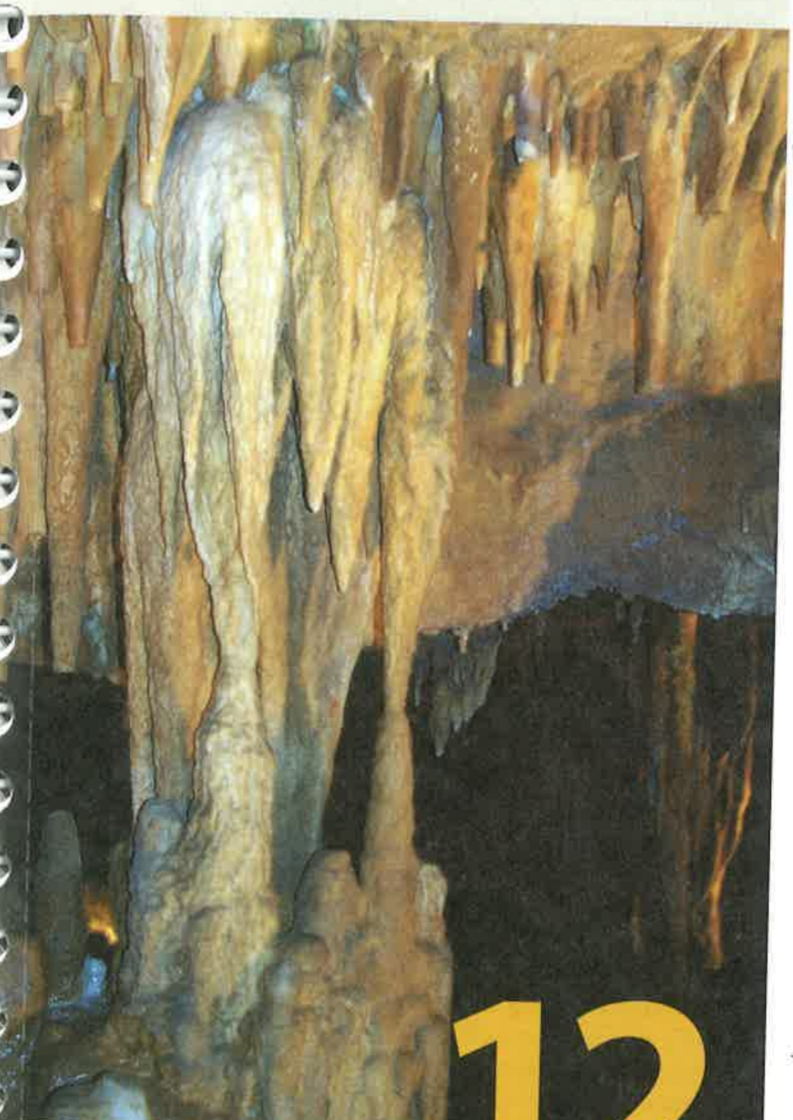

12

LABORATORY

Groundwater Processes, Resources, and Risks

CONTRIBUTING AUTHORS

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Stalactites hang from the ceiling of Luray Caverns, Virginia. Some merge with stalagmites forming on the cave floor.

BIG IDEAS

Groundwater is subsurface water, beneath the landscape rather than on its surface. Most bodies of groundwater form when rainwater seeps into the ground under the influence of gravity and fills up (saturates) spaces in cracks and between grains. Some groundwater is unconfined and must be pumped from the ground to be used. Confined groundwater is under pressure and will flow on its own if a well is drilled to its location. Karst topography and rapid movement of water can occur when groundwater dissolves caves in soluble rocks, and land subsidence can occur when humans withdraw groundwater faster than it can be replenished.

FOCUS YOUR INQUIRY

THINK About It | How does groundwater behave underground?

THINK About It | What is karst topography and how does water flow beneath it?

THINK About It | What can happen if groundwater is withdrawn faster than it is replenished?

Introduction

Water that seeps into the ground is pulled downward by the force of gravity through spaces in the soil and *bedrock* (rock that is exposed at the land surface or underlies the soil). At first, the water fills just some spaces and air remains in the other spaces. This underground zone with water- and air-filled spaces is called the *zone of aeration* (FIGURE 12.1; also called the *unsaturated zone* or *vadose zone*). Eventually, the water reaches a zone below the zone of aeration, where all spaces are completely saturated with water. This water-logged zone is called the *zone of saturation*, and its upper surface is the **water table** (FIGURE 12.1). Water in the saturated zone is called **groundwater**, which can also be withdrawn from the ground through a **well** (a hole dug or drilled into the ground). Most wells are lined with *casing*, a heavy metal or plastic pipe. The casing is perforated in sections where water is expected to supply the well. Other sections of the casing are left impervious to prevent unwanted rock particles or fluids from entering the well.

ACTIVITY

12.1 Groundwater Inquiry

THINK About It | **How does water behave underground?**

OBJECTIVE Experiment with water to determine its behavior in confined and unconfined spaces and in relation to shale and sandstone.

PROCEDURES

1. **Before you begin,** do not look up definitions and information. Use your current knowledge, and complete the worksheet with your current level of ability. Also, this is **what you will need** to do the activity:

   ____ empty plastic drink bottle (2 liter), water, tape
   ____ nail, drill, or other object that can be used to safely make small holes in a plastic bottle
   ____ Activity 12.1 Worksheet (p. 321) and pencil

2. **Complete the worksheet in a way that makes sense to you.**
3. **After you complete the worksheet,** be prepared to discuss your observations and ideas with others.

ACTIVITY

12.2 Karst Processes and Topography

THINK About It | **What is karst topography and how does water flow beneath it?**

OBJECTIVE Explore and evaluate the topographic features, groundwater movements, and hazards associated with karst topography.

PROCEDURES

1. **Before you begin,** read the Introduction and Caves and Karst below. Also, this is **what you will need:**

   ____ calculator, colored pencils
   ____ Activity 12.2 Worksheet (p. 323) and pencil

2. **Then follow your instructor's directions** for completing the worksheet.

Recall the last time that you consumed a drink from a fast-food restaurant (a paper cup containing ice and liquid that you drink using a plastic straw). The mixture of ice and liquid (no air) at the bottom of the cup was a zone of saturation, and your straw was a well. Each time you sucked on the straw, you withdrew liquid from the drink container just as a homeowner withdraws water from a water well. After you drank some of the drink, the cup contained both a zone of saturation (water and ice in the bottom of the cup) and a zone of aeration (ice and mostly air in the upper part of the cup). The boundary between these two zones was a water table. In order to continue drinking the liquid, you had to be sure that the bottom of your straw was within the zone of saturation, below the water table. Otherwise, sucking on the straw produced only a slurping sound, and you obtained mostly air. Natural water wells work the same way. The wells must be drilled or dug to a point below the water table (within the zone of saturation), so that water can flow or be pumped out of the ground.

Porosity and Permeability

The volume of void space (space filled with water or air) in sediment or bedrock is termed *porosity*. The larger the voids, and the greater their number, the higher is the porosity. If void spaces are interconnected, then fluids (water and air) can migrate through them (from space to space), and the rock or sediment is said to be *permeable*. Sponges and paper towels are household items that are permeable, because liquids easily flow into and through them. Plastic and glass are *impermeable* materials, so they are used to contain fluids.

Aquifers

Permeable bedrock materials make good **aquifers**, or rock strata that conduct water. Some examples are sandstones and limestones. Impermeable bedrock materials prevent the flow of water and are called **confining beds** (or **aquitards**). Some examples are layers of clay, mudstone, shale, or dense igneous and metamorphic rock. But how does groundwater move through aquifers?

Confined aquifers are sandwiched between two confining beds, the groundwater fills them from confining bed to confining bed, so there is no water table. The weight of the groundwater (being pulled downward by gravity) in a confined space creates water pressure, like the pressure inside of a garden hose or kitchen sink faucet. If a confined aquifer is penetrated by a well, then water flows naturally from the well. When aquifers are not confined (i.e., they are **unconfined aquifers**), the groundwater establishes a water table just beneath the surface of the land (**FIGURE 12.1**). For this reason, unconfined aquifers are also called *water table aquifers*. If an unconfined aquifer is penetrated by a well, then the water must be pumped from the ground using a submersible pump lowered into the well on a cable. An electric line runs from the top of the well to the submersible pump, and a water hose runs from the submersible pump to the top of the well.

Hydraulic Gradient

Groundwater in an unconfined (water table) aquifer is pulled down by gravity and spreads out through the ground until it forms the water table surface (such as the one in the drink cup full of crushed ice described previously). You can see the water table where it leaves the ground and becomes the level surface of a lake (**FIGURE 12.1A**) or springs flowing from a hillside. However, because groundwater is

Water Table Contours and Flow Lines

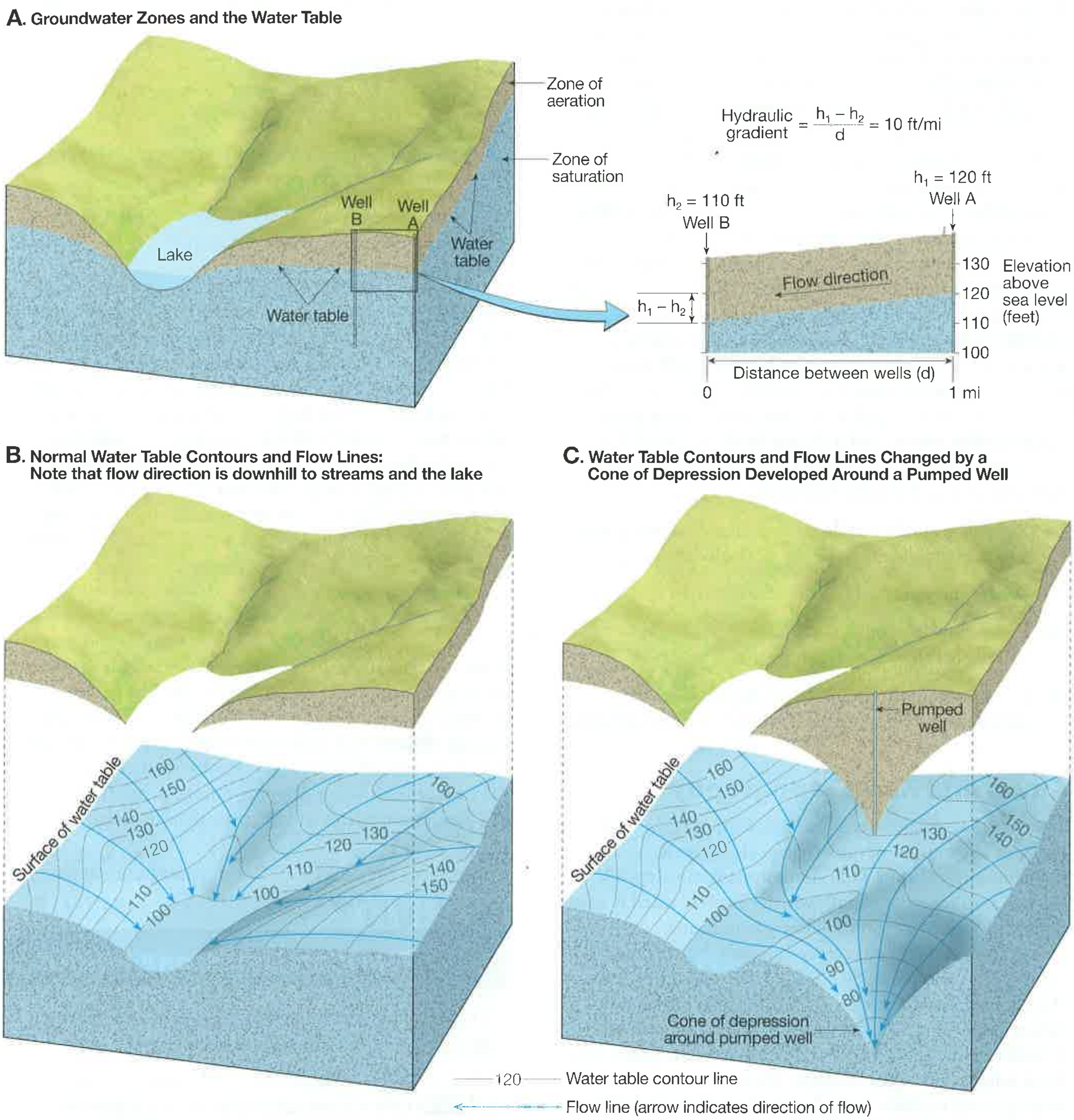


FIGURE 12.1 Water movement through an unconfined aquifer. A. Rainwater seeps into the *zone of aeration* (unsaturated zone, vadose zone), where void spaces are filled with air and water. Below it is the *zone of saturation,* where all void spaces are filled with water. Its upper surface is the water table. Water in the saturated zone is called groundwater, which always flows down the hydraulic gradient in unconfined aquifers. B. A water table surface is rarely level. Contour lines (contours) are used to map its topography and identify flow lines—paths traveled by droplets of water from the points where they enter the water table to the points where they enter a lake or stream. Flow lines with arrows run perpendicular to contour lines, converge or diverge, but never cross. C. A pumped well is being used to withdraw water faster than it can be replenished, causing development of a cone of depression in the water table and a change in the groundwater flow lines.

continuously being replenished (recharged) upslope, and it takes time for the water to flow through the ground, the water table is normally not level. It is normally higher uphill, where water flows into the ground, and lower downhill, where water seeps out of the ground at a lake or springs. The slope of the water table surface is called the **hydraulic gradient** (FIGURE 12.1A)—the difference in elevation between two points on the water table (observed in wells or surfaces of lakes and ponds) divided by the distance between those points.

Mapping Water Table Topography

To better understand the topography of the water table in a region, geologists measure its elevation wherever they can find it in wells or where it forms the surfaces of lakes and streams. The elevation data is then contoured to map the **water table contour lines** (FIGURE 12.1B). Since water always flows down the shortest and steepest path it can find (path of highest hydraulic gradient), a drop of water on the water table surface will flow perpendicular to the slope of the water table contour lines. Geologists use **flow lines with arrows** to show the paths that water droplets will travel from the point where they enter the water table to the point where they reach a lake, stream, or level water table surface. Notice how flow lines have been plotted on FIGURES 12.1B and 12.1C. In FIGURE 12.1C, notice how water is being withdrawn (pumped) from a well in an unconfined aquifer faster than it can be replenished. This has caused a cone-shaped depression in the water table (**cone of depression**) and a change in the regional flow of the groundwater. Thus, water table contour maps are useful for determining the following:

- Paths of groundwater flow (flow lines on a map), along which hydraulic gradients are normally measured
- Where the water comes from for a particular well
- Paths (flow lines) that contaminants in groundwater will likely follow from their source
- Changes to groundwater flow lines and hydraulic gradients caused by cones of depression at pumped wells

Caves and Karst Topography

The term **karst** describes a distinctive topography that indicates dissolution of underlying soluble rock, generally limestone (FIGURE 12.2). Limestone is mostly made of calcite (a carbonate mineral), which dissolves when it reacts with acidic rainwater and shallow groundwater.

Rainwater may contain several acids, but the most common is carbonic acid (H_2CO_3). It forms when water (H_2O) and carbon dioxide (CO_2) combine in the atmosphere ($H_2O + CO_2 = H_2CO_3$). All natural rainwater is mildly acidic (pH of 5–6) and soaks into the ground to form mildly acidic groundwater. There, bacteria and other underground organisms produce carbon dioxide (CO_2) as a waste product of their respiration (metabolic process whereby they convert food and oxygen into energy, plus water and carbon dioxide waste). This carbon dioxide makes the groundwater even more acidic, so it easily dissolves the calcite making up the limestone by this reaction:

$$\underset{\text{Calcite}}{CaCO_3} + \underset{\text{Carbonic acid}}{H_2CO_3} = \underset{\text{Calcium ions dissolved in groundwater}}{Ca^{+2}} + \underset{\text{Bicarbonate ions dissolved in groundwater}}{2HCO_3^{-1}}$$

A typical karst topography has these features, which are illustrated in FIGURE 12.2 and visible on the US Topo orthoimage of the Park City, Kentucky Quadrangle in FIGURE 12.3.

- (**Sinkholes**)—surface depressions formed by the collapse of caves or other large underground void spaces.
- (**Solution valleys**)—valley-like depressions formed by a linear series of sinkholes or collapse of the roof of a linear cave.
- (**Springs**)—places where water flows naturally from the ground (from spaces in the bedrock).
- (**Disappearing streams**)—streams that terminate abruptly by seeping into the ground.

Much of the drainage in karst areas occurs underground rather than by surface runoff. Rainwater seeps into the ground along fractures in the bedrock (FIGURE 12.4), whereupon the acidic water dissolves the limestone around it. The cracks widen into narrow **caves** (underground cavities large enough for a person to enter), which may eventually widen into huge cave galleries. Sinkholes develop where the ceilings of these galleries collapse, and lakes or ponds form wherever water fills the sinkholes. The systems of fractures and caves that typically develop in limestones are what make limestones good aquifers.

Eventually, the acidic water that was *dissolving* limestone becomes so enriched in calcium and bicarbonate that it turns alkaline (the opposite of acid) and may actually begin *precipitating* calcite. Caves in karst areas often have *stalactites* (FIGURE 12.5), icicle-like masses of chemical limestone made of calcite that hang from cave ceilings (FIGURE 12.5 and FIGURE 6.8). They form because calcite precipitates from water droplets as they drip from the cave ceiling. Water dripping onto the cave floor also can precipitate calcite and form more stout *stalagmites.*

ACTIVITY

12.3 Floridan Limestone Aquifer

THINK About It | **What is karst topography and how does water flow beneath it?**

OBJECTIVE Construct a water table contour map and determine the rate and direction of groundwater movement.

PROCEDURES

1. **Before you begin**, read the Introduction and Caves and Karst (above, if you have not already done so) and the Floridan Aquifer (below). Also, this is **what you will need:**

   ___ calculator
   ___ Activity 12.3 Worksheet (p. 325) and pencil

2. **Then follow your instructor's directions** for completing the worksheet.

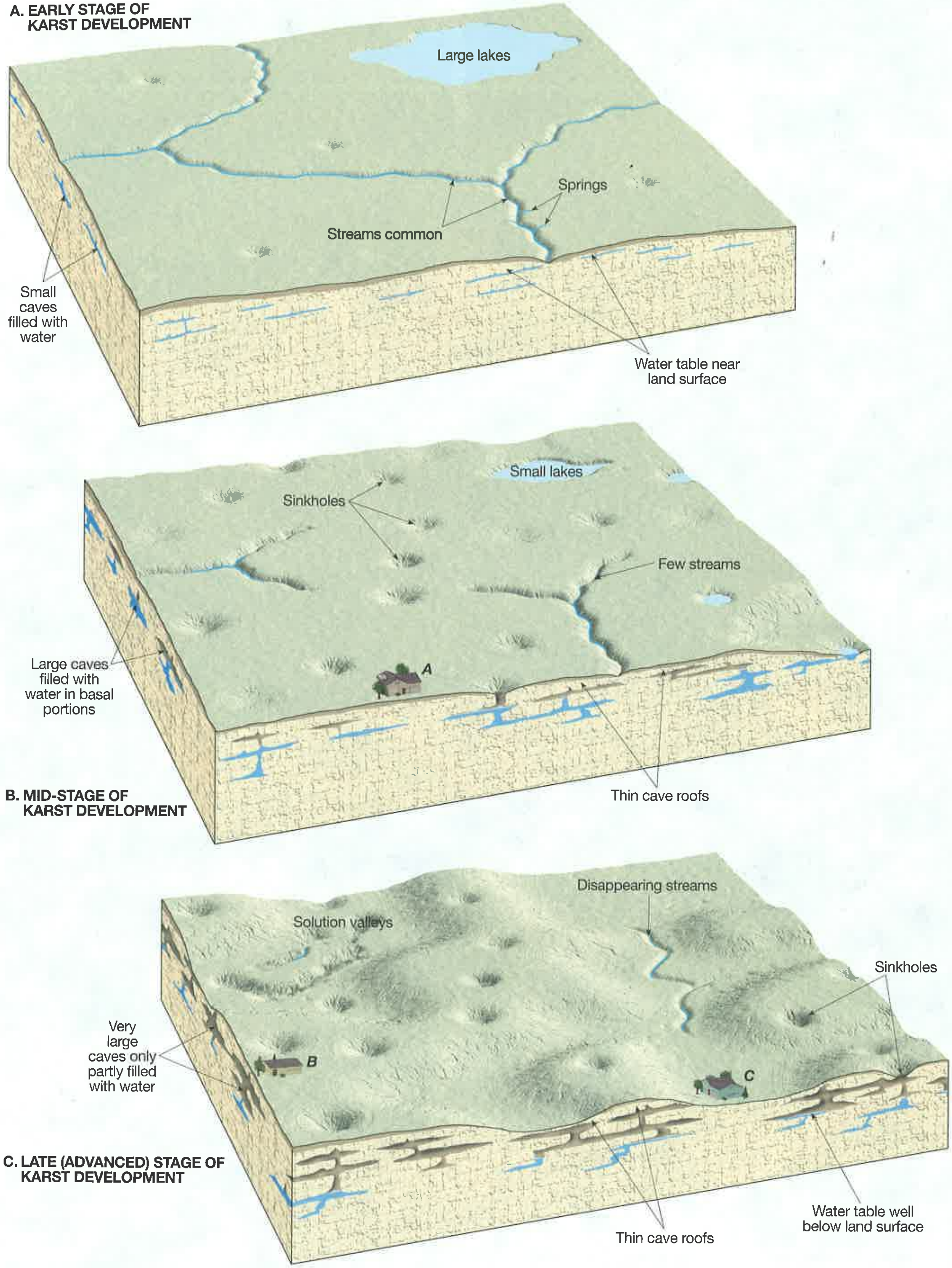


FIGURE 12.2 Stages in the evolution of karst topography. Karst topography is the result of dissolution of soluble bedrock (usually limestone).

FIGURE 12.3: Park City, Kentucky 7.5′ Quad (US Topo, 2010)

FIGURE 12.4 Water flow through fractures. Looking east toward the Arkansas River from Vap's Pass, Oklahoma (15 miles northeast of Ponca City). The Fort Riley Limestone bedrock *crops out* (is exposed at the surface) here. There is no soil, but plants have grown naturally along linear features in the bedrock.

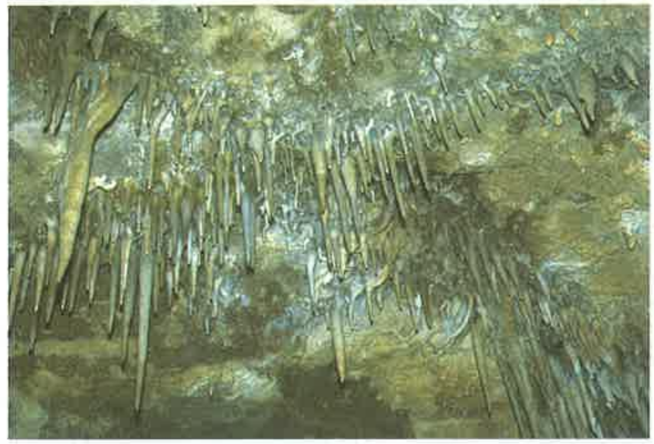


FIGURE 12.5 Stalactites. These stalactites formed on part of the ceiling of Cave of the Winds, which has formed in Paleozoic limestones near Manitou Springs, Colorado.

The Floridan Aquifer

FIGURE 12.6 shows karst features developed in the Floridan Limestone Aquifer in the northern part of Tampa, Florida. Notice the abundant lakes and ponds. They are mostly sinkholes, which are filled with water and surrounded by hachured contour lines (contours with small tick marks that point inward, indicating a closed depression). By determining and mapping the elevations of water surfaces in the lakes, you can determine the slope of the water table and the direction of flow of groundwater here (as in FIGURE 12.1B).

ACTIVITY

12.4 Land Subsidence from Groundwater Withdrawal

THINK About It **What can happen if groundwater is withdrawn faster than it is replenished?**

OBJECTIVE Evaluate how groundwater withdrawal can cause subsidence (sinking) of the land.

PROCEDURES

1. **Before you begin,** read Land Subsidence Hazards Caused by Groundwater Withdrawal below. Also, this is **what you will need:**
   ____ calculator
   ____ Activity 12.4 Worksheet (p. 327) and pencil
2. **Then follow your instructor's directions** for completing the worksheet.

Land Subsidence Hazards Caused by Groundwater Withdrawal

Land subsidence caused by human withdrawal of groundwater is a serious problem in many places throughout the world. For example, in the heart of Mexico City, the land surface has gradually subsided up to 7.6 m (25 ft). At the northern end of California's Santa Clara Valley, 17 square miles of land have subsided below the highest tide level in San Francisco Bay and now must be protected by earthworks. Other centers of subsidence include Houston, Tokyo, Venice, and Las Vegas. With increasing withdrawal of groundwater and more intensive use of the land surface, we can expect the problem of subsidence to become more widespread.

Subsidence induced by withdrawal of groundwater commonly occurs in areas underlain by stream-deposited (alluvial) sand and gravel that is interbedded with lake-deposited (lacustrine) clays and clayey silts (FIGURE 12.7A). The sand-and-gravel beds are aquifers, and the clay and clayey silt beds are confining beds.

Subsidence in Unconfined and Confined Aquifers

In FIGURE 12.8, the water in the lower aquifer ("sand and gravel") is confined between impermeable beds of clay and silt and is under pressure from its own weight. Thus, water in wells **A** and **C** rises naturally from the confined aquifer to the *potentiometric* (water-pressure) *surface*. Such wells are termed **artesian wells** (water flows naturally from the top of the well). The sand in the water table aquifer (FIGURE 12.8) contains water that is not confined under pressure, so it is an **unconfined aquifer** (also called a *water table aquifer*). The water in well **B** stands at the level of the water table and must be pumped up to the land surface.

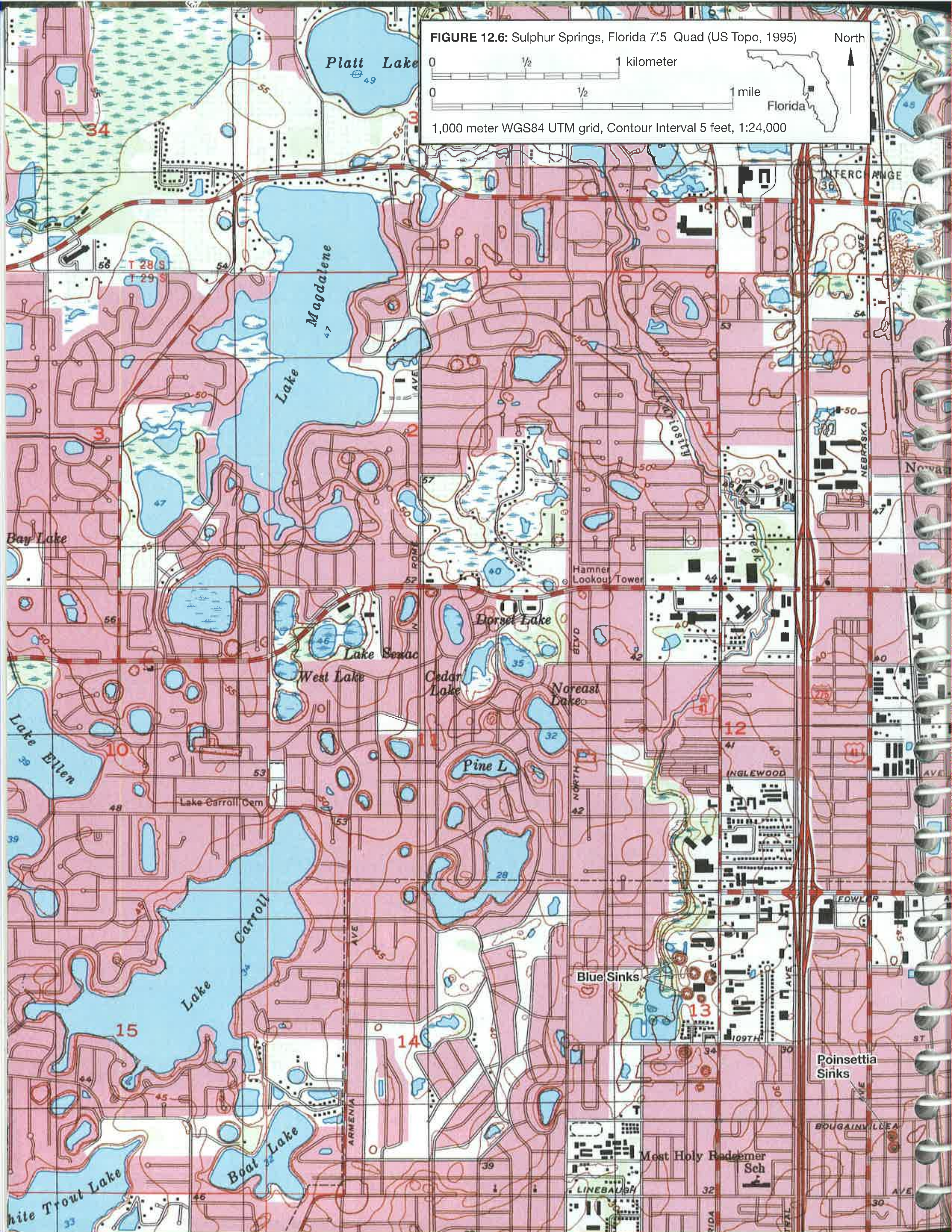


FIGURE 12.6: Sulphur Springs, Florida 7.5' Quad (US Topo, 1995)

1,000 meter WGS84 UTM grid, Contour Interval 5 feet, 1:24,000

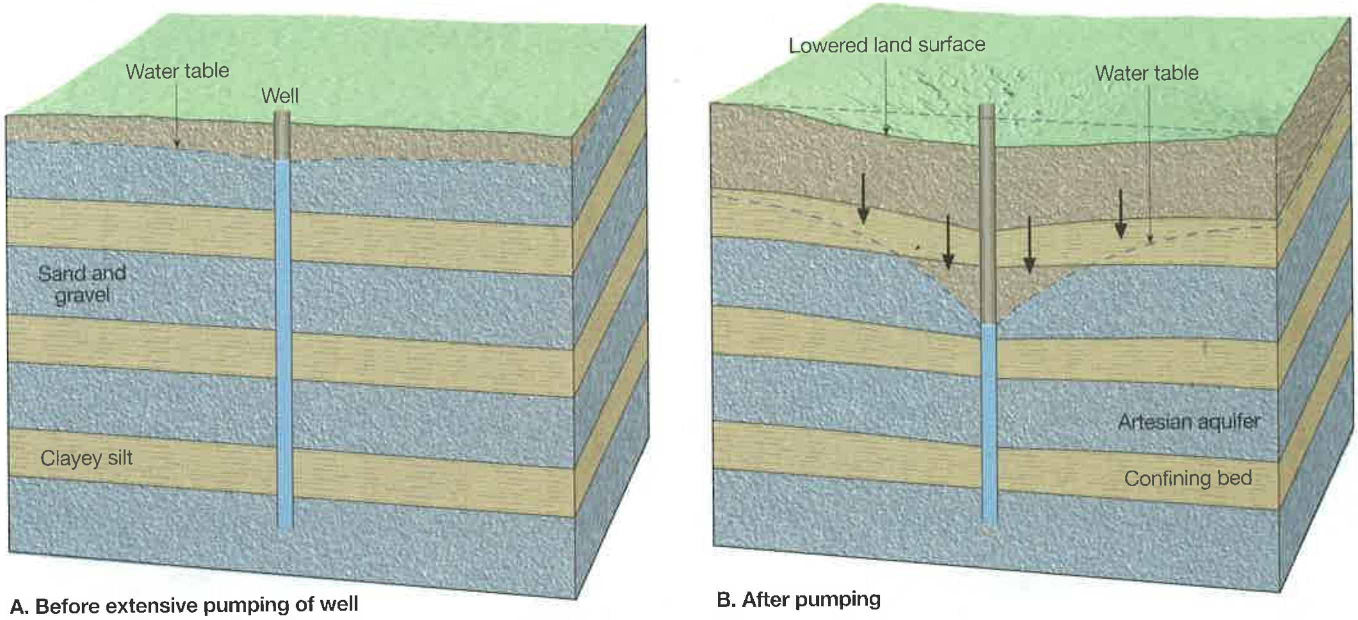


FIGURE 12.7 Before (A) and after (B) extensive pumping of a well. Note in **B** the lowering of the water-pressure surface, compaction of confining beds between the aquifers, and resulting subsidence of land surface. Arrows indicate the direction of compaction caused by the downward force of gravity, after the opposing water pressure was reduced by excessive withdrawal (discharge) of groundwater from the well.

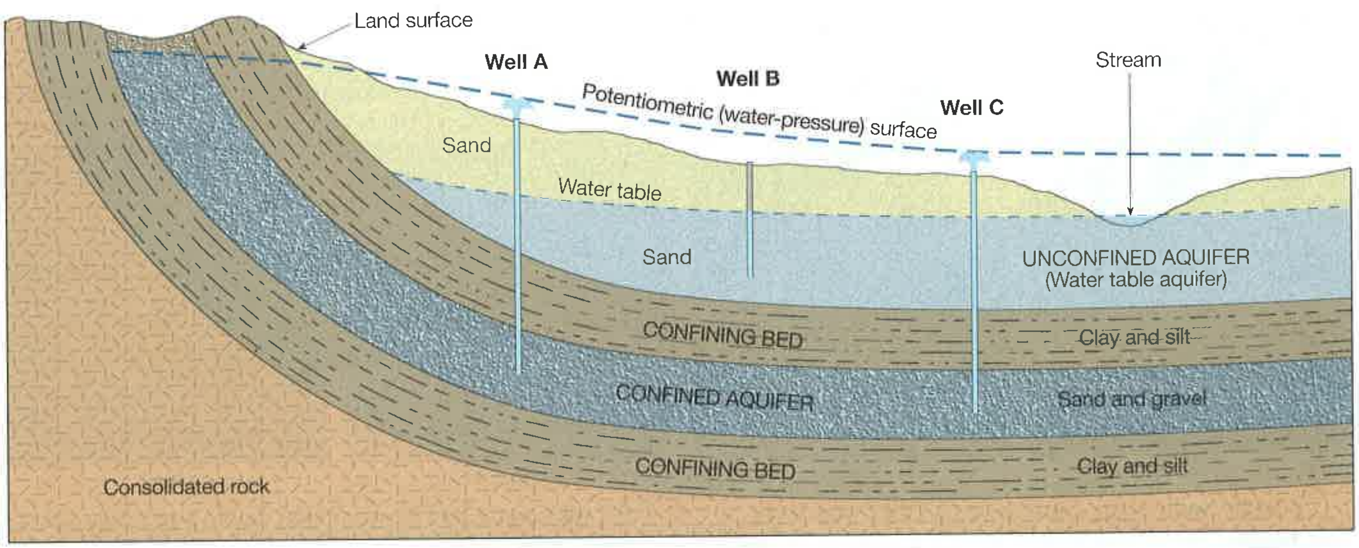


FIGURE 12.8 Geologic cross section of unconfined and confined aquifers. Vertical scale is exaggerated.

Land subsidence (FIGURE 12.7B) is related to the compressibility of water-saturated sediments. Withdrawing water from wells not only removes water from the system, but it also lowers the potentiometric surface and reduces the water pressure in the confined artesian aquifers. As the water pressure is reduced, the aquifer is gradually compacted and the ground surface above it is gradually lowered. The hydrostatic pressure can be restored by replenishing (or **recharging**) the aquifer with water. But the confining beds, once compacted, will not expand to their earlier thicknesses.

Subsidence in the Santa Clara Valley

The Santa Clara Valley (FIGURE 12.9) of California is a very important center of agriculture that depends on groundwater for irrigation. It was one of the first areas in the United States where land subsidence due to withdrawal of groundwater was recognized. The Santa Clara Valley is a large structural trough filled with alluvium (river sediments) more than 460 m (1500 ft) thick. Sand-and-gravel aquifers predominate near the valley margins, but the major part of the alluvium is silt and clay. Below a depth of 60 m (200 ft), the groundwater is confined by layers of clay, except near the margins.

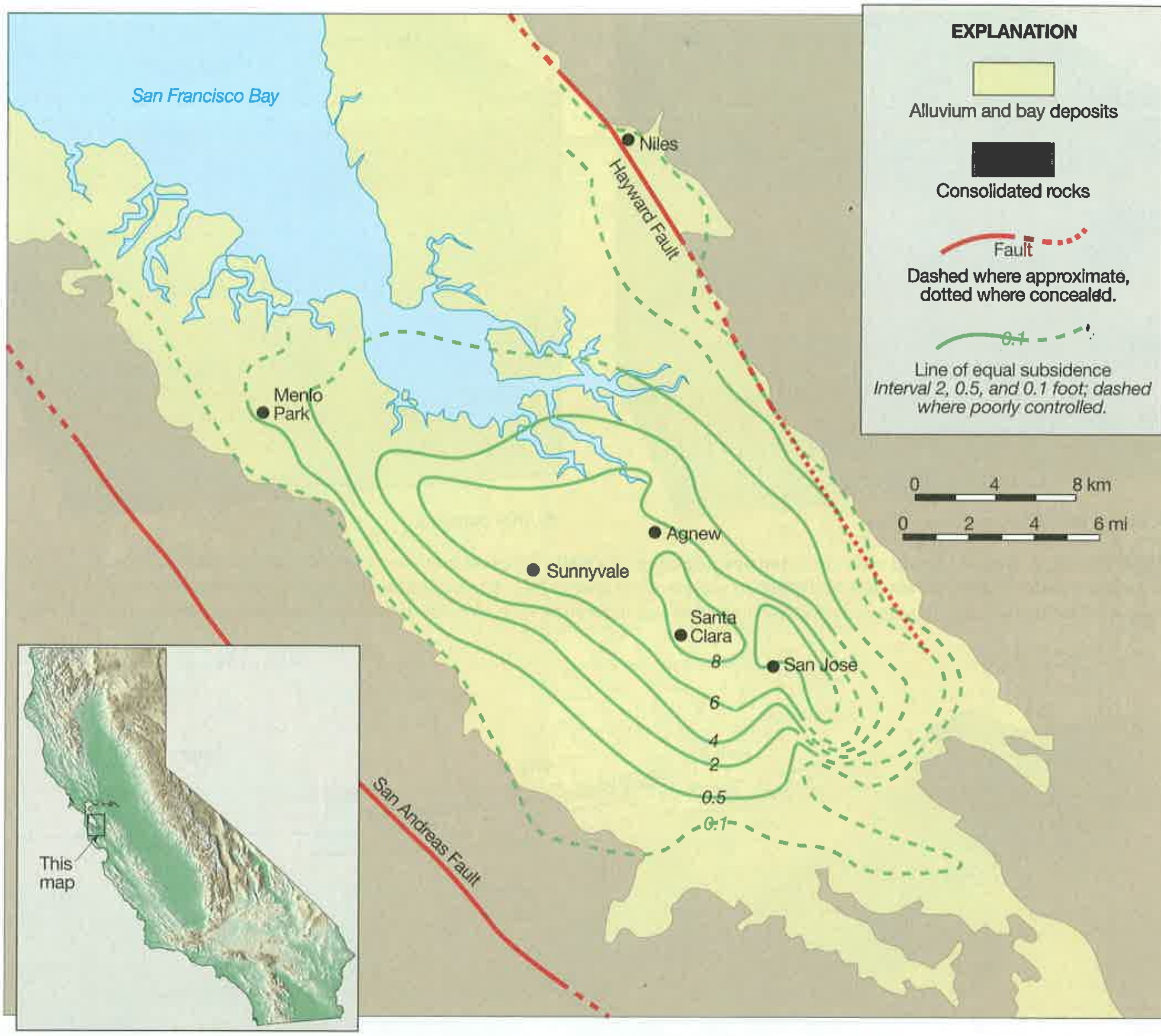


FIGURE 12.9 **Land subsidence, 1934–1967, in the Santa Clara Valley, California.** (Courtesy of U.S. Geological Survey)

Initially, wells as far south as Santa Clara were artesian, because the water-pressure surface was above the land surface. However, pumping them for irrigation lowered the water-pressure surface 40–60 m (150–200 ft) by 1965. This decline was not continuous. Natural recharge of the aquifer occurred between 1938 and 1947. As of 1971, the subsidence had been stopped due to a reversal of the water-level decline.

Most wells tapping the artesian system are 150–300 m (500–1000 ft) deep, although a few reach 365 m (1200 ft). Well yields in the valley are 500–1500 gallons per minute (gpm), which is very high.

ACTIVITY 12.1 Groundwater Inquiry

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

Consider the following experiments to understand how groundwater flows or is confined. Do not look up information. Just consider the experiments and complete the worksheet as well as you can.

A. EXPERIMENT 1: Analyze what happened when water was dropped on the rocks.

1. In general, what effect do you think layers of shale would have on groundwater movement or storage? Why?

2. In general, what effect do you think layers of sandstone would have on groundwater movement or storage? 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.

Shale   Sandstone   Shale   Sandstone

B. EXPERIMENT 2: Analyze the procedures in the image on the next page, then plot the data on the graph.

1. How is the distance of the water jet related to the height of water in the bottle? Why?

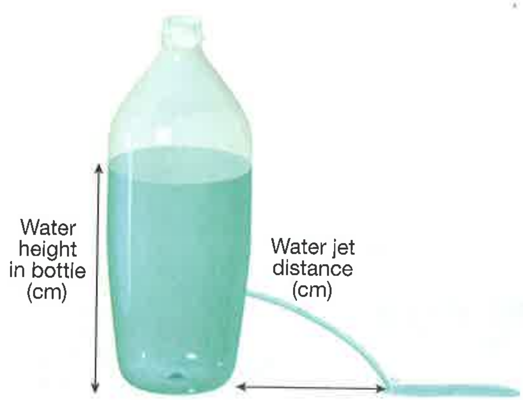
2. Some water wells flow like a water hose and are called **artesian**. The water actually flows up and out of the well on its own. In non-artesian wells, the water must be pumped from the ground, because the water will not flow up and out of the well on its own.
   a. Label the part of your Experiment 2 graph where the hole in the bottle can be considered artesian, and explain your reasoning used to label that part of the graph.

b. Label the part of your Experiment 2 graph where the hole in the bottle would be considered non-artesian, and explain why you decided to label that part of the graph.

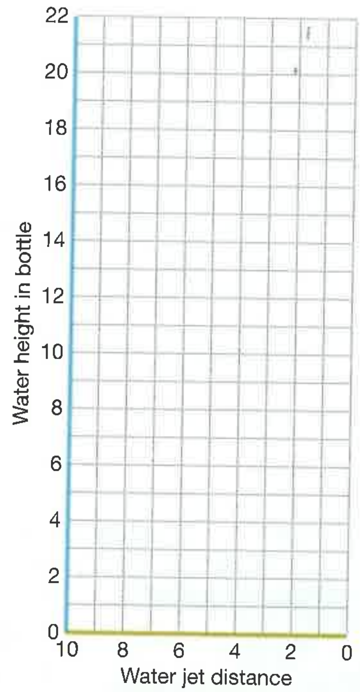
EXPERIMENT 2: What happens when water drains from a hole in the side of a bottle?

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
6.5 (hole height)	0



C. REFLECT & DISCUSS In Experiment 2, the jet of water was horizontal for a few centimeters, and then gravity exceeded the horizontal force and pulled the jet of water down onto the table. Water wells are normally vertical. Make a sketch of how you would re-arrange the materials from Expeiment 2 in order to get the jet of water to flow in more of a vertical position, like a natural artesian well, and explain how such a situation could occur among layers of sandstone and shale underground.

12.2 Karst Processes and Topography

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

A. Analyze **FIGURES 12.4** and **12.5**.

1. In the area photographed in **FIGURE 12.4**, there is 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 **FIGURE 12.4**, where would you drill (relative to the pattern of plant growth) to find a good supply of water? Why?

3. **REFLECT & DISCUSS** How is **FIGURE 12.5** related to **FIGURE 12.4**?

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 **FIGURE 12.2**, relative to sinkhole hazards.

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

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

3. **REFLECT & DISCUSS** Imagine that you are planning to buy a new-home construction site in the region portrayed in **FIGURE 12.2**. 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 orthoimage of the Park City (Kentucky) topographic map in **FIGURE 12.3**. Almost all of this area is underlain by limestone. 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.

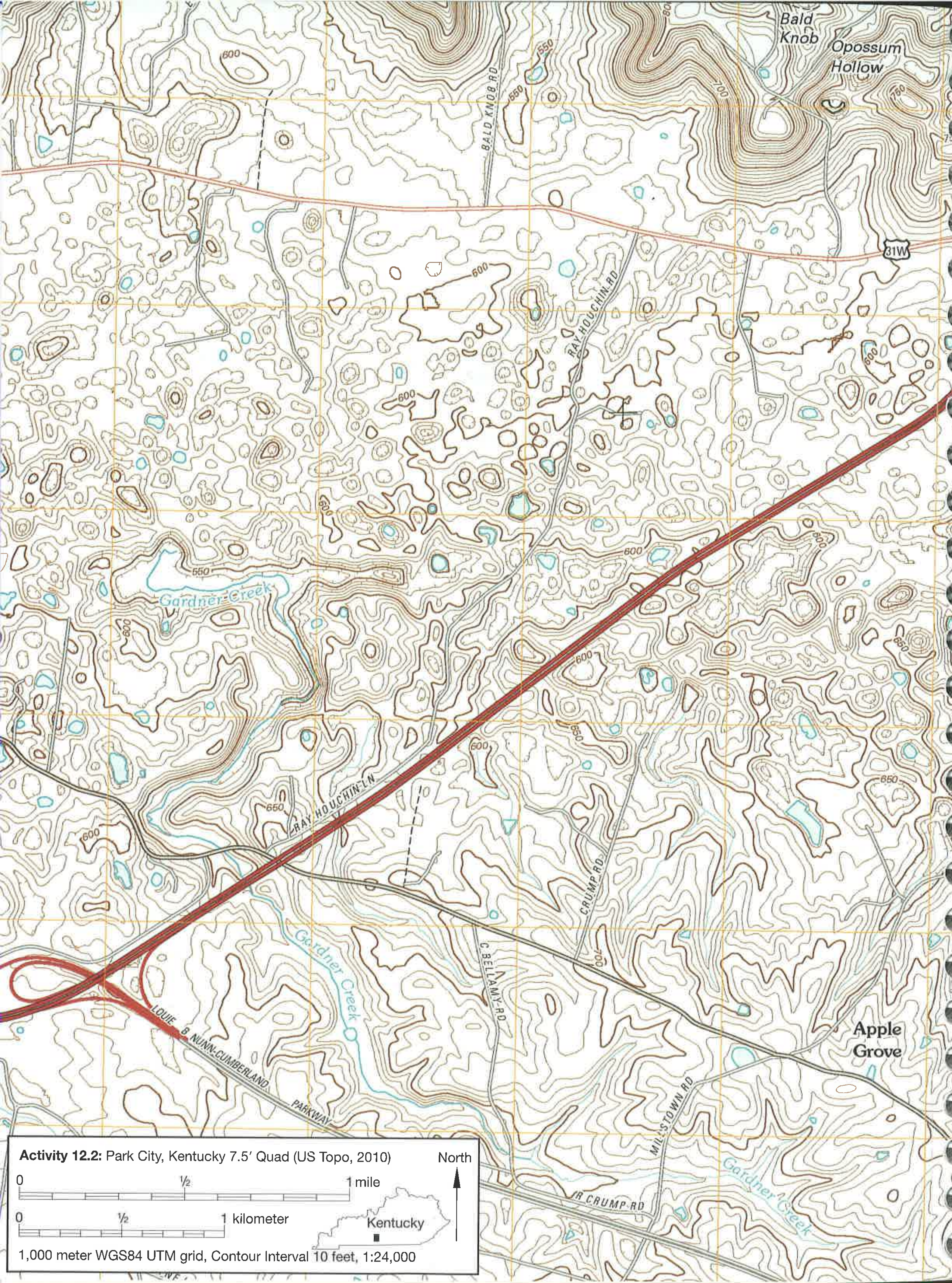
1. How can you tell the area on this orthoimage where limestone crops out at Earth's surface?

2. Recall that on a topographic map, a depression is shown by a contour line, with hachures (tic marks), that forms a closed loop. Describe the pattern of depressions on the topo map of Park City. Why do some of the depressions contain ponds, while 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 the map on the back of this page, a topographic map of the orthoimaged area in **FIGURE 12.3**.

1. Compare the map and orthoimage, then draw a contact (line) on the map that separates limestone with karst topography from forested, more resistant sandstone. Color the sandstone bedrock with a colored pencil.
2. Gardner Creek is a *disappearing stream*. Place arrows along all parts of the creek to show its direction of flow, then circle the location where it disappears underground. Circle the disappearing end of two other disappearing streams.
3. Notice that there are nine different springs that flow from the east-west trending hill on which Apple Grove is located. Label the elevation of each spring (where it starts a stream), then use the elevation points to draw a flow line with a large arrow to show the direction that water travels down the hydraulic gradient within the hill.
4. Find and label a solution valley anywhere on the map.
5. **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 dark blue edge of the pond, then how deep below that surface location was the well drilled just to reach the water table? Show your work.



Activity 12.2: Park City, Kentucky 7.5′ Quad (US Topo, 2010)

1,000 meter WGS84 UTM grid, Contour Interval 10 feet, 1:24,000

ACTIVITY 12.3 Floridan Limestone Aquifer

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

Refer to **FIGURE 12.6** (Sulphur Springs Quadrangle) and the "sketch map" on page 326.

A. On the sketch map, mark the elevations of water levels in the lakes (obtain this information from **FIGURE 12.6**). The elevations of Lake Magdalene and some lakes beyond the boundaries of the topographic map already are marked for you.

B. Contour the water table surface (use a 5-foot contour interval) on the sketch map. 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 the sketch map is at right angles to the contour lines. The groundwater flows from high elevations of the hydraulic gradient to lower elevations, just like a stream. Draw three or four flow lines with arrows on the sketch map to indicate the direction of shallow groundwater flow in this part of Tampa. The southeastern part of **FIGURE 12.6** 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 (see **FIGURE 12.6**). Note their closely spaced hachured contour lines. 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 **FIGURE 12.8**, and label them "Blue Sinks."

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

F. On **FIGURE 12.6**, note the stream and valley north of Blue Sinks. This is a fairly typical disappearing stream. Draw its approximate course onto the sketch map. 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 hours later in Sulphur Springs, on the Hillsborough River to the south (see sketch map). Use these data to calculate (show your work) the approximate velocity of flow in this portion of the Floridan Aquifer:

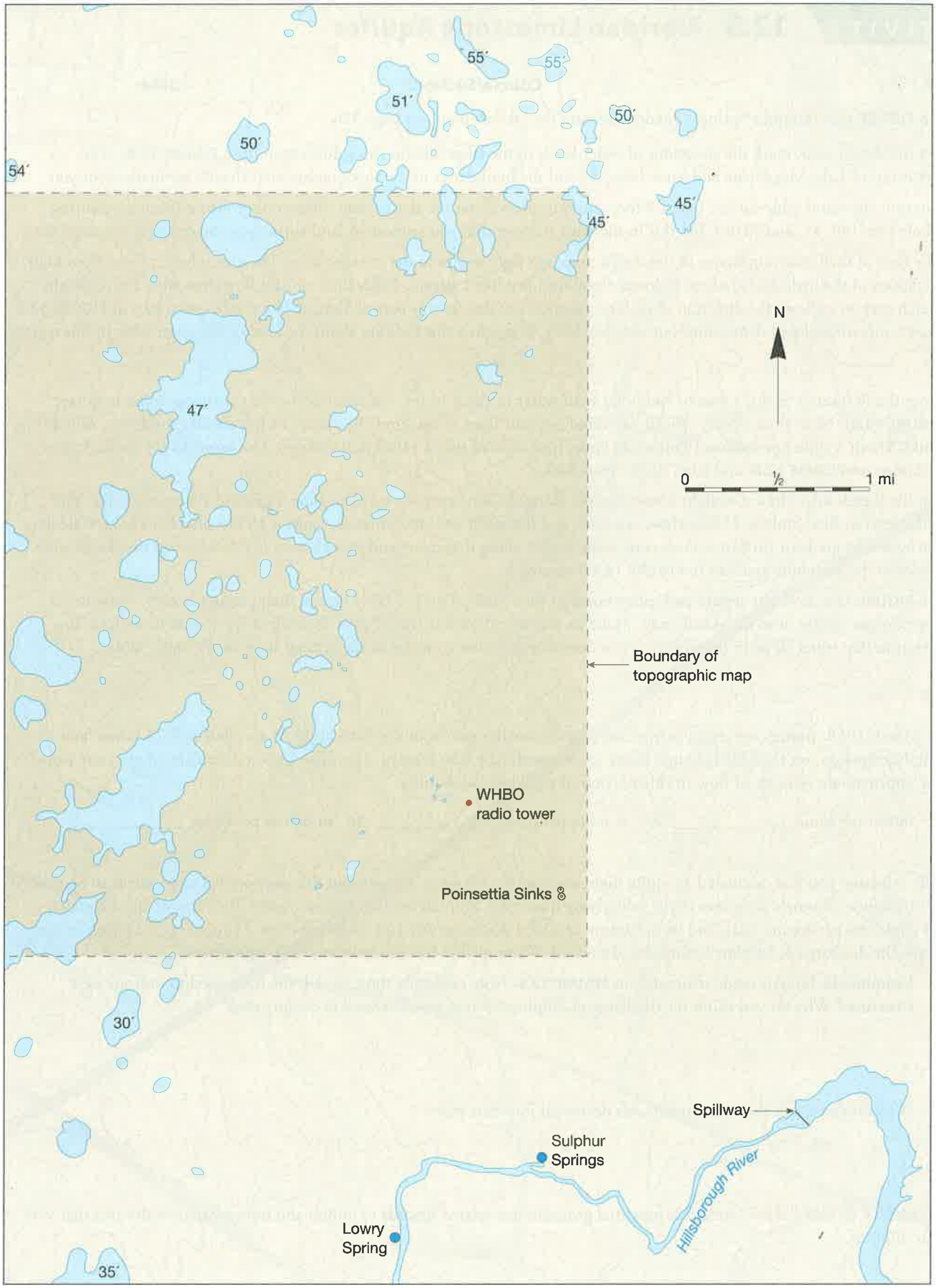
1. in feet per hour: ____________ **2.** in miles per hour: ____________ **3.** in meters per hour: ____________

H. The velocities you just calculated are quite high, even for the Floridan Aquifer. 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. Examine the human-made structures on **FIGURE 12.6**. Note especially those in red, the color used to indicate new structures. Why do you think the discharge of Sulphur Springs has 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 to homes and homeowners in the area that you can think of.



Sketch map of the area shown in **FIGURE 12.6** (Sulphur Springs Quadrangle) and surrounding region.

ACTIVITY 12.4 Land Subsidence from Groundwater Withdrawal

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

A. Santa Clara Valley, California.

1. In **FIGURE 12.9** on page 320, where are the areas of greatest subsidence in the Santa Clara Valley?

2. What was the total subsidence at San Jose (**FIGURE12.10**) 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 12.10 **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 per year?

4. Analyze **FIGURE 12.9**. 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 areas of **FIGURE 12.9**? Explain.

6. By 1960, the total subsidence at San Jose had reached 9.0 feet (**FIGURE 12.10**). What was the average annual rate of subsidence (in feet per year) for the seven-year period from 1960 through 1967? (Show your work.)

7. Refer to Figure 12.11 on the back of this page. What was the level of the water in the San Jose well in:

a. 1915? __________ feet **b.** 1967? __________ feet

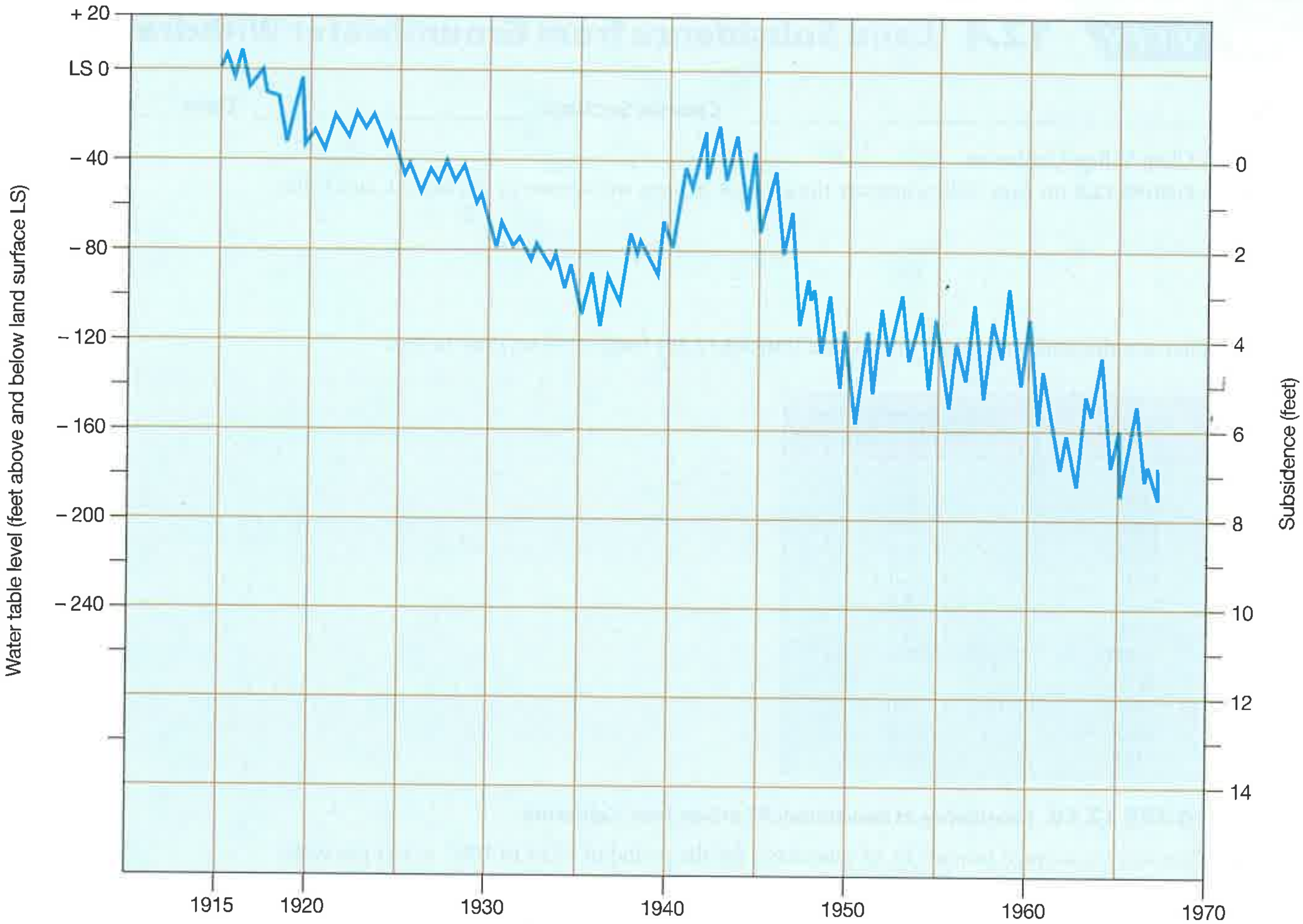


FIGURE 12.11 Hydrograph showing changes of water level in a well at San Jose, California.

8. During which years would the San Jose well have been a flowing artesian well?

9. How can you explain the minor fluctuations in the hydrograph (FIGURE 12.12) like those between 1920 and 1925?

10. In FIGURE 12.11, the slope of a line joining the level of the land surface in 1915 with subsidence that had occurred by 1967 gives the average rate of subsidence for that period. How did the rate of subsidence occurring between 1938 and 1948 differ from earlier rates?

B. REFLECT & DISCUSS Adolf Hitler came into power as head of the National Socialist German Workers' Party (Nazi Party) in 1933 and German Troops invaded Austria in 1938 and Poland in 1939 to initiate World War II. Japan invaded China in 1932, withdrew, and then launched a full-scale invasion of China in 1937. The United States officially entered World War II in 1941 (when Japan attacked Pearl Harbor). Explain how these world events could have caused the change in subsidence rates noted in Question 10.

C. REFLECT & DISCUSS Subsidence was stopped by 1971. What measures might have been taken to accomplish this?