Name: ______________________ **Course/Section:** ______________ **Date:** __________

The rate of groundwater flow depends on properties of the rock and on the pressure gradient that drives the flow.

A **EXPERIMENT 1** Analyze what happened when water was dropped on the rock specimens **Fig. A12.1.1**.

1. In general, what effect do you think layers of fine-grained sedimentary rock like mudstone or shale are likely to have on the speed of groundwater movement or the volume of groundwater that can be stored? Why?

2. In general, what effect do you think layers of sandstone are likely to have on the speed of groundwater movement or the volume of groundwater that can be stored? Why?

EXPERIMENT 1: What happens when a drop of water is applied to shale and sandstone?
Procedure: A drop of water was placed on four different rocks. This is what happened after 5 seconds.

Figure A12.1.1

B **EXPERIMENT 2** Obtain two pieces of 1.25 cm (½ in.) inside-diameter clear-plastic flexible tubing, each about 1 m long, from the plumbing section of a hardware store. In one tube, put enough sand to fill perhaps 10 cm of the tube's length, and in the other tube place a similar amount of finer-grained dry soil that is at least half clay-sized particles. Put a ball of cotton loosely on each side of the sediment to hold the sediment in place (**Fig. A12.1.2A**). Hold each tube so that it is in the shape of a U with the sediment at the bottom, and gently add water to both sides until the water reaches about a third of the way up each side (**Fig. A12.1.2B**).

1. Starting with the tube that contains sand, lift one side of the tube ~10–20 cm above the other so that water from the high side flows into the lower side (**Fig. A12.1.2C**) and measure the time needed for the water levels in the two sides to return to the same elevation. __________ sec

2. Do the same experiment with the tube that contains the finer sediment. __________ sec

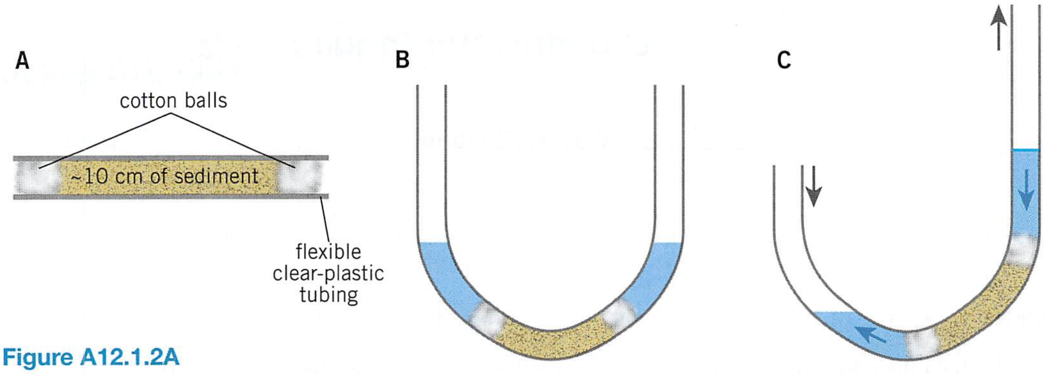


Figure A12.1.2A

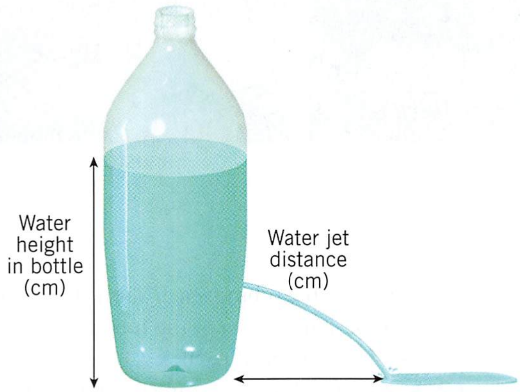
3. How does the rate at which water flows through sand differ, if at all, from the rate at which water flows through the finer-grained sediment? Why?

C **EXPERIMENT 3** Analyze the procedures in Fig. A12.1.3 and then use a pencil to plot the data on the graph. When you are confident in the accuracy of your plot, use a pen to make your data points more visible. How is the distance of the water jet related to the height of water in the bottle? Why?

EXPERIMENT 3: What happens when water drains from a hole in the side of a bottle?

Procedure:

1. A small hole was punched in the side of a 2-liter plastic bottle, 6 cm above its bottom.
2. Tape was placed over the hole.
3. The bottle was filled with water to a height of 22 cm.
4. The tape was removed, and a jet of water shot out of the hole. The distance that the water jet shot from the bottle to the table top was recorded for specific water heights in the bottle.
5. Plot the data on the graph paper to see if there is a trend.



Water height in bottle (cm)	Water jet distance (cm)
22.0	10.0
18.5	9.5
16.5	9.0
14.0	8.0
13.0	7.5
11.0	6.0
10.0	5.5
9.0	4.5
8.0	3.5
7.5	2.5
7.0	2.0
6.0 (hole height)	0

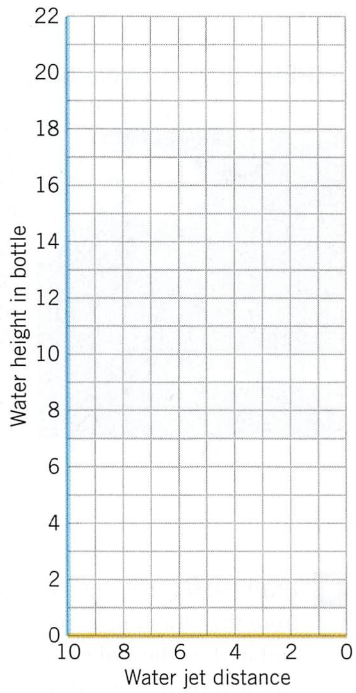


Figure A12.1.3

D **REFLECT & DISCUSS** In the initial moments of Experiment 3 after the hole was first opened, the jet of water seemed to have a lot of energy as it shot through the air. Imagine changing the experiment so that instead of shooting into the air, the water entered a clear plastic tube that curved back up toward the top of the bottle. About how high do you think the water would rise in the tube as compared with the water level in the bottle? (*Hint:* Think about the water levels in the two sides of the plastic tube in Experiment 2.)

Where Is the Nasty Stuff Going? Activity 12.2

Name: ____________________ **Course/Section:** ____________________ **Date:** ____________

Figure A12.2.1 is a map showing a grid of well-located sites where the elevation of the water table has been measured. The water-table elevations are listed (in ft.) next to the piezometer locations. The elevations were measured relative to a local permanent benchmark whose location and elevation were determined by a professional surveyor. The aquifer is a permeable sandstone with no confining layer in the map area.

A Using a pencil, make a topographic contour map of the water table at a contour interval of 1 foot. When you think your contours are accurate, label and trace over your contours with a pen. Parts of the 4-foot and 8-foot contours are done for you.

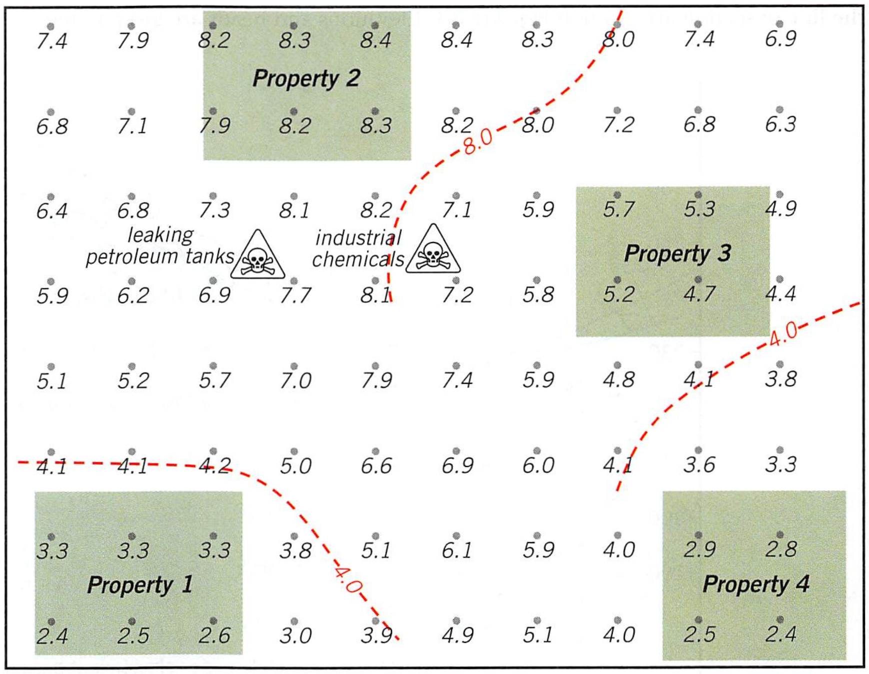


Figure A12.2.1

B Four properties are for sale in the map area, and you need to choose one for new athletic fields that will be used by thousands of children over many years. All properties have private wells, so well water would be used to irrigate the playing fields and for food services at the facility.

Unfortunately, there are two sources of groundwater pollution in the area: one that has leaking underground petroleum tanks and another where industrial chemicals were improperly stored and disposed. Pollutants from these sites are toxic and can be expected to move with the groundwater. The location of the pollution sources are indicated by symbols on the map. Groundwater along the water table flows perpendicular to the water-table contours from high to low elevation (**Fig. 12.3**). Use the water-table contours as a guide, and draw a flow line from each of the pollution sources that extends to the edge of the map.

C Using the flow lines you just constructed, choose the property where children will be least likely to be endangered by the toxic chemicals.

Activity 12.3 Using Data to Map the Flow of Groundwater

Name: ______________________ **Course/Section:** ______________________ **Date:** ______________

We want to understand how groundwater flows below the water table as viewed in a vertical plane through an unconfined aquifer. At several locations along the line of section, a set of piezometers was installed that extended to different depths. This set is called a nest of piezometers. The elevation of the open (screened) base of each of the piezometers was determined—the elevation head. The height to which the water rose in each piezometer was also measured—the pressure head. The total head can be determined by adding the elevation head and the pressure head.

The profile of the ground surface, the water table (marked by the triangles), and the total head at dozens of points along the line of section are given in **Fig. A12.3.1**. Elevations and heads are given in feet.

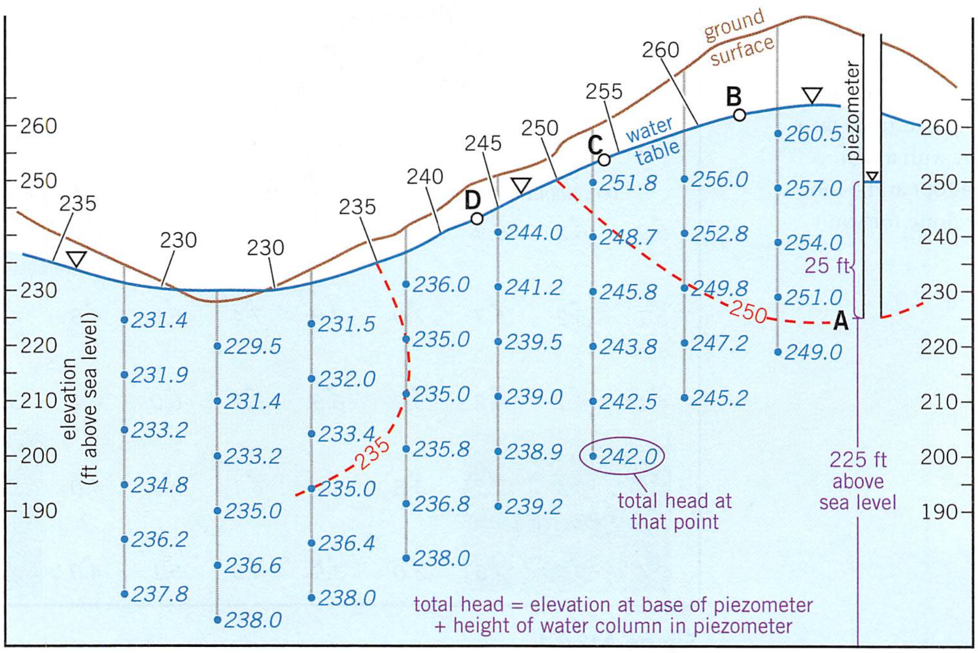


Figure A12.3.1

A Examine the piezometer on the right side of the section at whose base is point **A**.

1. What is the *pressure head* for point **A**? Refer to **Fig. 12.4** if you need help. ______________________ ft.
2. What is the *elevation head* for point **A**? ______________________ ft.
3. What is the *total head* for point **A**? ______________________ ft.

B Using the total head for point **A** and all of the other total head values noted on the section, construct contours of equal total head at a contour interval of 5 ft., similar to the contours shown as dashed red curves in **Fig. 12.5**. It is best to start contouring in pencil and then go over your contours in pen after you are confident about your work. Parts of the 235 ft. and 250 ft. contours are provided in **Fig. A12.3.1** to help you get started.

C The contours you just constructed are part of 3-dimensional equal total-head (or *potentiometric*) surfaces. Groundwater flows perpendicular to these potentiometric surfaces from high total head to low total head (**Fig. 12.3**). Draw a flow line from each of the labeled points—**A**, **B**, **C**, and **D**—and continue the flow lines until they end at the water-table surface or reach the edge of the cross-section.

Name: ______________________ Course/Section: ______________________ Date: ______________

A Analyze **Figs. 12.8** and **12.9**.

1. In the area photographed in **Fig. 12.8**, there is little or no soil developed on the limestone bedrock surface, yet abundant plants are growing along linear features in the bedrock. What does this indicate about how water travels through bedrock under this part of Oklahoma?

2. If you had to drill a water well in the area pictured in **Fig. 12.8**, where would you drill (relative to the pattern of plant growth) to find a good supply of water? Why?

3. **REFLECT & DISCUSS** How is **Fig. 12.9** related to **Fig. 12.8**?

B It is common for buildings to sink into newly formed sinkholes as they develop in karst regions. Consider the three new home construction sites (labeled **A**, **B**, and **C**) in **Fig. 12.6**, relative to sinkhole hazards.

1. Which new home construction site (**A**, **B**, or **C**) might be the *most* hazardous? Why?

2. Which new home construction site (**A**, **B**, or **C**) might be the *least* hazardous? Why?

3. **REFLECT & DISCUSS** Imagine that you are planning to buy a vacant lot on which to build a new home in the region portrayed in **Fig. 12.6**. What could you do to find out if there is a sinkhole hazard in the location where you are thinking of building your home?

C Study the orthophoto map of part of the Park City (Kentucky) 7.5-minute quadrangle in **Fig. 12.7**. The center of this map area is located at 37.073°N, 86.090°W. This entire area is underlain by limestone, although the limestone is overlain by sandstone in the small northern part of this image (Bald Knob, Opossum Hollow) that is covered by dense dark green trees.

1. How can you tell in the area on this orthoimage where limestone crops out at Earth's surface?

2. Recall that on a topographic map, a depression is shown by a contour line with hachures (tic marks) that form a closed loop. Describe the pattern of depressions on the topo map of Park City (**Fig. A12.4.1**). Why do some of the depressions contain ponds, but others do not?

3. **REFLECT & DISCUSS** Notice that there are many naturally formed circular ponds in the northwest half of the image. (The triangular ponds are surface water impounded behind dams constructed by people.) How could you use the elevations of the surfaces of the ponds to determine how groundwater flows through this region?

D Refer to **Fig. A12.4.1**, which is a topographic map of the northernmost ~75% of the map area in **Fig. 12.7**.

1. Compare the map and orthoimage, and then use a pencil to trace on **Fig. A12.4.1** the contact that separates limestone with karst topography from forested, more resistant sandstone. Color the sandstone bedrock with a colored pencil on **Fig. A12.4.1**.

2. Gardner Creek is a *disappearing stream.* On **Fig. A12.4.1**, place arrows along Gardner Creek to show its direction of flow, and then circle the location where it disappears underground. Circle the disappearing end of two other disappearing streams in the southeast quarter of the map.

3. Find and label a solution valley anywhere on **Fig. A12.4.1**.

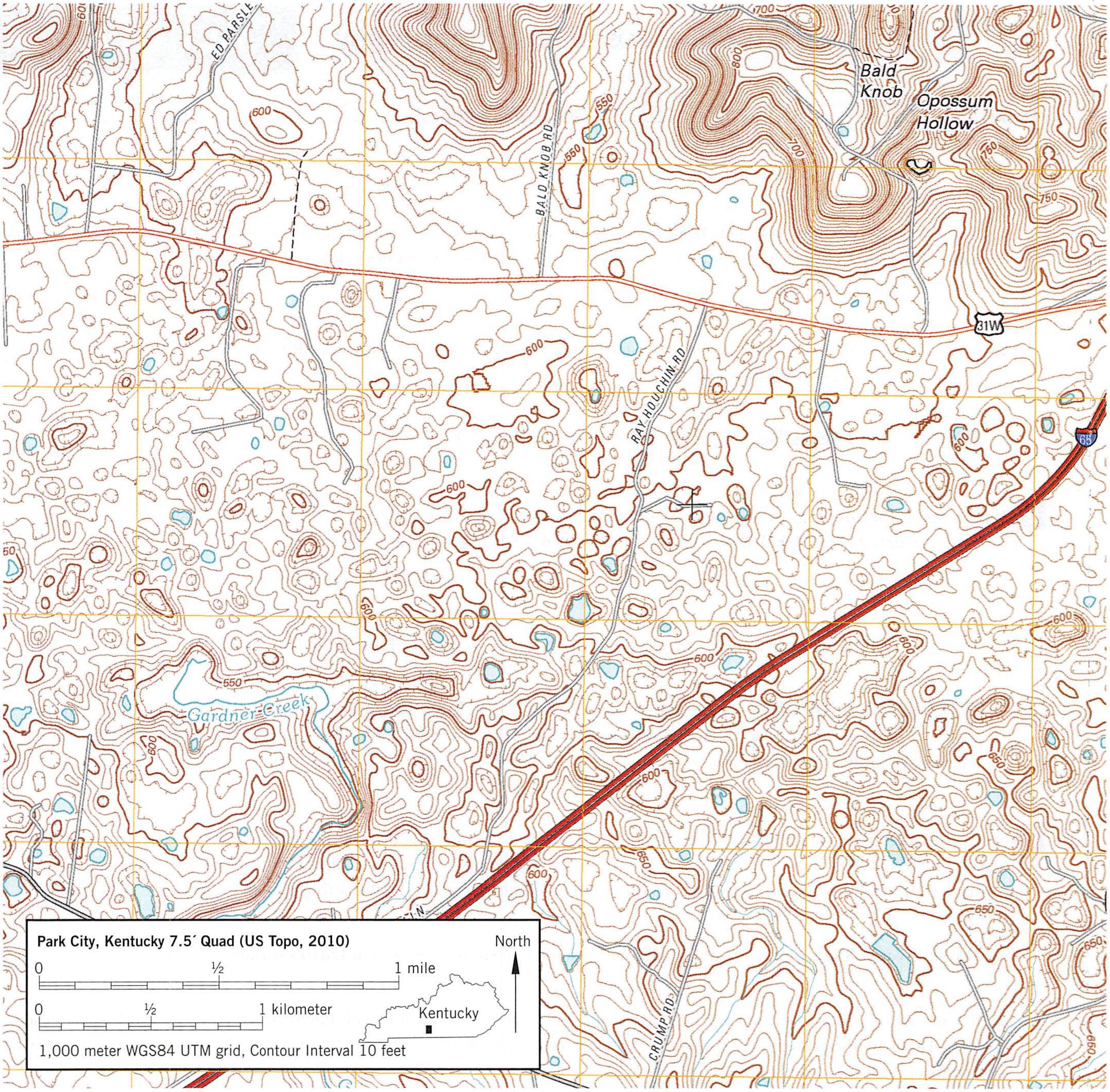


Figure A12.4.1

4. **REFLECT & DISCUSS** Notice that a pond has been constructed on the sandstone bedrock on top of Bald Knob and filled with water from a well. If the well is located on the edge of the pond, how deep below that surface location was the well drilled just to reach the water table? Show your work.

Name: ______________ **Course/Section:** ______________ **Date:** ______________

Refer to **Figs. 12.10** (Sulphur Springs Quadrangle) and **A12.5.1**.

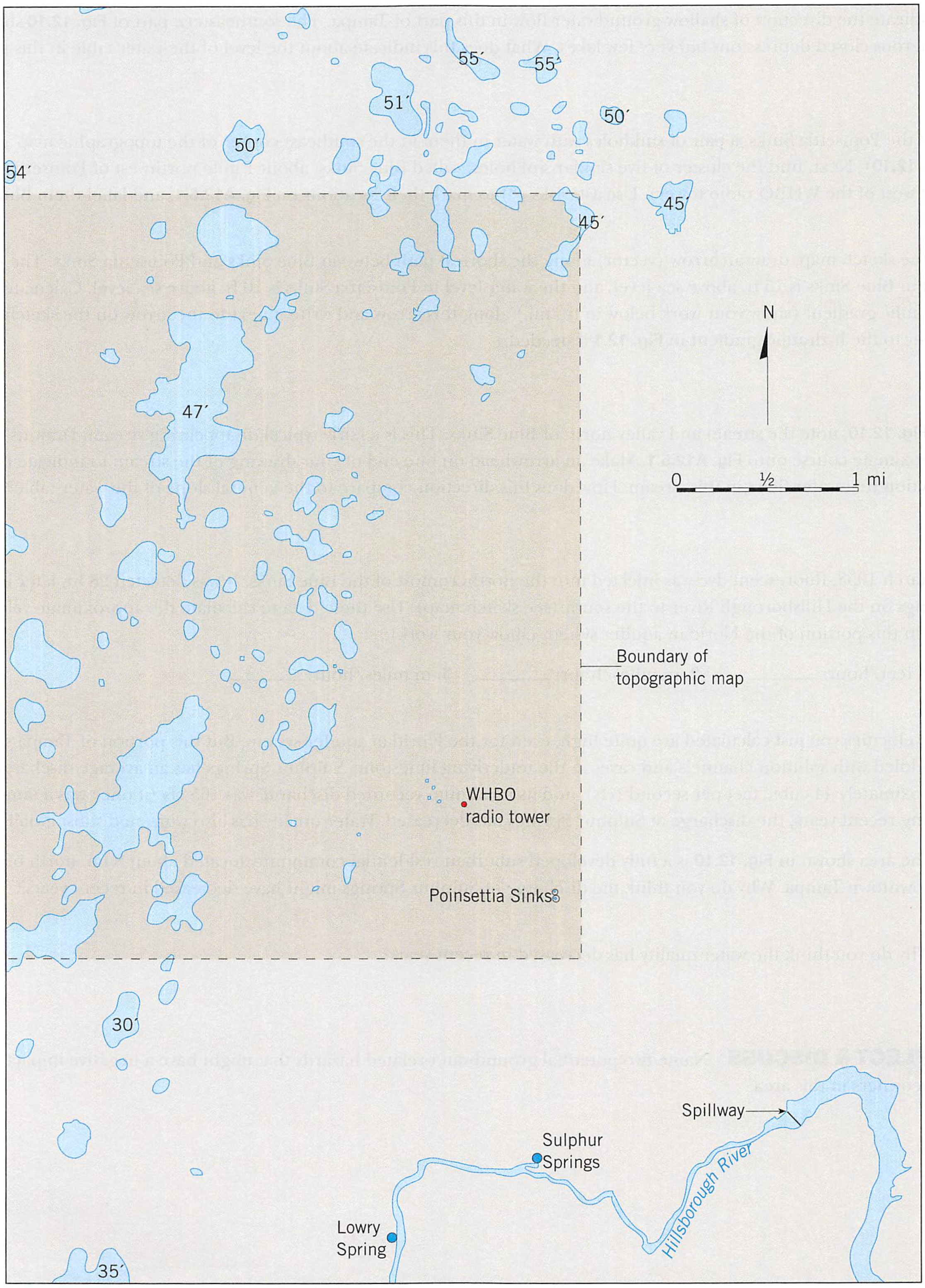


Figure A12.5.1

A On **Fig. A12.5.1**, mark the elevations of water levels in the lakes (obtain this information from **Fig. 12.10**). The elevations of Lake Magdalene and some lakes beyond the boundaries of the topographic map are marked already for you.

B Contour the water-table surface (use a 5-foot contour interval) on **Fig. A12.5.1**. Draw only contour lines representing whole fives (40, 45, and so on). Do this in the same manner that you contoured land surfaces in the topographic maps lab.

C The flow of shallow groundwater in **Fig. A12.5.1** is at right angles to the contour lines. The groundwater flows from high elevations of the water table to lower elevations, just like a stream. Draw three or four flow lines with arrows on **Fig. A12.5.1** to indicate the direction of shallow groundwater flow in this part of Tampa. The southeastern part of **Fig. 12.10** shows numerous closed depressions but very few lakes. What does this indicate about the level of the water table in this region?

D Note the Poinsettia Sinks, a pair of sinkholes with water in them in the southeast corner of the topographic map (**Fig. 12.10**). Next, find the cluster of five similar sinkholes, called Blue Sinks, about 1 mile northwest of Poinsettia Sinks (just west of the WHBO radio tower). Use asterisks (*) to mark their locations on **Fig. A12.5.1**, and label them Blue Sinks.

E On the sketch map, draw an arrow (vector) along the shortest path between Blue Sinks and Poinsettia Sinks. The water level in Blue Sinks is 15 ft. above sea level, and the water level in Poinsettia Sinks is 10 ft. above sea level. Calculate the hydraulic gradient (show your work below in ft./mi.) along this arrow and write it next to the arrow on the sketch map. (Refer to the hydraulic gradient in **Fig. 12.1** if needed.)

F On **Fig. 12.10**, note the stream and valley north of Blue Sinks. This is a fairly typical disappearing stream. Draw its approximate course onto **Fig. A12.5.1**. Make an arrowhead on one end of your drawing of the stream to indicate the direction that water flows in this stream. How does this direction compare to the general slope of the water table?

G In March 1958, fluorescent dye was injected into the northernmost of the Blue Sinks. It was detected 28 hr. later in Sulphur Springs on the Hillsborough River to the south (see sketch map). Use these data to calculate the approximate velocity of flow in this portion of the Floridan aquifer system (show your work):

1. in feet/hour: ________ **2.** in miles/hour: ________ **3.** in miles/hour: ________

H The velocities you just calculated are quite high, even for the Floridan aquifer system. But this portion of Tampa seems to be riddled with solution channels and caves in the underlying limestone. Sulphur Springs has an average discharge of approximately 44 cubic feet per second (cfs), and its maximum recorded discharge was 165 cfs (it once was a famous spa). During recent years, the discharge at Sulphur Springs has decreased. Water quality has also worsened substantially.

1. The area shown in **Fig. 12.10** is a fully developed suburban residential community located about 8 mi. north of downtown Tampa. Why do you think the discharge of Sulphur Springs might have decreased in recent years?

2. Why do you think the water quality has decreased in recent years?

I **REFLECT & DISCUSS** Name two potential groundwater-related hazards that might have a negative impact on homeowners in this area.

Land Subsidence from Groundwater Withdrawal

Activity 12.6

Name: ______________________ **Course/Section:** ______________ **Date:** __________

A Santa Clara Valley, California.

1. Based on **Fig. 12.11**, where are the areas of greatest subsidence in the Santa Clara Valley?

2. What was the total subsidence at San Jose (**Fig. A12.6.1**) from 1934 to 1967 in feet?

Year	Total Subsidence (feet) from 1912 level
1912	0.0
1920	0.3
1934	4.6
1935	5.0
1936	5.0
1937	5.2
1940	5.5
1948	5.8
1955	8.0
1960	9.0
1963	11.0
1967	12.7

Figure A12.6.1 Subsidence at benchmark P7 in San Jose, California.

3. What was the average annual rate of subsidence for the period of 1934 to 1967 in feet/year?

4. Analyze **Fig. 12.11**. At what places in the Santa Clara Valley would subsidence cause the most problems? Explain your reasoning.

5. Would you expect much subsidence to occur in the darker shaded (tan) areas of **Fig. 12.11**? Explain.

6. By 1960, the total subsidence at San Jose had reached 9.0 ft. (**Fig. A12.6.1**). What was the average annual rate of subsidence (in feet/year) for the seven-year period from 1960 through 1967? Show your work.

7. Refer to **Fig. A12.6.2**, which shows the variation in several factors relevant to the subsidence of the Santa Clara Valley since ~1915.

   (a) Using **Fig. A12.6.2A**, about how much has the elevation of benchmark P7 changed since 1970? _____ ft.

   (b) The water table in San Jose was just about at the ground surface in 1915 but steadily increased to a maximum in the mid-1960s. Using **Fig. A12.6.2B**, estimate the maximum water-table depth below the ground surface. _____ ft.

   (c) Since the mid-1960s, the water-table depth has steadily decreased. What effect has the rising water table had on the elevation of the ground surface in San Jose?

   (d) Think about the trend in precipitation since ~1916 shown in **Fig. A12.6.2C**. Precipitation and snowmelt recharge the aquifer. What effect might the observed trend in precipitation have had on the water-table depth?

   (e) Groundwater has been pumped in support of agriculture throughout the 20th century. Examine **Fig. A12.6.2D** and describe any trend that you can see in the rate of pumping between 1915 and the mid-1960s. What effect did that have on the water-table depth?

(f) Changes in water policy in the mid-1960s resulted in projects to artificially recharge the aquifer, using water brought to the area from the Sierra Nevada Mountains by aqueducts. Examine **Fig. A12.6.2D** to determine how the rate of pumping changed since the mid-1960s. What effect did artificial recharge and changes in pumping seem to have had in the Santa Clara Valley?

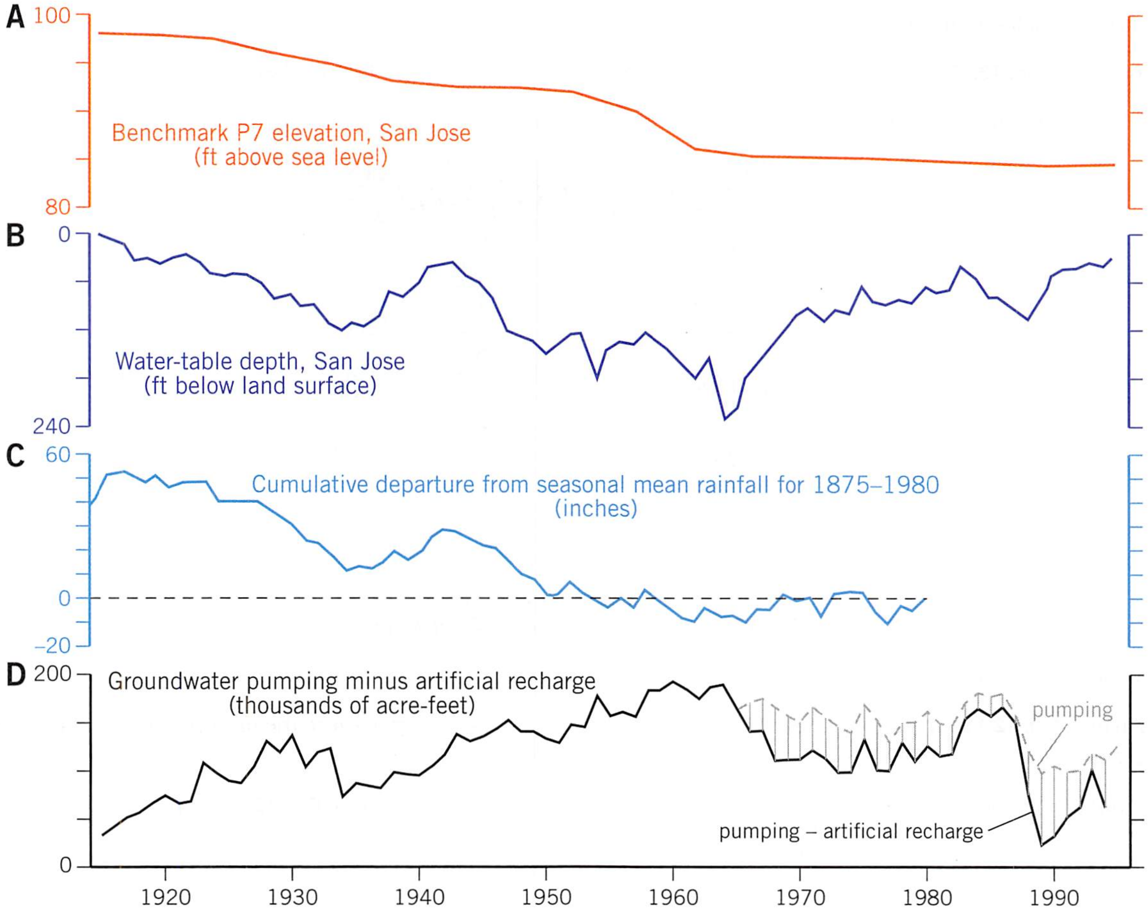


Figure A12.6.2 Variation in several factors affecting groundwater and subsidence in the Santa Clara Valley, California.

B REFLECT & DISCUSS The Santa Clara Valley and surrounding areas have changed from being an agricultural area into a global center for digital technology that is commonly known as Silicon Valley. How might water usage change in an area like this as it transitions from agricultural to urban?