GROUNDWATER BASICS

SUBJECTS:
Math (Advanced), Science (Physics)
TIME:
1 class period
MATERIALS:
calculator
paper
pencil
student sheet and figures

OBJECTIVES

The student will do the following:

1. Compute math problems dealing with volume of groundwater.

2. Calculate average porosity in one type of aquifer.

3. Calculate the volume of water that will supply a particular well and its recharge rate.

BACKGROUND INFORMATION

Groundwater accounts for a major portion of the world's freshwater resources. Estimates of the global water supply show groundwater as 0.6 percent of the world's total water and 60 percent of the available fresh water resources. The total volume of readily available global groundwater is about 4.2 x 106 km3 as compared to 0.126 x 106 km3 (kilometers cubed) stored in lakes and streams. Next to glaciers and icecaps, which do not have readily available water, groundwater reservoirs are the largest holding basins for fresh water in the world hydrologic cycle (Figure 1).

The age of groundwater may range from a few years or less to tens of thousands of years or more. For the United States, it is estimated that about 25 percent of precipitation becomes groundwater.

It is estimated that the total usable groundwater in storage is about equivalent to the total precipitation for ten years, or the total surface runoff to streams and lakes for 35 years, although all of this groundwater is not available for practical use. In the United States, groundwater storage exceeds by many times the capacity of all surface reservoirs and lakes, including the Great Lakes.

Recoverable groundwater is that water released from storage in the subsurface zone of saturation whose capacity is the total volume of the pores or openings in soil or rocks that are filled with water.

The porosity values of specific materials are shown in Figure 2.

Groundwater movement is dependent on the degree of interconnection of the porous space (permeability) and the gradient or slope of the water table. These factors vary greatly depending on the aquifer type. Groundwater in a carbonate aquifer can occasionally move through limestone caverns as rapidly as surface water (1-3 ft/sec). In sandy aquifers, groundwater can move as slowly as 3 ft/day or even as slowly as 1 in/day. For those reasons, groundwater cleanup, or remediation, can only be done by enhanced methods.* These methods are complex and expensive, making groundwater pollution prevention quite economical. There are obvious health protection reasons for groundwater pollution prevention, as well.

Terms:

carbonate aquifer:

underground layer of limestone that is saturated with usable amounts of water

gradient:

change of elevation, velocity, pressure, or other characteristics per unit length; slope

hydrologic cycle:

the cyclical process of water's movement from the atmosphere, its inflow and temporary storage on and in land, and its outflow to the oceans; cycle of water from the atmosphere by condensation, and precipitation, then its return to the atmosphere by evaporation and transpiration.

permeability:

the capacity of a porous material to transmit fluids. Permeability is a function of the sizes, shapes, and degree of connection among pore spaces, the viscosity of the fluid, and the pressure driving the fluid.

porosity:

the spaces in rock or soil not occupied by solid matter.

water table:

upper surface of the zone of saturation of groundwater

ADVANCE PREPARATION

A. Copy Figures 1 and 2, Student Sheets, and Activity Section for students.

B. Complete the math problems before students are given them. (See the teacher sheet.)

** For information on enhanced methods, see activity "Groundwater: Cleaning Up" in this chapter.*

PROCEDURE

I. Setting the stage

A. Give students Conversion Student Sheet, Figures 1 and 2, and Activity Section.

B. If students need help with the math, give them the Hint Page.

II. Activity

Problems:

A. How many gallons are represented by 4.2 x 106 km3 of global groundwater?

B. If 1 x 106 mi3 of subsurface water exists in a volume of the earth's crust that covers 5 x 107 mi2 of the land surface land is ½ mile deep, what is the average porosity (in %) of the upper layer of the Earth's crust?* (assuming that the entire depth is saturated)

C. If a recharge area of a water well measures 1000 acres and the well is 800 meters deep, and soil porosity is that of a sand and gravel mix, what volume of water might theoretically supply the well?*

D. In question C above, what is the annual recharge rate (gallons/year) if precipitation is 55 inches per year, 7 inches of which become groundwater?

**Note: Solutions to B, C, and D are oversimplifications of these types of determinations but generally demonstrate the principles of recharge, yield, and infiltration calculations.*

RESOURCES

Bouwer, Herman, Groundwater Hydrology, McGraw Hill Book Company, New York, NY, 1978,
pp. 2-3, 6-8.

Groundwater and Wells, Johnson Division, UOP, Inc. St. Paul, MN, 1975, pp. 17-18.

Groundwater Pollution and Hydrology, Princeton University Short Course, 1983, pp. 1-2.

The Earth's Water Resources

SOURCE	SURFACE AREA (mi2)	WATER VOLUME (mi3)	% OF TOTAL WATER
Surface water freshwater lakes = ½ mi. deep	330,000	30,000	.009
Saline lakes	270,000	25,000	.008
Stream channels	---	500	.0001
Subsurface water <½ mi. deep	50,000,000	1,000,000	.31
Subsurface water >½ mi. deep	50,000,000	1,000,000	.31
Soil moisture + water in vadose zone	50,000,000	16,000	.005
Glaciers/ice caps	6,900,000	7,000,000	2.15
Atmosphere	197,000,000	3,100	.001
Oceans	139,500,000	317,000,000	97.2
TOTAL		326,000,000	

Figure 1

Porosities

Porosities of specific materials. Approximate ranges are:

Materials	Porosity, percentage
Silts and clays (that have not been significantly compacted)	50 - 60
Fine sand	40 - 50
Medium sand	35 - 40
Coarse sand	25 - 35
Gravel	20 - 30
Sand and gravel mixes	10 - 30
Glacial till	25 - 45
Dense, solid rock	<1
Fractured and weathered igneous rock	2 - 10
Permeable, recent basalt	2 - 5
Vesicular lava	10 - 50
Tuff	30
Sandstone	5 - 30
Carbonate rock with original and secondary porosity	10 - 20

Figure 2

CONVERSIONS

1 yd 3 = 27 ft3

1 acre = 4047 m2

1 hectare = 10,000 m2

1 m = 3.28 ft

1 acre = 43,560 ft2

1 ft3 = 7.48 gal

1 m3 = 35.31 ft3

HINT PAGE - Use Student Sheet on Conversions.

A. To start this problem, look at the conversion sheet.

1. Convert to m3.
2. Convert m3 to ft3.
3. Convert ft3 to gallons.

B.

1. Porosity = $\frac{\text{mi3 of H2O}}{\text{mi3 of soil}}$ $\frac{\text{(volume of H2O)}}{\text{(volume of soil)}}$

2. Volume = area x depth.

   (mi3 of soil = mi2 of land x depth in miles)

C.

1. Convert acres to meters.
2. Volume = area x depth.
3. Water yield = volume x porosity (convert to decimal).

D.

1. Convert inches to ft.
2. Convert ft to meters.
3. Convert acres to m2.
4. Multiply area (m2) x rainfall that becomes groundwater (m) = m3.
5. Must convert m3 to ft3 first.
6. Convert ft3 to gallons.

A. To start this problem, you must look at the conversion sheet.

1. Convert to m3.

$$4.2 \times 106 \text{ km3} \quad \times \quad \frac{1 \times 109\text{m3}}{1 \text{ km3}} = 4.2 \times 1015 \text{ m3}$$

2. Convert m3 to ft3.

$$\frac{4.2 \times 1015 \text{ m3}}{1 \text{ m3}} \quad \times \quad 35.31 \text{ ft3} = 1.483 \times 1017 \text{ ft3}$$

3. Convert ft3 to gallons.

$$\frac{1.483 \times 1017 \text{ ft3}}{1 \text{ ft3}} \quad \times \quad 7.48 \text{ gal} = 1.11 \times 1018 \text{ gal}$$

B.

1. Porosity = $\frac{\text{mi3 of H2O}}{\text{mi3 of soil}}$ $\frac{\text{(volume of H2O)}}{\text{(volume of soil)}}$

2. Volume = area x depth.

mi3 of soil = mi2 of land x depth in miles
mi3 of soil = (5 x 107) x 0.5 = 2.5 x 107 mi3

$$\text{Porosity} = \frac{1 \times 106}{2.5 \times 107} = 0.04 \text{ or } 4\%$$

C.

1. Convert acres to meters.

$$1000 \text{ acres} \quad \times \quad \frac{4074 \text{ m2}}{1 \text{ acre}} = 4.074 \times 106 \text{ m2}$$

2. Volume = area x depth.

4.074 x 106 m2 x 800 m = 3.26 x 109 m3

3. Water yield = volume x porosity (convert to decimal).

3.26 x 109 m3 x 0.20 = 6.52 x 108 m3

D.

1. Convert inches to ft.

   $$7 \text{ in} \quad \text{x} \quad \frac{1 \text{ ft}}{12 \text{ in}} \quad = \quad 0.58 \text{ ft}$$

2. Convert ft to meters.

   $$0.58 \text{ ft} \quad \text{x} \quad \frac{1 \text{ m}}{3.28 \text{ ft}} \quad = \quad 0.177 \text{ m of rain into groundwater}$$

3. Convert acres to m2.

   $$1000 \text{ acres} \quad \text{x} \quad \frac{4047 \text{ m2}}{1 \text{ acre}} \quad = \quad 4.047 \text{ x } 106 \text{ m2}$$

4. Multiply area (m2) x rainfall that becomes groundwater (m) = m3.

   $$4.047 \text{ x } 106 \text{ m2} \quad \text{x} \quad 0.177 \text{ m} \quad = \quad 7.16 \text{ x } 105 \text{ m3}$$

5. Must convert m3 to ft3 first.

   $$7.16 \text{ x } 105 \text{ m3} \quad \text{x} \quad \frac{35.31 \text{ ft3}}{1\text{m3}} \quad = \quad 2.53 \text{ x } 107 \text{ ft3}$$

6. Convert ft3 to gallons.

   $$2.53 \text{ x } 107 \text{ ft3} \quad \text{x} \quad \frac{7.48 \text{ gal}}{1\text{ft3}} \quad = \quad 1.89 \text{ x } 108 \text{ gal}$$