EXERCISE 16

Groundwater Overdraft and Saltwater Intrusion

INTRODUCTION

Groundwater accounts for about 25 percent of the total fresh water used in the United States, and untapped resources have great potential to meet future needs. Even though vast amounts of groundwater are available, in some areas pumping rates are such that water levels have declined hundreds of feet, wells have gone dry, the cost of pumping the water has increased substantially, and water of poor quality has been induced to flow into aquifers. Areas of large irrigation systems, such as that part of the Great Plains states underlain by the High Plains or Ogallala aquifer, exemplify the problems of groundwater overuse. Irrigation is the largest user of groundwater, although areas of dense population and heavy industry also consume large quantities.

Techniques have been devised to halt or reduce the water-level decline in some water-short areas. The most obvious method is to conserve water and reduce pumping. In other instances it may be possible to divert surface water, including treated wastewater, to infiltration basins, pits, or wells, which will allow the water to percolate into the ground at a rate that is considerably greater than that permitted by natural conditions. These techniques are collectively known as artificial recharge and have been used successfully throughout the world.

In this exercise we examine an agricultural area along the Mississippi River that has seen the groundwater level decline for over 100 years and a southeastern urban coastal region with an even longer period of declining water levels. In the rice-growing Grand Prairie region (east of Little Rock, Arkansas), the Mississippi River Alluvial Aquifer is predicted to soon become useless and a deeper aquifer there is declining as well. In the Savannah, Georgia, area, declining water levels in the coastal Floridan Aquifer are impacting the water supplies of that city and nearby communities including those in South Carolina.

The general objectives of this exercise are to explore changes in water levels and flow directions in overpumped aquifers, the environmental and economic impacts of such changes, and responses to groundwater overdraft in these two settings.

PART A. OVERUSE OF A GROUNDWATER RESOURCE: GRAND PRAIRIE REGION, ARKANSAS

The Grand Prairie region is in east-central Arkansas. This region is characterized by low relief, which, in conjunction with an extensive aquifer and warm climate, provides an ideal setting for rice irrigation. In 1904 the Mississippi River Alluvial Aquifer became the irrigation source for rice farming in the district and since 1915 the water table has declined about 1 ft/yr in some areas. The configuration of the water level in the Alluvial Aquifer in 1915 is shown in Figure 16.1. Concentrated pumping of irrigation water from this sandy aquifer has caused a substantial overdraft in the groundwater supply and a decline in water levels of several tens of feet. The objective of Part A of this exercise is to examine water-level and flowline changes due to overpumping and the responses of the Grand Prairie region.

Groundwater plays a key role in rice production here. As the water level declines, the cost of pumping water increases. In the long run, pumping costs and other farm operating costs could be greater than the value of the crop. The economic impact of a declining water level is obvious.

In order to evaluate the rate and areal extent of water-level decline and to determine remedial measures, maps of conditions in 1915 and 1954 were prepared and evaluated.

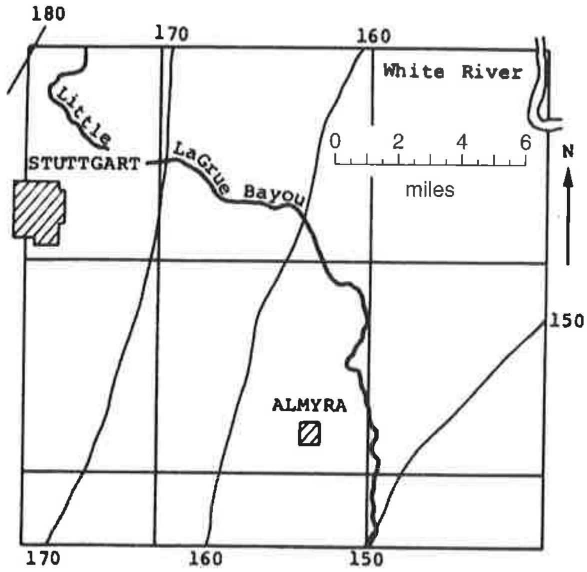

FIGURE 16.1 Altitude (in feet) of water level in Grand Prairie region in 1915.

(Modified from Sniegocki, 1964)

Note: Subsequent studies of the Alluvial Aquifer predict that it will become completely useless by 2015.

QUESTIONS 16, PART A

1. a. On Figure 16.2 construct a map that shows the configuration of the water-level surface in March 1954, using a contour interval of 10 feet. Compare this map with Figure 16.1. What are the major differences?

b. On Figure 16.3 construct a map that shows the net decline of water levels from 1915 to 1954. Use a contour interval of 10 feet. What area has had the greatest decrease in water levels?

c. Starting at the east edge of Stuttgart, draw a flowline across the 1915 map (Figure 16.1). Draw a similar flowline passing through Almyra. What was the general direction of groundwater movement in 1915 at

Almyra?

Stuttgart?

d. On Figure 16.2 draw the flowlines passing through Stuttgart and Almyra. What was the general direction of groundwater movement in 1954 near

Almyra?

Stuttgart?

2. Calculate the gradients that existed in 1915 and 1954 using the flowlines that pass through Almyra.

a. Gradient in 1915:

b. Gradient in 1954:

3. The hydraulic conductivity of the water-bearing deposits averages 260 ft/day, and the effective porosity averages 17 percent. What was the groundwater velocity in the vicinity of Almyra (refer to Exercise 12 for formula details; $v = KI/n_e$)

a. in 1915

b. in 1954

4. Assume that the saturated sand in the northeastern part of Figure 16.2 (along line A–A′) is 40 feet thick. How much groundwater, in ft^3/day, flowed across A–A′ during a single day in March 1954? ($Q = KAI$)

5. Figure 16.3 indicates that there has been a significant lowering of water level. This means that more water is pumped from the aquifer than is flowing into it. This negative change in groundwater storage is termed overdraft. What could be done to decrease the rate of decline, maintain the existing level, or cause the water level to rise?

6. "Ever think you'd run out of water where you live? Neither did the people in the Grand Prairie area of eastern Arkansas. That's why this web site has been created .... so you can understand what the Grand Prairie Area Demonstration Project (GPADP) is all about." At the Army Corps of Engineers website you can see what the area's response was to a study that predicted the loss of the upper Alluvial Aquifer and the decline of the deeper Sparta Aquifer. It was estimated that without the project, rice production would drop to 23 percent of current value, partially replaced by less productive dryland farming, and waterfowl recreation income would decrease. The Sparta Aquifer is the source of high-quality drinking water and, because it was being used

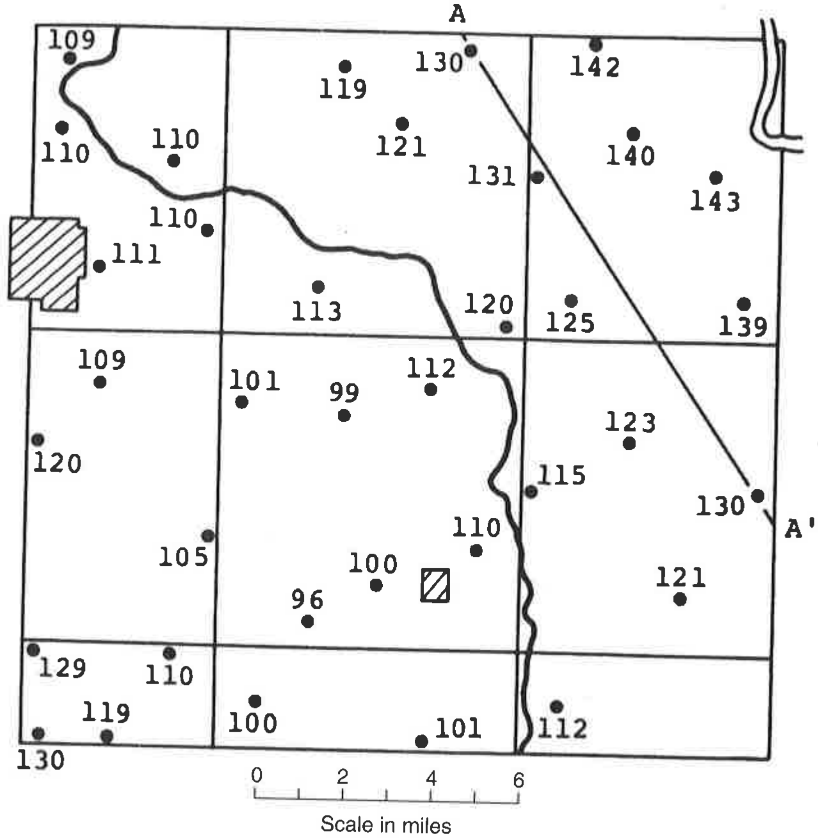

FIGURE 16.2 Altitude (in feet) of water level in Grand Prairie region in March 1954.
(Data from Sniegocki, 1964)

for irrigation too, it also was declining at > 1 foot per year. Farmers did not expect much increase from the Sparta Aquifer because of a low specific yield (~ effective porosity) of only 0.01 (cf., Alluvial Aquifer 0.30) so the capacity was not there. Also the recharge was slow and the cost of pumping was higher and increasing.

Check out the following websites (and others) to determine the expected economic and environmental impacts from the loss of irrigation water in this area of Arkansas known as the rice and duck capital of the world (Stuttgart is the headquarters of Riceland Foods). The brochure (website below) for the project will be particularly useful in answering this question. The site for the Grand Prairie Area Demonstration Project (also known as the Grand Prairie Irrigation Project) is http://www.mvm.usace.army.mil/grandprairie/maps/pdf/GPADProj.pdf. See also USGS Fact Sheet 111-02 at http://pubs.usgs.gov/fs/fs-111-02/, and the news item of July 21, 2006, by L. Satter in the *Arkansas Democrat Gazette* (http://www.nwanews.com/adg/News/161090/) for more information on the project and its status.

a. List two or three types of structures that are to be built in the Grand Prairie Area Irrigation Project.

b. What is the purpose of the project?

c. From where will much of the water come for this project?

d. List several economic and environmental benefits of the project.

e. List several objections that environmental groups have had to the project.

f. Although there have been many starts and stops to the project over decades, what did Judge Bill Wilson do on July 20, 2006?

What was the name of the bird that was a factor in the decision?

g. Why would area farmers not plan to continue expanding their use of the lower aquifer (Sparta Aquifer) but instead would like to use water from the GP Irrigation Project?

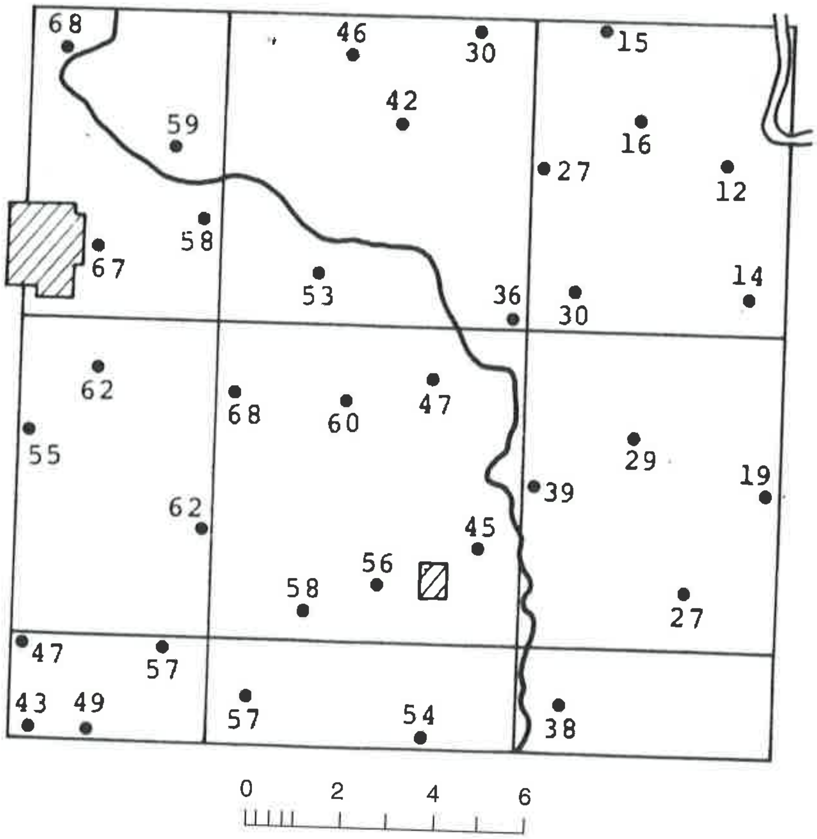

FIGURE 16.3 Net decline of water levels in the Grand Prairie region from 1915 to 1954.
(Data from Sniegocki, 1964)

h. Search online to determine the current status of the irrigation project and any economic and environmental changes that have occurred since 2006 in this area that has been aware of groundwater overdraft for more than 100 years.

PART B. OVERUSE OF A GROUNDWATER RESOURCE: SALTWATER INTRUSION IN A COASTAL AQUIFER

The intrusion of saltwater into a fresh groundwater reservoir is surprisingly common throughout the world. Saltwater intrusion is generally caused by excessive pumping of groundwater and leads to deterioration of water quality. In inland areas it is caused by the upward movement of the fresh- and saltwater interface; in coastal regions it is commonly caused by both vertical and horizontal migration of sea water into a coastal aquifer. For example, during the Dec 26, 2004, tsunami in the Indian Ocean, coastal areas were flooded by seawater. Some wells were filled with saltwater; some freshwater aquifers were contaminated by saltwater infiltrating the land surface.

Although geologic and hydrologic conditions may be exceedingly complex, the mechanics of saltwater intrusion may be visualized in the following manner. Assume that an aquifer crops out on the continental shelf and is hydrologically connected to the ocean. Normally, fresh water discharges from a coastal aquifer into the ocean along seepage faces or through springs (Figure 16.4A). As fresh water is pumped from the aquifer, the water pressure in the aquifer is lowered, reversing the hydraulic gradient (Figure 16.4B). With a reversal in gradient, sea water migrates inland and may eventually contaminate pumping wells.

Occurrences of saltwater intrusion are relatively common in coastal areas. Problem areas include much of the Atlantic coast from Florida to New England and many regions of the west coast where there are large withdrawals of groundwater.

Several techniques have been used to control saltwater intrusion. These include reducing the amount of pumping; constructing physical barriers, such as pumping cement into the rocks (Figure 16.4C); pumping wells nearer to the coast and allowing the water to flow back into the ocean (Figure 16.4D); and artificial recharge (Figure 16.4E). The simplest solution is to reduce pumping, but commonly this is not feasible because of existing water demands. The most promising approaches are artificial recharge and water conservation. In the artificial recharge method, water is injected into the ground through pits and wells. This forms a hydraulic barrier (injection ridge) due to the higher water or water-pressure surface in the vicinity of the recharge sites, which lie between the well field and the coast (Figure 16.4E). The hydraulic barrier tends to reverse the water gradient and forces the saline water out of the aquifer.

In many coastal areas, saltwater intrusion has not yet occurred, but an examination of existing groundwater levels and pumping data indicates that there is a strong potential for future intrusion. If potential saltwater intrusion sites are analyzed before contamination actually occurs, it may be possible to develop adequate solutions before the supply situation becomes critical.

The objectives of Part B of this exercise are to examine water-level declines in a coastal region, areas

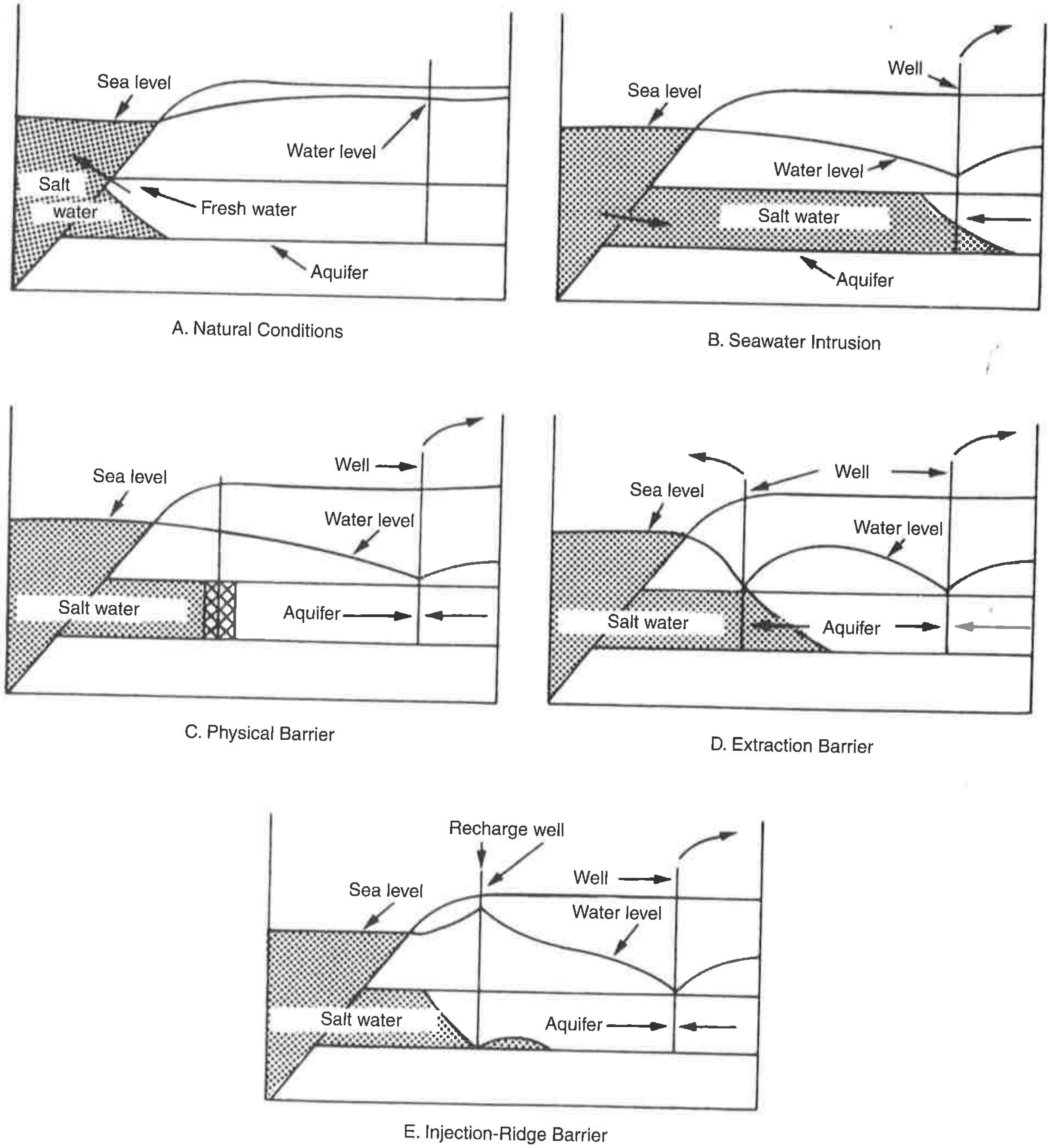

FIGURE 16.4 Saltwater intrusion of a confined coastal aquifer and the use of barriers to prevent contamination of water supplies. Water level is the water-pressure surface (See text for explanation of A through E.)

of potential saltwater intrusion, methods that could be used to halt the intrusion, and community plans for future water needs.

Potential Saltwater Intrusion in the Savannah Area

Large quantities of groundwater are used in the Savannah, Georgia, area for industrial, municipal, and domestic purposes. The first water well in the Upper Floridan Aquifer was drilled in 1885; between 1900 and 2000, the pumping rate increased from 10 million gal/d to 300 million gal/d. Over the years, water levels in wells have declined to more than 120 feet below sea level. This has caused concern that the water supply might become seriously depleted or contaminated. Most of the groundwater used in the Savannah area is pumped from a confined, limestone aquifer that lies about 100 feet (northeast) to 350 feet (southwest) below land surface.

Although groundwater in the Savannah area has not yet become salty, the supply at Parris Island, about 25 miles northeast, has deteriorated due to saltwater intrusion. The pumping of groundwater in the Savannah area will no doubt increase and, as a result, intruding saltwater may eventually reach the pumping center and contaminate the water supply.

The Savannah River, which flows through the area, has been used as a partial source of water, but locally it is contaminated by industrial and municipal wastes. Furthermore, water can only be withdrawn from it at certain times because the river is influenced by tidal waters of high salinity.

In addition to these impacts on the local ground water supplies, rising sea levels will further increase the salinity and decrease storage space in some coastal aquifers.

QUESTIONS (16, PART B)

1. A water-level map of the Savannah area representing conditions that existed in 1880 is shown in Figure 16.5. Construct four equally spaced flowlines showing the direction of groundwater movement in 1880. Remember that flowlines cross the water-pressure contours at right angles. What was the general direction of flow? Was groundwater at Parris Island likely to have been salty in 1880? Why or why not?

2. Using Figure 16.6, construct a water-level map showing the conditions that existed in 1961. Use a contour interval of 10 feet down to the −40 feet level, then use an interval of 20 feet.

3. Starting at the southwest and northwest corners of Figure 16.6, and at Parris Island, construct flowlines showing the general direction of groundwater movement in 1961. In what general direction was the water moving

a. in the southwest corner?

b. in the northwest corner?

c. at Parris Island?

4. Study Figure 16.7 and describe the changes from 1961 to 1984 at Hilton Head Island, Savannah, Georgia, and 25 miles up the Savannah River from the center of the cone of depression.

5. How much has the water-pressure surface been lowered at Savannah between 1880 and 1984?

6. From what area do you expect the fresh water/saltwater interface to first reach the Savannah area? SW or NE (circle one) Why? (Hint: Examine the water-level contours, and the variation in depth of the aquifer described in the introduction.)

7. Figure 16.8 is a cross section extending into Port Royal Sound from the NE end of Hilton Head Island showing simulated changes in the brackish and salt water zones for the years 2000, 2016, and 2032. The model assumes no change in the rates of groundwater withdrawals on Hilton Head Island or inland near Savannah.

a. What value is used as the transition between freshwater and brackish water?

b. In the period between 2000 and 2032, how many meters will the brackish/freshwater interface have moved?

c. What is the average annual rate of projected advance of this interface between 2000 and 2032?

d. About when will the interface reach the edge of the island?

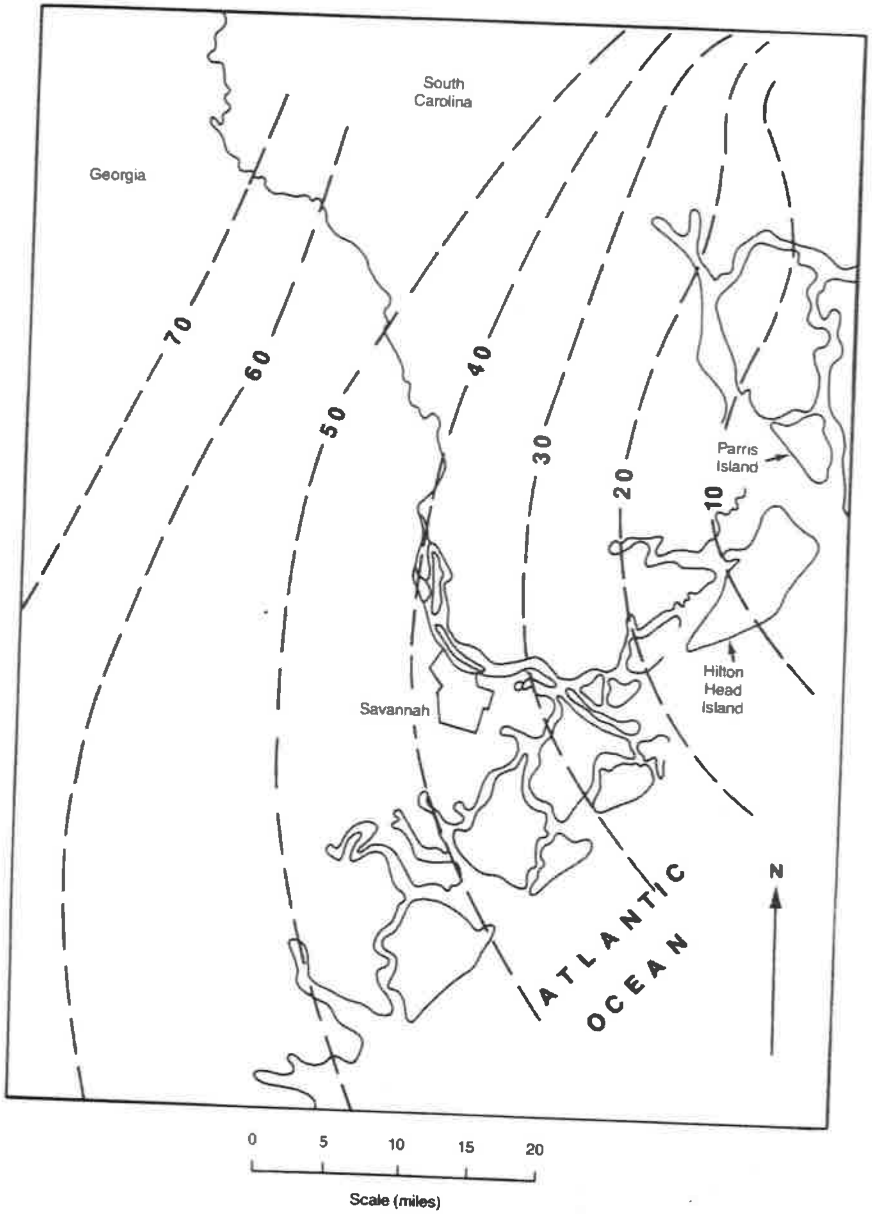

FIGURE 16.5 Altitude (in feet) of water level in the Savannah area in 1880. (Modified from Wait and Callahan, 1965)

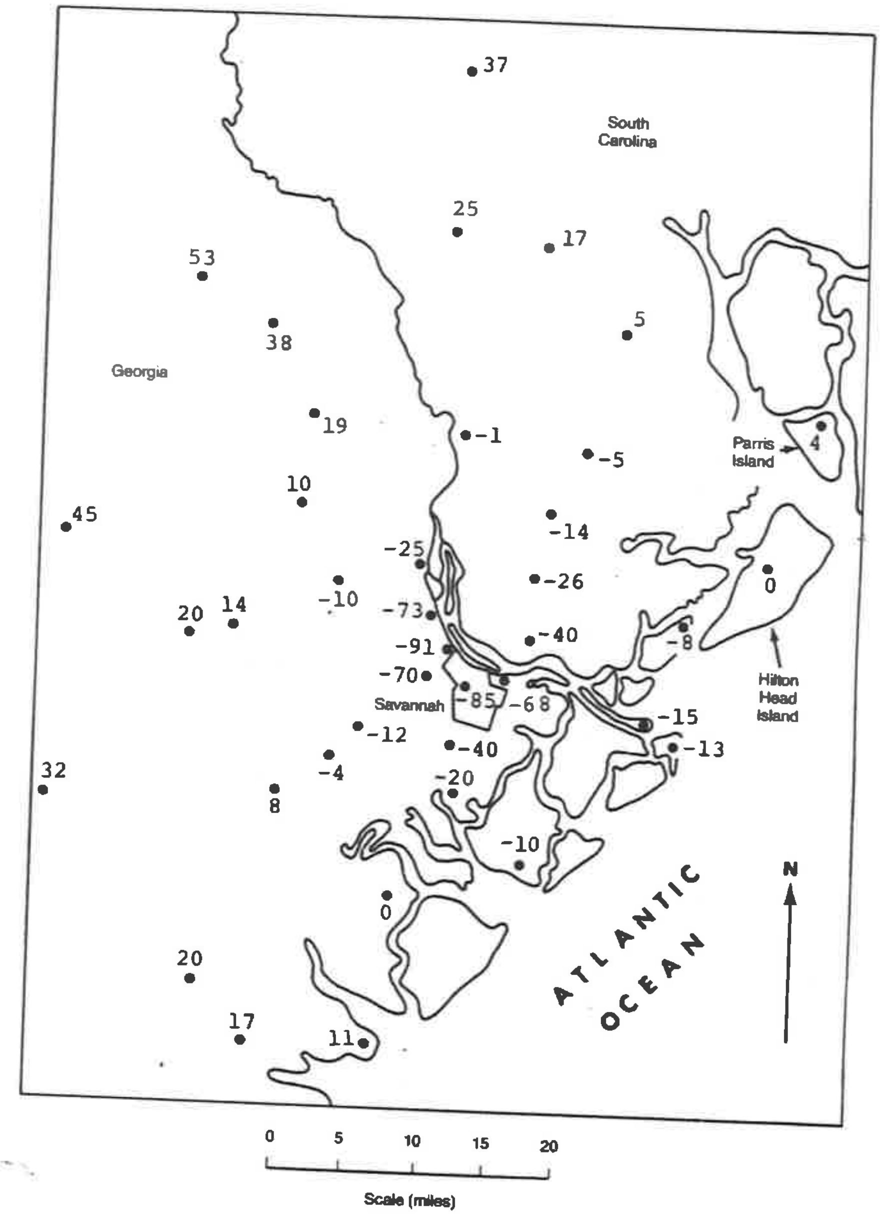

FIGURE 16.6 Altitude (in feet) of water level in the Savannah area in 1961. (Data from Wait and Callahan, 1965)

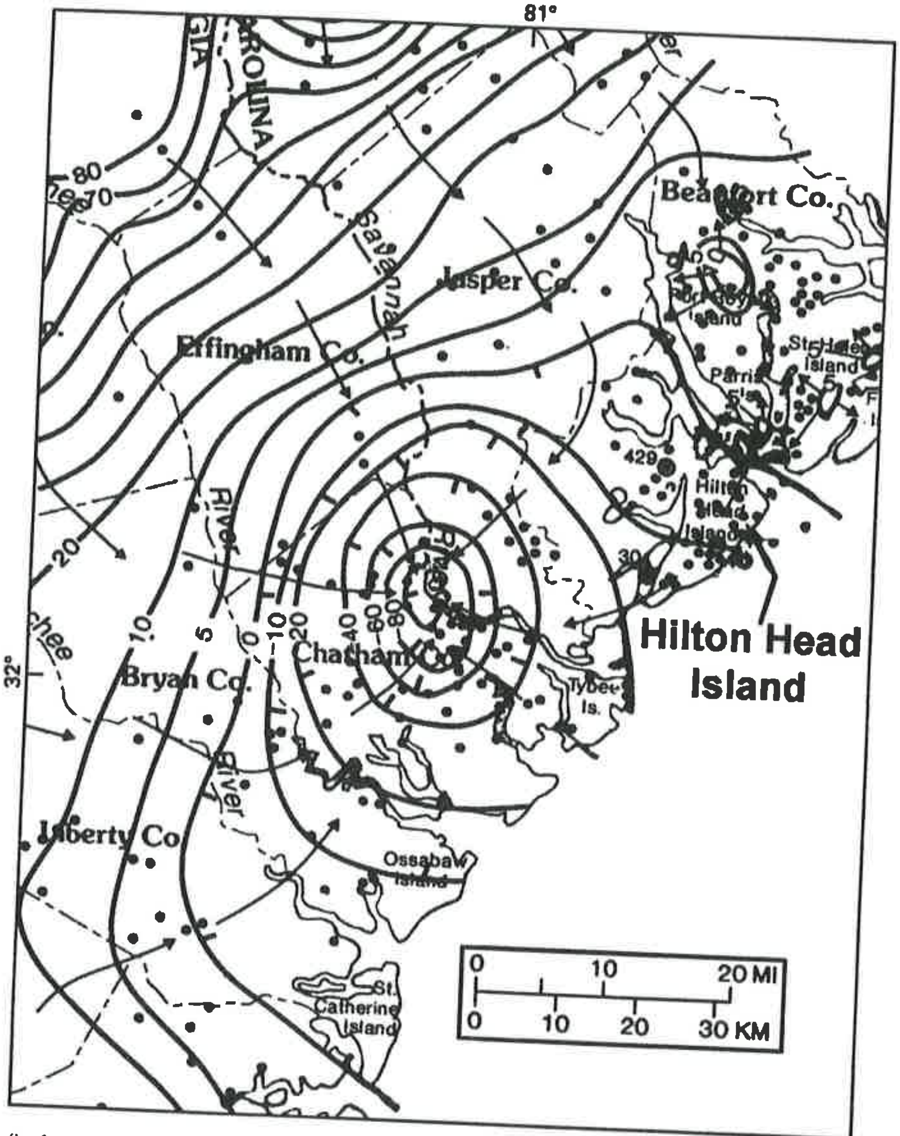

FIGURE 16.7 Altitude (in feet) of water level in the Savannah area in 1984. Dots are wells; arrows indicate general direction of groundwater flow. Parris Island is north across Port Royal Sound from Hilton Head Island.

(Modified from Smith, 1988)

8. a. What techniques might be used to halt or slow saltwater intrusion into the area of Hilton Head Island? (Consider engineering and management techniques [Figure 16.4] to stop the advance of the brackish water in the aquifer beneath the sound and the island).

b. Explain Figure 16.4E or one other provided by your instructor.

Read the following information and then answer **Questions 9 and 10** below. Groundwater overdraft in the Floridan Aquifer System of the southeastern coastal region has produced cones of depression in SE Georgia and neighboring South Carolina. The decline in artesian pressure in this porous limestone/dolostone aquifer has resulted in saltwater intrusion in the coastal areas. Some of the intrusion is lateral from the ocean or downward from eroded river channels (as near Hilton Head, SC) or upward through fractured limestone units in the Lower Floridan Aquifer as at Brunswick, Georgia. Georgia recognized that the rate of decline in the water pressure surface (water table) and the increasing salinity posed a threat to sustainable water resources in the region. A 1997 report described the conditions and trends in the Floridan Aquifer, a primary water supply source for many in the region. An *interim strategy* (1997–2005) was developed to reduce further overdraft of the aquifer, pending the Sound Science Report (released in 2005).

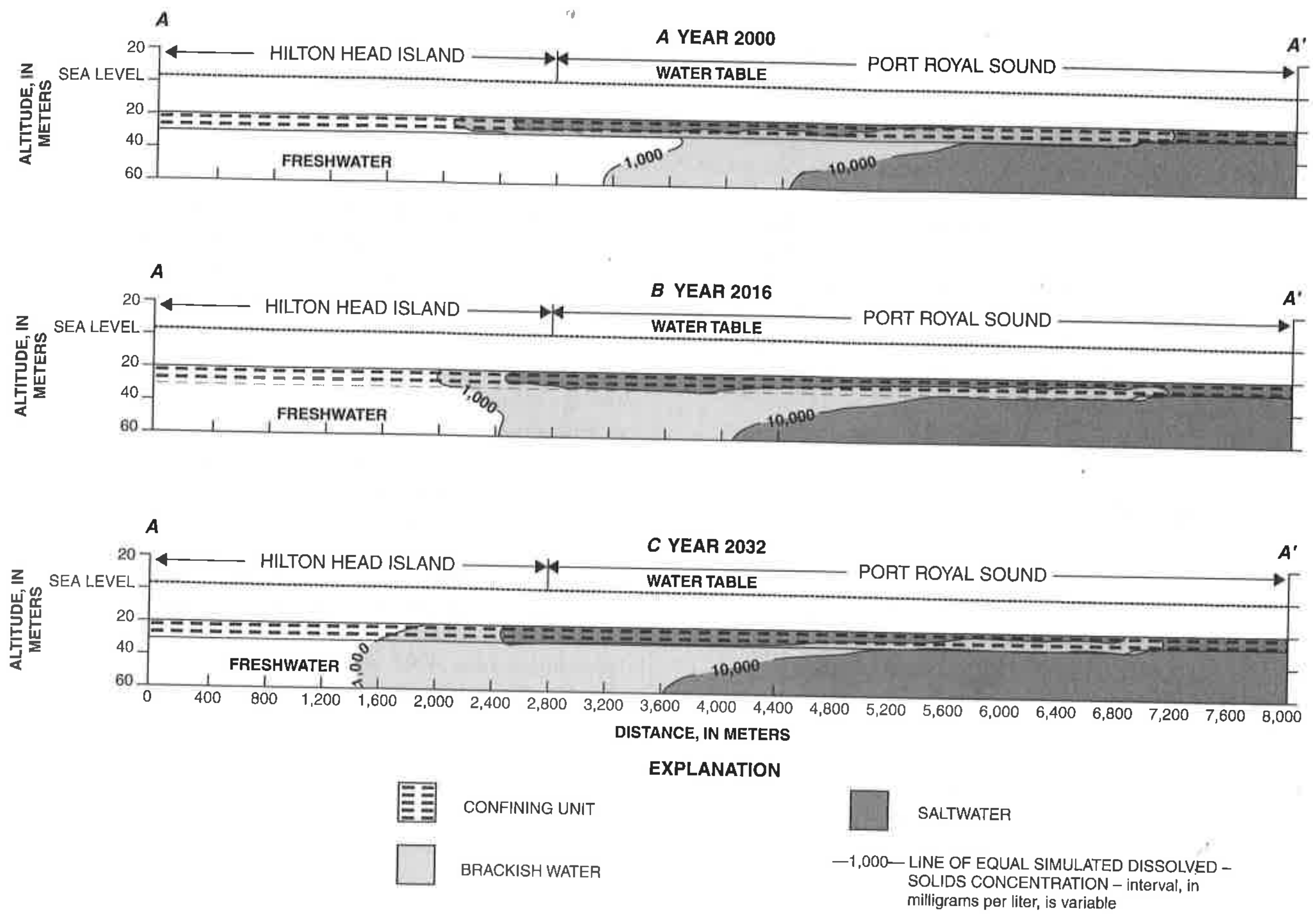

FIGURE 16.8 Simulated dissolved-solids concentrations in the aquifer beneath Hilton Head Island and Port Royal Sound. Modeling shows changes in the confining bed and the aquifer for the years 2000, 2016, and 2032, assuming no changes in withdrawal rates for Hilton Head and Savannah area. The clayey-silt confining unit contains slowly moving fresh, brackish, and salt waters.

(From Smith, 1994)

The interim regulations (until release of the 2005 report) included the following: (1) reduced the quantity of water available for withdrawal under current permits (essentially capping future withdrawal at 1997 levels), (2) allowed no new permits in worst areas, instead suggested surface sources, (3) made 36 million gallons per day additional extraction available outside the worst areas, (4) required 24 coastal communities to prepare plans for future water needs [this focused the need for land-use planning and consideration of possible population growth], and (5) required additional monitoring wells and modeling of groundwater flow [Florida and South Carolina also increased monitoring of their *Upper* Floridan Aquifer]. Additional use of the *Lower* Floridan Aquifer was discouraged until connections between the two aquifers was understood.

In addition to what you learned about the scope of the declining water pressure surface and possible engineered barriers to saltwater intrusion from other questions in this exercise, use the interim regulations and description above to help answer **Question 9.**

9. As a community leader of one of the 24 small communities in the region, you have been asked to join a team to develop your community's plan for future water needs. Before the first meeting of this new committee, all the members of the committee are asked to prepare a list of short statements or items that should be part of the discussion for planning future water needs. You organize and complete your response under the following headings:

a. List of data needed to make the plans for future water needs.

b. List of possible objectives for a sustainable community (for next 50 years) and your preferred objective.

c. List of possible options that could be considered for meeting your water needs for the community.

d. List of factors that might make an unsustainable community with respect to water resources (even with a plan for sustainable water resources).

10. Now use information from the Sound Science Report (2005) that is available from several sources online and indicated below to prepare a water supply plan for your community. (Your instructor may assign this as an in-class or homework activity. Check the reference section of this manual for additional references. You may choose to submit your responses on a separate sheet of paper.)

The key questions to be answered now are:

a. Will engineered barriers to prevent saltwater intrusion be suitable for your community? (See http://www.gadnr.org/cws/Documents/What_Have_We_Learned.pdf)

b. A plume of salt water in the vicinity of Hilton Head Island has advanced 6 miles since 1965. By 2005, what was the average rate of advance in feet per year over that period?

c. From the information available in the 2005 Sound Science Initiative report, how long would it be before there is a problem with the aquifer in the Savannah area of Georgia?

d. What are the alternatives for meeting water needs according to what you have found in your searches? (http://www.gadnr.org/cws/Documents/Determining_Future_Water_Demand_Needs_Water_Systems.pdf)

e. What are the recommendations that you (or your group) would make to provide (possibly through several sources) sustainable water supplies for your coastal community. Consider changing populations and climates in your recommendations. (Optional additional information: http://www.gadnr.org/cws/Documents/saltwater_management_plan_june2006.pdf)

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