

Part 1. Groundwater Model

At Station 1, examine the physical model of a simple groundwater aquifer system. The basic components of the model include three wells (Well A, B, and C), and a sequence of unconsolidated, layered sediments (Units 1, 2, and 3). Answer the following questions.

1. Make some basic stratigraphic observations regarding the physical sedimentology of Units 1, 2, and 3. Refer to your sedimentology notes as needed. Fill in the table below.

Unit No.	Bed Thickness (cm)	Grain Size (mm)	Sediment Name	Sorting
1	<u>9.5</u>	<u>5-20 min</u>	<u>GRAVEL</u>	<u>MODERATE-WELL</u>
2	<u>1.5</u>	<u><0.0625</u>	<u>CLAY</u>	<u>WELL</u>
3	<u>3.5</u>	<u>0.5-1.0</u>	<u>COARSE-MEDIUM SAND</u>	<u>WELL</u>

2. On the graph provided on the next page, draw a cross-section to scale, showing the basic configuration of the layered sediments. Use a fractional scale of 1:2 (1 unit on the cross-section = 2 units on the groundwater model). Use a ruler to measure the thickness of the sediment beds to the nearest millimeter. Include in your cross-section a diagrammatic illustration of grain size for each unit, label all parts of your cross-section appropriately.

SEE ATTACHED SHEET

3. Pour a small volume of water (about 5 ml) onto the surface of Unit 3. Describe your observations of Unit 3 in terms of texture, porosity, and permeability.

UNIT 3? - WELL SORTED SAND
 - MODERATE TO HIGHLY POROUS
 - HIGHLY PERMEABLE

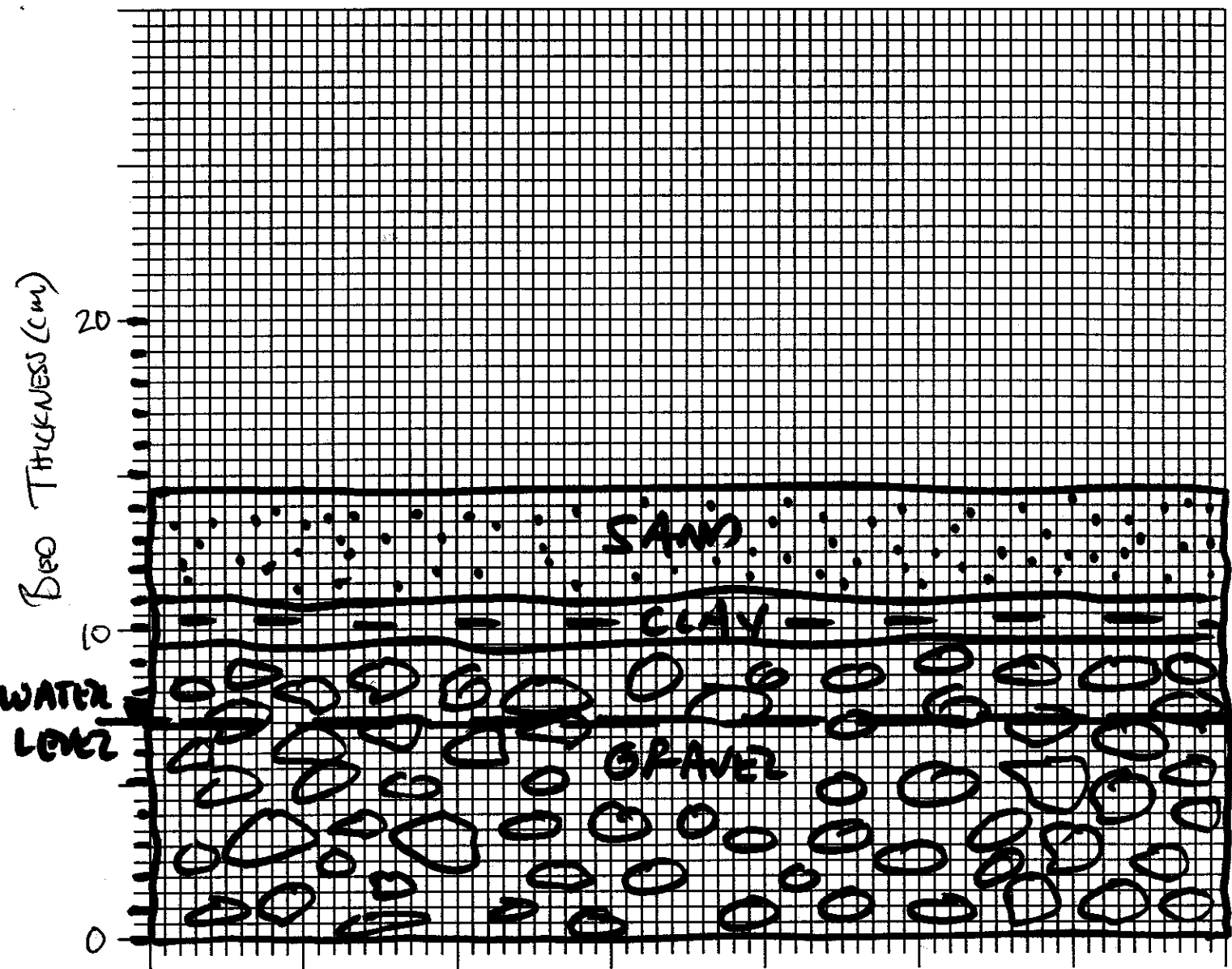
Is Unit 3 presently saturated with respect to groundwater? Explain your observations and answer.

NO - UNIT 3 IS UNSATURATED AND REPRESENTS A "ZONE OF AERATION"

How about Units 1 and 2? Explain as above; draw diagrams as necessary.

UNIT 1: - MOD. - WELL SORTED GRAVEL
 - HIGHLY POROUS & PERMEABLE
 - PARTIALLY SATURATED

UNIT 2: - WELL SORTED
 - VERY LOW PERMEABILITY
 - A GOOD ACQUITARD



Cross-sectional profile of groundwater model. Scale 1:2.

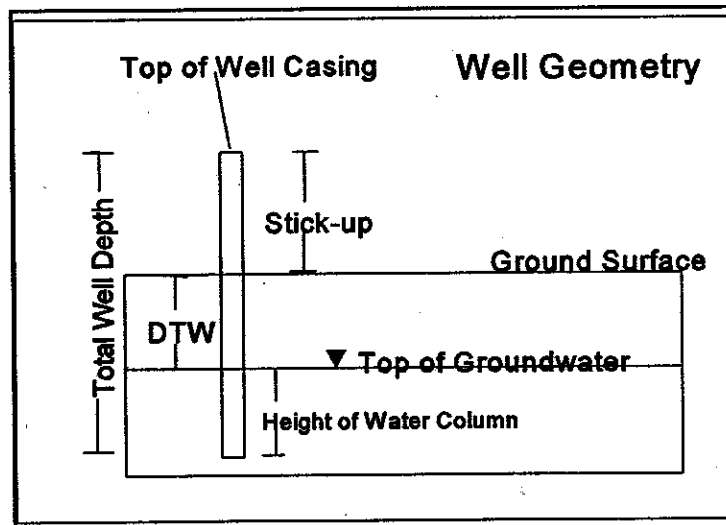
4. Based on grain size and sorting characteristics, identify the relative porosity and permeability of the three stratigraphic units comprising the model. Use descriptive terms such as highly porous/permeable, moderately porous/permeable, low porosity/permeability. Fill in the table below.

Unit	Porosity	Permeability
1	<u>HIGH</u>	<u>HIGH</u>
2	<u>LOW</u>	<u>LOW</u>
3	<u>MOD.-HIGH</u>	<u>MOD.-HIGH</u>

5. Based on your observations from the physical model, which of the following tend to make good aquifers and aquitards. Your choices for answers include "good" or "poor".

	Aquifer?	Aquitard?
Poorly Sorted Clayey Sand	<u>POOR</u>	<u>GOOD</u>
Clay	<u>POOR</u>	<u>GOOD</u>
Well-Sorted Gravel	<u>GOOD</u>	<u>POOR</u>
Well-Sorted Sand	<u>GOOD</u>	<u>POOR</u>
Shale	<u>POOR</u>	<u>GOOD</u>
Fractured Limestone	<u>MOD.-GOOD</u>	<u>POOR</u>

6. Perform the following measurements on the groundwater model, fill in the data table.
- Measure the stick-up (above ground surface) of the well casings (the distance from the ground surface to the top of the well). Measure in centimeters to the nearest decimal place.
 - Use the "dip stick" to measure the depth to the top of water in each well.
 - Determine the depth to water below "ground surface" (total depth to water minus well stick up). Measure in centimeters to the nearest decimal place.
 - Measure the total depth to the bottom of the well. Measure in centimeters to the nearest decimal place.
 - Calculate the height of the column of water in each well (in centimeters, to the nearest decimal).



Well I.D.	1 Well Casing Stick-up (cm)	2 Depth to Water from top of well (cm)	3 DTW below ground surface (cm) (2-1)	4 Total Well Depth (cm)	5 Height of Water Column (cm) (4-2)
A	<u>16</u>	<u>24</u>	<u>8</u>	<u>30.7</u>	<u>6.7</u>
B	<u>7.8</u>	<u>DRY</u>	<u>DRY</u>	<u>11.8</u>	<u>0</u>
C	<u>17</u>	<u>25</u>	<u>8</u>	<u>31.2</u>	<u>6.2</u>

7. Are any of the wells "dry" with no ground water? Which ones?

YES, WELL B

Which stratigraphic unit is associated with the dry well (hint: compare your well depth to the depth of strata in the model).

UNIT 3 = UNSATURATED

By looking at the model, what would be the minimum depth that you would have to drill to find an abundant supply of ground water (answer in cm below ground surface). Which stratigraphic unit is the best aquifer in this case?

UNIT 1 IS THE BEST AQUIFER

A WATER-BEARING WELL WOULD REQUIRE A MINIMUM DEPTH OF 8 CM

8. By looking at the model, do you see any visible flow of the ground water through the system? (is the ground water flowing "like an underground river").

NO, GROUNDWATER IS NOT FLOWING

9. Let's create an imaginary frame of reference with respect to elevation. Let's assume that the ground surface of the model lies at an elevation datum of +500 cm above relative sea level. From your table of data above, determine the elevation of the top of the ground water surface at each of the wells. Fill in the table below.

Well I.D.	Depth to water from ground surface (cm) (FROM COL. 3 ABOVE)	Elevation of ground surface (cm)	Elevation of top of well casing (cm) (500 + COL. 1 ABOVE)	Elevation of top of water (cm) (500 - COL. 3 ABOVE)
A	<u>8</u>	<u>500</u>	<u>516</u>	<u>492</u>
B	<u>DRY</u>	<u>500</u>	<u>507.8</u>	<u>DRY/N-A</u>
C	<u>8</u>	<u>500</u>	<u>517</u>	<u>492</u>

10. Compare your calculations in question 9 to your observations in question 8, what can you conclude about changes in elevation of the ground water surface and ground water flow velocity? Write a conceptual equation that relates water surface elevation change to ground water flow velocity.

$$\text{EL. CHANGE BETWEEN WELL A \& WELL C} =$$

$$492\text{cm} - 492\text{cm} = 0\text{cm}$$

WHEN "A EL. OF WATER SURFACE = 0, GROUNDWATER FLOW = 0

Station 2 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 (MARBLES)	<u>HIGH</u>	<u>HIGH</u>	<u>INTERGRANULAR</u>
B (BASALT) ^{VES.}	<u>HIGH</u>	<u>HIGH</u>	<u>VESICULAR</u>
C (COQUINA)	<u>HIGH</u>	<u>HIGH</u>	<u>INTERGRANULAR</u>
D (QUARTZITE) SS	<u>LOW</u>	<u>LOW</u>	<u>INTERGRANULAR</u>
E (FRACTURED) GRANITE	<u>MEDIUM</u>	<u>HIGH ALONG FRACTURES</u>	<u>FRACTURE</u>
F (ROCK SALT)	<u>MEDIUM</u>	<u>HIGH ALONG CAVITIES</u>	<u>SOLUTION</u>

LABORATORY TWELVE

Groundwater Processes, Resources, and Risks

OBJECTIVES

- A. Understand the topographic features and ground water movements associated with karst topography.
- B. Construct a water table contour map and determine the rate and direction of ground water movement.
- C. Evaluate how ground water withdrawal can cause subsidence (sinking) of the land.
- D. Evaluate hazards and risks associated with the use and contamination of ground water.

STUDENT MATERIALS (Remind students to bring items you check below.)

- _____ laboratory manual
- _____ laboratory notebook
- _____ pencil with eraser
- _____ metric ruler (cut from GeoTools sheet 1)
- _____ calculator (or provided by instructor)

_____:

INSTRUCTOR MATERIALS (Check off items you will need or provide.)

- _____ calculator (or obtained by students)
- _____ ground water modeling jars (optional, see Instructor Note 2 below)

_____:

INSTRUCTOR NOTES AND REFERENCES

1. General information. Refer to the Laboratory 12 on the Internet site at <http://www.prenhall.com/agi> for additional information and links related to this laboratory.
2. Groundwater Model. You can make a simple groundwater model by filling a jar with aquarium gravel, then adding water colored red with food coloring until about half of

the gravel is submerged. Replace the lid tightly. When students turn the jar upside down, they will see the red water flow under the influence of gravity to form a zone of saturation, zone of aeration, and water table. No matter how they orient the jar, these three features reform.

3. Reading Fine Print. Some printed words and numerals on maps are very small and difficult for some students to read. Plastic sheet magnifiers aid in map reading. They can be purchased in most bookstores for a few dollars (or less) each. They also come in large sheet or credit card sizes.
4. Florida Ground Water References (Part 12B). Two useful references are:

Rosenau, J.C., Faulkner, G.L., Hendry, C.W., and R.W. Hull. 1977. Springs of Florida. *Florida Bureau of Geology Bulletin* 31:461p.

Stewart, J.W., and L.R. Mills. 1984. Hydrogeology of the Sulphur Springs area, Tampa, Florida. U.S. Geological Survey *Water Resources Investigations Report*:83-4085.

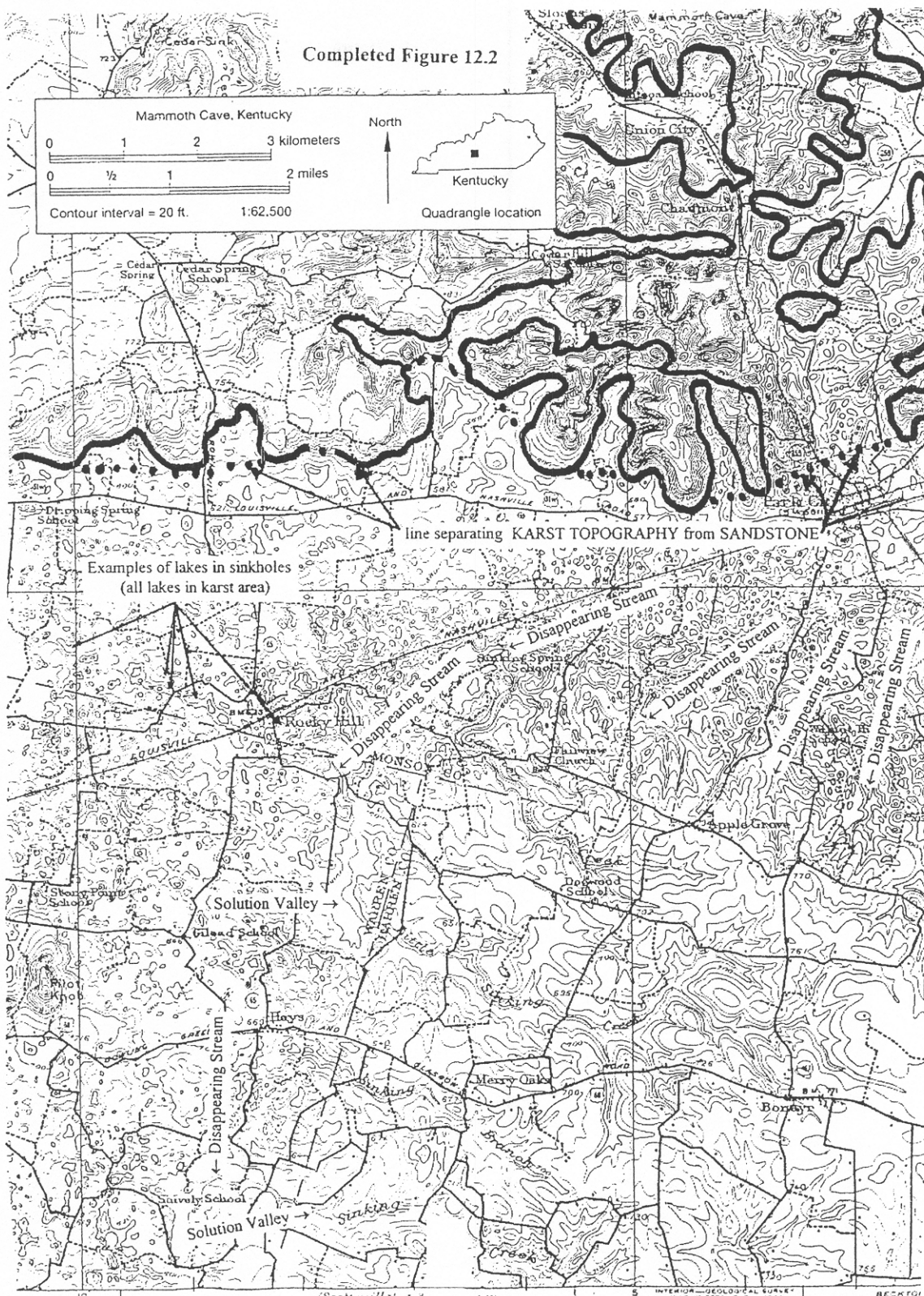
ANSWERS TO QUESTIONS IN LABORATORY 12

Part 12A: Caves and Karst Topography

1. The plants are growing along lines running in two different directions. Ground water into the bedrock must be channeled along these linear features, which probably represent fractures or faults in the bedrock. There are two sets of these fractures/faults at roughly right angles to one another. Surface water probably seeps into the bedrock along these fractures/faults, where it becomes ground water that the plants require for their survival and growth.
2. The groundwater is contained in, and flowing along, the fractures/faults. A well drilled at a point where two or more of the fractures/faults intersect would be expected to produce more water than a well drilled along just one fracture/fault or between the fractures/faults. Aerial photographs made in spring or summer, when plants are growing along the fractures/faults could be used to identify them and locate the best place to drill a well using the above logic.
3.
 - The features in both figures are developing as a result of the solution of limestone bedrock by acidic groundwater.
 - The bedrock in both locations has intersecting fractures/faults along which groundwater flows.
 - Figure 12.5 is a cave that could be developing beneath an area like 12.4.

- 4a. Site B is the most hazardous, because it is located directly over very large caves that are only partly filled with water. The weight of a new home (and the lack of hydrostatic pressure), or vibrations from heavy equipment, may cause the cave roof to collapse and form a large sinkhole.
- 4b. Site C is the least hazardous because it is not located directly over any caves.
- 4c. Drill holes into the bedrock to check for caves beneath the site.
- 5a. -There are sinkholes, small lakes, solution valleys, and disappearing streams on the portions of the map where limestone bedrock occurs at/near the surface of the land.
-The areas underlain by limestone generally are of low elevation and the hills lack steep slopes (because the bedrock is chemically decayed).
- 5b. See the bold black line on completed Figure 12.3 on the next page of this book.
- 5c. Disappearing stream: See completed Figure 12.3 on the next page of this book.
- 5d. Lake in a sinkhole: See completed Figure 12.3 on the next page of this book.
- 5e. Solution valley: See completed Figure 12.3 on the next page of this book.
- 5f. The highest hills in the sandstone region are about 900 feet in elevation. Water levels in the limestone bedrock under the sandstone (seen in flooded sinkholes of solution valleys developed in limestone between sandstone hills) are at elevations of about 580 feet (southern edge of sandstone outcrop) to 660 feet (northern edge of map). So you would have to drill about **320 to 240 feet** to encounter water. For the very highest hill in the northern part of the map, you would have to drill 260 feet to encounter the water level in the limestone.
- 5g. The landscape in the southern part of the map occurs at elevations 40 to 60 feet above the water table (whereas the landscape of the surrounding areas is much lower and closer to the water table), so cave roofs are thicker and have not collapsed as commonly to produce sinkholes.

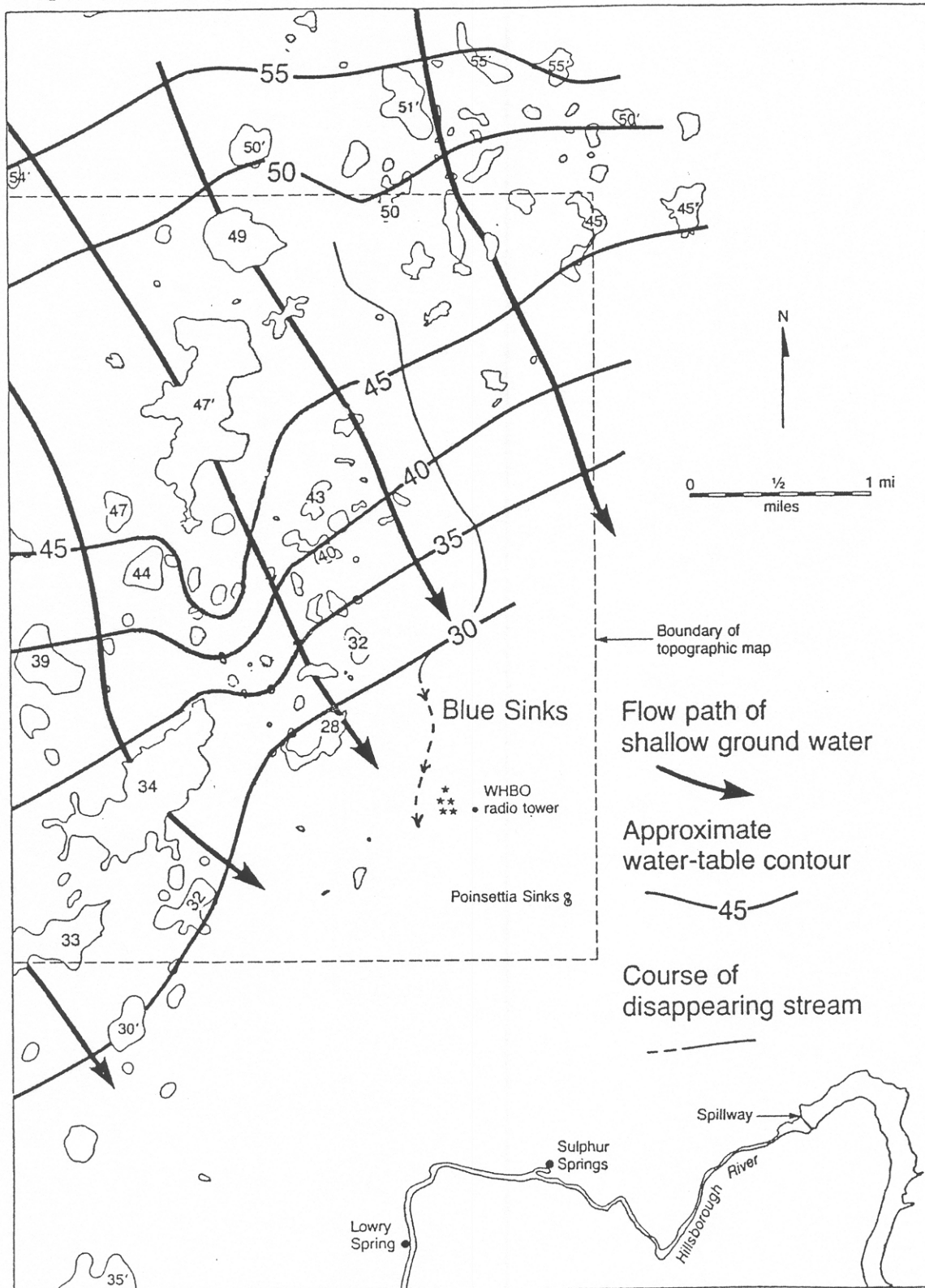
Completed Figure 12.3



Part 12B: Location and Movement of Groundwater in the Floridan Limestone Aquifer

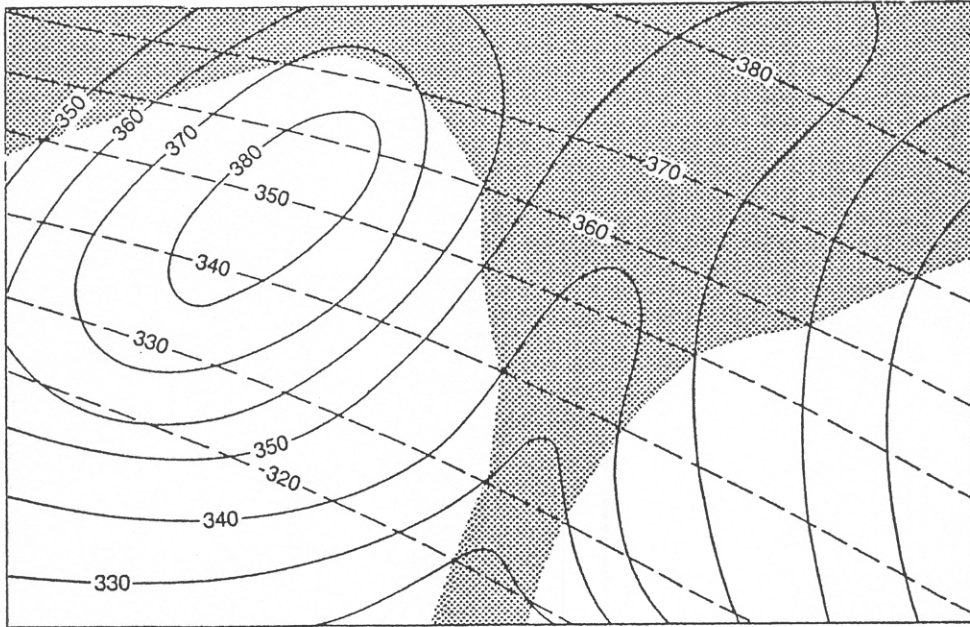
6. See completed Figure 12.8 on the next page of this book.
7. See completed Figure 12.8 on the next page of this book.
8. See arrows drawn on the completed Figure 12.8 on the next page of this book. There are few lakes in the southern part of the map because the water table is generally lower than the bottom of the closed depressions.
- 9a. about 10–15 feet
- 9b. Refer to the course of the disappearing stream as plotted (narrow black line) on completed Figure 12.8 on the next page. The stream generally flows southeast like the slope of the ground water table in the region.
- 10a. about 400 feet/hour
- 10b. about 0.076 miles/hour
- 10c. about 123 meters/hour
- 11a. Student answers will vary widely but should reflect understanding of ground water supply issues. Most of the topographic map in Figure 12.6 is red, indicating the new development that results in more water being withdrawn from the Floridan Aquifer. Many of the new structures are buildings much larger than the size of a typical home, so they may be businesses using more water per day than an average family. Increased pumping and withdrawal of water from the aquifer is reducing the amount of water that reaches Sulphur Springs.
- 11b. Student answers will vary widely but should reflect understanding of ground water quality issues. Greater development of the land produces greater amounts of runoff from roads, parking lots, construction sites, lawns, landfills, and storm drains. Such water contains motor oil, gasoline, trash, and other materials that may chemically or biologically contaminate the aquifer. Also, there are probably sewage pipes (that may leak) and on-site septic systems that provide sewage contamination of the aquifer.
12.
 - subsidence caused by formation of sinkholes
 - flooding in areas of low elevation
 - changes in groundwater level if drainage/supply problems change from human or natural factors
 - possible contamination of groundwater (drinking water supplies) and streams (where people swim, fish, boat)

Completed Figure 12.8



Part 12C: Land Subsidence Hazards Caused by Groundwater Withdrawal

13a–b. See completed Figure 12.12 below.



14. in the center of the valley, near the towns of San Jose and Santa Clara
15. The subsidence from 1934 to 1967 was: $12.7 \text{ feet} - 4.6 \text{ feet} = 8.1 \text{ feet}$.
16. The subsidence rate is 8.1 feet over 33 years, or **0.25 feet/year**.
17. Either of these answers is possible:
 - southeast of San Jose, where the subsidence contours are closest together (Figure 12.11), because this is where the most tilting of the land occurs
 - near the southern end of San Francisco Bay, because increased subsidence will cause present land areas to be flooded
18. No. The darker areas are consolidated rocks that will not impact much if their ground water is withdrawn.
19. The rate was $(12.7 \text{ feet} - 9.0 \text{ feet}) \div 7 \text{ years} = 0.53 \text{ feet/year}$.
- 20a. Water in the San Jose well was at the land surface in 1915.
- 20b. Water in the San Jose well was about 180 feet below the land surface in 1967.
21. Extrapolation of the hydrograph curve (Figure 12.14) to the left suggests that the well may have been artesian before 1915 and that it flowed intermittently through about 1917.

22. There are five fluctuations of equal duration between 1920 and 1925, so these are annual fluctuations caused by seasonal changes in recharge of the aquifer and by variations in discharge from the aquifer for irrigation.
23. From about 1935 to 1948 the water level in this well was above the average rate of subsidence; whereas, in the other years the water level in the well dropped about the same rate as the land subsided. The rate of land subsidence also decreased during the period of about 1935 to 1948.
24. Close inspection of the hydrograph in Figure 12.14 reveals that the dramatic increase in water recharging the well occurred in the years of 1938 through 1944. It took until about 1948 for water levels to again match subsidence rates.

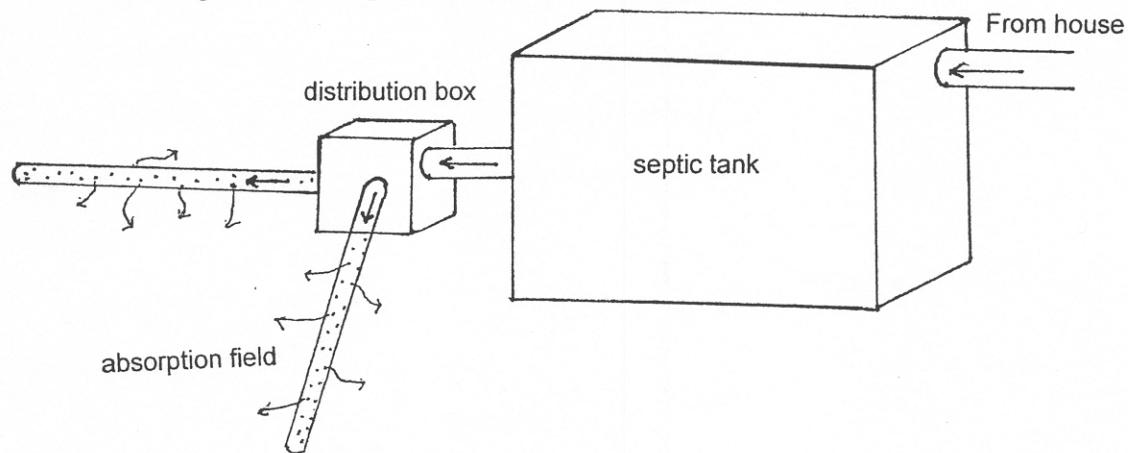
Students may suggest that the years 1938 through 1944 were particularly wet, so the well was recharged at above normal rates. **However, the years 1938–1944 actually correspond to U.S. manufacturing and military efforts for World War II.** Adolf Hitler came into power as head of the Nazi Party in 1933 and German troops invaded Austria in 1938. Japan invaded China in 1932, withdrew, and then launched a full-scale invasion of China in 1937. Consequently, by 1937 the United States was recovering from the Great Depression and was initiating wartime manufacturing industries. Workers from depression-era farms flocked to higher-paying factory jobs created to manufacture war goods for U.S. allies in Europe and the Pacific. Also note the large increase in the well level during 1941, 1942, and 1943. The United States entered World War II in 1941 (when Japan attacked Pearl Harbor) and American men and women flocked to factories and to the military. **Irrigation equipment and farm workers were in short supply, so ground water withdrawal was much reduced and water levels rose in the well.**

25. Some possible reasons are:
 - development and use of ground water conservation practices (voluntary regulation of water use)
 - government and farm regulation of irrigation (government regulation of water use)
 - land use practices may have changed, so fewer farms were available to irrigate
 - more sources of water (dams, lakes, aqueducts from mountain sources) were developed, so reliance on ground water was reduced.

Part 12D: Home Septic Systems and Groundwater Contamination

26. The main purposes of a home (on-site) septic system are to:
 - dispose of wastewater/sewage
 - treat and distribute wastewater/sewage so that it does not adversely affect humans or the environment
 - provide a wastewater/sewage treatment alternative to public systems

- 27a. The **septic tank** is the large main reservoir of wastewater and sewage from a home or business. Bacterial action in the tank breaks down solids, so they can flow out of the tank to the distribution box and absorption field (drain field). Materials that do not break down must be periodically pumped from the tank.
- 27b. Partially treated sewage and wastewater flows to the **distribution box** from the septic tank (by means of a small pipe, or attached directly to the septic tank). The distribution box distributes the fluids to perforated drain pipes of the absorption field (drain field).
- 27c. The **absorption field** (or drain field) is the area of land where the partially treated sewage and wastewater from the distribution box is run through perforated pipes that help spread the fluids to all parts of the absorption field. The pipes are set in a bed of gravel above permeable soil and covered with a porous fabric.



28. -The soil beneath the absorption field must be aerated and permeable so fluids will percolate down through it and bacteria can decompose the sewage. (The soil should pass a percolation test, or “perc test.”)
- The soil beneath the absorption field must not be too permeable (must not perc too fast), or wastewater will flow untreated into the ground and ground water. (The soil must pass a percolation test to be sure that it does not perc too fast.)
- The soil cannot be waterlogged, as in a marsh or swamp, because wastewater would not percolate downward. The absorption field must be constructed in soil above the wet-season water table.
29. -suspended solids (SS)
- nitrogen and nitrates (from human sewage)
- phosphorous (from phosphorous-based detergents and human sewage)
- bacteria (commonly fecal coliform bacteria and *Staphylococcus*)
- viruses (from human sewage)
- hormones (from human sewage)
- helminths (intestinal worms from human sewage)
- intestinal protozoa (unicellular organisms)
- hazardous chemical products (insecticides, paint, drugs, petroleum products, etc.)

- 30.
- Pump the septic tank every 2–4 years to remove solids that did not break down.
 - Avoid flushing dense paper products and other solids into the system because they may clog pipes, not break down, or clog the perforated pipes in the absorption field.
 - Avoid flushing large amounts of grease and soap into the system, which may clog pipes and not break down.
 - Avoid flushing petroleum products, insecticides, paint, etc., into the system because they may kill the bacteria that break down waste and because they may pass through the system and into ground water supplies of drinking water.
 - Periodically add yeast or another septic enhancer to boost bacterial activity in the septic system and enhance sewage treatment.
 - Periodically check for cracks in the sewage tank or distribution box.
 - Do not flush more water into the septic system than it was designed to treat.
 - Do not drive or build over the septic system, because it may crack structures or compact the absorption field (making it less permeable).

G202 Lab 7 Answer Key - Groundwater

1. The linear plant trends are related to fractures in the limestone. The fractures provide enhanced porosity and permeability, and create a conduit for water flow to the root zone.
2. To drill for water in Fig. 11.3, it seems that the fractures provide the greatest permeability. I would want to maximize the rock permeability to produce the greatest volume of water. So, drilling at the intersections of two cross-cutting fractures seems appropriate.
3. Fig. 11.4 shows stalactites (formed by dripping roof water in a cave) that are geometrically arranged along fracture trends. It seems that fractures in the limestones provide enhanced permeability, and encourage the stalactite formation in geometric patterns.
4. Most hazardous home condition is Home B as it is located over a very large cavern, which has significant potential for collapse. The least hazardous condition is Home A, since the bedrock is largely in tact beneath it, with little risk of eminent collapse.

Here are the steps I would take to evaluate sink hole hazards: 1) look at a topographic map for sink hole features in the area, 2) look at a geologic map to assess the spatial distribution of limestone bedrock (since the limestone dissolves to form caves and sink holes), 3) look at a soils map to assess the spatial distribution of limestone-based soils (which would indicate limestone), 4) look for other karst features on air photos like sinking streams, karst springs, etc.

5. a) the limestone crops out in the areas with extensive sink hole development, lack of surface streams, and limited vegetative cover
b) the sandstone crop line pretty much follows the trend of Route 31w, the Louisville and Nashville road (with sandstone to the north, and limestone to the south).
c-e) see attached map for labelled objects
f) the sandstone hills are about 820 ft above sea level (to the north of Rt 31W). The closest sink hole lakes are located just southwest of Park City, and their elevation is about 600 ft. Assuming that the top of the sink hole lakes represent the top of the water table in this region, I would have to drill:

820 ft - 600 ft = 220 ft to hit groundwater beneath the sandstone hills

6. See topo map for lake elevations.
7. See topo map
8. See map for ground water flow lines.

The presence of numerous closed depressions but no lakes in the southeastern part of the map suggests that the groundwater elevation is well below the base of the sink holes in this area.

- 9a. The elevation of the water table at Blue Sinks is about 20 feet, at the base of the sinks.

- 9b. The stream flows south to west of Blue Sinks, where it disappears into a swallow. The general direction of stream flow is parallel to regional groundwater flow.
10. Dye Test Results:
- distance from Blue Sinks to Sulphur Springs = 2.2 miles = 2.2 mi (1 km /0.62mi) = 3.548 km = 3548 m
- travel time of dye = 28 hours
- Velocity = 2.2 mi / 28 hr = 0.079 mi / hr = 0.13 km /hr = 126.7 m /hr
11. a. the abundance of new structures on the map (fig. 11.5) suggests that this is a high growth area. It seems that all these houses depend on groundwater as their primary source. The increased land use of the area has resulted in greater groundwater extraction, and net decrease in discharge to the Sulphur Springs area.
- b. Possible reasons for decrease in water quality include: increased sewage discharge to the groundwater system (due to population growth), increased industrial waste discharge (more people need more jobs and materials from industry), possibly related to decreased groundwater flow.
12. Potential groundwater hazards near Sulphur Springs include: sink hole collapse, excessive groundwater withdrawal and reduced water supply, severe water contamination due to the increased land use and high rates of groundwater flow in this region.
13. See attached map of Fig. 11.11
14. Two areas of greatest subsidence on Fig. 11.10 include Santa Clara and San Jose (both greater than 8 feet subsidence from 1934 to 1967).
15. Total subsidence = 12.7 - 4.6 = 8.1 feet
16. Average annual rate of subsidence = 8.1 feet / 33 years = 0.25 ft / yr
17. Subsidence problems would occur where buildings are located. A building that subsides 5-8 feet will likely be subject to structural and foundation damage.
18. No I would not expect much subsidence in the darker areas, and in fact the map on Fig. 11.10 bears this out. The darker areas represent consolidated bedrock. The zone of subsidence is located in unconsolidated alluvium and bay deposits, which will readily subside during excessive groundwater withdrawal (they are very compressible soft sediments). The bedrock zone is much more competent, and incompressible compared to the sediments.
19. Amount of subsidence from 1960 to 1967 = 12.7 - 9.0 ft = 3.7 ft
- Rate of subsidence = 3.7 ft / 7 yr = 0.53 ft / yr
20. The water level in the well in 1915 was at landsurface (0 ft below surface grade). The water level in 1967 was -180 feet below surface grade.

21. The well would have been seasonally artesian (where the water level was above ground surface) from 1915 to 1917.
22. The minor fluctuations of up and down on the graph reflect seasonal wet and dry weather conditions. In the Bay Area, the weather is very dry in summer (associated with low water level spikes) and wet in winter (associated with high water level spikes).
23. Between 1935 and 1948, the area experienced slow rates of subsidence, with no subsidence at all in 1944. Earlier periods were associated with very high rates of subsidence.
24. The decreased rate of subsidence during 1935-1948 period was associated with active recharge of the regional aquifer, primarily by means of controlled infiltration landuse practices (the book tells you this on p. 201).
25. By 1971, the subsidence of the area stopped. Likely this was due to landuse regulations that prevented over pumping of the aquifer, and changes in groundwater use regulations.

