Properties of the groundwater aquifer beneath the soccer field

In this exercise, we will determine some of the hydraulic characteristics of the material which lies below the soccer field. If we wanted to use water from this aquifer for irrigation or other purposes, we would need to know how much water is present, how deep the water lies, and whether or not the water would flow readily to a well. We can determine many of these factors by conducting a pump test, in which one well is pumped and the water level in other wells is monitored. We will use a series of five or so wells which have been driven to a depth of about four or five meters at the west edge of the soccer field.

Conducting the pump test

Each group will monitor the water level in one of the observation wells. It is important to note the depth of the water table below the ground surface before starting the test. Drop the probe down the well and note the length of line and probe when the circuit is completed. Lay the line against a measuring tape to determine the depth of the water table below the surface (Remember to compensate for the difference between the pipe level and the ground surface). Note the number on the worksheet (to centimeters). Now tape a ruler to the probe wire in such a way that the level of the undisturbed water table gives a reading of something near 1 cm. and the ruler is up so you can monitor the water table level as it drops. Record the beginning measurement to the nearest mm.

After we begin to pump, each group will take readings of water table depth at one minute, two minutes, four minutes, and at two minute intervals thereafter. Record the number - to the nearest millimeter - on the ruler when the circuit is completed at each time. We will pump for about 30 minutes and then allow the system to recover (continuing the readings) for another 20 minutes or so. Record your data on the accompanying worksheet.

While two or three people in each group monitor the well during the drawdown phase, other people can convert the measured distance from the top of the pipe into depth of water table below the surface and begin to plot curves of drawdown versus time for that well. After pumping ceases, quickly calculate the total drawdown (in millimeters) and final saturated aquifer thicknesses (in meters, to two decimal places). Continue to plot drawdown versus time for the recovery phase. To determine the hydraulic conductivity of the aquifer below the field, you will need the calculation of the final saturated aquifer thicknesses from the nearest and furthest observation well, as shown on the accompanying worksheet. Many interesting results can be derived while on the soccer field. We will then calculate hydraulic conductivity (**bring a calculator!**) and draw some graphs of the drawdown.

As a group, we will complete these calculations and discuss the questions below.

1. Plot the actual drawdown curve (distance and drawdown for all observation wells) on semi-log paper. Use the logarithmic axis for distance and the arithmetic axis for drawdown.

2. Plot a graph on normal graph paper showing the initial position of the ground surface, the bedrock, the initial water table position, and the final water table position at all the wells when pumping stops.

3. Plot a graph for your observation well showing time in minutes (horizontal) versus water table depression in mm (vertical).

4. Calculate the hydraulic conductivity and convert your number to cm/sec. Compare the hydraulic conductivity of the soccer field aquifer with general values for different materials. Based on this comparison, what kind of material do you think underlies the soccer field? Would you characterize it as high, moderate, or low hydraulic conductivity? Does your answer make sense, considering the geomorphic position of the soccer field?

5. What are the relative elevations of the water table under the soccer field and the Cannon River near this point? (Use the initial values of water table depth from each group).

6. Is the Cannon River presently an influent or an effluent stream (does it lose water to the groundwater system, or gain water from it)?

7. Where does the water in the soccer field aquifer come from?

8. Do you think the soccer field aquifer is a useful source of water for the college?

References: DeWiest, Roger, 1965, Geohydrology: New York, John Wiley, 366 p. Freeze, R. Allan and Cherry, John A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Well No.______________Distance from pumping well___________m.

Depth of pumping well 5.00 meters
Depth of water table below top of pipe________m.
Height of pipe above ground or depth below ground______m.
Initial depth of water table below ground surface______m.

Reading on ruler of initial water table depth
(should be about 1 cm) ___________________cm.

Pumping rate ___________liters/minute x 1.44=________M^3/day

Nearest well:
Depth of pumping well below ground surface 5 meters

(minus) initial water table depth below ground surface meters
(equals) initial saturated aquifer thickness meters

(minus) total amount of drawdown during pump test meters
*(equals) final saturated aquifer thickness meters

*Distance from pumping well _____________meters

Farthest well:
Depth of pumping well below ground surface 5 meters

(minus) initial water table depth below ground surface meters
(equals) initial saturated aquifer thickness meters

(minus) total amount of drawdown during pump test meters
*(equals) final saturated aquifer thickness meters
*Distance from pumping well _____________meters
*Indicates the values that need to be used for the equation

Drawdown phase readings (to nearest millimeter):

Time	Reading on ruler	Depth of water table
1 min		
2 min		
4 min		
6 min		
8 min		
10 min		
12 min		
14 min		
16 min		
18 min		
20 min		
22 min		
24 min		

Recovery phase readings:

Time	Reading on ruler	Depth of water table
2 min		
4 min		
6 min		
8 min		
10 min		

Brief summary of groundwater movement

The flow of groundwater is summarized by an expression called Darcy's law which states that the discharge of water through a particular cross-section of soil is equal to the cross-sectional area, times the gradient (height difference over total length of flow), times the hydraulic conductivity (related to permeability of the soil).

(1) $$Q = KiA$$ Q=discharge (in units of volume per second; e.g. cubic centimeters/sec)

k=hydraulic conductivity (in units of velocity, e.g. cm/second)
i=hydraulic gradient (head loss divided by length of flow) (dimensionless)
A=cross-sectional area (in length squared; e.g. square centimeters)

By comparing this equation to the continuity equation for stream flow ($Q = Av$), you can see that K, the hydraulic conductivity, has units of velocity (e.g. cm/second). Typical values of hydraulic conductivity for different materials are given in the table on the next page. The hydraulic conductivity depends not only on the properties of the material in the aquifer, but also on the properties of the fluid passing through this material. Closely related to the hydraulic conductivity is another variable called the permeability, which is an intrinsic property of the aquifer material. The relationship between hydraulic conductivity and permeability is given by the equation

(2) $$K = \frac{k\rho g}{\mu}$$ (Freeze and Cherry, p. 27)

where K is hydraulic conductivity
k is permeability
ρ is fluid density
μ is fluid viscosity
g is gravitational acceleration

When a pumping test is conducted, water flows into the pump from a conical area called the cone of depression. The shape of this volume necessitates some changes in the formulation of Darcy's law, which was originally formulated for a rectangular solid. Most formulas assume that the aquifer is homogeneous, isotropic and that the wells penetrate the full extent of the aquifer. The formula we will use also assumes that the flow is steady - that is, that the cone of depression has reached an equilibrium state and the pumping rate is constant. Because we aren't going to pump the aquifer for very long, the flow may not be steady. This formula calculates the hydraulic conductivity as follows:

(3) $$K = \frac{Q}{\Pi(h_2^2 - h_1^2)} \ln\left(\frac{r_2}{r_1}\right)$$

K=hydraulic conductivity, cubic meters per square meter per day (=m/day)

Q=discharge (pumping rate, M^3/day

r_1=distance to nearest observation well, meters

r_2=distance to farthest observation well, meters

h_1=final saturated aquifer thickness, nearest well, meters

h_2=final saturated aquifer thickness, farthest well, meters

$\frac{h_2 - h_1}{r_2 - r_1} = i$ in equation 1.

The hydraulic conductivity is calculated for a unit cross-sectional area, so the term A drops out of the equation.

Some helpful conversions while solving this equation:
1 liter/minute = 1.44 m^3/day
1 meter/day = 0.00116 cm/sec

<u>Range of values of hydraulic conductivity</u>*

Rocks	K(cm/sec)
karst limestone	10^{-4} - 1
permeable basalt	10^{-5} - 1
fractured igneous and metamorphic rocks	10^{-6} - 10^{-2}
limestone and dolomite	10^{-7} - 10^{-3}
sandstone	10^{-8} - 10^{-3}
unfractured metamorphic and igneous rocks	10^{-12} - 10^{-8}
shale	10^{-11} - 10^{-7}
Unconsolidated deposits	
gravel	10^{-1} - 100
clean sand	10^{-4} - 1
silty sand	10^{-5} - 10^{-1}
silt, loess	10^{-7} - 10^{-3}
glacial till	10^{-10} - 10^{-4}
unweathered marine clay	10^{-10} - 10^{-7}

*From Freeze and Cherry, 1979, Groundwater: Prentice-Hall, Englewood Cliffs, p. 29.