Name ____________________

Ground Water

Introduction

The following exercises focus on the occurrence and movement of ground water. They examine how Earth materials store water, how water moves in the underground, and how ground water is mapped. The velocity and direction of ground-water flow is considered in a case of ground-water pollution.

The amount of freshwater stored beneath the surface of the Earth is very large. Worldwide it is over 65 times more abundant than all the freshwater in lakes and rivers. It constitutes an invaluable natural resource. In the United States as a whole, it provides over 40% of the country's freshwater needs, and a much larger percentage in the more arid western states.

Water in the underground is stored in, and moves through, openings or interstices of varying size and shape in Earth materials. The study of underground water, therefore, becomes a study of holes in unconsolidated materials and rocks, as well as the connections among these holes.

Exercise 31: Porosity

Introduction

Openings in sediments and rocks are small, and the movement of water through them is slow compared with water on the surface. There are two major exceptions. One is in caves, where openings are so large that water may run with velocities comparable to those of surface streams. The other exception is in lava, where lava tubes—tunnels evacuated by lava flowing beneath a solidified surface crust—and extensive cooling joints allow rapid passage of water.

Types of Porosity

The shapes and sizes of pore spaces in Earth materials vary widely. We can, however, group them as intergranular pores; as partings along bedding planes; as interstices caused by rock fracturing; and as modifications of some of these by solution.

Intergranular Porosity: Most sedimentary deposits are composed of individual mineral grains. Some units are well sorted, with a narrow range of grain sizes, and others are poorly sorted with a broad range of grain sizes. They do not, however, fit neatly together to make a continuous, unbroken mass. There is some space between individual grains. The sand sample in the preceding question set, for instance, has grains all about the same size, between 0.5 and 1.0 mm, arranged in a pattern similar to that in Figure 63.

Bedding plane porosity: When a sedimentary deposit is lithified, the rock often breaks preferentially along bedding planes and provides avenues for water movement. These may direct the flow of water laterally or may affect the rate of downward percolation.

Fracture porosity: Rocks are brittle. Under the stress of movement, they fracture (joints and faults) and break into blocks of different sizes and shapes. These fractures, particularly joints, provide paths along which groundwater may move through the rock, albeit slowly. They also contribute an important amount of porosity to sedimentary rocks, such as conglomerate, sandstone, shale, and limestone. Joints in sedimentary rocks break across individual beds and provide fractures connecting bedding planes as well as intergranular interstices.

Fracturing creates porosity in otherwise massive nonporous igneous rocks such as granite and gabbro. It also contributes high porosity to extrusive igneous rocks such as basalt. On cooling, lava contracts and fractures. Columnar jointing in lavas is a common type of such fracturing.

Fractures provide porosity to nonfoliated metamorphic rocks like quartzite. Foliated metamorphic rocks usually exhibit low porosity, the result of fractures, planes of foliation, and cleavage in such rocks as slate, schist, and gneiss.

Solution porosity: Modification of fracture and bedding plane porosity occurs in many limestones. Joints and bedding-plane partings in these rocks may be enlarged, and porosity increased, as water seeping through them slowly dissolves the rock along the fracture and bedding plane walls. This process of solution leads to a complicated system of openings in the rock and eventually to caves. When these caves collapse, sinkholes may develop at the surface. Very large flows of water are often associated with solution porosity.

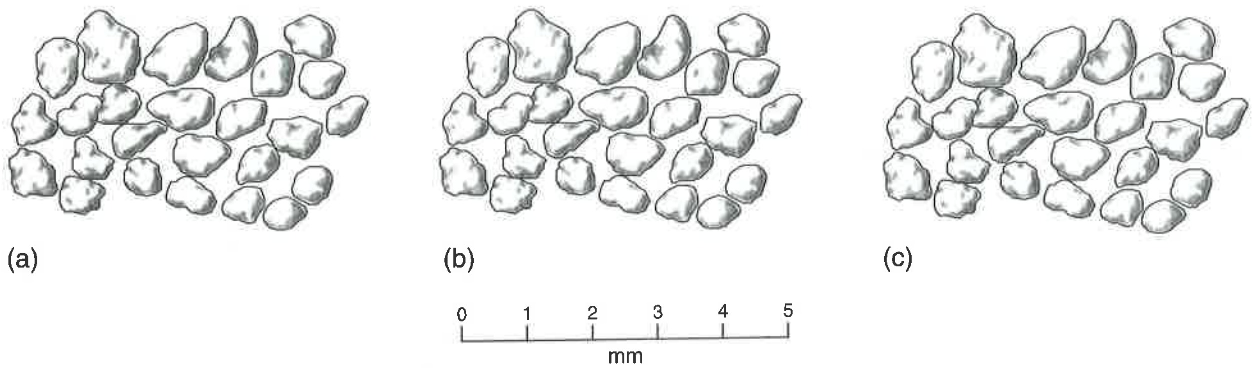

Figure 63. **Three identical views of unconsolidated sand grains. (a) Shows the porosity for this type of arrangement; (b) and (c) are identical diagrams on which to show two ways to reduce porosity.**

Question Set 51: Reduction of Intergranular Porosity

i. Think about some ways in which the porosity of the type of deposit in Figure 63 a might be reduced. Give two possibilities below. Illustrate these on Figures 63 b and 63 c with appropriate labels.

a. First possibility

b. Second possibility

Name ____________________

Determining porosity

Openings in Earth material give it a **porosity**, which is defined as the volume of void space in the material. It is often expressed as a fraction or portion of the total volume of the material—e.g., porosity = 0.30—or as the percentage of the volume of the material concerned—e.g., porosity = 30%.

$$\text{Porosity} = \frac{\text{volume of pore space (cm}^3\text{)}}{\text{volume of sample (cm}^3\text{)}}$$

$$= \text{porosity fraction or} \times 100 = \text{porosity \%}$$

If the sample has a volume of 1,000 cubic centimeters and the volume of the pore space is 250 cubic centimeters, then

$$\text{Porosity} = \frac{250}{1{,}000} = 0.25 \text{ or } 25\%$$

Question Set 52: Calculating Porosity

The easiest way to measure porosity is to saturate a sample with water. The amount of water that the material will hold when it is saturated is a measure of the volume of the pore space. The table below gives volumes of samples of different Earth materials and examples of the pore space for each.

Determine the percent porosity for each sample in the space provided.

Type of Material	Volume of Sample (cm3)	Volume of Pore Space (cm3)	Porosity (%)
i. Gravel	500	210	
ii. Medium-grained sand	600	270	
iii. Poorly cemented sandstone	650	163	
iv. Well-cemented sandstone	800	40	
v. Clay	825	404	
vi. Shale	435	57	
vii. Limestone	950	123	
viii. Unfractured granite	500	5	
ix. Fractured granite	700	35	

Name ______________________

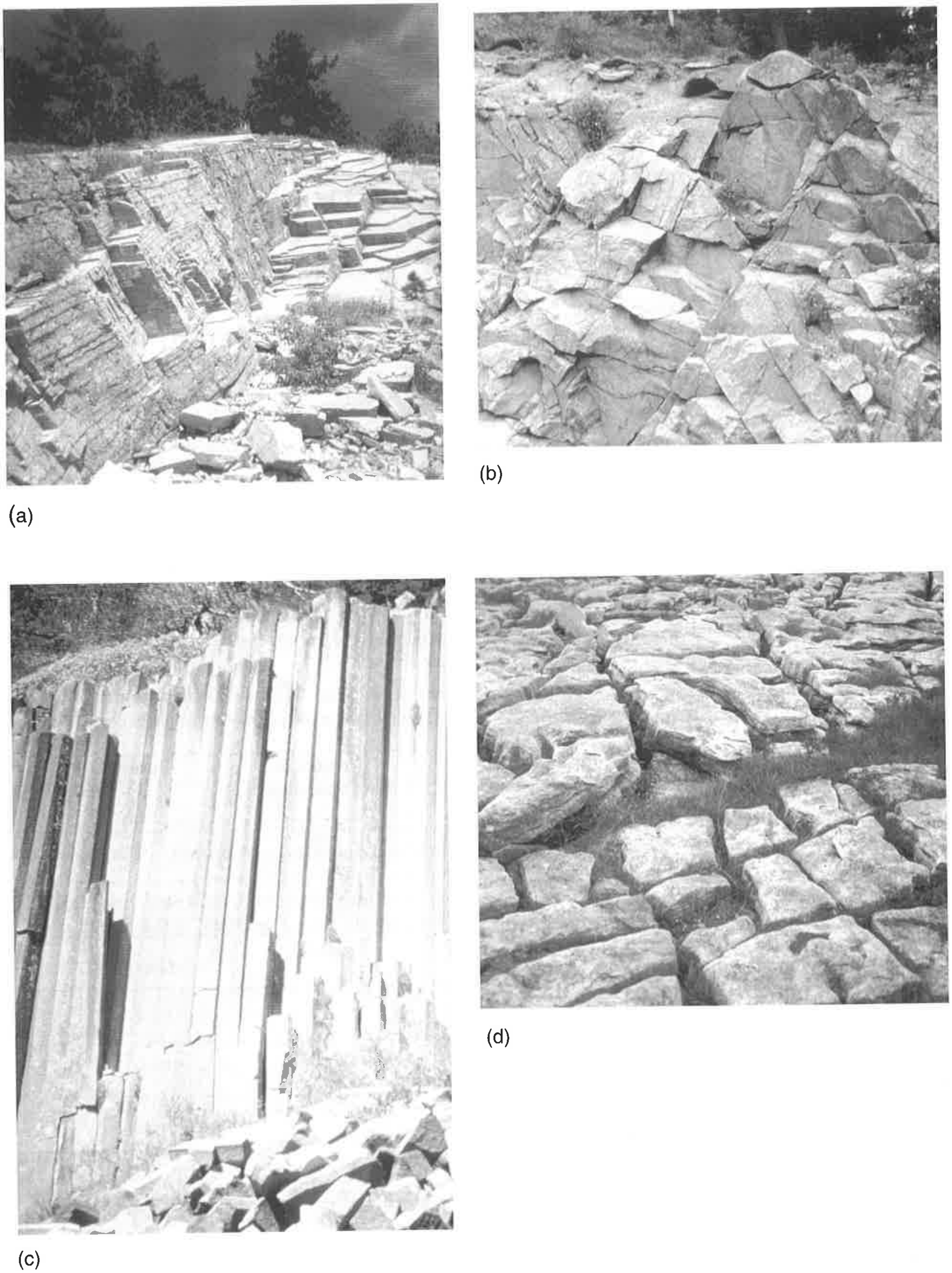

Figure 64. **Rocks illustrating different types of porosity. (a) Sandstone, Boulder, Colorado. (b) Granite near Estes Park, Colorado. (c) Basalt, Devil's Post Pile, California. (d) Limestone, County Clare, Ireland.** *(c) Pamela Hemphill*

Question Set 53: Porosity in Rocks

i. What factors contribute to the porosity of the sandstone in Figure 64 a.

ii. What kind of porosity is developed in the granite in Figure 64 b?

iii. What kind of porosity is illustrated by the basalt in Figure 64 c and how did it develop?

iv. How did the porosity in the limestone in Figure 64 d develop?

Exercise 32: Permeability

Introduction

In addition to porosity, Earth material must have the characteristic called **permeability** before water will move from one place to another. Permeability—the ability to transmit water—is absolutely necessary in developing water wells. The greater the permeability the greater the production.

Figure 65 illustrates the general relationship between permeability and porosity in unconsolidated sediments. Porosity is shown as % porosity. Permeability is reported in the unit called the **darcy**, which measures the ease of flow of fluids in rocks or sedimentary deposits. Figure 65 also illustrates the average range of water-well production in relation to these characteristics.

Name ____________________

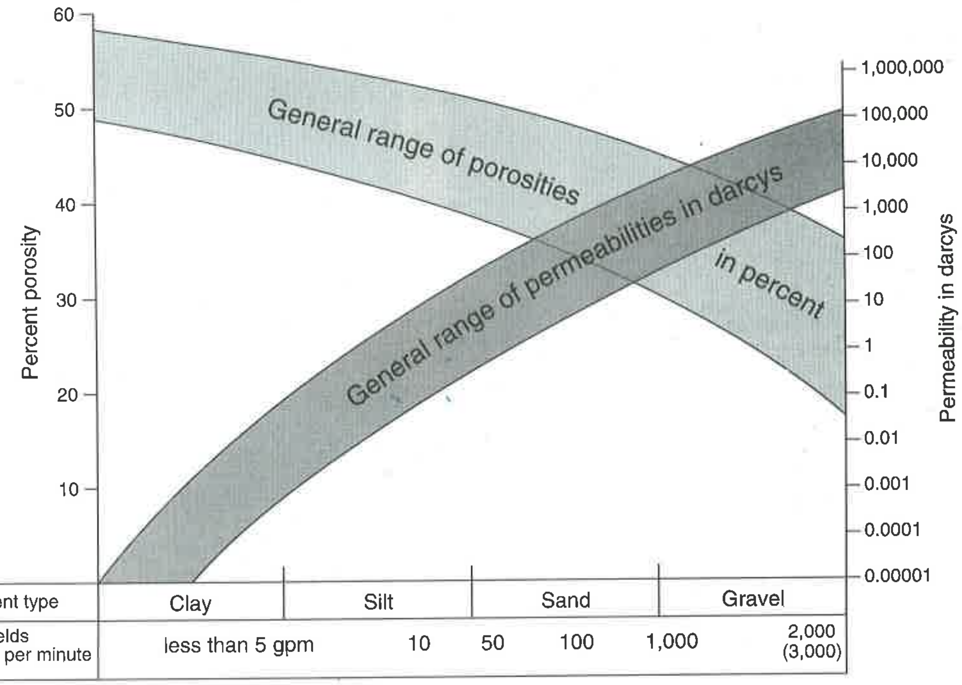

Figure 65. **Diagram showing general ranges of porosity and permeability, as well as range of well productivity in gallons per minute, in unconsolidated sediments. Porosity percent is on an arithmetic scale; permeability in darcys is given on a logarithmic scale. Well yields in any sediment vary within wide ranges.**

Question Set 54: Porosities, Permeabilities, and Unconsolidated Sediments

i. In the table in Question Set 52, you calculated porosities of three unconsolidated sediments. Plot these porosities on Figure 65.

Now consider Figure 65.

ii. What is the general relationship between porosity and sediment type?

iii. What is the general relationship between permeability and sediment type?

iv. What is the general relationship between sediment type and potential yield of water wells?

Question Set 55: Comparison of Porosities and Permeabilities

i. In Column 2 of the table below, fill in the appropriate porosity values you calculated in the table in Question Set 52.

ii. Estimate the porosity and permeability ranges for clay and sand from Figure 65 and enter in columns 3 and 4 in the table below.

iii. Fill in Column 5 of the table below, the well yield range from data in Figure 65.

iv. Clay and sand have been lithified to shale and sandstone, respectively.

a. How have the porosities changed because of lithification for clay to shale and for sand to sandstone?

b. How have the permeabilities changed because of lithification for clay to shale and for sand to sandstone?

v. How would you explain the changes?

vi. What will these changes do to the productivity of a water well?

1 **Material**	2 **Porosity Range** from Question Set 52 (%)	3 **Porosity Range** in part from Figure 65 (%)	4 **Permeability Range** in part from Figure 65 (darcys, d)	5 **Well Yield** in part from Figure 65 (gal/min, gpm)
Clay				
Shale		~10–30%	~0.0001 d	under 5 gpm*
Sand				
Sandstone		~5–30%	~0.001–.5 d	5–200 gpm*

*Shale yields can increase modestly with fracturing. Sandstone yields vary with degrees of sorting, of cementation, and of fracturing.

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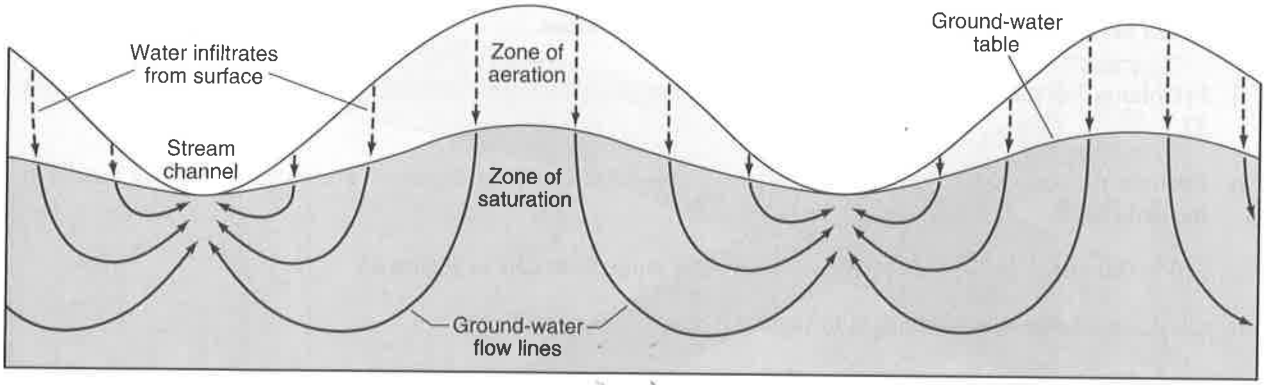

Figure 66. **Ground-water flow in a homogenous body of sand.**

Exercise 33: The Water Table

Introduction

Within a few hundred meters of the surface, most Earth materials have some porosity and contain some groundwater. Usually we find a zone, immediately below the surface, that may contain some moisture but that is far from being saturated with water (Figure 66). This is called the **zone of aeration** and through it water moves downward to a zone that is completely saturated with water, the **zone of saturation.** The contact between the zone of saturation and the zone of aeration is called the **ground-water table,** or simply the **water table,** and can be seen as the level to which water rises in a well. It is the saturated zone that provides water to wells, provided the porosity and permeability are favorable.

Figure 66 is an idealized diagram of the flow of water through a homogeneous, unconsolidated sand with good permeability. Water filtering from the surface into the underground has completely saturated the pores in the sand until a hill of groundwater has built up beneath the high spots in the landscape. The top of this saturated zone is the groundwater table. Figure 66 shows groundwater flowing to stream channels. A **ground-water divide** separates the water flowing to channels in adjacent valleys. Beneath the surface, ground-water flows. Although water added to the groundwater at the high will flow to the outlet (the stream channel), it does not follow a straight-line path. Rather, it moves in a broad looping path, flowing first downward and then upward toward the stream channel.

Question Set 56: Aspects of the Ground-water Table

i. In Figure 66, what is the relationship of the water table to surface topography?

ii. Considering the cost of drilling and operating a ground-water well, where would you site the least expensive well?

iii. Label on Figure 66 two ground-water divides.

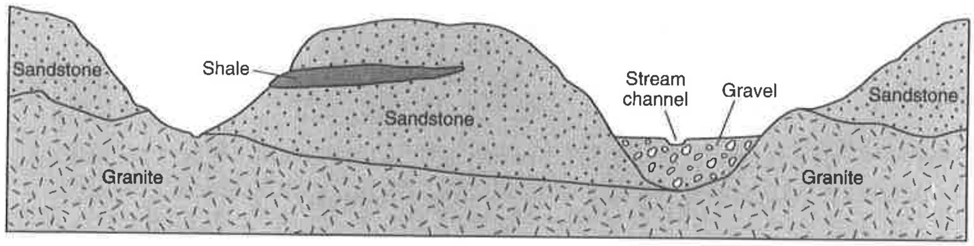

Figure 67. **Geologic section with rocks of differing permeability in a humid climate.**

Exercise 34: Aquifers and Aquitards

Introduction

Ground water can flow through a sand deposit because the sand is porous and permeable. Because water is transmitted easily, the sand is called an **aquifer,** from the Latin for *water* plus *bearing*. An aquifer is defined more fully as a body of Earth material that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs.

Most materials will transmit some water. Some, however, transmit so slowly that they do not qualify as aquifers. We call such a material an **aquitard,** from the Latin for *water* plus *slow.* Their presence in association with permeable materials creates a variety of different groundwater flow systems. For instance, ground water may accumulate above a small bed of shale enclosed in a larger unit of sandstone. The upper limit of this groundwater is called a **perched water table,** separated by the low permeability shale from the main ground-water table below.

Question Set 57: Effects of Permeability Variation on the Position of the Water Table

Figure 67 is a geologic section on which are indicated several rock types with differing permeability.

i. Which geologic units would you expect to be aquifers?

ii. Which would you expect to be aquitards?

iii. Which unit would make the best aquifer?

iv. Draw in on Figure 67 the position of the main water table. Indicate the location of any perched water tables and springs.

Name ____________________

Exercise 35: Mapping the Water Table

Introduction

The water table is a surface, and like the surface of the ground it can be mapped by drawing contours. Such a map will show the general surface of the ground-water table and delineate its highs and lows. It also gives a picture of the slope of the water table at any point. Because ground water will flow in the direction of the slope, the map will give a general picture of the directions in which the ground water is flowing. Figure 68 is a base map on which are located the positions of surface streams as well as a number of wells. The elevation of the water table in each well is given.

Question Set 58: Contouring the Water Table

i. Contour the water table on Figure 68 using an interval of 50 meters. A small area is contoured to get you started.

ii. With a pencil differing in color from the one with which you drew the contours, indicate the direction of flow of the groundwater. To do this draw a short arrow, about a half centimeter long, indicating the direction of flow at each well site. A few arrows have been put in to illustrate. The flow will be at right angles to the contours on the water table, which are lines of equal elevation.

iii. With a dashed line indicate the approximate position of groundwater divides.

iv. Into which creek does water flow at the points indicated on Figure 68:

Point W ____________________

Point X ____________________

Point Y ____________________

Point Z ____________________

Name ______________________

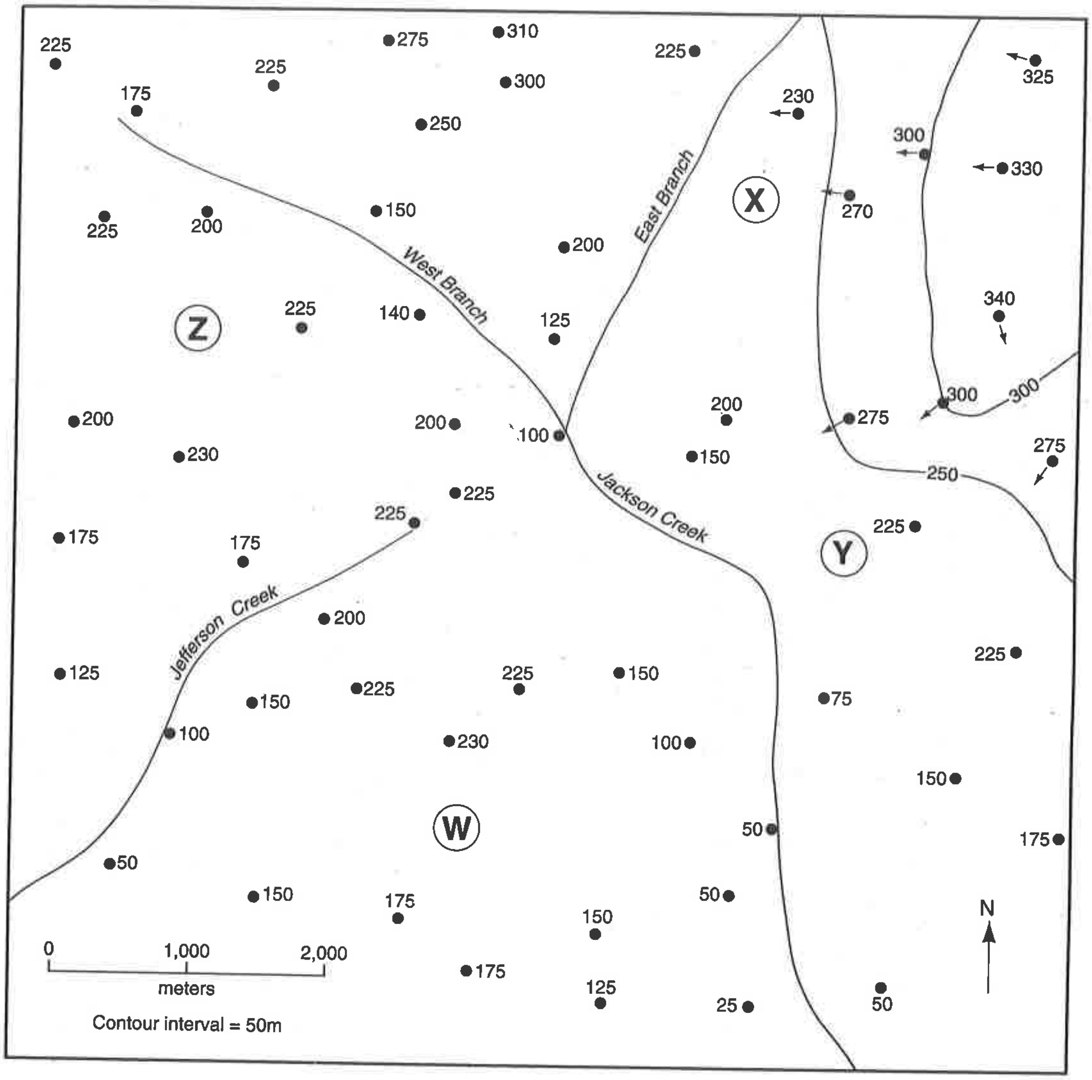

Figure 68. **Base for contouring a water table. Dots indicate positions of wells; numbers represent elevation of the water table in each well, in meters.**

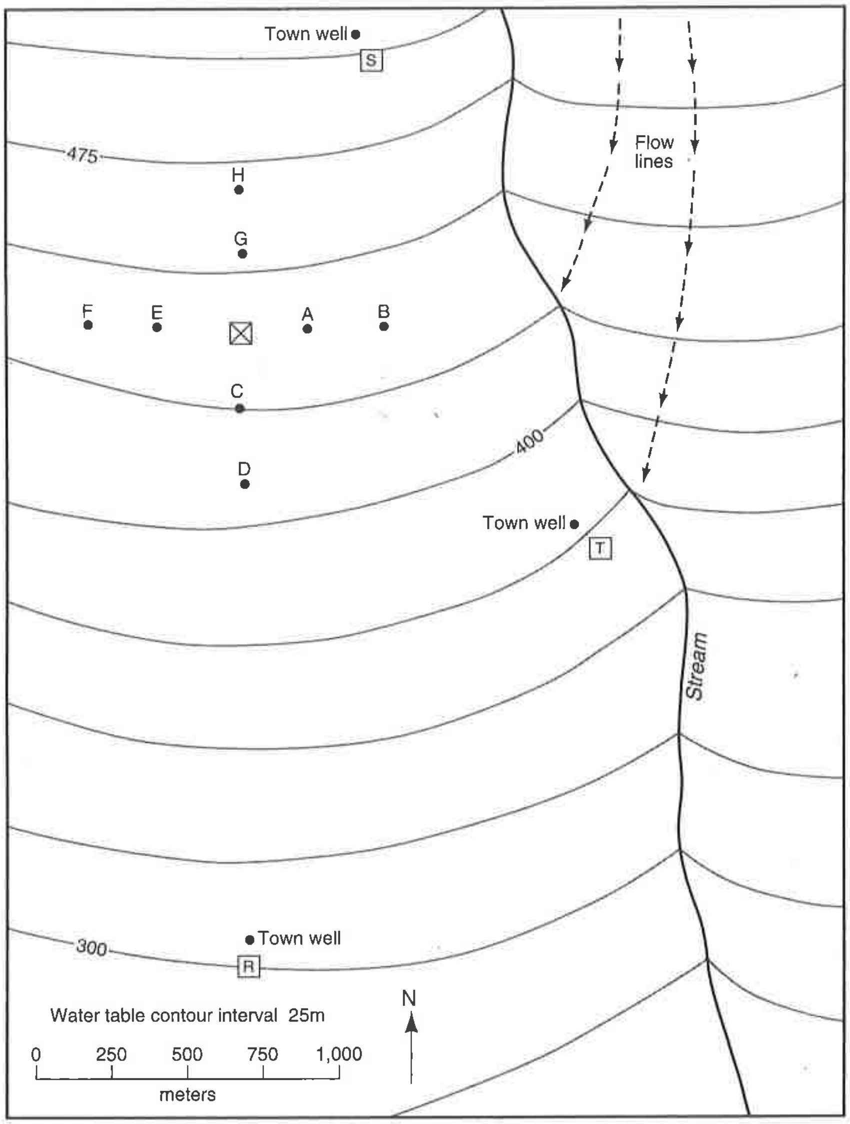

Figure 69. **A contour map of a water table. The map shows the location of three towns, "R," "S," and "T," as well as the location of an injection well at "X." Locations of town wells and of monitoring wells are also shown.**

Exercise 36: Pollution and Ground-Water Flow

Introduction

Determining the velocity of ground-water movement is difficult because ground water moves very slowly compared with surface flow, because it lies hidden from view beneath the surface, and because the actual flow paths are curved (Figure 66). It can be important, however, to know the velocity of ground-water flow. For instance, if the ground water becomes polluted at one place, it is useful to know how long it will take the polluted water to reach another area down-flow from the point of pollution. We deal with an example in the question set that follows.

Question Set 59: Pollution Risk and Ground-water Flow

Figure 69 is a map of a contoured water table in a weakly cemented sandstone. The map shows a source of pollution, a stream course, and several monitor wells. The factory at X wishes to dispose of a fluid toxic waste. Instead of piping it overland a kilometer to a waste disposal site, the factory managers opt to put it into the underground through an **injection well** at X, which may be illegal. An injection well is one through which fluids are added to the ground water. Before beginning injection, a network of wells, labeled A through H, is installed to monitor the quality of the ground water. Before injection, all monitored wells had a good quality water. Thirty days after beginning injection, no wells showed any deterioration of water quality. Fifty days after injection began, well C recorded contamination by the factory's waste fluid.

i. On the map in Figure 69, indicate the flow directions for the ground water. Remember that the flow lines are at right angles to the contours on the water table. Flow lines are shown in a small area of the map.

ii. What is the apparent speed of the ground water, in meters per day, between the injection well and well C? This is called the apparent speed, since water travels on curved paths as shown in Figure 66 and not straight-line paths as we might calculate it here. In addition to time elapsed, you need to know how far it is between the injection well and well C.

Apparent ground water speed = ______________ m/day

iii. At this rate of flow how long will it take the pollution to travel from the injection point to well D?

______________ days

iv. Town R draws its water from the well indicated on the map. One of the members of the town board drives a truck for a crew that services the monitoring wells and has learned about the pollution there. What should the board know about the risk of contamination of its town well?

v. News gets around fast. What can you tell Town S about the risk to its well and the reason for your answer?

vi. Town T asks the same question. What do you tell them? And why?