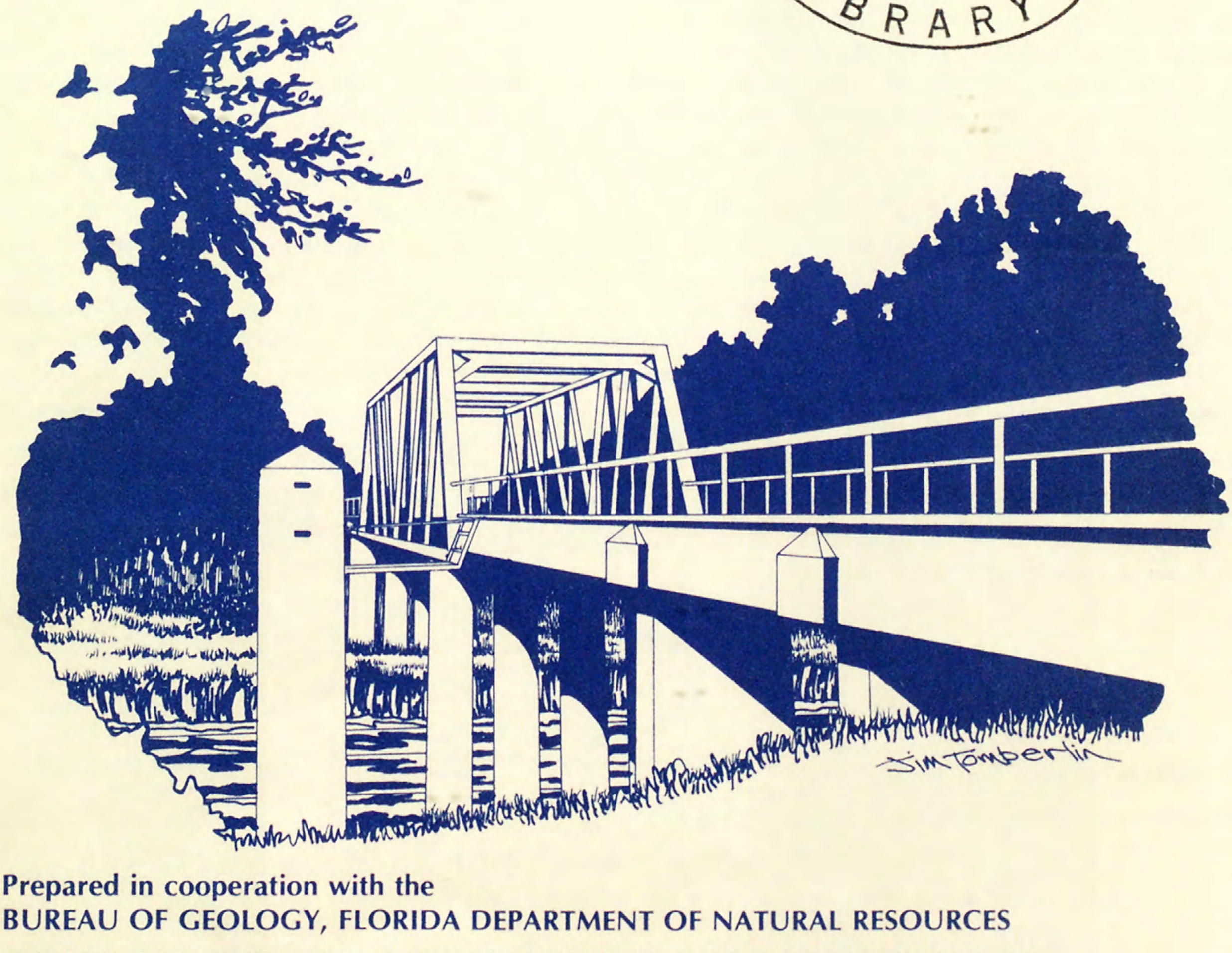
EFFECTIVENESS OF PILOT CONNECTOR WELL IN ARTIFICIAL RECHARGE OF THE FLORIDAN AQUIFER, WESTERN ORANGE COUNTY, FLORIDA

U.S. GEOLOGICAL SURVEY

Water Resources Investigations 77-112



Prepared in cooperation with the
BUREAU OF GEOLOGY, FLORIDA DEPARTMENT OF NATURAL RESOURCES
BUREAU OF WATER RESOURCES MANAGEMENT, FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION
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16. Abstracts The connector well pilot installation, near Doctor Phillips, Florida, has been in continuous operation since December 4, 1970, and is transferring water from the lower sand aquifer to the Floridan aquifer at a rate of 13 gallons per minute or about 6.8 million gallons per year. The recharge water was untreated and analyses show it to be chemically and physically compatible to the water in the Floridan aquifer. The transfer of water from the lower sand aquifer to the Floridan aquifer did not cause a significant buildup of artesian pressure in the receiving aquifer, but it did cause a significant decrease in the artesian pressure in the lower sand aquifer which was supplying the recharge water. This effect was not transmitted to the upper sand aquifer because of the low permeability of the intervening hardpan layer. The transfer of water had no serious, harmful effect on the quality of water in the Floridan aquifer. The principal chemical and physical effects on the water were a general improvement in chemical quality and an increase in color.

17. Key Words and Document Analysis. 17a. Descriptors

*Artificial Recharge, *Ground-Water Recharge, *Ground Water, *Water Management (applied), Water Quality, Water Wells, Observation Wells, Hydrogeology, Aquifers, Confined Aquifers, Unconfined Aquifers, Aquifer Characteristics, Limestone, Sand.

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Connector well, Orange County, Florida.

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November 1977

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ILLUSTRATIONS

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English-metric conversion factors

English unit	Multiply by	Metric unit
inch (in)	25.4	millimeter (mm)
foot (ft)	.3048	meter (m)
cubic foot (ft^3)	.028	cubic meter (m^3)
acre	.405	hectare (ha)
gallon (gal)	3.785	liter (L)
gallons per minute (gal/min)	.603	liters per second (L/s)

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EFFECTIVENESS OF PILOT CONNECTOR WELL IN ARTIFICIAL RECHARGE OF THE FLORIDAN AQUIFER IN WESTERN ORANGE COUNTY, FLORIDA

By

Frank A. Watkins, Jr.

ABSTRACT

A connector well pilot installation, in continuous operation in western Orange County since December 4, 1970, was transferring water from the lower of two shallow sand aquifers to the Floridan aquifer at a rate of 13 gallons per minute when measured on September 23, 1971. The recharge water is untreated and analyses show it to be chemically and physically compatible with the water in the Floridan aquifer. The temperatures of the recharging and receiving waters were identical, 23°C.

The transfer of water from the lower sand aquifer to the Floridan aquifer caused only a small buildup of artesian pressure in the Floridan aquifer but it lowered the artesian head 4 feet in the lower sand aquifer near the well which supplied the recharge water. Water levels in the upper sand aquifer were not affected, probably because of the low permeability of an intervening hardpan layer. However, after six auger holes back-filled with sand connected the two sand aquifers on April 5, 1972, a rise of water levels in the lower sand aquifer was noted.

The principal chemical and physical effects on the water in the Floridan aquifer were a general improvement in chemical quality and an increase in color. The color may decrease as more water moves through the sand aquifer and the material responsible for the high color is removed by flushing.

The results indicate the technical feasibility of connector wells to artificially recharge the Floridan aquifer. However, in areas that are hydrologically similar to the installation in western Orange County, some modification in the design and operation of connector wells might be considered to improve their efficiency.

INTRODUCTION

The rapidly increasing population and economic growth in the six counties which comprise the East Central Florida Regional Planning Council have resulted in an increasing stress on the water resources of the area. Although water is in abundance, it is not of suitable quality everywhere in the Region, the supply of surface water is seasonal, and ground water of acceptable quality and quantity is not always available in shallow sand formations. The Floridan aquifer, the principal source of potable water in the Region is capable of furnishing large quantities of water to wells. A means of facilitating the movement of water downward from the sand aquifers through the less permeable formations to recharge the Floridan aquifer is desirable. This investigation of the use of a connector well as a technique in artificial recharge to the Floridan aquifer was made in cooperation with the East Central Florida Regional Planning Council.

Purpose and Scope

The purpose of this investigation is to conduct a pilot study to determine the feasibility of artificially recharging the Floridan aquifer by means of connector wells. A connector well is a well that connects two or more aquifers that otherwise are almost hydraulically separate. For a connector well to operate--that is to transfer water from one aquifer to another--a hydraulic head differential must exist between the two aquifers being tapped, with the receiving aquifer having the lower head. Where such a hydraulic differential does exist, the connector well acts as a hydraulic "short circuit" which routes the water in the upper aquifer directly into the lower aquifer, bypassing the intervening material of lesser permeability--the confining bed. In this investigation, the upper aquifer is a sand aquifer which is separated from the Floridan aquifer by a clay, sand, and shell layer of low permeability. In areas where the water in the upper aquifer occurs under water-table conditions and the water level is at or near the land surface, the connector wells could reduce the need for surface drainage systems.

The report includes determinations of variations in ground-water levels, chemical quality of ground waters, investigation of the characteristics of the water-bearing formations, and interpretations of water data.

Location and Extent of Area

The pilot study area is in southwest Orange County, Florida (fig. 1), near the town of Doctor Phillips. The connector well and all observation wells are in an 80-acre tract in the W½NW¼ sec. 3, T.24 S., R.28 E. This property is part of an industrial park under development by the Dr. P. Phillips Foundation.

Related Investigations

Artificially recharging an aquifer by injecting water into wells has been accomplished in some parts of the country but only one instance of a controlled study of recharge through a connector well was known before the beginning of this investigation (Cederstrom and others, 1964). In that experiment a recharge well was drilled through three sand and gravel aquifers. The water level in the shallowest aquifer was the highest of the three and the aquifer was recharged from a nearby stream.

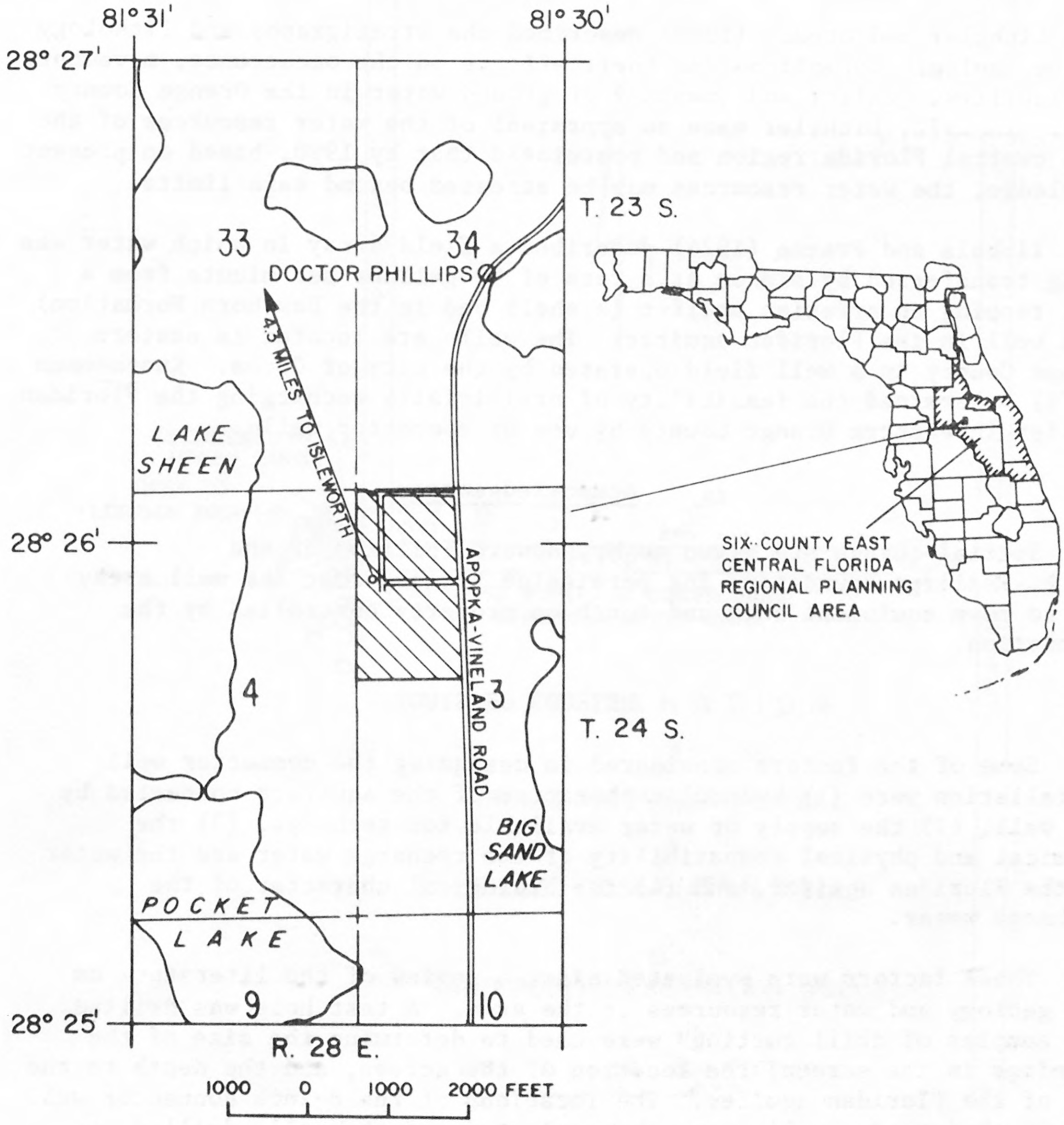

FIGURE 1.--Location of connector well pilot study site (shaded area) near Doctor Phillips.

Water was supposed to move down the casing from the near-surface aquifer and to recharge the lower two. However, sand was carried downward along with the water and the effectiveness of the test was marred by clogging of the deeper aquifer with sand and silt from the shallow aquifer.

Lichtler and others (1968) described the stratigraphy and lithology of the geologic formations and their effects on the occurrence, movement, availability, quality and quantity of ground water in the Orange County area. In 1972, Lichtler made an appraisal of the water resources of the east central Florida region and postulated that by 1990, based on present knowledge, the water resources may be stressed beyond safe limits.

Tibbals and Frazee (1976) described a field array in which water was being transferred by siphon at a rate of 90 gallons per minute from a well tapping an artesian aquifer (a shell bed in the Hawthorn Formation) to a well in the Floridan aquifer. The wells are located in eastern Orange County in a well field operated by the city of Cocoa. Knochenmus (1974) determined the feasibility of artificially recharging the Floridan aquifer in eastern Orange County by use of connector wells.

Acknowledgements

Special thanks are given to Mr. Howard Phillips of the Dr. P. Phillips Foundation for permission to construct the well array and to move equipment back and forth on property controlled by the Foundation.

METHODS OF STUDY

Some of the factors considered in designing the connector well installation were (1) hydraulic character of the aquifers connected by the well, (2) the supply of water available for recharge, (3) the chemical and physical compatibility of the recharge water and the water in the Floridan aquifer, and (4) the biological character of the recharge water.

These factors were evaluated after a review of the literature on the geology and water resources in the area. A test hole was drilled and samples of drill cuttings were used to determine the size of the openings in the screen, the location of the screen, and the depth to the top of the Floridan aquifer. The locations of the 8-inch connector well and 26 observation wells were then selected and the wells drilled. Their locations are shown in figure 2. Short pumping tests were run to determine the hydraulic character of the aquifer. Continuous water-stage recorders were installed on two wells and periodic water-level measurements were made on the remaining 25 wells. A nonrecording rain gage was installed at the site. Representative water samples from the various aquifers, including the Floridan, were collected and analyzed. Electric, gamma-ray, caliper, and current-meter logs were run in the connector well and the logs were used in the interpretations in this report.

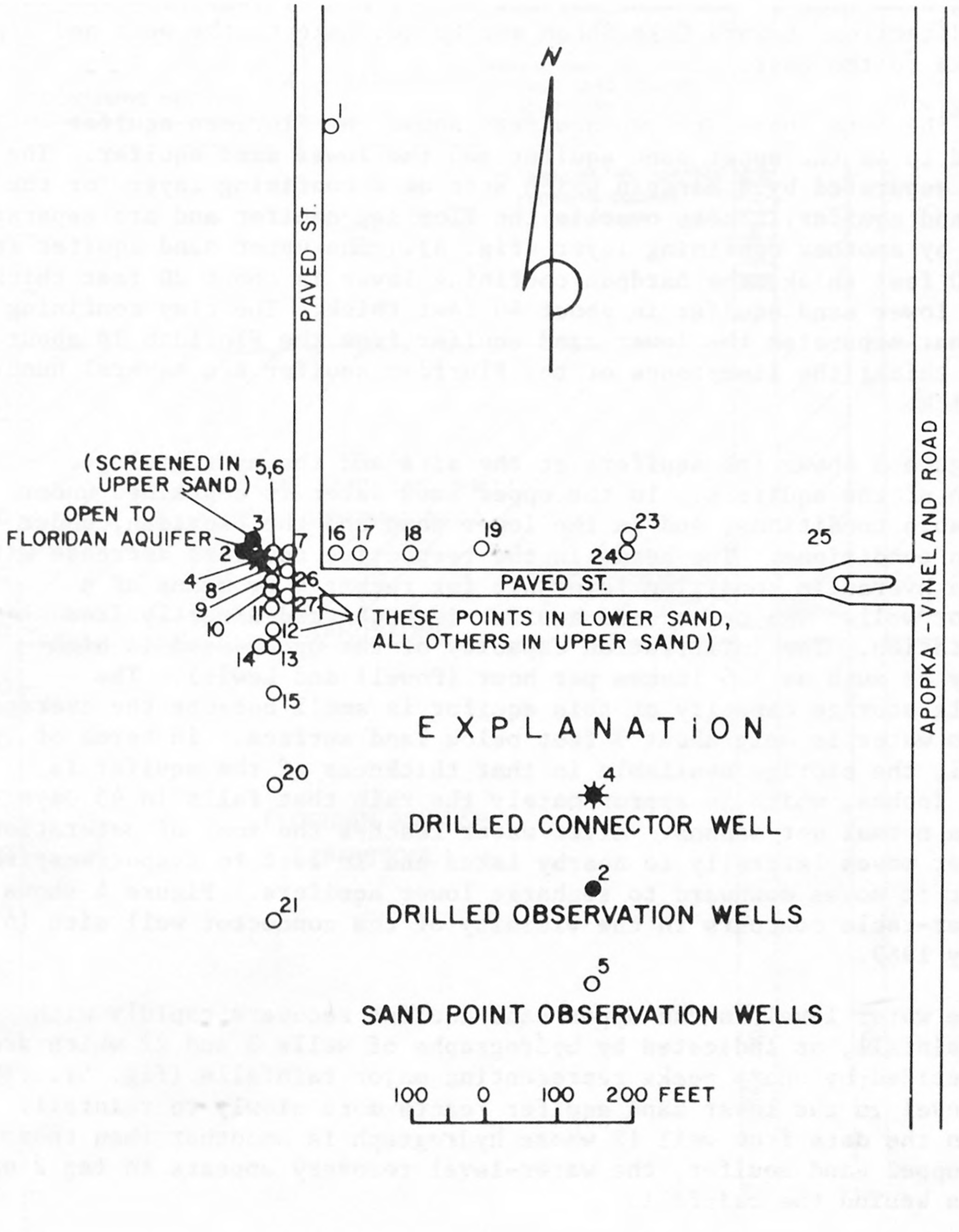

FIGURE 2.--Location of connector well and observation wells.

HYDROGEOLOGIC FEATURES OF THE AREA

The site of the connector well pilot study is on a north-south trending sand ridge. The land surface slopes gently away from the site in all directions toward Lake Sheen and Pocket Lake to the west and Big Sand Lake to the east.

At the site there are two aquifers above the Floridan aquifer referred to as the upper sand aquifer and the lower sand aquifer. The two are separated by a hardpan which acts as a confining layer for the lower sand aquifer. These overlie the Floridan aquifer and are separated from it by another confining layer (fig. 3). The upper sand aquifer is about 20 feet thick, the hardpan confining layer is about 20 feet thick, and the lower sand aquifer is about 40 feet thick. The clay confining layer that separates the lower sand aquifer from the Floridan is about 50 feet thick; the limestones of the Floridan aquifer are several hundred feet thick.

Figure 3 shows the aquifers at the site and the hydrogeologic relation of the aquifers. In the upper sand water is contained under water-table conditions; and in the lower sand and the Floridan, under artesian conditions. The heads in the respective aquifers decrease with depth, a hydraulic condition favorable for recharge by means of a connector well. The upper sand aquifer is recharged directly from precipitation. The infiltration capacity of the upper sand is high--probably as much as 3.5 inches per hour (Powell and Lewis). The available storage capacity of this aquifer is small because the average depth to water is only about 3 feet below land surface. In terms of rainfall, the storage available in that thickness of the aquifer is about 9 inches, which is approximately the rain that falls in 45 days during a normal wet season. After water reaches the zone of saturation, the water moves laterally to nearby lakes and is lost to evapotranspiration, or it moves downward to recharge lower aquifers. Figure 4 shows the water-table contours in the vicinity of the connector well site in February 1969.

The water level in the upper sand aquifer recovers rapidly with local rainfall, as indicated by hydrographs of wells 3 and 22 which are characterized by sharp peaks representing major rainfalls (fig. 5). The water level in the lower sand aquifer reacts more slowly to rainfall. Based on the data from well 12 whose hydrograph is smoother than those of the upper sand aquifer, the water-level recovery appears to lag 2 or 3 months behind the rainfall.

The hydrographs of well 4 (the connector well) and well 2, both tapping the Floridan aquifer, do not depict natural conditions but rather the effects of the transfer of water from the lower sand aquifer to the Floridan aquifer superimposed on the natural trends. The connector well was placed in operation December 4, 1970.

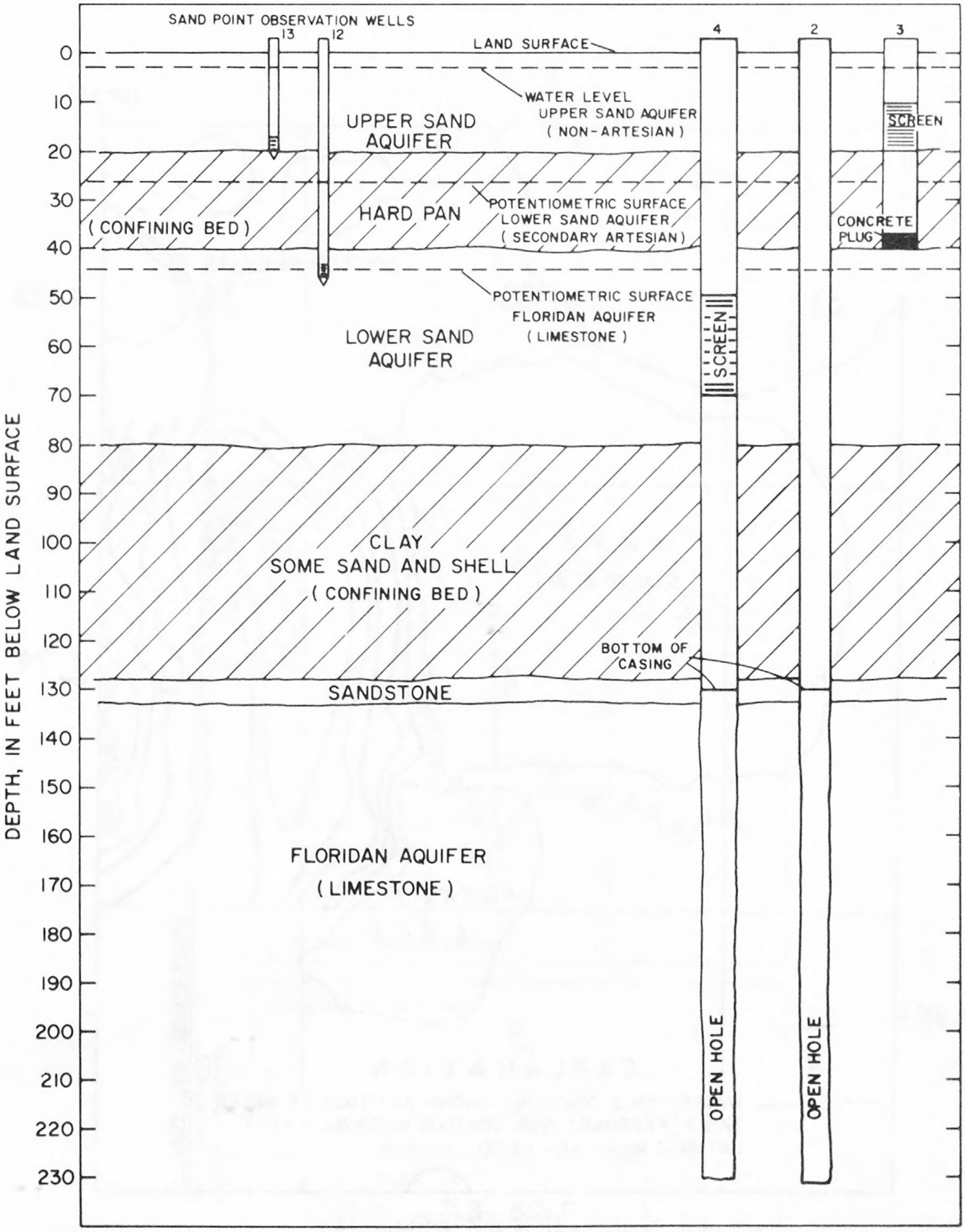

FIGURE 3.--Diagram showing the three water-bearing zones, confining beds, and water levels on December 4, 1970, before the connector well was put into operation. (Location of wells shown on figure 2.)

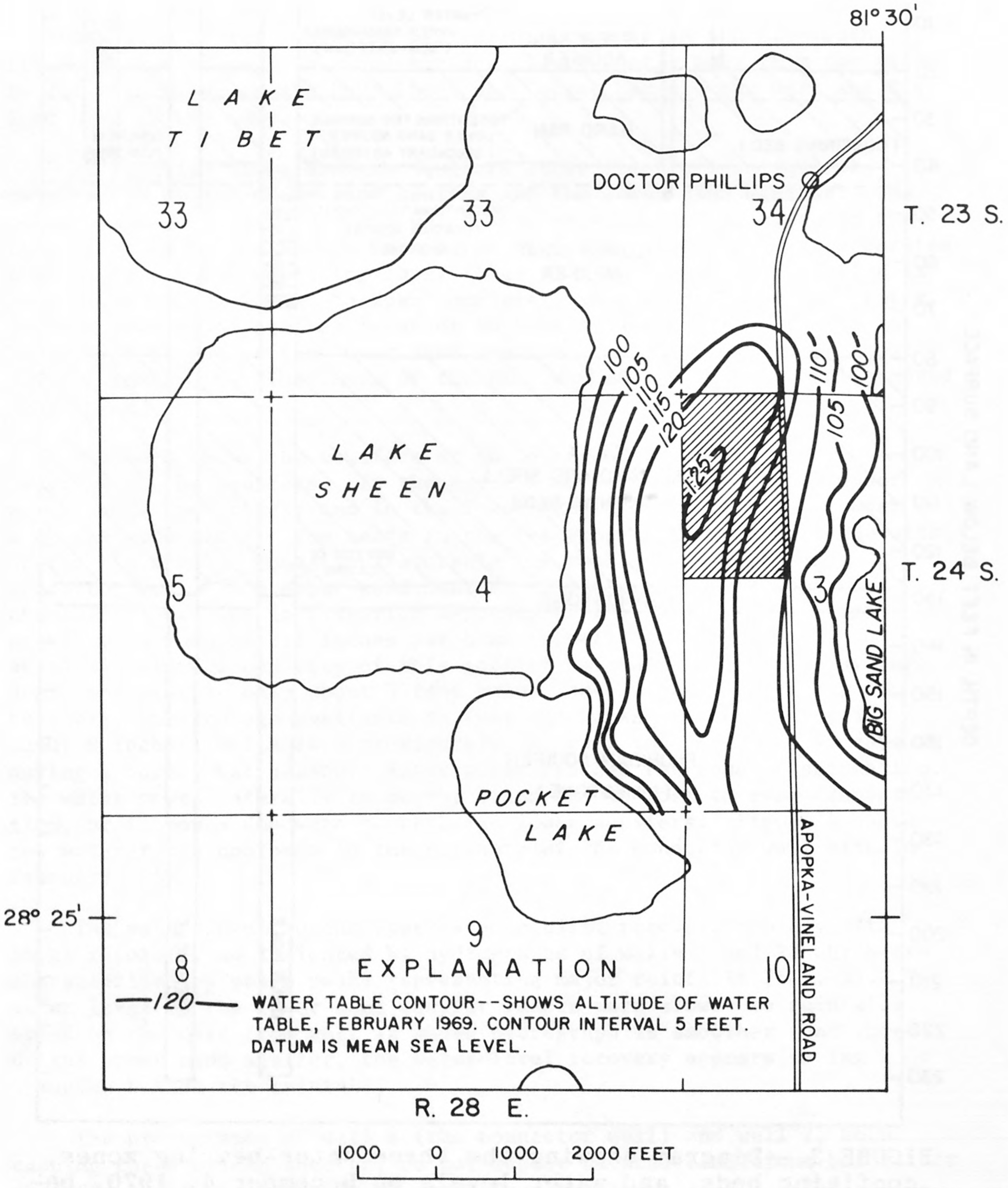

FIGURE 4--Water-table contours at the connector well site, February 1969.

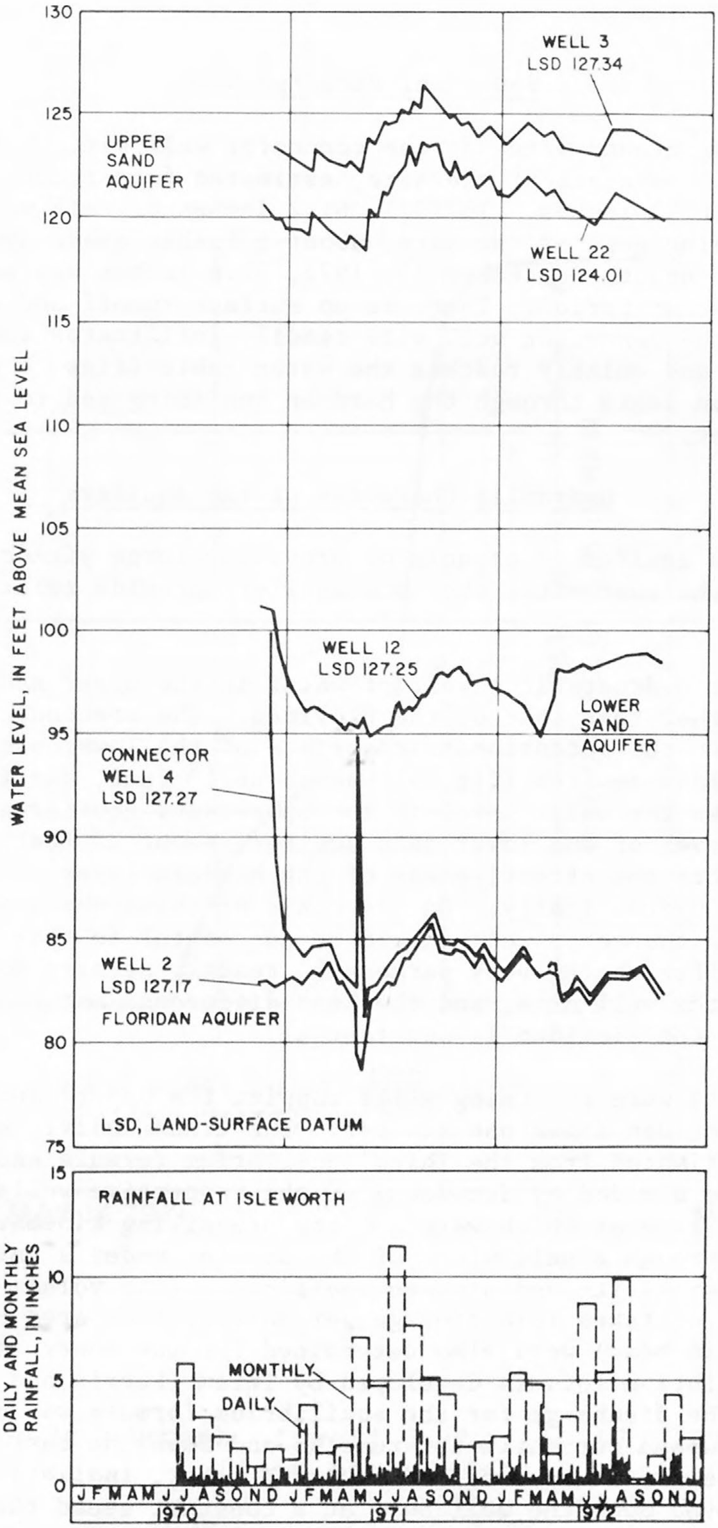

FIGURE 5.--Hydrographs of wells 3, 22, 12, 4, and 2, and rainfall at Isleworth, July 1970-December 1972.

Source of Recharge Water

The source of ground water at the connector well site is local rainfall. The average annual rainfall at the site, estimated from records of nearby stations, is about 53 inches. In 1971, 61.2 inches of rain was measured with a non-recording gage at the site, about 8 inches above average. From January 1, 1972, through September 15, 1972, 32.6 inches was measured, below normal for that period. There is no surface runoff and almost all rain falling at the connector well site readily infiltrates the clean sand in the soil zone and quickly reaches the water table (figs. 6 and 7). Some of this water then leaks through the hardpan confining bed to recharge the lower sand aquifer.

Hydraulic Character of the Aquifers

The Floridan aquifer is capable of providing large yields to wells in the vicinity of the test site; the sand aquifers provide relatively small yields.

The head, or hydrostatic level, of water in the upper sand aquifer is about 40 feet higher than that of the Floridan. The preconnector-well head difference between the potentiometric surface of the lower sand aquifer and that of the Floridan aquifer (fig. 3) was about 18 feet, and the head difference between the water level in the upper sand aquifer and the potentiometric level of the lower sand aquifer, about 22 feet. The large difference reflects the effectiveness of the hardpan layer in separating the two aquifers hydraulically. On the basis of these observations, it would seem that a connector well should be successful in this general area, the Floridan aquifer, being very permeable, readily permits movement of water away from the well site, and the head difference between the lower sand aquifer and the Floridan is substantial.

Aquifer tests were run using wells tapping the upper sand, the lower sand, and the Floridan limestone aquifer. The transmissivities of the aquifers were estimated from the Thiem equilibrium formula and the specific capacities (yield divided by drawdown) of the respective wells. Transmissivity is the rate at which water of the prevailing kinematic vicosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. Transmissivity and storage coefficient (the volume of water an aquifer releases or takes into storage per unit surface area of the aquifer per unit change in head) were also determined for the lower sand aquifer by use of the equilibrium formula developed by Thiem (Ferris and others, 1962, p. 91). The discharge for the equilibrium formula was determined by making constant speed current meter runs up and down the cased part of the connector well below the screen. The current meter, indicating less water velocity when moved down the well bore at a constant speed than when moved up at the same speed, showed that the water was moving down the well. The water velocity was determined as one-half the difference in indicated water velocity when the current meter was moving down the hole from the indicated water velocity when the meter was moving up the hole. Knowing this

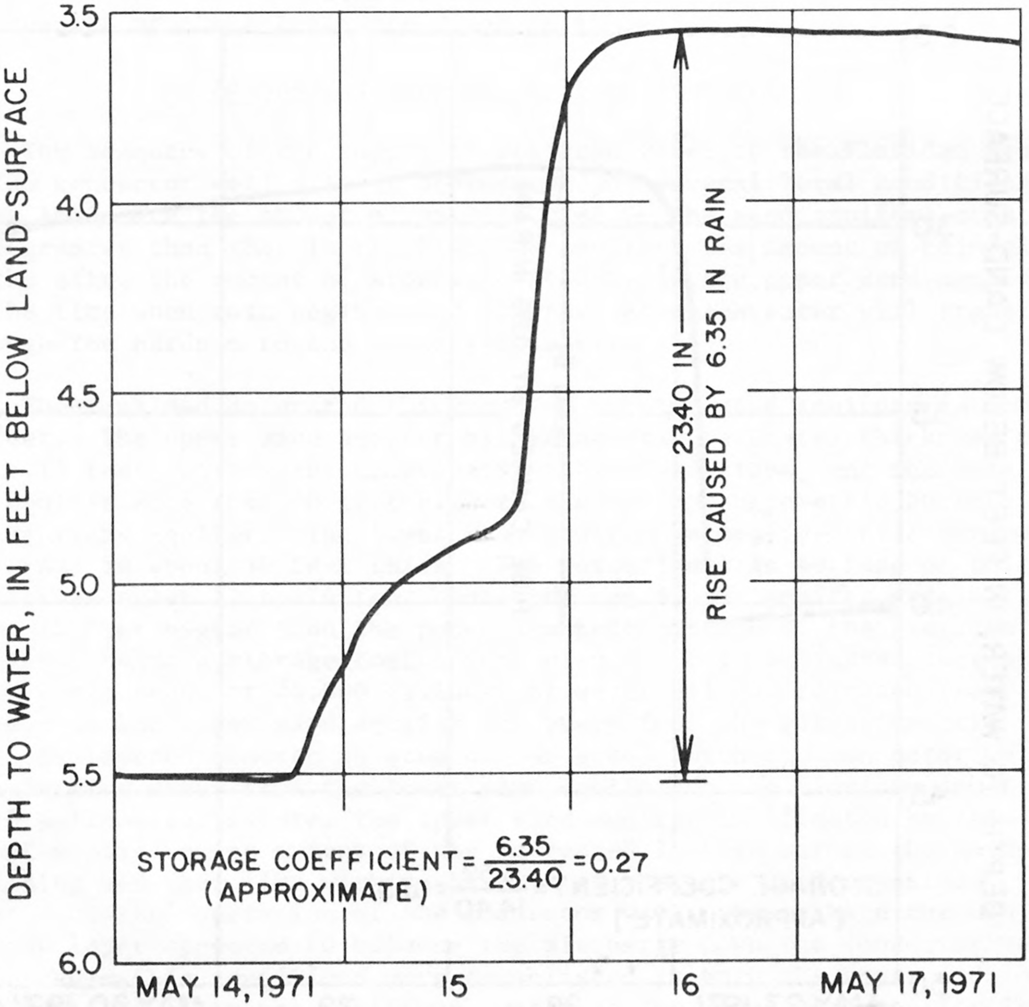

FIGURE 6.--Hydrograph of well 3, May 14-17, 1971, showing effect of rainfall.

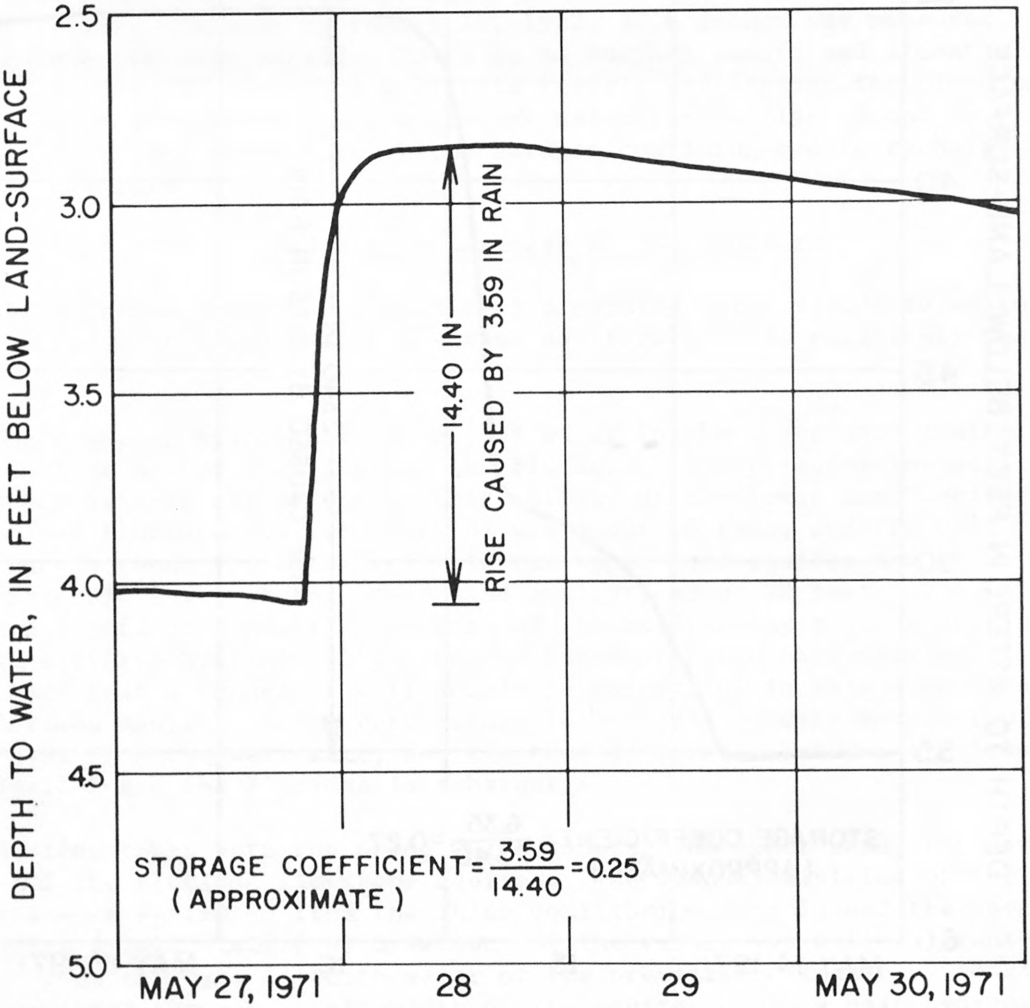

FIGURE 7.--Hydrograph of well 3, May 27-30, 1971, showing effect of rainfall.

velocity, and the casing diameter, the flow rate was computed to be 13 gallons per minute. The storage coefficient of the upper sand aquifer was determined by observing the rise in water level caused by a measured rain, with the storage coefficient equal to the rainfall, in inches, divided by the rise in water in the aquifer, in inches (figs. 6 and 7). The results of these tests are given in table 1.

Adequacy of Supply of Recharge Water

The adequacy of the supply of recharge water to the Floridan aquifer at the connector well site is dependent upon several local conditions. Among these are the amount of water stored in the sand aquifers at a head greater than that in the Floridan aquifer, the amount of rainfall at the site, the amount of storage available in the upper sand aquifer at the time when rain begins, and the rate at which water will transfer through the hardpan to the lower sand aquifer.

The combined saturated thickness of the two sand aquifers is about 55 feet. The upper sand aquifer has an average saturated thickness of about 15 feet, with water under water-table conditions, and the base of the aquifer more than 20 feet higher than the potentiometric surface of the Floridan aquifer. The lower sand aquifer is confined by a hardpan layer and is about 40 feet thick. The potentiometric surface of this aquifer is about 12 to 14 feet above the top of the aquifer and initially about 18 feet higher than the potentiometric surface of the Floridan aquifer. Using a storage coefficient of 0.08 it is estimated that about 3,500 cubic feet, or 26,000 gallons, of water will be released from storage in the lower sand aquifer for every foot the potentiometric level is lowered beneath an area of one acre. With the connector well transferring water from the lower sand aquifer to the Floridan aquifer at 13 gallons per minute, the upper sand aquifer is affected by this transfer only to the extent of the increased leakage across the hardpan confining bed that lies within the area of the cone of depression. After 2-months' operation of the connector well, the leakage through the hardpan layer appeared to balance the discharge down the connector well and steady-state conditions were established in both the upper and lower sand aquifers. Although additional water in the upper sand aquifer is available for recharge, the quantity of water that can be transferred to the lower sand aquifer is limited by the permeability of the hardpan layer. Figure 8 shows head conditions in the vicinity of the connector well on February 2, 1971, after 61 days of operation. The water level in the upper sand appeared not to have been affected by the operation of the well.

It should be possible to transfer water from the upper sand to the lower sand, then to the Floridan aquifer through properly constructed connector wells. Using a storage coefficient of 0.25 it is estimated that about 11,000 cubic feet, or 81,700 gallons, of water will be released from storage for every foot the water level is lowered beneath an area of 1 acre. If the water level in the upper sand aquifer is drawn down

TABLE 1.--Aquifer constants at the connector well site.

Constant	Aquifers		
	Upper sand	*Lower sand*	*Floridan*
Specific capacity, in gallons per minute per foot	0.1	0.97	5.8
Transmissivity, in square feet per day	27	270	1,600
Storage coefficient	.25	.08	.0016[a]
Hydraulic conductivity, in feet per day	1.9	6.8	16.1

a From Lichtler and others (1968, p. 137).

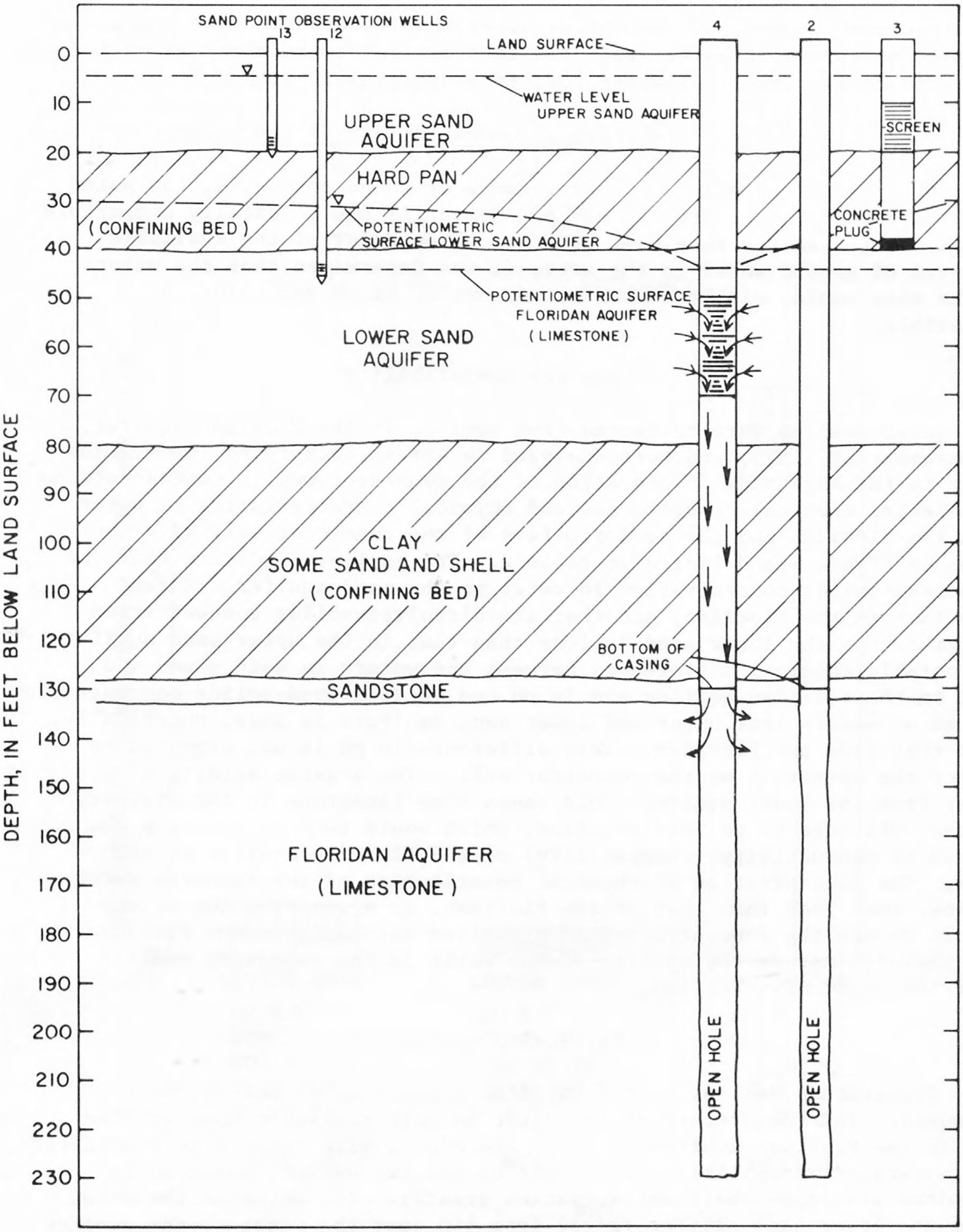

FIGURE 8.--Diagram showing water levels in the three water-bearing zones at the connector well site on February 2, 1971, after the connector well had been in operation for 61 days.

5 feet, about 33 percent of the saturated thickness, each acre of aquifer would yield about 408,500 gallons of water and thereby make the space occupied by this much water available to store future rainfall as well as to reduce the amount of water lost to evapotranspiration.

Chemical and Physical Compatibility of the Waters

For optimum operation and maintenance of connector wells, the water from the recharging aquifer should be chemically and physically compatible with the water in the receiving aquifer. From study of the available analyses of ground water in the area, it was determined that the waters at the site would, with the possible exception of pH and color, be compatible.

Chemical Compatibility

Water samples were collected from well 2, in the Floridan aquifer, on November 18, 1970, and were analyzed to obtain background information prior to the beginning of operation of the connector well. Concentrations of selected chemical constituents and physical characteristics of water from the Floridan and the sand aquifers at the connector well site are shown in figure 9 and listed in table 2. The analyses indicate that the dissolved-solids concentration in water in the sand aquifers is less than that in the Floridan, and that the dissolved-solids concentration in water from the lower sand is less than that in the upper sand aquifer. The notable chemical differences between the waters in both sands and that in the Floridan aquifer are in pH and in dissolved-solids concentration. The pH of waters from upper and lower sand aquifers is less, numerically, than that from the Floridan. This difference in pH is not expected to affect the operation of the connector well. The greater acidity of the water from the lower aquifer could cause some limestone in the vicinity of the well bore to go into solution, which would tend to increase the hydraulic conductivity (permeability) of the Floridan aquifer at the site. The concentration of chemical constituents of the recharge water is low, much less than that of the Floridan, so mixing the two waters should reduce the concentration of dissolved materials in the Floridan and thereby improve the quality of the water in the receiving aquifer near the point of injection.

Physical Compatibility

Temperature and color, two physical properties of waters, were measured. The temperature of the water in both the lower sand aquifer and in the Floridan aquifer is 23°C; therefore, with respect to temperature, the waters are compatible. The color of the two waters, measured in standard platinum-cobalt units, varies greatly. The color of the water from the lower sand aquifer ranged from 640 near the start of the aquifer tests, May 6-7, 1971, to 45 near the end of the tests. The color of

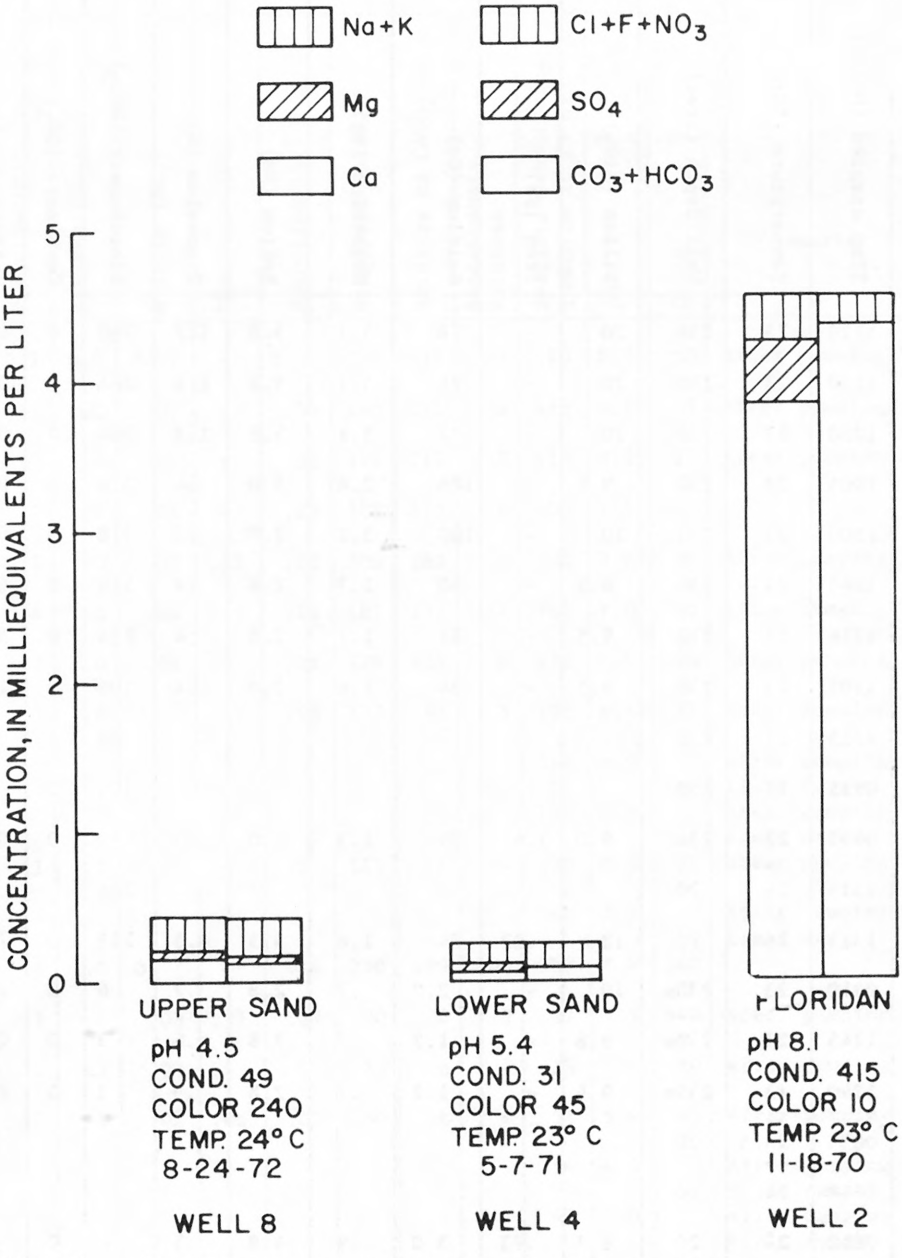

FIGURE 9.--Major constituents in water from wells that tap the upper sand, the lower sand, and the Floridan aquifer. (Dissolved solids concentration: Well 8, 75 mg/L; Well 4, 50 mg/L; Well 2, 276 mg/L.)

TABLE 2.--Chemical analyses of waters from the connector well
Survey; in milligrams per

Well no.	Date sampled	Time sampled (hours)	Temperature (°C)	Well depth (feet)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (FO_4)
2	11-18-70	1120	23	230	20	-	78	5.1	5.8	1.7	260	0	0
2	11-18-70	1150	23	230	20	-	76	5.1	5.8	1.8	264	0	0
2	11-18-70	1250	23	230	20	-	77	5.1	5.8	1.8	264	0	0
2	03-26-71	1005	23	230	9.8	-	106	2.4	3.0	.4	328	0	0
2	05-07-71	1500	23	230	10	-	100	3.2	2.8	.5	318	0	0
2	08-25-71	1046	23	230	8.3	-	50	1.7	2.8	.4	144	0	5.2
2	08-25-71	1116	23	230	9.5	-	51	1.7	2.8	.4	156	0	5.2
2	02-22-72	1105	23	230	9.5	-	34	1.6	2.8	.4	106	0	1.6
2	07-25-72	1315	23	230							80	0	
2	08-24-72	0935	23	230							108	0	
2	08-24-72	0935	23	230	9.0	3.6	29	1.3	3.0	.3	90	0	0
3	07-25-72	1315	26	20							236		
3	07-25-72	1315	26	20	12	.27	74	1.6	5.3	4.5	228	0	7.2
4	05-06-71	0940	23	230a	10	-	2.0	.7	2.8	.7	6	0	0
4	05-06-71	1245	23	230a	9.8	-	1.2	.7	2.8	.6	3	0	0
4	05-07-71	1240	23	230a	9.6	-	1.2	.7	2.8	.5	3	0	0
6	08-24-72	0835	24.5	20									
8	08-24-72	0850	24	20									
8	08-24-72	0850	24	20	6.7	.73	3.0	.9	4.9	.5	0	0	.8
11	08-24-72	0915	25.5	10							2	0	
14	08-24-72	0925	27	5							20	0	

a Total depth of well, packer set below screen at 85 feet, water is from lower sand aquifer only.

site near Doctor Phillips. (Analyses by the U.S. Geological liter except as noted.)

Well no.	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Nitrite (NO_2)	Phosphate (PO_4)	Strontium (Sr)	Dissolved Solids	Hardness as $CaCO_3$	Noncarbonate hardness	Specific conductance (umho/cm at 25°C)	pH	Color	Remarks
2	6.0	0.1	0.0	0.02	-	0.33	276	216	3	410	8.0	30	After pumping ½ hr.
2	6.0	.1	.0	.01	-	.30	280	211	0	415	8.1	5	After pumping 1 hr.
2	6.0	.1	.0	.01	-	.32	276	214	0	415	8.1	10	After pumping 2 hrs.
2	6.0	.1	.0	.01	-	.23	308	275	6	500	7.5	20	
2	6.0	.2	.0	.02	.31	.22	300	263	3	520	8.2	30	After pumping 1 hr.
2	7.0	.4	.0	.02	-	.11	187	132	14	265	7.0	80	After pumping ½ hr.
2	7.0	.2	.0	.01	-	.11	179	134	6	270	7.9	30	After pumping 1 hr.
2	6.5	.1	.0	0	-	.08	123	92	5	195	6.4	25	After pumping 1 hr.
2										147	6.0		After pumping 1 hr. field data
2										178	6.0		After pumping 1 hr. field data
2	6.0	.1	.0	.01	-	.1	111	78	4	170	6.6	70	After pumping 1 hr.
3										360	7.0		After pumping 3 3/4 hrs. field data
3	8.0	.5	.0	0	-	.14	230	190	400	380	7.8	360	
4	5.0	.1	.1	.03	.31	.02	100	8	3	37	5.5	640	After pumping 40 min.
4	5.0	.1	.1	.02	.4	.02	74	6	4	35	5.4	80	After pumping 3 3/4 hrs.
4	5.5	.1	.0	.02	.06	.02	50	6	4	31	5.4	45	After pumping 3 3/4 hrs.
6										54	4.3		After pumping ¼ hr. field data
8										45	4.0		After pumping ¼ hr. field data
8	9.0	.1	.0	0	-	.06	75	11	11	49	4.5	240	After pumping ¼ hr.
11										47	4.7		After pumping ¼ hr. field data
14										97	5.2		After pumping 10 min. field data

water from the Floridan aquifer prior to the beginning of operation of the connector well ranged from 5 to 30. Although color in the recharge water from the lower sand aquifer is somewhat higher than 30, the effect on water in the Floridan is considered negligible.

Biological Quality of the Recharge Water

Water samples were collected July 25, 1972, and August 1, 1974, from the upper sand aquifer and the Floridan aquifer and were tested for the presence of coliform bacteria. On July 25, 1972, the total, or immediate concentration of coliform bacteria in the water from well 2, in the Floridan aquifer well, was 62 colonies per 100 mL (milliliters), and 60 colonies immediate coliform bacteria per 100 mL, 1 colony fecal coliform bacteria per 100 mL and 400 colonies fecal streptococci per 100 mL on August 1, 1974. Total immediate concentration of coliform bacteria in the water from well 3, in the upper sand aquifer, was 200 colonies per 100 mL.

On the basis of these tests, water from both aquifers met the 1972 bacteriological quality standards of the National Academy of Sciences - National Academy of Engineering (1972, p. 58).

A small amount of data was collected during this investigation on concentrations of the two nutrients, nitrate and phosphate, in water from the lower sand aquifer and from the Floridan aquifer. The analyses are shown in table 2. The concentrations of both are negligible.

The recharge water at the connector well site was assumed to be relatively free of pathogenic organisms because the site is relatively remote from possible sources of contamination, and is near the high of the local water table so that ground-water movement is away from the site; also, there is about 50 feet of sand and hardpan above the top of the screen in the connector well which acts as a filter.

From a sanitary standpoint, blending water from the lower sand aquifer with that in the Floridan should pose no problem.

PHYSICAL LAYOUT OF SITE AND WELL CONSTRUCTION

The general physical layout at the connector well site is shown in figure 2. In addition to the 8-inch diameter connector well, observation well 2 is about 20 feet west, and 8-inch observation well 3 is about 20 feet north of the connector well. Also, a line of seven 1¼-inch observation wells extends about 800 feet east and another line of eleven extends about 1,000 feet south from the connector well.

Connector Well

The connector well is screened in the lower sand aquifer and open to the Floridan aquifer and was constructed so as to exclude surface water and water from the upper sand aquifer. The screen of the connector well was set in the lower sand aquifer between 50 and 70 feet below land surface and the casing was set in a thin sandstone stratum at about 130 feet. Drilling was continued into the limestone to 230 feet so that the well is open to the Floridan 130-230 feet below land surface. The well is equipped with a continuous water-stage recorder. Figure 10 is a diagram of the connector well and also shows the generalized geology and the gamma-ray log at the site.

Observation Wells

The 6-inch diameter well 2 was also drilled to 230 feet and the casing was seated at 130 feet. A pump was installed in this well so that water samples could be collected from it while recharge was taking place. Water levels at this well were measured periodically.

The 8-inch well 3 was drilled to about 40 feet, screened 10-20 feet opposite the upper sand aquifer, and plugged with concrete to exclude all water except that which enters through the screen. This well was equipped with a continuous water-stage recorder.

The remaining observation wells are completed with sand points 1¼ inches in diameter and range from 5 to 46 feet deep. Well 14 is 5 feet deep; wells 10, 11, 15-23 and 25 are 10 feet deep; and wells 1, 5, 6, 9, 13, and 24 are 20 feet deep. Well 12 is 46 feet deep and, prior to April 4, 1972, was the only observation well screened in the lower sand aquifer, except the connector well. Water levels in these wells are measured weekly thru April 1972 and monthly for the remainder of the year.

On April 4 and 5, 1972, two 2-inch diameter wells, with 1¼-inch diameter screens were set in the lower sand aquifer. These wells, numbers 26 and 27, are 46 and 42 feet deep, respectively. At the same time that the above wells were installed, six holes were augered through the hardpan in the vicinity of the connector well and back-filled with sand. These holes, spaced about 25 feet apart, are located about 5 feet off the west side of the pavement of the north-south street from a point about 75 feet north of well 7 south to a point opposite well 12.

SIGNIFICANCE OF THE TESTS

The data collected during this study allowed at least some evaluation of the technical feasibility and the short-term effects of the use of connector wells for artificial recharge of the Floridan aquifer. The ultimate success of this type of artificial recharge may depend, however, on cumulative effects that may not become evident until the system has been in operation for a long period, or upon economic considerations beyond the scope of the investigation.

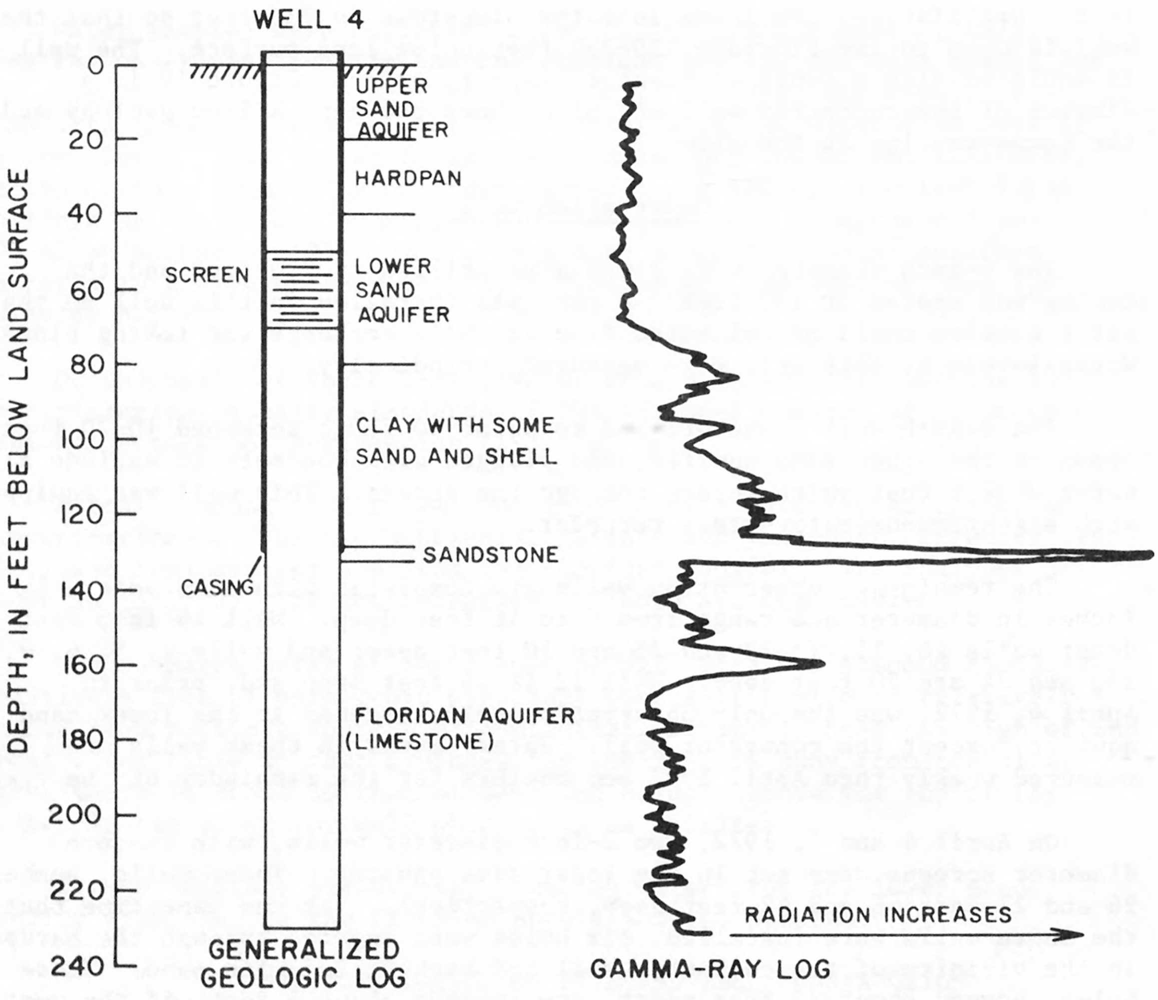

FIGURE 10.--Generalized geologic and gamma-ray logs of connector well.

Changes in the Physical and Chemical Character of the Water

Chemical analyses of water from the Floridan aquifer at the connector well site show that dissolved-solids concentrations decreased in the Floridan after transfer of water from the lower sand aquifer to the Floridan aquifer began.

The nature of this change is shown by comparison of the analyses in table 2 of water from observation well 2 taken on November 1970 prior to the start of recharge on December 4 and those taken after December 4. There was a marked increase in calcium, bicarbonate, dissolved solids, hardness, and specific conductance into May 1971, then a decrease (fig. 11). The reason for the initial increase in these constituents is not known but it is postulated that they were caused by a reaction of water with chemicals in the drilling mud and cement used in construction of the wells. This postulate is given more credence by the analyses of the water (table 2) from well 3, which was drilled into the upper sand aquifer about 10 feet from the mud pit and also has a cement plug set in the bottom and a surface casing cemented into place. A sample of water from this well collected July 25, 1972, had a pH of 7.8 and specific conductance of 380 micromhos per centimeter at 25°C, while the pH of all other samples of water from the sand aquifers ranged from about 4.0 to 5.5 and specific conductances ranging from 31 to 97 micromhos per centimeter at 25°C, which suggests that the chemical quality of the water from well 3 was affected by the cement and drilling mud used in its construction.

Continuous operation of the connector well has apparently cleared the reacting substances from the vicinity of its well bore. The analyses of the water from well 2 sampled after May 7, 1971, show a progressive decrease in dissolved solids concentration in the water from the Floridan.

The two physical characteristics measured during this test were temperature and color. The maximum difference in temperature was only 4°C between the water in the upper 5 feet of the upper sand aquifer and that in the Floridan aquifer. The temperature of the water from the lower sand aquifer and from the Floridan is 23°C.

Color, on the other hand, could be a problem because of the differences in the color of the two waters, yet it is not likely to be a serious problem. The maximum color observed in water from well 4, sampled after the packer was installed on May 6, 1971, was 640. After additional pumping the color dropped to 80 and then to 45 the following day. Thus, it appears that some mechanism is lowering the color level of the recharged water, perhaps a flushing of constituents responsible for the color in the water of the lower sand aquifer near the connector well. Prior to the beginning of recharge, the color of the receiving water was 30. The maximum color observed in the mixed water in the receiving aquifer after recharge began was 80 and the minimum was 20.

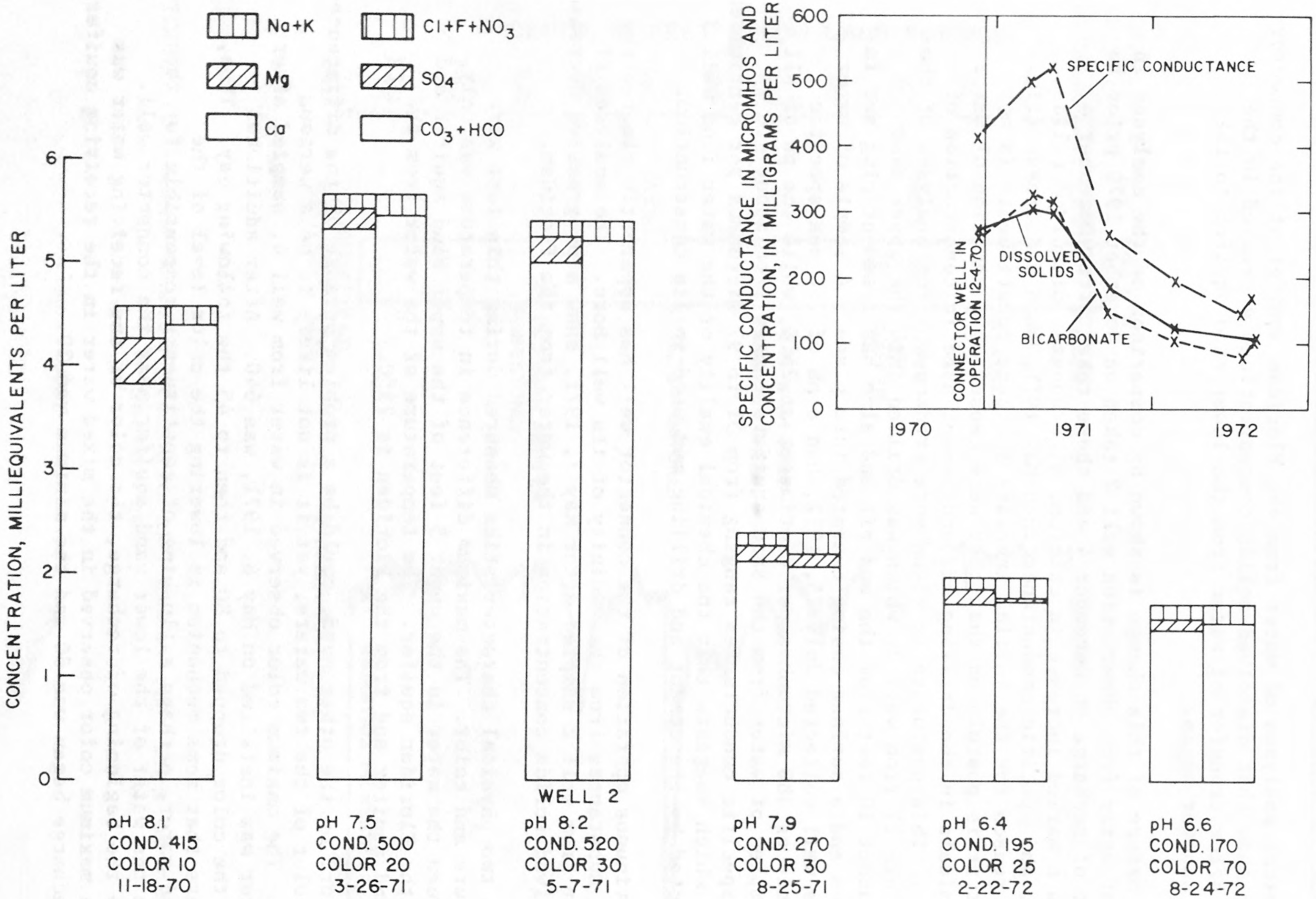

FIGURE 11.--Major constituents in water from the Floridan aquifer, November 1970-August 1972. (Connector well placed in operation December 4, 1970.)

Effects on the Aquifers and the Connector Well

The transfer of water from the lower sand aquifer to the Floridan aquifer at the rate of 13 gallons per minute caused the water level in well 2, open only to the Floridan aquifer, to rise only slightly, about 0.2 foot between November 30 and December 11, 1970. The daily variations in water levels as a result of natural, climatic variations, and withdrawals from the aquifers, obscured the effects of water transfer (fig. 5). This transfer of water has established a measurable gradient away from the connector well in the Floridan aquifer; that is, the water level in the connector well is about 0.2 foot higher in altitude than that in observation well number 2, which is 20 feet to the west. The water level in the connector well dropped from that of the lower sand aquifer to near that of the Floridan when the well was placed in operation December 4, 1970; and the level in the lower sand dropped about 4 feet in well number 12, which is 100 feet south of the connector well. Following that initial change, the slight water-level rise in the Floridan and the large drop in the lower sand aquifer were superimposed on the seasonal trend.

The rise in the water level in the connector well early in May 1971 (fig. 5) was caused when a pneumatic packer was placed, temporarily, below the screen in order to run pumping tests in the lower sand aquifer. The water level in the well rose 12 feet, to that of the level in the lower sand aquifer, then declined abruptly when the plug was removed. The decline in the water level in the Floridan aquifer in well 2 when the packer was installed and the recovery in level when it was removed (fig. 5) indicate that there is at least some local effect on water levels from the water transfer.

Drawdown of Water Level in Sand Aquifers

The effect of operating the connector well on the water levels in the upper sand aquifer is minimal because the hardpan layer retards the downward movement of water from the upper to the lower sand aquifer. The effect of the connector well on the water-level in the lower sand aquifer was immediate. A 4-foot decline in level in well 12 was noted after the connector well was put in operation (fig. 5). This declining trend appeared to have ended after about 2 months, perhaps meaning that steady-state flow conditions were then established: that the leakage through the confining bed within the cone of depression, plus increased lateral flow toward the connection well, was equal to the amount of water being discharged through the connector well. After this equilibrium condition was established, water-level fluctuations in well 12 were in accord with the seasonal trends.

An experiment to connect the upper sand aquifer to the lower sand aquifer so as to increase the amount of water available to the connector well, and also, to lower the water levels in the upper sand aquifer, was begun on April 5, 1972, when six 6-inch diameter holes were augered through the hardpan and backfilled with surface sand. The only visible result, however, was a rise in water level in well 12 (fig. 5), which is open to the lower sand aquifer. The rise in water levels in this well after April 5, 1972, continued into September while water levels in other wells in the vicinity were on a general downward trend, and a new equilibrium water level appears to have been established in well 12.

METHODS AND TECHNIQUES FOR FURTHER ARTIFICIAL RECHARGE

The results of the present study indicate that certain considerations in the design of and techniques for installing a connector well system for subsurface injection would increase the chances of success of this type of artificial recharge operation.

No serious problems are anticipated in connection with continued recharge through the connector well, and the recharge operations have caused no apparent damage to water yields or the aquifers. It is suggested that at any future sites where a confining bed separates two sand aquifers, the connector well be designed to accept water from both. This could be done at the present site by setting a second screen opposite the upper sand; or by connecting the two sand aquifers by small diameter connector wells that would transfer water from the upper sand aquifer to the lower sand aquifer which, in turn, would transfer the water to the Floridan aquifer through well 4. Wells with screens set in the upper sand aquifer would, however, require some arrangement to shut them off to prevent the possibility of plugging due to aeration of the screens.

The connector well will need periodic maintenance, such as cleaning, and probably redevelopment. At intervals, as determined on the basis of its operating efficiency, cleaning and surging of the screened part of the well will probably be necessary.

The continued collection of operational data will allow a realistic determination of the life of the pilot installation. The collection of various operational data would help to properly evaluate the results of artificial recharge through connector wells. These data include records of quantity of water transferred, fluctuations of ground-water levels at the site and, as control data in the general vicinity, the amount and intensity of precipitation, and periodic determinations of the chemical, physical, and biological character of the water from both the recharging aquifer and the receiving aquifer.

CONCLUSIONS

The major conclusions resulting from this study are as follows:

1. Water can be transferred to the Floridan aquifer from the overlying sand aquifer by connector wells in the area investigated.

2. The connector well was transferring water at a rate of 13 gallons per minute when measured on September 23, 1971. This would amount to 6.8 million gallons per year although it is unlikely that this transfer rate would remain constant indefinitely.

3. The connector well has lowered the water level about 4 feet in the lower sand aquifer at a distance of about 100 feet from the connector well. The level in the upper sand aquifer at the connector well site has not declined noticeably.

4. The only effect on the quality of the water in the Floridan aquifer from the transfer has been a decrease in the dissolved solids concentration and a small increase in the color.

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