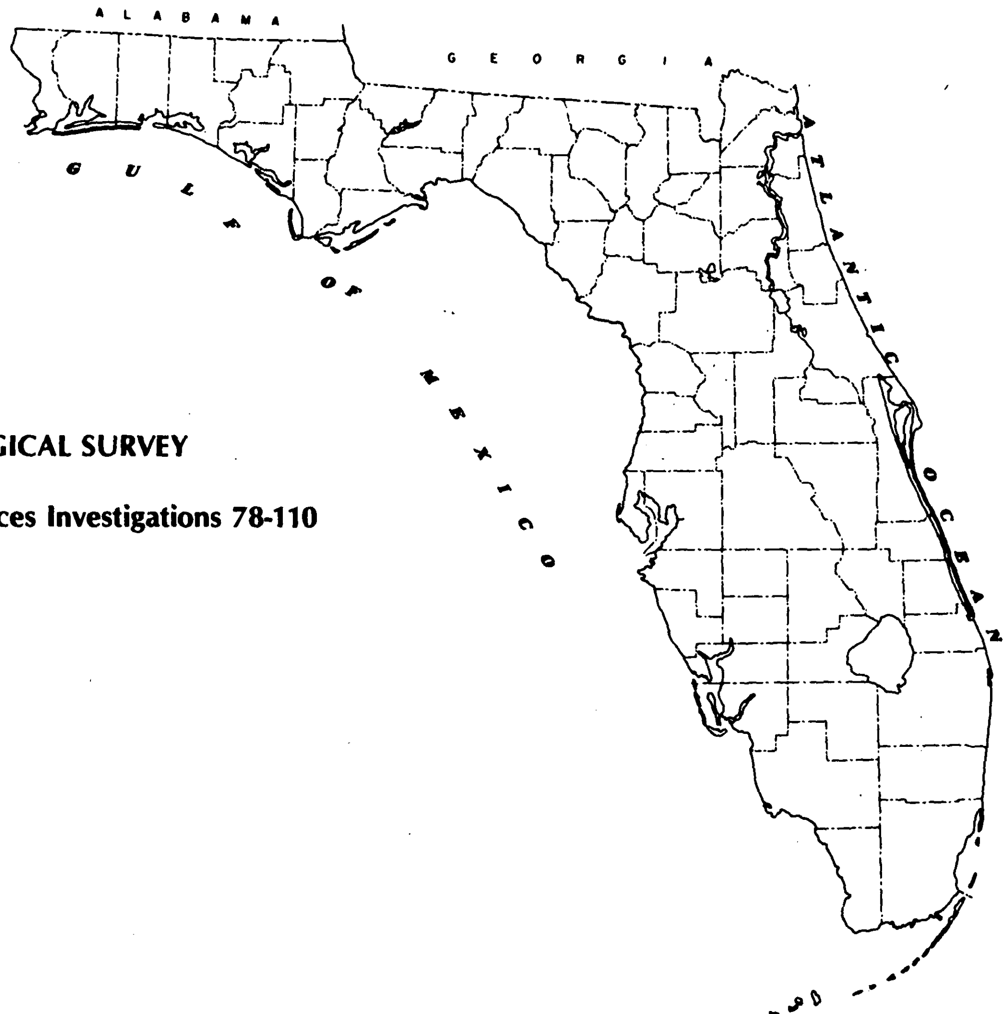
RESULTS OF TESTING LANDSPREADING OF TREATED MUNICIPAL WASTEWATER AT ST. PETERSBURG, FLORIDA



U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-110

Prepared in cooperation with the
CITY of ST. PETERSBURG, FLORIDA

WRI 78-110 RESULTS OF TESTING LANDSPREADING OF TREATED MUNICIPAL WASTEWATER AT ST. PETERSBURG, FLORIDA

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ABSTRACT

Chlorinated secondary-treated effluent was used to irrigate a grassed 4-acre site at rates of 2 and 4 inches per week for periods of 11 and 14 weeks, respectively. Part of the site was drained by tile lines 5 feet below land surface. Chemical and bacteriological changes in the acidic ground water in the shallow sand aquifer and in the effluent from the drains were studied.

Irrigation of the drained plot resulted in rapid passage of the applied wastewater through the soil and, consequently, poor nitrogen removal. The rapid percolation permitted nitrification but prevented denitrification. Thus, the effluent from the drains contained as much as 5.2 milligrams per liter nitrate-nitrogen. Irrigation of the undrained plot resulted in more extensive nitrogen removal.

Total phosphorus in the shallow ground water at the site increased from a maximum of 1.4 milligrams per liter before irrigation to as much as 5 milligrams per liter in the ground water 5 feet below land surface.

Concentrations of nitrogen and phosphorus did not increase in ground water downgradient from the site, although increased chloride concentrations demonstrated downgradient migration of the applied wastewater.

Prior to irrigation, total coliform bacteria were not detected in ground water at the site. After irrigation, total and fecal coliforms were detected in the ground water at the site and downgradient. The nitrifying bacteria <u>Nitrosomonas</u> and <u>Nitrobacter</u> at the irrigated site were most abundant at the soil surface; their numbers decreased with depth.

INTRODUCTION

St. Petersburg (fig. 1), on the southern tip of Pinellas County in west-central Florida, operates four secondary wastewater treatment plants that utilize the activated sludge process. The chlorinated effluent is discharged into Tampa Bay, east of the city, or to Boca Ciega Bay, west of the city. Existing treatment facilities (and expansions thereof) that discharge to Tampa or Boca Ciega Bays are required to provide advance treatment or an alternative disposal in order 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; 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 which 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).

City officials recognized that grassed areas in the city might be sprinkler irrigated with treated wastewater, thereby reducing the irrigation demand on the area's freshwater resources and recharging the thin freshwater zone in the shallow sand aquifer underlying the peninsula. The shallow aquifer is generally unused except for lawn irrigation.

Objectives

In July 1971, the U.S. Geological Survey began an investigation of the hydrologic effects of an effluent-disposal system using sprinkler irrigation in Pinellas County. The objectives of the investigation were to determine: (1) the chemical and bacteriological character of the treated wastewater, (2) the changes that occur in the ground water in the shallow aquifer, and (3) the practical irrigation rates.

The approach was to monitor a plot on which treated wastewater was used for sprinkler irrigation of grass. Data were collected from July 1971, before irrigation commenced, to January 1974, and included application rates, ground-water-level changes, measurement of discharge from the

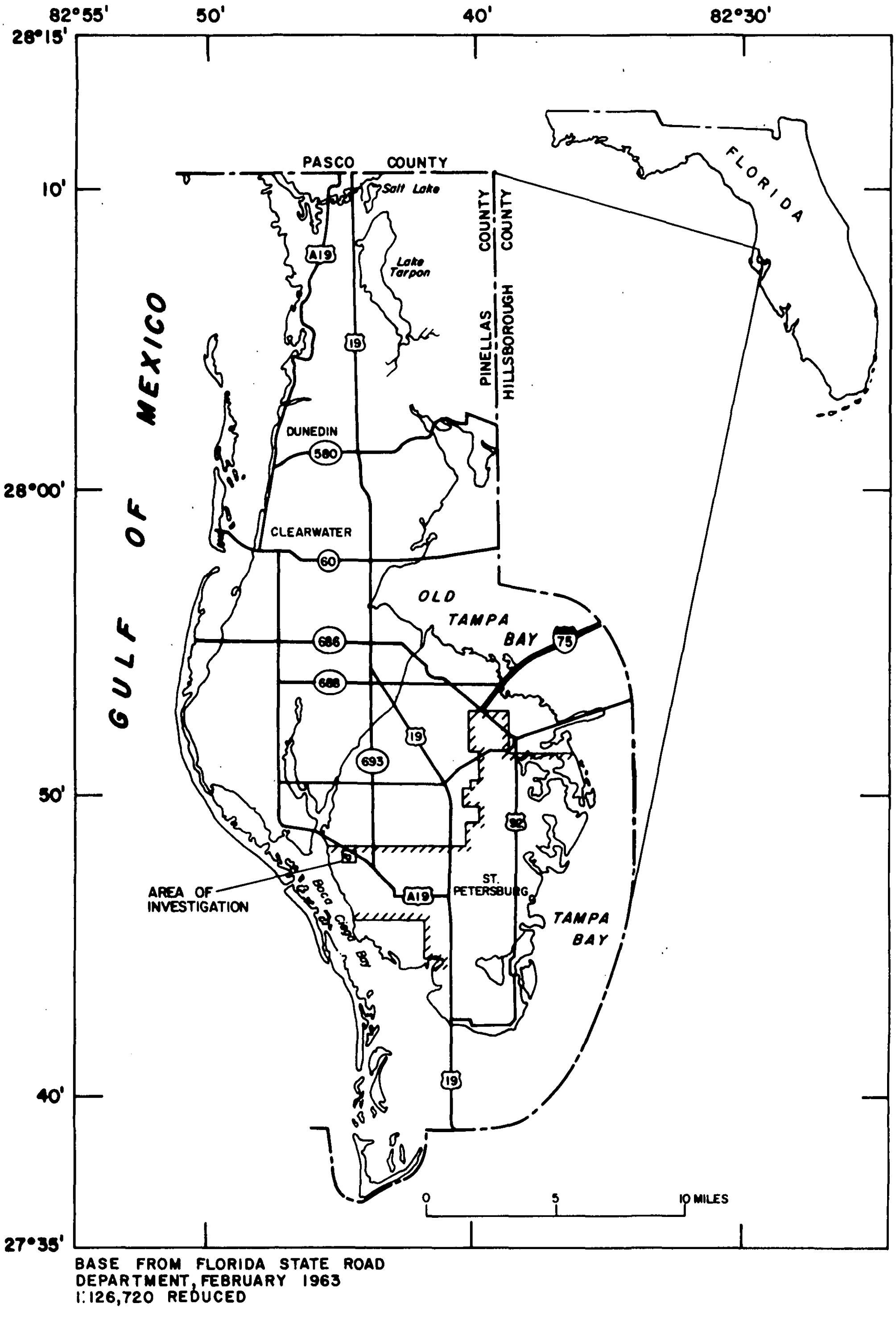

Figure 1.--Location of area of investigation.

area, and chemical and bacterial determinations of ground water, effluent, and soil. This report details investigation of irrigation of drained and undrained grassed plots at rates of 2 in. (inches) per week and 4 in. per week between August 1973 and January 1974.

Previous Investigations

Before July 1973, the study site was irrigated for periods of as much as 6 weeks at rates of 2, 4, and 11 in. per week. Preliminary findings were reported by Cherry and others (1973). Data collected during these preliminary tests confirmed that high rates of effluent application required site drainage. To accomplish drainage, a network of subsurface drains was installed about 5 ft (feet) below land surface under part of the study site (fig. 3). Afterward, that part of the site was irrigated at 11 in. per week. At this higher rate, the upper water surface was within 18 in. of land surface. After 6 weeks of effluent application at 11 in. per week, effluent from the subsurface drains contained 6.2 mg/L of total nitrogen (N) and 3.0 mg/L of total phosphorus (P).

These concentrations were in excess of the limits of 3 mg/L of nitrogen and 1 mg/L of phosphorus permissible under existing Florida statutes for treated effluent discharged to surface waters. The rapid percolation of the wastewater through the shallow sandy soil did not allow time for the physical, chemical, and biochemical processes to reduce the nitrogen and phosphorus to acceptable levels.

Acknowledgments

Many personnel of the city of St. Petersburg, by their advice and actions, aided the authors. Art Day, District Conservationist of the U.S. Department of Agriculture, Soil Conservation Service, provided advice regarding site design. The cooperation of Dr. F. M. Wellings, Director, Epidemiology Research Center, Florida Department of Health and Rehabilitative Services, who concurrently conducted virus studies at the site, is acknowledged.

SITE DESCRIPTION

The 6.2-acre study site was located near St. Petersburg's Northwest Wastewater Treatment Plant which is near Boca Ciega Bay on the southwest side of Pinellas County (fig. 1). For the study, the site was leveled, diked, and fenced. Coastal bermuda and argentine bahia grasses were established. An irrigation-pipeline network, a monitor-well network, subsurface drains, and associated drain-discharge pipe were installed.

The site was designed to permit irrigation, at differing rates, of a drained plot, an undrained plot, or the entire site. Sprinklers, 18 in. high, were placed 75 ft apart along lateral lines spaced 75 ft apart. Perforated 6-in. drains were buried 5 ft beneath the soil surface on the west part of the site. The two lateral drains were connected to a weir and discharge was routed to a submerged outfall in the lake (fig. 2).

A network of wells was constructed within and near the site (fig. 3). The network consisted of clusters of wells whose casings consisted of 2-in. diameter PVC-pipe (polyvinylchloride) terminating in slotted PVC screens 12 to 18 in. long. The clusters consisted of wells placed into augered holes 2, 5, 10, 15, and 20 ft deep. Water-level recorders were placed on two wells in the drained part of the site (well cluster CB-1). The recorders continuously monitored water levels 5 ft and 10 ft below the surface.

Wells clustered at CB-1 and CB-3 were sampled to determine water quality below that part of the site covered by coastal bermuda grass. Wells at AB-1 were likewise sampled to determine water quality below the part of the site covered by argentine bahia grass. Wells at sites CB-2 and CB-4 were sampled to determine water quality between the irrigated site and the lake. One well at site BG-1 was sampled to determine water quality outside the irrigated site.

Hydrogeology

The hydrogeology of Pinellas County has been described by Heath and Smith (1954). The sequence of marine deposits underlying the study site includes the shallow aquifer (water-table aquifer) consisting of about 50 ft of sand and shelly sand with increased proportions of clay near the bottom. The shallow aquifer is underlain by the Miocene Hawthorn Formation, consisting of about 100 ft of quartzose and calcareous sediment ranging in texture from sand to sandy clay. The clay content of the Hawthorn Formation is sufficient to confine the water of the underlying Floridan aquifer, the top of which is about 150 ft below land surface. The Floridan aquifer is a sequence of limestones with numerous large and very permeable, cavernous zones. It is not locally a source of public water supply because of potential saltwater encroachment, but it is tapped by irrigation wells, small industrial supply wells, and isolated domestic (private) wells.

The Immokalee soil series (Vanatta and others, 1972), which appears at the surface of the shallow aquifer at the study site, consists of fine-to-very-fine non-calcareous acid sand (pH 4 to 5) with varying amounts of clay and disseminated organic matter. Downward from the gray-white surface soil, the sand is increasingly stained by decaying organic materials (humate). Staining is greatest in the dark brown-to-black acid sands of the spodic horizon, commonly referred to as the organic-stain layer or hardpan, about 5 ft below land surface.

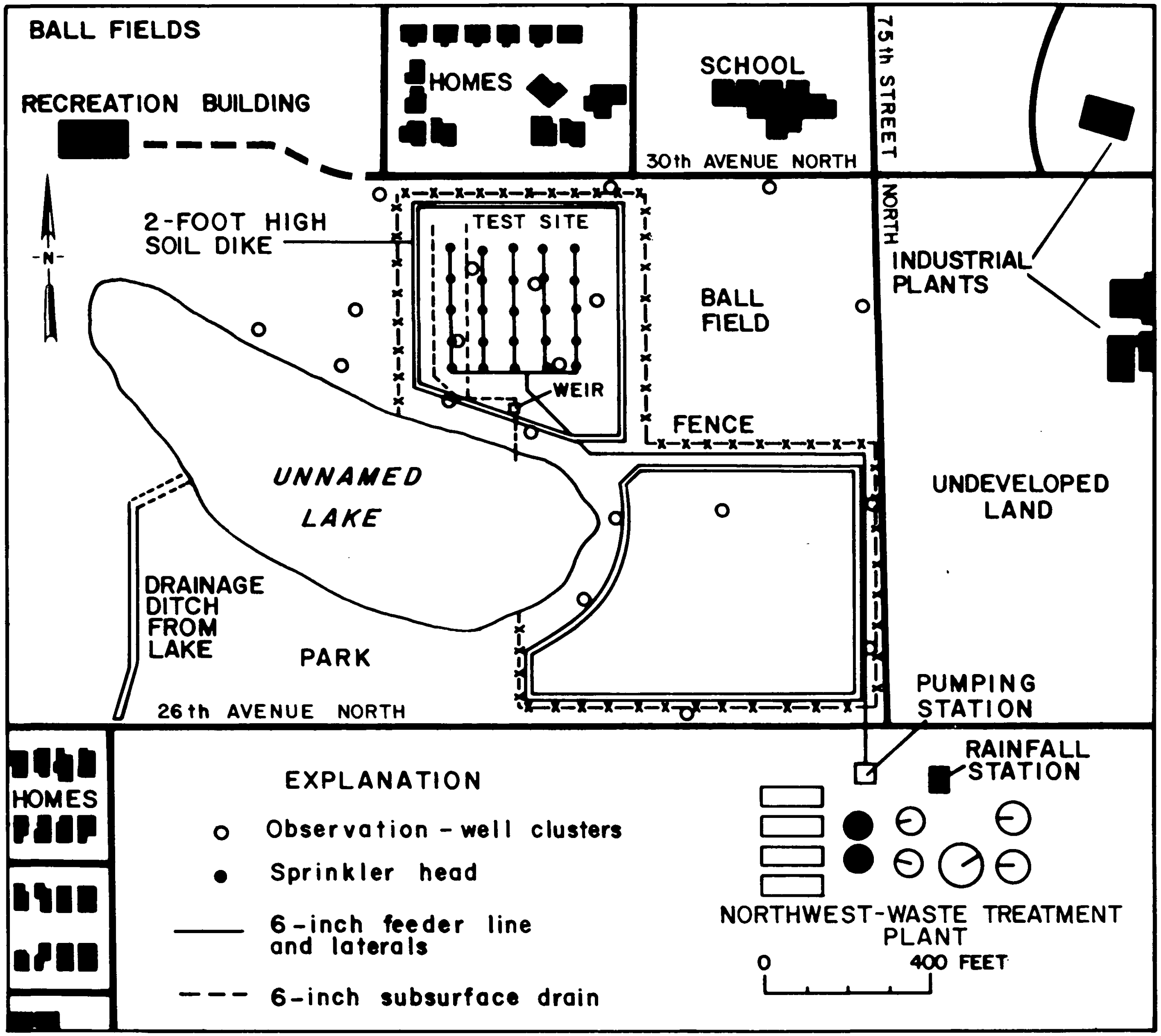

Figure 2.--Plan of the wastewater disposal site.

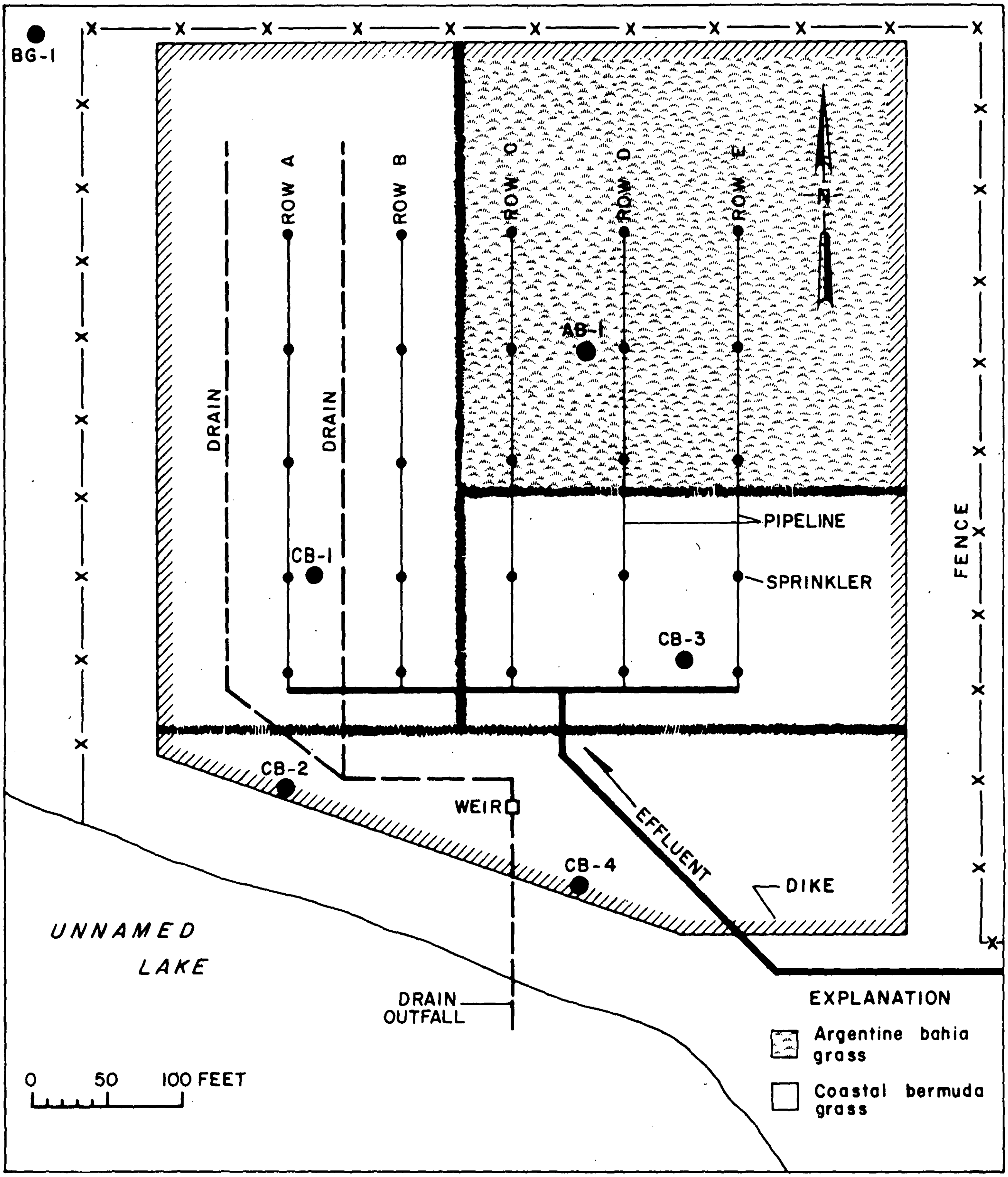

Figure 3.--Locations of the monitor wells, layout of the irrigation-pipeline network and location of the subsurface drains.

The spodic horizon is the zone of accumulation of water-soluble humic and fulvic acids (humate) leached over many decades from decaying surface vegetation. It consists of humate-cemented quartz sand stained or coated with dark brown organic matter that is a small percentage of the total sediment.

Swanson and Palacas (1965) reported that the organic carbon content of humate-cemented sand elsewhere in Florida varied from 0.57 to 5.42 percent by weight and that the total organic matter ranged from 1 to 8 percent by weight. The principal constituents in the humate (in decreasing order of concentration) are carbon, oxygen, hydrogen, nitrogen and sulfur. Analyses of the humate by the U.S. Geological Survey indicate phosphorus is present at the St. Petersburg site, though no data are available on its percentage by weight.

The mobility of the Florida humate in aqueous solutions has been described as unique and intriguing by Swanson and Palacas (1965). Percolating surface water, which is weakly alkaline to nearly neutral, easily removes the material from the surficial sediments. Precipitation or floculation of the humate occurs by one or a combination of the following processes: (a) the absorption or complexing of dissolved cations such as aluminum, ferric iron or magnesium; (b) complexing with clay colloids; and (c) a lowering of pH. All of these conditions are encountered as humate in solution is carried deeper in the shallow aquifer under the site.

The poorly permeable hardpan (Cherry and others, 1973) produces two different water zones in the shallow aquifer. In this report the two water-bearing units are referred to as the upper and lower units of the shallow aquifer and the hydraulic gradient is generally downward. Other water-bearing units in the shallow aquifer, deeper than 20 ft below land surface, were not identified in this study.

Below the spodic horizon the shallow aquifer consists of various layers of sand, sandy clay, and clay to a depth of about 50 ft (fig. 4). Laboratory analysis of cores from the shallow aquifer to a depth of 50 ft shows (1) the water-storage capacity is high (effective porosity of about 35 to 40 percent); (2) pH is low (4 to 5); (3) ion-exchange capacity is less than 11 milliequivalents per 100 g (grams); (4) median grain size ranges from 0.17 to 0.21 mm (millimeters); and (5) the vertical hydraulic conductivity ranges from 1.9 ft/d (feet per day) to 30 ft/d (Cherry and others, 1973).

The water surfaces of the upper and lower units of the shallow aquifer were mapped in August 1971 before the drains were constructed or the site irrigated (figs. 5 and 6). Altitude of the land surface is about 25 ft above mean sea level.

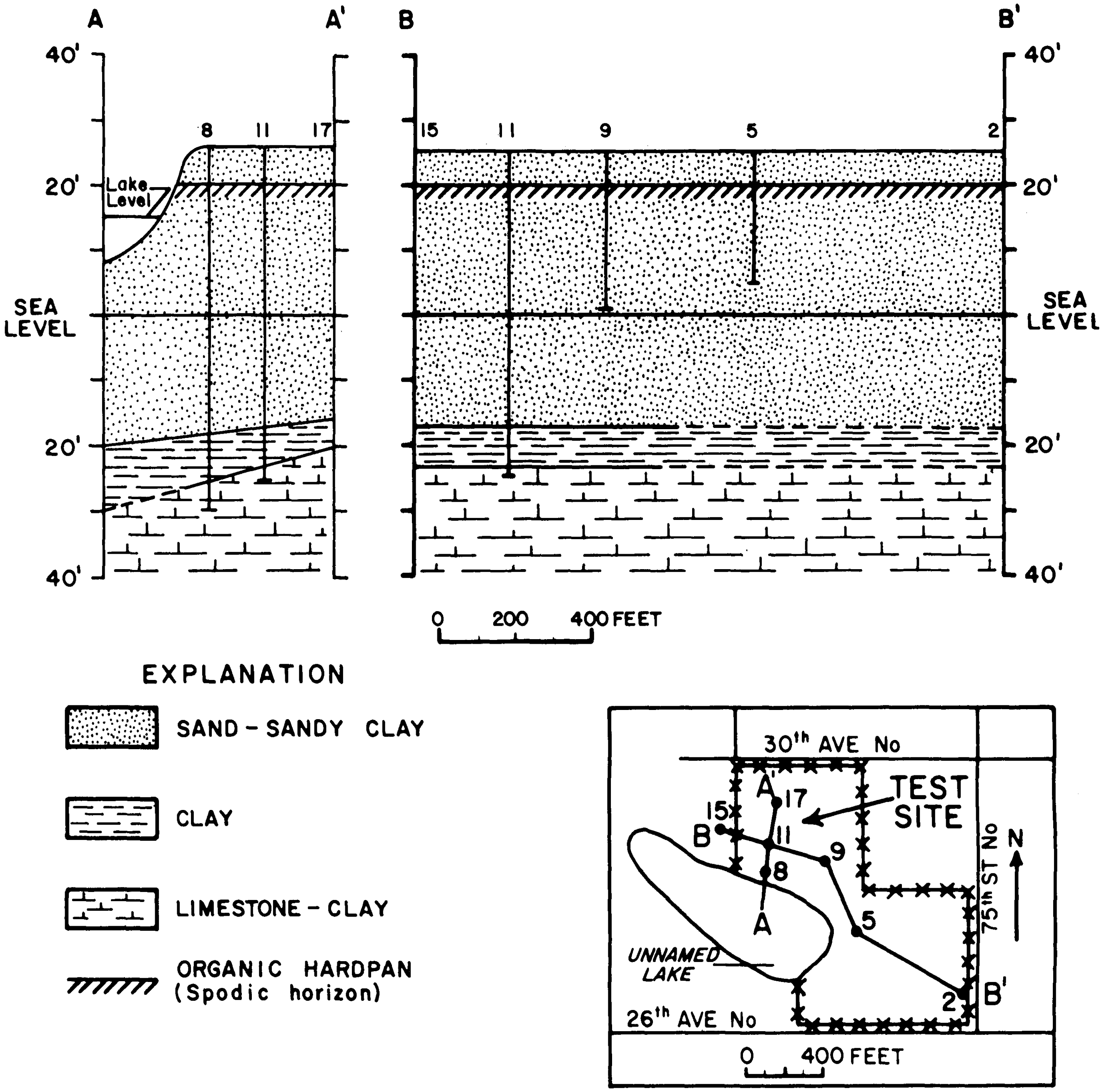

Figure 4.--Geologic sections through the shallow aquifer.

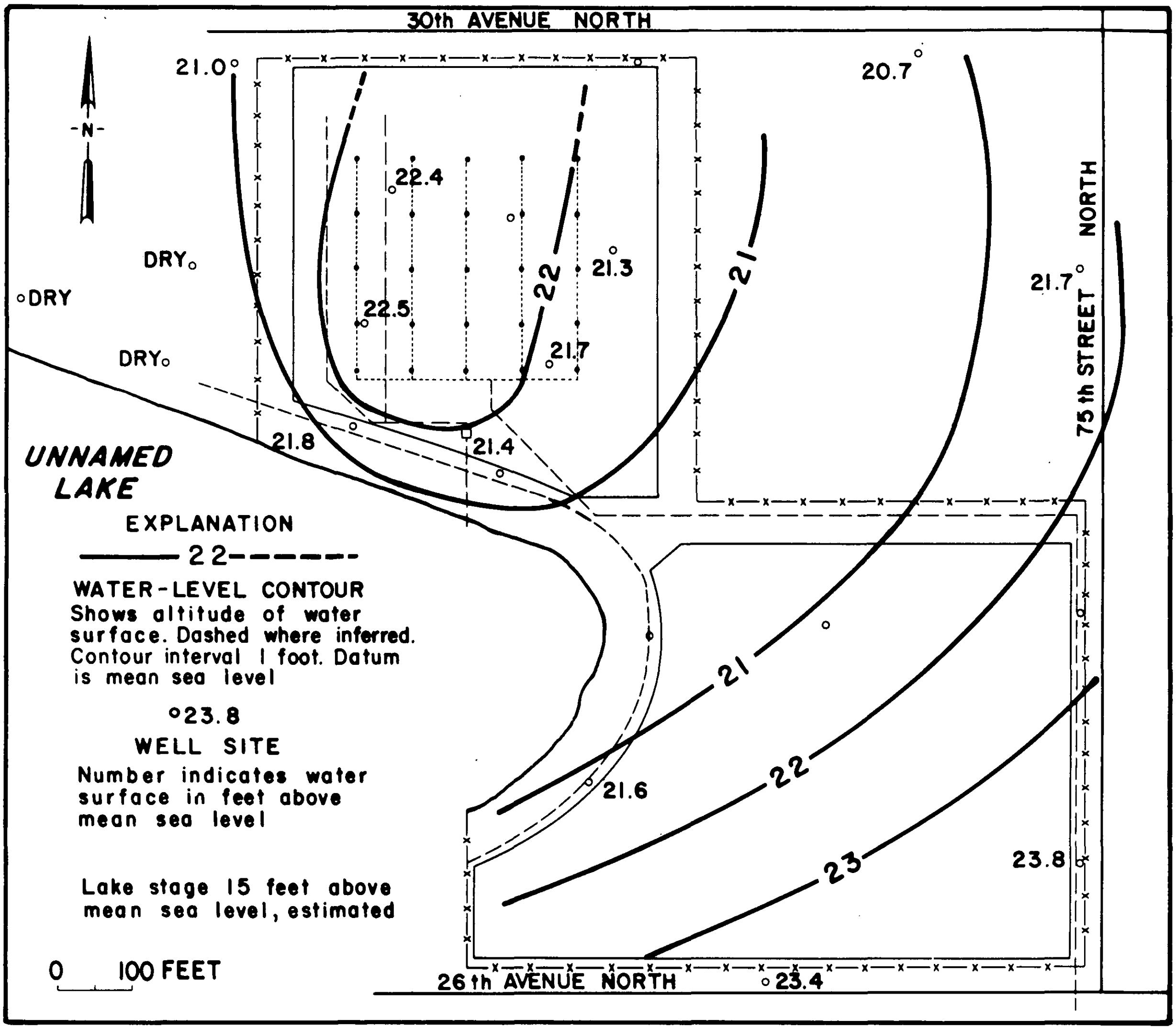

Figure 5.--Altitude of the water surface in the ~~lower~~ upper unit of the shallow aquifer, August 1971.

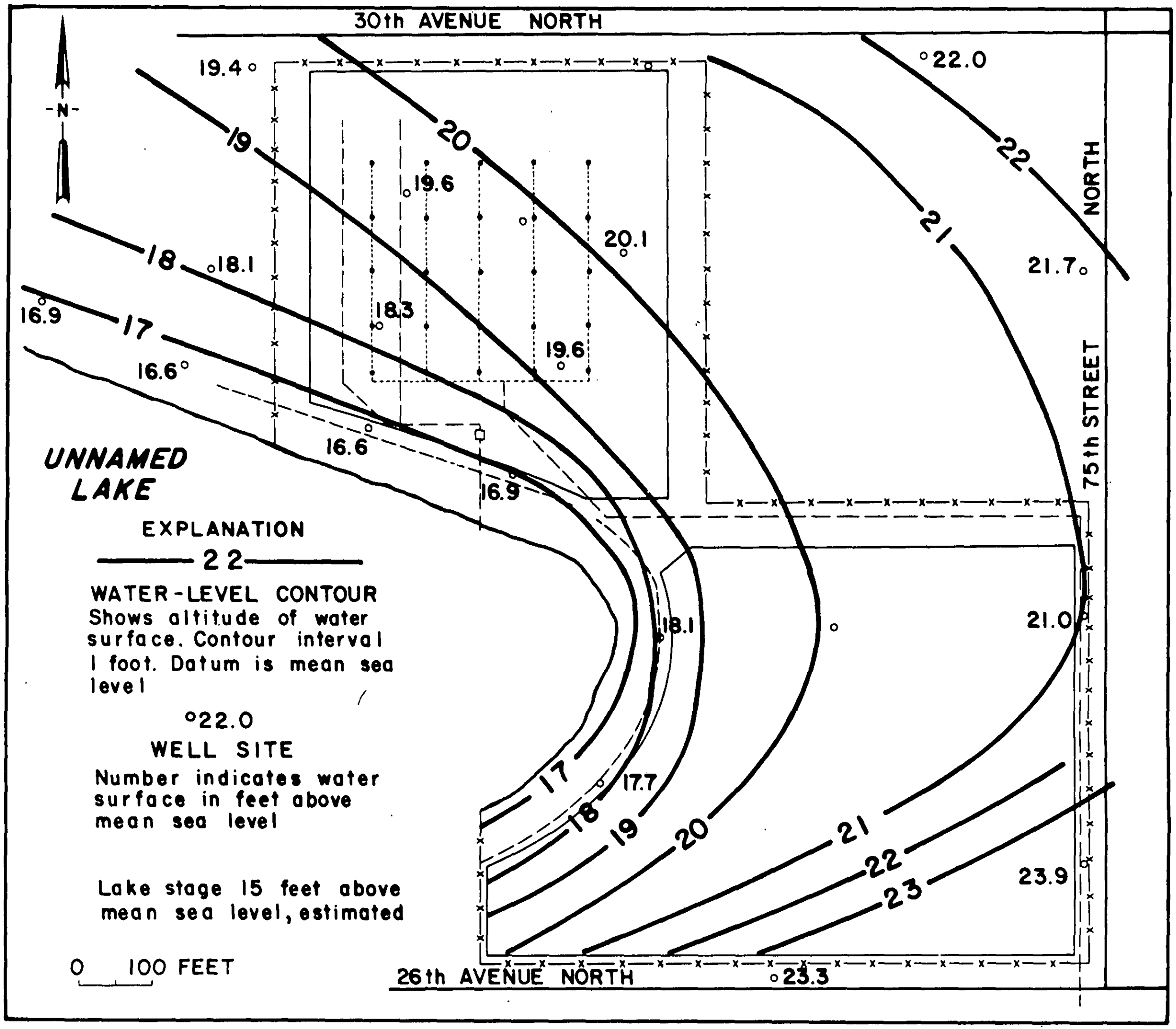

Figure 6.--Altitude of the water surface in the lower unit of the shallow aquifer, August 1971.

Character of the Treated Wastewater

Analyses made of the treated wastewater from the plant are shown in table 1. Total nitrogen in the wastewater ranged from 8.6 to 19 mg/L and averaged 14 mg/L, chiefly as ammonia and organic nitrogen. Total phosphorus ranged from 0.9 mg/L to 3.2 mg/L and averaged 2.0 mg/L primarily as inorganic orthophosphate which averaged 1.7 mg/L. The wastewater was generally alkaline, pH ranging from 7.2 to 7.4. The chloride concentration averaged 120 mg/L and ranged from 110 to 150 mg/L. COD (chemical oxygen demand) in the wastewater averaged about 55 mg/L and varied from 48 to 60 mg/L. Based on records at the treatment plant, the 5-day BOD (biochemical oxygen demand) averaged about 12 mg/L and suspended solids averaged about 15 mg/L.

Water Quality in the Shallow Aquifer Before Irrigation

The water in the shallow aquifer was sampled prior to irrigation of the site with treated wastewater from August 1971 to February 1972. Samples were collected from wells 5, 10, 15, and 20 ft deep at sites CB-1 and CB-2 (fig. 3) and are considered representative of water quality throughout the shallow aquifer at the study site before wastewater was applied. The analyses are listed in table 2.

Total nitrogen concentration ranged from 2.3 mg/L to 6.9 mg/L, predominantly in the forms of ammonia nitrogen and organic nitrogen; nitrate nitrogen was absent from the samples. Total phosphorus ranged from 0.40 to 1.4 mg/L in the shallow ground water and organic carbon ranged from 28 to 132 mg/L. Maximum chloride concentration was 26 mg/L. Total and fecal coliform bacteria were not detected in water from the shallow aquifer.

METHODS OF INVESTIGATION

The site was irrigated twice weekly for 11 weeks at 2 in. per week commencing August 1, 1973. Samples of the wastewater, ground water, and soil were collected 15, 43, and 76 days after the irrigation of the site began. The irrigation rate was increased to 4 in. per week for the ensuing 14 weeks, and samples of the wastewater, ground water, and soil were collected 24, 52, and 94 days after the rate increase. A summary of activities at the site is shown in table 3.

About 9 Mgal (million gallons) of treated wastewater were applied to the site during the two tests. Ground water was sampled at the background well (BG-1) outside the area irrigated. Also, ground water was sampled from the drained part of the site (CB-1), from the undrained part (AB-1 and CB-3), and downgradient from the site (CB-2 and CB-4). The effluent from the drains was also sampled. All locations are shown in figure 3.

Table 1.--Chemical analyses of the treated wastewater

[Concentrations are reported as milligrams per liter except where noted. All analyses are by the U.S. Geological Survey.]

Date of collection	Nitrate, total as N	Nitrogen, ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Phosphorus, total ortho as P	Phosphorus, total as P	pH	Specific conductance (micromhos/cm at 25°C)	Sodium (Na), dissolved	Chloride (Cl), dissolved	Chemical oxygen demand (COD)	Carbon, organic dissolved
8-15-73	0.01	7.1	4.7	12	1.6	1.6	7.4	750	64	110	48	14
9-12-73	.05	6.2	2.3	8.6	.79	.90	7.3	750	63	110	58	20
12-13-73	.01	16	3.2	19	2.4	3.2	7.4	900	--	150	--	--
1-23-74	0.00	14	2.2	16	2.2	2.4	7.2	810	77	110	60	24
AVERAGE	.02	11	3.1	14	1.7	2.0	---	802	68	120	55	19

Table 2.--Chemical analyses of the ground water in the shallow aquifer sampled before irrigation

[Samples collected between August 1971 and February 1972. Concentrations are in milligrams per liter except where noted. All analyses are by the U.S. Geological Survey.]

Sample depth (ft)	Well site	pH	Specific conductance (micromhos/cm at 25°C)	Sodium (Na), dissolved	Chloride (Cl), dissolved	Chemical oxygen demand (COD)	Carbon, organic dissolved	Nitrate, total as N	Nitrogen, ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Phosphorus, total as P
5	CB-1	4.8	---	--	--	--	---	--	--	---	---	--
10	CB-1	4.1	102	6.4	6.2	45[a]	132	0.00	1.5	1.6	3.1	1.2
15	CB-1	4.5	153	9.1	13.0	40[a]	35	0.00	2.0	1.4	3.4	.70
20	CB-1	4.5	165	12.0	16.0	54[a]	66	0.00	4.1	2.8	6.9	1.4
5	CB-2	---	86	5.8	26.0	--	28	--	.81	1.1	---	.63
10	CB-2	---	160	13.0	14.0	140	103	0.00	1.4	2.6	4.0	1.3
15	CB-2	---	193	13.0	19.0	56	90	0.00	.70	1.6	2.3	.40
AVERAGE IN SHALLOW GROUND WATER		---	143	9.9	16.0	67	76	0.00	1.7	1.8	3.9	.94

a = Sampled in September 1972 at CB-3.

Table 3.--Activities at the test site between July 1971 and January 1974, including duration and intensity of irrigation and volumes of wastewater applied

Dates	Duration of period	Intensity of irrigation	Description of activity and remarks
7/71 to 7/73	2 years	varied	Construction of facilities; numerous short-term tests of low rates of irrigation up to 4 in. per wk; extended period of testing a low-rate irrigation (4 in. per wk for 10 weeks) and high-rate irrigation (11 in. per wk for 6 weeks); evaluation of data collected; preparation of preliminary report (Cherry, Brown, Stamer and Goetz, 1973); total volume of wastewater applied was 14.7 Mgal.
7/73 to 8/73	1 month	varied	Sampled ground water previous to commencing irrigation.
8/1/73 to 10/18/73	11 weeks	2 in. per wk	Sampled ground water 15, 43 and 76 days after start of the irrigation period.
10/22/73 to 1/25/74	14 weeks	4 in. per wk	Doubled the irrigation rate; sampled ground water 24, 52 and 94 days after start of the testing period; total volume of treated wastewater applied during the two irrigation periods was 9 Mgal.

Soil and water samples were collected periodically for enumeration of bacteria. Nitrifying and denitrifying bacteria were chosen for study to evaluate nitrogen removal from the treated wastewater. Pathogen-indicating bacteria were studied in order to evaluate contamination of ground water.

Water levels in the upper and lower units (above and below the organic-stain layer) were measured continuously during the tests at the drained part of the site, and periodically elsewhere.

RESULTS

Water-Level Responses

Hydrographs relating the irrigation and rainfall on the site, and the depths to water in the shallow aquifer under the drained and undrained parts of the site for the irrigation periods are shown in figures 7 and 8.

Water levels above and below the stain layer rose in response to irrigation of the site; however, there was no marked difference in the water levels as the rate increased from 2 to 4 in. per week (figs. 9 and 10). Ponding did occur in a low area in the undrained part of the site for a short time during a rainy period in December 1975. Where present, the drains maintained the water levels about 3 ft below the soil surface throughout the tests.

Water Quality

In the Drained Coastal Bermuda Grass Plot

During the irrigation periods samples were collected from the wells at site CB-1 (fig. 3) to determine water-quality changes in the vicinity of the drained coastal bermuda grassed plot (table 4). Effects of the irrigation with treated wastewater were most prominent in ground water less than 10 ft deep.

The pH increased from less than 5 before irrigation to 5.3 to 7.5 after irrigation, more like the pH of the effluent. The pH change was limited to the 5-ft depth.

Chloride concentration increased from less than 26 mg/L at all depths to a maximum 160 mg/L at the 5-ft depth and to 140 mg/L at the 10-ft depth, but averaged 129 mg/L at both depths. Deeper than 10 ft,

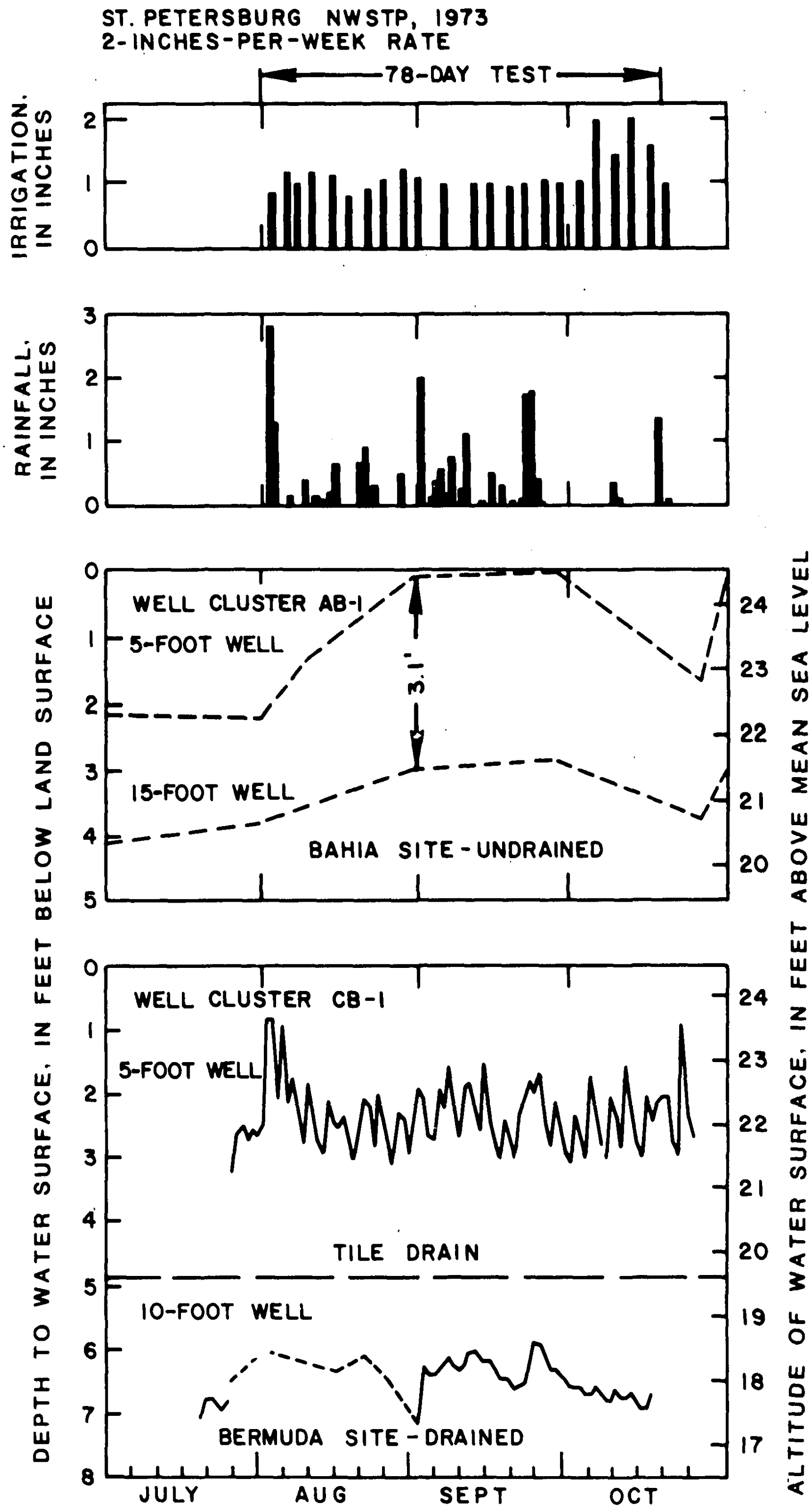

Figure 7.--Rainfall, irrigation and variation of the water surface in the shallow aquifer during the 2-inches-per week irrigation period.

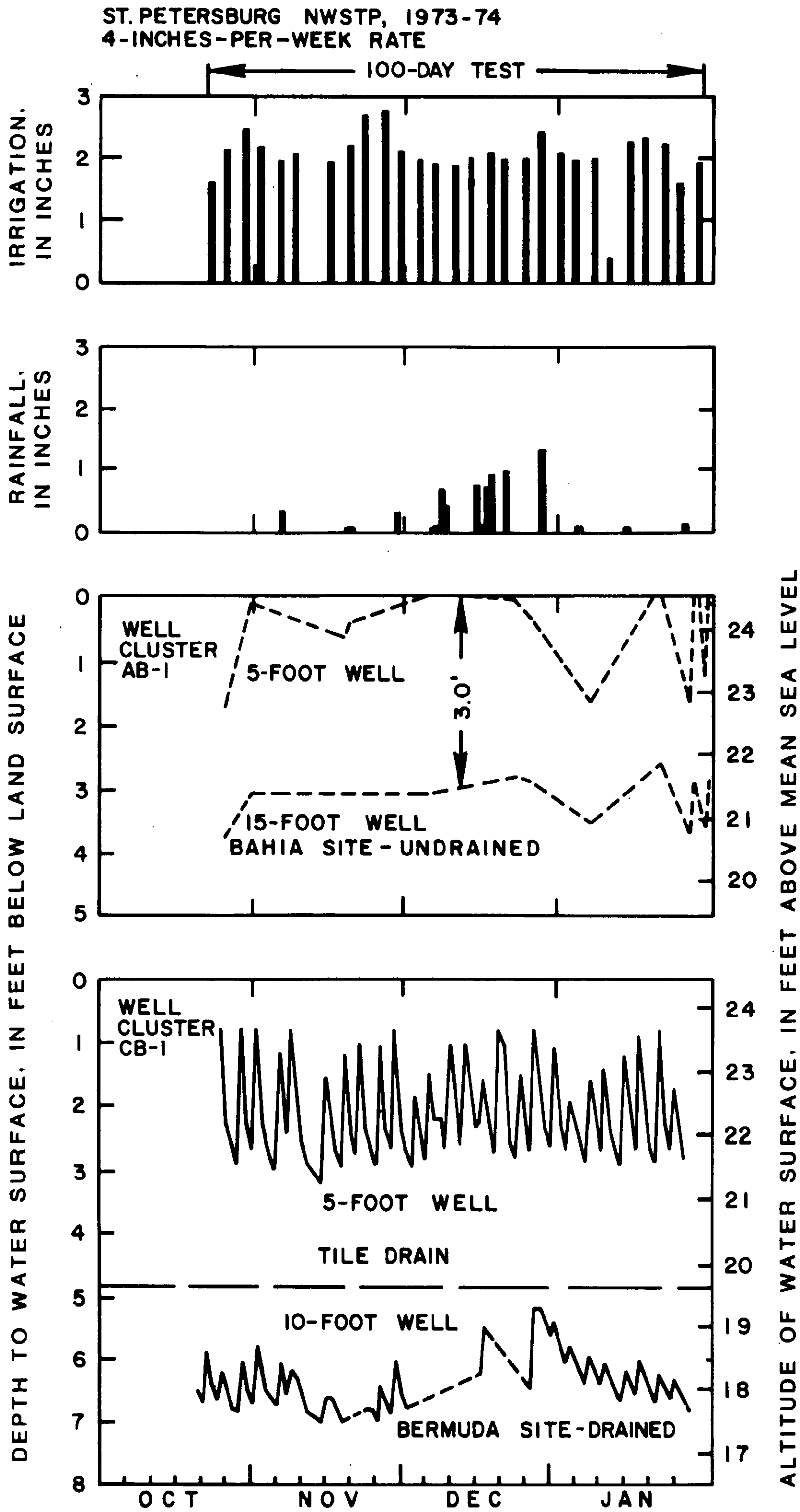

Figure 8.--Rainfall, irrigation and variation of the water surface in the shallow aquifer during the 2-inches-per-week irrigation period.

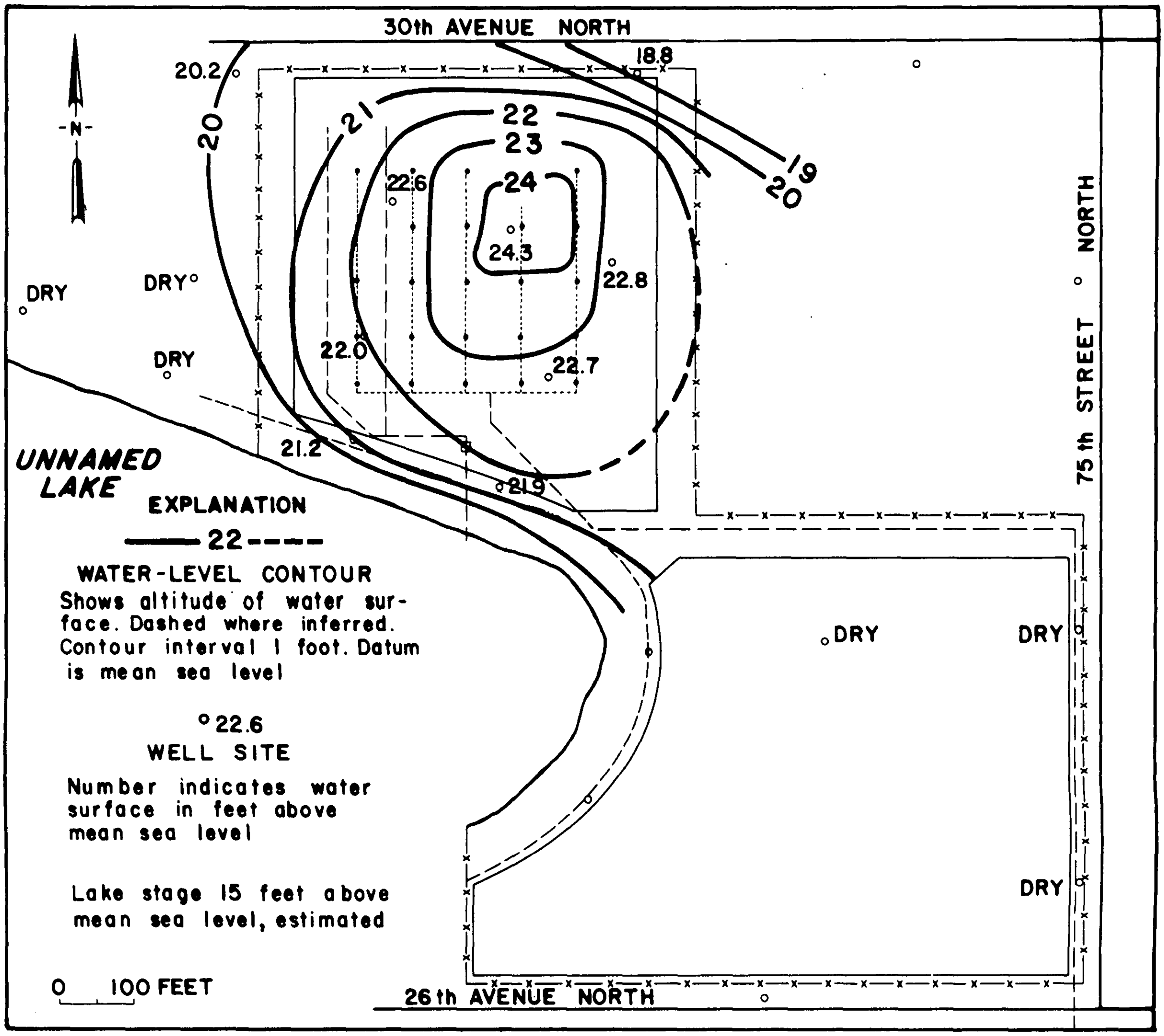

Figure 9.--Altitude of the water surface in the upper unit of the shallow aquifer in December 1973.

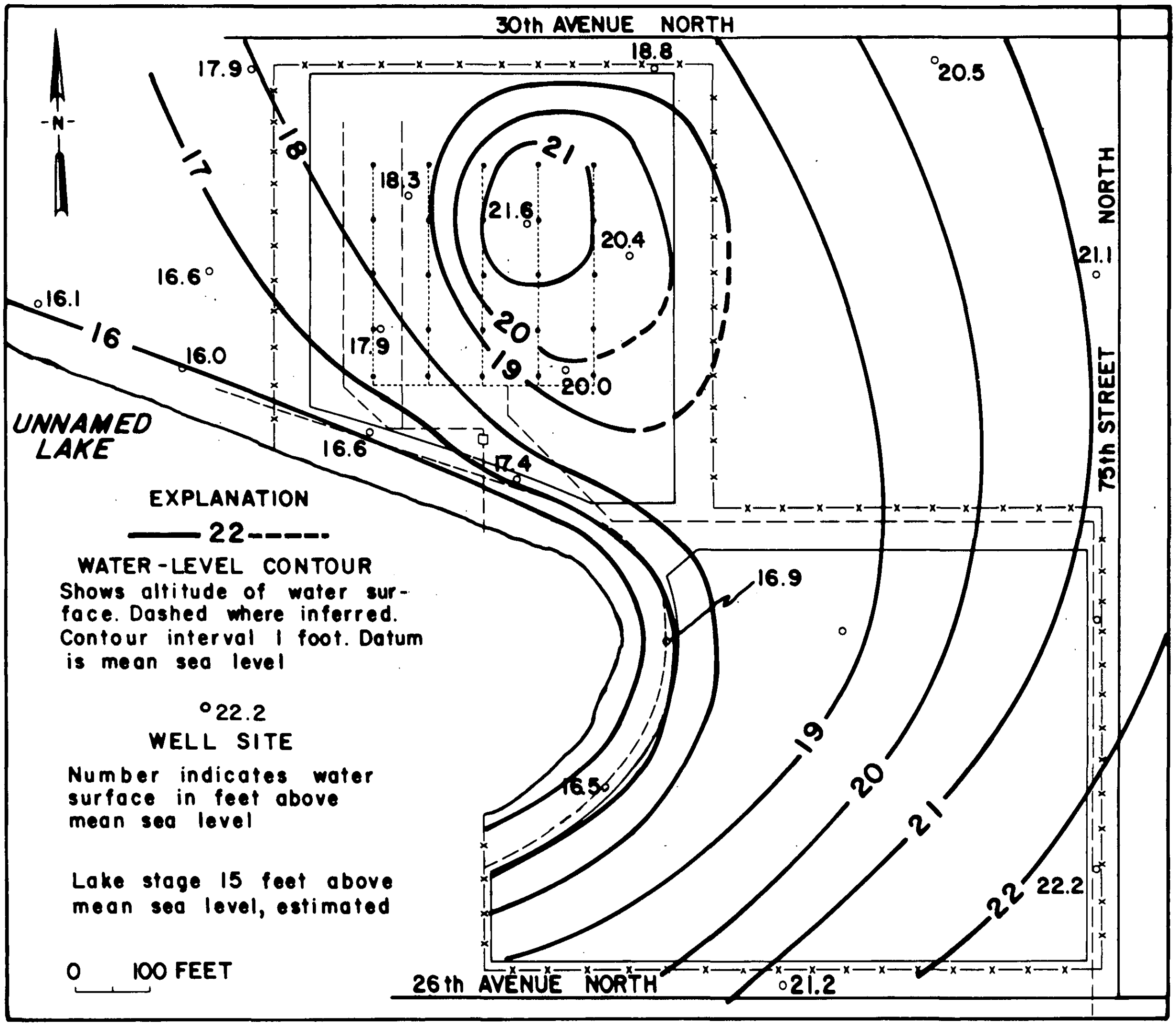

Figure 10.--Altitude of the water surface in the lower unit of the shallow aquifer in December 1973.

Table 4.--Chemical analyses of ground water from site CB-1

[Concentrations are in milligrams per liter except where noted. All analyses are by the U.S. Geological Survey.]

Sampling site	Depth sampled	Rate (in. per week)	Date of collection	Calcium (Ca), dissolved	Chloride (Cl), dissolved	Phosphorus, total as P	Nitrate, total as N	Nitrogen, ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Carbon, organic total	pH
CB-1	5 ft	-	7-03-73	42.0	160	5.0	0.67	5.4	1.2	7.3	20	7.5
		2	8-15-73	38.0	91	4.0	3.8	.57	1.5	5.9	22	6.1
		2	9-12-73	44.0	120	2.3	3.0	.25	2.1	5.4	11	6.7
		2	10-15-73	50.0	120	1.7	4.3	.06	1.0	5.4	15	7.7
		4	11-15-73	55.0	140	4.0	13.0	.16	1.2	14.0	13	---
		4	12-13-73	--	160	5.3	15.0	.11	.89	16.0	--	5.6
		4	1-23-74	47.0	110	4.6	14.0	.11	1.1	15.0	16	5.3
CB-1	10 ft	-	7-03-73	5.0	130	1.6	0.19	3.6	0.76	4.6	11	3.8
		2	8-15-73	5.9	140	1.5	.96	3.0	2.8	6.8	15	4.0
		2	9-12-73	4.2	130	1.2	0.00	3.1	1.2	4.3	19	3.7
		2	10-15-73	6.0	120	1.3	.17	3.4	.49	4.1	14	3.8
		4	11-15-73	6.6	120	1.2	.51	3.1	.58	4.2	18	---
		4	12-13-73	--	130	1.0	1.2	3.0	.72	4.9	--	3.7
		4	1-23-74	6.0	130	1.1	1.1	3.2	.97	5.3	21	3.7

Table 4.--Chemical analyses of ground water from site CB-1 - continued

Sampling site	Depth sampled	Rate (in. per week)	Date of collection	Calcium (Ca), dissolved	Chloride (Cl), dissolved	Phosphorus, total as P	Nitrate, total as N	Nitrogen, ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Carbon, organic total	pH
CB-1	15 ft	-	7-03-73	2.0	20	1.2	0.00	2.3	1.6	3.9	41	4.2
		2	8-15-73	1.7	15	1.1	0.00	2.0	1.3	3.3	31	5.9
		2	9-12-73	6.2	18	.58	0.00	1.9	1.6	3.5	26	4.3
		2	10-15-73	3.1	23	.50	0.00	2.3	1.6	3.9	35	5.7
		4	11-15-73	5.2	41	.54	0.00	3.2	.08	3.3	27	---
		4	12-13-73	--	61	.37	0.00	3.4	3.8	7.2	--	4.3
		4	1-23-74	4.2	57	.19	0.00	3.8	.91	4.7	19	4.5
CB-1	20 ft	-	7-03-73	25.0	22	.78	0.00	1.8	.83	2.6	24	5.2
		2	8-15-73	24.0	18	.30	0.00	1.5	.33	1.8	15	6.0
		2	9-12-73	23.0	26	.27	0.00	1.5	.84	2.3	17	4.6
		2	10-15-73	25.0	38	.16	0.00	1.8	.69	2.5	27	5.1
		4	11-15-73	27.0	46	.18	0.00	2.1	.63	2.7	18	5.7
		4	12-13-73	--	37	.24[b]	0.00	2.1	2.6	4.7	--	4.9
		4	1-23-74	23.0	32	.18	0.00	2.7	.64	3.3	16	4.5

Table 4.--Chemical analyses of ground water from site CB-1 - continued

Sampling site	Depth sampled	Rate (in. per week)	Date of collection	Calcium (Ca), dissolved	Chloride (Cl), dissolved	Phosphorus, total as P	Nitrate, total as N	Nitrogen, ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Carbon, organic total	pH
CB-1	50 ft	-	7-03-73	110	23	1.2	0.00[a]	0.88[a]	0.8	0.96	49	7.5
		2	8-15-73									
		2	9-12-73									
		2	10-15-73									
		4	11-15-73									
		4	12-13-73									
		4	1-23-74	110	22	.19[a]	0.00[a]	.70[a]	6.9	7.6	13	6.1

a = Dissolved value only (too turbid).

b = Orthophosphate value.

chloride concentrations increased gradually through the period, reaching a high of 61 mg/L in December at the 15-ft depth and 46 mg/L in November at the 20-ft depth.

At the 5-ft depth, total phosphorus concentration increased to 5 mg/L after irrigation of the site began; decreased to 1.7 mg/L by the end of the 2-in.-per-week irrigation period; but increased to nearly 5 mg/L by the end of the 4-in.-per-week irrigation period. Total phosphorus in the water from 10 ft below land surface was as high as 1.6 mg/L, probably a residual effect from earlier high-rate tests on the site. Total phosphorus in water from the 15- and 20-ft deep wells was generally about the same or less than pre-irrigation values.

The most prominent effect of irrigation of the drained plot was the increase in nitrate concentrations less than 10 ft below the surface. During 11 weeks of irrigation at 2 in. per week, the nitrate concentration at CB-1 increased to a maximum 4.3 mg/L (as N) at a depth of 5 ft below the land surface, and to about 0.2 mg/L (as N) at 10 ft. After the irrigation rate was increased to 4 in. per week, nitrate concentrations increased to as much as 15 mg/L (as N) at the 5-ft depth, and to as much as 1 mg/L (as N) at the 10-ft depth. No nitrate was detected deeper than 10 ft.

During the entire test period, the ammonia concentration in ground water from the 5-ft depth was lower than the pre-irrigation values of about 1 mg/L, as N. However, in samples from the 10-ft deep well, the ammonia concentration ranged from 3.0 to 3.6 mg/L, as N. In samples from the 15- and 20-ft deep wells, ammonia concentration was also higher than before irrigation started and increased during both tests. The increase was greater during the 4-in.-per-week test. At the end of the irrigation periods, the concentrations of organic-nitrogen in the shallow aquifer at all depths sampled were less than pre-irrigation values.

Soil samples tested during Feburary 1973 from the drained plot and from outside the irrigated site were analyzed for coliforms. The number of total coliforms within the drained plot was 45,000 MPN/g (most probable number per gram) of soil; outside the site the total coliform count was 4,900 MPN/g of soil. The fecal coliform count from within the drained plot was 420 MPN/g of soil; outside the site the fecal coliform count was less than 170 MPN/g of soil. The higher counts of coliform organisms within the test site indicate that irrigation with the treated effluent encouraged the growth of the total and fecal coliform organisms at the soil surface.

The treated wastewater contained 118 col/100 mL (colonies per 100 milliliters) total coliforms and 15 col/100 mL fecal coliforms. After irrigation commenced, both types were present in ground water from the upper unit of the shallow aquifer; total coliform concentrations ranged from 20 to 1,900 col/100 mL (table 5).

Table 5.--Bacterial analyses of ground water and soil from site CB-1

[All analyses are by the U.S. Geological Survey.]

Site sampled	Depth sampled	Rate (in. per week)	Date of collection	Total coliform colonies per 100 mL	Fecal coliform colonies per 100 mL	*Nitrosomonas*	*Nitrobacter*	Denitrifiers
				GROUND WATER				
						(Values are most probable number per 100 mL)		
CB-1	5 ft	-	7-03-73	1500	<1	<300	240,000	43,000
		2	8-14-73	110	<1	700	90	7000
		2	9-12-73	63	<1	--	---	---
		2	10-16-73	70	3	430	750	9300
		4	11-15-73	1900	<1	--	---	---
		4	12-13-73	400	8	--	---	---
		4	1-23-74	20	<1	2400	9300	140
CB-1	10 ft	-	7-03-73	<1	<1	--	---	3000
		2	8-14-73	8	<1	<30	<30	930
		2	9-12-73	5	<1	--	---	---
		2	10-16-73	23	<1	<30	<30	1500
		4	11-15-73	18	<1	--	---	---
		4	12-13-73	21	<1	--	---	---
		4	1-23-74	150	<1	<30	---	40

Table 5.--Bacterial analyses of ground water and soil from site CB-1 - continued

Site sampled	Depth sampled	Rate (in. per week)	Date of collection	Total coliform colonies per 100 mL	Fecal coliform colonies per 100 mL	*Nitrosomonas*	*Nitrobacter*	Denitrifiers
CB-1	15 ft	-	7-03-73	460	<1	--	--	4000
		2	8-14-73	83	<1	<30	<30	<30
		2	9-12-73	1200	<1	--	--	--
		2	10-16-73	<1	<1	<30	<30	70
		4	11-15-73	--	-	--	--	--
		4	12-14-73	23	<1	--	--	--
		4	1-24-74	270	<1	<30	150	280
CB-1	20 ft	-	7-03-73	<1	<1	--	--	<3000
		2	8-15-73	20	<1	<30	<30	<30
		2	9-12-73	21	<1	--	--	--
		2	10-17-73	570	<1	<30	<30	<30
		4	11-16-73	23	<1	--	--	--
		4	12-14-73	<1	<1	--	--	--
		4	1-24-73	5	<1	<30	1500	40

Table 5.--Bacterial analyses of ground water and soil from site CB-1 - continued

Site sampled	Depth sampled	Rate (in. per week)	Date of collection	Total coliform colonies per 100 mL	Fecal coliform colonies per 100 mL	*Nitrosomonas*	*Nitrobacter*	Denitrifiers
CB-1	50 ft	-	7-03-73	<1	<1	--	--	4000
		2	8-15-73	--	--	--	--	--
		2	9-12-73	--	--	--	--	--
		2	10-17-73	--	--	--	--	--
		4	11-16-73	--	--	--	--	--
		4	12-14-73	--	--	--	--	--
		4	1-24-74	--	--	--	--	--
					SOIL			
						(Values are most probable number per gram of sample (dry weight))		
CB-1	0 ft	-	7-06-73	--	--	45,000	48,000,000	9,700,000
		2	10-18-73	--	--	260,000	≥26,000,000	1,000,000
		4	1-28-74	--	--	2,600,000	260,000	12,000,000
CB-1	1 ft	-	7-06-73	--	--	4600	2,600,000	460,000
		2	10-18-73	--	--	12,000,000	2,700,000	2,700,000
		4	1-28-74	--	--	260,000	500,000	2500

Table 5.--Bacterial analyses of gound water and soil from site CB-1 - continued

Site sampled	Depth sampled	Rate (in. per week)	Date of collection	Total coliform colonies per 100 mL	Fecal coliform colonies per 100 mL	Nitrosomonas	Nitrobacter	Denitrifiers
CB-1	2 ft	-	7-06-73	--	--	<330	82,000	330
		2	10-18-73	--	--	180,000	30,000	53,000
		4	1-28-74	--	--	2800	2800	490
CB-1	3 ft	-	7-06-73	--	--	<360	52,000	<360

Nitrosomonas, *Nitrobacter*, and denitrifying bacteria were much more numerous in the soil than in ground water (table 5). Concentrations of these organisms were greatest near the surface and decreased with depth. The presence of the nitrifying aerobacters (*Nitrosomonas* and *Nitrobacter*) is likely the source of the great amount of nitrate in the shallow ground water.

Under the Undrained Argentine Bahia Grass Plot

Under the undrained argentine bahia grassed plot, the most pronounced chemical changes in ground water from site AB-1 (fig. 3) were increases in pH and total phosphorus in the upper 10 ft of the aquifer, and an increase in chloride and total coliform concentrations at all depths (tables 6 and 7), compared to pre-irrigation conditions at sites CB-1 and CB-2 (table 2).

Chloride concentrations in ground water from the 2-, 5-, 10-, and 15-ft depths of AB-1 were similar to that in the applied wastewater, but varied throughout both tests from a low of 83 mg/L in a sample from a depth of 2 ft, to a high of 220 mg/L in a sample from a depth of 5 ft.

The pH increased in ground water from the 2- and 5-ft depth but remained similar to pre-irrigation values in samples from the 10- and 15-ft depth. The high pH (usually greater than 6) in samples from the 20-ft deep well probably reflects the increased amounts of shell fragments, as evidenced by increased calcium in water from that depth (see table 6).

At the start of the tests, total phosphorus was higher than pre-irrigation levels in the ground water from 2 ft and 5 ft below land surface, probably as a result of previous periods of irrigation of the site with wastewater. The total phosphorus concentration in ground water from 2 ft below land surface increased to more than 5 mg/L by the conclusion of the tests. The total phosphorus concentration also increased at the 5-ft depth during the latter part of the irrigation period of 4 in. per week. At a depth of 10 ft or greater, total phosphorus decreased or remained less than the maximum pre-irrigation value of 1.4 mg/L.

Nitrate concentration was negligible in ground water from all depths except in a sample collected from the 2-ft deep well during the middle of the irrigation period of 4 in. per week. The sample contained 0.76 mg/L of nitrogen.

Ammonia concentrations in ground water from the 2- and 5-ft deep wells were similar to pre-irrigation concentrations throughout the irrigation period. However, in ground-water samples from 10 and 15 ft below land surface, ammonia increased.

Organic-nitrogen and organic-carbon concentrations in most of the ground-water samples from all depths below the land surface at site AB-1 remained near pre-irrigation levels at the conclusion of the test. Thus,

Table 6.--Chemical analyses of ground water from site AB-1

[Concentrations are in milligrams per liter except where noted. All analyses are by the U.S. Geological Survey.]

Sampling site	Depth sampled	Rate (in. per week)	Date of collection	Calcium (Ca), dissolved	Chloride (Cl), dissolved	Phosphorus, total as P	Nitrate, total as N	Nitrogen, ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Carbon, organic total	pH
AB-1	2 ft	-	7-03-73									
		2	8-15-73	26	83	2.0	0.00	0.42	2.0	2.4	51	5.8
		2	9-12-73	36	110	1.2	0.00	.13	1.6	1.7	25	6.3
		2	10-15-73	38	110	1.9	.05	.14	1.5	1.7	32	6.5
		4	11-15-73	45	150	2.2[b]	0.00	.34	.48	.82	20	---
		4	12-13-73	--	190	2.8	.76	.31	1.2	2.3	--	6.4
		4	1-23-74	51	130	5.2	0.00	.37	1.3	1.7	26	6.2
AB-1	5 ft	-	7-03-73									
		2	8-15-73	33	220	3.3	0.00[a]	1.1	2.3	3.4	56	6.1
		2	9-12-73	26	120	2.3	0.00	.37	2.1	2.5	43	5.9
		2	10-15-73	28	110	1.6	0.00	.26	1.7	2.0	42	6.2
		4	11-15-73	34	140	1.3[b]	0.00	.90	.69	1.6	27	---
		4	12-13-73	--	170	1.7	.04	.60	1.1	1.7	--	6.2
		4	1-23-74	42	180	2.9	0.00	.71	1.4	2.1	71	5.9

Table 6.--Chemical analyses of ground water from site AB-1 - continued

Sampling site	Depth sampled	Rate (in. per week)	Date of collection	Calcium (Ca), dissolved	Chloride (Cl), dissolved	Phosphorus, total as P	Nitrate, total as N	Nitrogen, ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Carbon, organic total	pH
AB-1	10 ft	-	7-03-73	2.6	130	4.6	0.00	5.0	1.6	6.6	69	3.9
		2	8-15-73	2.2	170	3.2	0.00	3.8	2.4	6.2	45	3.5
		2	9-12-73	2.4	180	3.0	0.00	2.5	1.5	4.0	59	3.5
		2	10-15-73	2.3	120	3.7	0.00	2.4	2.3	4.7	69	3.6
		4	11-15-73	1.2	180	3.6	0.00	2.7	2.6	5.3	92	---
		4	12-13-73	---	110	2.6	0.00	2.0	1.2	3.2	--	3.7
		4	1-23-74	1.8	150	1.7	0.00	2.0	1.3	3.3	58	3.5
AB-1	15 ft	-	7-03-73	1.5	110	0.95	0.00	2.9	1.4	4.3	60	4.0
		2	8-15-73	1.3	120	.24	0.00	3.6	.53	4.1	20	3.8
		2	9-12-73	1.0	160	.27	0.00	2.9	1.1	4.0	28	3.6
		2	10-15-73	2.2	170	.53	0.00	3.8	.79	4.6	38	3.5
		4	11-15-73	1.8	130	.47	0.00	3.2	1.1	4.3	36	---
		4	12-13-73	---	110	.24[a]	0.00	2.8[a]	4.1[a]	6.9	--	3.7
		4	1-23-74	---	130	.18[ab]	0.00	3.4[a]	1.4	4.8	44	3.5

Table 6.--Chemical analyses of ground water from site AB-1 - continued

Sampling site	Depth sampled	Rate (in. per week)	Date of collection	Calcium (Ca), dissolved	Chloride (Cl), dissolved	Phosphorus, total as P	Nitrate, total as N	Nitrogen, ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Carbon, organic total	pH
AB-1	20 ft	-	7-03-73	98	77	0.9	0.00	1.6	0.87	2.5	93	6.7
		2	8-15-73	83	64	.98	0.00	1.7	.83	2.5	47	6.5
		2	9-12-73	87	60	.42	0.00	1.2	1.1	2.3	58	6.5
		2	10-15-73	64	72	.69	0.00	1.4	.59	2.0	53	6.7
		4	11-15-73	83	55	.68	0.00	1.8	.83	2.6	52	6.2
		4	12-13-73	--	48	1.10[b]	0.00	1.2[a]	2.80[a]	4.0	--	6.5
		4	1-23-74	--	34	.33[b]	0.00	1.1	.91	2.0	33	5.6

a = Dissolved values only (too turbid).

b = Orthophosphate.

Table 7.--Bacterial analyses of ground water and soil from site AB-1

[All analyses are by the U.S. Geological Survey.]

Sampling site	Depth sampled	Rate (in. per week)	Date of collection	Total coliform colonies per 100 mL	Fecal coliform colonies per 100 mL	*Nitrosomonas*	*Nitrobacter*	Denitrifiers
				GROUND WATER		(Values are most probable number per 100 milliliters)		
AB-1	2 ft	2	8-14-73	900	110	--	--	--
		2	9-12-73	740	<1	--	--	--
		2	10-16-73	100	2	230	150	9300
		4	11-15-73	123	<1	--	--	--
		4	12-13-73	720	2	--	--	--
		4	1-23-74	1300	<1	--	--	--
AB-1	5 ft	2	8-14-73	19	<1	--	--	--
		2	9-12-73	73	3	--	--	--
		2	10-16-73	20	<1	23	150	2100
		4	11-15-73	22	<1	--	--	--
		4	12-13-73	440	<1	--	--	--
		4	1-23-74	930	2	--	--	--

Table 7.--Bacterial analyses of ground water and soil from site AB-1 - continued

Site sampled	Depth sampled	Rate (in. per week)	Date of collection	Total coliform colonies per 100 mL	Fecal coliform colonies per 100 mL	*Nitrosomonas*	*Nitrobacter*	Denitrifiers
				SOIL				
						(Values are most probable number per gram of sample, dry weight)		
AB-1	0 ft	-	7-05-73	--	--	98,000	190,000	980,000
		2	8-17-73	--	--	290,000	25,000	27,000
		2	10-18-73	--	--	600,000	15,000,000	130,000
		4	1-28-74	--	--	5,000,000	1,300,000	4600
AB-1	1 ft	-	7-05-73	--	--	410	110,000	25,000
		2	8-17-73	--	--	11,000	<3600	--
		2	10-18-73	--	--	120,000	6,200,000	160,000
		4	1-28-74	--	--	29,000	5100	11,000
AB-1	2 ft	-	7-06-73	--	--	<350	1,700,000	2400
		2	8-17-73	--	--	<3900	<3900	--
		4	1-28-74	--	--	12,000	12,000	12,000
AB-1	3 ft	-	7-05-73	--	--	510	5500	510

Table 7.--Bacterial analyses of ground water and soil from site AB-1 - continued

Site sampled	Depth sampled	Rate (in. per week)	Date of collection	Total coliform colonies per 100 mL	Fecal coliform colonies per 100 mL	Nitrosomonas	Nitrobacter	Denitrifiers
AB-1	10 ft	-	7-03-73	160	<1	<300	24,000	15,000
		2	8-14-73	8	<1	--	--	--
		2	9-12-73	<1	<1	--	--	--
		2	10-16-73	<1	<1	30	30	4300
		4	12-13-73	<1	<1	--	--	--
		4	1-23-74	77	<1	30	30	40
AB-1	15 ft	-	7-03-73	13	<1	--	--	--
		2	8-15-73	440	<1	--	--	23,000
		2	9-12-73	70	<1	--	--	--
		2	10-16-73	<1	<1	<30	<30	210
		4	11-15-73	3	<1	--	--	--
		4	12-14-73	15	-	--	--	--
		4	1-23-74	14	<1	--	--	--
AB-1	20 ft	-	7-05-73	22	-	--	--	--
		2	8-15-73	10	<1	--	--	--
		2	9-12-73	1	<1	--	--	--
		2	10-17-73	3	<1	--	--	--
		4	11-16-73	3	<1	--	--	--
		4	12-14-73	270	<1	--	--	--
		4	1-24-74	8	<1	--	--	--

irrigation of the undrained plot resulted in more extensive nitrogen removal from the wastewater than did irrigation of the drained plot.

Concentrations of total coliform bacteria (table 7) increased over pre-irrigation concentrations in ground water from all depths. Concentration of total coliforms was highest (1,300 col/100 mL) in ground water from the 2-ft deep well and generally decreased with depth. Fecal coliform bacteria were detected in several samples from the 2-ft and 5-ft depths with counts ranging from 110 col/100 mL to less than 1 col/100 mL. Below 5 ft, no fecal coliforms were detected.

In both soil and water samples from site AB-1, numbers of nitrifying and denitrifying bacteria (table 7) were greater than concentrations at site BG-1 (table 14), outside the site. Soil samples had the highest concentrations of nitrifying and denitrifying bacteria (tables 7 and 14).

Downgradient from the Irrigated Site

Data from well sites CB-2 (tables 8 and 10) and CB-4 (tables 9 and 10) were used to evaluate changes in ground water downgradient from drained and undrained plots, respectively (fig. 3) by comparison with pre-irrigation data from wells CB-1 and CB-2. Samples were collected from depths of 5, 10, and 15 ft before and during irrigation periods.

Downgradient from the drained plot at CB-2, chloride concentration increased and ranged from 90 to 140 mg/L in all samples from the 5- and 10-ft depths (table 8). There were no pronounced changes in pH, total phosphorus, total nitrogen or organic carbon. Total nitrogen, total phosphorus and organic carbon concentrations were generally lower than pre-irrigation levels.

Downgradient from the undrained plot, at site CB-4, samples from all depths indicated small increases in pH, and pronounced increases in chloride concentration. Ammonia concentrations in samples from the 10- and 15-ft deep wells increased slightly compared to pre-irrigation levels, but all other constituents sampled were near or below pre-irrigation values (table 9).

Downgradient from both plots, total coliform organisms were detected in samples from 5-, 10- and 15-ft deep wells (table 10). Also, fecal coliforms were detected in ground water 10 ft below land surface.

Table 8.--Chemical analyses of ground water from site CB-2

[Concentrations are in milligrams per liter except where noted. All analyses are by the U.S. Geological Survey.]

Sampling site	Depth sampled	Date of collection	Calcium (Ca), dissolved	Chloride (Cl), dissolved	Phosphorus, total as P	Nitrate, total as N	Nitrogen, ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Carbon, organic total	pH
CB-2	5 ft	7-03-73	7.4	110	0.31	0.00	0.67	0.69	1.4	27	4.1
		8-15-73	14.0	130	.25	0.00	.52	.71	1.2	18	3.7
		10-15-73	14.0	140	.31	0.00	.50	.83	1.3	29	---
		1-23-74	13.0	140	.51	0.00	.48	.69	1.2	24	3.5
CB-2	10 ft	7-03-73	9.8	110	0.17	0.00	0.66	0.71	1.4	18	3.5
		8-15-73	8.0	130	.10	0.00	.62	1.9	2.5	14	3.5
		10-15-73	5.2	90	.21	0.00	.39	2.1	2.5	94	---
		1-23-74	8.4	120	.13	0.00	.46	.79	1.2	25	3.2
CB-2	15 ft	8-15-73	4.2	29	0.27	0.00	1.0	0.72	1.7	25	4.5
		10-15-73	5.4	32	.26	0.00	.61	.58	1.2	21	---
		1-23-74	5.4	32	.26	0.00	.67	.69	1.4	19	3.8

Table 9.--Chemical analyses of ground water from site CB-4

[Concentrations are in milligrams per liter except where noted. All analyses are by the U.S. Geological Survey.]

Sampling site	Depth sampled	Date of collection	Calcium (Ca), dissolved	Chloride (Cl), dissolved	Phosphorus, total as P	Nitrate, total as N	Nitrogen, ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Carbon, organic total	pH
CB-4	5 ft	8-15-73	22.0	220	2.0	0.30	0.06	1.9	2.3	10	3.6
		10-15-73	10.0	100	1.0	0.00	.18	.90	1.1	16	---
		1-23-74	2.0	---	.55	0.00	1.0	1.1	2.1	42	4.2
CB-4	10 ft	7-23-73	40.0	130	0.12	0.00	2.1	1.2	3.3	25	3.1
		8-15-73	7.5	140	.20	0.00	2.1	.48	2.6	14	3.4
		10-15-73	9.6	140	.19	0.00	1.7	1.6	3.3	14	---
		1-23-74	4.4	120	1.3	0.00	1.5	.86	2.4	24	4.0
CB-4	15 ft	7-03-73	14.0	150	0.21	0.00	2.8	0.54	3.3	14	3.8
		8-15-73	8.4	140	.32	0.00	2.2	.51	2.7	13	3.9
		10-15-73	7.2	120	.40	0.00	1.9	.27	2.2	20	---
		1-23-74	8.1	120	.32	0.00	.19	.74	.93	21	4.4

Table 10.--Bacterial analyses of ground water from sites CB-2 and CB-4

[All analyses are by the U.S. Geological Survey.]

Site sampled	Depth sampled	Date of collection	Total coliform colonies per 100 mL	Fecal coliform colonies per 100 mL
CB-2	5 ft	7-05-73	<1	<1
		8-13-73	<1	<1
		1-26-74	370	-
CB-2	10 ft	7-05-73	12	7
		8-13-73	14	<1
		10-15-73	<1	<1
		1-26-74	1200	33
CB-2	15 ft	8-13-73	170	<1
		10-15-73	7	<1
		1-26-74	--	<1
CB-4	5 ft	8-13-73	77	<1
		10-15-73	7	<1
		1-26-74	43	<1
CB-4	10 ft	7-05-73	1	<1
		8-13-73	5	<1
		10-15-73	<1	<1
		1-26-74	14	<1
CB-4	15 ft	7-05-73	3400	<1
		8-13-73	<1	<1
		10-15-73	--	<1
		1-26-74	16	<1

Changes in the Effluent from the Drains

Samples of the effluent from the subsurface drains underlying part of the site were collected at a weir downgradient from the site (table 11 and fig. 3) during the irrigation periods. Compared to the applied wastewater, the drain effluent was generally lower in pH, higher in concentrations of total phosphorus and organic carbon, and similar in chloride concentration.

The greatest differences between the treated wastewater and the effluent from the drain were in concentrations of nitrogen species. For example, the effluent from the drains contained more nitrate and less ammonia, organic nitrogen and total nitrogen (table 11). Total nitrogen in the effluent from the drains doubled (from a maximum of 2.0 to 5.2 mg/L) after the irrigation rate was increased from 2 to 4 in. per week.

Total coliform counts in the drain effluent ranged from 35 to 7,000 col/100 mL during the irrigation periods (table 12). Fecal coliform counts in the drain effluent ranged up to 547 col/100 mL. Pathogen-indicating bacteria moved downward through 5 ft of soil and into the drains. The number of bacteria in the effluent from the drains was higher than the number in the applied wastewater, indicating that conditions at the soil were favorable for the growth and multiplication of at least some of the total coliform organisms.

Concentrations of Nitrosomonas, Nitrobacter, and denitrifiers increased markedly over the corresponding values in ground water from the 10-ft deep background well BG-1 (table 14). Samples of the drain effluent contained high concentrations of Nitrosomonas and Nitrobacter.

Changes Upgradient from the Irrigated Site

The ground water in the shallow aquifer outside the site was sampled at site BG-1 before and during the irrigation periods. The data are shown in tables 13 and 14. The major changes in water quality detected during the entire study were decreases in total phosphorus and organic carbon.

Total coliform organisms were detected in samples from the well BG-1 twice during the irrigation periods (table 14). The concentrations were 50 col/100 mL and 11 col/100 mL. Fecal coliform organisms were not detected in samples from the well.

Nitrosomonas and Nitrobacter concentrations were 400 MPN/100 mL or less at the well (BG-1), outside the site, during both irrigation periods. Concentrations of denitrifiers were less than 3,000.

Table 11.--Chemical analyses of the drain effluent

[Concentrations are in milligrams per liter except where noted. All analyses are by the U.S. Geological Survey.]

Sampling site	Date of collection	Rate (in. per week)	Calcium (Ca), dissolved	Chloride (Cl), dissolved	Phosphorus, total as P	Nitrate, total as N	Nitrogen, ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Carbon, organic total	pH
Drain	7-03-73										
	8-15-73	2	88	96	2.6	1.6	0.68	2.6	4.9	29	7.1
	9-12-73	2	84	96	2.3	1.8	.58	1.9	4.5	48	7.0
	10-15-73	2	88	100	1.8	2.0	.24	1.3	3.6	--	6.8
	11-15-73	4	85	140	2.8	5.2	.81	1.6	7.6	20	---
	12-13-73	4	--	150	3.1	4.7	2.3	1.2	8.3	--	6.8
	1-23-74	4	78	110	3.2[a]	4.9	.96	1.0	6.9	15	6.0

a = Orthophosphate only.

Table 12.--Bacterial analyses of the drain effluent

[All analyses are by the U.S. Geological Survey.]

Site sampled	Date of collection	Total coliform colonies per 100 mL	Fecal coliform colonies per 100 mL	*Nitrosomonas* most probable number per 100 mL	*Nitrobacter* most probable number per 100 mL	Denitrifiers most probable number per 100 mL
Drain	8-16-73	190	<1	24,000	2300	9000
	9-12-73	35	2	--	--	--
	10-18-73	90	2	4300	21,000	1500
	11-16-73	350	<1	--	--	--
	12-12-73	7000	547	--	--	--
	1-25-74	270	5	11,000,000	93,000	300

Table 13.--Chemical analyses of the ground water from site BG-1

[Concentrations are in milligrams per liter except where noted. All analyses are by the U.S. Geological Survey.]

Site sampled	Depth sampled	Date of collection	Calcium (Ca), dissolved	Chloride (Cl), dissolved	Phosphorus, total as P	Nitrate, total as N	Nitrogen, ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Carbon, organic total	pH
BG-1	10 ft	7-03-73	1.1	8.5	1.1	0.00[a]	0.94[a]	1.9	2.8	124	4.0
		8-15-73	1.0	8.0	.47[ab]	0.00[a]	.91[a]	---	---	59	4.2
		10-15-73	3.2	9.4	.51	0.00	.61	1.6	2.3	66	4.0
		12-13-73	---	---	.57	0.00	1.1[a]	1.9[a]	3.0	--	4.1
		1-23-74	1.0	---	.52	0.00[a]	1.2[a]	1.0	2.2	54	4.0

a = Dissolved value only (too turbid).

b = Orthophosphate only.

Table 14.--Bacterial analyses of ground water and soil from site BG-1

[All analyses are by the U.S. Geological Survey.]

Site sampled	Depth sampled	Date of collection	Total coliform colonies per 100 mL	Fecal coliform colonies per 100 mL	*Nitrosomonas*	*Nitrobacter*	Denitrifiers
GROUND WATER							
					(Values are most probable number per 100 mL)		
BG-1	10 ft	7-05-73	1	<1	<300	400	<3000
		8-16-73	50	<1	<300	<300	<30
		10-18-73	<1	<1	<30	<30	<30
		1-25-74	11	<1	<30	<30	110
SOIL							
					(Values are most probable number per gram of sample, dry weight)		
BG-1	0 ft	8-16-73	--	-	90	450	9400
		10-18-73	--	-	<310	920	2000
		1-24-74	--	-	4300	240,000	94,000
BG-1	1 ft	1-24-74	--	-	2400	110,000	2900
BG-1	2 ft	1-24-74	--	-	<340	2600	2600
BG-1	3 ft	1-24-74	--	-	<370	5200	<370

SUMMARY AND CONCLUSIONS

The wastewater applied to the study site was alkaline, and increased the pH of the shallow ground water. As soil water pH increased after irrigation commenced, the humate was dissolved and mobilized by changes in the physical-chemical nature of the soil-water environment. The humate, because of its solubility in alkaline waters, is taken to be a source of some of the phosphorus in the effluent from drains under part of the site, and also a source of the phosphorus in ground water throughout the site. Effects such as increases in nitrogen and carbon, if they occurred, were probably masked by the high concentration of nitrogen and carbon in the applied wastewater, and the biological transformations naturally occurring in the soil system.

Nitrate is a very soluble form of nitrogen and is mobile in the ground water. However, under anaerobic (reducing) conditions, denitrifying bacteria are capable of rapidly reducing large amounts of nitrate to nitrogen gases. Several other complex reactions involving organic nitrogen compounds and small amounts of inorganic compounds occur in the soils concurrently, but are of minor importance in consideration of the major nitrogen-removal mechanisms.

Irrigation of the drained plot resulted in poor nitrogen removal owing to the rapid passage of the wastewater through the upper 5 ft of drained soil and into the drains. In that zone, the major phenomenon (especially at the 4-in.-per-week rate) was extensive oxidation of ammonia and some organic nitrogen in the wastewater to nitrate, where it was detected in high concentrations (as much as 15 mg/L) in the shallow ground water near the drains, and in the drain effluent. Rapid percolation prevented complete denitrification.

Conversely, irrigation of the undrained plot at a rate of as much as 4 in. per week resulted in more extensive nitrogen removal. Under that plot, no nitrate was detected. Ammonia concentrations increased to a maximum of 3.8 mg/L at a depth of 15 ft below land surface, and total nitrogen increased to a maximum of 6.9 mg/L at the same depth.

The undrained plot of argentine bahia grass was saturated with water to within a few inches of the surface during irrigation. Irrigation of 4 in. per week, coupled with only moderate rainfall, was nearly the maximum amount of water that the plot could accept weekly without extensive surface ponding. But the absence of drains and the frequent cyclic saturation of the soil in that plot slowed the percolating wastewater, permitting the processes of sorption, nitrification, and denitrification to remove nitrogen more effectively.

At no time during or after irrigation did total nitrogen or phosphorus concentrations increase in ground water downgradient from either plot. The minor changes in concentrations of ammonia and organic nitrogen noted are not attributed to either soil processes or to dilution.

The sprinkler irrigation of the grass-covered site, using chlorinated, secondary-treated wastewater, resulted in an enrichment of the nitrifying and denitrifying bacteria on the site. High concentrations of the aerobic, nitrifying bacteria, Nitrosomonas and Nitrobacter, were detected within the irrigated area. The concentrations of nitrifying and denitrifying bacteria were highest at the soil surface and decreased greatly below a depth of 2 ft, implying a large scale conversion of ammonium to nitrate in the soil within 2 ft of land surface.

Comparisons of chloride concentrations showed that dilution by native ground water was not sufficient to explain the reduction in total nitrogen in the upper 10 ft of the shallow aquifer. Therefore, denitrification may account for a significant part of the reduction in total nitrogen in wastewater applied to the site.

Prior to irrigation with the treated wastewater, total coliforms were not detected in ground-water samples from the site. After irrigation there were total coliforms and fecal coliforms in the soil and ground water throughout the site. Coliforms were also detected downgradient from the site.

This experience suggests that an irrigation rate of 4 in. per week was about the maximum desirable at the study site, and that installation of drain tiles to permit increased irrigation rates probably will result in inadequate reduction of nitrogen and phosphorus in the applied wastewater.

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CONVERSION FACTORS

For use of those readers who prefer to use metric units rather than U.S. inch-pound units, the conversion factors for the terms used in this report are listed below:

U.S. inch-pound units	Multiply by	To obtain metric units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectares (ha)
gallon (gal)	0.0038	cubic meter (m^3)
foot per day (ft/d)	0.3048	meter per day (m/d)