UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

EFFECTS OF EFFLUENT SPRAY IRRIGATION ON GROUND WATER AT A TEST SITE NEAR TARPON SPRINGS, FLORIDA

By David P. Brown

Open-File Report 81-1197

Prepared in cooperation with

PINELLAS COUNTY, FLORIDA

Tallahassee, Florida

1982

UNITED STATES DEPARTMENT OF THE INTERIOR

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EFFECTS OF EFFLUENT SPRAY IRRIGATION ON GROUND WATER AT A TEST SITE NEAR TARPON SPRINGS, FLORIDA

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ABSTRACT

Secondary-treated effluent was applied to a 7.2-acre test site for about 1 year at an average rate of 0.06 million gallons per day and 3 years at 0.11 million gallons per day. Chemical fertilizer was applied periodically to the test site and adjacent areas. Mounding of the water table occurred due to effluent irrigation, inducing radial flow from the test site.

Ground water in the surficial aquifer at the test site and adjacent areas showed substantial increases in most chemical and physical parameters (including chloride, specific conductance, pH, total nitrogen, and total carbon) above background values. Most values observed at the test site, however, were within the range of values observed in nearby areas that were irrigated with water from the Floridan aquifer and periodically fertilized.

In the surficial aquifer, about 200 feet downgradient from the test site, physical, geochemical, and biochemical processes effectively reduced total nitrogen concentration 90 percent and total phosphorus concentration more than 95 percent from that of the applied effluent. In the effluent, total nitrogen averaged 26 milligrams per liter and total phosphorus averaged 7.3 milligrams per liter. Downgradient, total nitrogen averaged 2.4 milligrams per liter and total phosphorus averaged 0.17 milligrams per liter. Increases in total phosphorus concentration were observed where the pH of ground water increased.

Microbiological data did not indicate fecal contamination in the surficial aquifer. Fecal coliform bacteria were generally less than 25 colonies per 100 milliliters at the test site and were not detected downgradient or near the test site. Fecal streptococcal bacteria were generally less than 100 colonies per 100 milliliters at the test site and on three occasions were detected adjacent to the test site. In the Floridan aquifer, total and fecal coliform bacteria were detected in 50 percent of the samples. Total coliform bacteria were generally less than 100 colonies per 100 milliliters and fecal coliform bacteria were generally less than 10 colonies per 100 milliliters.

INTRODUCTION

Pinellas County, on the west-central coast of Florida, has a pollution-control goal of zero discharge of waste-treatment plant effluent into the shallow coastal waters of the Gulf of Mexico and Tampa Bay. The goal was established because of legal, social, and economic factors. Treatment facilities that discharge to tidewater are required to provide advanced waste treatment or an alternative disposal method to comply with State regulations.

Florida regulations define advanced waste treatment as that which will provide an effluent containing no more than the following concentrations: 5-day BOD (biochemical oxygen demand), 5 mg/L (milligrams per liter); suspended solids, 5 mg/L; total nitrogen as N, 3 mg/L; and total phosphorus as P, 1 mg/L. Disinfection is required to be not less than 15 minutes contact time at maximum flow, and the effluent shall have a free chlorine residual of no less than 1 mg/L or the equivalent (Florida Department of Environmental Regulation, 1976a).

The Florida Department of Environmental Regulation defines alternate effluent disposal as a minimum of secondary treatment (90 percent removal) followed by an effluent disposal system approved by the Department that will prevent any effluent from being discharged to the surface waters of the State. Such disposal may include land disposal, deep injection wells, or combinations thereof, or other methods approved by the Department (Florida Department of Environmental Regulation, 1976b).

Even if discharged effluent met the standards proposed in the law, local public officials have been reluctant to allow any effluent to be discharged to shallow gulf and bay waters or through long outfalls extending into deeper parts of the gulf. An alternative for disposal of effluent in counties affected by State regulations is landspreading or spray irrigation.

Spray irrigation of treated effluent in Pinellas County can be beneficial for numerous reasons. These include (1) recharge to the surficial aquifer and eventually to the Floridan aquifer; (2) reduced demands from the Floridan aquifer for irrigation in an area where the aquifer is subject to saltwater encroachment; and (3) distribution of nutrients onto cultivated land, thus reducing chemical fertilizer requirements.

Purpose and Scope

The purpose of the study was to determine the effects of spray irrigation of waste-treatment plant effluent on the quality of ground water at and near a test site in northwest Pinellas County, Fla. During 1971-75, a network of wells was monitored for changes in water levels and water quality. This report includes monitoring and test drilling results and an evaluation of observed changes.

Previous Investigations

Landspreading of waste-treatment plant effluent has received intensive investigation in recent years as an alternative to more common methods of effluent treatment and disposal. Numerous reports on physical, chemical, and biological aspects of landspreading in general have been published (U.S. Environmental Protection Agency, 1974).

Cherry and others (1973) presented preliminary findings on the effectiveness of soil, bacteria, and vegetation for removing nitrogen and phosphorus from treatment plant effluent at a spray-irrigation test site in St. Petersburg, Fla. Reichenbaugh and others (1979) continued the study at the St. Petersburg test site. Reichenbaugh (1976) also determined the effects of low-rate pasture irrigation with sewage effluent near Lakeland, Fla., on soil similar to that of the northwest Pinellas County study area.

Acknowledgments

The cooperation of William Dunn, Pollution Control Director, and Donald Hammond of the Department of Pollution Control, Pinellas County, Fla., is gratefully acknowledged. The helpful cooperation of Arland Grant, Grounds Superintendent, Innisbrook, is greatly appreciated.

DESCRIPTION OF TEST SITE

The test site was a golf driving range within a 1,000-acre condominium-resort complex (Innisbrook) in northwest Pinellas County (fig. 1). At the 7.2-acre test site, which was about 1,000 feet long and 150 to 350 feet wide, land altitudes ranged from about 8 feet to over 20 feet above sea level. In the general area, altitudes ranged from sea level at the coast to more than 80 feet above sea level along a sandy ridge south of the test site.

Batteries of observation wells were installed in and near the test site for obtaining water-level measurements and water samples (tables 1A and 1B and fig. 2). Most batteries consisted of three wells about 10, 15, and 20 feet deep and spaced about 5 feet apart. The wells were constructed of 2-inch diameter PVC (polyvinylchloride) casing and a 1.25-inch diameter slotted PVC screen about 1 foot long.

Waste was treated from July 1971 to April 1975 by a complete mix (activated sludge) process at a temporary plant just south of the test site. Chlorinated effluent from the plant was discharged into a holding pond from which the effluent was pumped to the test site. Excess effluent overflowed from the holding pond to a series of manmade lakes and canals in the golf course area. During 1971-72, daily discharge of the plant ranged from 0.015 to 0.116 Mgal/d. During 1973-74, the daily discharge ranged from 0.14 to 0.2 Mgal/d.

METHODS OF INVESTIGATION

The quality of ground water at and near the test site was evaluated from analyses of water samples from the monitoring network. Water samples were analyzed for selected inorganic constituents, nitrogen, phosphorus, carbon, and bacteria. Water samples collected during this study were analyzed in the laboratories of the U.S. Geological Survey.

Observation-well batteries within and near the test site were sampled to provide data relating to the vertical and horizontal movement of various chemical and microbiological constituents of the applied effluent. Water-quality samples were collected periodically (1971-75) from the following: (1) observation-well batteries 30 and 80 within the test site; and (2) observation-well battery 60, about 200 feet downgradient from the test site (table 1A and fig. 2).

Observation wells 123 (sampled October 1971 to October 1972) and 212 (sampled May 1974 and April 1975) near the site were sampled periodically during the study to provide information on water-quality changes in the surficial aquifer in areas unaffected by the effluent spray irrigation.

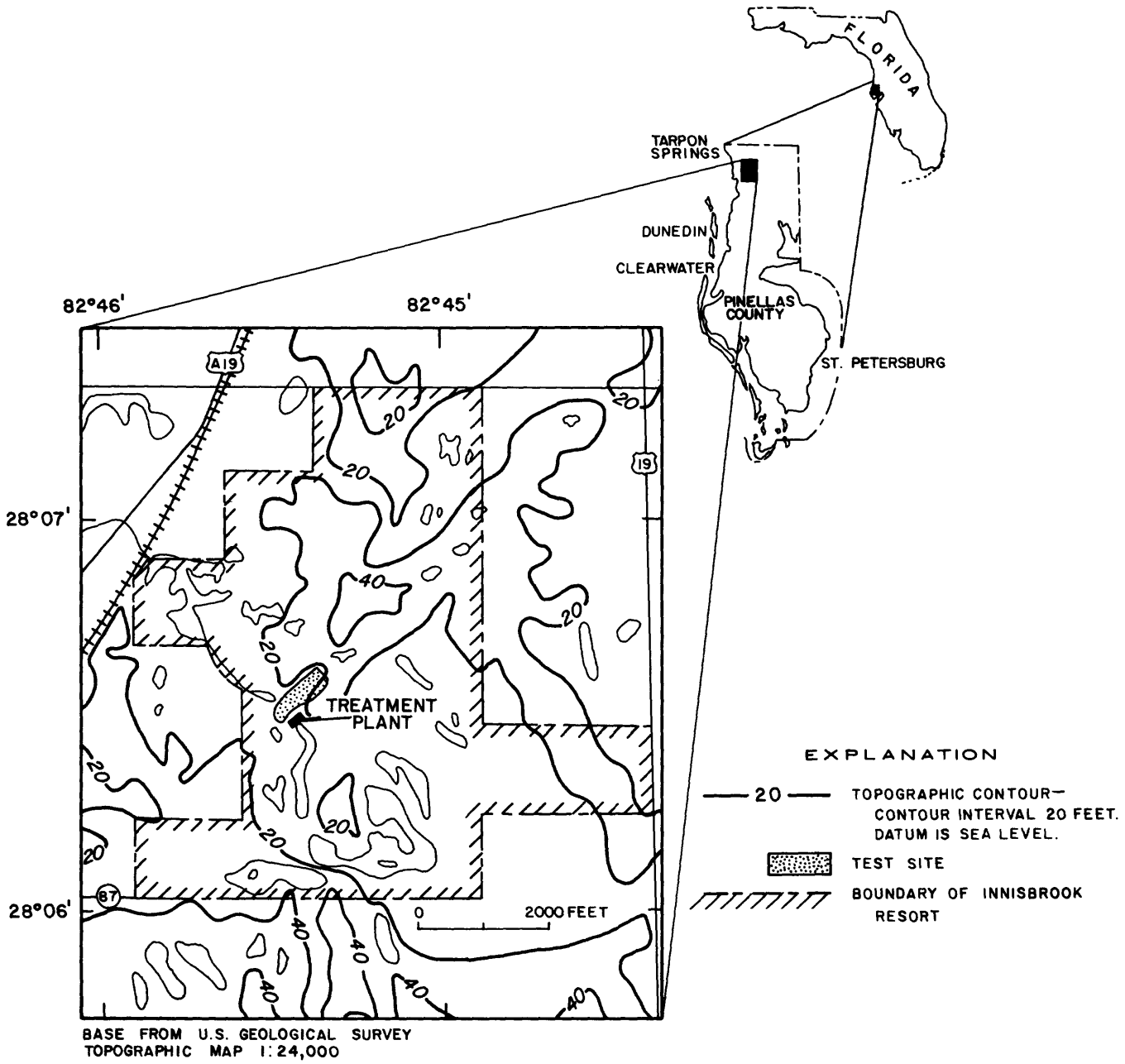

Figure 1.--Location and topography of the effluent spray-irrigation test site and surrounding area.

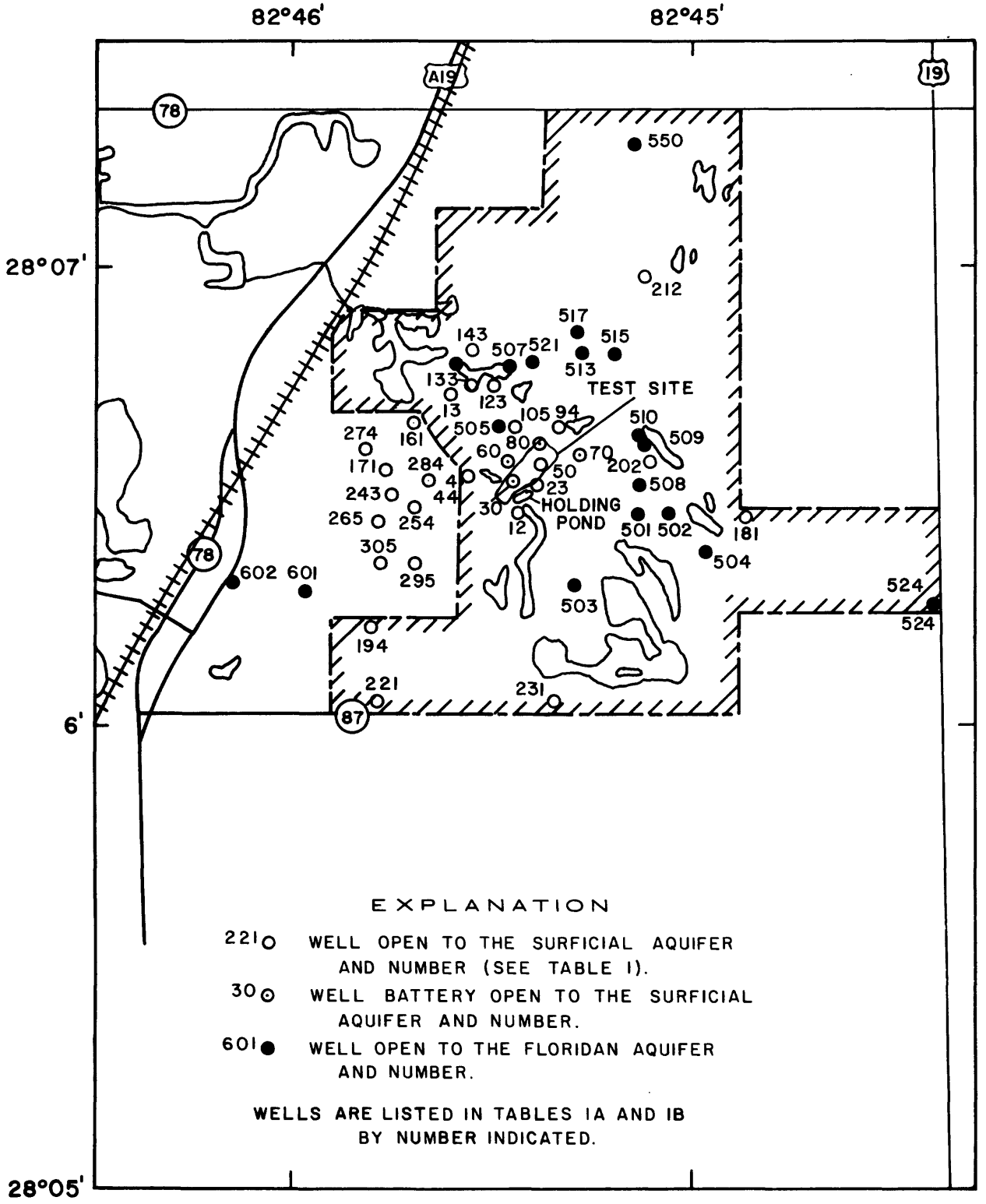

Figure 2.--Monitoring network in and near the effluent spray-irrigation test site.

Table 1A.--Observation wells penetrating the surficial aquifer in and near the effluent spray-irrigation test site

Observation well battery	Well	Latitude-longitude	Depth (ft)	Depth cased (ft)	Altitude of land surface (ft)	Altitude of measuring point (ft)
10	12	2806280824521.02	5	4	7	10.05
20	23	2806330824522.03	10	8	13	14.49
30	33	2806330824526.03	8	7	10	10.03
	34	2806330824526.04	14	12	10	9.85
	35	2806330824526.05	19	18	10	9.80
40	44	2806340824534.04	15	13	12	15.45
50	54	2806350824521.04	20	19	16	15.59
60	63	2806350824527.03	9	8	7	10.56
	64	2806350824527.04	15	13	7	10.58
	65	2806350824527.05	21	19	8	10.81
70	73	2806360824516.03	10	8	9	10.99
	74	2806360824516.04	15	13	8	10.77
	75	2806360824516.05	19	18	8	9.53
80	83	2806380824522.03	9	8	9	8.95
	84	2806380824522.04	14	12	9	9.06
	85	2806380824522.05	19	17	9	9.03
	86	2806380824522.06	38	36	9	9.06
90	94	2806390824519.04	14	12	15	14.60
100	105	2806390824526.05	19	18	17	21.25
110	113	2806440824536.03	9	8	14	16.43
120	123	2806450824529.03	9	8	10	9.99
130	133	2806460824533.03	9	8	10	10.06
140	143	2806500824533.03	10	8	6	8.30
	161	2806400824541.01	17	15	16	17.84
	171	2806340824546.01	8	7	9	10.21
	181	2806280824452.01	14	12	12	14
190	194	2806140824548.04	19	17	20	20
200	202	2806350824505.02	10	9	8	7.6
210	212	2806590824506.02	9	8	10	9.8
	221	2806030824547.01	25	23	25	26.3
	231	2806030824520.01	22	20	23	24.3
240	243	2806310824545.03	8	7	6	7.96
250	254	2806290824542.04	12	11	10	11.72
260	265	2806270824547.05	17	16	18	20.81
270	274	2806370824544.04	11	10	11	13.01
280	284	2806330824539.04	11	10	14	16.17
290	295	2806220824541.05	17	16	17	20.1
300	305	2806220824547.05	20	19	19	21.6

Table 1B lists 18 wells open to the Floridan aquifer in the vicinity of the test site. Water levels were measured periodically in four of these wells (524, 550, 601, and 602). Water samples were collected periodically from well 501, southeast of the test site, and well 505, northwest of the test site (fig. 2), to monitor the movement of various constituents from the test site.

The test site was irrigated at an average rate of about 0.06 Mgal/d during the first year of operation and about 0.11 Mgal/d during the remaining 3 years, equivalent to about 2 and 4 inches per week, respectively.

The test site was fertilized twice each year at a rate of 200 pounds per acre of 10-10-10 commercial fertilizer. The fertilizer accounted for about 288 pounds of total nitrogen (86 pounds of nitrate nitrogen and 202 pounds of ammonia nitrogen) and 126 pounds of total phosphorus applied to the test site annually.

HYDROGEOLOGY

The test site is underlain by three hydrogeologic units: the surficial aquifer, a confining bed, and the Floridan aquifer. These units are shown in figure 3.

Surficial Aquifer

The surficial aquifer is composed of fine-grained, well-sorted, angular, unconsolidated, white to brown, noncalcareous sand to clayey sand with finely disseminated organic material. The sand and clayey sand grade downward into a sandy clay. At the test site, the surficial aquifer is about 25 to 30 feet thick, but is about 10 to 30 feet thick elsewhere in the area (fig. 3). The sand and clayey sand that constitute the surficial aquifer are probably Pliocene and Pleistocene in age.

The surficial aquifer has an average total porosity of 33 percent (range 14 to 43 percent) and an average vertical hydraulic conductivity of 9 ft/d (range 5 to 23 ft/d) based on laboratory analyses of samples collected during construction of observation wells at the test site. Table 2 presents the lithology and physical characteristics of cored material from a typical well in the test site.

Locally, the surficial aquifer is recharged primarily from rainfall. Average annual rainfall at Tarpon Springs, near the test site, is about 53 inches per year (fig. 4). On the average, about 60 percent of the rainfall occurs from June through September; the remaining 40 percent is generally evenly distributed throughout the rest of the year. Some recharge comes from groundwater inflow from adjacent areas. Near the test site, the surficial aquifer is also recharged by irrigation water from wells penetrating the Floridan aquifer. Water levels in the surficial aquifer fluctuate seasonally; levels are high in September or October and low in May or early June (fig. 5). Water levels range from near land surface in the low areas to about 20 feet below land surface in higher areas. At the test site, water levels ranged from near land surface to 10 feet below land surface.

Table 1B.--Observation wells penetrating the Floridan aquifer in and near the effluent spray-irrigation test site

Well	Latitude-longitude	Depth (ft)	Casing		Owner	Use
			Depth (ft)	Diameter (in)		
501	2806280824507.01	150	81	10	Innisbrook	Maintain lake levels.
502	2806280824503.01	75	50	8	do.	Irrigation.
503	2806190824517.01	85	60	8	do.	Do.
504	2806230824458.01	120	80	8	do.	Abandoned.
505	2806390824528.01	105	60	8	do.	Irrigation.
506	2806480824535.01	85	40	8	do.	Do.
507	2806470824528.01	100	62	8	do.	Maintain lake levels.
508	2806320824507.01	130	80	8	do.	Irrigation.
509	2806410824504.01	85	60	8	do.	Maintain lake levels.
510	2806420824503.01	100	60	8	do.	Do.
513	2806490824516.01	150	--	8	do.	Irrigation.
515	2806490824511.01	100	--	4	do.	Maintain lake levels.
517	2806520824517.01	120	--	8	do.	Irrigation.
521	2806480824524.01	95	--	8	do.	Do.
524	2806160824424.01	100	--	8	do.	Unused.
550	2807170824508.01	100	--	8	do.	Irrigation.
601	2806180824558.01	200	--	10	Douglas	Do.
602	2806180824609.01	60	--	3	do.	Abandoned.

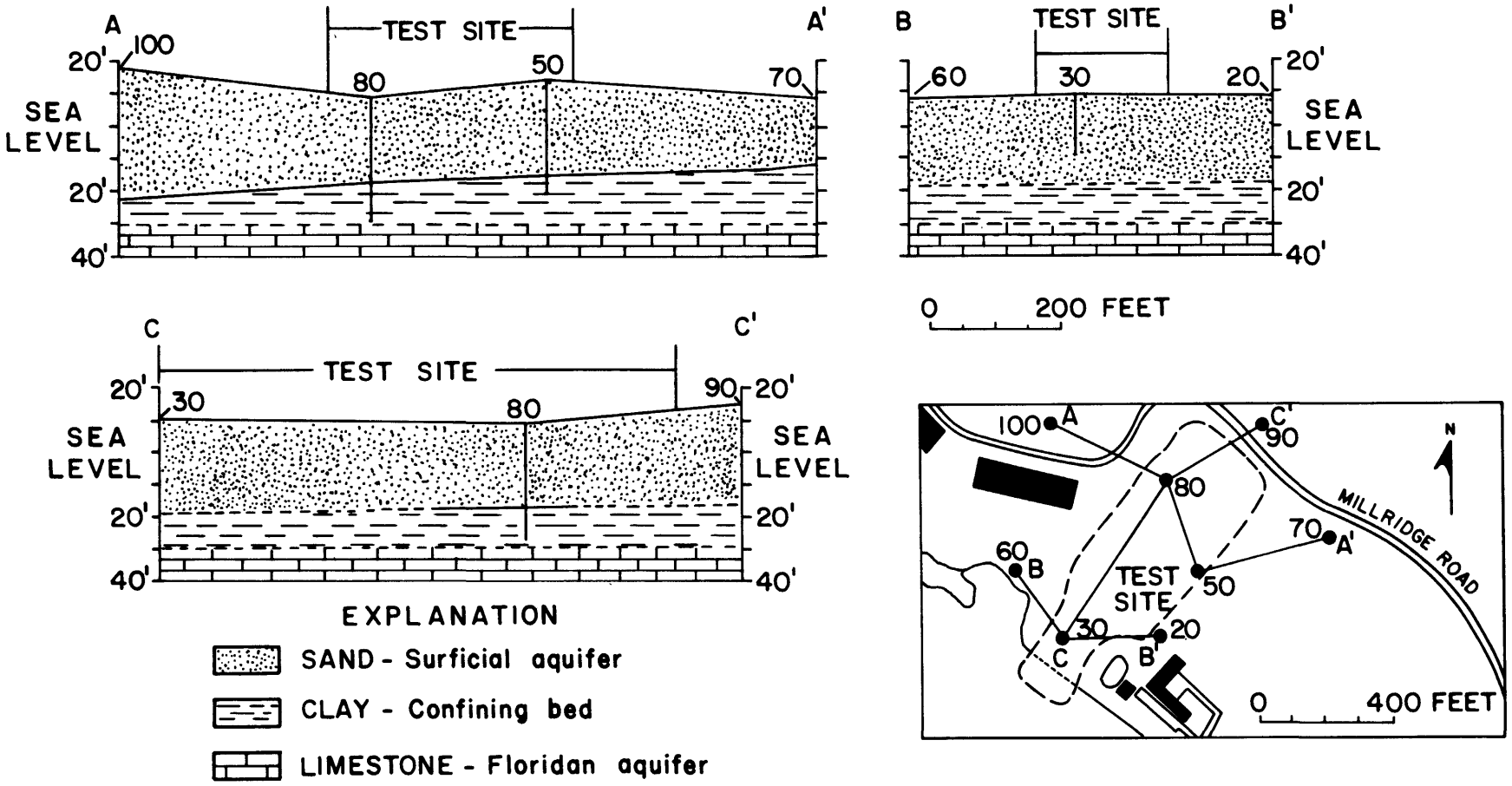

Figure 3.--Hydrogeologic sections through the spray-irrigation test site.

Table 2.--Lithologic log and physical characteristics of cored material from a representative site (well 50)

[Samples from 5 to 25 feet represent surficial aquifer; samples from 30 and 35 represent confining bed.]

Sample depth (ft)	Total porosity (percent)	Vertical hydraulic conductivity (ft/d)	Lithology
5	14.0	4.9	Sand, unconsolidated, very fine, light-brown, angular, noncalcareous; finely disseminated organic matter.
10	38.6	17	Sand, unconsolidated, very fine, white, angular, noncalcareous; organic material, roots.
15	35.6	6.6	Sand, very fine, light brown, angular, noncalcareous.
20	34.3	5.9	Sand, unconsolidated, very fine, white, angular, noncalcareous; finely disseminated organic material.
25	31.2	5.6	Sand, fine to fine gravel, white, slightly calcareous (shell fragments).
30	43.2	2.9×10^{-4}	Sand, very fine, white, angular; clay, white, noncalcareous.
35	47.7	1.6×10^{-3}	Sand, fine to very fine, light-brown, angular, noncalcareous; clay, sandy, cohesive, light- to dark-gray.

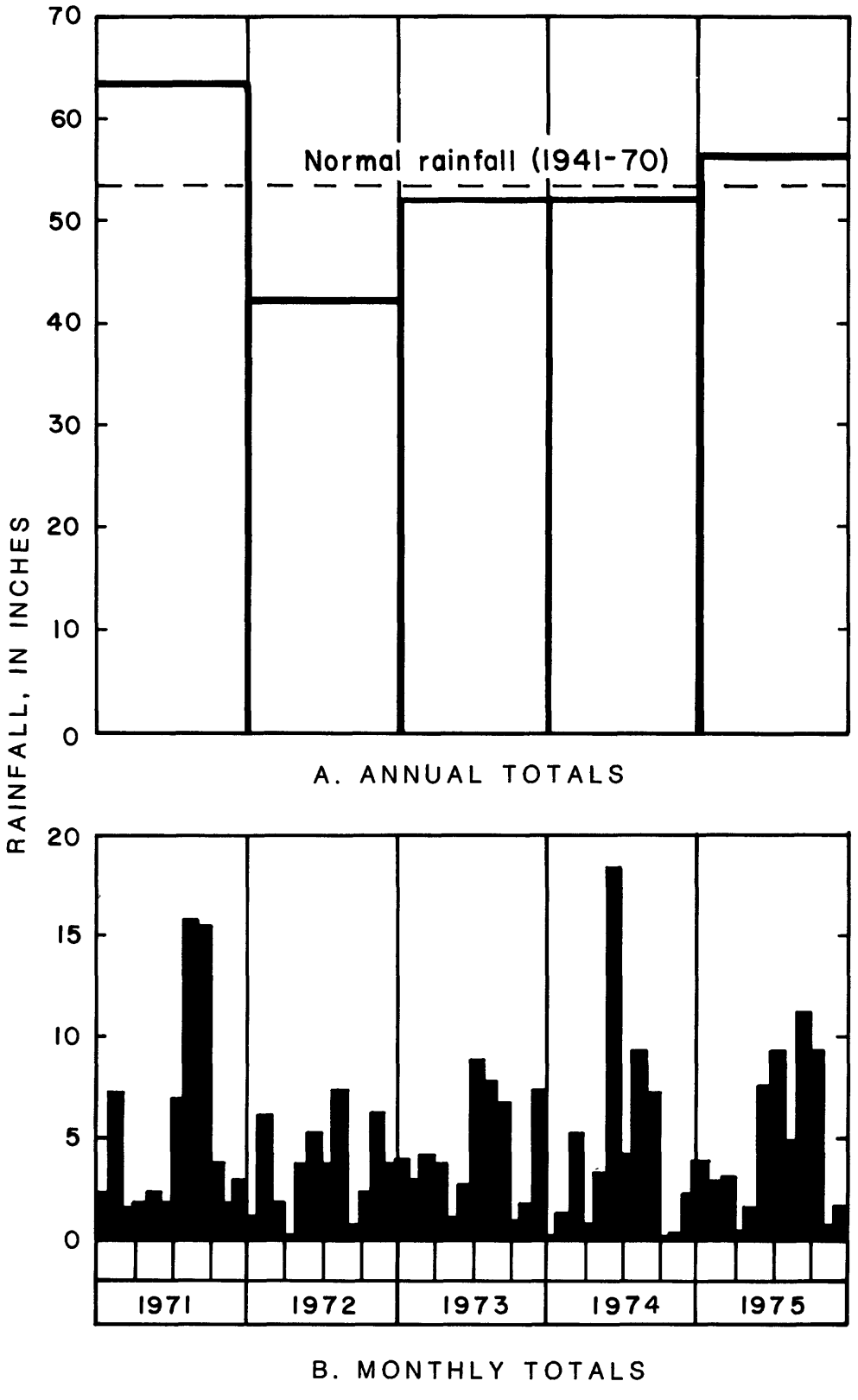

Figure 4.--Rainfall at Tarpon Springs, Florida, 1971-75.

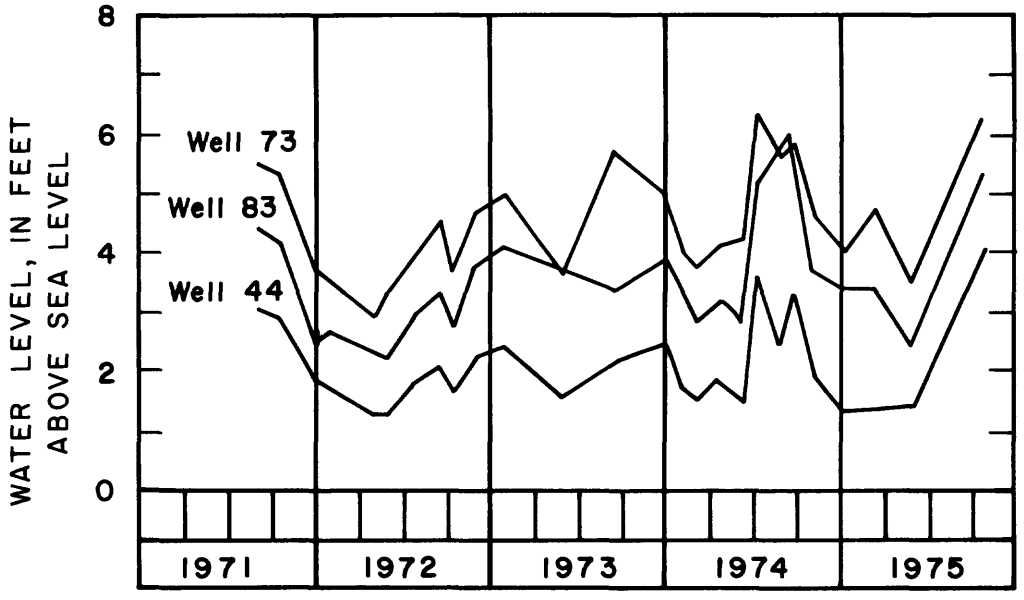

Figure 5.--Hydrographs of selected wells open to the surficial aquifer in and near the test site.

Ground-water flow in the area was north and west through the test site and west towards the Gulf of Mexico (fig. 6). Water levels at the test site ranged from 2 to about 6 feet above sea level. Water levels upgradient, southeast of the test site, were about 1 foot higher than at the test site. Downgradient, to the west and north, levels were about 0.5 to 2 feet lower.

Confining Bed

A confining bed of very compact white to bluish gray, very cohesive, sandy to gravelly clay separates the surficial aquifer from the underlying Floridan aquifer (fig. 3). The clay becomes more calcareous with depth. This clay confining bed is probably an upper Miocene marine sediment or the weathered upper part of the Tampa Limestone or both. The confining bed is 10 to 15 feet thick at the test site, but in the general area ranges from zero to about 40 feet in thickness.

Based on laboratory analyses of four cored samples collected during construction of observation wells at the test site, porosity of the sandy to gravelly clay ranged from 43.2 to 50.2 percent and averaged about 46 percent. Vertical hydraulic conductivity of the four samples ranged from 5.6×10^{-3} to 2.9×10^{-4} ft/d and averaged about 2×10^{-3} ft/d. Table 2 includes two cored samples of the confining bed from observation well 50 at depths of 30 and 35 feet below land surface. Samples of similar confining beds west of the test site consisted of quartz, montmorillonite, illite, and mixed-layered clay minerals. The weathered uppermost part of the Tampa Limestone, which is the confining bed in some parts of nearby areas, is primarily calcite with minor amounts of quartz and clay.

Floridan Aquifer

The Floridan aquifer underlies the area and consists of solution-riddled and fractured limestone and dolomite several hundred feet thick (Cherry and others, 1970). The uppermost part of the Floridan aquifer at the test site is a weathered limestone about 30 feet below sea level (40 to 50 feet below land surface) (fig. 3). In the general area, the top of the Floridan aquifer ranges from near sea level to more than 30 feet below sea level. The aquifer at the test site probably is the Tampa Limestone of early Miocene age (Heath and Smith, 1954).

In wells east of the test site, water levels ranged from about 3 feet to more than 5 feet above sea level; west of the test site they ranged from less than 1 foot to more than 2 feet above sea level (fig. 7). In the Floridan aquifer, ground-water flow was westward through the test site toward the Gulf of Mexico. The potentiometric surface of the Floridan aquifer at the test site was generally 1 to 2 feet lower than the water table in the surficial aquifer.

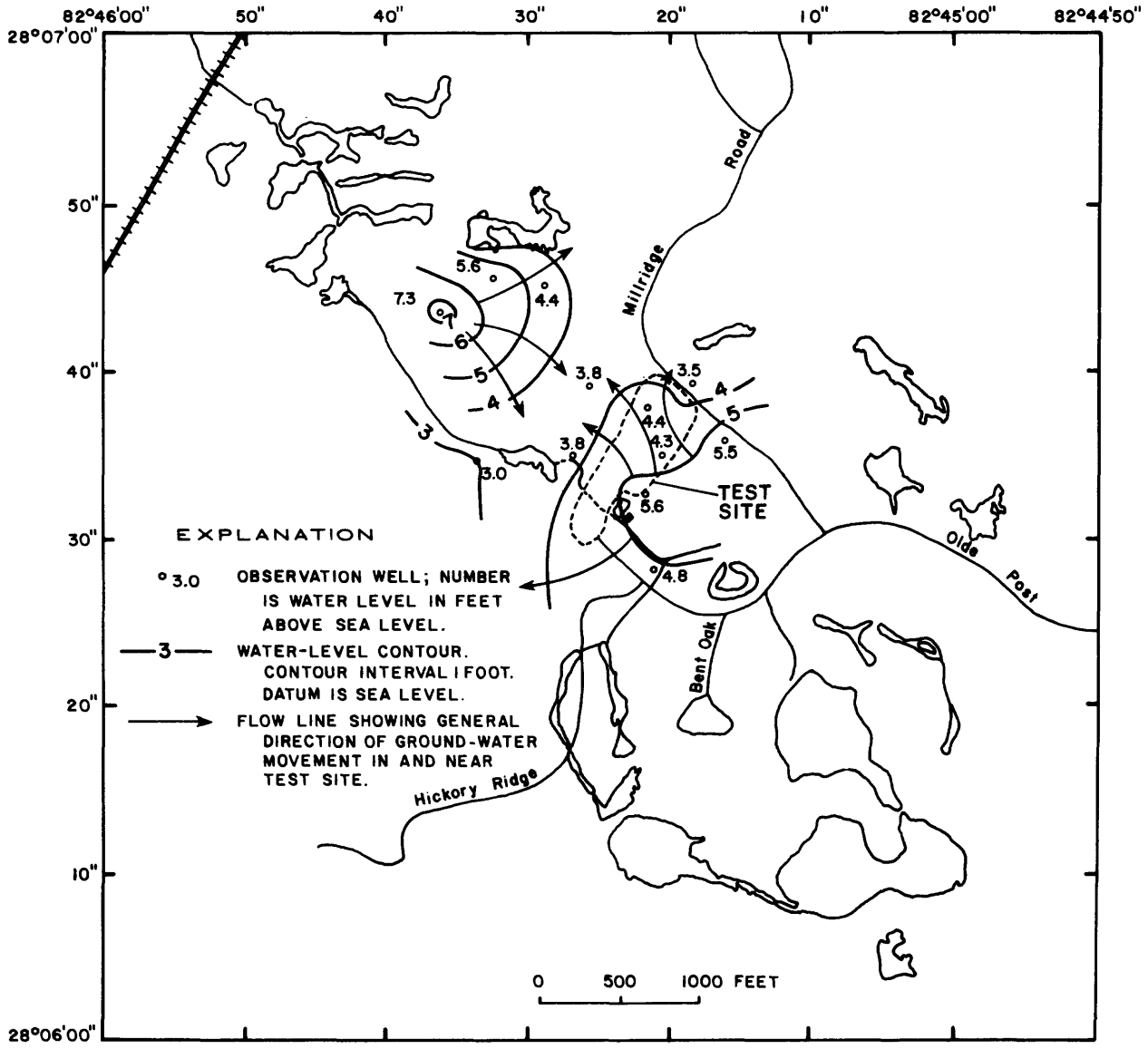

Figure 6.--Water-level contours in the surficial aquifer in and near the test site, September 1971.

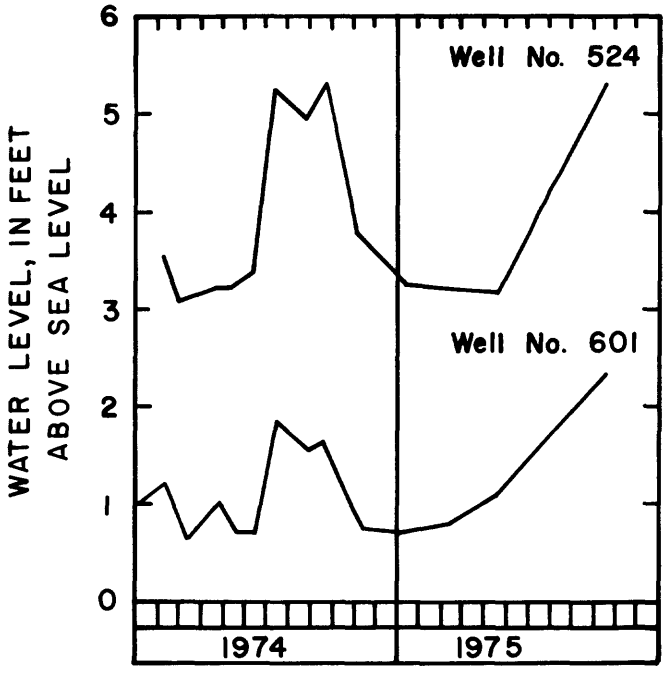

Figure 7.--Hydrographs of selected wells open to the Floridan aquifer near the test site.

WATER QUALITY

Character of the Effluent

Periodically during the 4-year study, effluent from the holding pond was sampled and analyzed to determine its chemical and microbiological quality. The analyses are presented in tables 3 and 4.

Specific conductance, which is directly related to the dissolved mineral (ionic) content of water, averaged 900 umho/cm at 25°C (micromhos per centimeter at 25° Celsius) during the study, equivalent to a dissolved-solids concentration of about 550 mg/L. The pH of the effluent was slightly alkaline.

The dominant nitrogen species in the effluent were ammonia nitrogen and organic nitrogen, ranging from 0.14 to 37 mg/L and 2.4 to 30 mg/L, respectively. Minor amounts of nitrite and nitrate nitrogen were present in the effluent. Total nitrogen concentrations averaged 26 mg/L and total phosphorus concentrations averaged 7.3 mg/L. The phosphorus was primarily orthophosphorus. The total organic carbon averaged 27 mg/L; total inorganic carbon averaged 60 mg/L.

The coliform group includes not only fecal coliform and fecal streptococcal bacteria, but also bacteria from nonfecal sources, mainly types of bacteria that thrive in the soil. Fecal coliform and fecal streptococcal bacteria, when present, indicate recent pollution from warm-blooded animals. Table 4 presents the microbiological analyses of the applied effluent collected during the 4 years of operation.

Background Water Quality in the Surficial Aquifer

Quality of ground water in the surficial aquifer before pretest conditions was determined from a sample from observation well 94, north of the test site (table 5). Although the sample was not from the test site itself, conditions at the well were probably similar to pretest conditions at the test site. The sample was taken in August 1971, shortly after the application of effluent had begun. Ground water at the observation well, although downgradient from the test site, was probably unaffected by effluent irrigation.

Ground water in the surficial aquifer under pretest conditions was low in specific conductance and acidic (table 5). The concentration of total nitrogen was 0.53 mg/L, predominantly in the form of organic nitrogen. Concentrations of ammonia, nitrite, and nitrate nitrogen and total phosphorus were low. The concentration of total coliforms was 10 col/100 mL (colonies per 100 milliliters); fecal coliform and fecal streptococcal bacteria were not detected.

Table 3.--Chemical analyses of the applied effluent, October 1971 to April 1975

[All values are in milligrams per liter unless otherwise indicated.]

Constituent or parameter	Date of collection						
	10-19-71	2-1-72	5-26-72	10-16-72	5-18-73	5-21-74	4-9-75
Chloride, dissolved	135	88	225	130	140	70	67
Specific conductance (umho/cm at 25¼C)	1,050	890	1,170	820	950	750	690
pH (units)	---	--	---	8.0	7.0	6.8	7.7
Chemical oxygen demand	23	--	---	28	69	71	270
Biochemical oxygen demand	50	77	8.0	8.4	40	5.4	62
Nitrogen, total (N)	27	43	3.0	21	45	19	24
Organic nitrogen, total (N)	9.3	5.5	2.4	20	30	3.9	4.5
Ammonia nitrogen, total (N)	18	37	.14	.58	15	15	19[a]
Nitrite, total (N)	.04	.02	.04	.10	.09	.03	0[a]
Nitrate, total (N)	0	0	.44	.29	0	.04	.01[a]
Phosphorus, total (P)	4.2	10	6.6	4.4	8.2	7.4	10
Orthophosphate, total (P)	4.2	10	6.6	4.4	8.2	7.4	8.4[a]
Organic carbon, total (C)	36	--	---	9.0	12	32	48
Inorganic carbon, total (C)	60	--	---	30	65	68	78

[a]Dissolved.

Table 4.--Microbiological analyses of the applied effluent, October 1971 to April 1975

[Colonies per 100 milliliters.]

Date of collection	Bacteria		
	Coliform	Fecal coliform	Fecal streptococcal
10-19-71	>8,000	>6,000	--
1-31-72	5,300,000	430,000	52,000
5-26-72	29,000	100	220
10-16-72	59,000	5,100	4,200
5-18-73	39,000	1,900	1,800
4- 9-75	460,000	460,000	--

Table 5.--Chemical analysis of the ground water from well 94 in the surficial aquifer, August 1971

[All values are in milligrams per liter unless otherwise indicated. Well depth 14 feet.]

Constituent	Value
Chloride, dissolved	20
Specific conductance (umho/cm at 25°C)	54
pH (units)	5.6
Chemical oxygen demand	52
Biochemical oxygen demand	0.4
Nitrogen, total (N)	0.53
Organic nitrogen, total (N)	0.50
Ammonia nitrogen, total (N)	0.02
Nitrite, total (N)	0.01
Nitrate, total (N)	0
Phosphorus, total (P)	0.04
Orthophosphate, total (P)	0.03
Organic carbon, total (C)	4
Inorganic carbon, total (C)	6

EFFECTS OF EFFLUENT SPRAY IRRIGATION

Test Results

Surficial Aquifer

Periodic mounding of the water table due to effluent spray irrigation occurred at the test site during the 4-year study, inducing raidal flow from the test site. Mounding of the ground water at the test site occurred in June and September 1974 (figs. 8 and 9), as indicated by higher water levels in wells at the test site than in the normally upgradient well and in other wells within the study area. The water table at the test site also rose from 1 to 3 feet between September 1971 and September 1974.

At the test site

During the study, water samples were collected from observation wells 33, 34, and 35 about 8, 14, and 19 feet deep, respectively, in the northwest part of the test site and from wells 83, 84, and 85 about 9, 14, and 19 feet deep, respectively, near the northeast edge of the test site (table 1A and fig. 2). Data from the wells (tables 6 and 7) were used to evaluate changes in ground water at the test site by comparison with preirrigation data from well 94 (table 5) and data from the applied effluent (tables 3 and 4).

Chloride concentrations increased from an estimated background concentration of 20 mg/L to a maximum of 310 mg/L at the 8- to 9-foot depth, 250 mg/L at the 14-foot depth, and 290 mg/L at the 19-foot depth, but averaged about 180 mg/L at all depths. The maximum chloride concentration of the applied effluent was 225 mg/L, less than the maximum values reported at the test site.

Specific conductance of the ground water increased from a background value of 54 umho/cm to a maximum value of 1,525 umho/cm at the 8- to 9-foot depth, 2,100 umho/cm at the 14-foot depth, and 1,100 umho/cm at the 19-foot depth. During initial sampling of wells at the test site in July and August 1971, specific conductance of water from wells 33, 34, and 35 ranged from 44 to 82 umho/cm, similar to the background value. After about 6 months, specific conductance of water from the wells increased and ranged from 820 to 2,100 umho/cm. Similar increases occurred in wells 84 and 85.

The pH of the ground water varied from 4.1 to 6.5 units from July-August 1971 to May 1974. At the last sampling in April 1975, pH had increased from background and previous sample values--the water had become more alkaline--and ranged from 6.2 to 7.7 units, similar to the pH of the effluent. Water from wells 8 to 14 feet deep ranged in pH from 7.0 to 7.7 units.

During the study, concentrations of total nitrogen in ground water at the test site varied greatly, ranging from 0.29 mg/L to greater than or equal to 77 mg/L. Total nitrogen generally increased above the background concentration of 0.53 mg/L, excluding initial sampling values (July and August 1971), but varied considerably among the sampling periods. For example, at about the 14-foot depth, total nitrogen in well 84 increased from an initial sampling value of

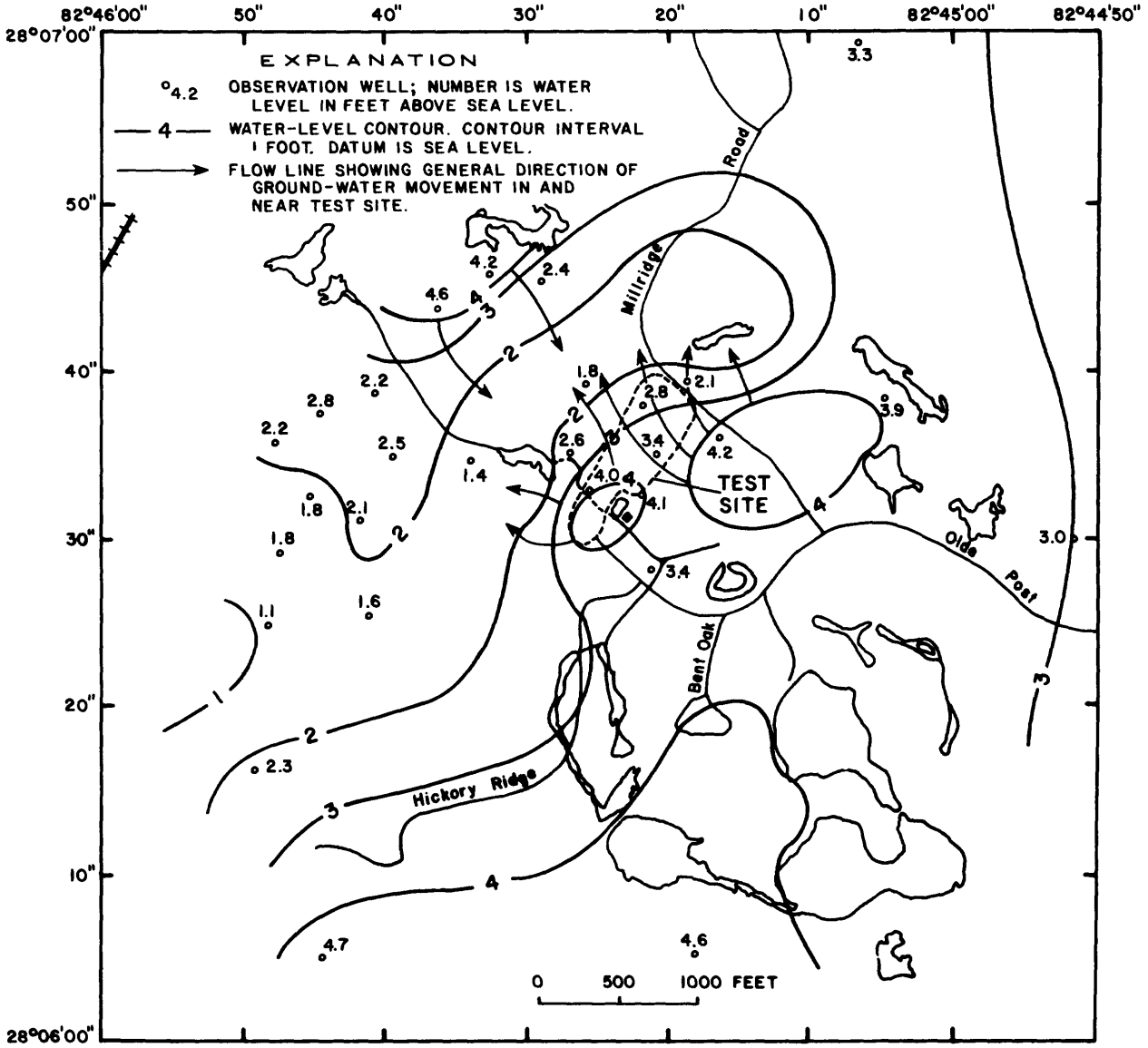

Figure 8.--Water-level contours in the surficial aquifer in and near the test site, June 1974.

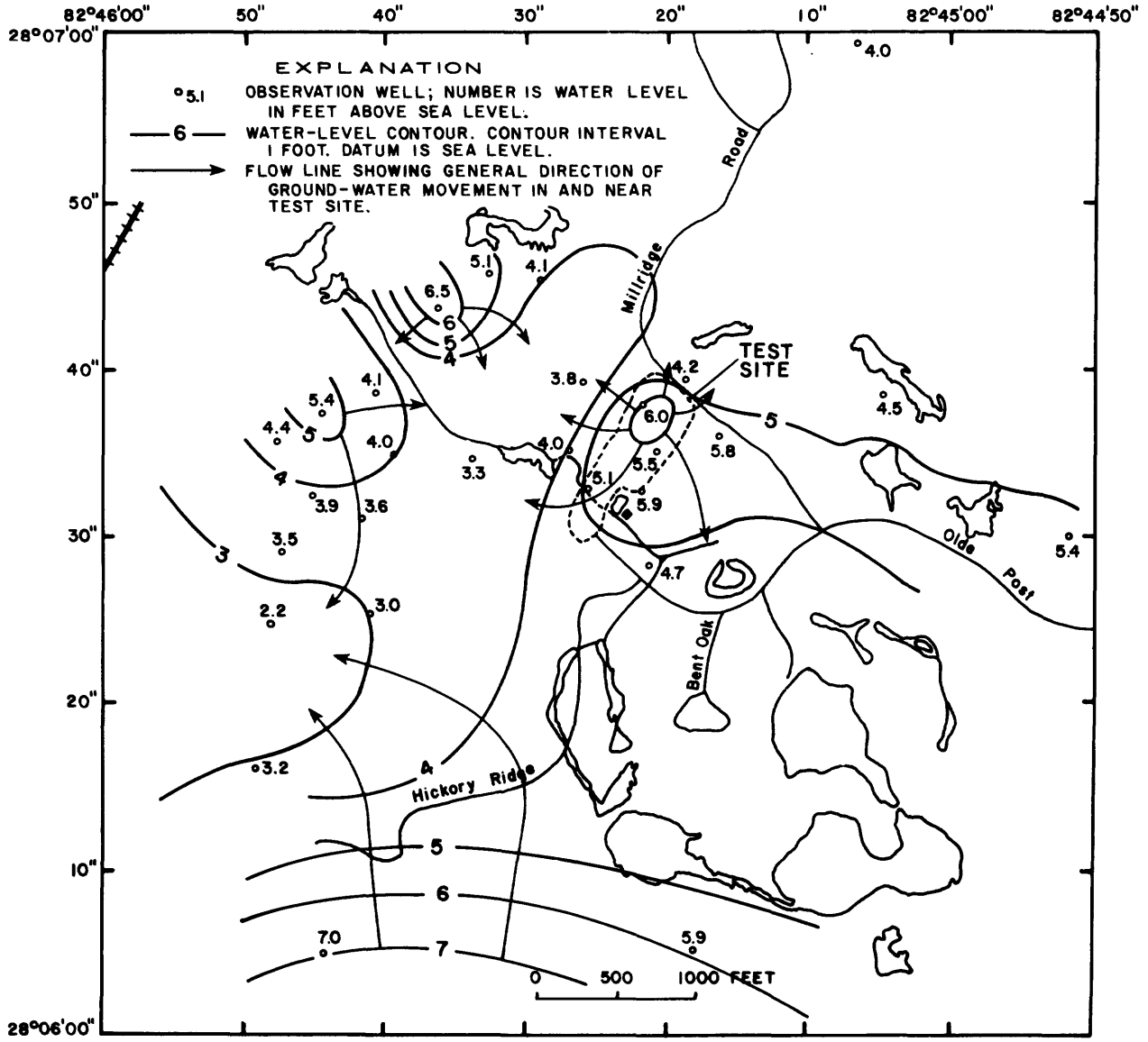

Figure 9.--Water-level contours in the surficial aquifer in and near the test site, September 1974.

Table 6.--Chemical analyses of the ground water in the surficial aquifer at the test site, July 1971 to April 1975

[All values are in milligrams per liter unless otherwise indicated.]

Well number	Depth (ft)	Date of collection	Chloride, dissolved (Cl)	Nitrate, total (N)	Nitrite, total (N)	Ammonia nitrogen, total (N)	Organic nitrogen, total (N)	Nitrogen, total (N)	Phosphorus, total (P)	Orthophosphate total (P)	Specific conductance, umho/cm at 25°C	pH, units	Chemical oxygen demand, COD	Biochemical oxygen demand, BOD	Organic carbon, total (C)	Inorganic carbon, total (C)
33	8	7-30-71	-	3.4	0.003	0.04	0.30	3.7	0.05	0	82	5.2	-	0.4	1.0	3.0
		1-31-72	200	62	0	14	-	≥76	.07	.05	1,525	-	-	.2	-	-
		5-31-72	230	2.2	.03	1.0	.51	3.7	.13	.09	890	4.3	-	.9	-	-
		10-19-72	81	.04	0	.04	.41	.49	.02	0	398	4.4	11	.7	0	7.0
		5-16-73	170	11	0	.03	.77	12	≥.11	.11	850	6.6	34	1.2	7.0	19
		5-20-74	220	7.5	0	.10	.62	8.2	.37	.37	1,000	5.4	20	-	6.0	29
		4-10-75	110	18	0	.19	.93	19	5.8	5.3	880	7.7	25	-	6.0	-
34	14	7-29-71	-	2.9	.01	.08	.64	3.6	.04	0	67	5.3	40	.6	2.0	5.0
		1-31-72	200	64	0	13	-	≥77	.05	.05	2,100	-	-	.2	-	-
		5-31-72	154	3.8	.02	8.2	.46	12	.10	.16	640	4.5	-	0	-	-
		10-19-72	250	1.8	0	>4.0	3.9	≥9.7	.10	.05	910	4.2	23	.6	0	13
		5-16-73	130	13	0	.04	1.3	14	≥.12	.12	690	4.6	30	.6	9.0	7.0
		5-20-74	150	13[a]	0[a]	.03[a]	2.5	16	0	0[a]	770	6.5	32	-	9.0	25
		4-10-75	83	12[a]	.01[a]	.14[a]	1.2	13	3.1	2.3[a]	599	7.5	20	-	9.0	-
35	19	7-29-71	-	0	.003	.09	.37	.46	.04	.01	44	5.3	29	.5	2.0	6.0
		2- 1-72	180	14	0	13	.10	27	.02	.02	820	-	-	.8	-	-
		5-31-72	160	22	.03	21	.21	43	.04	.04	1,060	4.2	-	.1	-	-
		10-19-72	190	9.7	.07	18	.60	28	.09	.06	870	4.2	7.1	.6	-	-
		5-16-73	150	6.4	0	.50	.28	7.2	≥.17	.17	660	4.3	15	.2	3.5	8.5
		5-20-74	170	7.0	.01	.50	.56	8.1	.01	.01	720	5.7	23	-	8.0	22
		4-10-75	181	38	0	.08	.14	38	.02	.01	1,100	6.2	0	-	20	-

Footnotes are at end of table.

Table 6.--Chemical analyses of the ground water in the surficial aquifer at the test site, July 1971 to April 1975--Continued

Well number	Depth (ft)	Date of collection	Chloride, dissolved (Cl)	Nitrate, total (N)	Nitrite, total (N)	Ammonia nitrogen, total (N)	Organic nitrogen, total (N)	Nitrogen, total (N)	Phosphorus, total (P)	Orthophosphate total (P)	Specific conductance, umho/cm at 25°C	pH, units	Chemical oxygen demand, COD	Biochemical oxygen demand, BOD	Organic carbon, total (C)	Inorganic carbon, total (C)
83	9	2- 2-72	228	19	0.01	51	0.39	70	0	0	1,450	-	-	0	-	-
		5-30-72	164	.37	0	.62	.45	1.4	.06	0	690	4.2	-	1.0	-	-
		10-18-72	310	.25	0	.11	.26	.62	.03	.03	1,130	4.5	16	.3	0	9.0
		5-17-73	140	.26	0	0	.24	.50	≥.20	.20	580	4.8	17	.6	1.5	5.0
		5-24-74	180	6.2	0	.03	.64	6.9	.01	.01	730	4.9	24	-	8.0	19
		4-10-75	200	12[a]	0[a]	.06[a]	1.0	13	.35	-	1,020	7.2	25	-	9.0	-
84	14	7-30-71	-	0	.01	.05	.34	.40	.09	.07	62	5.4	59	.2	30	10
		2- 2-72	140	48	.01	19	.20	67	0	.02	1,125	-	-	.1	-	-
		6- 1-72	215	28	.07	32	.14	60	.05	.01	1,420	-	-	.4	-	-
		10-18-72	210	7.4	0	3.6	8.3	19	.03	.03	840	4.7	7.1	.4	0	14
		5-17-73	220	12	0	.01	.34	12	≥.35	.35	980	4.6	12	.5	1.5	3.5
		5-24-74	180	.83	0	.02	.20	1.0	.02	.01	820	4.6	40	-	4.0	9.0
		4-10-75	97	12[a]	.02[a]	.07[a]	.82	13	.06	-	650	7.0	25	-	6.0	-
85	19	8- 3-71	-	0	.01	.16	.12	.29	.05	.02	68	5.5	86	13	-	-
		6- 1-72	135	34	.05	35	.08	69	.02	.01	930	-	-	1.0	-	-
		10-18-72	150	3.8	.01	18	.86	23	.23	.10	730	5.6	13	.7	0	16
		5-17-73	230	12	.01	1.4	.25	14	≥.30	.30	1,020	4.3	15	40	2.0	3.5
		5-24-74	290	3.2[a]	0[a]	.22[a]	.59	4.0	.36	.01[a]	1,100	4.1	20	-	6.0	4.0
		4-10-75	94	16[a]	.01[a]	.35[a]	.92	17	.14	.01[a]	570	6.2	20	-	5.0	-

[a]Dissolved value.

Table 7.--Microbiological analyses of the ground water in the surficial aquifer at the test site, July 1971 to April 1975

[Colonies per 100 milliliters.]

Well number	Depth (ft)	Date of collection	Total coliform	Fecal coliform	Fecal streptococci
33	8	7-30-71	3	<1	<3
		1-31-72	<1	<1	<1
		5-31-72	140	<1	<1
		10-19-72	20	<1	5
		5-16-73	1	<1	<1
		5-20-74	1[a]	<1	71
		4-10-75	<3	<3	--
34	14	7-29-71	33	<1	<1
		1-31-72	<1	<1	<1
		5-31-72	5	<1	<1
		10-19-72	80	<1	65
		5-16-73	<1	<1	<1
		5-20-74	25[a]	<1	760
		4-10-75	9	3	--
35	19	7-29-71	100	<1	<1
		2- 1-72	45	<1	<1
		5-31-72	21	<1	<1
		10-19-72	<1	<1	5
		5-16-73	1	<1	<1
		5-20-74	<1	<1	<1
		4-10-75	<1	<1	1[a]
83	9	2- 2-72	43	<1	6
		5-30-72	>800	>60	17
		10-18-72	3	<1	<1
		5-17-73	90	2	<1
		5-24-74	<1	<1	<1
		4-10-75	6[a]	<1	<1
84	14	7-30-71	86	20	3
		2- 2-72	190	<1	4
		6- 1-72	>800	6	>100
		10-18-72	1,700	<1	120
		5-17-73	5	<1	<1
		5-24-74	<1	<1	<1
		4-10-75	<3	23	--
85	19	6- 1-72	1	<1	180
		10-18-72	47	<1	5
		5-17-73	1	1	<1
		5-24-74	170[a]	<1	<1
		4-10-75	23	<3	--

[a]Value based on nonideal colony count.

0.40 mg/L in July 1971 to a maximum value of 67 mg/L after about 6 months of irrigation (table 6). During this period, total nitrogen concentration of the applied effluent was 27 mg/L in October 1971 and 43 mg/L in February 1972 (table 3). From June 1972 (the next sampling period) to May 1974, total nitrogen decreased to 1.0 mg/L. At the last sampling period in April 1974, total nitrogen increased to 13 mg/L. From May 1972 to April 1975, total nitrogen of the applied effluent ranged from 3.0 to 45 mg/L. The other wells at the test site showed similar variations.

The most prominent effect of irrigation of the test site was the many fold increase in concentration of nitrate nitrogen in ground water to depths of 19 feet above background and applied effluent values (tables 3 and 6). Nitrate nitrogen was the dominant nitrogen specie in most water samples from the test site following the application of effluent.

Organic nitrogen concentrations were generally less than 1.0 mg/L following effluent irrigation, substantially less than values found in the applied effluent but slightly more than the background concentration of 0.5 mg/L. Organic nitrogen in the water from well 34 had consistently higher values ranging from 1.2 to 3.9 mg/L from May 1972 to April 1975. The highest concentration, 8.3 mg/L, was detected in water from well 84 during the October 1972 sampling period. Values found in water from the well before and after October 1972 were less than 1.0 mg/L.

Concentrations of total phosphorus in most samples were less than 0.5 mg/L, about 5 percent of that of the applied effluent. In April 1975, two relatively high concentrations, 5.8 mg/L (10-foot depth) and 3.1 mg/L (15-foot depth), were found in observation-well battery 80 at the test site. An increase in the pH of water to 7.7 units at the 9-foot depth and 7.5 units at the 14-foot depth was associated with the phosphorus increase.

Total organic and inorganic carbon at the test site averaged 4.7 mg/L and 11 mg/L, respectively, above background, but only about 20 percent of the average concentration of the applied effluent.

Total coliform bacteria at the test site were about 5 percent of those of the applied effluent based on a comparison of each sampling period. Total coliform bacteria were generally less than 100 col/100 mL but were detected to a depth of 20 feet below land surface (table 7). Fecal coliform bacteria were detected in some samples of ground water at one observation well in battery 80. When detected, fecal coliform bacteria were generally less than 25 col/100 mL; they were not detected in more than 60 percent of the samples. Fecal streptococcal bacteria were generally less than 100 col/100 mL at the test site.

Downgradient from the test site

Data from observation wells 63, 64, and 65 were used to evaluate changes in ground water about 200 feet downgradient from the test site by comparison with preirrigation data from well 94 and with data from the test site. Samples were collected from depths of 9, 15, and 21 feet below land surface (table 8 and fig. 2).

Table 8.--Chemical analyses of the ground water in the surficial aquifer downgradient from the test site, October 1971 to April 1975

[All values are in milligrams per liter unless otherwise indicated.]

Well number	Depth (ft)	Date of collection	Chloride, dissolved (Cl)	Nitrate, total (N)	Nitrite, total (N)	Ammonia nitrogen, total (N)	Organic nitrogen, total (N)	Nitrogen, total (N)	Phosphorus, total (P)	Orthophosphate, total (P)	Specific conductance, umho/cm at 25°C	pH, units	Chemical oxygen demand, COD	Biochemical oxygen demand, BOD	Organic carbon, total (C)	Inorganic carbon, total (C)
63	9	10-14-71	-	0.36	0.01	3.5	1.2	5.1	0	0	1,380	-	2.0	0.4	6.0	62
		2- 1-72	140	0	0	.95	.82	1.8	0	.04	940	-	-	1.5	-	-
		5-25-72	65	.03	0	.68	.31	1.0	.09	.07	900	5.4	-	4.2	-	-
		10-19-72	110	.04	0	1.9	.48	2.4	0	0	1,090	5.1	47	2.0	0	120
		5-16-73	32	0	0	.68	.26	.94	≥.12	.12	260	5.0	29	.6	0	12
		5-20-74	35	0	0	1.0	.35	1.4	.01	.01	170	5.3	31	-	7.0	19
		4- 9-75	190	0	0	.64	.74	1.4	.05	.02	1,000	7.5	150	-	21	-
64	15	10-14-71	-	-	0[a]	.43	.01	≥.44	0	0	680	-	5.3	2.1	10	22
		2- 1-72	102	.05	0	.30	.40	.75	0	0	720	-		6.1	-	-
		5-25-72	80	0	0	2.5	.43	2.9	.13	0	970	4.9	-	3.8	-	-
		10-19-72	60	0	0	3.6	.64	4.2	.01	0	760	5.9	-	.6	12	84
		5-16-73	20	.57	.01	1.1	.44	2.1	≥.21	.21	233	6.4	37	1.0	0	19
		5-20-74	27	0	0	3.2	.67	3.9	.04	.04	239	5.7	95	-	23	28
65	21	5-25-72	22	.09	0	.04	.38	.51	.89	.04	347	7.7	-	1.0	-	-
		10-24-72	33	.09[a]	0[a]	3.5	1.1	4.7	.30	.35[a]	500	6.7	30	7.1	14	56
		5-20-74	47	.12[a]	0[a]	.6[a]	4.0	4.2	.04	0[a]	810	6.5	251	-	108	48
		4- 9-75	110	.02[a]	0[a]	1.1	.90	2.0	.48	0[a]	799	-	88	-	10	-

[a]Dissolved value.

Concentrations of chloride in shallow ground water to depths of 21 feet increased above background concentration, but were generally less than concentrations found at the test site. Concentrations in water from wells 63 and 64 (9 and 15 feet deep) varied considerably, ranging from 20 to 190 mg/L with no apparent trend. Chloride concentrations in water from well 65 (21 feet deep) increased from 22 mg/L in May 1972 to 110 mg/L in April 1975; however, the well was only sampled four times during the study.

Concentrations of total nitrogen in water from downgradient wells ranged from 0.94 to 5.1 mg/L, an increase above background value, but generally less than values found at the test site. During May 1972, total nitrogen ranged from 0.51 to 2.9 mg/L and averaged 1.5 mg/L at all depths. During the same sampling period, total nitrogen in ground water at the test site ranged from 1.4 to 69 mg/L and averaged 32 mg/L at all depths (table 6). In May 1974, total nitrogen at all depths averaged 3.2 mg/L downgradient from the test site and 7.4 mg/L at the test site.

The dominant nitrogen species were ammonia nitrogen and organic nitrogen. Nitrate nitrogen was generally less than 0.5 mg/L.

Concentrations of total phosphorus ranged from 0 to 0.89 mg/L. Well 65, 21 feet deep, had generally higher concentrations and averaged 0.42 mg/L. Concentrations of total phosphorus downgradient from the test site were similar to concentrations at the test site and slightly more than background concentration.

Concentrations of total organic and inorganic carbon averaged 18 mg/L and 47 mg/L, respectively, in samples from downgradient wells, substantially more than in those at the test site and the background sample.

Total coliform bacteria were generally less than 10 col/100 mL and were not detected in most samples (table 9). Fecal coliform bacteria were not detected and fecal streptococcal bacteria were detected only once.

Near the test site

Ground water in the surficial aquifer near the test site was sampled periodically from wells 123 and 212 to determine water-quality changes in areas irrigated by water from the Floridan aquifer and fertilized periodically, but unaffected by effluent irrigation. Well 123 is about 1,000 feet north of the test site; well 212 is about 2,500 feet northeast of the test site. Areas (golf fairways) where the wells are located were fertilized three times a year at a rate of about 600 pounds per acre per application.

Most inorganic constituents and physical parameters increased above background values (tables 5 and 10). For example, chloride concentrations increased from a background value of 20 mg/L to a maximum value of 340 mg/L, specific conductance increased from 54 umho/cm to a maximum value of 2,050 umho/cm, and total nitrogen increased from 0.53 to a maximum value of 95 mg/L.

The range of values of most constituents and physical parameters were similar to values observed at the test site (tables 6 and 10). Concentrations of total nitrogen ranged from less than or equal to 1.1 mg/L to 95 mg/L and were

Table 9.--Microbiological analyses of the ground water in the surficial aquifer downgradient from the test site, October 1971 to April 1975

[Colonies per 100 milliliters.]

Well number	Depth (ft)	Date of collection	Total coliform	Fecal coliform	Fecal streptococci
63	9	10-14-71	5	<1	<1
		2- 1-72	2	<1	<1
		5-25-72	<1	<1	<1
		10-19-72	<1	<1	<1
		5-16-73	<1	<1	<1
		5-20-74	<1	<1	<1
		4- 9-75	<1	<1	<1
64	15	10-14-71	5	<1	<1
		2- 1-72	2	<1	<1
		5-25-72	<1	<1	<1
		10-19-72	<1	<1	<1
		5-16-73	1	<1	<1
		5-20-74	10	<1	<1
65	21	5-25-72	<1	<1	<1
		10-24-72	<1	<1	23
		4- 9-75	<3	<1	--

Table 10.--Chemical analyses of the ground water in the surficial aquifer near the test site, October 1971 to April 1975

[All values are in milligrams per liter unless otherwise indicated.]

Well number	Depth (ft)	Date of collection	Chloride, dissolved (Cl)	Nitrate, total (N)	Nitrite, total (N)	Ammonia nitrogen, total (N)	Organic nitrogen, total (N)	Nitrogen, total (N)	Phosphorus, total (P)	Orthophosphate, total (P)	Specific conductance, umho/cm at 25°C	pH, units	Chemical oxygen demand, COD	Biochemical oxygen demand, BOD	Organic carbon, total (C)	Inorganic carbon, total (C)
123	9	10-15-71	-	<1[a]	0	0.01	0.05	<1.1	0.03	0.01	253	-	0	0.1	1	10
		2- 7-72	140	12	0	.17	.11	12	0	.01	570	-	-	.1	-	-
		5-24-72	300	64	.13	12	.05	76	0	0	1,630	4.1	-	.3	-	-
		10-24-72	340	65	.05	30	0	95	.07	.02	2,050	4.4	17	.1	0	20
212	9	5-22-74	190	14	.02	4.1	.46	18	0	0	890	5.1	26	-	4	1
		4-10-75	120	.18	0	.42	.61	1.2	.03	.01	510	7.0	25	-	10	-

[a]Dissolved value.

similar to concentrations at the test site, which ranged from 0.29 to about 77 mg/L. Chloride concentrations ranged from 120 to 340 mg/L; at the test site, chloride ranged from 83 to 310 mg/L.

Nitrate and ammonia nitrogen were the dominant nitrogen species. Concentrations of organic nitrogen averaged 0.21 mg/L, less than concentrations found at the test site. Concentrations of total phosphorus were low, ranging from 0 to 0.07 mg/L.

Total coliform bacteria ranged from less than 1 to 62 col/100 mL, but were not detected in most samples (table 11). Fecal coliform bacteria were not detected, but fecal streptococcal bacteria were detected twice.

Floridan Aquifer

Water quality of the Floridan aquifer remained almost unchanged during the 4-year study except for periodic increases in chloride and specific conductance (table 12).

At well 501, southeast of the test site, concentrations of total nitrogen showed no increase. To the north of the test site, total nitrogen concentration was higher in water from well 505 than water from well 501 during the same sampling periods.

Total coliform, fecal coliform, and fecal streptococcal bacteria were detected in 50 percent of water samples from the Floridan aquifer (table 13). Total coliform bacteria were generally less than 100 col/100 mL; fecal coliform bacteria were generally less than 10 col/100 mL.

Evaluation of Effects

During the 4-year study, ground water in the surficial aquifer at the test site showed increases in values of most physical, chemical, and microbiological constituents relating to background ground-water quality data. Ground water in the surficial aquifer downgradient and in nearby areas showed similar increases in most physical and chemical constituents.

The quality of ground water in the surficial aquifer at the test site after irrigation was similar to the quality of the applied effluent. Determining the effects on ground water of many constituents was complicated, however, by periodic application of chemical fertilizer to the test site. The average and range in values of most constituents, such as chloride, total nitrogen, and specific conductance, at the test site were similar to those observed in wells 123 and 212 near the test site. These wells were in areas irrigated with water from the Floridan aquifer and fertilized periodically, but unaffected by effluent spray irrigation.

Total nitrogen in the surficial aquifer at the test site increased substantially above background concentration. The relatively high concentrations of total nitrogen (greater than values of the effluent) observed at the test site

Table 11.--Microbiological analyses of the ground water in the surficial aquifer near the test site, October 1971 to April 1975

[Colonies per 100 milliliters.]

Well number	Depth (ft)	Date of collection	Coliform	Fecal coliform	Fecal streptococci
123	9	10-15-71	62	<1	<1
		5-24-72	<1	<1	<1
		10-24-72	6	<1	23
212	9	5-22-74	<1	<1	8[a]
		4-10-75	<1	<1	<1

[a]Value based on nonideal colony count.

Table 12.--Chemical analyses of the ground water in the Floridan aquifer near the test site, October 1971 to August 1975

[All values are in milligrams per liter unless otherwise indicated.]

Well number	Date of collection	Chloride, dissolved (Cl)	Nitrate, total (N)	Nitrite, total (N)	Ammonia nitrogen, total (N)	Organic nitrogen, total (N)	Nitrogen, total (N)	Phosphorus, total (P)	Orthophosphate total (P)	Specific conductance, umho/cm at 25°C	pH, units	Chemical oxygen demand, COD	Biochemical oxygen demand, BOD	Organic carbon, total (C)	Inorganic carbon, total (C)
501	10-19-71	73	-	0.01	0.11	0.05	-	0.05	0.03	520	-	6.0	0.4	-	-
	4-26-72	580	0.01	0	.46	.36	0.83	.06	.05	2,650	7.5	-	-	-	-
	5-18-72	250	-	-	-	-	-	-	-	1,150	-	-	-	-	-
	6- 2-72	100	.24	0	.02	.13	.39	.02	0	560	-	-	.3	-	-
	10-25-72	900	.04	0	.92	.22	1.2	.08	.08	3,300	-	24	.1	8.0	50
	6-19-73	170	-	-	-	-	-	-	-	850	-	-	-	-	-
	4-25-74	1,400	-	-	-	-	-	-	-	4,700	-	-	-	-	-
	5-21-74	190	.04	0	.16	.14	.34	.04	.04	950	7.7	26	-	3.0	40
	4-10-75	210	.07	0	.09	.22	.34	.05	.01	975	-	17	-	1.0	-
	8- 7-75	600	.05	0	.27	.24	.59	.07	.07	2,320	7.4	8.0	.3	2.0	-
505	4-26-72	180	.82	0	.15	.51	1.5	.06	.02	265	7.7	-	-	-	-
	5-18-72	21	-	-	-	-	-	-	-	-	-	-	-	-	-
	6- 6-72	20	.09	0	.02	.27	.38	.07	.03	-	8.2	-	-	-	-
	8- 7-75	72	1.2	.01	.07	.27	1.6	.05	.02	814	-	9.0	1.2	2.0	-

Table 13.--Microbiological analyses of the ground water in the Floridan aquifer near the test site, October 1971 to August 1975

[Colonies per 100 milliliters.]

Well number	Date of collection	Coliform	Fecal coliform	Fecal streptococci
501	10-19-71	2	9	<1
	6- 2-72	<1	<1	2
	10-25-72	<1	<1	<1
	5-21-74	76	<1	1
	4-10-75	43	4	--
	8- 7-75	<1	1	1[a]
505	6- 6-72	<1	--	--
	8- 7-75	300	<1	37

[a] Value based on nonideal colony count.

were probably due to sampling shortly after chemical fertilization because similar high concentrations were also observed in water from wells near the test site. Comparison between total nitrogen concentration at the test site to that of the applied effluent was also complicated by periodic application of chemical fertilizer to the test site. Total nitrogen reduction was occasionally more than 90 percent (table 5), but averaged less than 20 percent. Conversion of the predominantly ammonia nitrogen in the effluent to the predominantly nitrate nitrogen in the shallow ground water at the test site was primarily due to bacterial action. Similar conversions were attributed to nitrifying bacteria by Reichenbaugh (1976), Reichenbaugh and others (1979), and Cherry and others (1973).

Physical, geochemical, and biochemical processes effectively reduced total nitrogen concentrations downgradient from the test site compared to concentrations of applied effluent or at the test site. Total nitrogen reduction was as much as 95 percent. However, due to the possibility of contamination from chemical fertilization of the area, nitrogen reduction may have been more.

Soil and vegetation at the test site effectively reduced total phosphorus concentrations more than 95 percent from that of the applied effluent. Two relatively high concentrations of total phosphorus (5.8 and 3.1 mg/L) observed at the test site resulted from a change from acidic to alkaline conditions; similar high total phosphorus concentrations due to change in pH to alkaline conditions were observed by Reichenbaugh and others (1979) in their studies at St. Petersburg, Fla. Well 65, downgradient from the test site, showed high phosphorus concentrations due to increases in pH to alkaline conditions.

Microbiological data indicated that more than 95 percent of the bacteria were removed from secondary treated effluent during infiltration through the soil to depths of about 10 feet and greater. Downgradient from the test site, bacteria were only about 0.01 percent of that in the effluent. Fecal coliform bacteria were not detected downgradient or near the test site during the 4-year study. There was no evidence of fecal contamination in ground water of the shallow aquifer.

Increases in chloride and specific conductance in ground water from the Floridan aquifer were probably pumpage induced or related to natural fluctuations in a coastal area. However, periodic increases in certain constituents, such as total nitrogen, may have been due to leakage of ground water from the surficial aquifer to the Floridan aquifer. Whether the increase was due to effluent spray irrigation, application of chemical fertilizer, or to natural fluctuations in concentrations cannot be determined. There was no apparent pattern of fecal coliform contamination within the Floridan aquifer.

SUMMARY AND CONCLUSIONS

Secondary treated effluent was applied to a 7.2-acre test site in a condominium-resort complex for about 4 years. Application rates averaged about 0.06 Mgal/d (2 inches per week) during the first year of operation and about 0.11 Mgal/d (4 inches per week) during the remaining 3 years. Chemical fertilizer was also applied periodically to the test site and adjacent areas.

The test site is underlain by three units: (1) a surficial aquifer, consisting of about 30 feet of sand and clayey sand; (2) a confining bed, consisting of about 10 to 15 feet of clay; and (3) the Floridan aquifer, consisting of solution-riddled and fractured limestone and dolomite several hundred feet thick. Local ground-water flow in the surficial aquifer is generally toward the north and west through the test site. Ground-water flow of the Floridan aquifer is west through the test site. Periodic mounding of the water table due to effluent spray irrigation was noted at the test site during the 4-year study.

The surficial aquifer at the test site and adjacent areas showed increases in most chemical and physical constituents (including chloride, specific conductance, pH, total nitrogen, and total carbon) above background values. Most values observed at the test site, however, were within the ranges of values observed in nearby areas that were irrigated with water from the Floridan aquifer and fertilized periodically.

In the surficial aquifer 200 feet downgradient from the test site, physical, geochemical, and biochemical processes effectively reduced total nitrogen concentration 90 percent from levels in the applied effluent. Total phosphorus concentration was reduced more than 95 percent in ground water of the surficial aquifer about 200 feet downgradient from the test site from that of the applied effluent. In the effluent, concentrations of total nitrogen averaged 26 mg/L and total phosphorus averaged 7 mg/L. Downgradient, total nitrogen averaged 2.4 mg/L and total phosphorus averaged 0.17 mg/L. Substantial increases in total phosphorus were observed when the pH of the ground water increased.

Microbiological data indicated no evidence of patterns of fecal contamination in ground water of the surficial aquifer. Total coliform bacteria were generally less than 100 col/100 mL. Fecal coliform bacteria were generally less than 25 col/100 mL at the test site and were not detected downgradient or near the test site. Fecal streptococcal bacteria were generally less than 100 col/100 mL at the test site and were detected on three occasions near the test site.

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