NAME____________________

89.215 - FORENSIC GEOLOGY
A *CIVIL ACTION*

I. Introduction

In 1982 a lawsuit was filed on behalf of eight Woburn families by Jan Schlictmann. The suit alleged that serious health effects (childhood leukemia, cardiac arrhythmias, disorders of the immune and neurological systems) were caused by exposure to contaminated water from public supply wells G and H. The suit named W.R. Grace, Beatrice Foods, and subsequently UniFirst Corporation as the polluters. This lawsuit would ultimately become a *cause celebre* because of the book *Civil Action* and the subsequent movie of the same name that was based on this case. Because of the degree of contamination of the site, the site (Fig. 1)was designated a Super Fund site by the U.S. Environmental Protection Agency (EPA).

Figure 1. Aerial photograph of the *Civil Action* site in Woburn, Massachusetts.

Well G was drilled in 1966 and well H was drilled in 1968 as water supply wells for North Woburn. The water source tapped by these wells is a common one for many towns in Massachusetts. During the last period of continental glaciation N-S trending valleys were cut in the bedrock. When the glaciers retreated these valleys were filled with sand and gravel from glacial outwash. In places till (ground up rock debris) was also left behind. Till is impermeable, but the sands and gravels are both porous and permeable and, therefore, are ideal aquifers. However, given the shallow nature of these aquifers, they are also susceptible to contamination. After the wells were brought on line, residents who used water from this source complained that the water smelled and tasted bad. Tests by the local department of health showed no contaminants in the drinking water. In 1979 tests by the Massachusetts Department of Environmental Quality Engineering (now the Department of Environmental Protection) found several chlorinated compounds (TCE and PCE) in the wells. Both wells were closed on May 22, 1979. In this case, we will develop several lines of geologic evidence that address the question of the source of the pollutants for wells G and H.

II. Geologic cross-section

A fundamental piece of geologic information is the nature of the subsurface. There are a variety of ways in which information about the subsurface can be obtained. In this exercise we will use drill core data. A number of holes were drilled on the site and material was recovered from these drill holes. The material was characterized by a geologist into several sediment types. This exercise is somewhat simplified from the real case and we will consider only six types of sediment: peat, fine sand, medium sand, coarse sand, gravel, and till. Figure 2 shows the line (A - A') along which the holes were drilled. Figure 3 is a cross section along this line that shows the topography and the location of the basement (the metamorphic and igneous rock that underlies the site). The basement is fractured, and therefore somewhat permeable, but for the purpose of this exercise we will consider the basement rocks to be impermeable. Table 1 lists the sediment types encountered in each drill hole and their thickness. The list of sediment types for each drill hole starts at the top of the hole. The drill holes are shown on Figure 3. From the vertical scale given on the diagram, using a ruler, for each drill hole indicate the contacts between the different sediment types. Once you've done this for each drill hole, fill in the cross-section with the various sediment types. Your product should consist of series of sediment layers. Label each layer in a unique way - for example use small dots for fine sand and small circles for conglomerate. This cross-section is a fundamental piece of evidence that will be used in our subsequent investigation of the hydrologic behavior of this site.

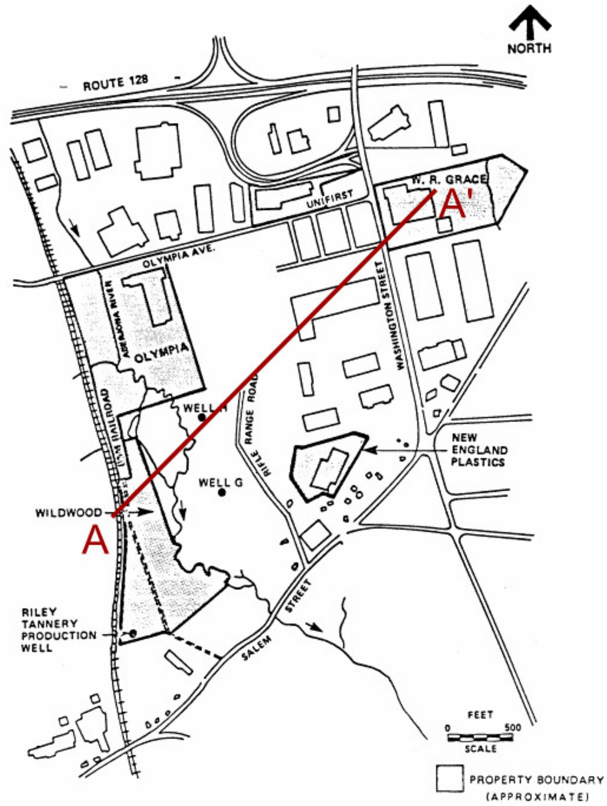

Figure 2. Site map and location of cross-section.

Table 1. Data for drill holes along section A - A'. Sediment thickness and type.

Hole	Description
1	4' fine sand, 60' medium sand, 7' gravel
2	11' fine sand, 67' medium sand, 13' gravel
3	7' peat, 7' fine sand, 68' coarse sand, 11' gravel
4	11' peat, 18' fine sand, 93' coarse sand, 7' gravel
5	18' peat, 9' fine sand, 95' coarse sand, 12' gravel
6	4' peat, 16' fine sand, 58' coarse sand, 38' gravel
7	4' fine sand, 28' coarse sand, 8' gravel
8	30' coarse sand, 5' gravel
9	9' coarse sand, 3' gravel
10	7' coarse sand, 29' gravel
11	16' gravel, 13' coarse sand, 4' till
12	5' gravel, 15' coarse sand, 4' till
13	38' till

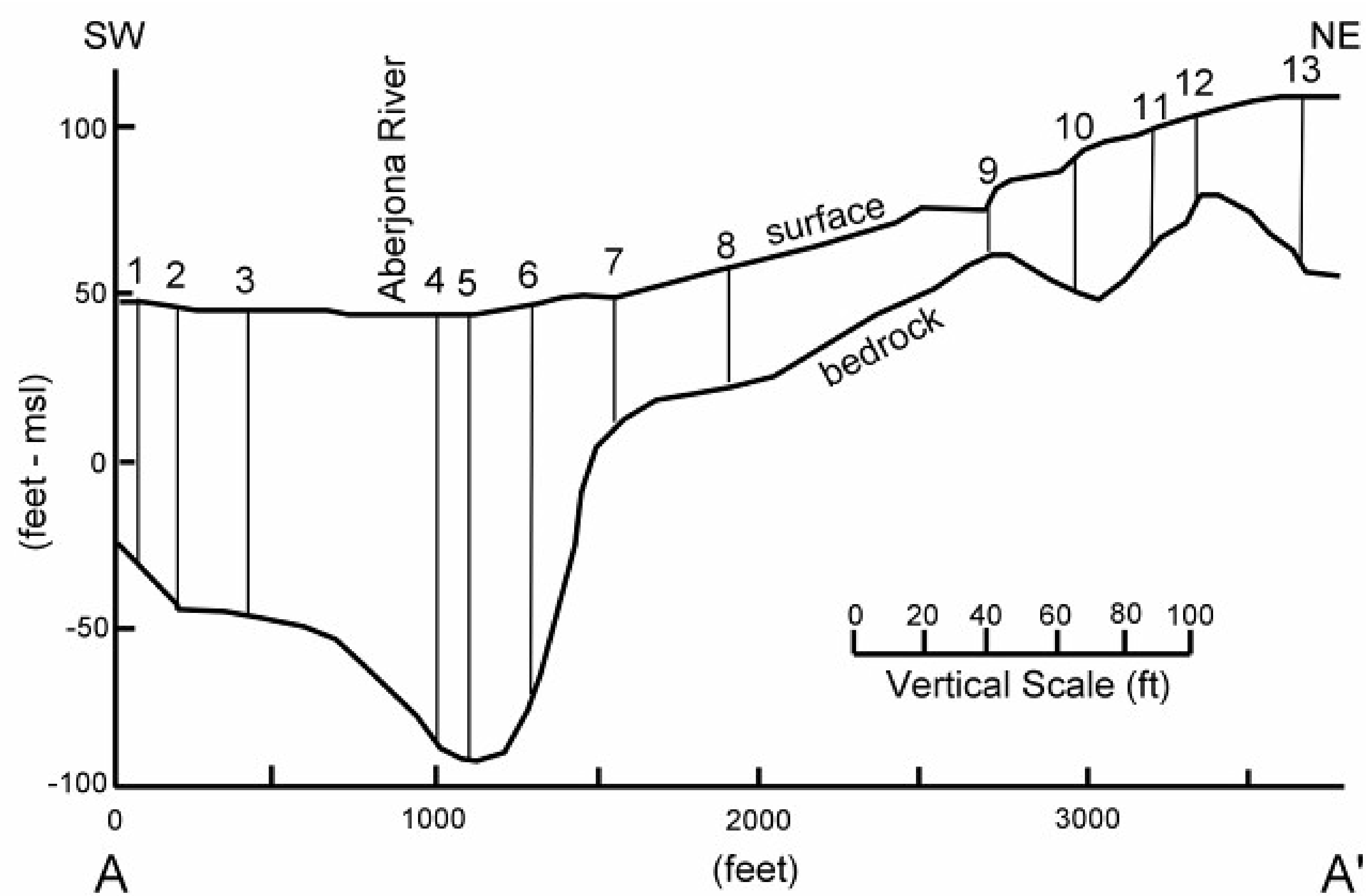

Figure 3. Template for geologic cross-section.

III. The Pump Test

On December 4, 1985, the United States Geological Survey started a pump test on the Aberjona River where it passes through the wetlands that contain wells G and H. Two stream gauges were installed on the site, one where the Aberjona River enters the wetland and the other where it exits the wetland. Streamflows (in gallons per minute, gpm) onto the site and off the site were measured at these two locations. The differences between these two values represents water either added to the stream (positive values) or lost from the stream (negative values). At the start of the test the change in streamflow between the two sites was +761 gpm indicating that water was added to the stream as it flowed through the site. Pumping was initiated at both wells G and H and streamflow measurements were made for approximately one month. During the time of the test mean daily temperatures were above freezing. The data from this test are listed in Table 2.

Table 2. Streamflow change data for Civil Action site

Date	Streamflow change (gpm)
12/05/1985	-144
12/06/1985	-346
12/09/1985	-341
12/13/1985	-126
12/16/1985	-18
12/18/1985	-381
12/23/1985	-476
12/30/1985	-650
01/03/1986	-556

1. Plot the data on Figure 4. Positive values are plotted above the center line and negative values are plotted below the center line. For each date draw a box that shows the streamflow change. The width of the box corresponds to the date of the sample and the height of the box represents the streamflow change. At the top or bottom of the box, whichever is appropriate, write the value for the streamflow change.

2. The defense team for W. R. Grace argued that when the wells were in use water flowed from the Aberjona River into the wells. This was an important part of the case because it raised the possibility that the contaminants in the wells were coming from the river, not the surrounding industrial activities. Based on the results of the pump test is the defense claim reasonable? Explain.

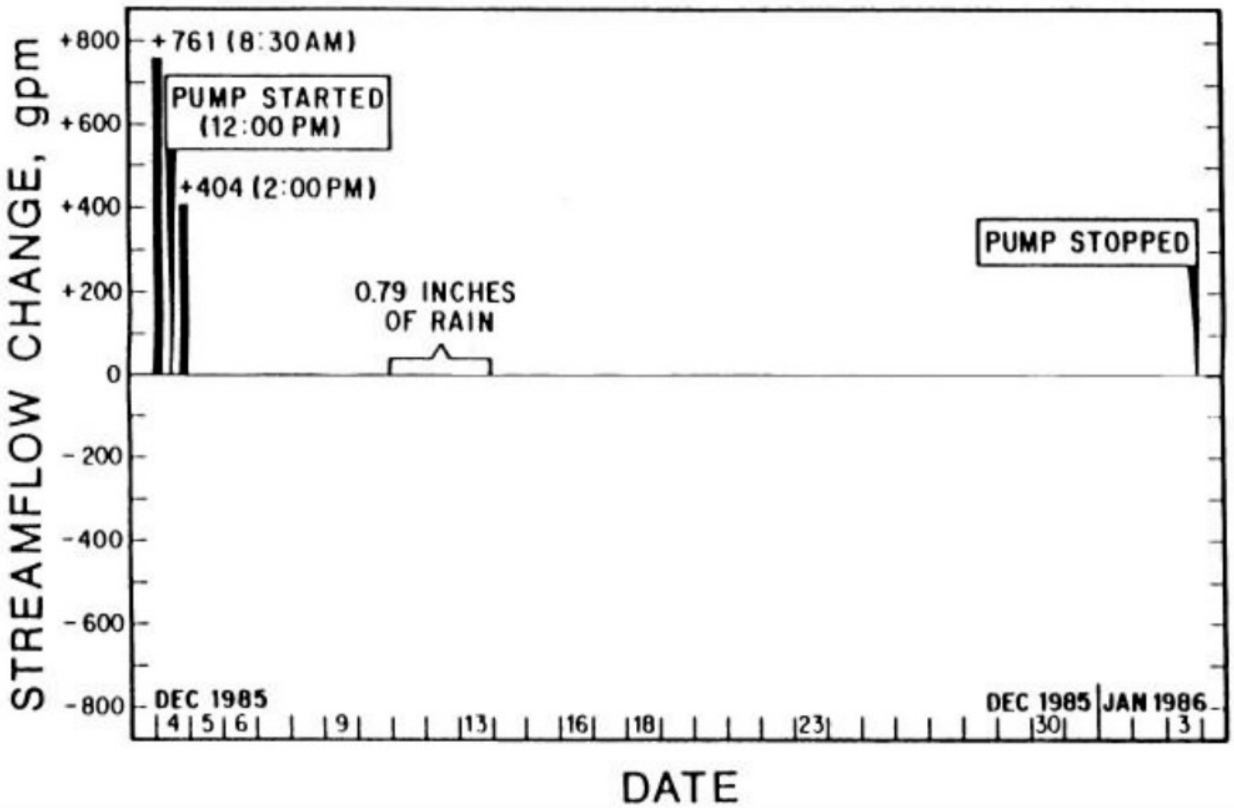

Figure 4. Graph for streamflow change data

IV. Elevation of water table

Prior to the start of the pump test, a number of wells were drilled on the site in order to monitor the elevation of the water table. The location of each monitoring well is shown on Figures 5 and 6 and the elevation of the water table before pumping (Figure 5) and after pumping (Figure 6) is also shown (relative to mean sea level). The water table generally shows a gently sloping topography, one wouldn't expect to find the hills and valleys typical of a topographic contour map, hence this is a much easier task than the earlier exercise involving the contouring of a topographic map.

3. Draw a contour map for the pre-pumping test (December 1985) and the post-pumping test (January 1986) water table. You will achieve the best results if you draw the following contour lines for each map:

   December 1985 (prior to pumping) - 43', 44', 45', 50', 55', 60', 65', 70', 75', 80', 85', 90', and 95'.

   January 1986 (after pumping) - 35', 40', 45, 50', 55', 60', 65', 70', 75', 80', 85', and 90'.

   Be sure to label your contour lines.

4. On each map draw arrows showing the direction of groundwater flow. Groundwater flows downhill (down the slope of the water table) at right angles to the contour lines.

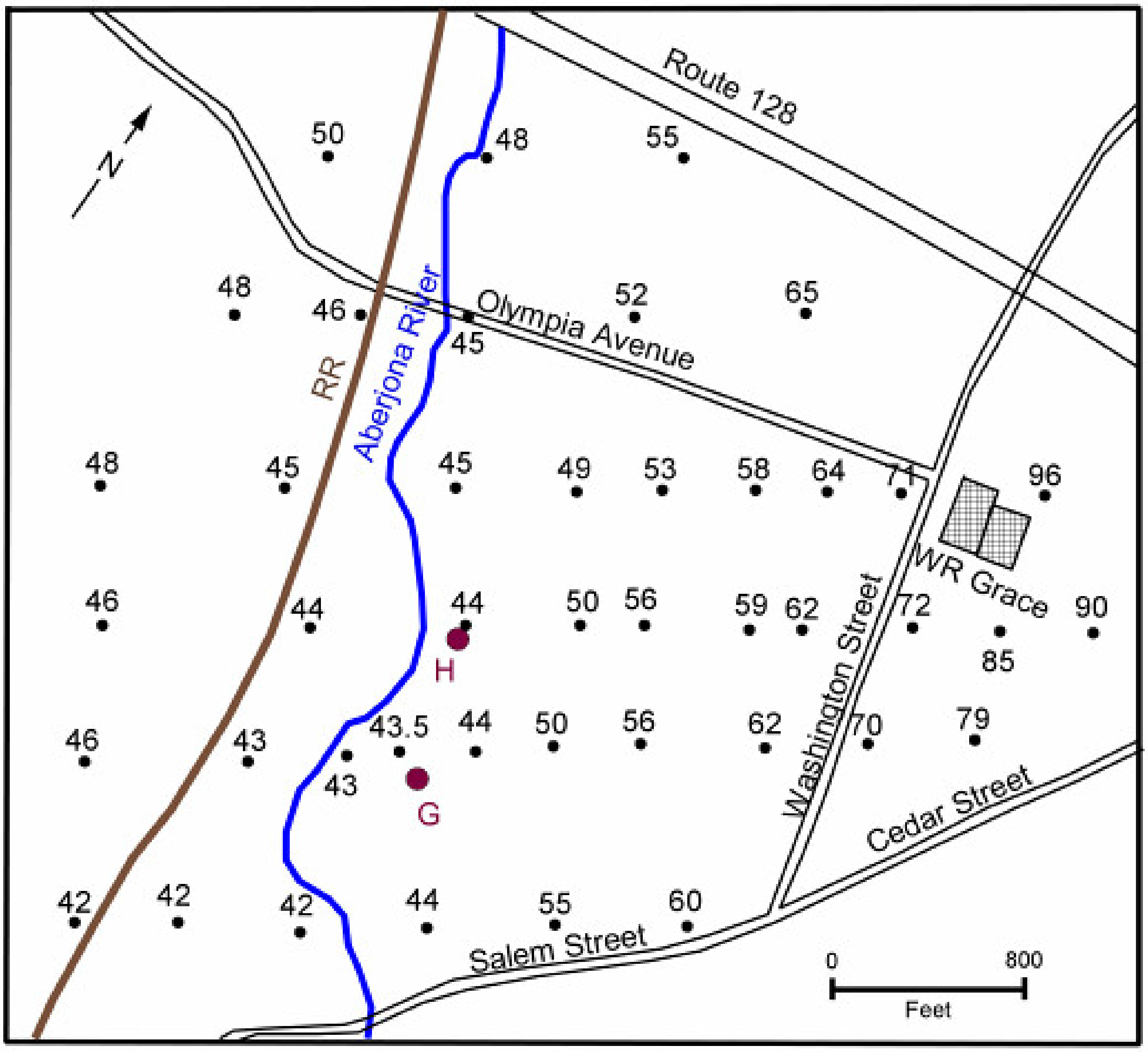

Figure 5. Elevation of the water table in December 1985, prior to the pump test.

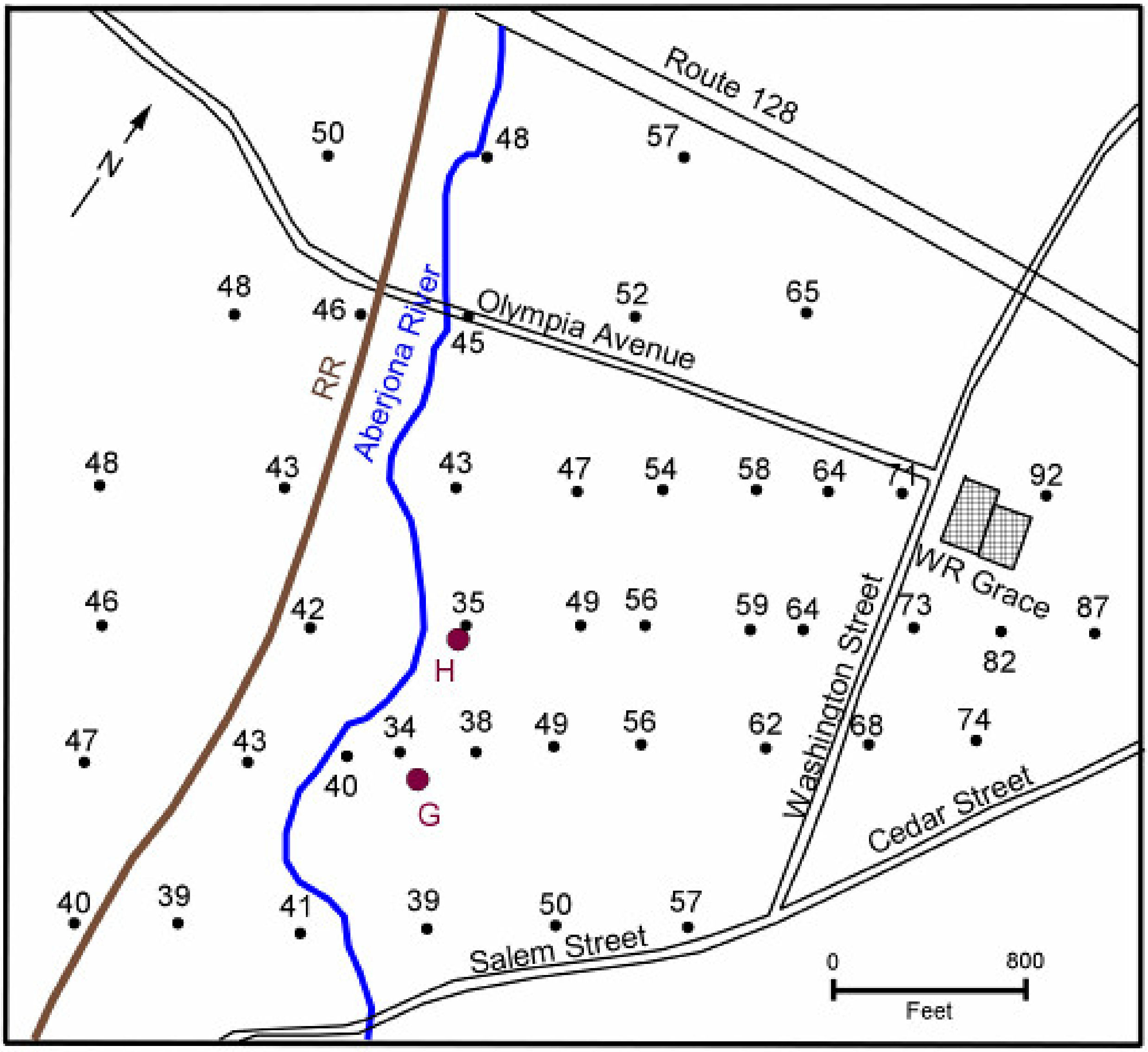

Figure 6. Elevation of the water table in January 1986, after the completion of the pump test.

5. From these two maps what can you conclude about the flow of groundwater on the site before and after the pump tests? Would water from the Abjerona River flow into the wells during the time they were active? Explain.

V. Darcy's Law and groundwater flow

Darcy's law relates the velocity of groundwater flow to the slope of the water table (which constitutes the hydraulic head) and the hydraulic conductivity (which is related to permeability). The more permeable a material the greater is the hydraulic conductivity and the greater is the velocity of groundwater flow. The slope of the groundwater table is equal to the change in elevation between two reference points on the water table divided by the horizontal distance between these reference points (Figure 7). The zone of aeration and the zone of saturation are also illustrated on Figure 7. If we extracted groundwater from the zone of saturation, this zone is then called an *aquifer*.

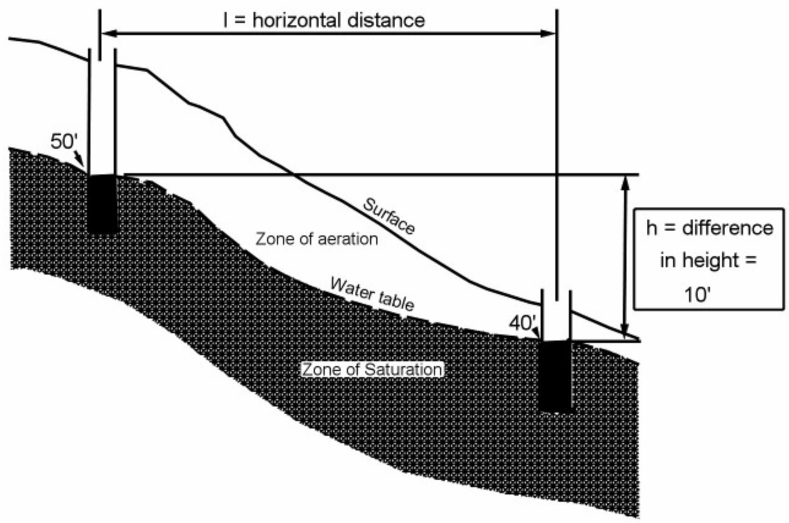

Figure 7. Illustration of the relationship between the change in elevation of the water table and horizontal distance. The change in elevation of the water table divided by the horizontal distance gives the slope of the water table. This is sometimes referred to as the *hydraulic head* or *hydraulic gradient*.

Darcy's Law can be written -

Velocity of groundwater flow = hydraulic conductivity X hydraulic gradient

As an example, suppose the change in vertical elevation of the water table, over a distance of 1000 feet, is 10 feet. The aquifer consists of coarse sand that has a hydraulic conductivity of 0.02 ft/s. Calculate the velocity of groundwater flow.

V = (0.002 ft/s) x (10 ft/1000 ft) = 0.00004 ft/s x 3600 s = 0.07 ft/hr x 24 hr = 1.7 ft/day x 365 d = 620 ft/y

This is a high groundwater flow velocity.

6. Using Figure 6, which shows the topography of the water table when the wells are active, measure the horizontal distance from the WR Grace site to Well H.

7. Determine the change in elevation of the water table between the WR Grace site and Well H.

8. Calculate the hydraulic head for groundwater flow from the WR Grace site to Well H.

9. With reference to the geologic cross-section, much of the site consists of coarse sand. An average hydraulic conductivity for coarse sand is 0.0002 ft/s. Calculate the groundwater velocity given this hydraulic conductivity. Give your answer in ft/y.

10. Referring to the geologic cross section (Figure 3) what type of material lies under the WR Grace site?

11. An average hydraulic conductivity for till is 0.0000000003 ft/s. Calculate the groundwater velocity given this hydraulic conductivity. Give your answer in ft/y.

12. Well H was opened in 1966 and closed in 1979. If TCEs were dumped on the WR Grace site in 1966, would they have reached well H by the time it closed in 1979? Explain and justify your answer.