ES476 Hydrology - Introduction to Groundwater Lab Demo Exercise

Part 1 Demo - Station 1 Activities.

Visit Station 2 and examine the display. There are four types of porosity that can be found in rock and sediments. These include (1) intergranular porosity (open pore spaces between grains, primarily the result of deposition), (2) solution porosity (open pore spaces result from chemical dissolution of salt and limestone deposits by ground water), (3) fracture porosity (open pore spaces result from fracturing of rocks by tectonic forces, the fractures form opening through which fluids can migrate), and (4) vesicular porosity (open pore spaces associated with vesicular volcanic rocks). Fractures are typically arranged in geometric patterns (rectangular shapes, etc.), depending on the orientation of tectonic forces at the time of fracture.

There are five earth materials samples at Station 2 with examples of different types and degrees of porosity and permeability. Use the water bottle and make observations for each sample with regards to its ability to store and transmit water. Use terms like Low, Medium, High for degree of porosity and permeability. For porosity type, your choices include intergranular, fracture, solution, and vesicular. Fill in the data table below.

Sample I.D.	Degree of Porosity	Degree of Permeability	Porosity Type
A	________________	________________	________________
B	________________	________________	________________
C	________________	________________	________________
D	________________	________________	________________
E	________________	________________	________________
F	________________	________________	________________

Part 1 Demo - Station 2: Groundwater Simulation Model

Visit the groundwater simulation model and answer the following questions.

4-1. Identify the earth materials comprising the following units, include a description of relative porosity, relative permeability, and whether the material is acting as an aquifer or aquitard.

	Material Type	Relative Porosity (High, Medium, Low)	Relative Permeability (High, Medium Low)	Aquifer or Aquitard?
Unit 1	_______	__________	________	_____________
Unit 2	_______	__________	________	_____________
Unit 3	_______	__________	________	_____________
Unit 4	_______	__________	________	_____________

4-2. Examine units 3A and 3B. Describe their composition, their potential as aquifers, and their lateral continuity with respect to other portions of unit 3 (i.e. are they laterally continuous or discontinuous?). Describe a depositional process that might result in the lateral geometry of units 3A and 3B illustrated in the model.

4-3. Is unit 1 acting as a confined or unconfined aquifer? Explain your answer.

4-4. Is unit 3 acting as a confined or unconfined aquifer? Explain your answer.

4-5. Is unit 4 in direct hydraulic communication with unit 3? (i.e. are the units readily exchanging fluids?) Explain your answer.

4-6. Is unit 4 in direct hydraulic communication with unit 1? Explain your answer.

4-7. If gasoline leaked from the storage tank, would it contaminate unit 1? Why or why not?

4-8. Examine the set of wells on the groundwater simulation model. Note that the top of the wells are all located at the same elevation. Assume the the groundwater model has a scale of 1:500 (i.e. 1 inch depth on the model = 500 inches depth relative to the Earth), and that the elevation of the top of the wells is 1500 ft above sea level (relative to the actual Earth's surface). Using a ruler and the scale, fill in the well data chart below.

Well ID	Depth to water (model inches)	Depth to Water (actual ground feet)	Elevation of Water Surface (ft elev.)	Is well in confined or unconfined aquifer?
A	____________	__________	___________	______________
B	____________	__________	___________	______________
C	____________	__________	___________	______________
D	____________	__________	___________	______________
E	____________	__________	___________	______________
F	____________	__________	___________	______________
G	____________	__________	___________	______________
H	____________	__________	___________	______________
I	____________	__________	___________	______________
J	____________	__________	___________	______________
K	____________	__________	___________	______________

4-9. True or False: groundwater flows from high elevation to low elevation, under the influence of gravity?

4-10. What is the elevation of water in the unconfined aquifer in well A? What is the elevation of water table in the unconfined aquifer in Well J? Using the model scale of 1:500, determine the actual ground-distance of the gradient of the water table between well A and well J (remember from the river lab: gradient = change in elevation / change in horizontal distance or rise / run). Calculate the gradient in ft/mi, show all of your work.

4-11. Which direction is groundwater flowing in the unconfined aquifer? Which direction is groundwater flowing in the confined aquifer?

4-12. Is well B in the confined or unconfined aquifer? Is well C in the confined or unconfined aquifer? How does the water level in well B compare that that in well C (answer in model elevation units)? Is the water level in well B above or below the top of the aquifer? Is the water level in well C above or below the top of the aquifer? Are the water levels in wells B and C measuring the same hydraulic pressure? Explain your answer.

4-13. Which aquifer is contributing water to Lake Bonneville? Which aquifer is contributing water to Smith Lake?

Part 2. Key Concept Questions
Using the attached lab manual figures and pages, define the following terms and answer the questions below.

A. Using p. 312 of your lab manual (attached), define the following terms and answer the following questions:

Aquifer

Aquiclude or Confining Bed

Unconfined Aquifer

Confined Aquifer

True or False: “Water Table Aquifer” is the same and an “confined artisian aquifer”

B. Examine Figure 12. 1 on p. 313-314 (attached), define the following terms and answer the following questions:

Zone of Aeration

Zone of Saturation

Hydraulic Gradient

Draw a cross-sectional sketch of a sloping water table in an unconfined aquifer, label the saturated and unsaturated zones, and write the equation for calculating hydraulic gradient.

True or False: the elevation of the water table surface can be mapped with contour lines showing elevations of equal hydraulic pressure.

True or False: pumping groundwater from a well will cause the water table to draw down into a cone of depression (lower water table elevation) around the well.

True or False: according to a groundwater contour map of a water table, groundwater flows through the aquifer from areas of high elevation to areas of low elevation, under pressure.

C. Examine Figure 12.2 on p. 315 (attached), define the following terms and answer the following questions.

Chemical formula for carbonic acid:

Chemical formula for limestone made of mineral calcite:

Describe happens to limestone when it is saturated with carbonic acid in groundwater?

Sinkhole?

Solution Valley?

Spring?

Cave?

“Karst”?

D. Examine Figure 12.8 on p. 319 (attached), define the following terms and answer the following questions.

Describe what happens to land surface elevations in regions where aquifers are extensively pumped and groundwater is withdrawn from an aquifer.

True or False: Clay and Silt tend to form confining beds or aquicludes.

True or False: Sand and Gravel tend to form porous and permeable aquifer material.

True or False: the term “water table” is applied equally to both confined aquifers and unconfined aquifers.

True or False: “potentiometric surface” is the term used to describe the artesian pressure surface, the level water rises under pressure, for confined aquifers.

True or False: confined aquifers are fully saturated with water and under pressure so that water rises above the top of the bed.

True or False: unconfined aquifers are associated with a water table that designates the boundary between the saturated zone and unsaturated zone.

LABORATORY 12

Groundwater Processes, Resources, and Risks

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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

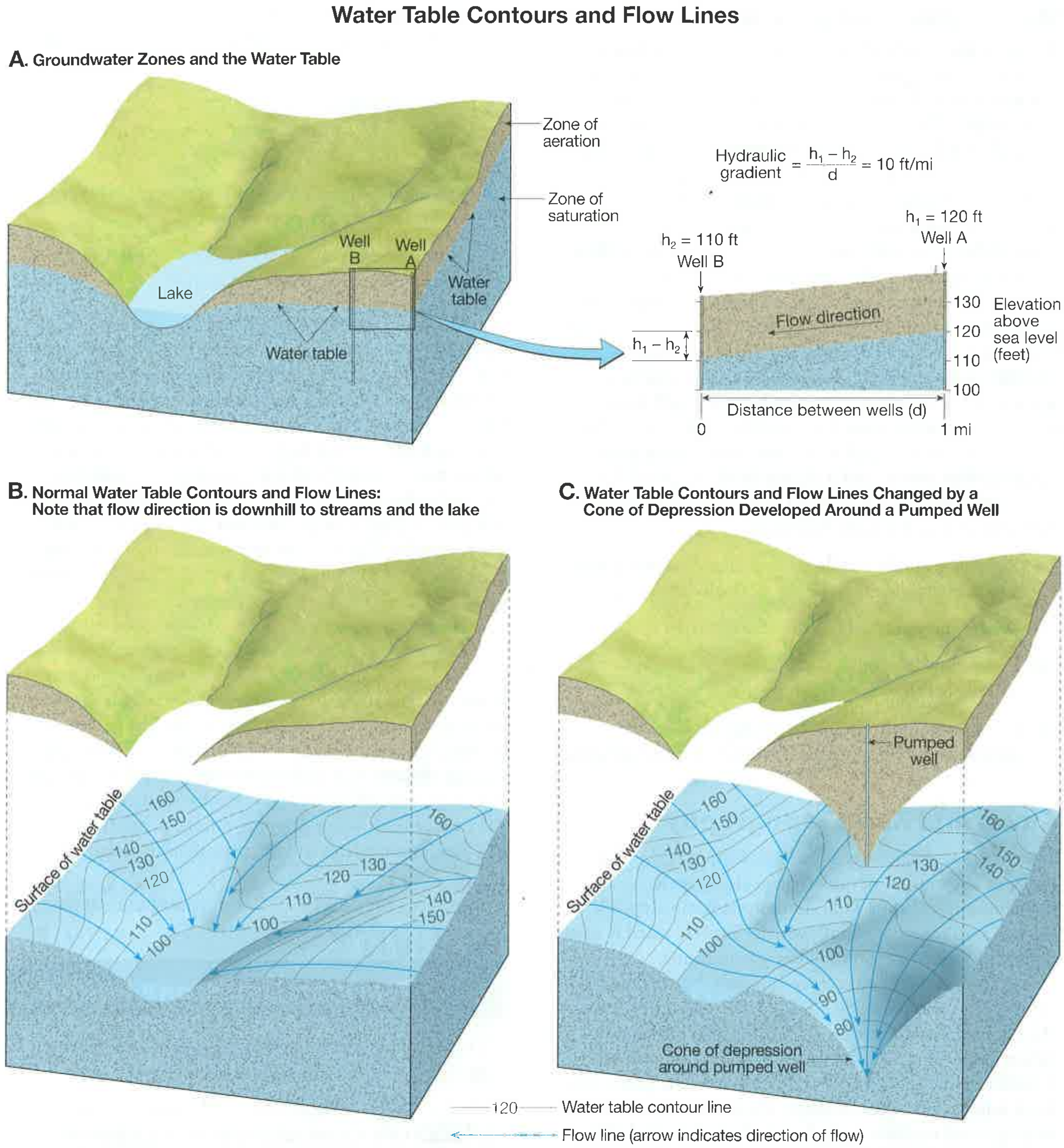

FIGURE 12.1 Water movement through an unconfined aquifer. A. Rainwater seeps into the *zone of aeration* (unsaturated zone, vadose zone), where void spaces are filled with air and water. Below it is the *zone of saturation,* where all void spaces are filled with water. Its upper surface is the water 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:

$$CaCO_3 + H_2CO_3 = Ca^{+2} + 2HCO_3^{-1}$$

Calcite; Carbonic acid; Calcium ions dissolved in groundwater; Bicarbonate ions dissolved in groundwater

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.

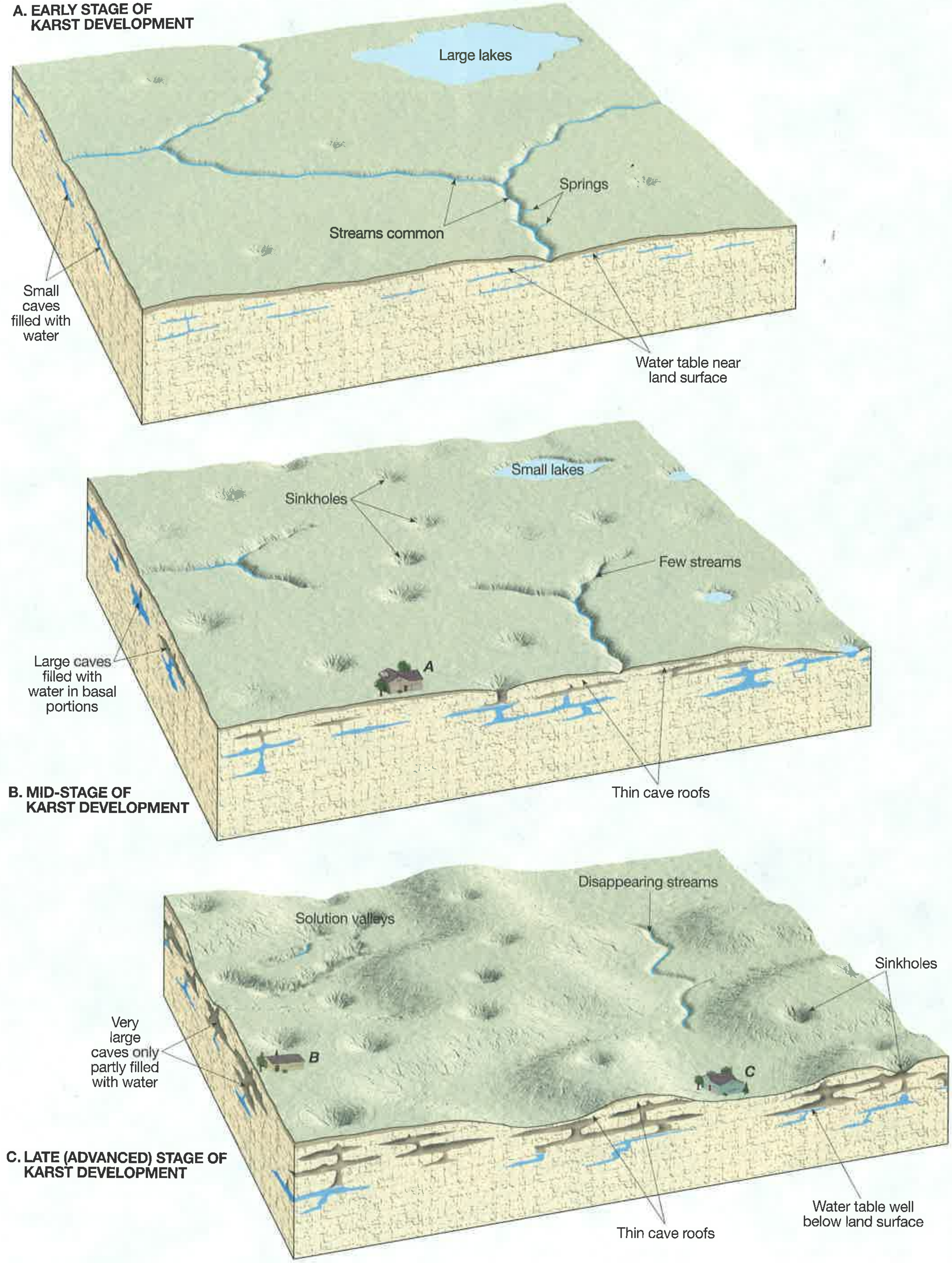

FIGURE 12.2 Stages in the evolution of karst topography. Karst topography is the result of dissolution of soluble bedrock (usually limestone).

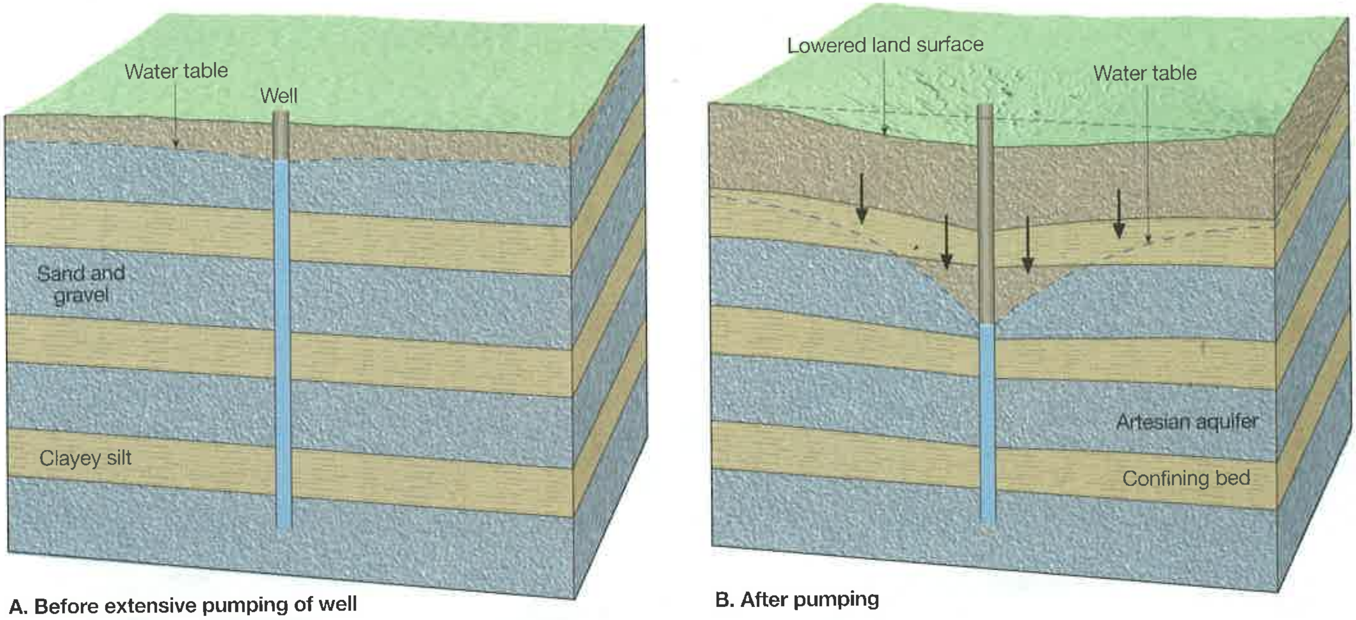

FIGURE 12.7 Before (A) and after (B) extensive pumping of a well. Note in **B** the lowering of the water-pressure surface, compaction of confining beds between the aquifers, and resulting subsidence of land surface. Arrows indicate the direction of compaction caused by the downward force of gravity,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

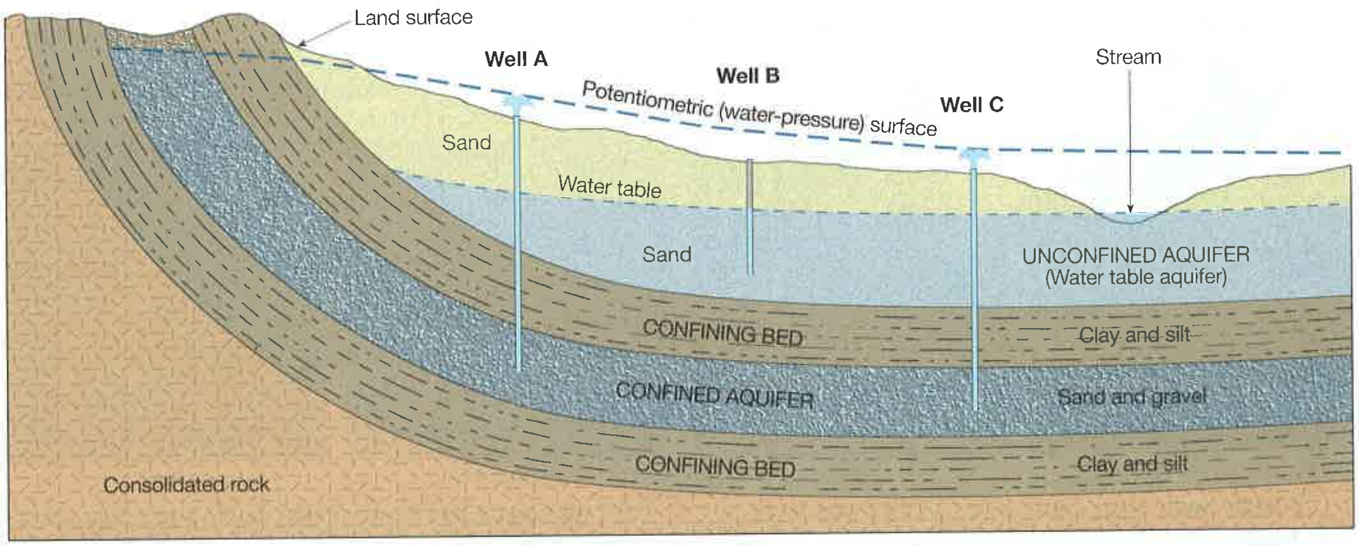

FIGURE 12.8 Geologic cross section of unconfined and confined aquifers. Vertical scale is exaggerated.

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.