HYDRAULIC HEAD

SUBJECTS:
Science (Physical Science, Physics), Math
TIME:
1 class period
MATERIALS:
Copies of student sheets and background information

OBJECTIVES

The student will do the following:

1. Apply knowledge of the controlling variables for groundwater flow.

2. Demonstrate groundwater flow direction based on hydraulic head observations.

BACKGROUND INFORMATION

The water in the ground (groundwater) fills pore spaces in the subsurface rocks and sediments. The water in the lower part of the zone of porosity fills all the pore spaces and creates a saturated material (Figure 1).

The groundwater is stored or flows through the pore spaces and is acted on by three outside forces. These forces are: (taken from Fetter, 1988)

1. gravity- that which pulls water downward.

2. external pressure- a combination of atmospheric pressure and the weight of over lying sediments and water.

3. molecular attraction- that which causes water to adhere to other surfaces and to itself.

When it hits the ground, rain will be drawn by gravity downward through the soil zone to a zone saturated by water. The external pressure on the saturated zone creates a pressure (fluid pressure) in the saturated zone. At this depth, the fluid pressure is greater than the external pressure. However, as the top of the saturated zone is approached, the fluid pressure decreases until at some depth the pressure of the fluid in the pores is equal to atmospheric pressure. This surface, where fluid pressure is equal to atmospheric pressure, is called the water table and defines the top of an unconfined aquifer.

In addition to the outside forces acting on the groundwater, there is an energy contained in the groundwater that causes the water to move. The total energy in groundwater consists of three components: pressure, velocity, and elevation of the water body (elevation head). Because groundwater velocities are low, this energy component is essentially zero. The remaining components can be defined by an equation called the Bernoulli equation (Figure 2). In this equation, the potential energy at a given point (hydraulic head) is equivalent to the elevation at a point of measurement (elevation head), such as a well screen, plus the depth of the water column that rises in a well (pressure head). The pressure head and how high the water column rises in a well are functions of the external pressure (Driscoll, 1986).

Figure 2

Bernoulli's Relationship

$h = Z + P$

Where: h = hydraulic head
Z = elevation head
P = pressure head

In a water table or unconfined aquifer, the top of the saturated zone is at atmospheric pressure, which is constant across a site. Because the pressure head is constant across the site, this component is generally not taken into consideration when calculating the energy to drive groundwater to a point of discharge. Therefore, the height of the water column, z, represents the actual energy available to drive water through aquifer materials to a point of discharge like a well or spring (Driscoll, 1986).

Just as heat flows through solids from higher to lower temperatures, groundwater flows through porous media from higher to lower hydraulic head. This concept is easiest to imagine when considering water table aquifers. The water table, because it is at atmospheric pressure, will follow approximately the contours of the surface topography (Figure 3). The differences in elevation head between point a, at a higher elevation head, and point b, at a lower elevation head, force the groundwater towards the lower energy potential or towards the lower elevation head. The rate of groundwater flow towards a well or spring is proportional to the difference in elevation head between the source (high) and discharge (low) areas.

Figure 3

Terms

atmospheric pressure:
the pressure or force per unit area, exerted by the atmosphere on any surface beneath or within it

Bernoulli Principle:
the statement in hydraulics that under conditions of uniform steady flow of water in a conduit or stream channel, the sum of the velocity head, the pressure head, and the head due to elevation at any given point is equal to the sum of these heads at any other point plus or minus the losses in head between the two points due to friction or other causes

elevation head:
the elevation of the point at which the hydrostatic pressure is measured, above or below an arbitrary horizontal datum

fluid pressure:
the mechanical energy per unit mass of a fluid, at any given point in space and time, with respect to an arbitrary state and datum (fluid potential)

groundwater:
water that infiltrates into the Earth and is stored in usable amounts in the soil and rock below the Earth's surface; water within the zone of saturation

hydraulic head:
the height of the free surface of a body of water above a given subsurface point; the sum of elevation, pressure, and velocity components at a given point in an aquifer

pore space:
the volume of the open spaces in rock or soil

porosity: the spaces in rock or soil not occupied by solid matter

pressure head:

the height of a column of liquid supported, or capable of being supported, by pressure p at a point in the liquid

saturated zone:

a portion of the soil profile where all pores are filled with water. Aquifers are located in this zone. There may be multiple saturation zones at different soil depths separated by layers of clay or rock.

unconfined aquifer:

an aquifer containing unpressurized groundwater, having an impermeable layer below but not above it

unsaturated zone:

a portion of the soil profile that contains both water and air; the zone between the land surface and the water table. The soil formations do not yield usable amounts of free-flowing water. It is also called the zone of aeration and vadose zone.

water table:

upper surface of the zone of saturation of groundwater

ADVANCE PREPARATION

A. Copy Background Information and Student Sheets for students.

B. Copy or put on board terms and definitions for students.

C. Enlarge and make transparencies of Figures 1-3 in Background Information.

PROCEDURE

I. Setting the stage

A. Discuss Background Information using transparencies.

B. Review vocabulary.

II. Activity

A. Have students complete the Infiltration, Discharge, and Flow Direction Student Sheet by indicating the direction of flow of groundwater based on differences in elevation heads. Indicate, above the picture, points where water is likely to infiltrate the water table or discharge into a surface water body.

B. Have students calculate the differences in head elevations between the highest point of the water table or h_{max} and the water bodies, Lake 1 (h_1) and 2 (h_2), on either side of the island.

Discussion questions:

1. Since h_1 is greater than h_2, does any water from L_1 flow across the island to discharge into L_2?

   Answer:

   h_{max} is greater than h_1; therefore, water is flowing from the island into L_1, and the water from L_1 does not contribute to L_2.

2. If the island were to experience drought and there were no more precipitation, what would happen to the water table and groundwater flow conditions?

   Answer:

   The water table would decline, probably becoming a nearly flat surface, and provide a gradient of flow between L_1 and L_2.

RESOURCES

Bates, R.L. and Jackson, J.A., Editors, 1987, Glossary of Geology, 3rd Ed., American Geological Institute, p. 788.

Driscoll, F.G., Groundwater and Wells, 2nd Ed., Johnson Division, 1986, p. 1089.

Fetter, C.W., Applied Hydrogeology, 2nd Ed., Merrill Publishing Co., 1988, p. 592.