-1620			190- 800	0-1340	192- 720		220- 640	0-2640	0-5880
	200 feet	180- 825	300-1620			0- 550	0- 750	0- 440		190- 440	0-2250	0-4320
	250 feet	180- 825	300-1620			0- 350	0- 340	0- 310		0- 280	0-2000	0-3840
	300 feet	180- 825	300-1620			0- 260		0- 230		0- 210	0-1560	
	400 feet	180- 825	300-1620								0-1130	
	500 feet	180- 825	300-1620								0- 820	
	600 feet	180- 825	300-1620								0- 660	
	700 feet	180- 825	300-1620								0- 590	
	800 feet	180- 825	300-1620								0- 510	
	900 feet										0- 400	
	1000 feet										0- 270	
6" Diameter (and larger)	30 feet	180-1290	300-2160	Not	Not	930-3400	Not	2000-4000	Not	0-2700	640-4000**	2160-7860
	50 feet	180-1290	300-2160	adaptable	adaptable	930-3000	adaptable	1800-3350	adaptable	0-2400	570-3600	1560-7560
	70 feet	180-1290	300-2160			930-2000		1620-2600		0-1600	480-3350	1200-7200
	100 feet	180-1290	300-2160			680-1300		1080-1750		0-1040	320-3120	120-6720
	125 feet	180-1290	300-2160			590-1000		830-1200		0- 800	160-2920	0-6300
	150 feet	180-1290	300-2160			230- 800		0- 720		0- 640	0-2640	0-5880
	200 feet	180-1290	300-2160			0- 550		0- 500		0- 440	0-2250	0-4320
	250 feet	180-1290	300-2160			0- 350		0- 310		0- 280	0-2000	0-3840
	300 feet	180-1290	300-2160			0- 260		0- 230		0- 210	0-1560	
	400 feet	180-1290	300-2160								0-1130	
	500 feet	180-1290	300-2160								0- 820	
	600 feet	180-1290	300-2160								0- 660	
	700 feet	180-1290	300-2160								0- 590	
	800 feet	180-1290	300-2160								0- 510	
	900 feet										0- 400	
	1000 feet										0- 270	

*Minimum capacity based on 6" stroke at 50 strokes per minute. Maximum based on 9" stroke at 45 strokes per minute.
**Larger units can be built to fit individual needs.

Review and Discussion of Step 7 Time required: 10 minutes

1. Review the summary information on page 34 with the participants.

2. Ask the participants who have experience with, or knowledge of, different disinfection methods to describe those methods and the results they produce. Record major points on the board or flipchart.

3. You may also want to provide additional information on disinfection methods that are especially appropriate to the participants' countries or regions.

4. When you are ready to proceed, ask the participants to turn to page 35.

Review and Discussion of Step 7

Step 1.	Location
Step 2.	Well Design
Step 3.	Construction
Step 4.	Development
Step 5.	Testing
Step 6.	Pump Selection
Step 7.	**Disinfection**
Step 8.	Operations and Maintenance

The seventh step in ground water utilization is to disinfect the entire installation.

Chlorination removes disease-causing bacteria and viruses from the water supply. Chlorination also has a residual germicidal action which provides continuing antibacterial and antiviral protection. Chlorination is often used to help remove undesirable minerals from the water. Since chlorine is also an effective oxidixing agent, many minerals, such as iron, will form precipitates which can then be removed by filtration.

Shock chlorination is performed after the well is drilled and before the well is put into service. Shock chlorination eliminates organisms which were introduced into the well during drilling. Continuous chlorination is used to control disease-causing organisms, particularly if water must be transported over a great distance from the well and, therefore, the likelihood of contamination is increased.

Chlorine is available in solid and liquid forms. One form, liquid sodium hypochlorite, is commonly sold as household bleach. Calcium hypochlorite, is the solid form of chlorine and can be obtained in soluble powder or tablet form.

Chlorination equipment is available in three types of units.

- Positive displacement feeders are electrically powered and operate by using a piston or diaphragm pump to inject the chlorine solution.
- Educator-type chlorinators use the natural vacuum created by the flow of water in a pipe to draw the chlorine solution from the disinfectant reservoir.
- Tablet or granule feeders allow solid disinfectants to contact the flowing water to be treated. As the disinfectant dissolves, gravity forces more disinfectant into the dissolving chamber.

Review and Discussion of Step 8 Time required: 20 minutes

1. Review the summary information on pages 35 and 36 with the participants.

2. Ask the participants who have experience with, or knowledge of, the operation and maintenance of pumps or wells to describe the steps that were taken and the results obtained. Record major points on the board or flipchart.

3. Provide any additional information on operation and maintenance that would be relevant to the participants.

Review and Discussion of Step 8

Step 1. Location
Step 2. Well Design
Step 3. Construction
Step 4. Development
Step 5. Testing
Step 6. Pump Selection
Step 7. Disinfection
Step 8. Operations and Maintenance

The eighth step in ground water utilization is to operate and maintain the pump, the well, and the area around the well.

Pump maintenance should be performed periodically. Over time, the moving parts and seals will wear out and require replacement. Routine pump maintenance is important in high capacity wells to help avoid the interruption of service.

Well maintenance is performed to eliminate or reduce slime-producing bacteria, build-up of sediment at the bottom of the well, and build-up of chemical scale on the screen.

- Slime-producing bacteria are treated with high concentrations of chlorine, called shock chlorination.

- Sediment requires the use of development methods such as overpumping, surging and high-velocity jetting.

- Chemical scale on the screen is treated by acids, and oxidizing agents. Development methods, such as overpumping, surging and high velocity setting, are often used concurrently to produce the best results.

Area maintenance is also important to ensure that contaminants do not enter the well. Most pollution of ground water results from the disposal of wastes on the land surface, in shallow excavations including septic tanks, or through deep wells and mines.

Review and Discussion of Step 8
(continued)

4. Summarize the eight steps of ground water utilization using the major points you recorded on the board or flipchart.

5. When you are ready to proceed, make a transition from the discussion of ground water utilization to ground water management, the topic of Part III. Show Part III of the slide/tape program, which is approximately twenty minutes in length.

<u>Review and Discussion of Step 8</u>
(continued)

Other causes of pollution include the use of fertilizers and other agricultural chemicals, leaks in sewers or storage tanks and animal feedlots. Ground water pollution from waste disposal or animal feedlots can be avoided if sites with the following conditions are selected:

- Significant thicknesses of unsaturated material containing clay and (or) organic material are present.
- Areas are as close as possible to places of natural ground water discharge.
- Overland runoff is excluded, and surface infiltration is held to the minimum amount possible.

INSTRUCTOR NOTES

PART III: GROUND WATER MANAGEMENT

Review and Discussion of Step 1 Time required: 20 minutes

1. After the participants view Part III of the slide/tape program, ask them if they have any questions.

2. Review the summary information on pages 37 and 38 with the participants.

3. Ask the participants who have experience with the selection of ground water systems in place of surface water supply systems to describe the selection process that was used and the results obtained. Record major points on the board or flipchart.

4. You may want to provide additional information on the cost differences between ground water and surface water supply systems.

PART III: GROUND WATER MANAGEMENT

Review and Discussion of Step 1

Step 1.	**Cost Comparison and Selection**
Step 2.	Natural Recharge
Step 3.	Artificial Recharge
Step 4.	Monitoring

The first step in ground water management is cost comparison and selection in order to select the most economical alternative.

Ground water systems often offer seven advantages over surface water systems:

GROUND WATER	SURFACE WATER
• Simple Staging New wells are drilled only as required by demand growth. New wells can be added swiftly or postponed easily.	Surface water systems require accurate long-term forecasts and construction of large and lumpy systems. The systems are not easily expanded.
• Flexible Financing Water users can support the cost of staged projects through user fees.	Surface water development requires large capital investments and borrowings.
• Little Land Ground water requires very little land acquisition. The land above an aquifer can be put to other productive uses.	Surface reservoirs require the acquisition of significant amounts of land.
• Minimal Maintenance Ground water reservoirs remain unchanged over time. Maintenance and operations costs are relatively small.	Surface reservoirs fill with silt and dams may lose their integrity. Operations and maintenance costs can be high.
• Eliminated Evaporation Ground water storage prevents evaporation.	Surface water reservoirs lose significant amounts of water.

Review and Discussion of Step 1
(continued)

5. When you are ready to proceed, ask the participants to turn to page 39.

Review and Discussion of Step 1
(continued)

GROUND WATER	SURFACE WATER
• Simple Treatment Ground water is filtered and purified by the earth. No extensive filtration is required.	Elaborate filtration is required to remove suspended matter. Costly treatment is required to make the water bacteriologically safe.
• Diminished Distribution The earth provides a natural distribution system and diminishes the size of a pipe distribution system.	Extensive pipe distribution systems are required to bring water from the source to the consumer.

Ground water development costs can be further reduced by reducing driling costs and increasing the number of shallow wells.

- Reduced Drilling Costs: Simple drilling methods and local manpower can replace large drilling rigs that require specialized laborers.

- Larger Numbers of Shallow Wells: A larger number of shallow wells can be more economical than a smaller number of deep wells. Lower construction costs with less sophisticated equipment are also possible with shallower wells.

Review and Discussion of Step 2 Time required: 20 minutes.

1. Review the summary information on pages 39 and 40 with the participants.

2. Ask the participants who have experience with the natural recharge alternatives to describe how they were used and what results were achieved. Record major points on the board or flipchart.

3. You may also want to provide additional information on the different natural recharge techniques that are particularly suitable in the participants' countries or regions.

Review and Discussion of Step 2

Step 1.	Cost Comparison and Selection
Step 2.	**Natural Recharge**
Step 3.	Artificial Recharge
Step 4.	Monitoring

The second step in ground water management is to identify techniques that are used where the replenishment of the aquifer comes from natural recharge.

Natural recharge is that portion of precipitation that infiltrates into the ground to become ground water.

- In humid parts of the country, recharge occurs in interstream areas, that is, all areas except along streams and their adjoining flood plains. (Streams and floodplains tend to be discharge areas.)

- In dry parts of a country, natural recharge conditions are more complex. They may occur in mountain ranges, on alluvial fans that border the mountain ranges, and along the channels of major streams where they are underlain by thick and permeable alluvial deposits.

Recharge rates are generally expressed in terms of volume (such as cubic meters or gallons) per unit of time (such as a day or year) and per unit or area (such as a square kilometer or acre). When these units are reduced to their simplest forms, recharge is expressed as a depth of water on the land surface per unit of time.

Recharge varies from year to year, depending upon the amount of precipitation, its seasonal distribution, air temperature, land use, and other factors. Recharge rates in forests are much higher than those in cities.

There are many management techniques that can take advantage of the water available from natural recharge. Some of them are discussed below.

- Well spacing - Planning a well field should include spacing the wells properly if they will be close to each other. Improperly spaced wells have intersecting cones of depression. These cones of depression lower water levels more than is necessary and, in turn, increase pumping costs.

Review and Discussion of Step 2
(continued)

4. When you are ready to proceed, ask the participants to turn to page 41.

Review and Discussion of Step 2
(continued)

There are three spacing considerations when planning a well field:

- The minimum distance between pumping wells should be at least twice the aquifer thickness if the wells are open to less than about half the aquifer thickness.

- Wells near recharging boundaries should be located along a line that is parallel to the boundary and as close as possible to the boundary.

- Wells near impermeable boundaries should be located along a line that is perpendicular to the boundary and as far from the boundary as possible.

- Induced infiltration - A second management technique, induced infiltration, is used to eliminate excessive drawdown. It can be used where there is a nearby source of recharge. The water from the recharge source infiltrates the ground and moves toward the well.

- Water interception - A third technique, water interception, is based on the premise that, in many places, the amount of water recharged to the earth equals the amount of water that is recharged. As a result, ground levels remain constant over time. When a pumping well intercepts water that would discharged at another point, then additional water is gained with no significant change in the water balance.

- Limited Withdrawal - A fourth technique, is to limit the withdrawals of water from an aquifer. It is used in situations where withdrawals exceed the natural recharge and, as a result, lower the water table. This technique is frequently enforced by governments in areas where there is a water shortage or where water levels are declining steadily. In this case, priorities are established and then limits are set based on proof of need and the benefits service. Frequently, current water users have priority over new applicants.

Review and Discussion of Step 3 Time required: 20 minutes

1. Review the summary information on pages 41 and 42 with the participants.

2. Ask the participants who have experience with the artificial recharge alternatives to describe how they were used and what results were achieved. Record major points on the board or flipchart.

3. You may also want to provide additional information on the different artificial recharge techniques that are particularly suitable in the participants' countries or regions.

Review and Discussion of Step 3

Step 1.	Cost Comparison and Selection
Step 2.	Natural Recharge
Step 3.	**Artificial Recharge**
Step 4.	Monitoring

The third step in ground water management is to determine how to use artificial recharge techniques to augment the natural infiltration of surface water into a ground water reservoir.

Artificial recharge can be achieved through surface applications or recharge wells.

Surface applications are used when permeable materials are close to the surface or where thin, less permeable deposits overlie the aquifer.

Surface applications can include the following methods:

- Flooding - High infiltration results can be achieved on land with undisturbed vegetation and soil covering. Flooding is most effective when the water is spread evenly and when wet and dry phases are alternated.

- Irrigation - Irrigation provides infiltration when the supply exceeds the needs of crops.

- Shallow ditches - Interconnected ditches are graded so that excess water flows away. For maximum effectiveness, the fine material that clogs soil openings should be removed periodically.

- Spreading basins - Spreading basins are formed by excavation or by construction of small dams. A common design is to place a series of small basins adjacent to a stream that does not contain water all year round. The basins require cleaning or scraping of the bottom during the dry season to increase recharge efficiency.

- Recharge pits - Recharge pits are excavated through less permeable materials into the upper portion of the aquifer. Periodic maintenance is required to remove accumulated materials from the sides and bottom of the pit.

<u>Review and Discussion of Step 3</u>
(continued)

4. When you are ready to proceed, ask the participants to turn to page 43.

Review and Discussion of Step 3
(continued)

Recharge wells are used where materials over the aquifer are thick or have low permeability. These wells are constructed through thick, slowly permeable deposits into the aquifer.

In addition to using artificial recharge to preserve the ground water resource, artificial recharge offers other benefits, some of which are listed below.

- Improved water quality - Where ground water contains undesirable quantities of minerals, artificial recharge is used to dilute the mineral content.

- Recycled waste water - In many cases, waste water can be used to provide artificial recharge and to reduce treatment costs. The waste water is applied to a hillside and then collected. The effluent at the bottom of the slope is recycled until the waste water is fully treated.

- Reduce stream flows - During periods of flooding, artificial recharge can provide another outlet for the water.

- Prevention of saltwater intrusion - Placing a line of recharge wells between a supply well and the saltwater can halt the advance of saltwater and provide the supply well with a barrier.

- Reduced land subsidence - Where water withdrawals from fine materials have caused the land to subside, artificial recharge has been used to reduce and prevent further elevation changes that cause land subsidence.

INSTRUCTOR NOTES

<u>Review and Discussion of Step 4</u> Time required: 20 minutes

1. Review the summary information on page 43 with the participants.

2. Ask the participants who have experience with any monitoring techniques to describe how they were used and what results they achieved. Record major points on the board or flipchart.

3. Provide any additional information on monitoring techniques that are particularly relevant to the participants' countries or regions.

Review and Discussion of Step 4

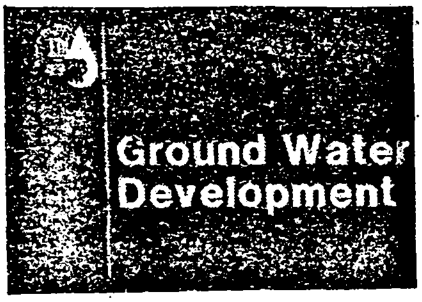
Step 1. Cost Comparison and Selection
Step 2. Natural Recharge
Step 3. Artificial Recharge
Step 4. Monitoring

The fourth step in ground water management is to monitor the ground water resource.

Several activities related to monitoring are described below.

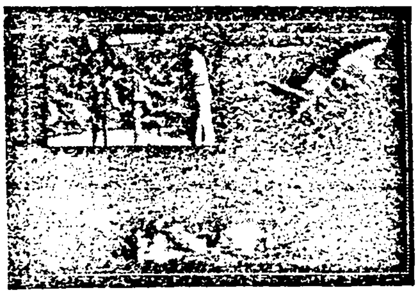
- Laws - Laws can be used to control ground water use. Two examples are laws to prevent contamination and laws to establish priorities for the use of scarce water.
- Regulations - Regulations set standards for complying with laws; however, regulations may only control the water used by large water users or public water supplies. Small water users and domestic suppliers are regulated less frequently.
- Quality - Monitoring quality requires regular evaluation of the bacteriological and chemical content of the ground water in order to detect any contamination.
- Quantity - Monitoring the quantity of ground water includes measuring the yields of aquifers and maintaining complete and accurate records of water levels within the aquifer.
- Conservation measures - Regulated or voluntary conservation measures may be required when ground water is consumed faster that it can be replenished. For example, metering can provide an economic incentive to conserve water.
- Modeling - Modeling involves the use of mathematical techniques to make long- and short-term projections of water quantity and quality.

<u>GROUND WATER DEVELOPMENT - PART I</u>

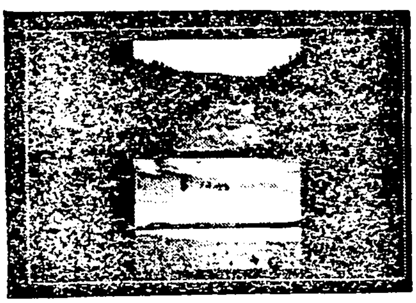
1. 

TITLE SLIDE:

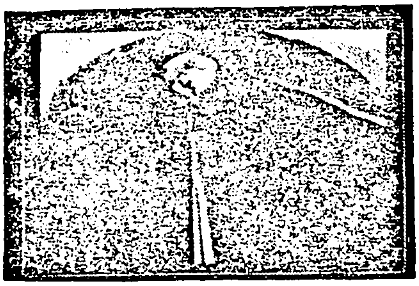
Ground Water Development

2. 

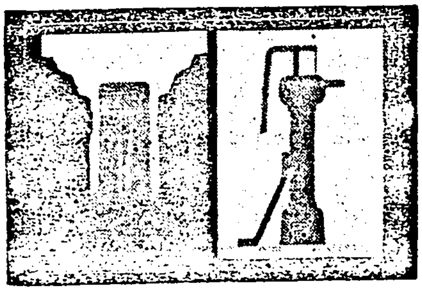
The survival and well being of man has always depended on his access to water: to satisfy his domestic needs for drinking and hygiene, to grow his food and to use in his industrial processes.

3. 

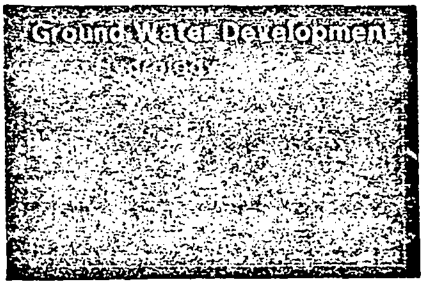
In his search for water, man has looked to two main sources: surface waters such as rivers and lakes...

4. 

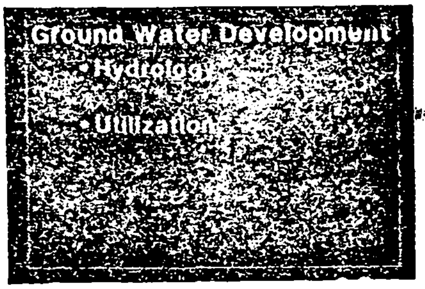
...and ground water under the earth's surface and normally not as easily seen as surface water.

5. 

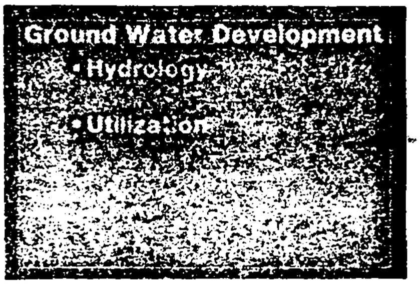
Although surface water is visible, and therefore, a ready alternative in meeting a community's needs, often ground water provides a more economic and appropriate solution.

6. 

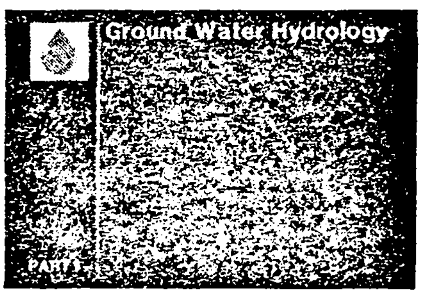
In this program, we will look at three aspects of ground water development. First, ground water hydrology which shows us how and where ground water occurs underground.

7. 

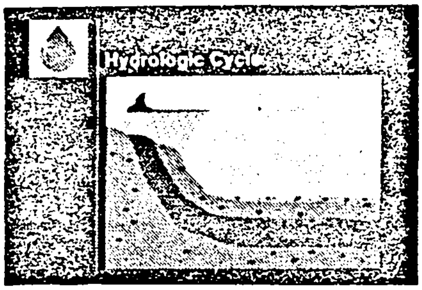
Second, ground water utilization: a systematic way of locating, developing, and maintaining ground water supplies.

8. 

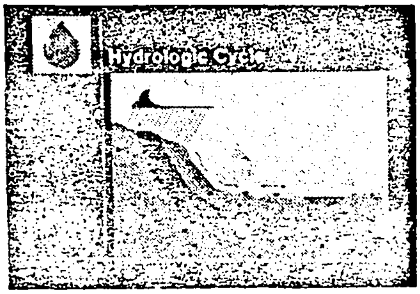
Third, ground water management where we will discuss ways to manage the resource so that ground water may be used efficiently, economically and reliably for years to come.

9. 

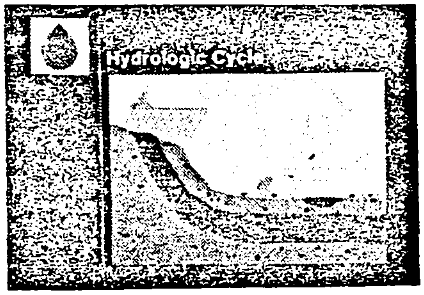
Let us now turn our attention to ground water hydrology where we will discuss the hydrologic cycle.

10. 

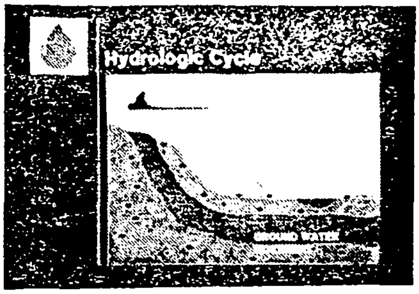
All the water on earth is part of the hydrologic cycle. Water that falls to the earth as precipitation may follow many different paths.

11. 

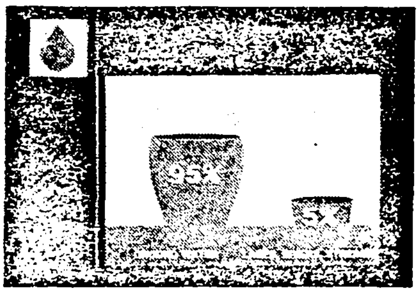
The water may flow over the ground and become surface runoff, eventually forming a river or lake.

12. 

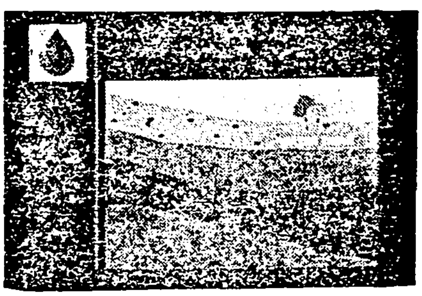
Some of the water may be transpired by plants and released back into the atmosphere. Or, water may be evaporated directly from the land and lakes back to the atmosphere where the process can begin all over again.

13. 

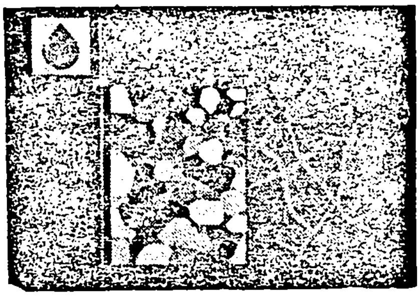
Finally, water may penetrate the soil and move through the earth as ground water. The ground water moves slowly through the ground into rivers and seas. This water, too, is eventually evaporated to complete the cycle that has been going on since the dawn of time.

14. 

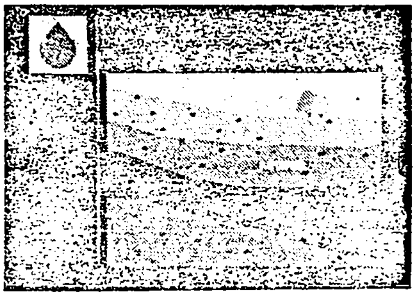
Ninety five percent of all the fresh water on earth occurs below the ground's surface. Only five percent of the available fresh water occurs in rivers, lakes and streams.

15. 

Water is held below the surface of the ground in cracks and openings of rocks and loose deposits. The upper surface of that zone, where all the rocks are saturated with water, is termed the water table.

16. 

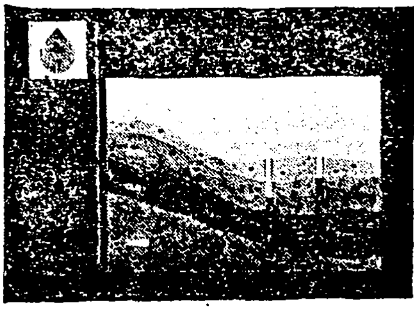
Ground water occurs in essentially two ways: in the pore spaces of sedimentary rocks such as sandstone, and in the fractures of non-porous rocks such as limestone, granite or basalt.

17. 

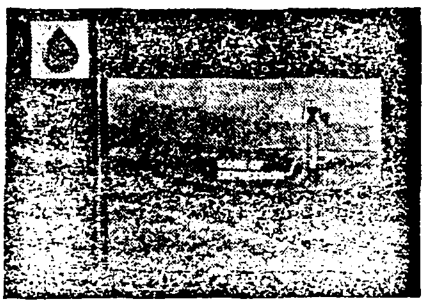
When these openings in the rock are interconnected, allowing water to be removed from the ground in appreciable quantities, the deposit or rock is termed an aquifer.

18. 

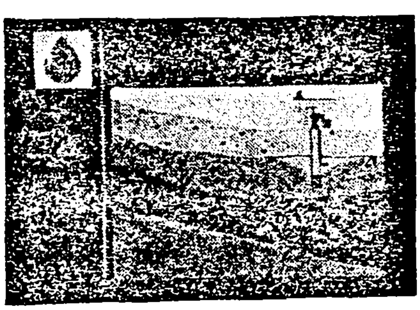
In order to withdraw the water from the aquifer, a well is constructed. Wells are of two types. The first is a water table well. It taps the first water zone encountered during drilling.

19. 

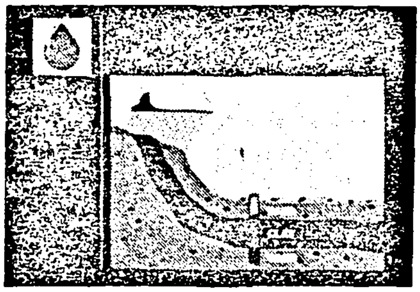
The second type is an artesian well. It taps an aquifer containing water under pressure. The pressure is released when a less permeable layer above the aquifer is penetrated. Sometimes the pressure is great enough to raise the water to the land surface.

20. 

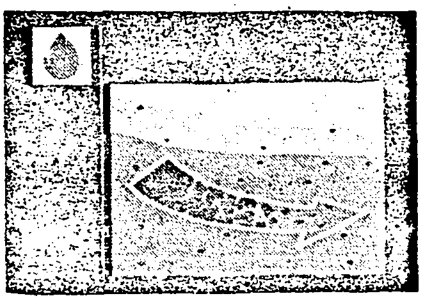
As water is withdrawn from either type of well, a cone of depression forms in the area surrounding the well. The cone of depression describes how the water table is lowered by the pumping well. The shape of the cone is determined by the pumping rate of the well and the permeability of the rocks surrounding the well.

21. 

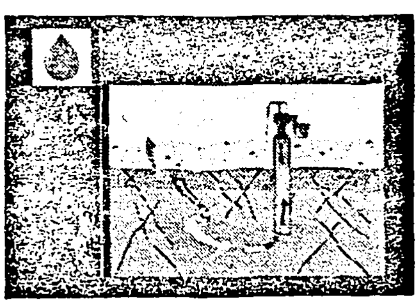
As water is withdrawn, the aquifer must eventually be replenished to keep producing. Water table aquifers are usually recharged from local sources of precipitation.

22. 

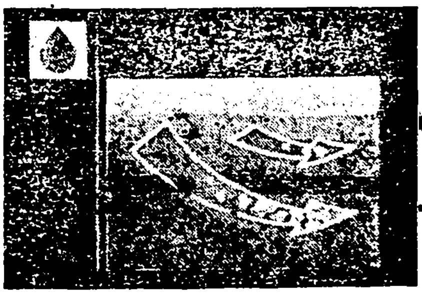
Artesian aquifers, however, frequently receive recharge many miles from the well.

23. 

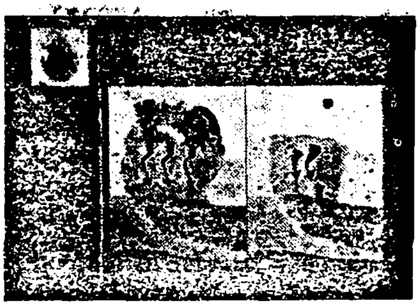
As the water moves through the ground, the earth filters and purifies the ground water.

24. 

The quality of the ground water is determined by the kind of earth material through which the water seeps. For example, where the rocks contain considerable amounts of calcium, magnesium or iron, the ground water may take these minerals into solution. At times, the leached minerals may make the ground water less suitable for domestic and industrial purposes unless it is treated.

25. 

In general, ground water from deep sand or rock layers contains more minerals than water from shallow deposits. Because the water has traveled a greater distance in the ground, it has had more time to slowly dissolve minerals.

26. 

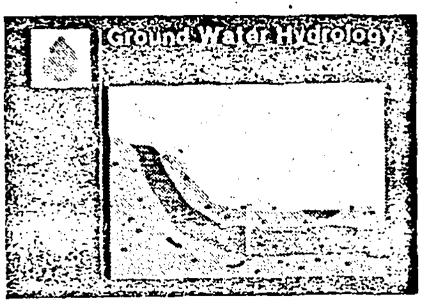
The quality of water may also be affected by human activities. Common sources of contamination are solid waste dumps and animal feedlots.

27. 

Improperly maintained or abandoned wells may also cause ground water quality to deteriorate.

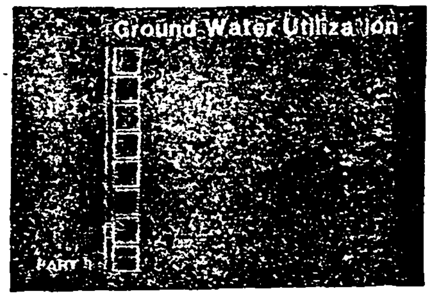
28. 

However, since ground water is insulated and protected below the surface of the earth, it is far less subject to contamination and pollution than the water in rivers and lakes.

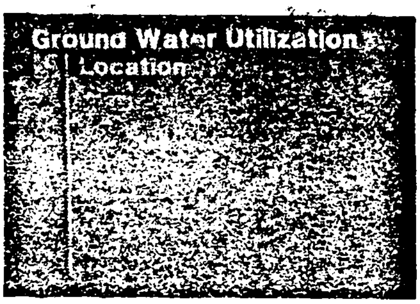
29. 

We have now seen where ground water fits within the hydrologic cycle and how different geologic deposits can yield ground water in varying quantities and qualities.

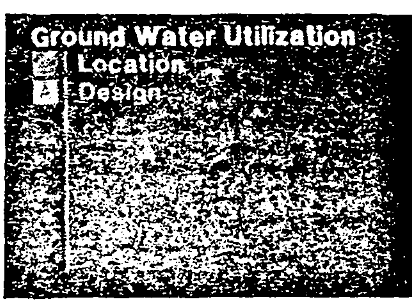
GROUND WATER DEVELOPMENT - PART II

30. 

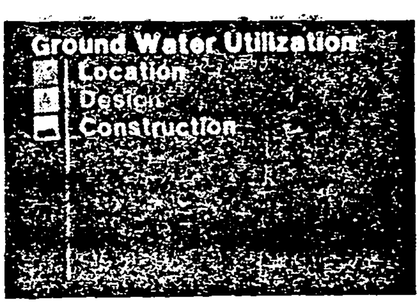
In part II of this program, on Ground Water Utilization, we will discuss the steps necessary to locate, develop, operate and maintain a ground water system.

31. 

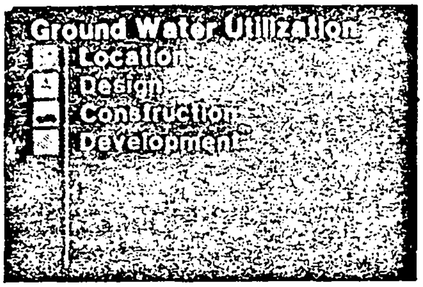
The first step is to identify the location of an adequate ground water supply and pinpoint the future well sites.

32. 

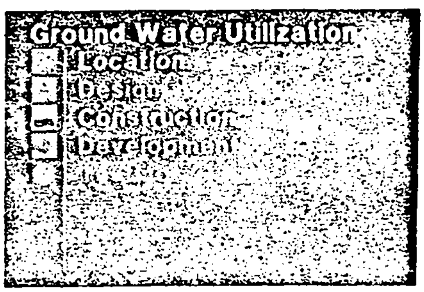
The second step is to choose the design of the well which is dictated by the hydrogeologic conditions of the area and the expected use of the well.

33. 

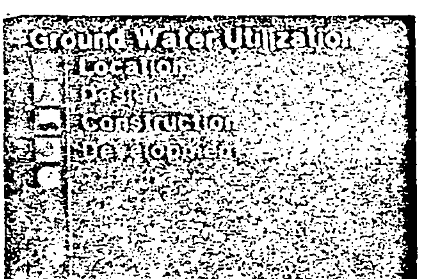
The third step is to construct the well using the most appropriate construction method.

34. 

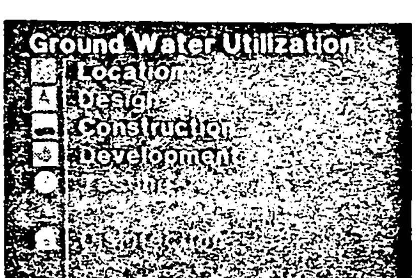
The fourth step is to develop the well to enable it to provide sustained production.

35. 

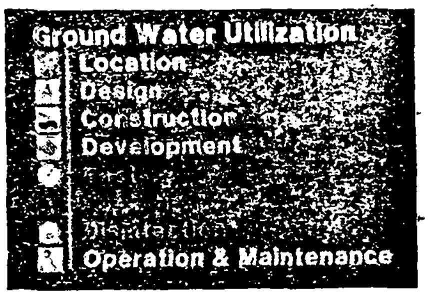
The fifth step is to test the well to estimate its future yield.

36. 

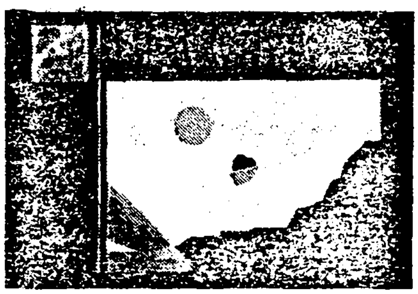
The sixth step is to select a type of pump that will provide reliable and economical service.

37. 

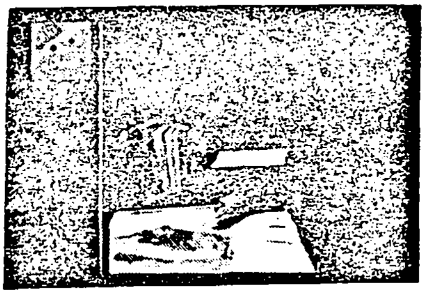
The seventh step is to disinfect the well to help provide sanitary water to the community.

38. 

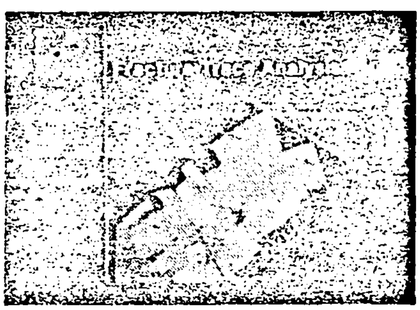
And, the final step is to operate and maintain both the well and the pump to ensure dependable and lasting benefits.

39. 

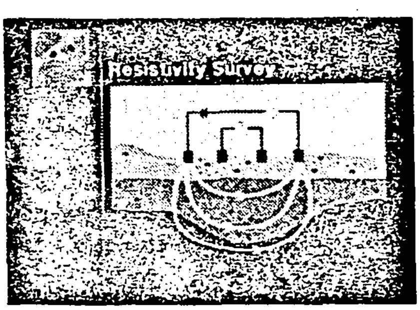
Now we will turn our attention to the first step, identifying the location of ground water. Although ground water exists almost everywhere, locating an adequate supply may call for specialized expertise. A ground water specialist can determine the best location for a well by studying the rocks and their water content.

40. 

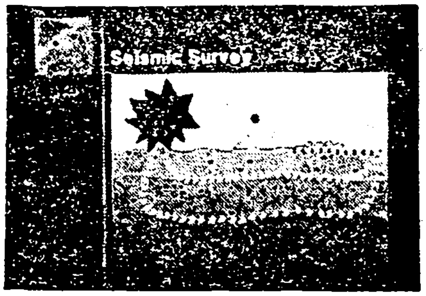
Readily available information from existing wells and published geologic reports, when coupled with a knowledge of the topography and vegetation in the area, helps the specialist in his review. When additional information is needed, more sophisticated data gathering methods become necessary.

41. 

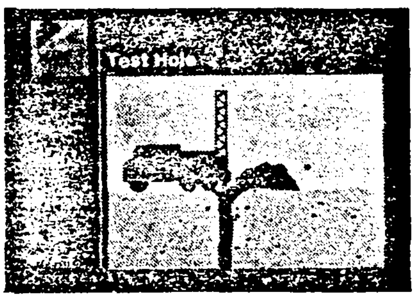
For example, fracture trace analysis uses aerial photography to detect fractures in rock that are not evident at the earth's surface. The well can then be located where fractures will yield the necessary amount of water.

42. 

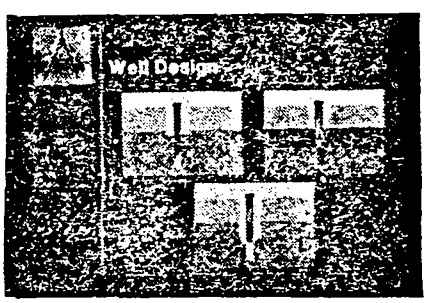
Another method is to use electrical resistivity surveys that inject electrical current into the ground and record the amount of resistance of the rock layers. By interpreting the data, the presence of ground water and the depth of bedrock can be inferred.

43. 

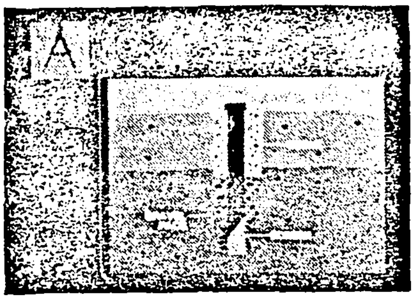
Then, too, seismic surveys may also be used. Seismic surveys apply a physical shock to the surface of the earth and measure the time it takes for the shock wave to be transmitted back to the surface. Seismic surveys are used to map buried channels, measure the depth to the water table and determine the type of rock in the area.

44. 

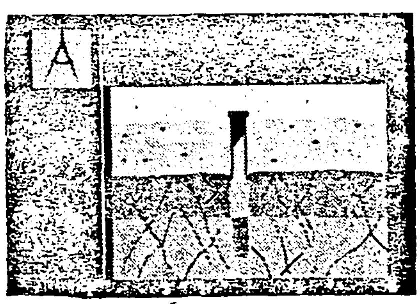
Regardless of the data source, test holes are frequently used to verify information before a large-scale well field is undertaken. Conversely, where only a small amount of water is needed, extensive reconnaissance efforts and sophisticated methods are not frequently employed.

45. 

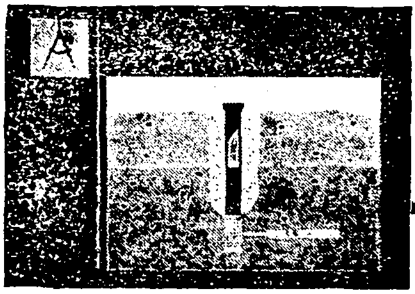
Once a site for the well is chosen, the second step in ground water utilization is to select the appropriate well design and construction method.

46. 

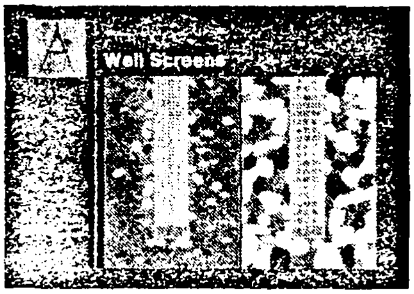
All wells provide a conduit from a productive water-bearing formation to the surface. This conduit may be a steel or plastic pipe called a casing which serves as a structural retainer to prevent caving of the hole and to shut out water of undesirable quality. The casing is sealed at the surface by a cap and may have a screen attached to the bottom. A gravel pack around the screen and grout around the casing may also be necessary.

47. 

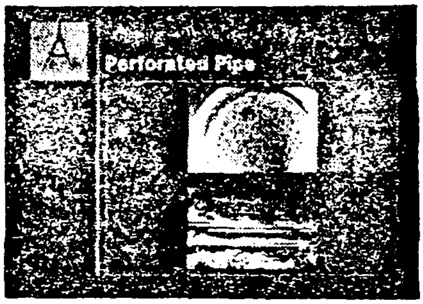
Where the well penetrates into hard rock, the casing typically needs to extend only through the loose materials.

48. 

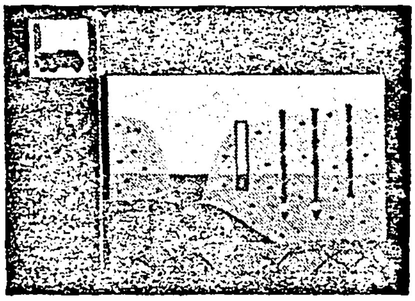
If the well terminates in loose deposits, a well screen may be placed below the water table as an extension of the casing. A well screen helps to support the loose formation, allows water to enter the well and prevents fine materials from coming into the well with the water.

49. 

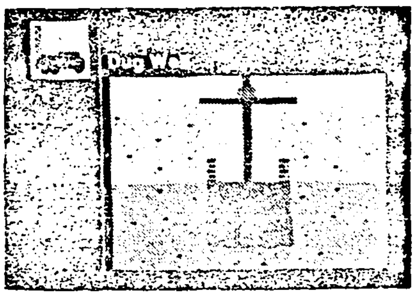
The openings in the screen are selected based on the grain size of the aquifer. In this way, the screen allows the maximum amount of water to enter the well while keeping fine materials out of the well.

50. 

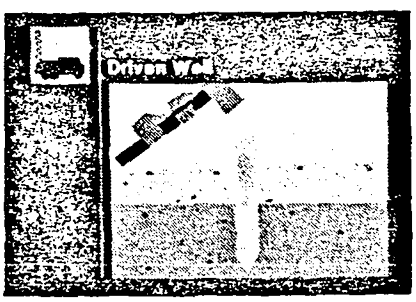
Perforated pipe is sometimes substituted for a well screen because it is less expensive; however, perforated pipe is often not as efficient as manufactured screens.

51. 

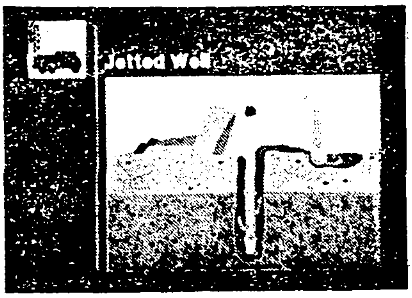
Once the design of the well has been selected, the third step, construction, can begin. Five common methods may be used to construct a well. The well may be dug, driven, jetted, bored or drilled.

52. 

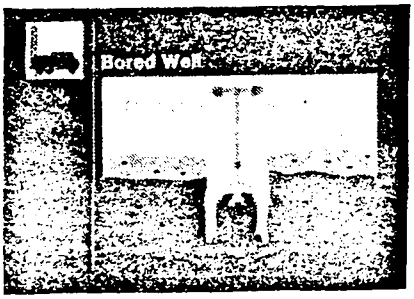
Dug wells are the oldest type of well construction. A dug well is made by digging a large-diameter hole into the water table by hand or power. Walls of brick, masonry or concrete are installed to keep the hole from caving. These wells are usually limited to shallow depths and are typically used only in loose materials.

53. 

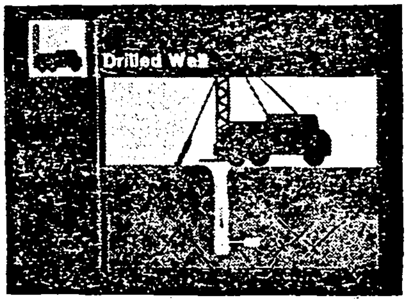
Driven wells are made by driving a pointed screen, called a well point, into the aquifer. This method can only be used in shallow loose materials where gravel and boulders are rare.

54. 

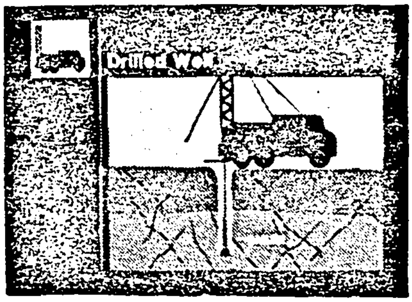
Jetted wells are similar to driven wells. In this method, water under pressure is circulated down through the well point to loosen material around the screen. The water carries the loosened material in the space around the pipe to the surface. Jetting is suitable for shallow wells in fine loose deposits.

55. 

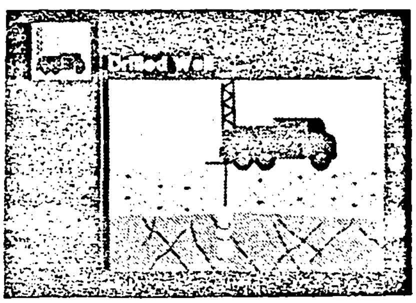
Bored wells are augered by hand or by power through loose materials into the water table. The casing is typically installed after the hole is completed to the desired depth. This method is best-suited where the deposits have enough clay to keep the hole open during installation of the casing.

56. 

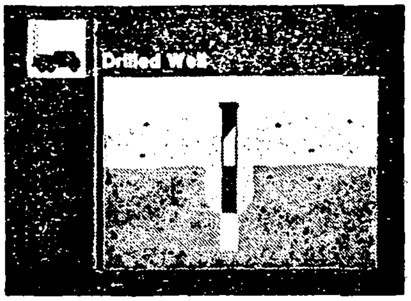
Drilled wells may be constructed by either the cable tool or rotary method. In cable tool drilling, a heavy drill bit and stem are raised and dropped to crush rock and loosen other material.

57. 

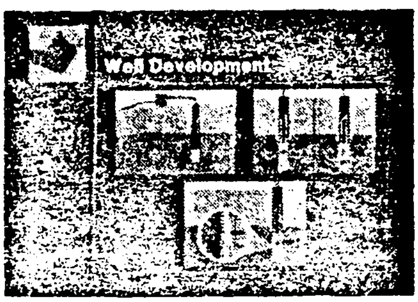
The stem and bit are periodically removed from the hole and the crushed material, mixed with water, is removed by a bailer. The casing is driven as drilling proceeds. Another technique, which is called "down-the-hole" drilling, combines the cable tool and rotary methods.

58. 

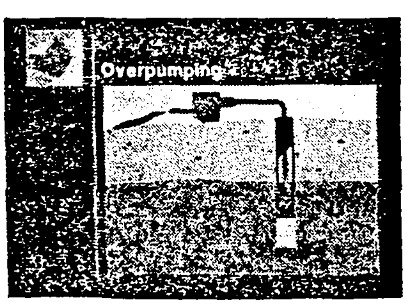
In rotary drilling, a rotating bit fixed to the lower end of the drill pipe breaks up rock and loosens other materials as the hole is deepened. Unlike cable tool drilling, it is not necessary to remove the drill stem from the hole to remove the cuttings. As drilling proceeds, drilling fluid or "mud" is circulated to remove the cuttings, cool the bit and keep the hole open. The casing is installed after the hole is completed to the desired depth.

59. 

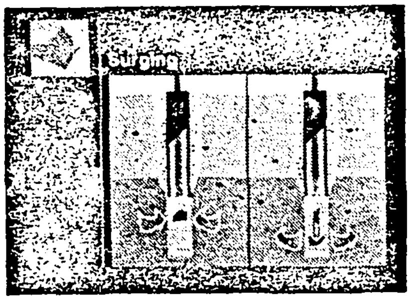
To help ensure sanitary protection of the well and to prevent surface water from entering the well, all openings around the casing are filled with grout. Grout is a mixture of concrete or bentonite that prevents water movement along the outside of the well casing.

60. 

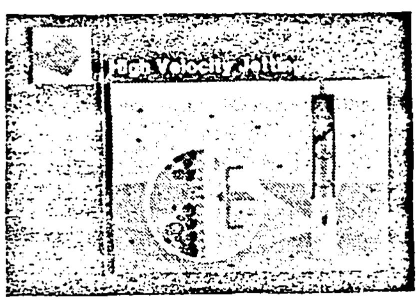
The fourth step is development of the well. Because all drilling methods leave a fine-grained residue in the well, the silt, fine sand and drilling mud must be removed before the well is put into use. This process is called development and is used to increase the yield of the well.

61. 

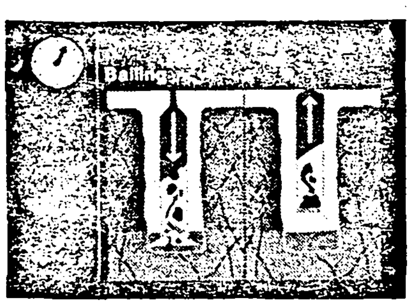
The simplest and most commonly used method of development is overpumping. In this method, an oversized pump is used to pump the well at a higher than normal rate. Although overpumping is the most extensively used development method, it is not the most effective.

62. 

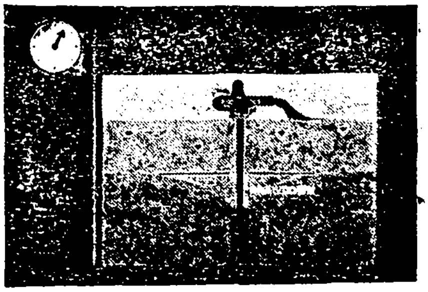
Where more extensive development is required, surging is often used. In this process, a plunger is moved up and down in the well, forcing water to move in and out of the aquifer. This action agitates the fine-grained materials, which can then be removed by pumping or bailing.

63. 

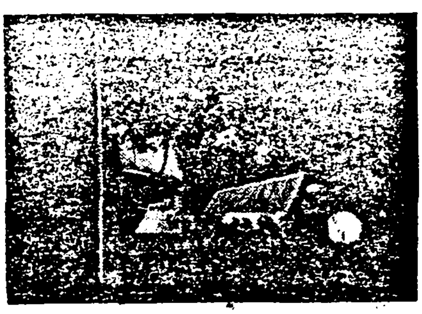
High-velocity jetting is used to develop high-capacity screened wells. The jetting tool directs water under pressure to small intervals along the screen. The well is pumped at the same time to remove any material that is dislodged.

64. 

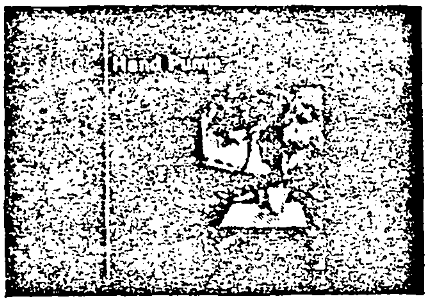
Once the well has been developed, the fifth step in ground water utilization is to test the well. The well may be tested to determine the amount of water that the well will efficiently provide. In wells with a diameter large enough to accommodate a bailer, a rough estimate of water yield can be provided by bailing.

65. 

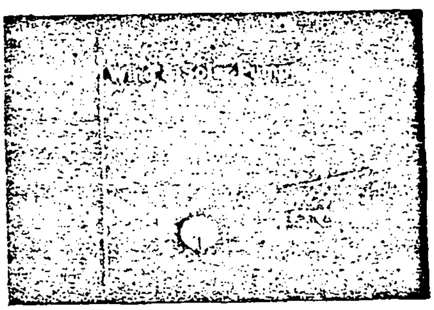
Where more accurate data is needed for high capacity wells, aquifers are tested by pumping the well at a known rate for specified periods of time. The decline of the water level inside the well, termed the drawdown, is recorded for the well and any other wells in close proximity to the pumped well. The data are analyzed using equations and graphs that most closely match the hydro-geologic conditions at the site.

66. 

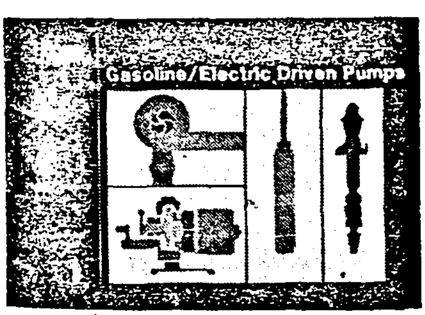
The sixth step in completing a well is to install a proper pump. Pumps are available in all shapes and sizes and are selected based on the diameter, depth, capacity and power requirements of the well.

67. 

Hand pumps are frequently used where no other source of power is available and where water requirements are small. Hand pumps can be adapted to fit almost all small- and large-diameter wells, and various designs are available to provide water from shallow and greater depths.

68. 

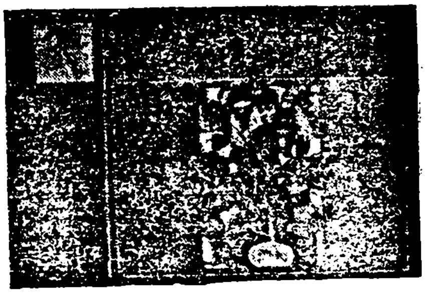
Wind- and solar-driven pumps may provide water for uses such as irrigation and livestock watering. There are pumps available for use in wells of most diameters and at most water depths; however, storage facilities must be constructed for the periods when supply is interrupted.

69. 

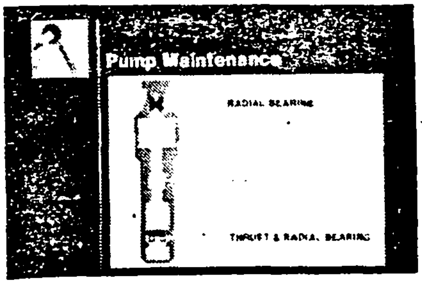
Gasoline-driven or electric powered pumps are used where a reliable source of fuel or electricity is available. Centrifugal, jet, submersible and turbine pumps provide water for all variations in supply and water depth requirements.

70. 

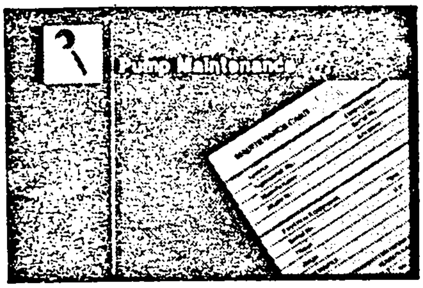
The seventh step in completing a well is to disinfect the entire installation. Chlorine in liquid or tablet form is the most commonly used disinfectant.

71. 

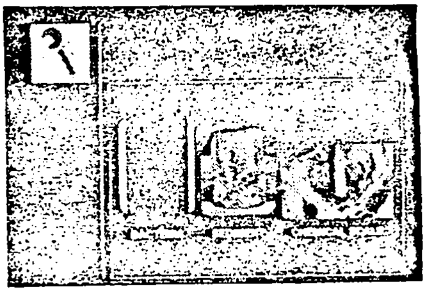
The eighth step in ground water utilization is to operate and maintain the well and pump. Once the disinfection has been completed, the properly designed well should be able to provide a reliable supply of ground water for many years with a minimum amount of maintenance.

72. 

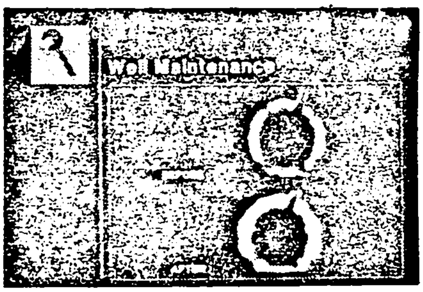
Periodic maintenance is necessary to keep the pump in good working order. All moving parts and seals will wear out with use and must be replaced.

73. 

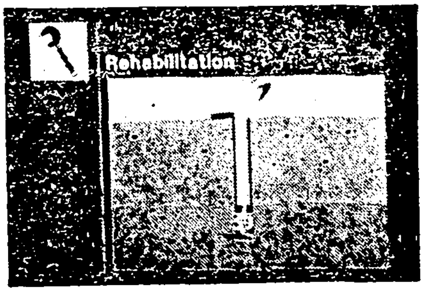
A routine pump maintenance schedule should be used in higher-capacity wells to help avoid interruption of service.

74. 

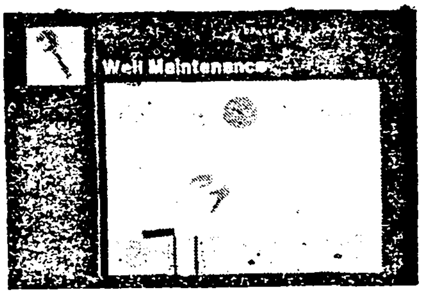
The well may also require maintenance. After a period of time, the yield of a well may decrease due to a collection of slime-producing bacteria, a build-up of sediment in the bottom of the well or a build-up of chemical scale on the screen. These conditions limit the amount of water that can enter the well.

75. 

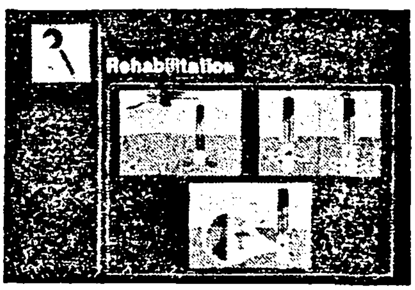
When this happens, maintenance may require rehabilitation of the well to help eliminate bacteria, sediment or chemical scale. Rehabilitation can be accomplished using several methods. The appropriate method of rehabilitation depends on the factors that are limiting the well yield.

76. 

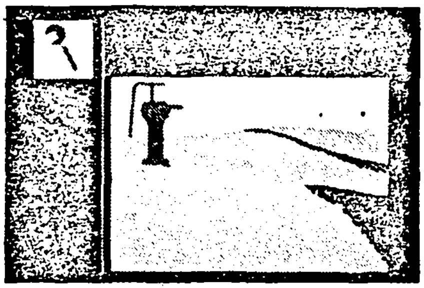
For example, acids, and oxidizing agents are used to remove a build-up of chemical scale.

77. 

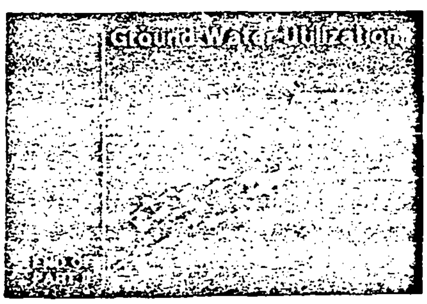
Bacterial slimes are treated with high concentrations of chlorine. This process is termed shock chlorination.

78. 

And, where a build-up of sediment occurs, development methods such as overpumping, surging and high-velocity jetting are employed to remove fine materials from the well. These methods are frequently used in combination with acids, oxidizing agents and shock chlorination to produce the desired results.

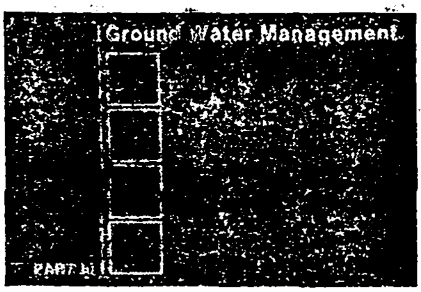
79. 

Finally, the area around the well must be maintained to ensure that animal wastes, road runoff or other contaminants do not enter the well.

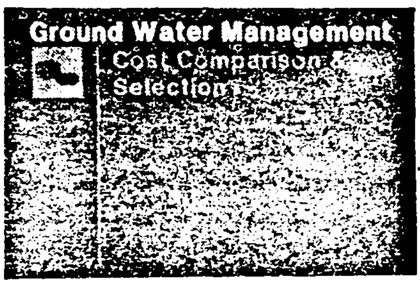
80. 

When the eight steps of ground water utilization are followed, ground water can provide a safe and reliable source of water to fill the community's needs for many years.

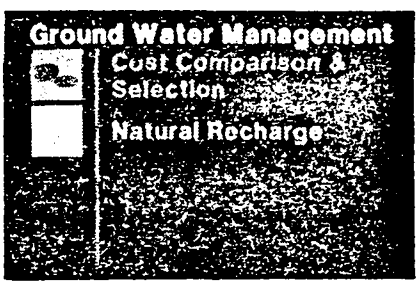
GROUND WATER DEVELOPMENT - PART III

81. 

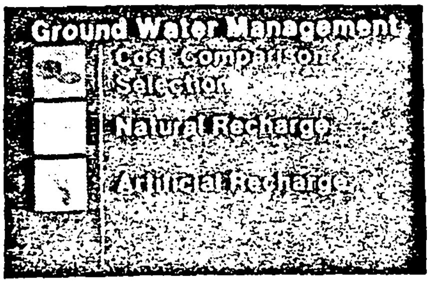
The third part of this program deals with ground water management techniques that will make ground water a reliable water supply both now and in the future.

82. 

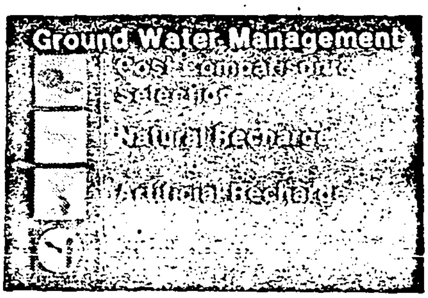
The first step in ground water management is to identify the costs for a ground water supply and compare them with the costs for a surface water supply, in order to select the most economical alternative.

83. 

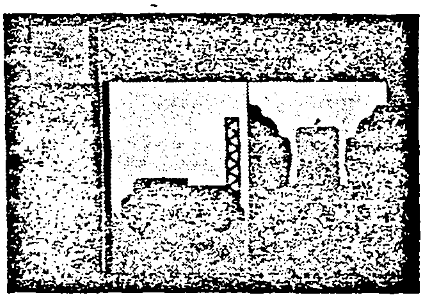
The second step is to evaluate the natural recharge of the aquifer and design and operate a system which makes optimum use of that available water.

84. 

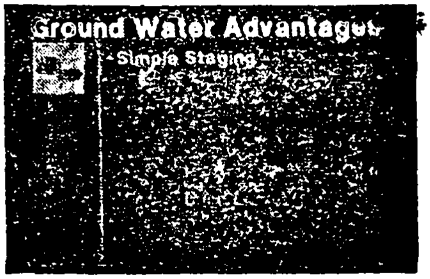
The third step is to explore artificial recharge methods to compliment the natural recharge of the aquifer.

85. 

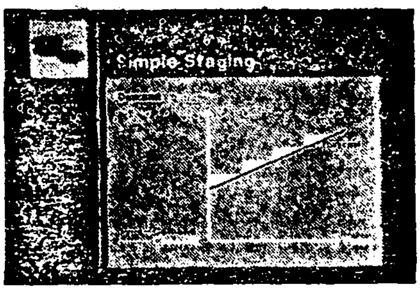
And the fourth step is to monitor ground water extraction and adopt laws and regulations to preserve the long-term availability of ground water.

86. 

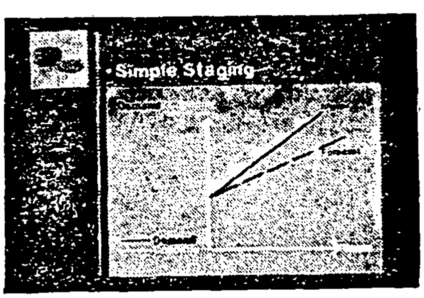
Now we will turn our attention to the first step, cost comparison and selection. In general, where it exists, ground water is more economical than surface water. Economic studies undertaken by the United Nations indicate that it is five times more expensive to build a dam and reservoir than it is to develop an equal quantity of water from an aquifer.

87. 

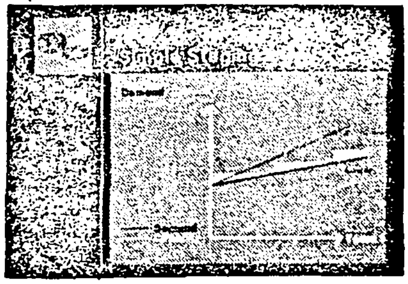
Ground water, as opposed to surface water, has seven major economic advantages. First, ground water can be developed in simple stages, drilling new wells only as the need for additional water arises.

88. 

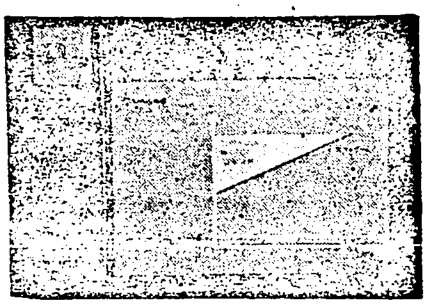
This flexible approach allows increases in the supply capacity to be closely tailored to meet demand growth.

89. 

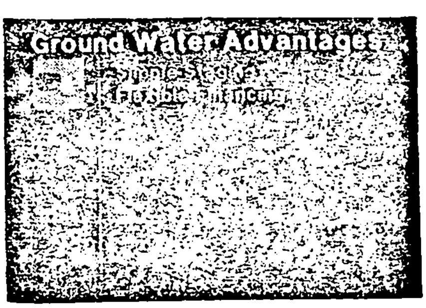
If actual water demand is higher than forecast, new wells can be added faster to the system.

90. 

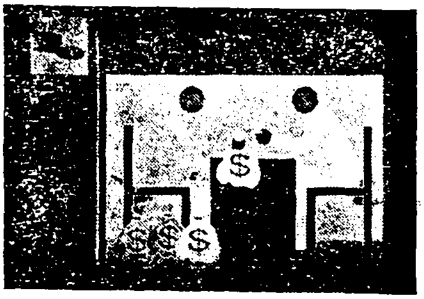
Conversely, if the actual water demand is lower than forecast, new wells can be postponed.

91. 

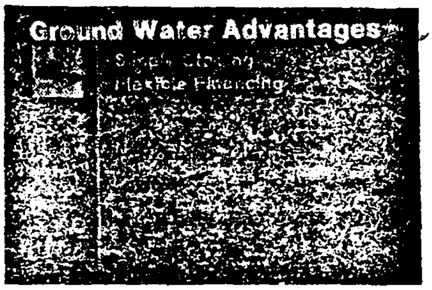
In contrast, surface water supplies require accurate long-term water supply forecasting and construction of a large and lumpy system. If the system proves insufficient to meet the demand, it cannot easily be expanded.

92. 

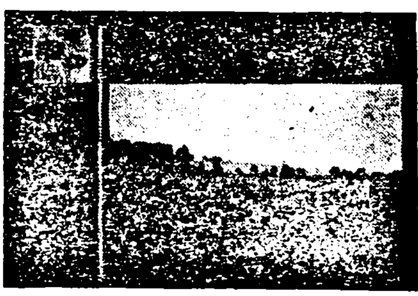
Second, staged development also allows flexible financing. Water users can often support the cost of the staged project through user fees.

93. 

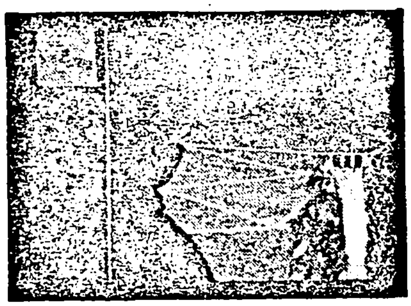
Conversely, surface water development requires large capital investments and borrowings that will have to be repaid with interest.

94. 

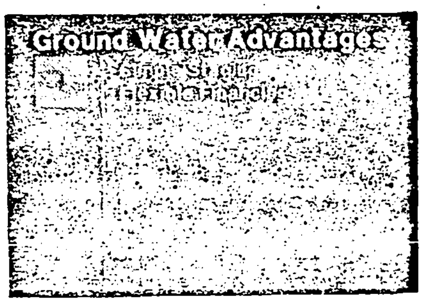
Third, since ground water is stored in vast quantities beneath the surface of the earth, the use of ground water requires little land to be acquired.

95. 

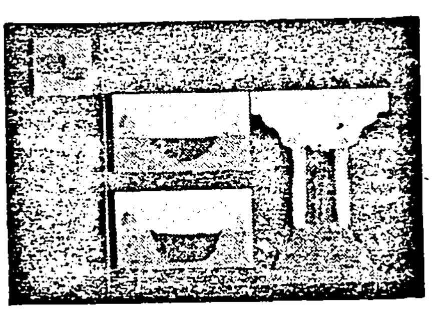
The land above the ground water aquifer may still serve as productive farmland.

96. 

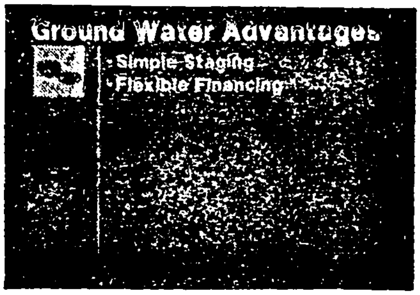
In contrast, the construction of surface reservoirs requires the acquisition of much land which is subsequently flooded and lost to agriculture and forestry.

97. 

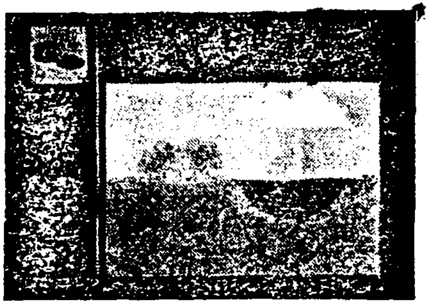
The fourth economic advantage of a ground water supply is its minimal maintenance costs and long life. Ground water reservoirs remain unchanged over time.

98. 

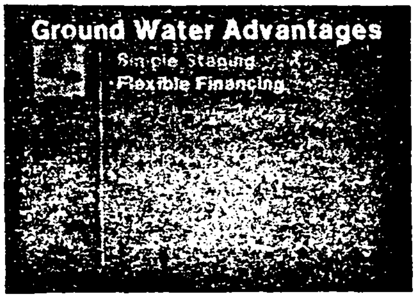
In contrast, surface reservoirs fill with silt, and dams may lose their integrity.

99. 

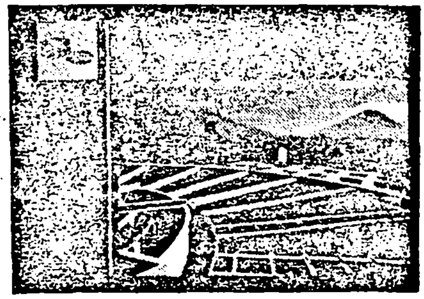
Fifth, water evaporation is eliminated in ground water storage.

100. 

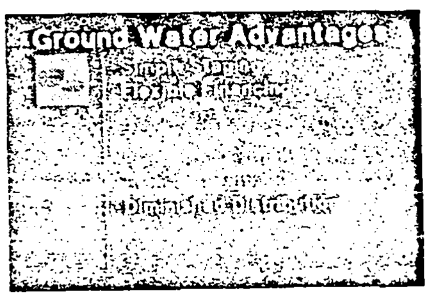
In contrast, surface water reservoirs lose significant amounts of water through evaporation.

101. 

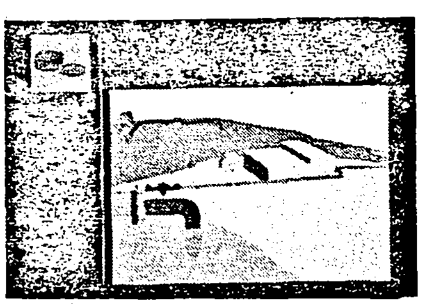
Sixth, ground water requires only simple treatment. Because ground water is naturally filtered and purified by the earth, ground water requires no extensive filtration.

102. 

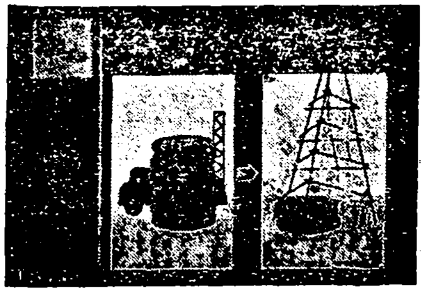
However, surface water frequently requires elaborate filtration to remove suspended matter, and costly treatment to make the water bacteriologically safe.

103. 

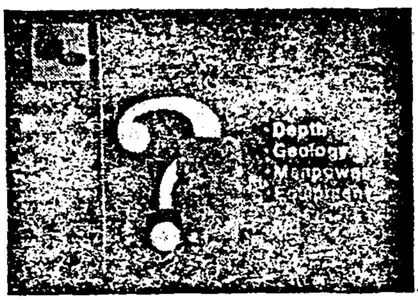
Seventh, because ground water is found almost everywhere, the earth provides a natural distribution system that diminishes the size of the piped distribution system.

104. 

Surface water supplies, however, frequently require extensive distribution systems to bring water from the source to the consumer.

105. 

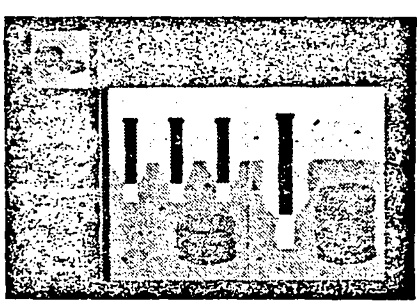
We have now explored the advantages of ground water versus surface water. In addition, there are ways to minimize the cost of ground water development.

106. 

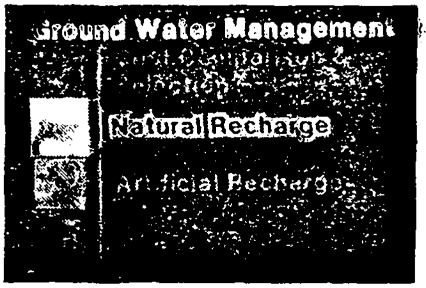
The cost of developing ground water depends, in part, on the capital investment in one or many wells. The cost of drilling a well depends on the depth of the well, the type of geologic materials, the manpower and the equipment needed to complete the well and the materials used in construction.

107. 

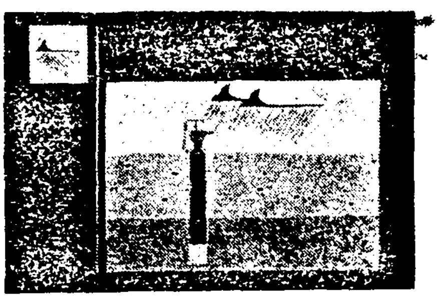
Historically, wells have been drilled throughout the world with highly sophisticated and expensive drilling machinery. Experience is now proving that simple equipment does an adequate job with significantly lower operation and maintenance costs. Such simple drilling equipment requires relatively less skilled manpower. This is particularly important since the large drilling rigs, when used in developing countries, have often only been used to a fraction of their capacity because of lack of skilled manpower to operate them.

108. 

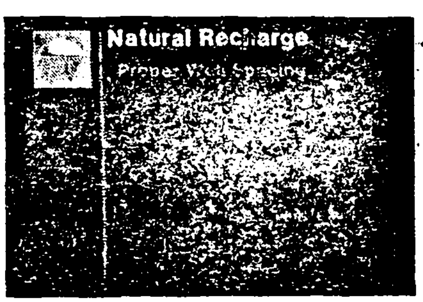
Experience has also shown that it may be more economical to drill a larger number of shallow wells than to drill a few deep wells. This practice lends itself not only to lower construction costs with less sophisticated equipment, but also reduces well maintenance costs.

109. 

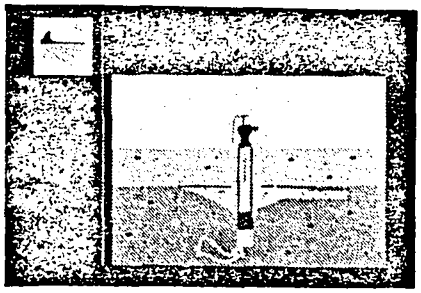
Now that we have discussed cost comparison and selection, we will review the second step in ground water management. It involves examining the techniques that are applicable in areas where the only replenishment of the aquifer comes from natural recharge.

110. 

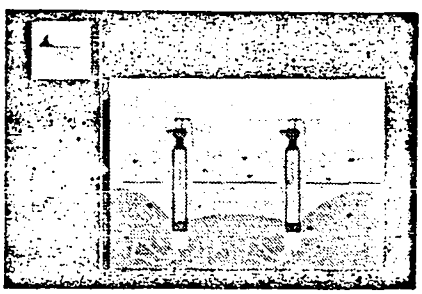
Natural recharge is that portion of precipitation which infiltrates into the ground to become ground water.

111. 

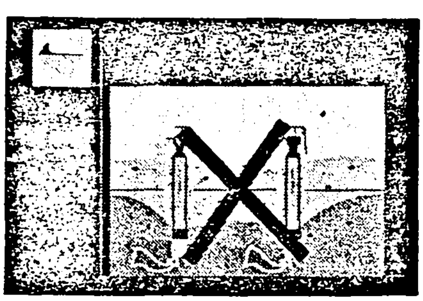
Natural recharge is facilitated by proper well spacing. Proper well spacing can be used when planning a well field where wells will be located close to one another. This technique can be used to minimize operation costs.

112. 

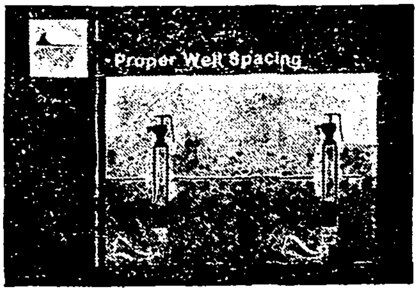
When pumped, each well produces a cone of depression. The drawdown in the well and the extent of the cone of depression are largely influenced by the geology of the area.

113. 

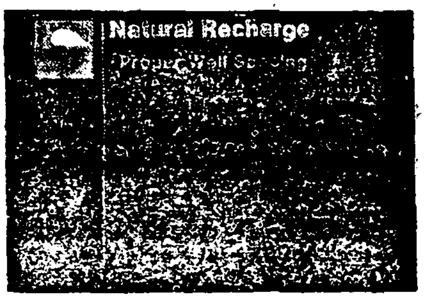
Where two cones of depression intersect, the resulting drawdown in each well is the sum of the two individual drawdowns.

114. 

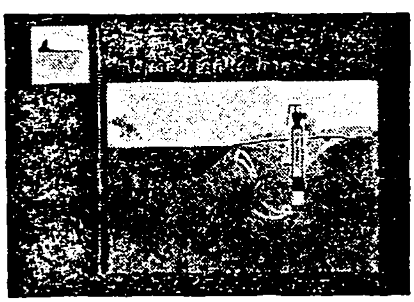
Improperly spaced wells have intersecting cones of depression which lower water levels more than necessary. These lower water levels result in increased pumping costs.

115. 

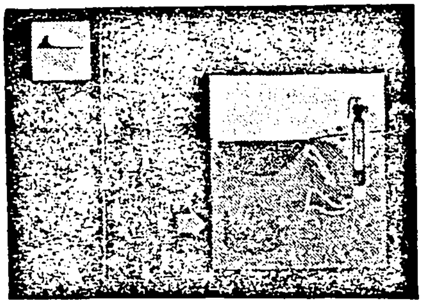
Properly spaced wells do not have intersecting cones of depression and, therefore, will have reduced operating costs.

116. 

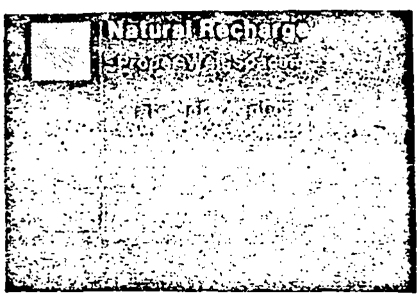
Induced infiltration is a second management technique which is used to eliminate excessive drawdown. It can be used where there is a nearby source of recharge such as a stream.

117. 

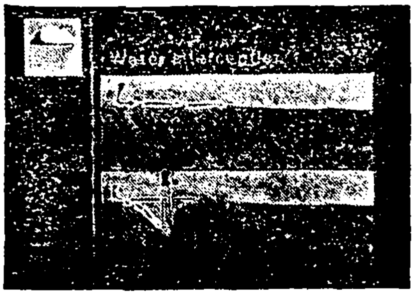
When a cone of depression intersects a stream, the water in the stream may infiltrate into the ground and move toward the well. This process, called induced infiltration, is commonly used as a way to naturally filter river water.

118. 

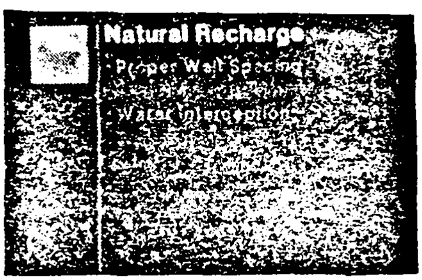
Induced infiltration limits the drawdown in the well. It can reduce operating costs for a ground water supply and, at the same time, eliminate the filtration required for a surface water supply.

119. 

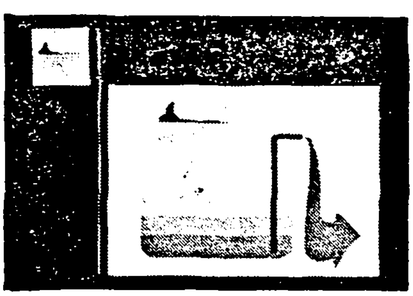
Another management technqiue involves water interception. In many places on earth the hydrologic cycle creates a water balance where the amount of water recharged to the earth equals the amount of water that is discharged. This equilibrium results in ground water levels that remain fairly constant over time.

120. 

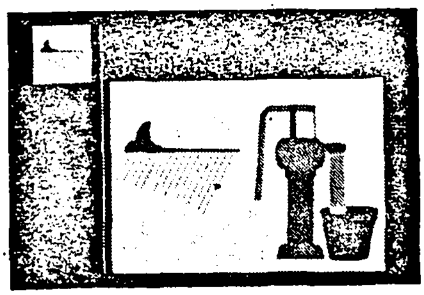
When a pumping well is introduced into the system, the well may intercept water that would have been discharged at another point such as an ocean. By intercepting the water that would have been lost to the sea, water is gained with no significant change in the water balance.

121. 

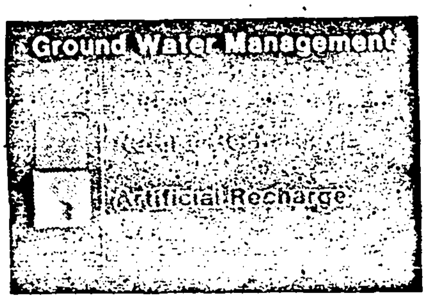
The fourth management technique limits the amount of water which can be withdrawn from an aquifer. In situations where withdrawals exceed the natural recharge, the result is a lowering of the water table.

122. 

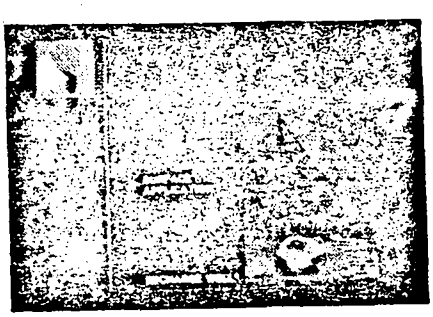
The quantity of water held in storage is then gradually being depleted and the water is being used consumptively.

123. 

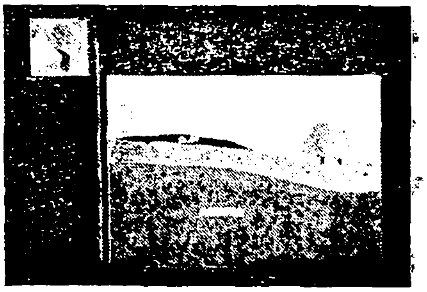
Licensing and monitoring requirements can set limits on water withdrawals so that they do not exceed the amount of natural recharge.

124. 

The third step in ground water management is to consider artificial recharge. Natural recharge can be increased by artificial recharge. Artifical recharge is a means of augmenting the natural infiltration of surface water into a ground water reservoir.

125. 

Artifical ground water recharge has been used throughout the world for more than two centuries. It can be accomplished by two main techniques: surface application and recharge wells.

126. 

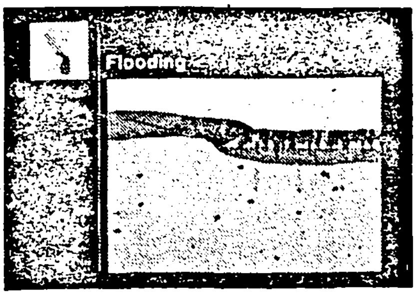
Surface applicaton is used when permeable materials are close to the surface or where thin, less permeable deposits overlie the aquifer.

127. 

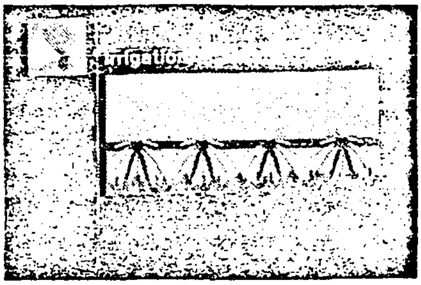
Recharge wells are used where the materials overlying the aquifer are thick and of low permeability.

128. 

A variety of methods such as flooding, irrigation, ditches, spreading basins, recharge pits and recharge wells may be used for artificial recharge.

129. 

Flooding of an area is effective because the highest infiltration rates occur on land with undisturbed vegetation and soil covering. Although large areas are necessary, there are minimal costs for land preparation. Flooding is most effective when the water is spread evenly, and wet and dry phases alternate.

130. 

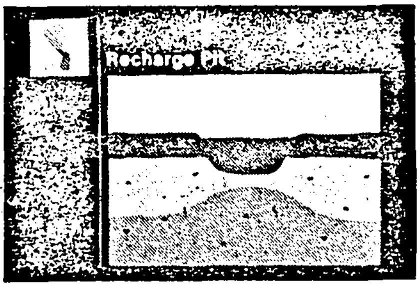
Irrigation provides water for infiltration when the supply exceeds the needs of the crop. Irrigation of cropland, particularly during the non-growing season, may add a significant amount of water to underground storage.

131. 

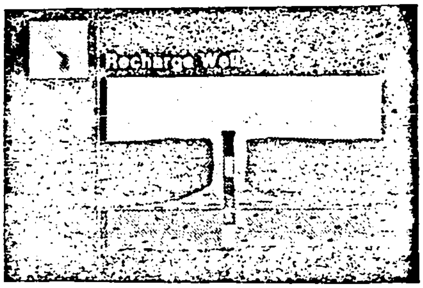
Shallow ditches may be constructed to enhance ground water recharge. The interconnected ditches are graded so that excess water flows away. Ditches require periodic removal of fine material that clogs the soil openings.

132. 

Spreading basins may be formed by excavation or by constructing small dams. The most common design consists of a series of small basins adjacent to a stream that does not contain water year-round. These basins require cleaning or scraping of the bottom during the dry season in order to retain maximum recharge rates.

133. 

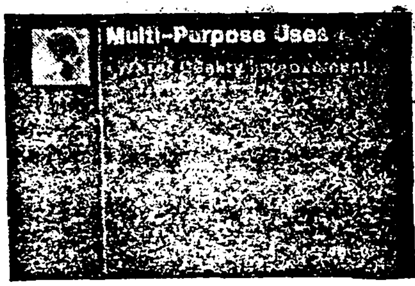
Recharge pits are excavated through less permeable materials into the upper portion of the aquifer. Periodic maintenance must be performed to remove accumulated material from the sides and bottom of the pit. In general, construction and maintenance are simple and inexpensive.

134. 

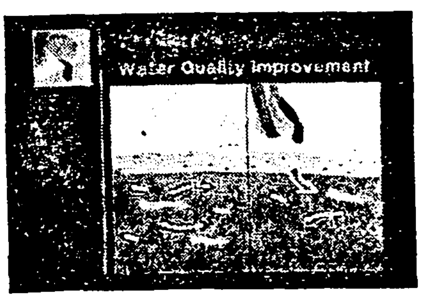
Recharge wells are constructed through thick, slowly permeable deposits into the aquifer. These wells are similar in design to production wells. Recharge wells may clog and require more extensive maintenance than other methods. When compared to other techniques, recharge wells are expensive to construct and maintain.

135. 

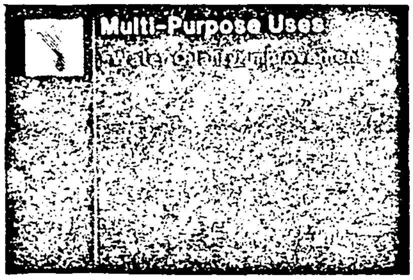
For artifical recharge to be successful, a source of water must be available at least intermittently. Excess flows from streams, water from industrial processes and waste water may all be utilized.

136. 

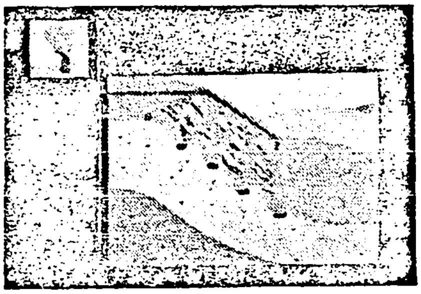
In addition to using artificial recharge as a tool to preserve the ground water resource, artificial recharge has been used for many other beneficial purposes. One of these is to improve the quality of the water.

137. 

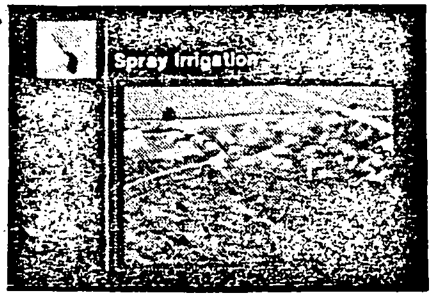
Where ground water contains undesirable quantities of minerals, artifical recharge has been used to improve water quality by diluting the natural mineral content.

138. 

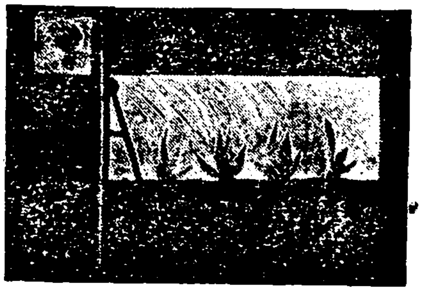
Another use of artifical recharge is to recycle waste water by land spreading. Care has to be taken in the selection of crops and the timing of waste water application so that the waste water does not pose any public health risk.

139. 

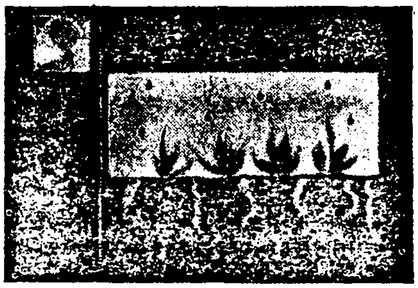
Tertiary treatment of waste water can be accomplished by applying waste water to a hill-side, then collecting and recycling effluent at the bottom of the slope until the waste water has been fully treated. This reduces sewage treatment costs and provides artifical recharge.

140. 

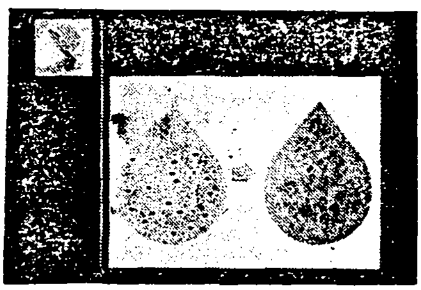
After receiving primary treatment, waste water can also be applied to cropland through spray irrigation. The aeration of the waste water provides additional treatment of the effluent.

141. 

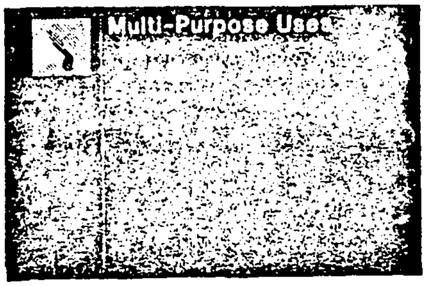
The cropland benefits by receiving both the waste water and the nutrients it contains. This, in turns, reduces fertilizer costs.

142. 

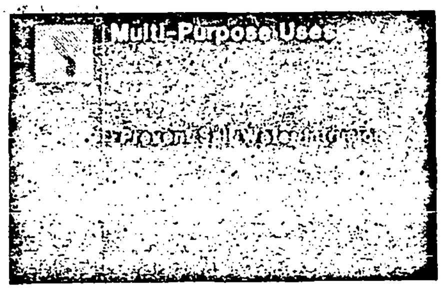
The waste water which is not used by the crop is naturally filtered and recharges the aquifer. Often such artifical recharge can be accomplished by land application during the non-growing season.

143. 

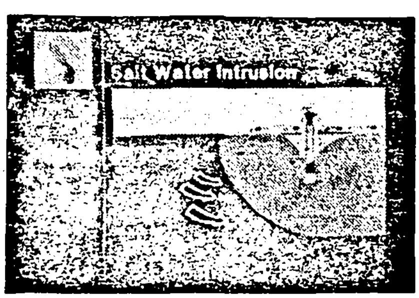
Finally, waste water recycling employs the forces of nature to turn an undersirable waste product into a natural resource which can be used again.

144. 

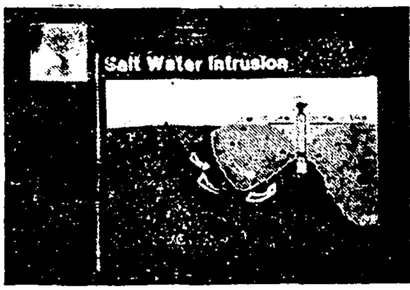
A third use of artificial recharge is to reduce stream flow during periods of flooding by providing another outlet for the water.

145. 

In coastal areas, artificial recharge can be used to prevent salt water intrusion.

146. 

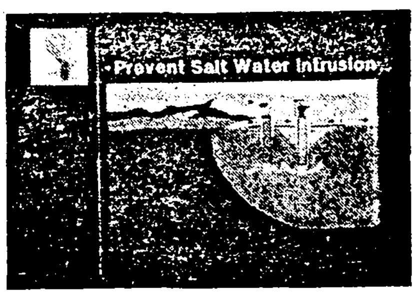
Salt water intrusion occurs when pumping of a supply well lowers ground water levels enough to permit salt water to move toward that well.

147. 

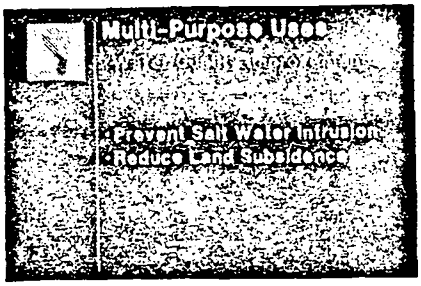
If the migration of the salt water is not stopped, the well will eventually turn salty and have to be abandoned.

148. 

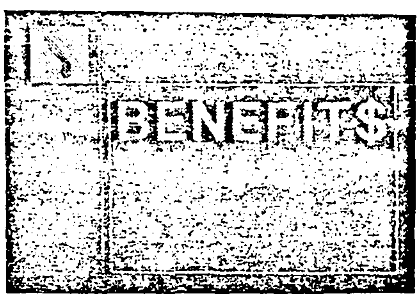
Placing a line of recharge wells between the supply well and the saltwater can halt the advance of the saltwater.

149. 

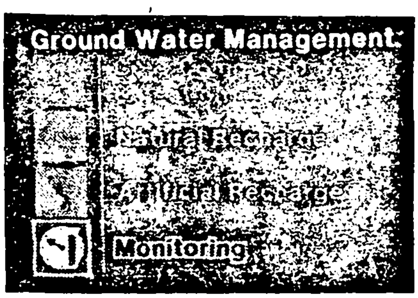
When water is artifically recharged through the wells, the reversal of the hydraulic gradient forms a barrier. This barrier prevents the saltwater from moving toward the supply well.

150. 

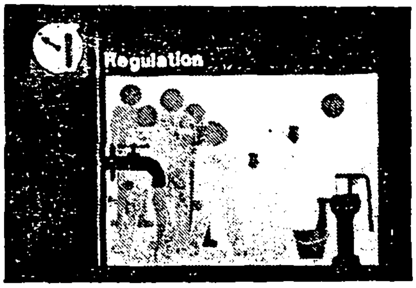
Last, artificial recharge has been used to reduce land subsidence. Where water withdrawals from fine materials have resulted in land subsidence, artifical recharge has helped prevent further elevation changes.

151. 

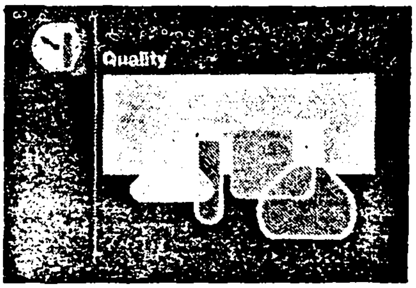
Although the costs associated with artifical recharge are not negligible, the variety of available recharge methodologies and the complementing benefits make this management alternative very attractive.

152. 

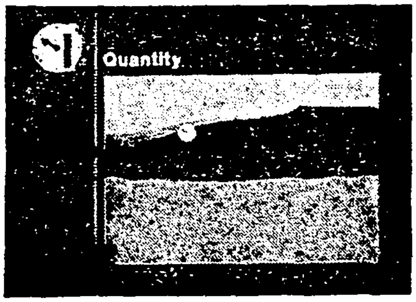
The fourth step in ground water management is monitoring. Because water is such a valuable resource, it is sometimes desirable to manage the resource by laws or regulations. Laws may be used to protect ground water from contamination and to establish user priorities for scarce water.

153. 

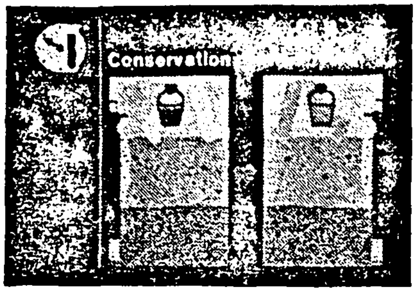
Monitoring often involves regulations. Regulations establish the standards that laws dictate. Often a distinction is made between small and large water users or between private and public water supplies. Frequently, only large users and public water supplies are regulated.

154. 

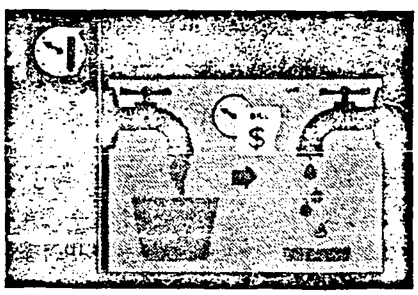
Ground water may be monitored in order to assess ground water quality. Quality monitoring is used to determine the chemical and bacteriological content of the water and to detect any contamination.

155. 

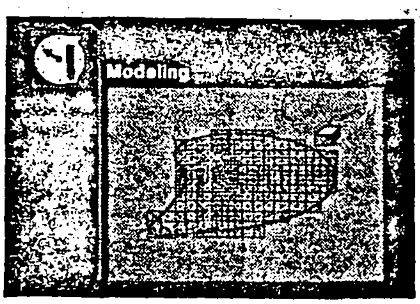
Monitoring ground water quantity involves measuring the amount of water withdrawn from the aquifer. Water level measurements or records of the withdrawals from wells provide information about the resource. The data may be subsequently used in a water management program.

156. 

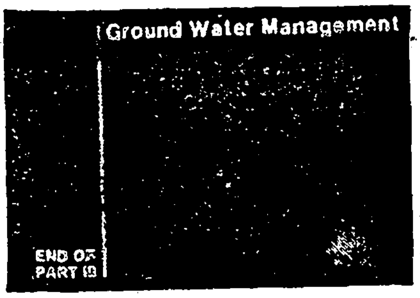
Where ground water is being used faster than it is replenished, it may be desirable to limit water use. This can be accomplished by regulation or through voluntary conservation measures.

157. 

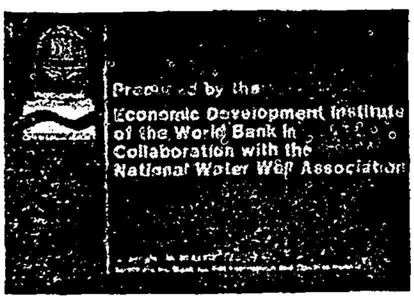
Economic incentives to conserve water through metering its extraction and raising its price may also serve to control excessive withdrawals.

158. 

Another monitoring technique is ground water modeling. Modeling uses mathematical techniques to make long- and short-term projections of water quantity and quality. These predictions can provide economic information, serve as evidence for legal action or be used as planning tools for water use, land use or environmental protection.

159. 

In summary, ground water can provide an attractive source of water supply, which can be managed effectively through regulation, monitoring, and voluntary and economic programs to provide safe water for present and future water needs.

160. 

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