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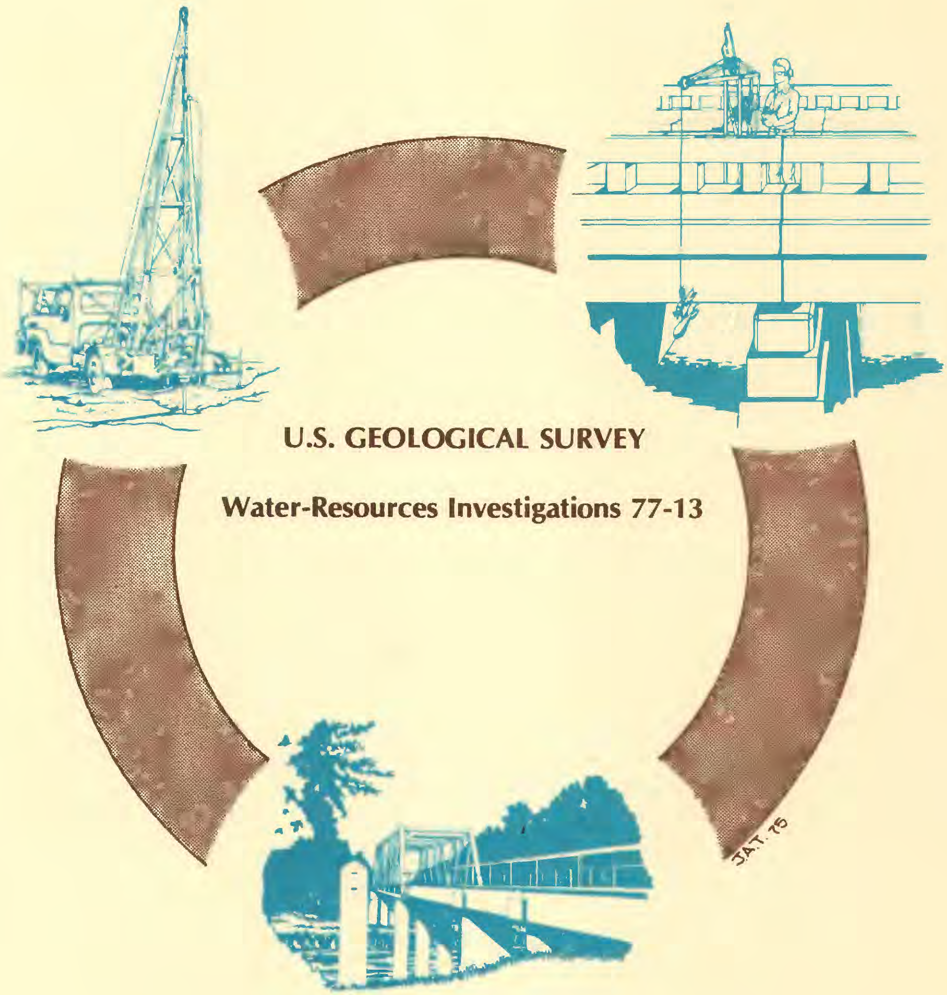
EXPERIMENTAL STUDY OF ARTIFICIAL RECHARGE ALTERNATIVES IN NORTHWEST HILLSBOROUGH COUNTY, FLORIDA



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Prepared in cooperation with the
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

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16. Abstracts

Extensive water withdrawal from the Floridan aquifer in the urban Tampa Bay area has induced leakage from the overlying surficial aquifer adversely effecting the water table and lake levels. Artificial recharge could reduce the impact of these adverse effects. Four experiments were conducted to investigate possible recharge alternatives; sinkhole recharge, water-spreading, connector wells, and subsurface-tile drainage to a deep well. Experiments indicate that all four methods can be effective. However, the sinkhole recharge experiment moved the greatest volume of water into the Floridan aquifer. The drain-tile experiment indicated greatest potential for draining the surficial aquifer. Combinations of the four methods could be used where potential exists for downward movement of water and sufficient unsaturated aquifer for water storage.

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UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

For additional information write to:

U. S. Geological Survey
325 John Knox Road, Suite F-240
Tallahassee, Florida 32303

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EXPERIMENTAL STUDY OF ARTIFICIAL RECHARGE ALTERNATIVES IN NORTHWEST HILLSBOROUGH COUNTY, FLORIDA

By

William C. Sinclair

ABSTRACT

Withdrawal of water from the Floridan aquifer in the urban Tampa Bay area is large. The average daily withdrawal from three major municipal supply well fields was about 9.5 million cubic feet in 1972. This large withdrawal induced leakage from the overlying water-table aquifer which has lowered the water table and lake levels. Artificial recharge could reduce the impact of these adverse effects. Four experiments were designed and carried out to investigate possible recharge alternatives in a 30-square mile area in northwest Hillsborough County.

The four recharge methods investigated were: (1) Sinkhole recharge- Those sinkholes having good hydraulic connection with the Floridan aquifer are an important means of natural recharge. Recharge could be increased by about 3.65 million cubic feet per year by maintaining a high water level in the sinkhole. (2) Water-spreading - Testing indicates that recharge to the surficial aquifer could be increased by water spreading. Recharge to the Floridan aquifer, however, would not be increased appreciably unless a good hydraulic connection exists between the surficial and Floridan aquifer at the water-spreading site. (3) Connector well - Connector-well experiments, designed to drain the surficial aquifer to the Floridan by gravity flow, have a potential to recharge about 535,000 cubic feet per year per well under the prevailing geologic and hydrologic conditions in the study area. (4) Subsurface-tile drainage - It is estimated that recharge by subsurface-tile drainage to a connector well open to the Floridan aquifer would recharge about 1.3 million cubic feet per year per 1,000 feet of tile.

The recharge experiments indicate that all four of the methods investigated can be effective. However, the sinkhole recharge experiment resulted in moving the greatest volume of water into the Floridan aquifer. The drain-tile experiment indicated the greatest potential for draining the surficial aquifer. Combinations of the four methods could be used in areas where there is potential for downward movement of water and a sufficient thickness of unsaturated aquifer for water storage.

CONVERSION FACTORS

For use of those readers who may prefer to use metric units rather than English units, the conversion factors for the terms used in this report are listed below:

English	Multiply by	Metric
in (inches)	2.54	mm (millimeters)
ft (feet)	.3048	m (meters)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.59	km^2 (square kilometers)
ft^3 (cubic feet)	.02832	m^3 (cubic meters)
Mft^3 (million cubic feet)	28,320	m^3 (cubic meters)
acres	.4047	ha (hectares)
ft^2/d (feet squared per day)	.09291	m^2/d (meters squared per day)
$(ft^3/min)/ft$ (cubic feet per minute per foot)	.09291	$(m^3/min)/m$ (cubic meters per minute per meter)
$(ft^3/d)/mi^2$ (cubic feet per day per square mile)	.0176	$(m^3/d)/km^2$ (cubic meters per day per square kilometer)

INTRODUCTION

Extensive water-resources development in an area north of Tampa, Florida (fig. 1), combined with a period of below-normal precipitation, has appreciably altered the natural hydrologic regimen in the area. Three major public-supply well fields have been established in northwestern Hillsborough and northeastern Pinellas Counties, and numerous drainage ditches and flood-control channels have been constructed. During 1960-70, precipitation was below normal in all but 2 years. This has resulted in decreased ground-water recharge, and lowered ground-water levels and lake levels in the area.

In 1972, withdrawals from the Floridan aquifer at the Eldridge-Wilde, Cosme, and Section 21 well fields (fig. 1) were about 9.5 Mft^3/d. This large withdrawal has lowered the potentiometric surface of the Floridan aquifer, thus increasing the difference in head between the potentiometric surface of the Floridan and the water table in the surficial aquifer. The greater head difference has caused increased downward leakage from the surficial aquifer and a decline in the water table and lake levels.

The effects of pumping are most obvious in the vicinity of the Section 21 well field. This field was completed in 1962 and pumpage from a 1-mi^2 area averaged about 2.3 Mft^3/d in 1972. Before 1962 the water level in an observation well finished in the Floridan aquifer near the center of pumping in the Section 21 well field averaged about 46 ft above sea level, with fluctuations due primarily to variations in precipitation (fig. 2). Beginning in 1963, when pumping started, the water level declined to lows of 28 ft during the summers of 1968, 1971, and 1972.

The changes in the hydrologic regimen have led to conflicts among water users and to an increased interest in the feasibility of augmenting natural ground-water recharge to the Floridan aquifer. In 1968, the U. S. Geological Survey, in cooperation with the Southwest Florida Water Management District, began an investigation to evaluate the feasibility of artificial recharge by diverting surface runoff from local watersheds. The area of investigation consists of about 30 mi^2 within the area affected by well field pumping (fig. 1). The terrain is characterized by low relief and by numerous sinkhole swamps and lakes. The low gradients of the swales and streams result in sluggish discharge. The sinkhole swamps and lakes fill when precipitation is great, then spill one into another as the water moves generally southwestward toward the gulf or Tampa Bay. Runoff accounts for nearly one-third of total precipitation, and evapotranspiration about two-thirds. Natural recharge to the Floridan aquifer is about 1 percent of precipitation (Cherry and others, 1970).

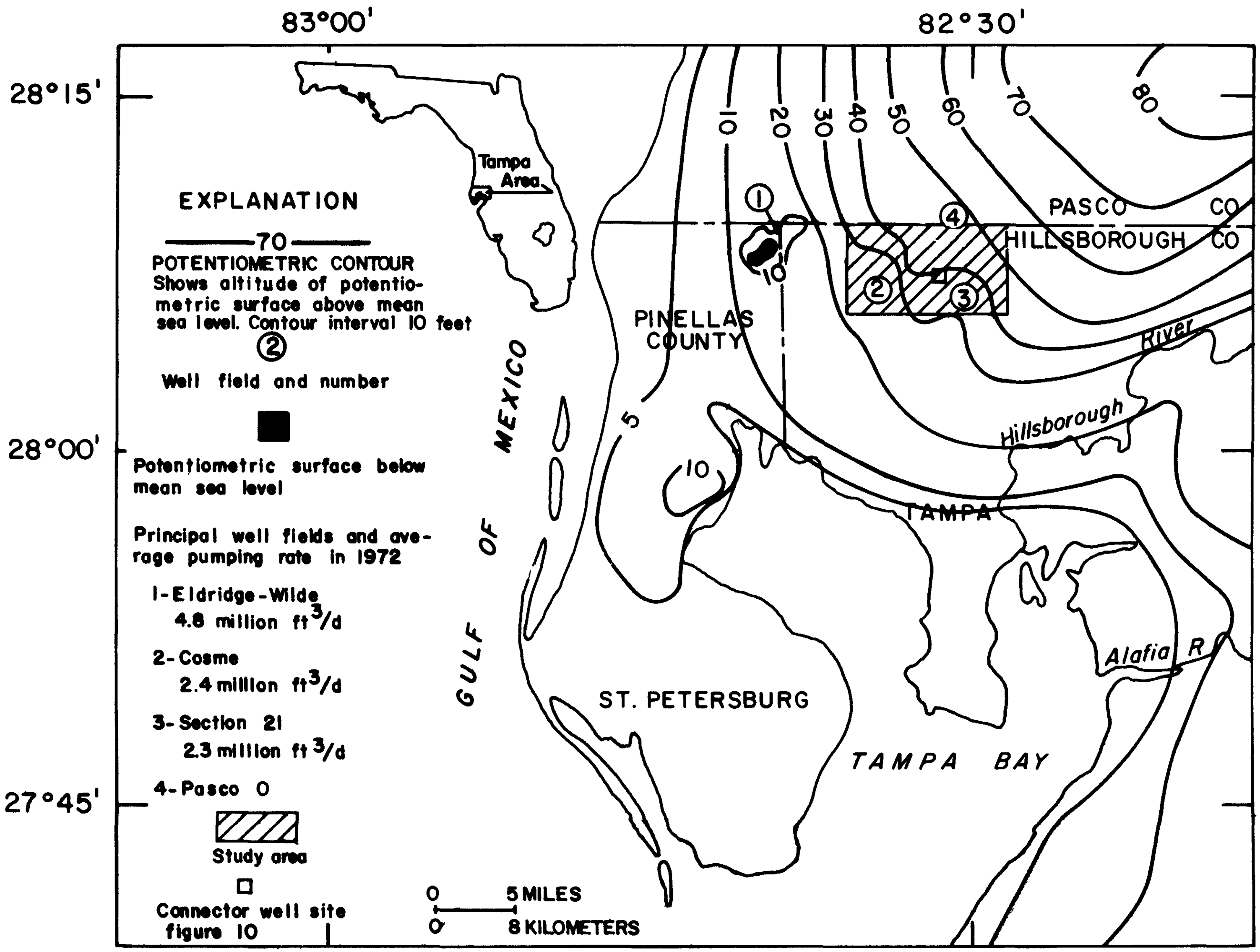


FIGURE 1.--Principal well fields and contours on the potentiometric surface of the Floridan aquifer in the Tampa area, May 1972.

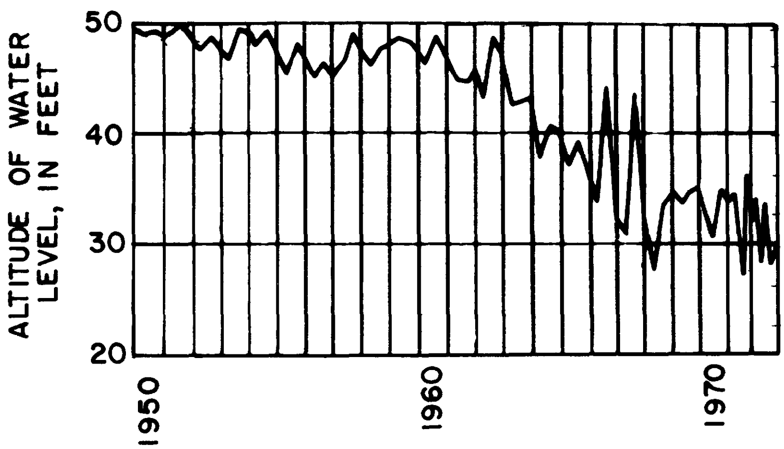


FIGURE 2.--Fluctuations of the potentiometric surface of the Floridan aquifer in the Section 21 well field.

Analysis of 10 years of streamflow records for two small streams in the study area indicates an average runoff of 96,000 $(ft^3/d)/mi^2$. The two watersheds are typical of the terrain throughout the study area. The low topographic relief and high rates of evaporation combine with the irregular and seasonal nature of the precipitation to make surface retention of water infeasible.

The results of test drilling in the study area were used to select several sites for recharge experiments. Conditions at the sites are thought to be representative of conditions presumed favorable for enhancing recharge. The experiments included diverting flow directly into a sinkhole swamp, spreading water over a sandy plain, recharging by gravity flow through connector wells, and installing drain tile to collect water and route it to a recharge well. The purpose of this report is to describe the hydrogeology of the study area as it affects recharge potential, describe the experiment and, based on the results, assess the potential for artificial recharge in the area.

Piezometers installed to monitor the effects of the connector-well and drain-tile tests were numbered on the basis of their location and depth. For example, well 2-20S-5 is 20 ft south of well C-2 and is 5 ft deep. Piezometers installed in a line away from the drain tile are all 5 ft deep and are numbered d-2, d-5, d-15 and so on to indicate they are 2, 5, and 15 ft distant from the drain tile.

The cooperation of the City of St. Petersburg Water Department is gratefully acknowledged, particularly the cooperation of Mr. Leon Jackson, manager of the City's water plant at Keystone, for allowing experiments within their Section 21 well field and for providing water for flooding Swamp Sink.

Mr. Ward Dougherty graciously allowed access to the Dundee Ranch for test drilling and permitted construction of facilities for the connector well and drain-tile experiments on the ranch property. The cooperation of Mr. Charles Moore, ranch manager, is also gratefully acknowledged.

The advice and assistance of Kenton Inglis and Rankin Peeden of the Soil Conservation Service, United States Department of Agriculture, Tampa, was of great value in designing and laying out the drain tile.

HYDROGEOLOGY

Two major aquifers are defined in the study area: the Floridan aquifer and the surficial aquifer. In most places, the two are separated by a clay confining bed.

The Floridan aquifer is tapped by most large-capacity wells and consists of a section of Tertiary limestone and dolomite several thousand feet thick. The freshwater part of the aquifer extends to more than 1,000 ft below sea level in the vicinity of the major well fields north of Tampa (fig. 1). The freshwater-saltwater interface slopes upward toward the Gulf of Mexico and is at sea level along a line nearly coincident with the shoreline.

Transmissivity of the Floridan aquifer in the study area is considered to be about 73,500 ft^2/d. The storage coefficient is about 1.0×10^{-4} (Stewart, 1968).

The regional gradient of the potentiometric surface of the Floridan aquifer is southwestward, from the topographically high area in the northeast, toward the Gulf of Mexico (fig. 1). The water is under artesian pressure throughout the area of figure 1 except in the immediate vicinity of some of the well fields during periods of heavy pumping.

A dense, plastic clay overlies the limestone of the Floridan aquifer throughout most of the study area. Thickness of the clay layer ranges from zero to about 10 ft. The clay layer is perforated by sinkholes where drainage through solution cavities in the limestone has caused stoping of the overlying surficial material. The clay layer is also absent where pinnacles of limestone stand above the general limestone surface. Vertical hydraulic conductivity of the clay is 1.3×10^{4} ft/d as determined by consolidation tests (Sinclair, 1974, p. 11). The relatively low value indicates that the clay layer acts as an effective confining bed, retarding movement of water from the surficial aquifer to the Floridan aquifer.

The upper part of the surficial aquifer consists of well sorted, fine-grained sand and the lower part consists of laminated sand and sandy clay overlying the clay bed. Thickness of the surficial aquifer averages about 40 ft. Transmissivity of the surficial aquifer in the test areas ranged from 270 to 430 ft^2/d depending upon aquifer thickness. Storage coefficient is about 0.20.

The water table in the surficial aquifer ranges from 3 to 5 ft below land surface through the flatwoods. It is at land surface or just below land surface where swamps are extensive, and is above land surface where sinkhole depressions in the land surface form cypress heads or lakes. The water table ranges from 5 to 15 ft above the potentiometric surface of the Floridan aquifer throughout the Tampa area, except near the well fields where pumping from the Floridan has increased the head difference.

LEAKAGE

Recharge to the Floridan aquifer occurs by downward leakage from the surficial aquifer. Pumping from the well fields has lowered the potentiometric surface of the Floridan aquifer, thus increasing the head differences between the two aquifers. As a result, the amount of leakage has increased over pre-pumping conditions, and cone of depression has developed in the water table of the surficial aquifer.

In the Section 21 well-field area, the potentiometric surface of the Floridan aquifer from May 15, 1972, (fig. 3) can be compared to the configuration of the water table for the same day (fig. 4). Although the cone of depression in the water table is deepest within the immediate vicinity of the pumped wells, water-table depressions do not coincide exactly with the cones of depression in the Floridan aquifer. This difference is due to local variations in vertical hydraulic conductivity and thickness of the surficial aquifer and confining layer. Southeast of Section 21 well field, for example, the water table is depressed to an altitude of less than 42 ft about to the same level as the potentiometric surface. Logs of test holes in this area indicate that the clay layer is thin or absent and the limestone is relatively close to the land surface (Sinclair, 1974).

Lake Charles, Saddleback Lake, and Round Lake (figs. 3 and 4) are being maintained at their natural levels by water pumped from the Floridan aquifer (Stewart and Hughes, 1974). As a result, the water table in the surficial aquifer is high in the vicinity of these lakes, even through considerable leakage is taking place. The head impressed by the leakage on the potentiometric surface of the Floridan aquifer is quickly dissipated (fig. 4) because of the relatively high transmissivity of the limestone.

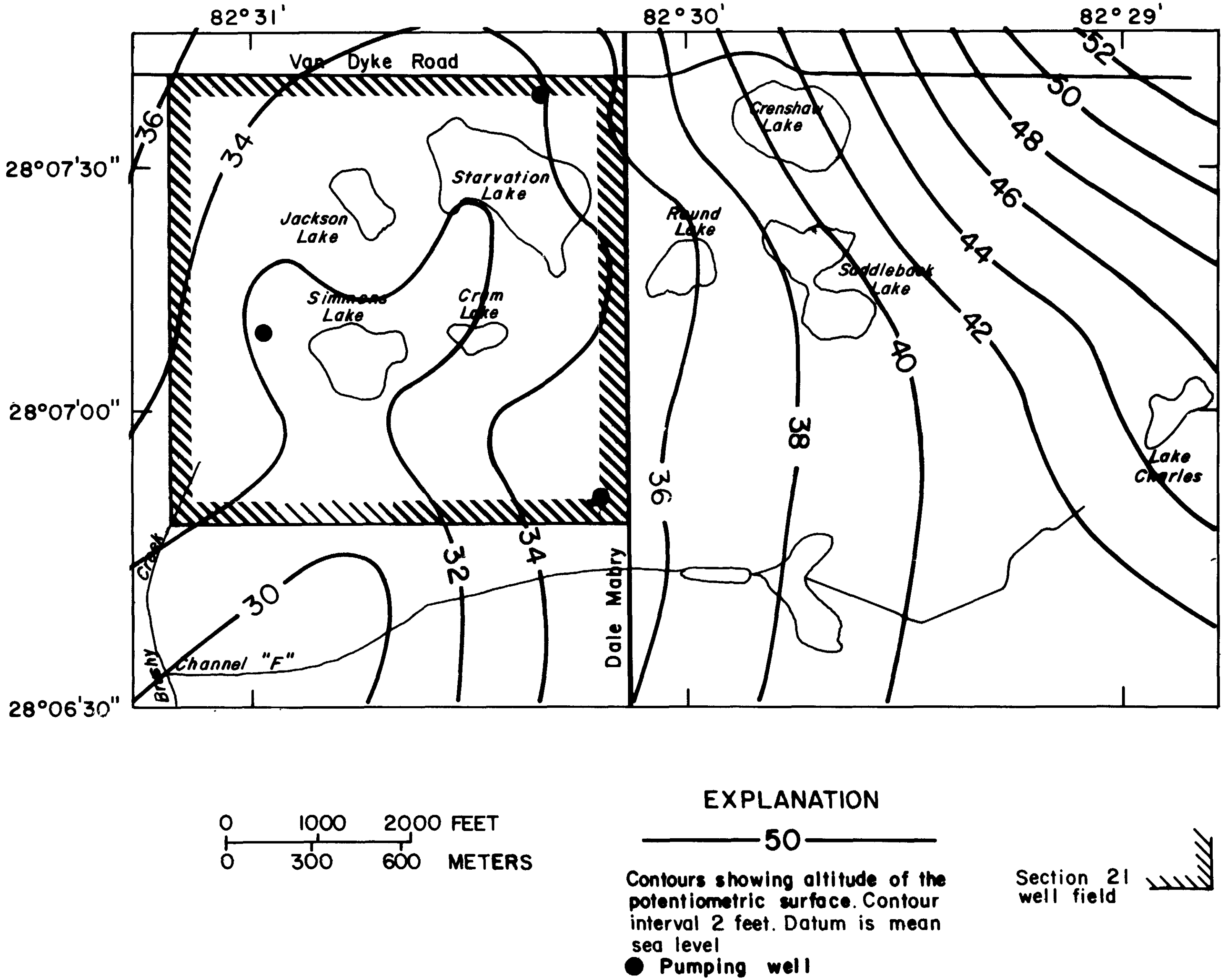


FIGURE 3.--Contours on the potentiometric surface of the Floridan aquifer, Section 21 well-field area, May 15, 1972.

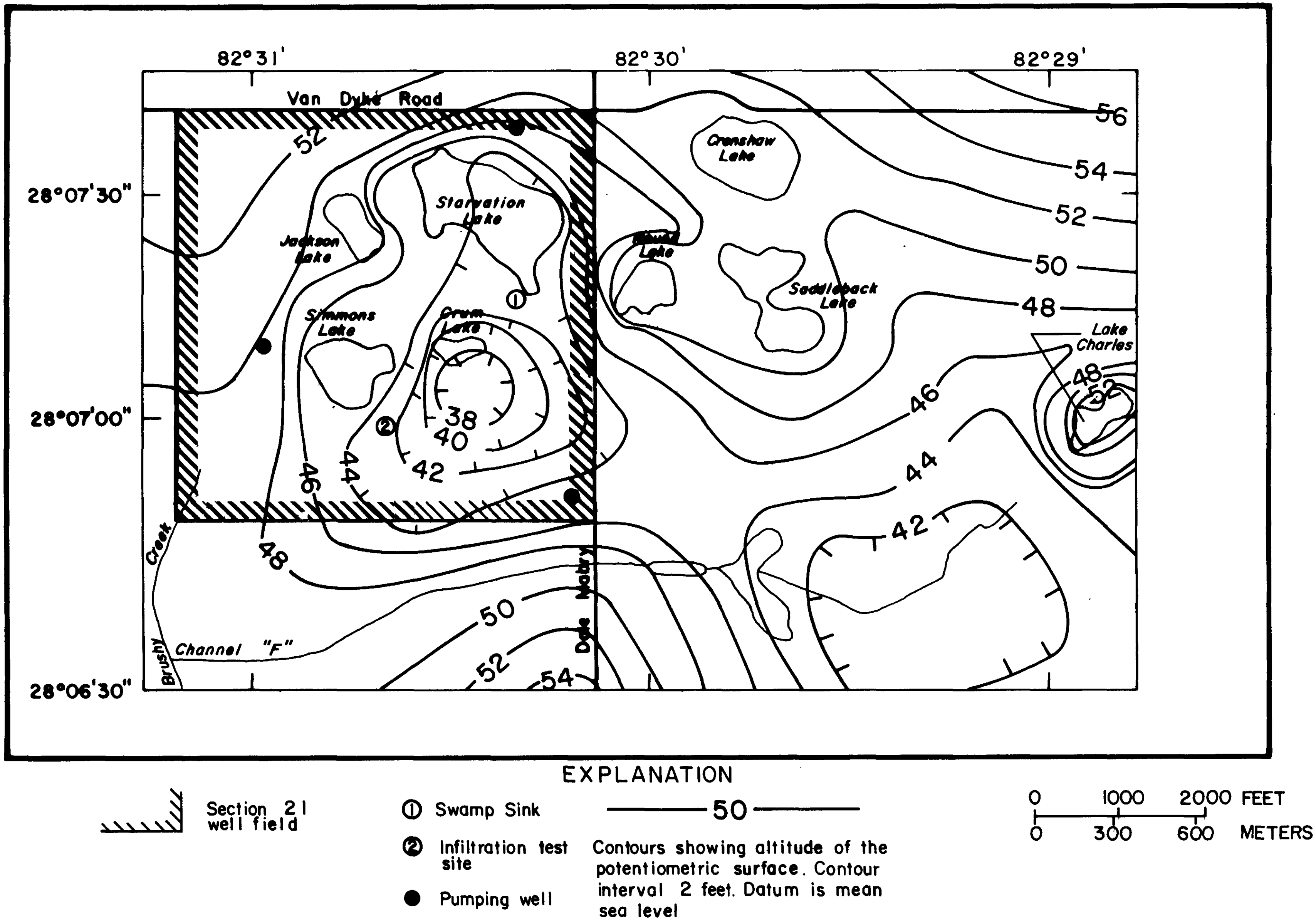


FIGURE 4.--Contours on the water table in the surficial aquifer, Section 21 well field area, May 15, 1972.

Estimates of leakage to the Floridan aquifer in the vicinity of Section 21 well field were made using three methods. The first method is based on the results of test drilling. Laboratory tests of sorting, specific yield, and hydraulic conductivity were made on 67 undisturbed samples of the surficial deposits, including the clay confining bed. Based on these test results and on lithologic and gamma ray logs of the wells, values of hydraulic conductivity were assigned to each hydrogeologic unit, and the vertical hydraulic conductivity of the surficial section was estimated. In section 21, the average coefficient of leakance at 23 test sites is about 5.35×10^{-5} per day. Taking the average difference in head between the surficial and Floridan aquifers in the Section 21 well field for May 15, 1972 as 12 ft, leakage from the surficial aquifer to the Floridan aquifer is calculated to be about 17,900 ft^3/d of water within the 1 mi^2 of the section.

In the second method, an analysis of flow through the surficial aquifer (flow-net analysis) indicates that about 17,000 ft^3/d of water crosses the 44-ft contour in the Section 21 well field, then moves vertically through the clay layer and into the Floridan aquifer. The area within the 44-ft contour is about 0.38 mi^2. However, leakage is occurring, to some extent, throughout the study area, not just within the 44-ft contour; therefore, the flow net calculation yields a minimum value.

The third method of estimating leakage is based on a coefficient of leakance of 1.5×10^{-3} $(gal/d)/ft^3$, which was calculated by Stewart (1968, p. 176) from a long-term aquifer test conducted in the well field. Applying this factor to the head difference of 12 ft yields a leakage of 67,000 ft^3/d for the 1-mi^2 area.

Daily pumpage from the well field in 1972 averaged 2.3 Mft^3. If the water table were to be maintained near its natural level, then the head difference between the two aquifers would be about 15 ft. The leakage, based on the three methods of estimation and a 15-ft head difference, would be between 22,400 ft^3/d and 83,800 ft^3/d or 1 to 3.6 percent of the total daily withdrawal within the 1-mi^2 Section 21 well field.

The water needed to sustain this volume of leakage could be obtained by diverting flow from Channel "F" (fig. 4) to the well field. If Channel "F" were extended eastward, as the Water Management District has proposed, to drain an area of about 14 mi^2, including six lakes, then average flow to the well field, based on flow analyses of natural streams, would be about 1,344,000 ft^3/d. Ten percent of the time flow would exceed 9.5 Mft^3/d, and 75 percent of the time flow would exceed 120,000 ft^3/d. Thus, the diverted flow from the proposed extension of Channel "F" would be adequate on the average to satisfy the potential for leakage in the well field area.

RECHARGE EXPERIMENTS

Four experiments were conducted to investigate possible recharge alternatives to the Floridan aquifer. The experiments were designed to take advantage of the natural filtration effect of the surficial aquifer and the natural head gradient from the surficial to the Floridan aquifer. The four experiments were: (1) sinkhole recharge, (2) water-spreading, (3) connector well, and (4) subsurface-tile drainage.

Sinkhole Recharge

The numerous small circular cypress swamps that dot the landscape are a characteristic feature of the Gulf Coastal Lowlands. Locally called cypress heads because of their characteristic dome shape, these swamps occupy sinkhole depressions in the land surface. As the depression develops, it becomes a sump for local runoff, and cypress and other phreatophytes thrive in it. Continued lateral expansion of the sinkhole depression results in younger and still younger cypress trees springing up in concentric circles around the center of the depression. As the depression continues to deepen and intercepts the water table, trees in the center are drowned out, resulting in a cypress-rimmed lake, a mature stage of sink development (Bishop, 1967). The appearance of a cypress head, then, indicates the presence of a sinkhole.

The cypress heads and lakes are probable points of natural recharge through pipes or solution cavities in the limestone. At these sites, subsidence had resulted in a break or perforation in the clay confining layer overlying the Floridan aquifer, allowing water from the surficial aquifer to move downward.

The decline in the water table in the Section 21 well field has dewatered Swamp Sink (fig. 4) - a typical cypress head - thus creating a natural laboratory for determining whether Swamp Sink cypress head is a recharge point, and whether recharge exceeds evapotranspiration from the swamp. Swamp Sink is a depression about 120 ft in diameter; its deepest point is 7 ft below the surrounding land surface.

Five wells were drilled in a line, at 50-ft intervals, outward from Swamp Sink (fig. 5). Each of the wells was finished with an 18-in length of screen set in the limestone at depths ranging from 48 to 69 ft. Two shallow wells were also installed alongside each of the five wells. In one of these shallow wells the screen was set in the sand 14 ft below land surface. In the other, the screen was set in the laminated sand and clay, about 30 ft below land surface.

A series of tests was conducted at Swamp Sink to determine the volume of water that might be induced to recharge the Floridan aquifer under different head conditions. Water was piped to the sink and daily measurements were made of (1) the water level in the sink; (2) water levels in wells tapping the surficial aquifer and the Floridan aquifer; (3) evaporation from a standard pan floating in the sink; and (4) the amount of water piped into the sink.

Transmissivity of the Floridan aquifer is 73,500 ft^2/d (Stewart, 1968, p. 170). A 10-day pumping test (of the surficial aquifer) was conducted during this study and transmissivity was calculated to be 270 ft^2/d. The water input to the sink, changes in head in the observation wells, and evaporation from the water surface can be measured. Therefore, it should be possible to determine the percentage of water recharged to each of the two aquifers and the amount lost by evaporation. Unfortunately, during the test nearby large-capacity wells pumping at erratic intervals caused abrupt changes in head in the Floridan aquifer, so that the effects of the experiment could only be determined from measurements in wells tapping the surficial aquifer. Recharge to the Floridan auqifer therefore was assumed to be the balance left after evaporation and recharge to the surficial aquifer were subtracted from input.

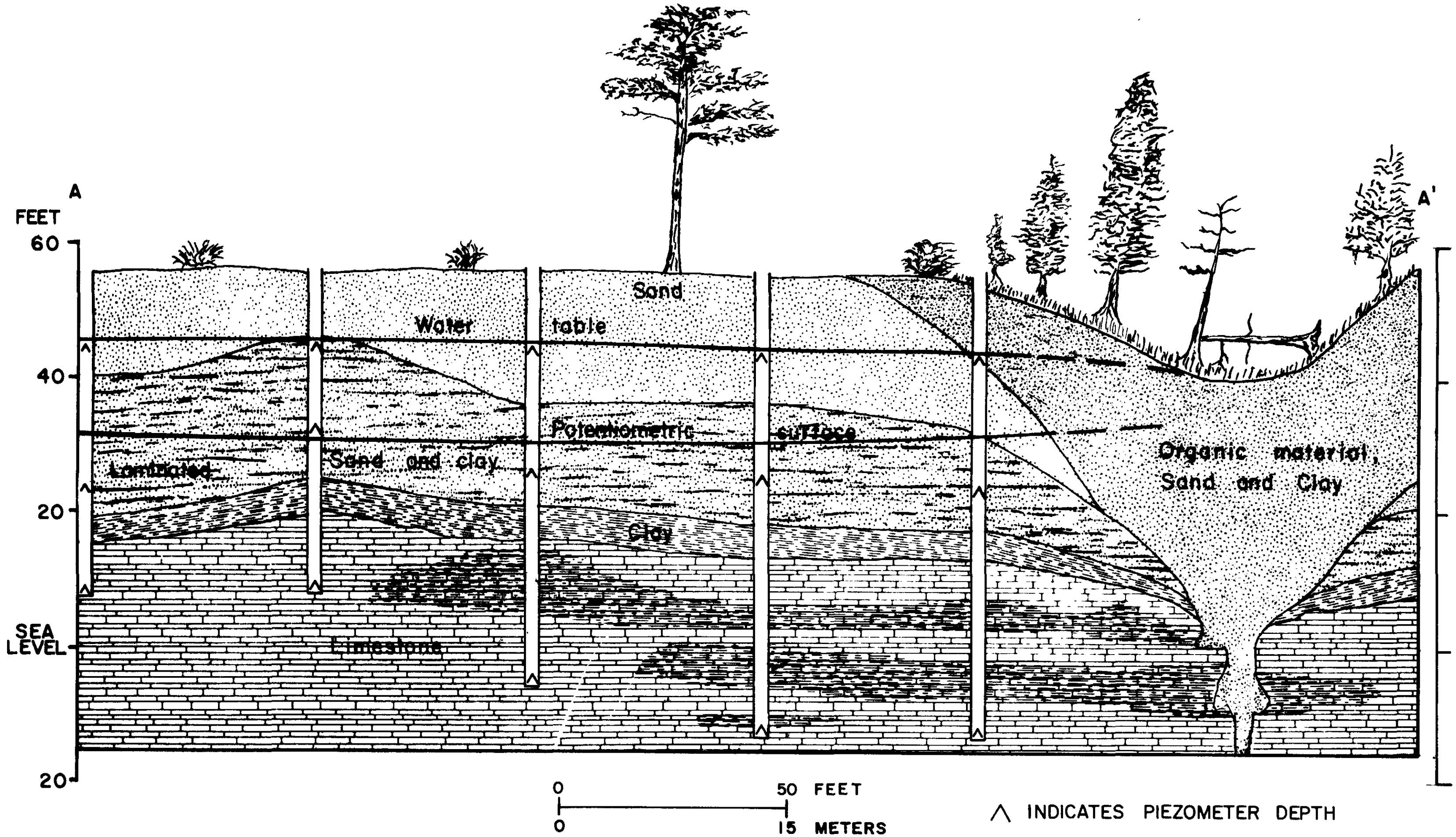


FIGURE 5.--Generalized geology and observation wells, Swamp Sink.

Observation of water levels began several weeks before the sink was flooded. The slope of the water table, shown in figure 6 for July 20, is typical of pre-test conditions. Precipitation in the preceeding 25 days had amounted to only 0.7 in, so the water-table gradient represents near steady-state conditions of natural drainage through the surficial aquifer to the sink. The surficial aquifer transmissivity of 270 ft^2/d and the water-table gradient as measured in the observation wells were used in the Thiem equation (Lohman, 1972) to compute a flow to the sink on July 20, 1970 of about 1,400 ft^3/d. Effective diameter of the sink was estimated to be 50 ft.

Flooding of the sink began on August 1. The daily input of water averaged 7,190 ft^3. The pond level rose slowly until about September 1 when the stage stabilized at an altitude of 50 ft at which time the input became balanced by discharge to the aquifers and evapotranspiration. In October, average daily input was increased to 15,400 ft^3 and by early November the stage had stabilized at 53 ft. Vegetal evidence, particularly the configuration of cypress roots, suggests that 53 ft is probably mean high water for Swamp Sink under normal conditions.

Figure 6 shows the configuration (with vertical exaggeration) of the water table on July 20, September 21, and November 30, 1970. Table 1 summarizes the effects of flooding of Swamp Sink on those dates. Daily measurements of water level indicate that the water-table gradients shown on figure 6 represent nearly steady-state conditions for the phase of the experiment they are chosen to illustrate.

Evaporation data for November indicate that loss of water from the pond surface was about 1 percent of inflow. Cypress and other vegetation was dormant due to low temperatures; thus, transpiration loss was negligible. Evaporation data for September were unreliable, but considering the small area of the pond surface, evaporation loss is presumed to have been negligible.

The results of the test suggest that under wet-period conditions for the area, with the stage of the swamp at an altitude of 53 ft, recharge to the Floridan auqifer by drainage of the surficial aquifer through Swamp Sink would be about 10,000 ft^3/d, that is 0.27 $(ft^3/d)/ft^2$ of pond area.

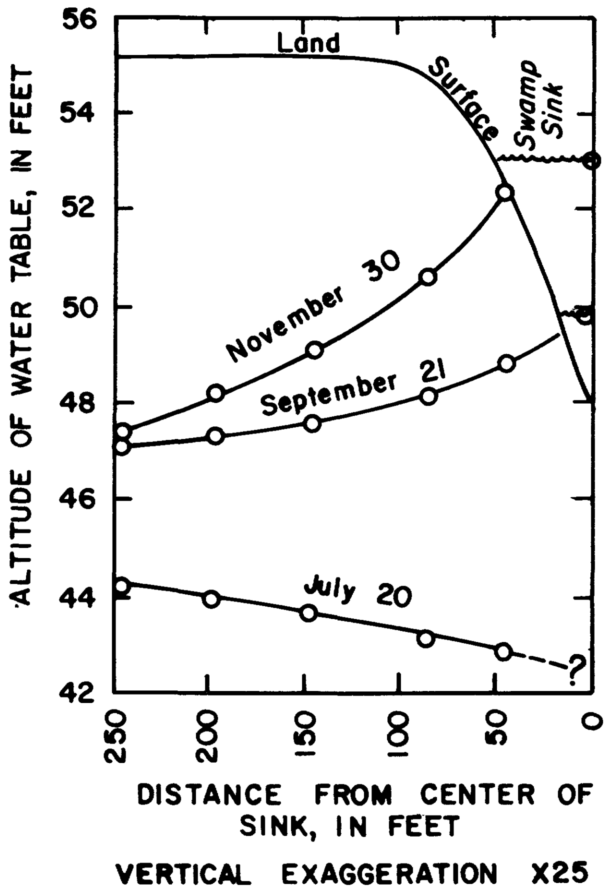


FIGURE 6.--Water levels in Swamp Sink and gradients of the water table, July 20, September 21, and November 30, 1970.

Table 1. -- Summary of the effects of flooding Swamp Sink.

Date, 1970	July 20	September 21	November 30
Total inflow to sink, ft^3/d	1400[1/]	7190[2/]	1400[2/]
Altitude of water surface, ft above sea level	--	50	53
Average head difference between surficial aquifer and Floridan aquifer	12	13	19
Area of pond surface, ft^2	0	12,500	35,400
Evaporation from water surface, ft^3/d - percent of total inflow	0	-	190/1
Recharge to surficial aquifer, ft^3/d - percent of total inflow	loss	1600/22	5250/34
Recharge to Floridan aquifer, ft^3/d - percent of total inflow	1400	5600/78	9960/65

1/ natural inflow calculated

2/ piped inflow, measured

The 19-ft head difference between the two aquifers is unnaturally high due to heavy pumping from the Floridan aquifer in Section 21. Leakage of 0.27 $(ft^3/d)/ft^2$ divided by 19 ft yields a coefficient of leakance of 1.4×10^{-2}, 2 to 3 orders of magnitude greater than the leakage values derived from pumping tests, the flow-net analysis, or estimates from test drilling data. It is apparent that these latter values, which were discussed in the section on leakage, are general values representative of leakage throughout a relatively large area in a particular terrain. The Swamp Sink experiment suggests that cypress heads overlie point sources of natural recharge, windows in the confining layer, which may contribute large volumes of water to the Floridan aquifer disproportionate to their small area.

The wet period, May through September, is the period of greatest potential evapotranspiration. Even so, water lost to evapotranspiration would probably be less than 5 percent of the volume draining to the Floridan auqifer at the 53-ft stage.

Leakage values derived from the experiment at Swamp Sink are probably typical of active sinkhole swamps throughout the area. The diversion of excess water to cypress heads would be a good conservation practice and would increase the rate of recharge of the Floridan aquifer.

Water Spreading

Experiments were conducted to determine the feasibility of increasing infiltration to the Floridan aquifer by spreading water on the flat sandy plains. Soil drainage in the area ranges from good to very poor. All soils are derived from the same parent material, the fine-grained quartz sand of the surficial aquifer. Differences among soil types, therefore, are due mainly to internal soil drainage which is ultimately controlled by the local topography.

The infiltration test was conducted on Ona-type soil which was selected as typical of the level, well-drained areas of pine, palmetto, and grass. A low dike was constructed around a test site 50 ft in diameter. Within the test site an observation well was finished in the Floridan aquifer, another one was finished a few feet below the water table, and an access tube extending below the water table was installed for insertion of a neutron moisture probe which was used to determine the moisture content in the unsaturated zone. Water for the tests was pumped from a nearby lake.

Test procedure was to sprinkle water on the test site in simulation of a rainfall of 0.5 in, 1 in, and 2 in at a rate of 0.5 in/hr, and also to flood the site for several hours.

The soil was dry before the tests. Only 1.35 in of precipitation was recorded during the preceeding 40 days. The vegetation therefore was dry and soil moisture was deficient.

Figure 7 illustrates the effects of spreading water in simulation of 2 in of rainfall. The 2 in of water did not saturate the soil; probably most of the water was intercepted by vegetation and subsequently transpired and evaporated. The water that did infiltrate below the root zone percolated downward but had not reached the water table after 120 hours. Probably all the water that infiltrated was retained by surface tension in the unsaturated zone and none recharged the aquifer. This result is also typical of the 1.0-in and 0.5-in water-spreading experiments.

Isolated showers, even rather intense showers, probably are not important factors in natural recharge unless the soil is saturated and moisture requirements of the vegetation already are satisfied. These requirements probably are satisfied during the summer when thundershowers occur almost daily.

Figure 8 illustrates the effects of flooding the test site with 37 in at the rate of 2 in/hr. At this rate water ponded on the surface to a depth of 2 to 3 in. Infiltration was rapid, and the water table began to rise at an accelerating rate. Had the delivery of water to the site not stopped after 18.5 hours, because of pump failure, but rather had continued for about 4 days, the recharge mound would probably have reached land surface.

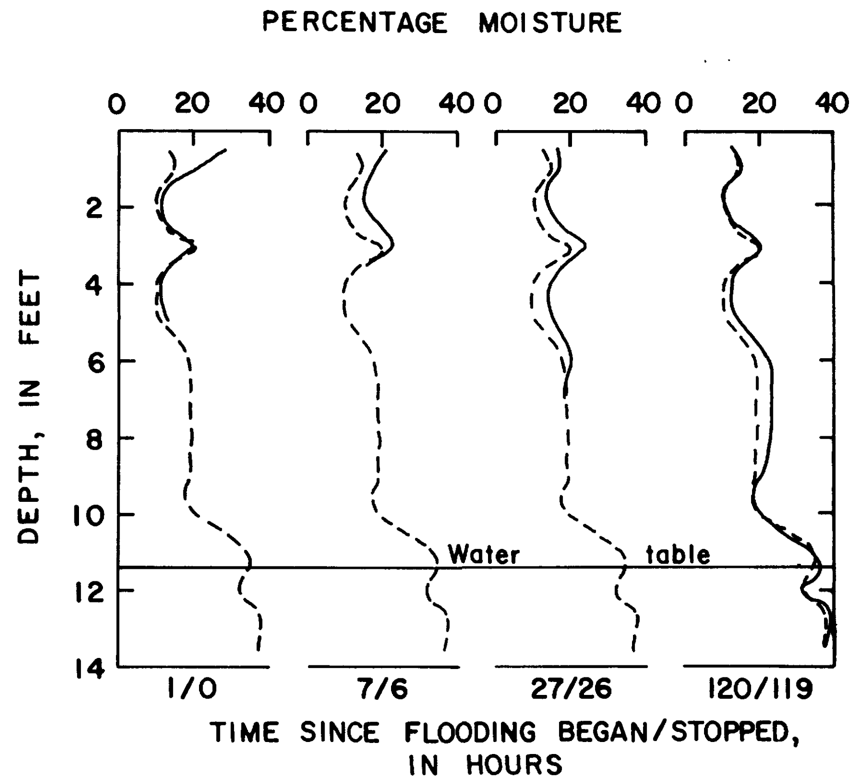


FIGURE 7.--Moisture profile at Ona site, March 1971.

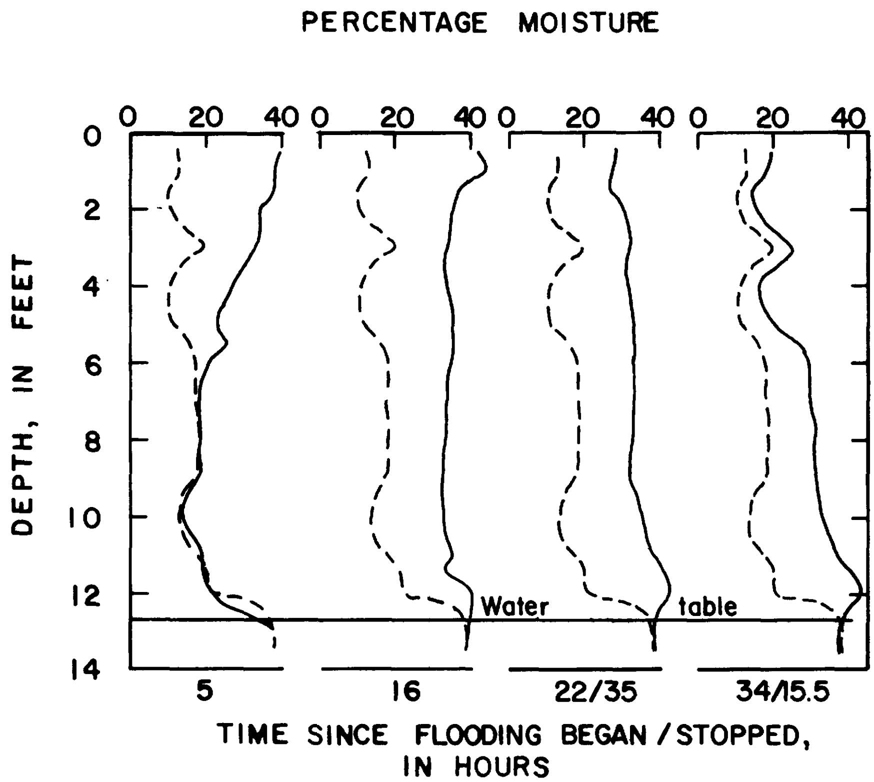


FIGURE 8.--Moisture profile at Ona site, July 1971

The infiltration capacity of the surficial aquifer based on the 18.5-hour test appears to be greater than 4 ft per day. Under these conditions the surficial aquifer soon would become saturated to land surface and infiltration would then be limited to the rate of lateral drainage away from the site plus the increased leakage through the confining layer due to the increased head.

Recharge by water spreading may be practical in areas where the confining layer is absent or perforated, or where water can be drained to deep storage as rapidly as it infiltrates the surficial aquifer. The depression in the water table southeast of Section 21 well field, shown in figure 4, is such an area. From knowledge of the hydrogeology of this area and the configuration of the cone of depression, leakage to the Floridan aquifer within the 42-ft contour was computed at about 1,600 ft^3/d in May 1972. The fact that the potentiometric surface of the Floridan aquifer lies less than 2 ft below the water table in the area implies that the confining layer is absent and that additional water would move rapidly from the surficial to the Floridan aquifer. Within the well field itself, the cone of depression in the water table is even more pronounced because it overlies the center of pumping. The head difference between the two aquifers is 10 to 12 ft, however, indicating relatively low inter-aquifer leakage. If Channel "F" were extended eastward, the runoff could be diverted to these areas for recharge by infiltration to the Floridan aquifer.

Connector Wells

Recharge through the confining layer might be augmented by gravity drainage through connector wells: wells screened to the surficial aquifer, cased through the confining layer and open to the limestone aquifer below. The concept stems from the widespread use, in some urban areas in Florida, of drain wells which conduct flood water from depressions and lakes to the Floridan aquifer. Connector wells, unlike the drain wells, would conduct water to the Floridan that first had been filtered through the sand of the surficial aquifer. The recharge would thus be similar to natural recharge and less likely to clog or contaminate the Floridan aquifer.

The volume of water moving from the surficial aquifer to the lower one will depend on the head difference between the two, the hydraulic characteristics of the two aquifers, and, to a lesser extent, the well diameter. Figure 9 illustrates the recharge that might be expected from surficial aquifers with a range of transmissivities and drawdowns, for a well diameter of 12 in. The curves are derived from an equation for ground-water flow under conditions where drawdown is constant and discharge varies with time, as discussed by Lohman (1972). These conditions would be met in a connector well once drainage from the surficial aquifer had approached steady state. For example, from figure 9, if the transmissivity of the surficial aquifer is 400 ft^2/d, a drawdown of 10 ft would cause about 3,500 ft^3/d to drain to the Floridan aquifer.

The 7-acre site selected for the connector-well experiment is located on the Dundee Ranch in northwest Hillsborough County, about 15 mi north of Tampa and about 1 mi northwest of the Section-21 well field (fig. 1). The site is an improved pasture surrounded by cypress swamps (fig. 10) which are wet most of the year. The pasture itself is poorly drained under natural conditions and may stand inundated for weeks at a time during a normal summer. This inhibits the growth of crops and interferes with their harvest.

The geology at the site is typical of that throughout the study area. The surficial aquifer is about 35 ft thick. It is composed predominantly of sand which becomes slightly to moderately clayey below a depth of about 10 ft and contains stringers and lenses of sandy clay. A dense layer of calcareous clay, or marl, underlies the surficial aquifer from about 35 to 40 ft below land surface. The clay lies directly on the limestone of the Floridan aquifer and forms the confining layer that separates the two aquifers.

The log of well 2-20E-54 shown in table 2 illustrates the physical characteristics of the surficial material at the site, although the clay lenses in the surficial section are discontinuous and the depth to the confining layer of the top of limestone varies by several feet from place to place. The sand throughout the surficial section is predominately very fine to fine grained and very well sorted.

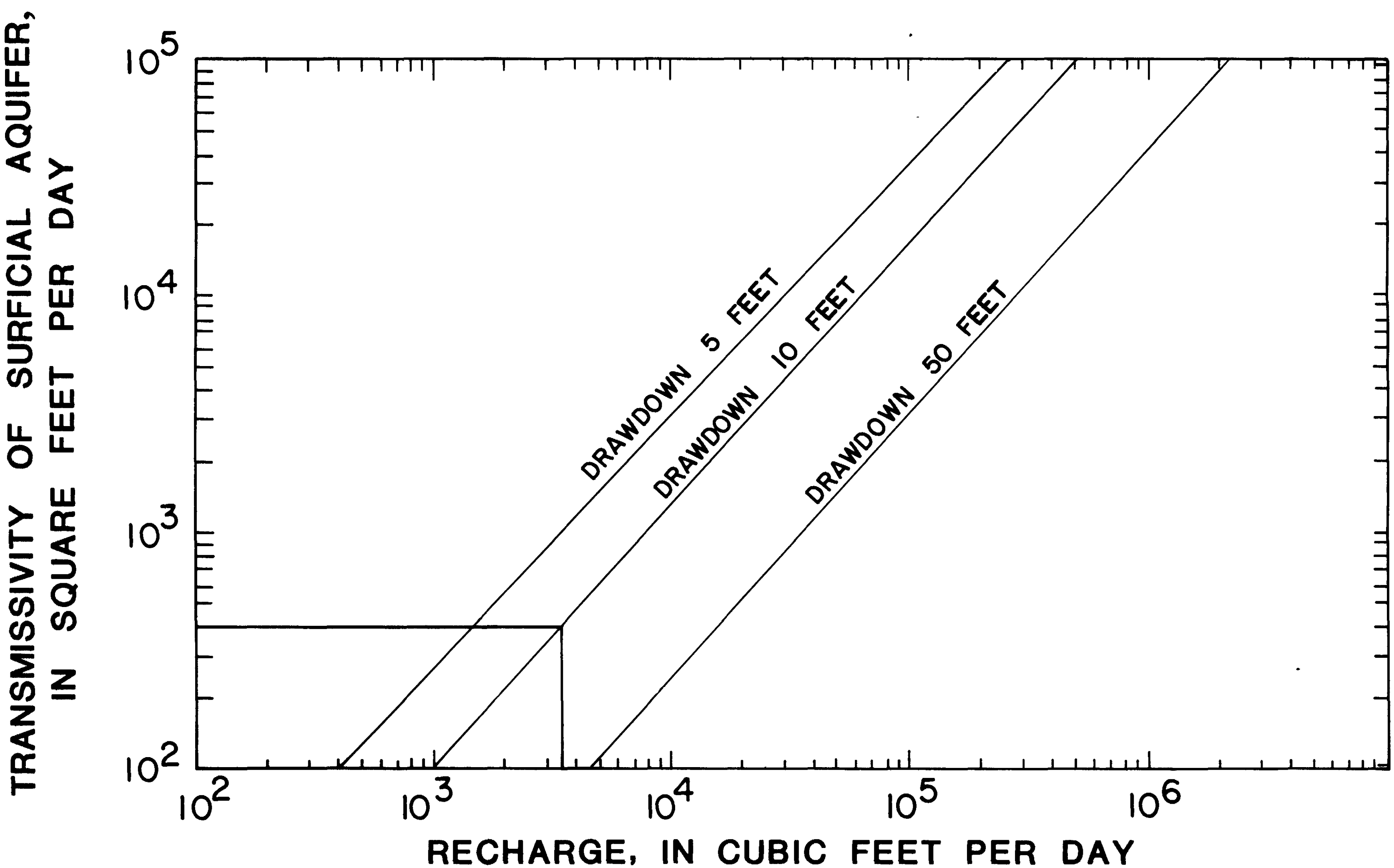


FIGURE 9.--Estimated potential yield of a connector well.

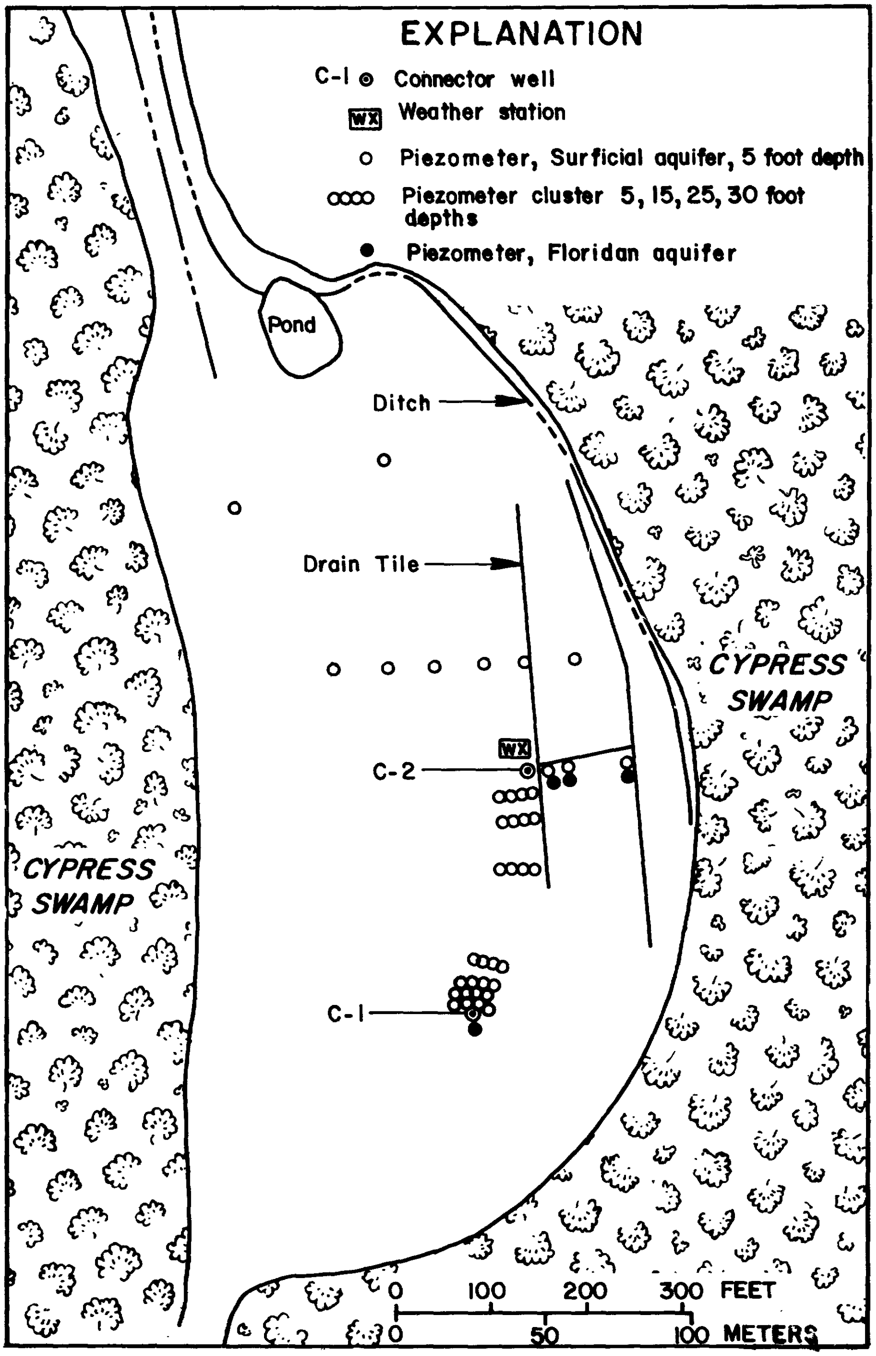
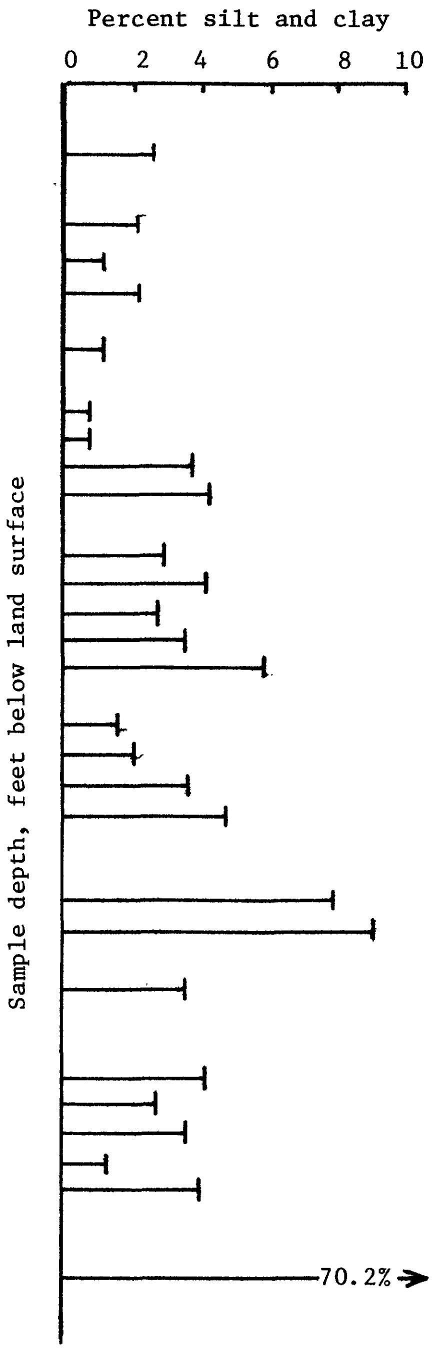


FIGURE 10.--Connector-well experiment site.

Table 2. -- Log of well 2-20E-54.



1	Sand, clear quartz, subangular to subrounded, slight black silt.
1.5	Sand, as above but with slight grayish-orange silt.
2	
3	Sand, as above but with less silt.
4	Sand, as above but with layers of sand cemented by black material.
5	
7	Sand, as at 1 ft.
7.5	
8.5	
9	Sand, pale brown with slight clay.
10	Sand, white, clean, with paper-thin laminae of pale-brown sandy clay.
12	
13	Sand, brown, clayey.
14	Sand, pale brown, less clay than at 13 ft.
15	Sand, brown, clayey.
16	Sand, grayish orange, clayey.
16.5	Sand, pale brown, clayey.
17	
18	
19	
20	
20.5	Sand, as above, slightly more clay.
21.5	Sand, with pale-brown clay.
22	
23	
23.5	Sand, with grayish-orange clay.
24.5	
25	
26.5	Sand, clear quartz (wash?).
27	Sand, grayish-orange clay.
28	
30	
31	
32	
33	
33.5	Sand, light gray clay and very pale orange clay.
38.5	Clay, white.
40	Limestone.
57	Limestone, very light gray, soft. Total depth.

The small amounts of clay mixed with the sand and the clay laminae which occur at intervals from 10 to 35 ft retard the downward percolation of water which is constantly recharging the system under natural conditions. The effect of this retardation is apparent in water levels measured in piezometers open to various depths in the section. The water levels in the shallowest piezometers are close to land surface. Water levels in successively deeper piezometers are successively lower. The head in the limestone aqufier, below the dense clay layer, is generally 10 ft or more below that in the deepest part of the surficial aquifer.

The relatively low vertical permeability, with respect to horizontal permeability of the surficial aquifer, results in the lower part of the unit acting as many thin leaky artesian aquifers. This complexity, though recognized, must be ignored in analytic treatment of the test results and the surficial aquifer is considered a single unit.

Figure 10 shows the location of the wells and equipment at the test site. Connector well C-1 and connector well C-2 were installed 250 ft apart. Clusters of four piezometers, open at depths of about 5, 15, 25, and 30 ft in the surficial aquifer, were installed at distances of 5, 10, 25, and 50 ft from C-1 along a line toward C-2. Similar clusters were installed 20, 40 and 100 ft from C-2 in the direction of C-1. The effects of tests in either well could thus be monitored as much as 250 ft from the well.

Four piezometers were installed in the Floridan aquifer at depths of 54 to 59 ft. One of these piezometers is 10 ft south of C-1. The other three are 20, 40 and 100 ft east of C-2 and are paired with shallow piezometers 5 ft deep. Piezometer 2-350N-7 is a control well, installed to monitor the shallow water table.

A weather station was installed to record precipitation, temperature, humidity, and barometric pressure. Evaporation from a standard pan and wind movement were read daily during the tests.

Connector-Well 1

C-1 was designed to drain water from the entire thickness of the surficial aquifer. Construction details are shown schematically in figure 11. The screen is 8 in in diameter and 25 ft long, extending from 6 to 31 ft below land surface. The bottom of the screen is welded to 6-in pipe which extends from 31 ft to 48 ft where it is grouted in limestone. A 5-in hole is open to the Floridan aquifer from 48 to 125 ft.

Slot size of the screen is based on grain size of the sand pack around the screen, which in turn is based on the grain size and the sorting of the aquifer material. Figure 12 shows an envelope of size-distribution curves of 30 samples taken from the surficial aquifer at depths ranging from 1 to 38 ft. Median grain diameter throughout the surficial section ranges from 0.004 to 0.006 in. Uniformity coefficient ranges from 1.8 to 2.7 and averages 2.1. Standard practice is to design the sand pack with grain diameters about 4 times those of the aquifer grains and as uniform in size as the aquifer uniformity. Slot size of the screen is designed to pass less than 10 percent of the sand pack. A slot size of 0.020 in was chosen.

The well was developed by surging and by jetting the screen face with compressed air while pumping. In spite of these measures, full efficiency was not achieved, as evidenced by the fact that drawdown in the well was considerably greater than drawdown in the sand pack and aquifer adjacent to the well.

After development, the well produced 1.3 ft^3/min from the surficial aquifer with 10 ft of drawdown. The limestone yielded 4.0 ft^3/min with 11 ft of drawdown. The ratio of discharge to drawdown, the specific capacity of a well, is a measure of the well's ability to yield or accept water. In this case, the specific capacity of the screened part of the well is 0.12 (ft^3/min)/ft. Drainage through a connector well is determined, ultimately, by the difference in water levels in the two aquifers. Recharge through C-1 would not be expected to exceed 1.3 ft^3/min when the water table is only about 10 ft above the potentiometric surface of the Floridan aquifer. Recharge will actually be less than theory suggests because the well will be less than 100 percent efficient and some back pressure can be expected to develop in the receiving aquifer thus reducing the head difference.

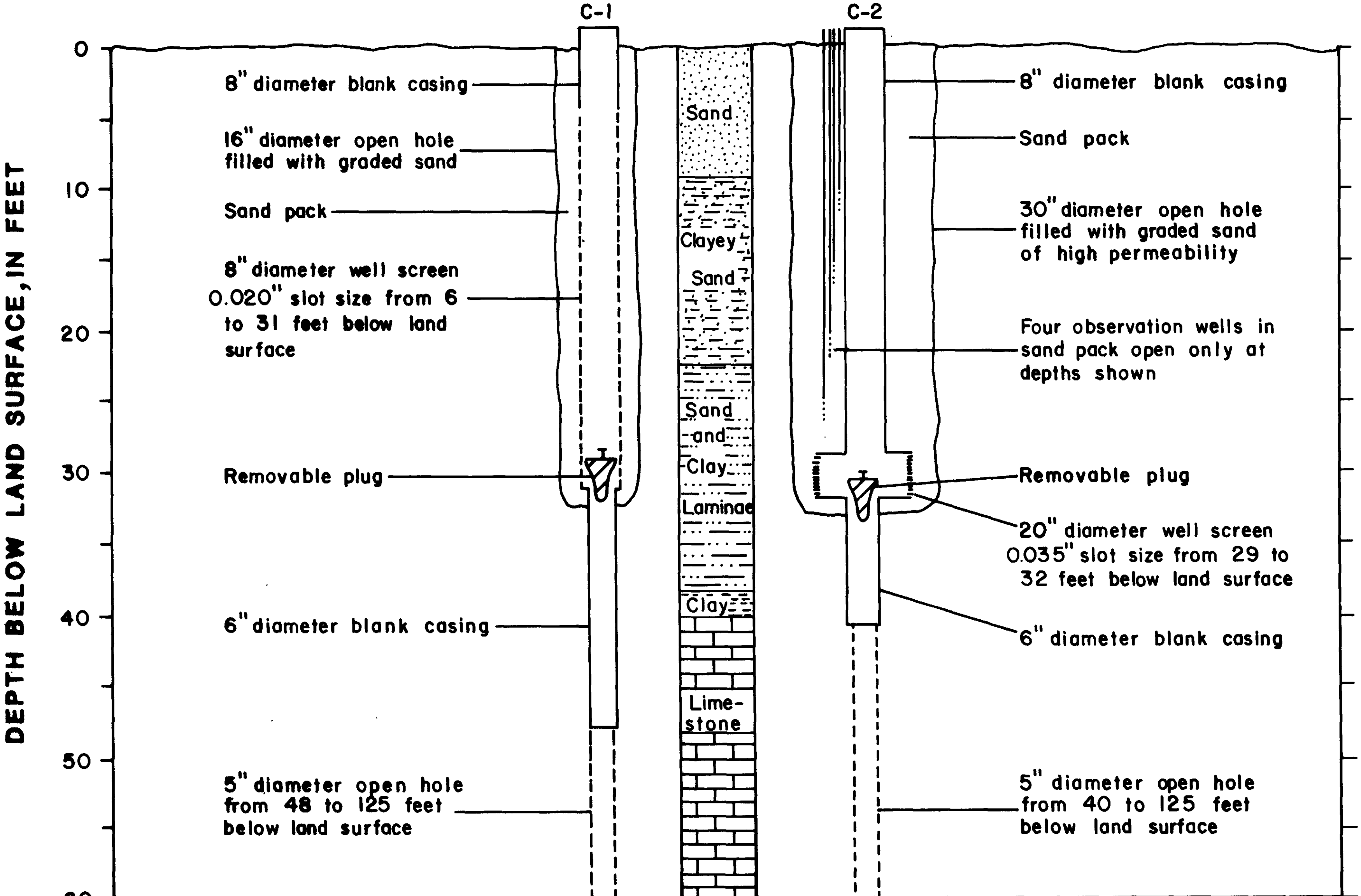


FIGURE 11.--Diagrams of connector wells C-1 and C-2.

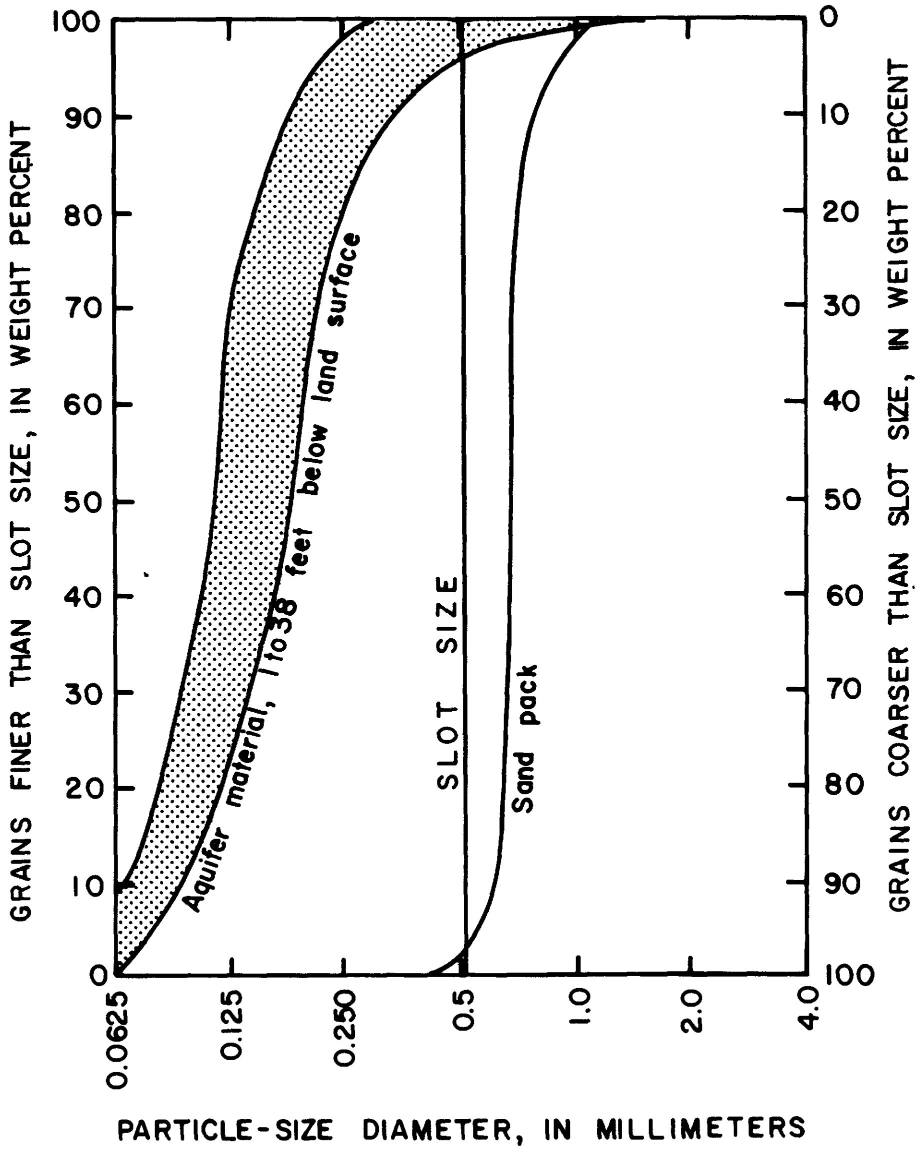


FIGURE 12.--Size-distribution curve of 30 samples of the surficial aquifer material from 1 to 38 feet below land surface and of the sand pack for C-1.

The water table in the surficial aquifer stood about 3 ft below land surface when the drain test of C-1 was begun. The potentiometric surface of the Floridan aquifer was about 20 ft below land surface. The plug (fig. 11) was removed and a flow meter installed in the blank casing below the screen. Flow down the well into the Floridan aquifer was 1.3 ft^3/min. Rainfall on the 14th and 15th days of the test caused a rise in the water table and beyond that time the volume of drainage from the surficial aquifer was a function of recharge to the surficial aquifer by infiltrating rain.

Transmissivity of the surficial aquifer was calculated from the test results to be 430 ft^2/d. Coefficient of storage, or specific yield, is 0.24.

Figure 13 illustrates the effects of the drain test on the surficial aquifer at the end of 10 days. Although the water level in C-1 dropped 14 ft when the drain was opened, the water level in the aquifer, adjacent to the screen, never dropped below the top of the screen, which is 6 ft below land surface. Drawdown at the nearest observation well, 5 ft from C-1, was 2.63 ft; and 100 ft from C-1, drawdown was 0.43 ft after 10 days. Drawdown was 1 ft or more within a radius of about 60 ft of C-1.

Observations of the effects of drainage over a period of several months indicate that the long-term effect on the water table would be approximately as shown in figure 13. Frequent rainfall during the summer provides recharge that maintains the water table near land surface. Under these conditions flow through the connector well is about 1.3 ft^3/min and water drained from the surficial aquifer is, in part, water that would otherwise be lost by transpiration during extremely wet periods. During the drier winter period, the water table would decline below the top of the screen and flow through the connector well would diminish accordingly.

Test results suggest that recharge to the Floridan aquifer through C-1 would be about 535,000 ft^3/yr. Construction costs for C-1 totalled \$2,500 (1973). Assuming 20 years of maintenance-free operation and straight-line depreciation, recharge at this rate would cost about \$0.23 per 1,000 ft^3. If a field of connector wells of this type were to be designed with optimum recharge and capture of evapotranspiration as the objective, they would need to be spaced on about 120-ft centers for a minimum inter-well drawdown of 1 ft, and on 60-ft centers for 2 ft of minimum drawdown.

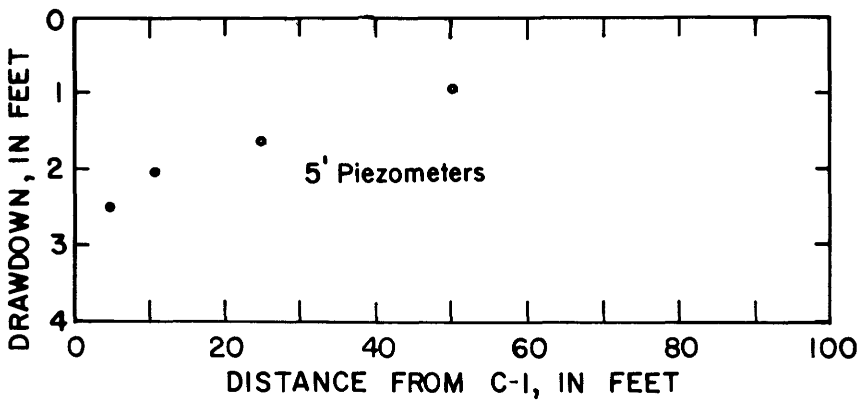


FIGURE 13.--Effect on the surficial aquifer of draining well C-1 an average 1.1 ft^3/min for 10 days.

Decrease of the saturated thickness of the surficial aquifer by drawdown at the well screen has a limiting effect on the volume of water drained from the aquifer. The thin saturated section and low permeability of the surficial aquifer combine to make extensive dewatering of the surficial aquifer and recharge to the Floridan aquifer by connector wells a marginal enterprise in this area.

The fact that the field experiments agree reasonably well with predictions based on the curves in figure 9 suggests that the curves may be used with confidence in predicting connector-well performance where aquifer characteristics are known. In situations where the ratio between hydraulic conductivities is not so great as it is between the surficial and Floridan aquifers at the test site, backpressure from the receiving aquifer may be an important consideration in retarding recharge.

Connector-well 2

Connector well C-2 was designed to drain a 3-ft bed of relatively clean, well sorted sand at the base of the surficial aquifer. The screen is 20 in in diameter and 3 ft long, extending from 29 to 32 ft below land surface. An 8-in casing welded to the top of the screen extends to 1 ft above land surface. The screen and upper casings are set in a 30-in diameter hole filled with graded sand. The bottom of the screen was welded to 6-in pipe which extends from 32 to 40 ft where it is grouted in limestone. Construction details are shown in figure 11. A 5-in hole was open to the Floridan aquifer from 40 to 125 ft during the connector-well tests.

Figure 14 shows the size-distribution envelope curves for samples taken from 30, 31, 32, and 33 ft below land surface. Median grain size for all samples is 0.006 in. Uniformity coefficient ranges from 2.2 to 2.4. A slot size of 0.035 in was chosen for C-2.

After development the well produced 0.69 ft^3/min with 10 ft of drawdown. The limestone yielded 2.7 ft^3/min with 5 ft of drawdown; specific capacities were therefore 0.07 (ft^3/min)/ft and 0.54 (ft^3/min)/ft, respectively.

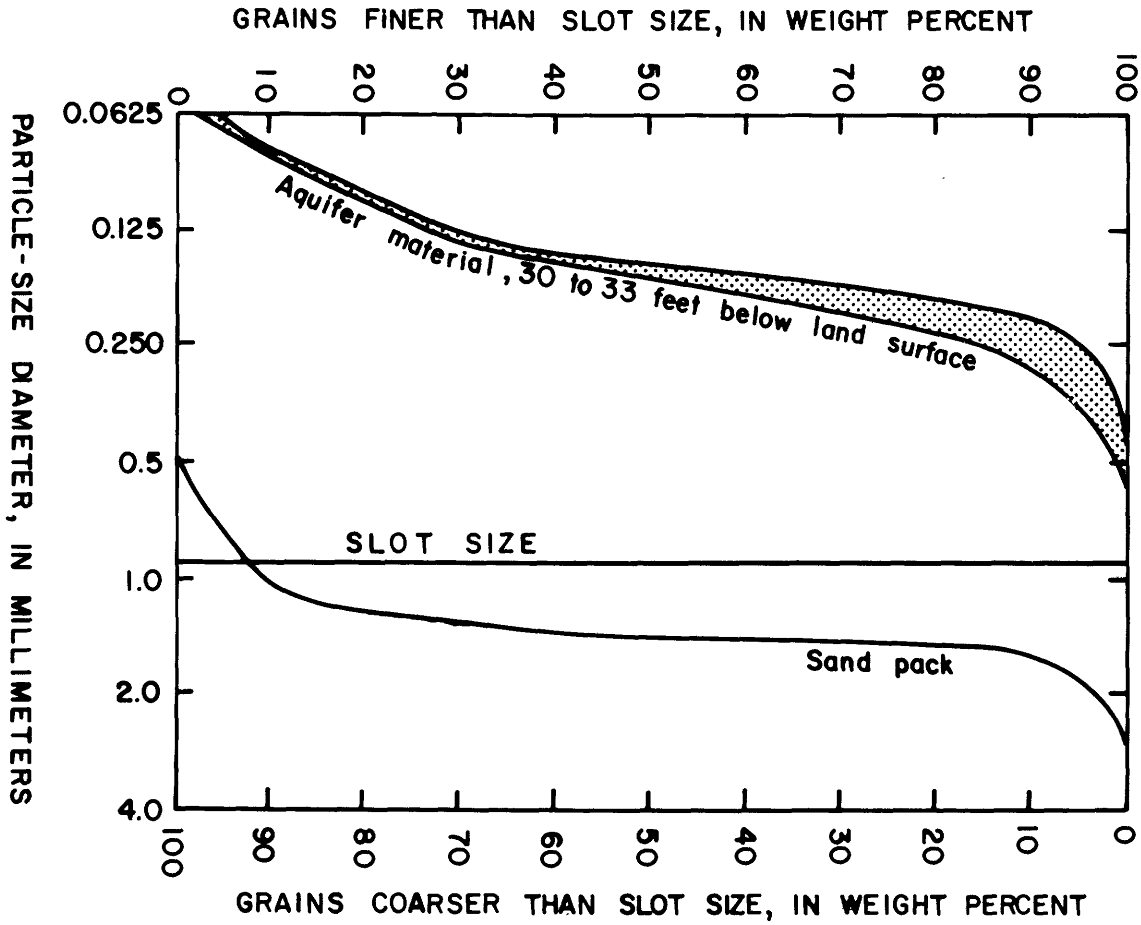


FIGURE 14.--Size-distribution curve of four samples of the surficial aquifer from 30 to 33 feet below land surface and of the sand pack for C-2.

The objectives of testing a well of this design were (1) to compare the relative merits of a large-diameter well with large slot size open only to the most transmissive section of the aquifer with a small-diameter well, such as C-1, with small slot size open to the entire surficial aquifer; (2) to study the effects of dewatering a zone that appeared to be more permeable than the surficial aquifer as a whole; and (3) to determine to what extent lowering the head in the lower zone might accelerate infiltration from the upper part of the aquifer.

The plug (fig. 11) was opened and flow through the well from the surficial to the Floridan aquifer was measured initially at 0.35 ft^3/min. The effects of the first 10 days of the test are illustrated in figure 15.

Water level in C-2 dropped 7.75 ft to meet the water level in the Floridan aquifer which rose 0.85 ft and then declined somewhat as the initial slug of water was dissipated. The response in other parts of the system was also rapid but slight. Water levels in the section of the surficial aquifer opposite the screen declined less than 0.5 ft after 1 day at distances of 40 and 100 ft from C-2. The effects on the water table itself, as shown by measurements from the 5-ft piezometers, were very small. Rainfall on the 2nd and 5th days of the test, 0.36 and 0.24 in respectively, was nearly sufficient to offset the effects of drainage on the lower section of the surficial aquifer and completely masked the effects of the water table. On the 8th day of the test, 2.36 in of rainfall brought the water table to within 0.5 ft of land surface. Measurements of flow and water levels were continued through this and subsequent rainfalls but the effects of the small volume of drainage through C-2 were negligible in comparison with the volume of natural recharge from rainfall and the increased effects of evapotranspiration from the shallow water table.

Attempts were made to increase the drainage flow through C-2 by breaking up the clay laminae in the surficial section with a power auger. The object was to induce more rapid drainage from the upper part of the surficial aquifer where the head is several feet higher than it was opposite the screen near the bottom of the aquifer. A line of auger holes 35 ft deep was drilled 30 ft south of C-2. Native material was allowed to fill the holes as the auger was withdrawn. A sample of this material was shown by laboratory analysis to have a hydraulic conductivity of 0.003 ft/d. A slight increase in head was measured in the deeper piezometers as the holes were augered, but no measurable increase in flow through C-2 was detected.

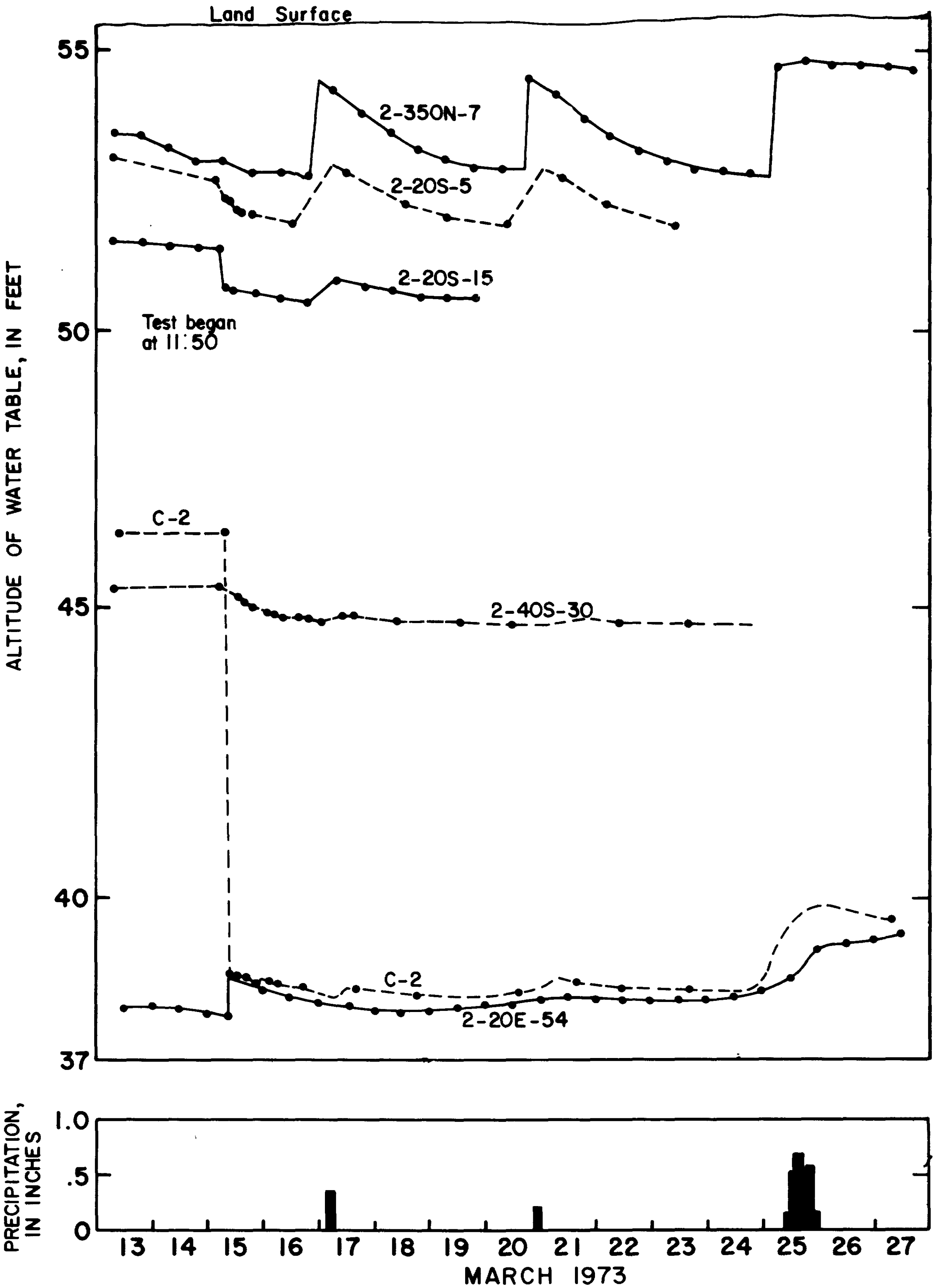


FIGURE 15.--Effects of drain test of C-2 on the surficial and Floridan aquifers.

Four holes 35 ft deep were augered in a circle 10 ft from C-2. Graded sand was washed down the hollow augers as they were withdrawn leaving the holes filled with the sand. Hydraulic conductivity of the sand is 1.7 ft/d, based on laboratory tests. Drainage through the four sand-filled holes increased the flow through C-2 by about 15 ft^3/d. This slight increase is within the margin of error of the flow meter.

Recharge to the Floridan aquifer through C-2 would be about 180,000 ft^3/yr. Construction costs for C-2 totaled $2,500 (1973). Recharge at this rate would cost about $0.07 per 1,000 ft^3, assuming 20 years of maintenance-free operation.

The 0.5-ft decline in head at the base of the surifical aquifer, as shown by measurements of water levels in the 30-ft piezometers, was not sufficient to cause an appreciable increase in downward percolation from the upper part of the aquifer.

Subsurface-Tile Drainage

Land drainage by subsurface tile is an established agricultural practice and much has been published on the design of tile networks for dewatering of land (Soil Conservation Service, 1973). The optimum configuration of a tile system designed to capture a maximum amount of water would be one long tile underlying the topographic low or natural surface drainage of the area. In this experiment, although maximum recharge to the Floridan aquifer was the principal objective, suppression of evapotranspiration and dewatering of marginal land were also of interest. The drainage configuration used was, therefore, a compromise designed to facilitate study of all factors. The objective was to drain about half of the test site leaving the other half unaffected for comparison and to take advantage of the location of existing piezometers.

About 1,000 ft of subsurface drain tile was installed at the test site as shown in figure 10. The tile is perforated plastic tubing, 4 in in diameter, laid in 0.25-in gravel at a depth of about 5 ft below land surface. The tile drains at a gradient of 0.22 ft per 100 ft to connector well C-2.

The tile is laid out in the form of a large H and drains about 3 acres of pasture. The east limb of the tile lies parallel to and about 10 ft distant from a ditch which drains northward along the edge of a cypress swamp.

A line of 7 piezometers was installed at right angles to the west limb of the drain tile. The piezometers are all 5 ft deep and range from 2 to 200 ft from the drain tile as shown on figure 10. The piezometers are numbered according to their distance from the drain tile, p-2, p-15, and p-200.

In order to accommodate the discharge from the tile field, C-2 was deepened to 265 ft below land surface of which 225 ft is open to the limestone. The limestone well yielded 8 ft^3/min with 6 ft of drawdown; specific capacity is 1.3 (ft^3/min)/ft.

The experiments with the drain tile began at a time when heavy precipitation has raised the water table to within 1 ft of land surface at the test site. Figure 16 illustrates the effects on the system when the plug was removed allowing the tile field to discharge through C-2 to the Floridan aquifer. The effect of the increased head on the Floridan aquifer was transmitted immediately through the aquifer as shown by the response measured in well 2-20E-54. Other fluctuations in the hydrograph of 2-20E-54 are probably due to changes in pumping rates of large capacity wells in the area.

Flow through C-2 declined steadily as the surficial aquifer was dewatered. The flow stabilized after about 10 days at 2.5 to 3 ft^3/min, or approximately 4,000 ft^3/d. Total flow measured in C-2 through the first 20 days was 183,000 ft^3; daily average was 9,000 ft^3.

The effects of drainage through the tile field on the surficial aquifer are illustrated by the hydrographs of wells d-2, d-15 and 2-350N-7 in figure 16. The water table at d-2 declined about 3 ft on the first day of the test. The effect at d-15 was only slightly less. Well 2-350N-7 was probably not affected appreciably by the drain tile in this short time because of its position and distance, 147 ft, from the end of the nearest drain. The hydrograph of 2-350N-7 is typical of watertable decline following a heavy rain and is useful as a control for comparison with the hydrographs of d-2 and d-15.

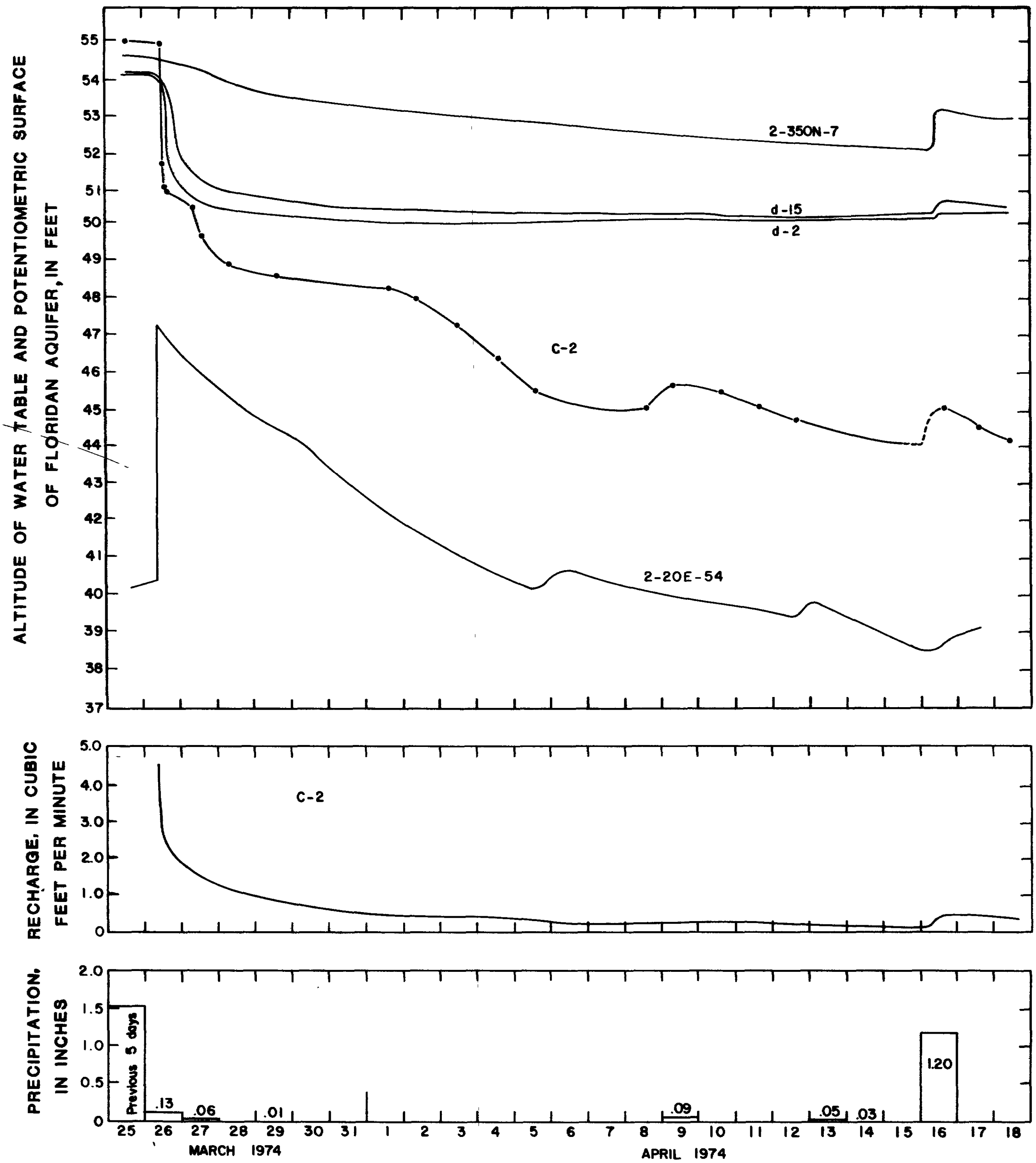


FIGURE 16.--Effects of the drain-tile test on the surficial and Floridan aquifers.

Response of the aquifers to 1.20 in of rain on the 21st day of the tests illustrates the value of maintaining the water table at a low level in order to facilitate recharge from rainfall to the surficial aquifer. Some of the rain was intercepted by the pasture grass. Some went to replenish soil moisture in the unsaturated zone and some percolated downward to recharge the surficial aquifer. Drainage through the drain tile and well increased in response to the rise of the water table from less than 2 to nearly 5 ft^3/min. Water levels in d-2 and d-15 rose only 0.1 and 0.2 ft, respectively. The surficial aquifer in the vicinity of the drain tile could easily have conducted several more inches of infiltrating rain to the tile. At 2-350N-7, however, and throughout the area beyond the effects of the drain, the water table rose more than 1 ft before resuming its decline.

The 183,000 ft^3 of water recharged to the Floridan aquifer during the first 20 days of the test represent that much storage capacity in the surficial aquifer that was made available for infiltration of subsequent rainfall.

Attempts to continue the test of the drain tile through the summer of 1974 were disrupted by several days of heavy rain which flooded the test site. Most of the recording instruments were damaged by water and, even after renovation, proved to be unreliable and inaccurate. Periodic measurements and visual inspection of the site indicated that the water level in d-2 and d-15 commonly rose 1 ft or more in response to heavy, near daily, rain but rapidly declined to pre-rain levels. During such periods the test site beyond the effects of the drain was water logged and poorly drained by runoff to the several ditches and surrounding cypress swamps.

No accurate measurements were made of the volume of water recharging the Floridan aquifer during this period. On several occasions, judging from the high water level in C-2, the well appeared to be draining at capacity. Water levels in the Floridan aquifer were also high, however, due to natural recharge, The difference in head between C-2 and 2-20E-54 was generally no more than 4 ft on these occasions so the well capacity of 1.3 (ft^3/min)/ft would permit only 5.2 ft^3/min recharge.

Final observations of the drain field were made on April 14, 1975. Precipitation in the previous 100 days had totaled 4.01 in and in the previous 20 days 0.32 in. Rainfall did not exceed 1.0 in in any day of this period, so recharge to the surficial aquifer was probably negligible. Drainage of the surficial aquifer to the tile, therefore, was approaching steady state. Flow from the drain tile through C-2 was measured at about 390 ft^3/d under these conditions.

The annual volume of recharge that might be expected from a drain field of this type could not be accurately calculated from the results of this study. A reasonable estimate, based on these results, might be derived by assuming recharge of 5.0 ft^3/min for the rainy months of June through September; 3.0 ft^3/min for the October-through-December period of water-table decline; and 0.25 ft^3/min January through May, when the water table is commonly at its seasonal low. The values would yield an estimate of 1.3 Mft^3/yr from 1,000 ft of drain tile.

Construction costs of the drain field were $2,000, and of the well $2,500, a total of $4,500 (1973). Assuming 20 years of maintenance-free operation, recharge by drain tile would cost about $0.17 per 1,000 ft^3.

Water management might best be served by a single drain tile installed beneath flood-control channels and tributary ditches. Between rains the water table would thus be kept low enough to permit mowing of the grass, creating a high-permeability, stable channel bottom, and keeping the channel free of obstructions, hydrophytes, and mosquitos. The channel would be open for storm runoff whose crests would be subdued to some extent by the infiltration thus induced. Structures could be installed to control the runoff in order to maximize infiltration.

CHEMISTRY OF THE WATER

Surface water in Florida is slightly acid, often highly colored and rich in organic material, but low in dissolved-solids concentration. These characteristics are typical of water in the surficial aquifer as well. Water in the limestone aquifer, however, has a relatively high pH, is high in dissolved-solids concentration, particularly calcium carbonate, and has little or no organic material or color.

As rain and surface water percolate through the surficial aquifer, suspended material is filtered out, pressure and temperature increase with depth, and the downward-moving water reacts toward equilibrium with its new environment. Ions dissolved from decaying vegetation and minerals in the upper strata may be re-precipitated at depth.

The soil which underlies most of the connector-well site has a pan of iron oxide at a depth of about 5 ft. This layer is discontinuous and, where present, contains irregularly shaped holes, suggesting that it is presently undergoing dissolution. Iron concentration of water in the surficial aquifer is greatest at 5 ft below land surface (table 3). Below that depth, dissolved iron decreases with depth in the surficial aquifer, apparently being re-precipitated as the pH increases.

Precipitation of iron was the only chemical problem observed during the tests with the connector wells and drain tile. The water level in C-1 was below the water level in the surficial aquifer just outside the screen. The water flowed through and cascaded down the inside of the screen. Aeration of the water caused iron to oxidize and an ocherous deposit became obvious within 1 week of operation. Deposition progressed rapidly until flow through the upper part of the screen nearly stopped. Periodic scrubbing and rinsing with acid would probably have been necessary to maintain the screen at peak efficiency.

The screen of well C-2 was not visible. This screen was set between 29 and 32 ft below land surface, the part of the surficial aquifer where iron dissolved in ground water was least. Flow through the screen was not aerated and presumably not turbulent, so iron probably was not deposited at the screen.

The drain tile receives water from the 5-ft level of the surficial aquifer, where dissolved-iron concentration is greatest. Samples were taken from a depth of 90 ft in well C-2 after the tile had been draining into it for several months. The samples were cloudy with suspended iron and required filtering twice before being analyzed. The sample contained 6.8 mg/L (milligrams per liter) of dissolved iron. Apparently the abrupt change in pH as the recharge water mixed with water of the limestone aquifer resulted in precipitation of the iron.

Iron could eventually fill the interstices of the limestone and clog the aquifer, except that the recharge water is acid and undersaturated with respect to calcium carbonate. Thus, solution of the limestone is enhanced at the same time and place that iron is being precipitated.

Table 3. -- Chemical analyses of water from four depths in the surficial aquifer and from the upper part of the Floridan aquifer. (S, surficial aquifer; F, Floridan aquifer.)

Chemical constituents (milligrams per Liter)

Well number	Aquifer	Depth (ft)	Date collected	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$	pH	Specific conductance (micromhos at 25°C)	Color (Pt-Co units)
2-100S-5	S	5	1-8-73	18	-	2.6	0.7	7.6	0.2	3	1.6	16	0.2	0.06	91	10	5.4	65	140
Drain tile	S	5	4-2-75	14	3.0	2.9	2.0	8.6	0.7	0	11.0	17	0.2	0.01	103	16	6.0	104	110
2-100S-16	S	16	1-9-73	49	2.7	2.0	1.6	9.0	0.3	9	0.8	17	-	0.0	84	12	6.2	75	60
2-100S-23	S	23	1-9-73	24	2.2	1.6	0.8	9.8	0.2	9	0.1	16	-	0.0	72	7	6.2	70	45
2-100S-29	S	29	1-9-73	48	1.4	1.1	0.2	12.0	0.1	11	0.8	16	0.2	0.0	74	4	6.9	70	20
2-20E-5A	F	54	1-8-73	15	3.5	83.0	8.8	14.0	1.2	340	4.0	18	0.3	0.0	35	240	7.6	570	20

SUMMARY AND CONCLUSIONS

Withdrawal of ground water from the Floridan aquifer in the area is large. The average daily withdrawal from three major municipal supply well fields was about 9.5 Mft^3 in 1972. The water table in the surficial aquifer and lake levels have declined because this withdrawal has caused water to leak from the overlying water-table aquifer. The objective of this study was to investigate recharge possibilities that could reduce the impact of these adverse effects. Possibilities for artificial recharge were investigated in a 30-mi^2 area in northwest Hillsborough County.

The study area has low relief and is underlain by sandy soil. It contains numerous sinkholes and lakes. Two aquifers were defined in the area: a surficial water-table aquifer and the underlying confined Floridan aquifer. The aquifers are separated by a clay-confining bed in most places. The surficial water-table aquifer is well sorted sand that averages about 40 ft thick. It has a high infiltration rate and a coefficient of storage of about 20 percent. A comparison of the potentiometric and water-table maps indicate the Floridan aquifer is recharged by downward leakage from the surficial aquifer. The area is not ideal for artificial recharge because the Floridan aquifer is confined over much of the area.

Four artificial recharge experiments were designed and carried out in 1970-1972 to evaluate different recharge methods.

The following summarizes the four recharge experiments:

1. Sinkhole recharge - Sinkholes have good hydraulic connection with the underlying Floridan aquifer and are an important means of natural recharge. Additional recharge could be provided at a rate of about 3.65 Mft^3/yr by maintaining a high water level in the sinkhole.

2. Water-spreading - Testing indicates that recharge to the surficial aquifer could be increased by water spreading. Recharge to the Floridan aquifer, however, would not be increased appreciably unless a good hydraulic connection exists between the surficial and Floridan aquifers at the water-spreading site.

3. Connector well - Connector well experiments, designed to drain the surficial aquifer to the Floridan by gravity flow, have a potential to recharge about 535,000 ft^3/yr per well for the prevailing geologic and hydrologic conditions in the study area.

4. Subsurface-tile drainage - It is estimated that recharge by subsurface-tile drainage to a connector well open to the Floridan aquifer could recharge about 1.3 Mft^3/yr per 1,000 ft of tile.

The recharge experiments indicate that all four of the methods investigated could be effective under favorable hydrologic conditions. However, the sinkhole recharge experiments resulted in moving the greatest volume of water into the Floridan aquifer. The drain-tile experiment indicated more potential for draining the surficial aquifer than did the others. Combinations of the four methods could be used in areas where the hydrologic conditions are favorable, namely (1) available storage space in the surficial aquifer, (2) potential gradient for downward movement, and (3) good hydraulic connection between the aquifers.

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UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
325 John Knox Rd., F-240
Tallahassee, Florida 32303

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