WASTEWATER APPLICATION BY SPRAY IRRIGATION ON A FIELD SOUTHEAST OF TALLAHASSEE, FLORIDA: EFFECTS ON GROUND-WATER QUALITY AND QUANTITY, 1980-82

By John F. Elder, James D. Hunn, and Calvin W. Calhoun

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CONVERSION FACTORS

The inch-pound units used in this report may be converted to metric units (SI) by the following conversion factors:

Multiply inch-pound unit	By	To obtain metric (SI) unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
acre	0.4047	hectare (ha)
mile (mi)	1.609	kilometer (km)
gallon (gal)	3.785	liter (L)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)

* *

Temperature units are converted from degrees Fahrenheit (°F) to degrees Celsius (°C) by the formula °C = 5/9 (°F - 32); from degrees Celsius to degrees Fahrenheit by the formula °F = 9/5 (°C + 32).

* *

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ABSTRACT

An 1,840-acre agricultural field southeast of Tallahassee, Florida, which has been used for land application of wastewater by spray irrigation, is the site of a long-term, ground-water monitoring study. The purpose of the study is to determine effects of wastewater application on water-table elevations and ground-water quality. The study was conducted in cooperation with the City of Tallahassee. This report summarizes the findings for the period 1980-82.

Wastewater used for spray irrigation has high concentrations, relative to those in ground water, of chloride, nitrogen, phosphorus, organic carbon, coliform bacteria, sodium, and potassium. At most locations, percolation through the soil has been quite effective in attenuation of these substances before they can impact the ground water. However, increases in chloride and nitrate-nitrogen were evident in ground water in some of the monitoring wells during the study, especially those wells which are within the sprayed areas. Chloride concentrations, for example, increased from approximately 3 milligrams per liter to 15 to 20 milligrams per liter in some wells and nitrate-nitrogen concentrations increased from less than 0.5 milligrams per liter to 4 milligrams per liter or more.

Ground-water levels in the area of the spray field fluctuated over a range of several feet. These fluctuations were affected somewhat by spray irrigation, but the primary control on water levels was rainfall.

As of December 1982, constituents introduced to the system by spray irrigation of effluent had not exceeded drinking water standards in the ground water. The system has not yet stabilized, however, and more changes in ground-water quality may be expected.

INTRODUCTION

Application of wastewater to land is a relatively common method of wastewater disposal. The practice is certainly not new to the field of sanitary engineering; successful and long-term irrigation systems begun many centuries ago in Europe have been reported (Thomas, 1973). In the United States, wastewater irrigation has been used since the late 1800's, especially in the west, where the resource value of wastewater provides additional incentive (U.S. Environmental Protection Agency and others, 1977). As quantities of wastewater have increased substantially during this century, the problems of its disposal have multiplied, and the land-application approach has become more popular. Land treatment may be accomplished in any of three ways--irrigation, overland flow, or rapid infiltration--and its successful implementation in a number of municipalities demonstrates its viability (Wright and Rovey, 1979).

There are several advantages of land application of wastewater (Sheaffer, 1979). Three benefits are wastewater disposal, crop fertilization, and water conservation. Land application also offers the advantage of being a convenient and relatively inexpensive treatment process. Because the vegetation and soils provide a natural filter system, extensive pretreatment of wastewater is theoretically not necessary before the wastewater is applied to the land. Wastewater is applied to land commonly after secondary treatment, and is often used as a substitute for the expensive tertiary treatment process (Franks, 1981).

Although repeated implementation has demonstrated its feasibility, land application is not without potential problems (Johnson, 1979). Primary and secondary treatment systems are designed primarily to reduce the levels of suspended solids, biochemical oxygen demand, and pathogenic organisms, but may leave relatively high concentrations of nutrients, some metals, and some bacteria and viruses. Some of these constituents are likely to be stripped from the water as it percolates past plant roots and through the soil. Others, however, may be only partially or temporarily bound by the plants and soil particles, with the result that leaching into the ground water can occur. Nitrate-nitrogen, for example, is extremely soluble and if there is an excess beyond that which can be utilized by the plants, it may be transported rapidly through the soils and into the ground water. As an anion, nitrate does not participate in ion-exchange reactions with the soil. Metals are much less soluble. Because of their cationic nature, they can be removed by chelation, precipitation-filtration, and ion exchange, and they tend to be quickly sorbed to soil particles (Iskandar, 1975). Retention of metals in the upper 10 inches of soil seems to be the general rule, regardless of soil characteristics (Brown and others, 1983). However, there may be a limit to the metal load which can be adsorbed, and if that is exceeded by heavy or continual loading, the result may be a gradual movement of the pollutants down through the soil horizons, eventually to reach the water table.

Bacterial contamination of ground water can be a serious problem, contributing to outbreaks of waterborne disease (Allen and Geldreich, 1975). Although mobility of organisms is limited in fine to medium substrates by straining, adsorption, and die-off, there have been reports of transportation of sewage-derived bacteria over distances of several hundred feet (Wesner and Baier, 1970).

History of Wastewater Application in Tallahassee

Spray irrigation of secondary-treated sewage from the city wastewater treatment plant was initiated in Tallahassee, Fla., in 1966. Two spray fields have been used (fig. 1). Until 1980, spray irrigation was limited to a 120-acre field southwest of the city and adjacent to the Thomas P. Smith Wastewater Treatment Facility (fig. 2). A number of test wells were installed in and around the field and, beginning in 1972, the U.S. Geological Survey, in cooperation with the City of Tallahassee, monitored water levels and quality of ground water. Two reports published earlier (Slack, 1975; Yurewicz, 1983) give the results of that monitoring program. Additional information about the Tallahassee spray irrigation project was given by Overman (1979) and Franks (1981).

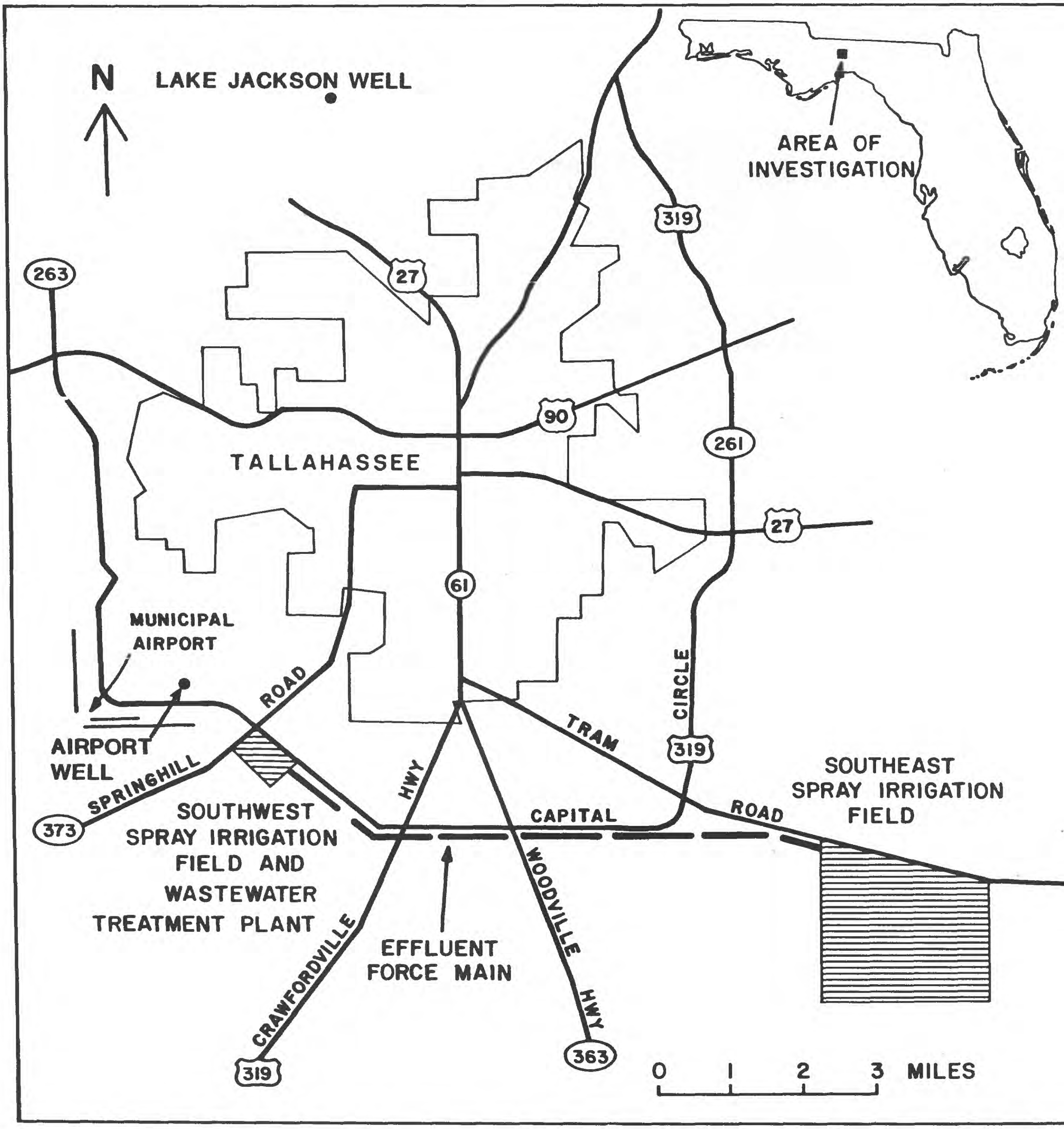


Figure 1.--Locations of the Thomas P. Smith Wastewater Treatment facility and the southwest and southeast spray fields near Tallahassee, Florida.

Figure 2.--Sewage treatment plant and the southwest spray field.

A new spray field southeast of Tallahassee began receiving land application of wastewater in November 1980. This field (fig. 3) is much larger than the southwest spray field, having an area of 1,840 acres. The western and central areas of the field (1,090 acres) have been irrigated primarily through a system of seven central-pivot spray units (fig. 4). The field has been planted with sorghum and livestock feed corn since irrigation began, and although initial corn yields were low due to the poor soil fertility, yields have steadily increased, indicating at least some success in the fertilizing effect of the spray irrigation program. For 28 months, the eastern part of the field (750 acres) received only a limited amount of overflow spray. It was not irrigated routinely until March 1982.

The southeast field is operated as a full-scale farm by a farmer on contract with the City of Tallahassee. Fertilizers, pesticides, and herbicides are used as needed. No-till farming is the method chosen by the farmer.

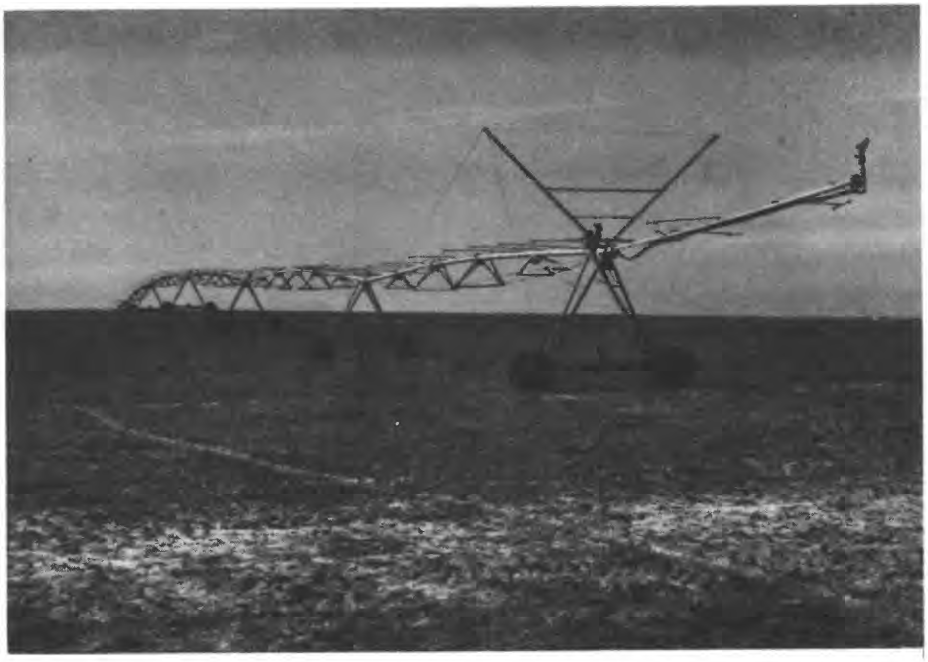
The initiation of spray irrigation at the southeast field, 8.5 miles from the original field, provided the City of Tallahassee an opportunity to acquire baseline data in the spray area prior to and during irrigation. Such a before-and-after type of investigation had not been accomplished at the southwest field because the ground-water monitoring did not begin until 6 years after spray irrigation began. The City intends to continue the spray-irrigation method of wastewater disposal indefinitely, provided that it does not result in serious damaging effects on ground-water quality. Wastewater disposal will be gradually shifted from the southwest field, where the program began, to the new southeast field.

Figure 3.--The southeast spray field.

Terminology and Numbering System

Throughout this report, wells will be referred to by numbers or letters corresponding to the numbers shown in figure 5. Also shown are the circled numbers which are assigned to the individual central-pivot spray units. The western half of the field, containing pivots numbered 1 through 7, is the section which has been irrigated since November 1980 and where crop farming has been done. The eastern half, containing pivots 8 through 11 was not irrigated until March 1982 and, as of the end of 1982, had not been planted. The wells in that section, numbers 37 through 49, were installed in 1981 and not sampled until 1982. Because of these major differences in the two halves of the field, data analysis has been done separately for each. For convenience, the two areas will be termed "area A," meaning the western half, or pivots 1 through 7, and "area B," meaning the eastern half, or pivots 8 through 11.

Each well is also identified by a site identification number (table 1) based on the grid system of latitude and longitude. This 15-digit number provides the geographic location of the well and is unique for each site. The first six digits denote the degrees, minutes, and seconds of latitude, the next seven digits denote degrees, minutes, and seconds of longitude, and the last two digits comprise a sequential number for sites within a 1-second grid.



4A.--Close-up view.

4B.--Unit in operation.

Figure 4.--Central-pivot spray unit.

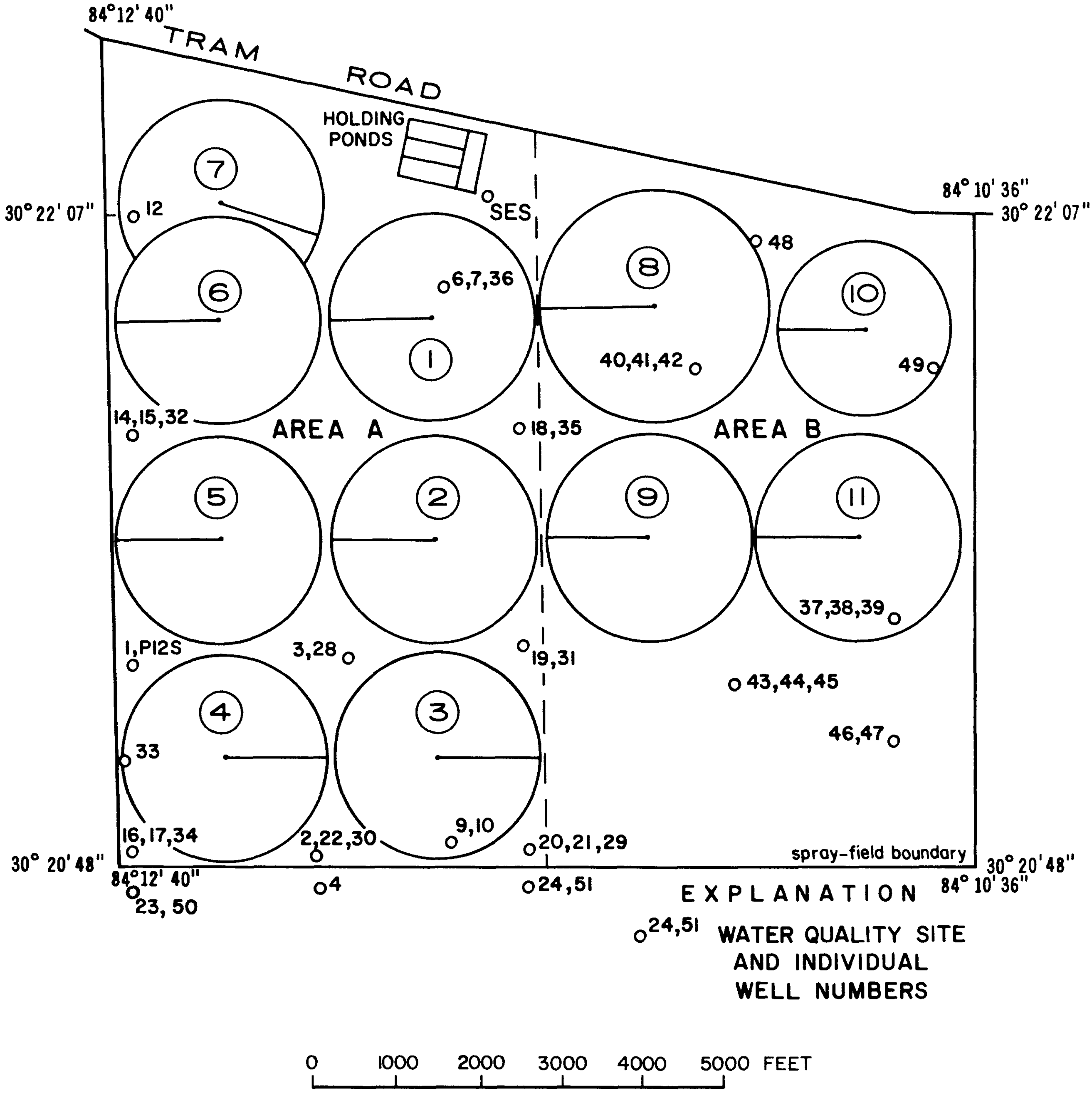


Figure 5.--Southeast spray field showing numbered well sets and center-pivot irrigation system. Area A = western half (pivots 1-7). Area B = eastern half (pivots 8-11).

Objectives

In 1980, the U.S. Geological Survey began a cooperative project with the City of Tallahassee to assess the effects of wastewater spray irrigation on ground-water quality and hydrologic features of the southeast spray field. This report presents the results of the first 3 years of data collection (1980-82).

The objectives of the study were:

1. To describe the hydrogeology and the effects of spray irrigation on the local ground-water-flow system;

2. To determine changes over time in ground-water quality, both vertically and horizontally.

The second objective is not completely fulfilled by the data presented in this report because the ground-water quality in and near the spray field area has not stabilized. Continuing data collection after 1982 will monitor further changes in the system.

Scope

The geographical area of the study is the southeast spray field and immediate vicinity (fig. 5). It does not deal with the southwest field, although some data from that field are presented for comparative purposes. To achieve perspective, it is also useful to compare the Tallahassee data with those reported for land-application programs in other areas. Some reference to other studies will therefore be presented.

Data collection at the southeast field began in November 1979 and continues at the present time (September 1983). This report is based on data from February 1, 1980, through December 31, 1982. Special attention was paid to trends, both in the hydrologic characteristics and the water quality of the aquifer at the southeast spray field.

Water-quality properties and constituents, which have been monitored, include temperature, pH, specific conductance, nutrients, major cations and anions, heavy metals, and fecal bacteria (coliform and streptococci). The program did not include a study of viruses or organic substances, other than measurement of dissolved organic carbon. Hydrologic information is based on water-level measurements at each monitoring well, coinciding with each water sample taken, and continuous recording of water levels at one central well (well 3).

Acknowledgments

The authors express their appreciation to City of Tallahassee personnel, especially Thomas P. Smith, Director of Underground Utilities, and William G. Leseman, Director of the Water-Quality Laboratory, for their support of this study. Mr. Leseman also critically reviewed the manuscript.

METHODS

Installation of Monitor and Test Wells

Monitor wells used in the Tallahassee southeast spray-irrigation field monitor three principal zones of depth: deep wells (150-250 feet deep), intermediate wells (40-149 feet), and shallow wells (10-39 feet). Most wells are located near or around the eleven spray-irrigation pivots in the spray field (fig. 5). Table 1 lists physical characteristics of these wells. All wells except numbers 28-36 are deep or intermediate and tap the Upper Floridan aquifer. The shallow wells are sampled with a bailer; the deep and intermediate wells are sampled with a pump. Most wells have permanently installed pumps (fig. 6).

The deep and intermediate wells were installed by reverse rotary and cable-tool methods. After setting steel or PVC casing, the wells were grouted to land surface. The shallow wells were installed by hand or power augering. Samples of cuttings from wells 2-7, 9, 10, 12, 14-24, 37-49, and 51 were examined for lithology. Gamma ray logs were run on wells 2-7, 9, 10, 12, 14-24, 37, 40, 43, 46, 48, 49, 51, and SES.

Sampling and Analytical Techniques

Field Procedures

Six field measurements were made at each well as the water samples were collected. These include:

1. Water levels.--At least two tape measurements were taken at each well.

2. Pumping volume.--After making water-level measurements, but before sample collection, twice the volume of water in the casing of the well was pumped or bailed out.

3. Temperature.--Read to nearest half-degree Celsius, from pumped or bailed sample.

4. pH (hydrogen ion concentration).--Measured with a temperature-compensated meter readable to ±0.02 pH units.

5. Specific conductance.--Taken with a battery-operated meter equipped with temperature compensator and direct readout in microsiemens per centimeter (µs/cm) at 25°C (77°F).

6. Alkalinity.--Determined by using incremental method of titration.

Field measurement data, and information peculiar to each sample, were supplied with the sample to the appropriate laboratory. Samples were transported or shipped to the laboratory on the day that they were collected. Time-critical analyses were performed within allowable time limits either in the laboratory or in the field. All methods or techniques used conform to standard field and laboratory practices of the U.S. Geological Survey and its Central Laboratory.

Table 1.--Well descriptions

[Casing material: P, PVC; S, Steel. Finish: E, open end; H, open hole; "--", unknown; X, perforated of slotted. Aquifer tapped: F, Floridan; N, surficial]

Map No. (fig. 5)	Site identification No.	Altitude, in feet, of: Land surface	Altitude, in feet, of: Bottom of: Hole	Altitude, in feet, of: Bottom of: Casing	Altitude, in feet, of: Water level at drilling	Diameter of casing (inches)	Casing material	Finish	Aquifer tapped
1	302116084123701	20.38	- 50.62	- 36.63	13.07	4	S	E	F
2	302049084120901	26.05	- 19.95	- 15.95	12.94	4	S	--	F
3	302116084120701	42.02	- 19.98	- 11.18	16.69	4	S	H	F
4	302045084120901	27.57	- 19.43	- 14.63	16.49	4	S	H	F
5	302204084102401	40.00	- 85.00	- 82.10	24.00	4	S	H	F
6	302157084115101	50.16	- 69.84	- 51.84	14.51	8	S	H	F
7	302157084115102	51.11	-190.89	-163.49	14.88	4	S	--	F
9	302053084115101	36.99	- 15.01	- 13.61	13.22	4	S	--	F
10	302053084115102	39.20	- 93.80	- 84.80	-.-	4	S	--	F
12	302208084123801	46.56	- 8.44	- 4.44	-.-	4	P	E	F
14	302141084123601	35.44	- 15.56	11.56	-.-	4	P	H	F
15	302141084123602	34.80	- 75.20	- 60.70	-.-	4	S	--	F
16	302051084123502	29.84	- 40.16	- 30.16	-.-	4	P	--	F
17	302051084123501	31.38	- 91.62	- 81.12	-.-	4	S	H	F
18	302141084114001	59.44	- 3.56	7.44	11.44	4	S	H	F
19	302117084113801	46.88	- 27.12	- 4.42	-.-	4	S	--	F
20	302051084113802	29.92	- 23.08	- 19.68	-.-	4	P	H	F
21	302051084113801	30.22	-108.78	- 94.78	-.-	4	S	--	F
22	302051084120901	27.96	-107.04	- 85.04	-.-	4	P	--	F
23	302045084123701	32.48	- 26.52	- 15.52	-.-	4	P	--	F

Table 1.--Well descriptions--Continued

Map No. (fig. 5)	Site identification No.	Altitude, in feet, of: Land surface	Bottom of: Hole	Bottom of: Casing	Water level at drilling	Diameter of casing (inches)	Casing material	Finish	Aquifer tapped
24	302046084113801	24.55	- 33.45	- 31.45	-.-	4	P	--	F
28	302116084120702	42.05	18.30	--	-.-	2	P	X	N
29	302051084113803	30.21	7.87	7.87	12.94	2	P	X	N
30	302049084120902	27.19	12.04	12.04	-.-	2	P	X	N
31	302117084113802	46.16	21.37	21.37	-.-	2	P	X	N
32	302141084123603	34.94	12.94	12.94	-.-	2	P	X	N
33	302101084123701	26.95	9.70	9.70	-.-	2	P	X	N
34	302051084123503	31.02	8.52	8.52	-.-	2	P	X	N
35	302141084114002	59.02	16.18	16.18	-.-	2	P	X	N
36	302157084115103	49.43	9.49	9.49	-.-	2	P	X	N
37	302114084105201	32.17	-207.83	-158.83	7.17	4	S	E	F
38	302114084105202	32.73	- 82.27	- 68.27	12.73	4	S	E	F
39	302114084105203	32.28	- 40.72	- 30.72	11.28	4	S	H	F
40	302151084111901	47.20	-146.80	-116.80	12.20	4	S	--	F
41	302151084111902	47.27	- 86.73	- 72.73	12.27	4	S	--	F
42	302151084111903	47.84	- 17.16	4.84	12.84	4	S	--	F
43	302110084110601	40.30	-142.70	-133.70	5.30	4	S	--	F
44	302110084110602	41.67	- 78.33	- 67.33	1.67	4	S	--	F
45	302110084110603	42.39	- 29.61	- 12.61	7.39	4	S	--	F
46	302058084105101	27.41	-146.59	-143.59	9.41	4	S	--	F

Table 1.--Well descriptions--Continued

Map No. (fig. 5)	Site identification No.	Altitude, in feet, of: Land surface	Altitude, in feet, of: Bottom of: Hole	Altitude, in feet, of: Bottom of: Casing	Altitude, in feet, of: Water level at drilling	Diameter of casing (inches)	Casing material	Finish	Aquifer tapped
47	302058084105102	27.71	- 17.29	- 3.29	10.71	4	S	--	F
48	302203084110001	54.18	- 40.82	- 34.82	12.18	4	S	--	F
49	302150084103801	33.41	- 21.59	- 13.59	12.41	4	S	--	F
50	302045084123702	32.93	- 96.07	-.-	7.93	4	S	--	F
51	302046084113802	25.67	-144.33	-120.33	10.67	4	S	--	F
SES	302212084114401	46.61	-153.39	- 69.39	-.-	6	S	--	F
P12S	302117084123501	-.-	-.-	-.-	-.-	1-½	P	--	F
WCW	302253084142001	56.60	- 50.40	-.-	21.06	4	S	--	F

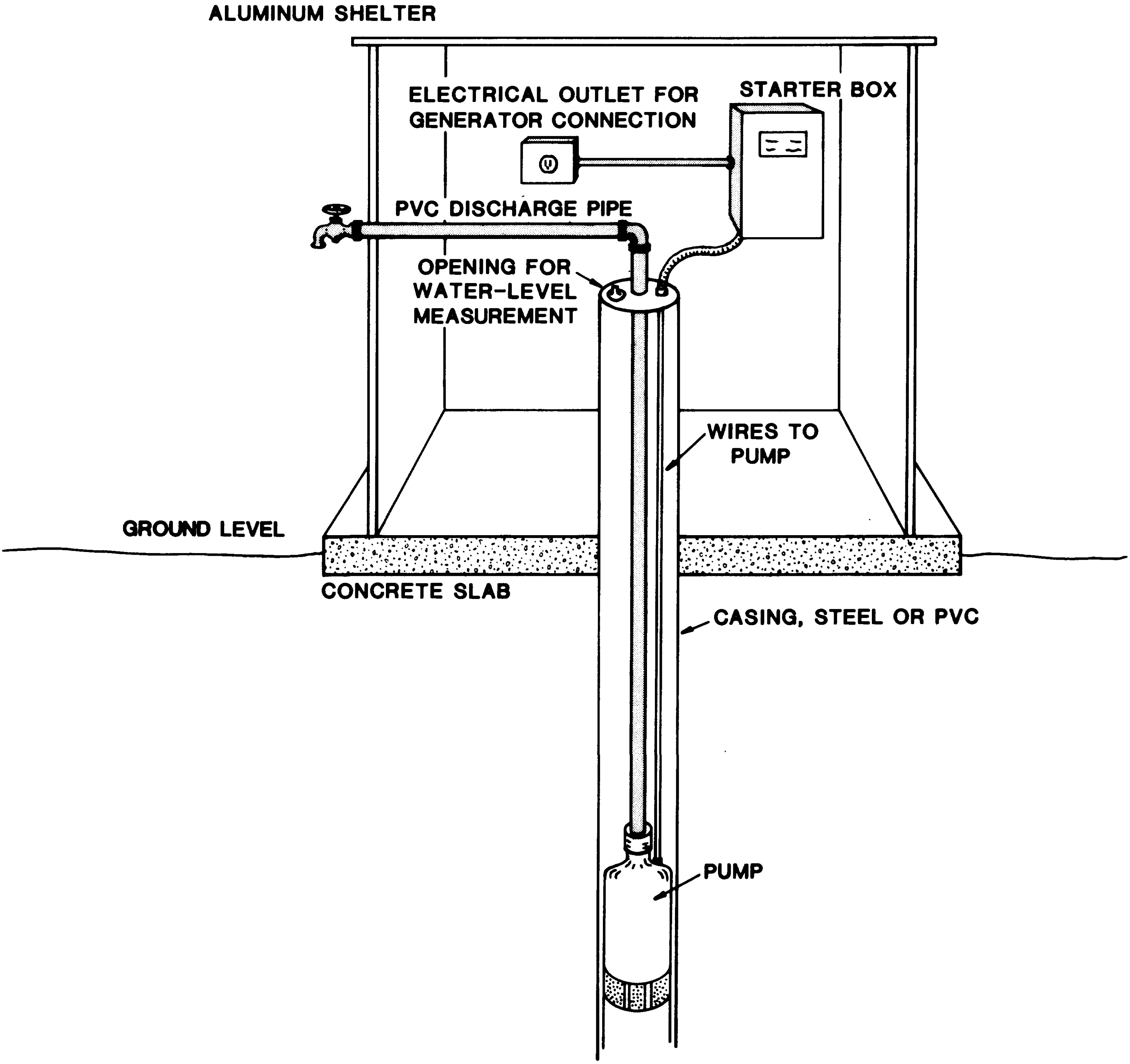


Figure 6.--Most common well construction in southeast spray field.

Table 2 gives the frequency range of data collection at wells and the analytical procedures used for each constituent. The field was visited on a regular monthly basis, but for any particular well and any particular constituent or property, the frequency can be less.

Table 2.--Data-collection frequency range and analytical procedures for chemical constituents

[All methods follow Skougstad and others (1979) unless otherwise indicated]

Constituent	Frequency range (number per year per well) 1980	1981	1982	Analytical method
Nitrogen,				
Nitrite plus nitrate, total NO_3 + NO_2 (mg/L as N)	1-7	1-2	4-12	Colorimetry cadmium-reduction reduction-automated[1]
Ammonia, total NH_3 (mg/L as N)	1-6	1-10	1-7	Colorimetry indophenol automated[1]
Ammonia plus organic, total TKN (mg/L as N)	1-6	0-10	0-7	Block digestion plus colorimetry, automated
Phosphorus, total P (mg/L as P)	1-6	0-10	0-7	Colorimetric, phosphomolybdate, automated.
Fecal bacteria (colonies/100 ml)	0-6	0-10	0-4	Membrane filter method
Common ions (mg/L of each ion)	0-6	0-10	0-4	Atomic absorption, direct
Carbon, dissolved organic DOC (mg/L as C)	1-6	0-10	0-4	Wet oxidation
Metals (μg/L of each metal)	0-6	0-8	0-2	Atomic absorption
Chloride, dissolved (mg/L as Cl)	1-7	3-16	6-12	Colorimetry, automated

[1]Greenburg and others (1980).

Laboratory Analytical Techniques

The City of Tallahassee Water-Quality Laboratory performed a major part of the analytical work for the investigation. These analyses were supplemented by those of the U.S. Geological Survey laboratories in Ocala, Fla., and Doraville, Ga. The use of reference materials, spiked samples, and samples split between laboratories were used to evaluate laboratory performance data.

Identification of the analyses and the methods used to determine their concentrations are given in table 2.

HYDROGEOLOGY

Physiography and Topography

The spray field southeast of Tallahassee is in an area named the "Woodville Karst Plain" by Hendry and Sproul (1966) and consists of a buried limestone surface with sinkholes, overlain by sand, silt, and clay. The limestone is part of the Floridan aquifer system, the principal source of ground water in north Florida. The spray field is located on a topographic high that continues to higher altitudes to the north. Land surface slopes from altitudes of 70 to 20 feet above sea level in the spray field toward the Gulf of Mexico to the south and to adjacent areas east and west of the field (fig. 7). To the east of the spray field there are small lakes and intermittent tributaries to the St. Marks River. Some ponds and swamps may be found to the west. Some ponds also exist in the southern half of the spray field, but no streams drain the field. Before development of the spray field the area was a forest of planted pine trees.

Surficial Aquifer

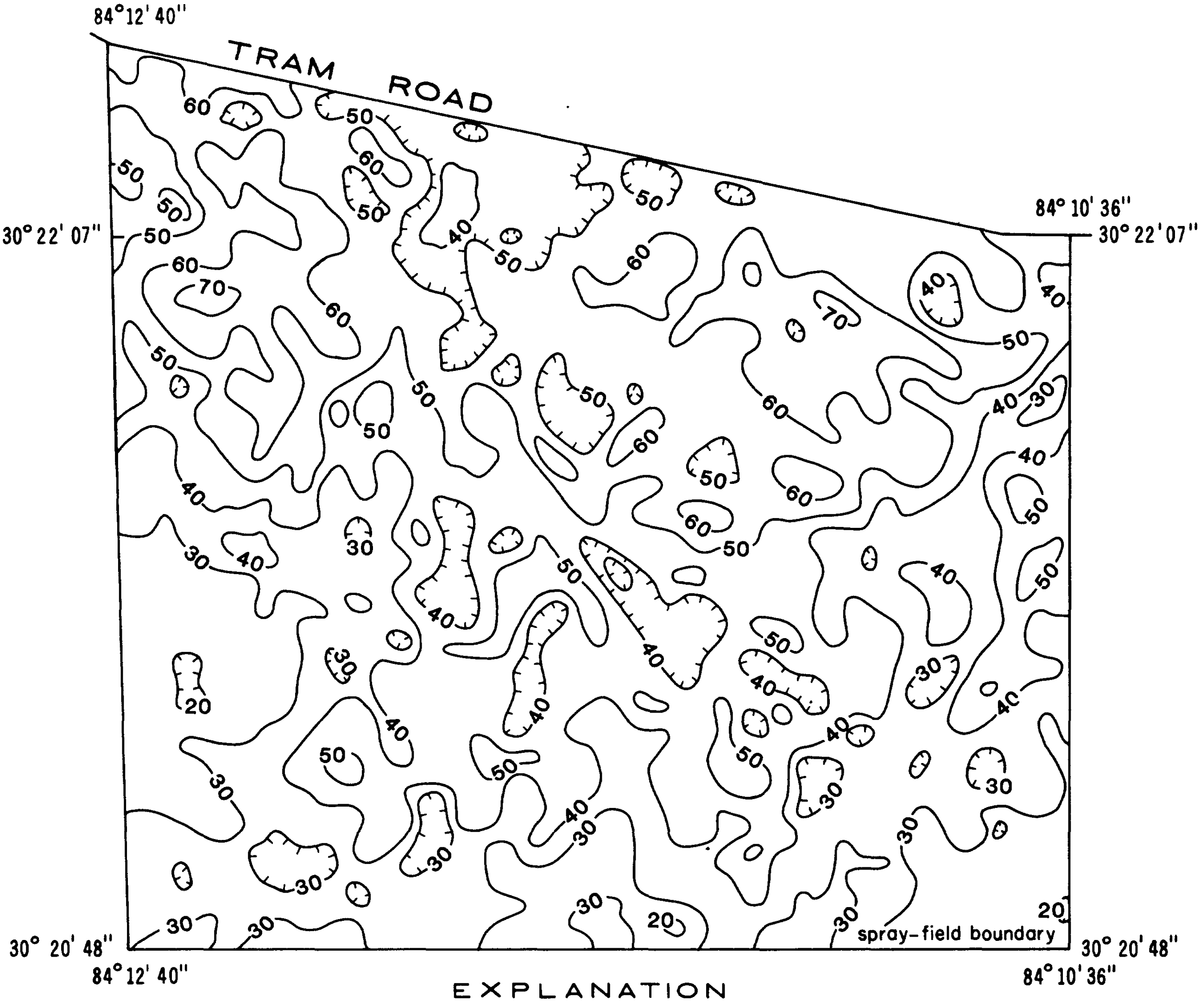
The surficial aquifer consists of the deposits between land surface and the Floridan aquifer system. The upper few feet has been described by Sanders (1981). The predominant soils in the spray field are Kershaw and Ortega sands, consisting generally of sand with 7 percent or less silt and clay to a depth of about 6 feet. The soil zone is unsaturated except in the vicinity of the ponds in the southern part of the spray field.

The surficial material above the Floridan aquifer system has been described by Schmidt (1979) and by Hendry and Sproul (1966) as mostly clayey sand and medium to fine sand and silt.

Examination of the lithologic samples from the test wells confirm that the surficial aquifer consists of clayey, silty, very fine to coarse sand with layers of clay, which, in general, become thicker and more numerous with increasing depth. The geologic and hydrogeologic units underlying the spray field are shown in table 3. Figure 8 shows thickness of the unconsolidated deposits, based on geophysical logs, drillers' logs, and examination of well cuttings. A geologic section, marked A-A' in figure 8, is illustrated in figure 9. The surficial aquifer does not appear to be permeable enough to be a good source of water for drive-point wells and apparently is less permeable than the surficial material at the southwest spray field as described by Slack (1975).

Part of the surficial material at the southeast field is saturated, and the water table in the surficial aquifer is above the potentiometric surface of the Upper Floridan aquifer. The water table follows the slope of land surface to some extent. Data on the position of the water table are not sufficient to permit mapping.

The clay layers within the surficial aquifer do not constitute an effective, continuous confining bed because of interfingering with the sand and because of breaching by sinkhole development. Most of the ground-water flow from the surifical aquifer into the Floridan probably occurs where the clay layers are thin or missing.



EXPLANATION

——30—— TOPOGRAPHIC CONTOUR SHOWS ALTITUDE OF LAND SURFACE IN FEET. CONTOUR INTERVAL 10 FEET. HATCHURES INDICATE DEPRESSIONS. DATUM IS SEA LEVEL.

0 1000 2000 3000 4000 5000 FEET

Figure 7.--Southeast spray field showing surface topography. (Modified from U.S. Geological Survey Woodville 7.5-minute quadrangle, 1954.)

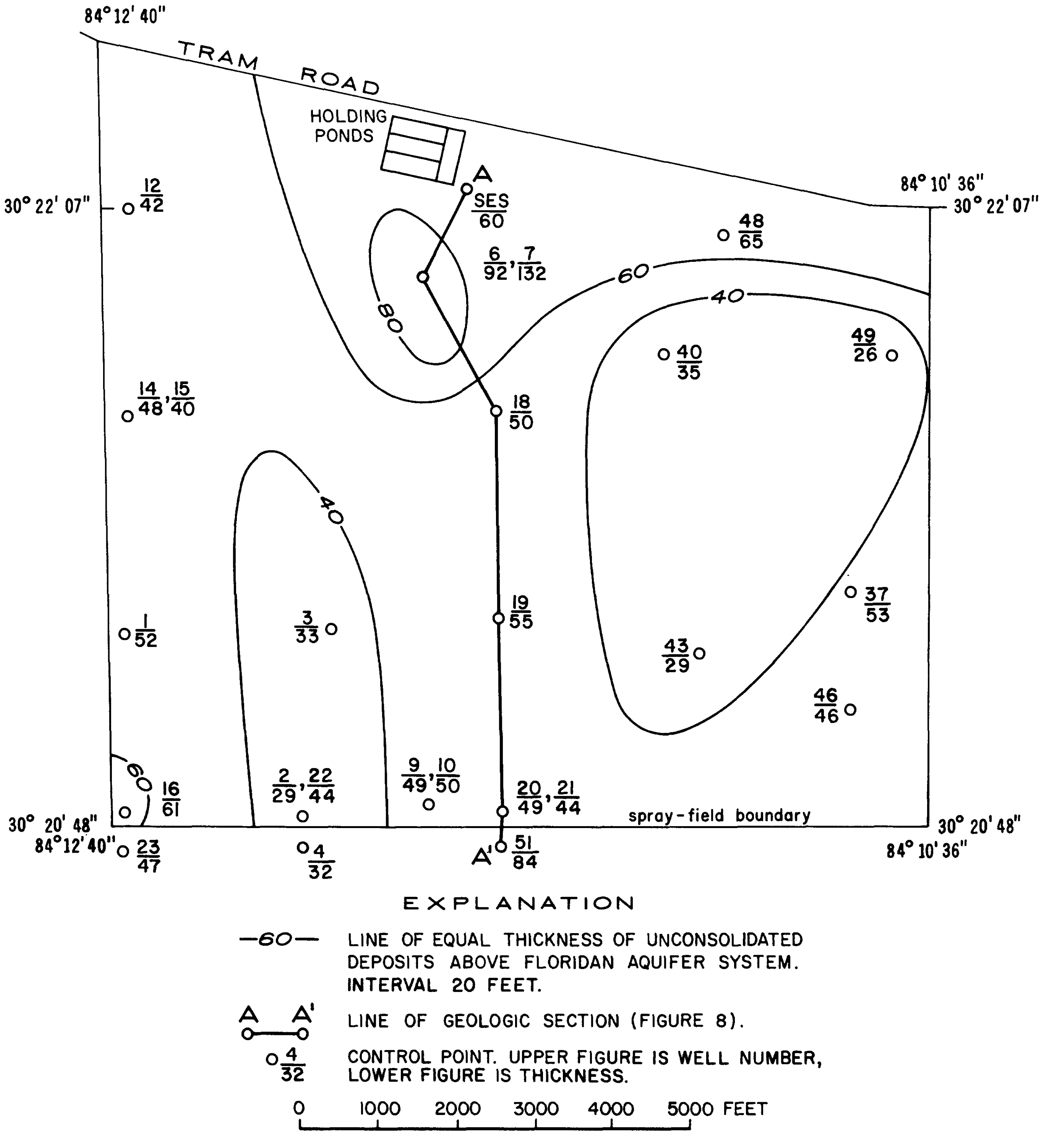


Figure 8.--Thickness of unconsolidated deposits and location of cross section A-A'.

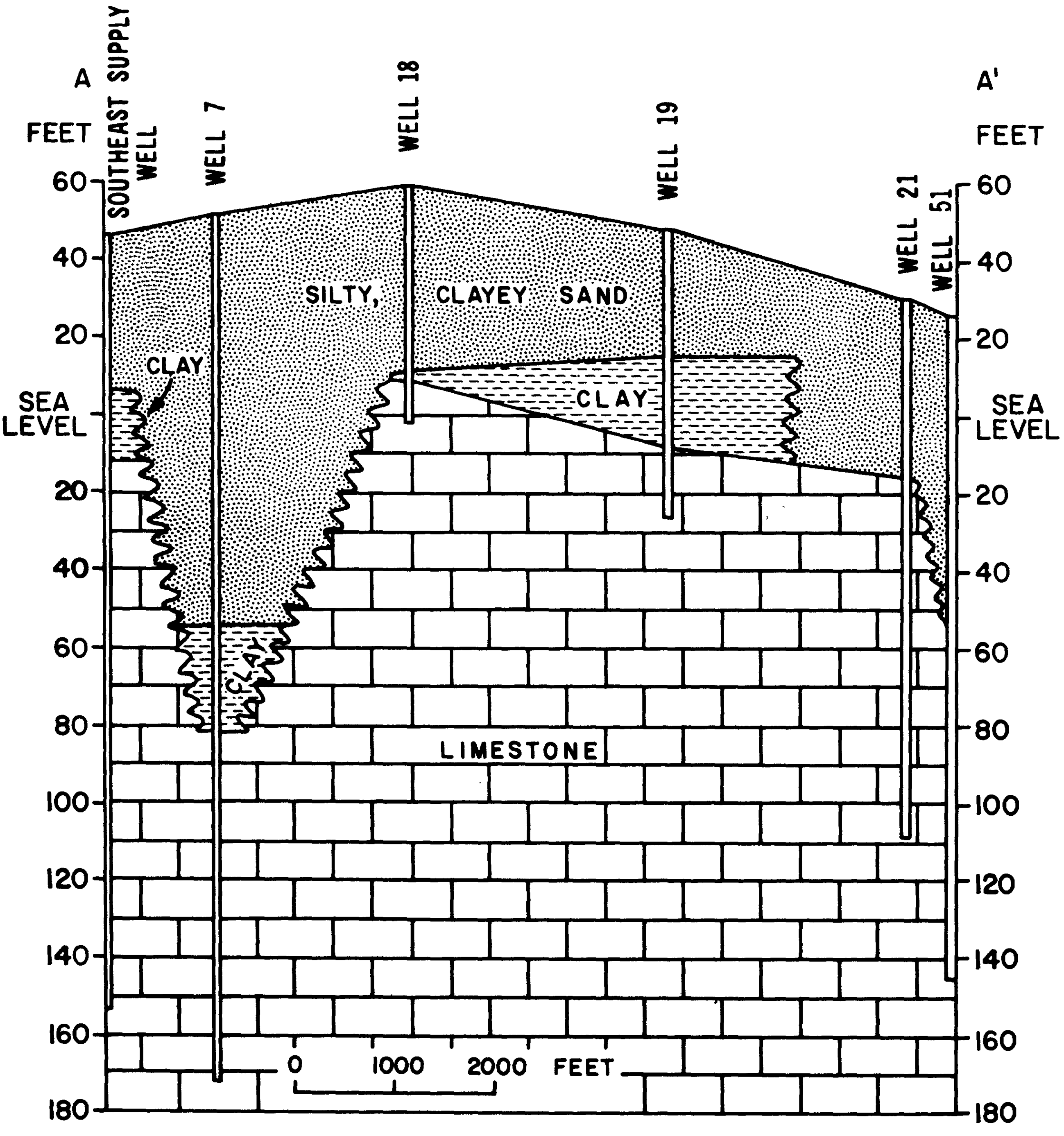


Figure 9.--Cross section of the southeast spray field, north to south.

Table 3.--Hydrogeologic units

[From Schmidt (1979), Hendry and Sproul (1966), and Miller (1982b)]

Series	Formation	Hydrogeologic unit	Thickness (feet)
Holocene to Miocene	Fine sand and silt, clayey sand, and clay	Surficial aquifer	30-60[1]
Miocene	St. Marks Formation	Floridan aquifer system	1,600
Oligocene	Suwannee Limestone		
Eocene	Ocala Limestone Avon Park Formation		
	Undifferentiated fine-grained clastics	Confining bed	Unknown

[1]Thickness is much greater in buried sinkholes. The greatest thickness of buried materials found was about 130 feet in well 7.

Floridan Aquifer System

The geologic units that constitute the Floridan aquifer system (Miller, 1982b) are shown in table 3. The top of the aquifer is about 0 to 50 feet above sea level in the vicinity of the spray field (Kwader and Schmidt, 1978), and slopes to the south at an irregular rate to altitudes of 0 to 50 feet below sea level along the Gulf Coast in Wakulla County.

Lithologic samples, gamma-ray logs, and drillers' logs from the test wells were used to prepare a detailed map of the altitude of the top of the Floridan aquifer system at the spray field (fig. 10). The upper part of the Floridan (St. Marks Formation) appears to be a poorly consolidated and partly clastic deposit. Some shallow open-hole wells caved during drilling, indicating structural weakness of the St. Marks Formation. New sinkholes could form at any time, especially during and following droughts or extensive development of high yielding wells. The deepest test wells (7 and 37) penetrate the Suwannee Limestone.

The base of the Floridan aquifer system in this area is described by Miller (1982a) as the top of undifferentiated units of "silty, highly glauconitic, micaceous, fine-grained sand interbedded with brown, lignitic clay" of early Eocene age, with an altitude about -2,000 feet. The Floridan in the spray-field area is about 1,600 feet thick, based on Miller (1982c), and it thickens to the south to about 2,300 feet along the Gulf Coast of Wakulla County.

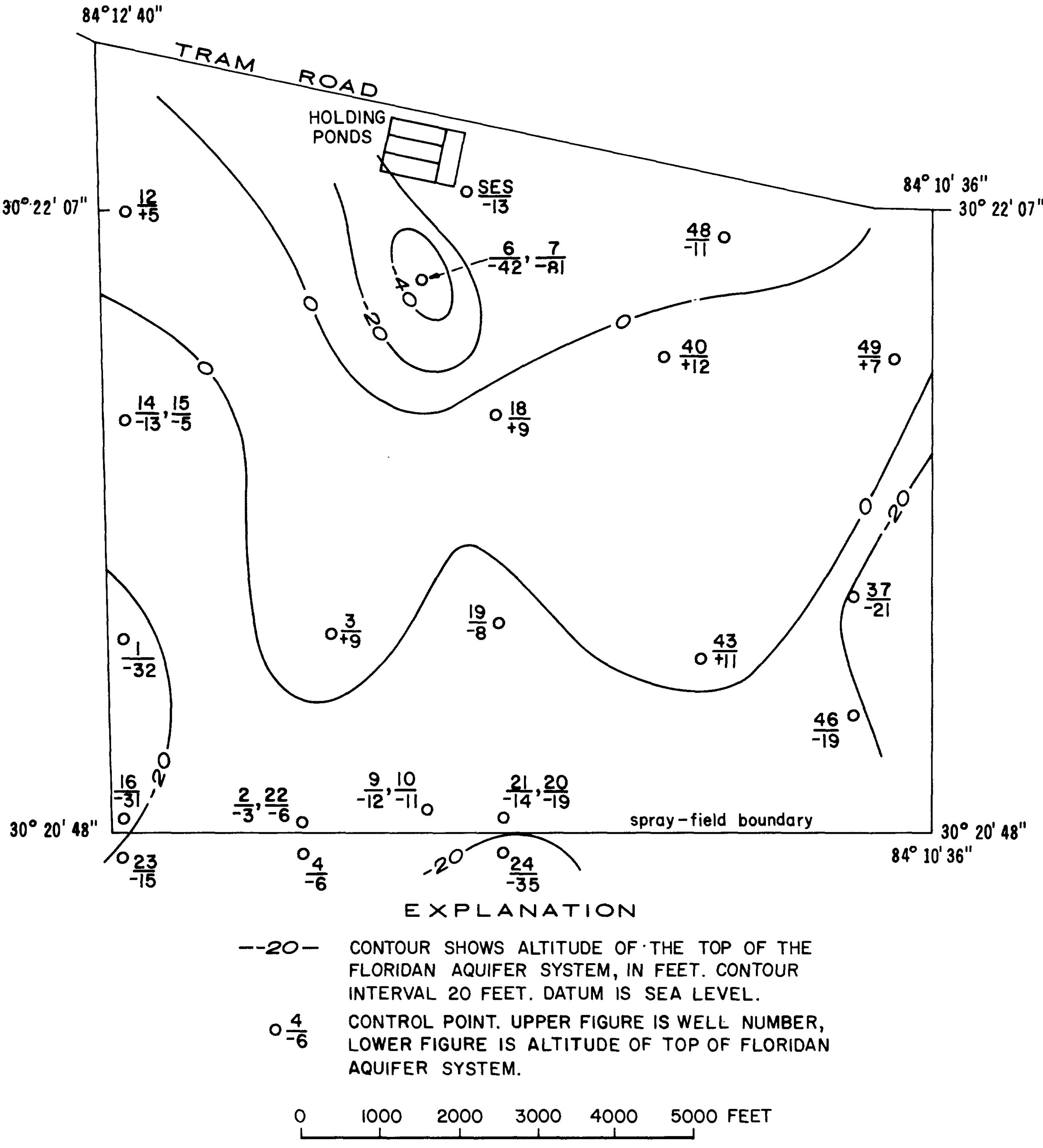


Figure 10.--Altitude of the top of the Floridan aquifer system.

The potentiometric surface of the Upper Floridan aquifer in May 1980 (fig. 11) is shown by Rosenau and Milner (1981). The flow of ground water is approximately at right angles to the contours from the potentiometric surface highs in north Florida and south Georgia toward the Apalachee Bay. Additional recharge to the aquifer occurs along the flow path. The spray-field area is classified as an area of high recharge by Stewart (1980). Recharge rates in such areas generally range from 10 to 20 inches per year. Computer model simulations of the predevelopment flow of the Floridan aquifer system by Bush (1982) estimate the rate of recharge to be 15 to 20 inches per year in the spray-field area.

In the particular area of the southeast spray field, the direction of lateral ground-water flow in the Floridan aquifer system is toward the southwest (figs. 11 and 12). As in the surrounding area, recharge occurs along the flow path, and such recharge is augmented by spray irrigation. The direction of vertical hydraulic gradient in the upper 150 feet of the Floridan, based on water levels in deep and shallow limestone wells at the sampling sites, is upward throughout most of the field (fig. 13). Where the vertical hydraulic gradient is upward, recharge from the uppermost limestone layers is not entering the deeper limestone layers. The upward gradient may be changed to a downward gradient by continued spray irrigation or by heavy rainfall. The downward gradient near the southern edge of the spray field is probably a local phenomenon. The gradient must be upward near the St. Marks and Wakulla Rivers in order to discharge the water.

Discharge from the Upper Floridan aquifer is to numerous springs (Rosenau and others, 1977), to the spring-fed St. Marks and Wakulla Rivers to the south, to evapotranspiration near these streams, and to the Gulf of Mexico. Pumpage constitutes a very small part of the discharge from the aquifer system in this area. The city of Tallahassee uses about 18 Mgal/d from wells distributed throughout the city. A commercial establishment about 3 miles west of the spray field and the supply well at the spray field each use less than 0.01 Mgal/d. These withdrawals have little effect on the potentiometric surface in the spray field because of the very high transmissivity and high recharge rate of the Floridan aquifer system. Bush (1982) estimates a transmissivity of greater than 1,000,000 ft^2/d, based on computer model simulation of predevelopment flow in the Floridan aquifer system.

SPRAY IRRIGATION RATES AND WATER-LEVEL CHANGES

The amount of wastewater applied by spray irrigation to the southeast field ranged from 24 to 350 million gallons per month, from the initial application in November 1980 through December 1982. During the first 16 months, all wastewater was applied to the western part of the field (area A) through pivots 1 through 7 (fig. 5). In March 1982, the eastern pivots in area B, numbered 8 through 11, were put into service. The monthly volumes of irrigation translate to application rates varying from 0.8 inch to nearly 10 inches per month, with a monthly mean of 6.3 inches. Figure 14 shows the monthly variation of spray rates in both area A and area B.

Also shown in figure 14 is monthly precipitation during 1980-82 at the National Weather Service site near the Tallahassee airport. The precipitation rate varied over nearly the same range as did the wastewater application rate. The driest month during this period was December 1980 with 0.89 inch of rainfall, and the wettest month was July 1982 with 11.75 inches. Summing the precipitation and irrigation rates through 1982 yields total monthly water deposition rates on the surface of area A. These total rates range from 4.1 inches in November 1980 to 18.3 inches in July 1982.

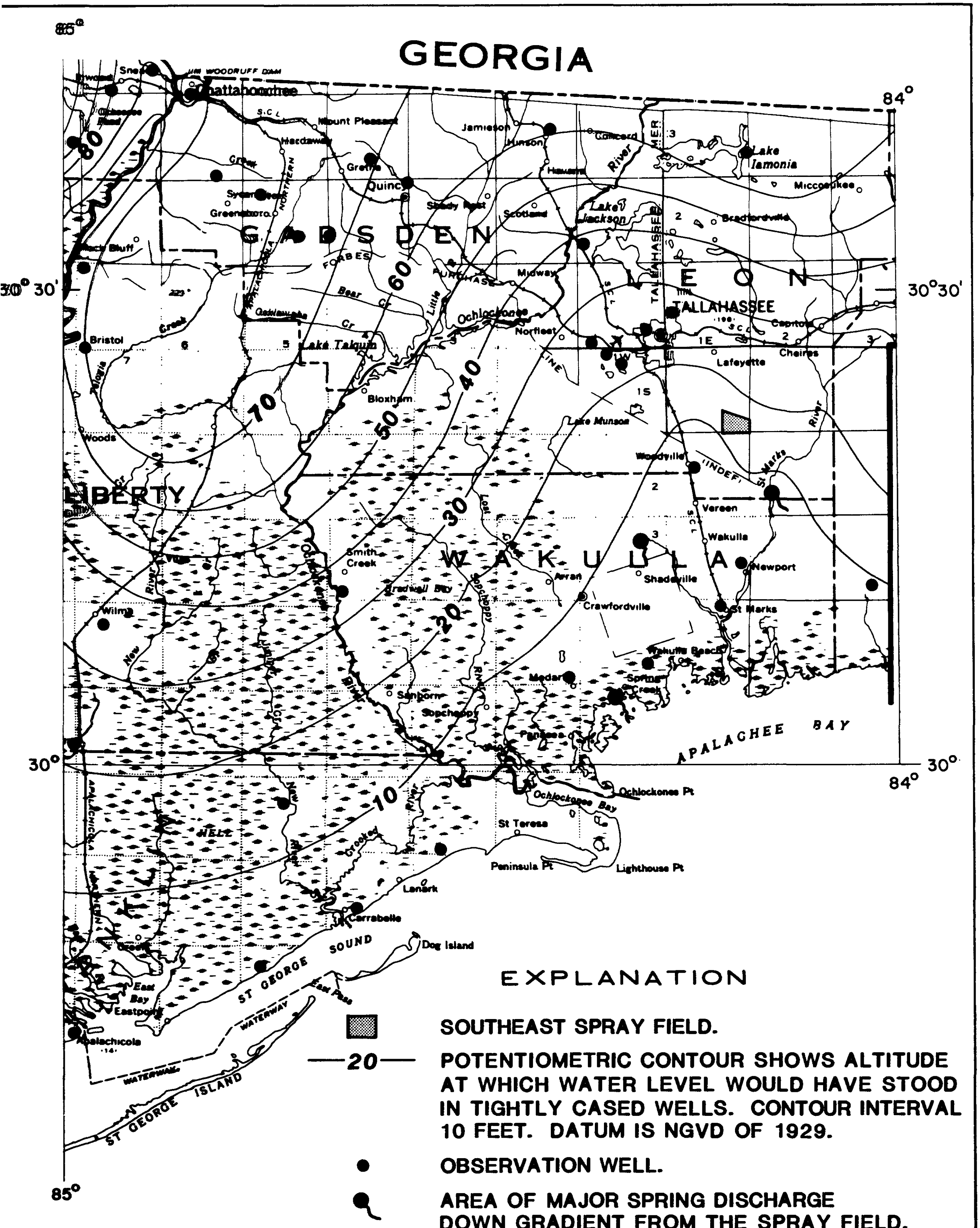


Figure 11.--Potentiometric surface of the Upper Floridan aquifer, May 1980, in part of north Florida. (Modified from Rosenau and Milner, 1981.)

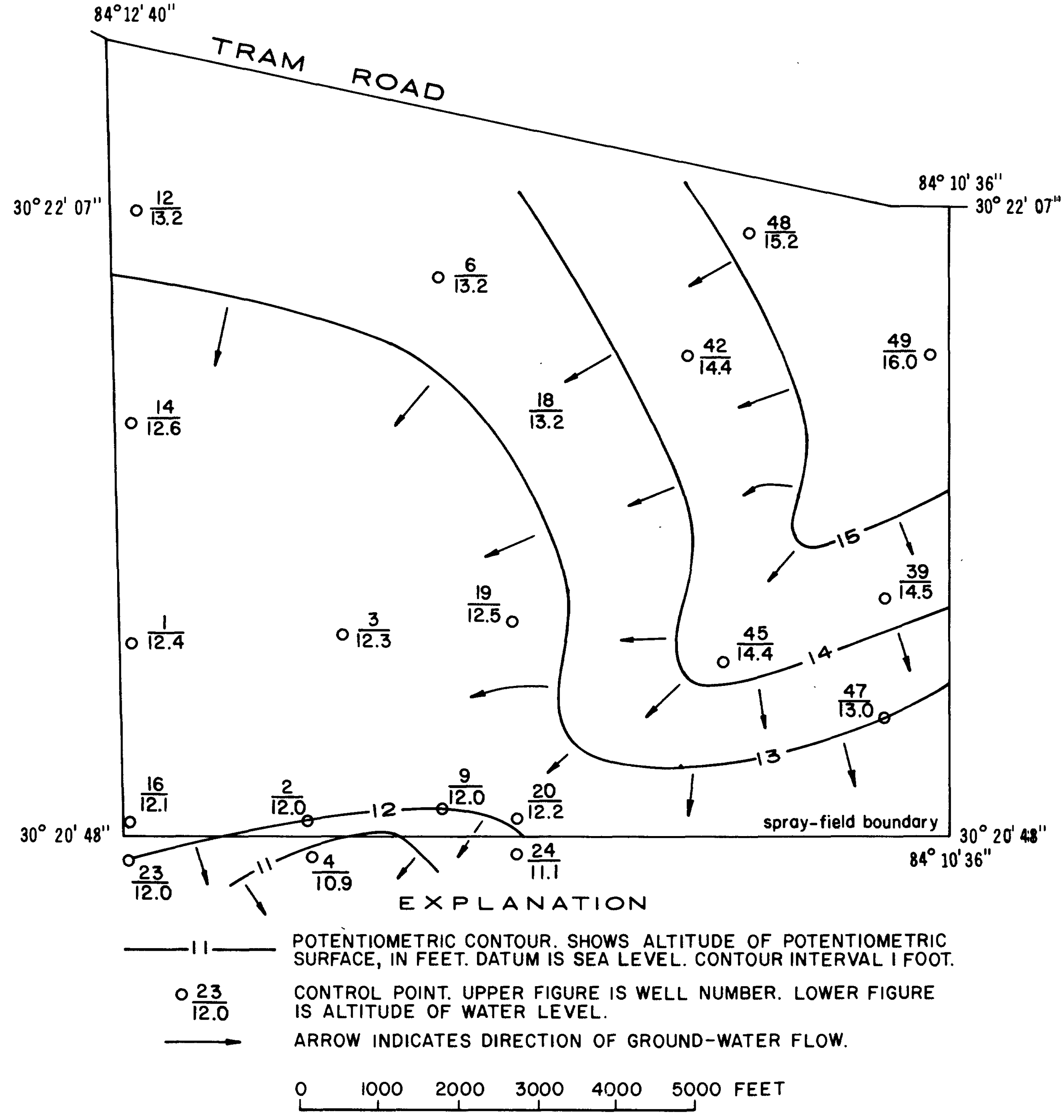


Figure 12.--Altitude of potentiometric surface of the upper 40 feet of the Upper Floridan aquifer, March 16-17, 1982.

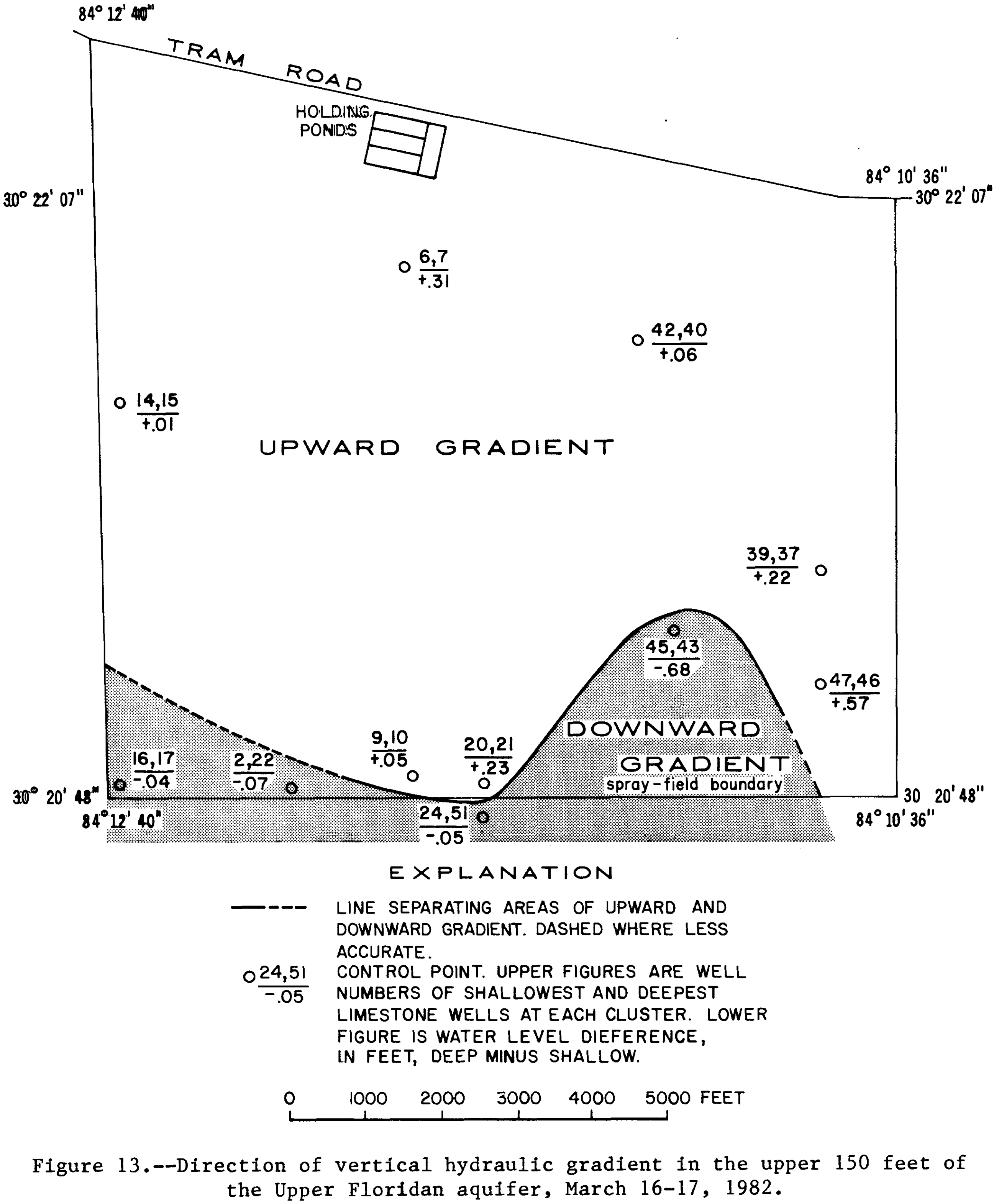


Figure 13.--Direction of vertical hydraulic gradient in the upper 150 feet of the Upper Floridan aquifer, March 16-17, 1982.

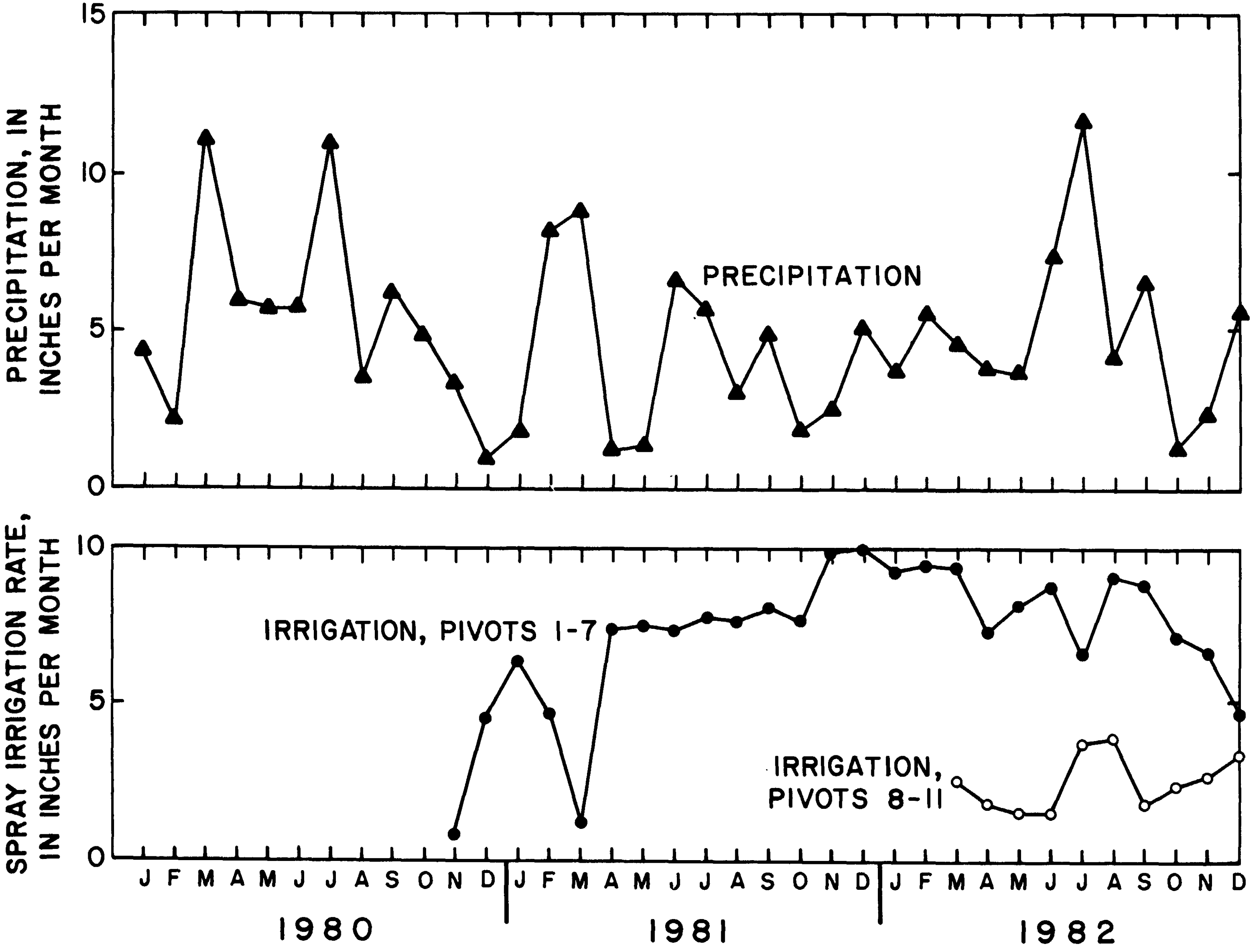


Figure 14.--Precipitation and wastewater spray irrigation rates, by month, 1980-82.

Monthly water-levels in all wells were compared to rates of both precipitation and spray irrigation using least-squares linear regression. The results are shown in table 4. Data from all wells were matched with precipitation, those from area A were matched with irrigation rates from pivots 1 through 7, and those from area B were matched with irrigation rates from pivots 8 through 11. Nine wells were found to correlate with precipitation at a probability level of 0.05, and six others showed correlations at a probability level of 0.10.

Table 4.--Wells whose water-level changes with time correlated significantly with precipitation or irrigation rates

[Area A includes pivots 1-7 and all wells except wells 37 through 49. Area B includes pivots 8-11 and wells 37-49 only. α = significance level]

	Independent variables		
	Precipitation	Irrigation rates	
	Areas A and B (01/80-12/82)	Area A (11/80-12/82)	Area B (03/82-12/82)
Wells showing correlation at $\alpha = 0.05$	1, 2, 4, 9, 10, 14, 16, 19, 32	None	38, 40, 41, 48, 49
Additional wells showing correlation at $\alpha = 0.10$	6, 7, 15, 17, 20, 21	14	39, 42

Two of the area A wells which showed highly significant correlation between water levels and precipitation were wells 1 and 9. Plots of their water-level changes with time are compared with the previously illustrated precipitation and irrigation curves in figure 15. The two wells followed very similar patterns. Water-level plots for wells 48 and 49, from area B, are also shown. Like wells 1 and 9, their water-level fluctuations are very similar.

Overall water deposition rates on the land surface, including precipitation as well as spray irrigation, apparently have some effect on ground-water levels in the area. Since the total annual volumes of precipitation and irrigation on the field were not greatly different, it is not obvious that one dominated over the other as being the primary influence on water levels. However, closer inspection of monthly variability gives indications that the primary controlling variable was precipitation, and irrigation was of secondary importance.

The hydrographs for wells 1 and 9 (fig. 15), show two major peaks during the period of complete record (1981-82). Those peaks occurred in February 1981 and August 1982. In addition, it appears that there were peaks in March and April 1980 and in July 1980, although the record for that year was not complete. All four of these peaks coincided with the major rainfall peaks of the same month or 1 month earlier. For example, the February 1981 peak was matched by a large increase in rainfall, and the 1982 peak in August was preceded by a rainfall peak 1 month earlier. This suggests that rainfall effects are subject to a lag time which is on the order of 1 month or less, the precise time depending on numerous physical and hydrologic conditions.

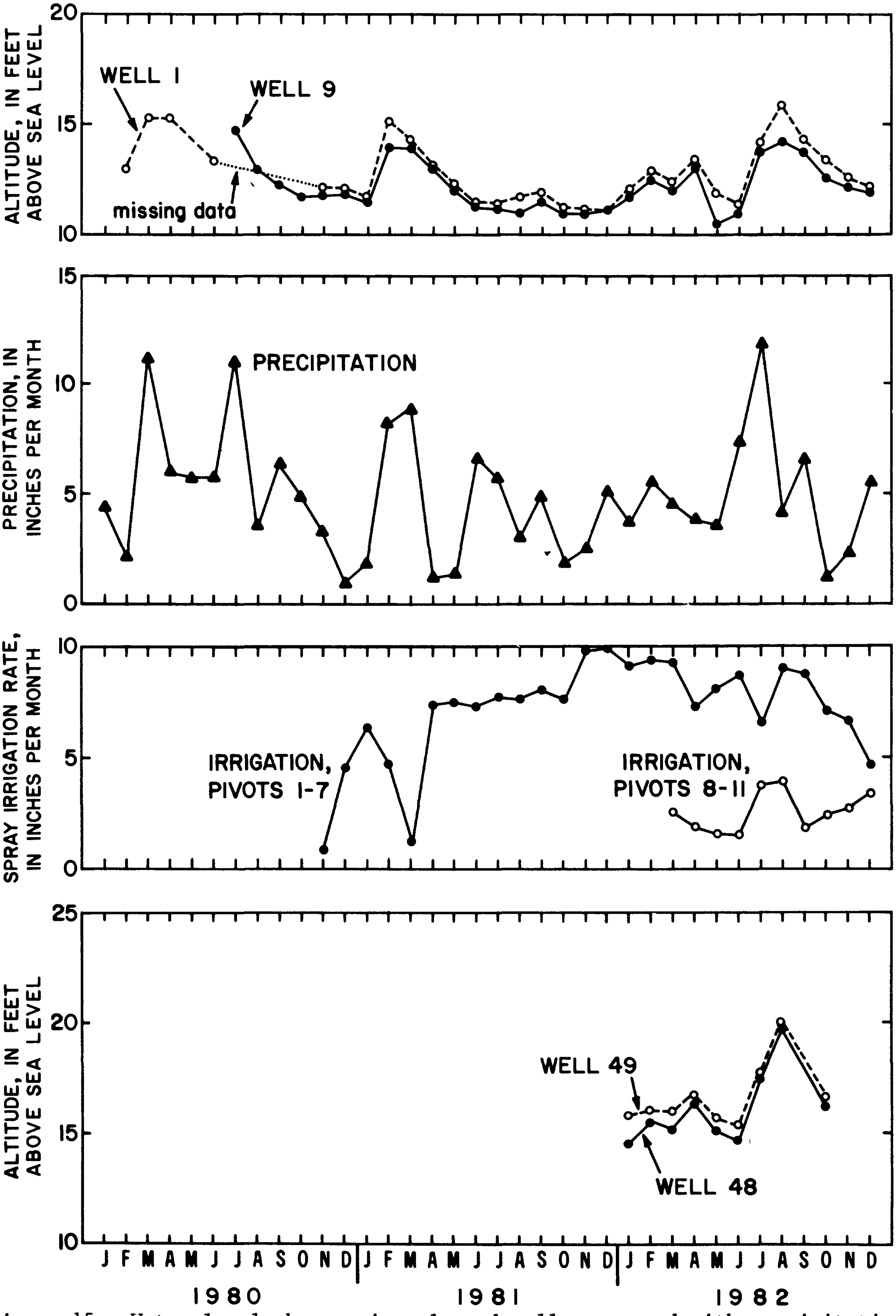


Figure 15.--Water-level changes in selected wells compared with precipitation and irrigation rates.

The statistical correlations shown in table 4 also demonstrate effects of precipitation. The irrigation rate in area A had very little influence on water levels (table 4). Comparison of the plots of area A irrigation and precipitation (fig. 15) indicates that the two rates fluctuated in very different patterns. At times their fluctuations were in opposite directions, as in January through April 1981, July and August 1982, and November and December 1982. Hence, it is not surprising that water levels do not correlate to both factors. The effect of the precipitation input is apparently the dominant of the two.

A different explanation is required for the results of regression analysis for area B. Among those wells, there were none whose water levels showed close correlation with rainfall, but there were several that were apparently closely related to the area B irrigation rates. This seems to be opposite to the area A results. Further analysis, however, suggests that the primary dependent variable is still rainfall, and the irrigation rate in area B, unlike area A, happens to fluctuate in nearly the same manner as rainfall (fig. 14). The reason that the correlation with rainfall did not appear was that the rainfall effects were delayed. Regression analysis of area B water levels against the rainfall from the previous month shows very high correlation. At wells 48 and 49, the correlation coefficients (r^2) were 0.83 and 0.90, which are significant at $\alpha = 0.001$. Water levels in all other area B wells except number 37 were correlated to 1-month-lagged rainfall at significance levels of $\alpha = 0.05$ or less.

The effects of local precipitation alone on water levels in the Upper Floridan aquifer can be seen by figure 16. The same 1980-82 precipitation data are compared with water levels from two Tallahassee wells which are distant from the spray fields (fig. 1). These give further evidence that rainfall has an important effect on water-level fluctuations in the Upper Floridan aquifer. Peaks in the well hydrographs occurred in April 1980, August 1980, March and April 1981, and August 1982. At the Lake Jackson well, there was also a noticeable rise in water level from January through April 1982. All of the hydrograph peaks coincided quite closely with rainfall peaks of approximately 1 month earlier. There were some additional, smaller rainfall peaks which did not have any apparent effect on ground-water levels. Most of these occurred in the spring and summer when evapotranspiration would be likely to consume considerable quantities of water at or near land surface.

Although the ground-water levels responded to major changes in water deposition rates on the surface, they were quite independent of minor fluctuations. During the period from June 1981 through May 1982, precipitation and irrigation rates did not fluctuate a great deal. The minor fluctuations in water levels at wells 1 and 9 during the same period show no appreciable relation, by inspection of the hydrographs, to either rainfall or irrigation.

The principal effect of irrigation on ground-water levels may be considered as an indirect one. With the exception of some fluctuations during the first few months of application, the irrigation rate tends to be more uniform than rainfall. This keeps the soil and unsaturated zone at high moisture levels, and when precipitation occurs, it is nearly all available for recharge. Evapotranspiration (ET) can also remove considerable quantities of water (in excess of 6.3 inches potential ET per month during the growing season, as calculated by the method of Thornthwaite and Mather, 1957). However, rainfall is usually quite heavy during the same months, helping to provide for ET demands.

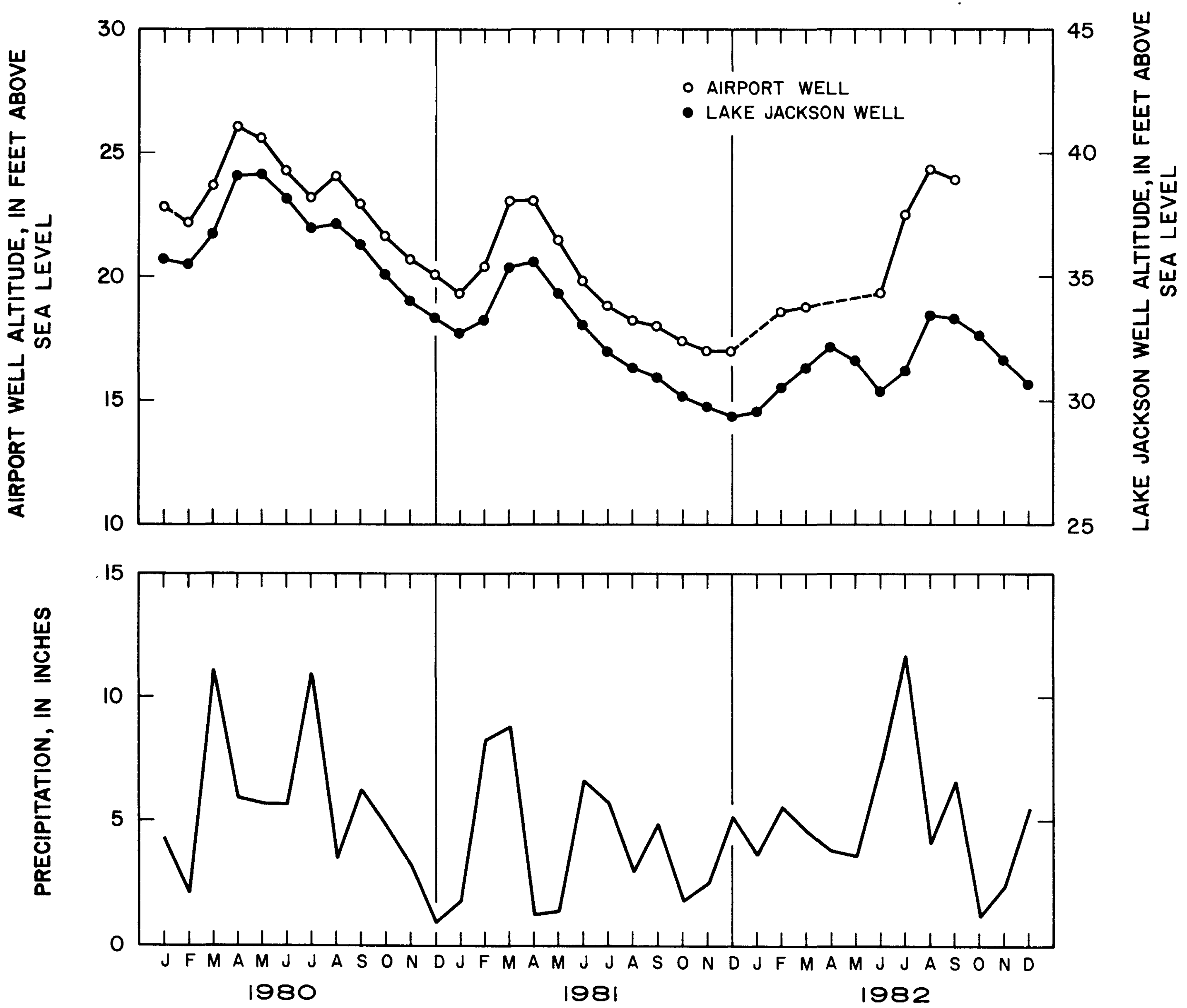


Figure 16.--Hydrographs of two wells in Tallahassee distant from spray fields. The wells are: City of Tallahassee Airport well near Tallahassee, Fla. (well no. 302424084311301) and USGS observation well at Lake Jackson near Tallahassee, Fla. (well no. 303142084214601) (see locations on fig. 1). The wells are 194 feet and 225 feet deep, respectively, and tap the Upper Floridan aquifer. Precipitation record, as in figures 11, also shown.

EFFECTS OF SPRAY IRRIGATION ON GROUND-WATER QUALITY

Initial Water Quality

Wastewater application by spray irrigation began in November 1980, but data collection from wells in area A began early in that year. Hence, there were several months of data collection which provided information on the quality of the ground water before any possible effects of spray irrigation. Mean data from all area A wells for the first 10 months of 1980 are presented in table 5. Also shown are mean concentrations of the same constituents in the wastewater sampled from the holding ponds at the field nine times between April 1981 and July 1982.

Table 5.--Mean concentrations of chemical constituents in ground water at southeast field prior to spraying (mean data from all area A wells in first 10 months of 1980) and in wastewater sampled from pump inlet prior to spraying on the field (mean data for nine samples, April 1981-July 1982)

[All values in milligrams per liter unless otherwise indicated. Mean pH values were calculated as actual hydrogen ion activities. * indicates dissolved concentrations; otherwise total recoverable]

Constituent	Ground water	Waste-water	Constituent	Ground water	Waste-water
*Chloride	3.2	50	Fecal coliform (#/100 ml)	2	110
*Sulfate	7.6	29			
*Fluoride	0.1	0.3	Total coliform (#/100 ml)	3	210
pH (units)	8.0	7.4			
Alkalinity	94	130	Fecal streptococcus (#/100 ml)	7	16
Nitrogen (as N):					
Ammonia	.02	1.70	Arsenic (μg/L)	1.5	1.5
Nitrate	.20	6.5	Cadmium (μg/L)	--	0.3
Nitrite	.01	0.82	Chromium (μg/L)	4.0	2.1
Organic	.09	4.0	Copper (μg/L)	9.7	10.0
			Iron (μg/L)	200	48
Total phosphorus	.04	6.4			
*Organic carbon	1.9	11	Lead (μg/L)	3.9	0.5
*Calcium	30	37	Manganese (μg/L)	4.9	9.2
*Magnesium	5.1	9.6	Mercury (μg/L)	0.11	0.10
*Sodium	2.2	43	Selenium (μg/L)	1.2	0.3
*Potassium	0.4	7.5	Zinc (μg/L)	6.7	20

Comparisons of wastewater quality with that of the ground water shows substantial differences in some constituents and virtually none in others. Constituents which were notably higher in the wastewater included chloride, all nitrogen species, phosphorus, organic carbon, and coliform bacteria. Among the major cations, sodium and potassium were at much higher concentrations in wastewater than in ground water, but calcium and magnesium were not. Fluoride, alkalinity, pH, and fecal streptococcal bacteria were not significantly different in the two water types. None of the trace elements showed differences which would suggest potential impact of the wastewater application. In some cases, particularly iron and lead, concentrations were actually higher in ground water than in the wastewater.

Water-Quality Changes During Study Period

Chloride and Inorganic Nitrogen

Not only are chloride and inorganic nitrogen species among the chemical variables found in substantially higher concentrations in wastewater than in ground water (table 5), but they are also highly soluble and quite conservative, resulting in relatively high mobility through soils (Childs and others, 1974). Nitrate-nitrogen is a very common contaminant in ground water, especially in agricultural areas (Freeze and Cherry, 1979; Foster and others, 1982). The various forms of dissolved nitrogen are subject to transformation and uptake by vegetation, but in oxidizing conditions, nitrate-nitrogen is the stable form. It might therefore be expected that chloride and inorganic nitrogen would be the first indicators of wastewater inflow to the ground-water system.

The 1980-82 data for each well in area A were analyzed using the Seasonal Kendall test (Hirsch and others, 1982), a non-parametric trend analysis technique. Figure 17 shows plots of chloride and inorganic nitrogen from wells 9, 10, 22, and 29 in the southern section of the field, and well 36 in the northern section. At these five wells, two of which are surficial (29 and 36), significant trends of chloride, and, in most cases, total inorganic nitrogen were found (see fig. 17 caption). Where total inorganic nitrogen was found not significant (wells 22 and 29), the trend test was also performed on nitrate-nitrite data. Significance was shown for both wells. The reason that addition of ammonia data rendered the trend not significant was that ammonia analyses were less frequent, making the number of data points too small to yield significant results with the trend analysis test.

The data from well 9, in particular, indicate that water-quality impact on the ground water began to appear in late 1981 (fig. 17), approximately 1 year after spray irrigation began. Both chloride and total inorganic nitrogen were relatively stable until that time, then began to show marked increases which continued through 1982. This pattern was also observed at wells 10, 22, and 36, although there were more random fluctuations superimposed on the general trend.

The 1-year delay in water-quality impact is much longer than the 1-month lag time between rainfall and its effects on water levels. This difference can be explained principally by the mechanism of breakthrough. Chloride or other constituents move into and through the aquifer in a "plume," radiating out from the area of application. The area is extremely small relative to the entire aquifer, and may thus be considered a point source. Rainfall, on the other hand, is regional, and when substantial changes occur, there is regional response in the aquifer water levels. Response may be especially rapid in the spray-field wells because recharge is facilitated by the saturation caused by spray irrigation.

An overall view of effects of spray irrigation on chloride concentrations in the ground water is shown in figure 18. Chloride data from medium-depth wells (40-80 feet) are shown, representing the October-December periods during the 3 years of the study. The 1980 October-December data may be considered background conditions because irrigation had not yet begun.

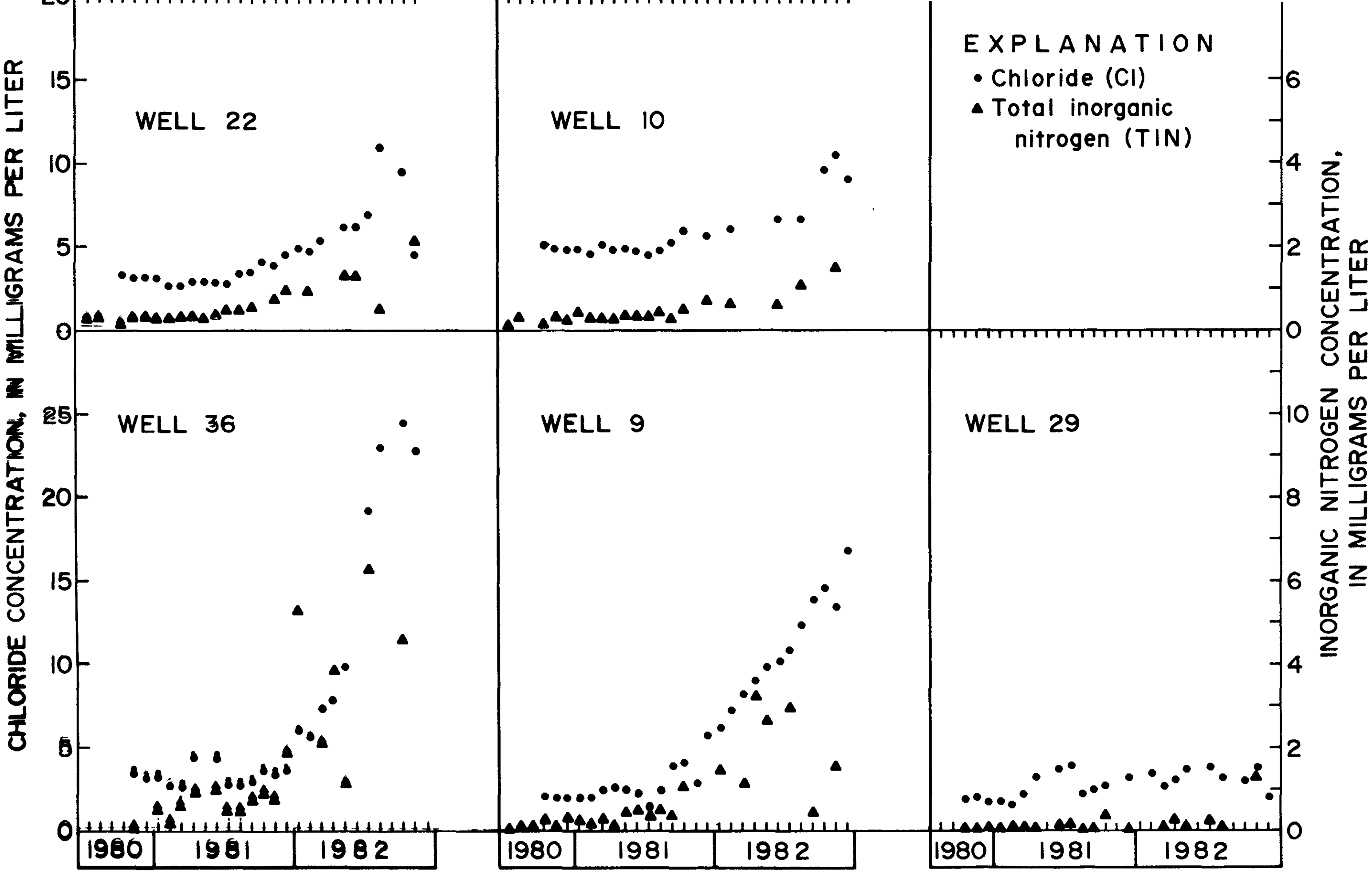


Figure 17.--Monthly values of chloride and total inorganic nitrogen (ammonia + nitrite + nitrate) at five area A wells. The Seasonal Kendall test for trend analysis showed trend significance as follows:

Well	Chloride	Total inorganic nitrogen
22	**	N.S.
36	*	*
10	**	**
9	**	**
29	*	N.S.

where ** = highly significant (α = 0.05)
* = significant (α = 0.10)
N.S. = not significant

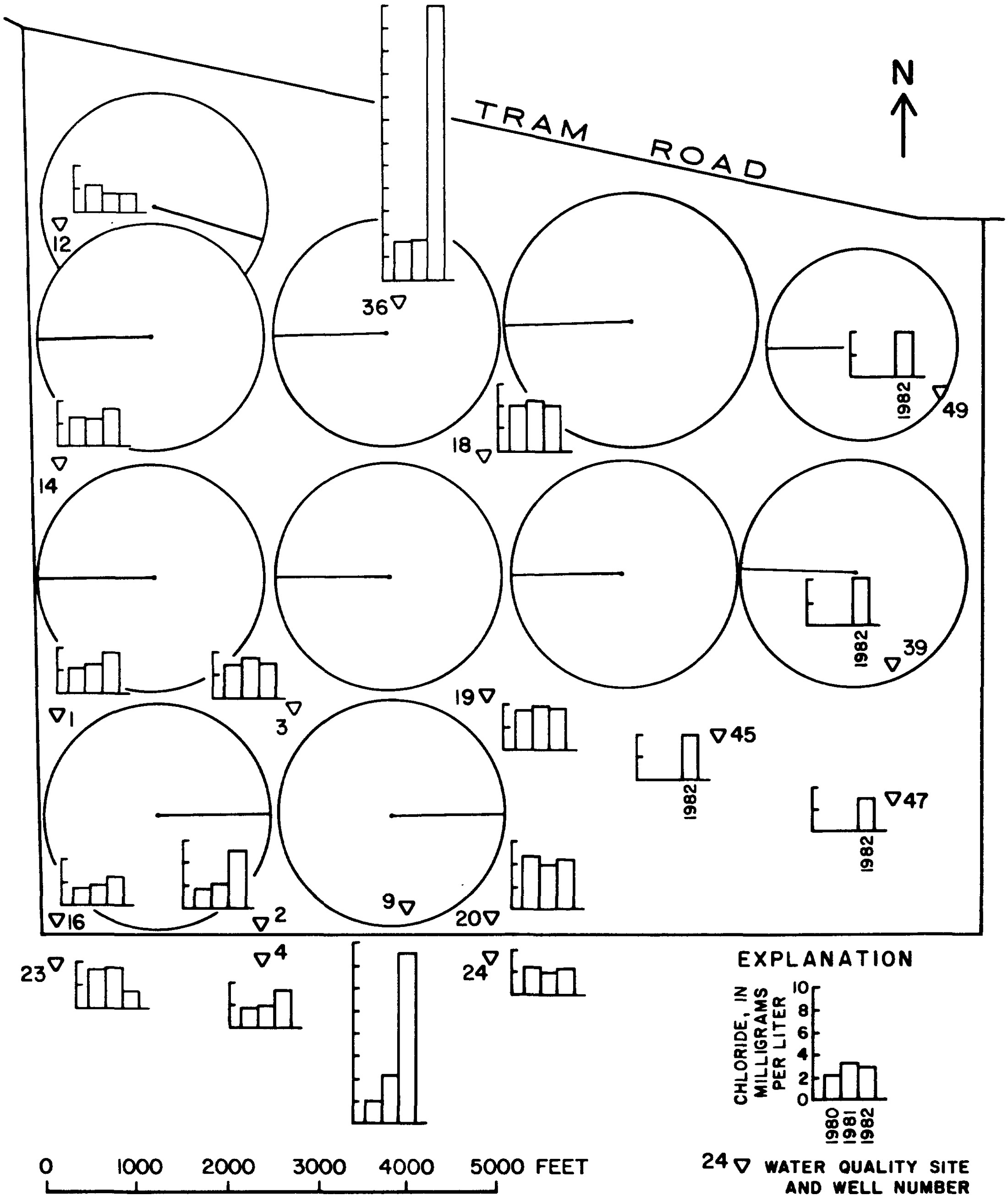


Figure 18.--Mean chloride concentrations in medium-depth wells (40-80 feet) during October-December of calendar years 1980, 1981, and 1982.

The only areas where ground-water chloride concentrations in medium-depth wells clearly increased were at wells 9 and 36. These wells are located inside the center-pivot spray areas numbers 3 and 1, respectively, and are thus subject to direct vertical infiltration of irrigation water. At all wells, there was no appreciable difference in chloride concentrations between the October-December periods of 1980 and 1981. It was only in 1982 that the impact was significant, and then only at the two wells directly affected. Presumably, there is or will be horizontal migration to other wells outside the center pivot areas but no evidence of such migration was shown by the data from medium-depth wells through December 1982. All of the outer wells showed no substantial increase in chloride concentrations from the background levels found in 1980.

It was previously observed (fig. 17) that there were chloride and nitrate increases at wells 10, 22, and 29, in addition to wells 9 and 36. The former group is not shown in figure 18 because they are deeper wells. Their chloride increases do show, however, that water-quality effects from irrigation have reached quite deep into the aquifer. There is also some evidence of lateral migration of high-chloride water to some of the deeper wells on the southern perimeter of the field. Well 22 (136 feet deep) showed an increase in chloride with time (fig. 17) although neither its companion well 2 (50 feet deep) or nearby well 4 (44 feet deep) were similarly affected. The explanation for this is probably that horizontal migration in a southwesterly direction away from center-pivot circle 3 was accompanied by downward movement, so that only the deeper well was affected. This conclusion is supported by the fact that there is a local gradient downward in the Upper Floridan aquifer near the southern boundary of the field.

Other Constituents

The observation of significant upward trends of chloride and inorganic nitrogen at certain wells (fig. 17), coupled with the data showing that the wastewater being sprayed on the field is much higher than the ground water in chloride and inorganic nitrogen concentrations (table 5), suggests that wastewater infiltration into ground water has occurred at those wells. If this is true, it may be expected that other constituents borne in high concentrations by the wastewater would also show upward trends. To test this possibility, Seasonal Kendall trend analyses were applied to other constituents at the same wells where the chloride and nitrate increases occurred.

Very few significant trends were found for other constituents. Those which were found are illustrated in figures 19 and 20. Highly significant downward trends of pH were observed at wells 9 and 36 and an upward trend of specific conductance appeared at well 9. No corresponding trends in pH or specific conductance occurred in the effluent sprayed on the field during this period.

In a considerable number of cases where trend analyses were attempted, the results were inconclusive because of insufficient data. For example, the test showed a significant downward trend in magnesium at well 10. Examination of the data reveals that only three data values are recorded for 1982, and they all happen to be slightly lower than the values for corresponding months in 1981. This is clearly an insufficient data base upon which to claim that a real trend exists. As further data are collected in future years, the likelihood of obtaining more conclusive results will be enhanced.

Phosphorus retention in soils has been demonstrated to be high (Childs and others, 1974; Leland and others, 1979). Phosphorus removal, sometimes more than 90 percent of original concentrations in irrigation water, can be attributed to a combined effect of plant uptake and soil adsorption (Khalid and others, 1982). At the Tallahassee spray field, phosphorus is greater than 100 times more concentrated in wastewater than in ground water (table 5) yet trend analysis did not support identification of significant increasing phosphorus concentrations, even at wells where trends in chloride and nitrogen did occur. Nevertheless, the phosphorus data merits additional inspection; the complete circumstances are not revealed by purely statistical treatment.

Sixteen wells in area A showed considerable phosphorus concentration increases from 1980 to 1982. At well 10, for example, the mean phosphorus concentration, by year, was 0.034 milligrams per liter (mg/L) in 1980, 0.029 mg/L in 1981, and 0.30 mg/L in 1982. The increase from 1981 to 1982 was by a factor of ten. None of these phosphorus changes was statistically significant by the Seasonal Kendall test, primarily because the data, over a 3-year span, are still too limited to establish a trend unless a very large and consistent change is observed. However, the changes were substantial and warrant further interpretation.

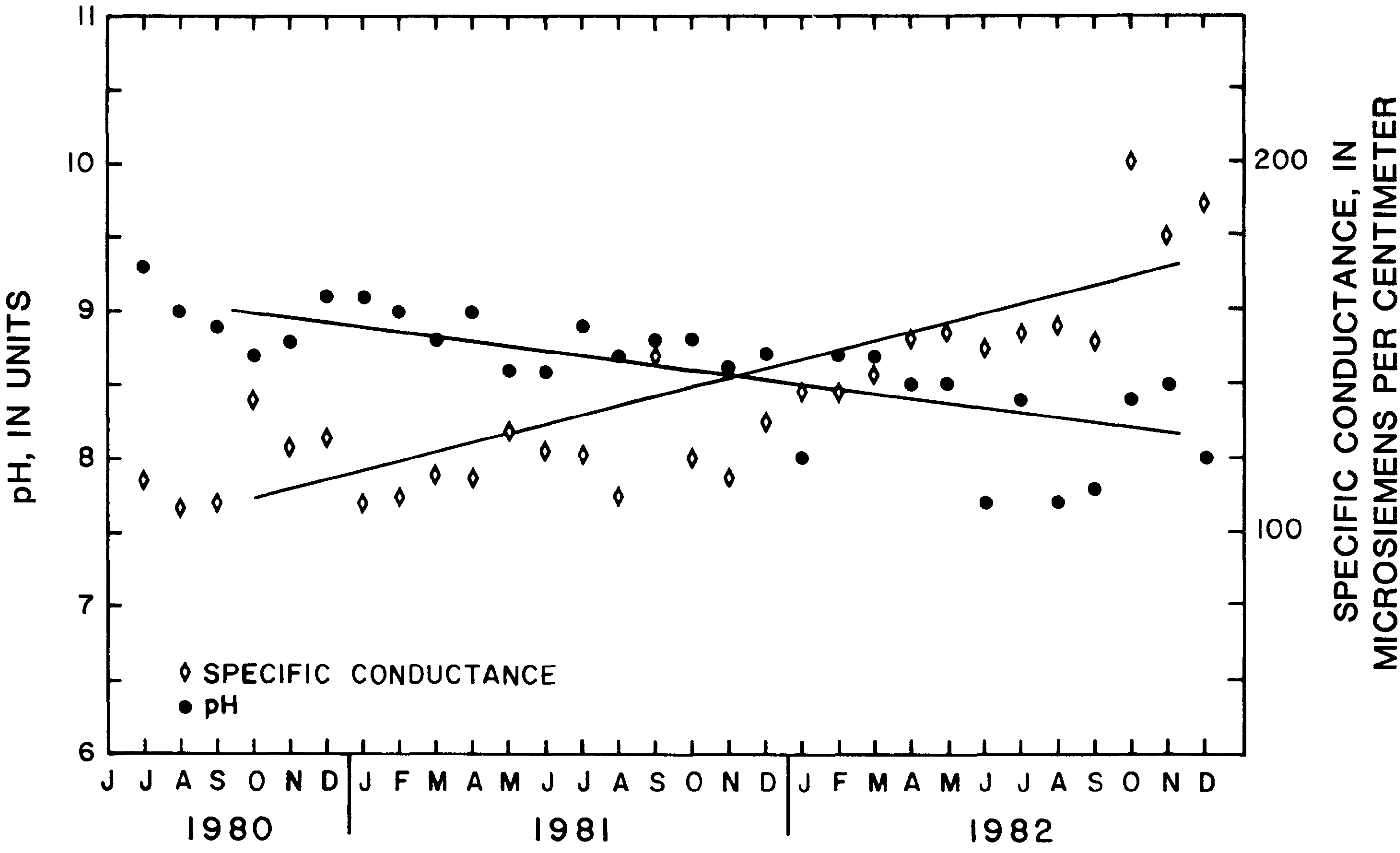


Figure 19.--Monthly values of pH and specific conductance, and slopes estimated by Seasonal Kendall trend analysis at well 9.

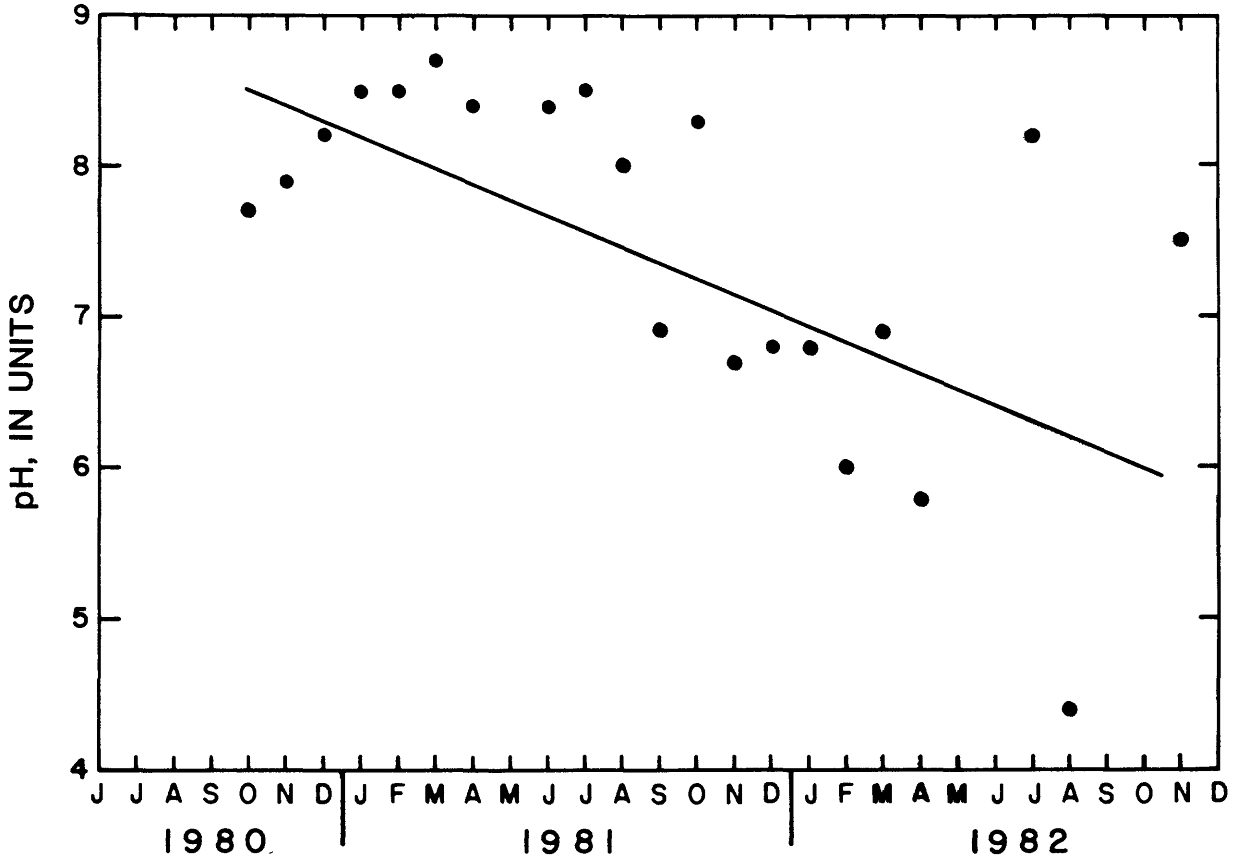


Figure 20.--Monthly values of pH and slopes estimated by Seasonal Kendall trend analysis at well 36.

The observed increases in phosphorus concentration may be linked with pH decreases (fig. 19). A model and measurements of phosphorus transport through soil by Overman and others (1976) indicated that dissolved phosphorus contained in the irrigation water would be sorbed rapidly within the top 50 inches of soil. However, a decrease in pH caused by the application of effluent water could produce some dissolution of phosphate rocks. Thus the spray irrigation is likely to be the cause, but not the source, of the increase in solute phosphorus.

The pH decrease may in turn be associated with changes in another constituent. Dissolved organic carbon (DOC) concentrations decreased with time at some wells, although initial ground-water concentrations of DOC were much lower than the observed levels in wastewater (table 5). As in the case of phosphorus changes, no statistically significant trends were found, but concentrations commonly dropped from mean values greater than 1 mg/L in 1980 to 0.2 to 0.3 mg/L in 1982. Dissolved organic carbon is likely to be largely removed during infiltration through the substrate (Thomas and Bendixen, 1969). Oxidation of organic material by increased microbial activity is the likely cause of the DOC changes. This process also was suggested by Wood and Petraitis (1984) as the cause of increased concentrations of carbon dioxide with depth in the unsaturated zone. Release of carbon dioxide would tend to lower pH levels, as observed at well 9 (fig. 19).

None of the fecal bacteria, major cations, anions other than chloride, or trace elements showed any consistent pattern of change with time at any of the wells. For Ca, Mg, SO_4, F, and trace elements, these results are consistent with what might be expected from data shown in table 5: little potential for change was indicated by comparison of the background water-quality data with wastewater data, and indeed, no change was found. On the other hand, coliform bacteria, sodium, and potassium were at much higher concentrations in wastewater than in ground water, yet still did not increase in ground water during the spray irrigation. This is not surprising in view of the limited mobility of coliform bacteria in clayey soils and the likelihood of cation exchange retention of sodium and potassium on clay particles (Freeze and Cherry, 1979).

The specific conductance changes that were observed at some wells (such as well 36, fig. 19) probably relate to the increases in common ions. A chloride concentration increase from 5 mg/L to 15 mg/L, such as that observed at well 9 from late 1980 to late 1982, can account for an increase in specific conductance of approximately 40 µs/cm (Greenburg and others, eds., 1980). The actual increase should be somewhat more than that because of contributions by other ions along with chloride. The data indicated a conductance increase of approximately 70 µs/cm during the 2-year period.

The decrease in pH may be due to some decrease in the buffering capacity of the water, and perhaps some dissolution of carbon dioxide. The lower alkalinity of ground water relative to wastewater (table 5) implies reduced capability of the water to neutralize acidity of inflowing water. Both wells where decreasing pH trends were observed are relatively shallow. No such trends appeared in deeper ground water.

General Water-Quality Considerations

In overall view, water quality of the ground water beneath the southeast spray field showed unmistakable effects of the land application of wastewater by spray irrigation. This should not be interpreted as a sign of serious degradation of water quality, only that there have been changes, some of which have unquestionably resulted from the spray irrigation. Increases of chloride to 25 mg/L and inorganic nitrogen to 5 mg/L still leave these constituents at concentrations well below drinking water maximum limits, (Florida Department of Environmental Regulation, 1982). But these increases at certain wells within the center-pivot spray areas are evident, especially beginning in the latter part of 1981. In nearly all cases, they also establish upward trends which have been statistically confirmed.

The lack of obvious water-quality changes at most wells indicates that as of December 1982, horizontal migration of irrigation-water constituents was very limited. At particular points of recharge, especially within center-pivot areas, concentrations of conservative constituents were readily impacted by wastewater irrigation, but the effect was still diluted rapidly by the voluminous flow in the Upper Floridan aquifer. Horizontal migration, or plume development, was not yet important.

It is useful to consider these results in comparison to observations by Slack (1975) and Yurewicz (1983) at the southwest field after 15 years of wastewater spray irrigation. Chloride levels in many wells from the southwest field were well above background levels, clearly showing an effect of the irrigation. However, conditions there seemed to stabilize after several years of increasing trends. For example, at a 51-foot well 1,800 feet downgradient from the southwest spray field, chloride increased from 2 mg/L (background) to approximately 17 mg/L during 1972 and 1973 (Slack, 1975) but then seemed to stabilize. Later, from 1975 to 1980, Yurewicz (1983) observed chloride concentrations which consistently remained within the 10-20 mg/L range. Similarly, the nitrate-nitrogen trend showed a 1- or 2-year increase but then leveled to a relatively constant value.

The data from the much newer southeast field give no indication that a steady-state condition had been reached at any of the monitor wells by the end of 1982. Future monitoring of these sites may show a leveling-off period which could be a sign of relatively "steady state" conditions. As of the end of 1982, at the wells where increasing trends have occurred, the leveling off has not yet begun. Other wells, deeper or more distant from the recharge zone, might be expected to follow delayed but similar trend patterns as the irrigation water moves horizontally and vertically.

This study did not include any analysis of organic compounds other than dissolved organic carbon. Because of the use of pesticides in the fields, the possibility of industrial wastes in Tallahassee wastewater, and the potential formation of chlorinated hydrocarbons by chlorination treatment of wastewater, it is suggested that future monitoring include some organic analyses.

SUMMARY

Since late 1980, the City of Tallahassee, Fla., has utilized a 1,840-acre field southeast of the city for spray irrigation of secondary-treated wastewater from its wastewater treatment facility. The field is used for cultivation of livestock feed crops. The irrigation rate during the period 1980-82 ranged from 0.8 inch to nearly 10 inches per month, with a mean of 6.3 inches per month.

The U.S. Geological Survey began monitoring water levels and water quality of ground water at the spray field 9 months before irrigation was initiated. The purpose was to determine effects of the spray irrigation on water levels and water quality of the ground water. The study continues but this report provides information from the first 3 years of data collection (1980-82).

The spray field is underlain by a surficial aquifer consisting of fine silt and clayey sand, which is partially separated from the deeper upper Floridan aquifer by a discontinuous clay layer. The Floridan, composed of various limestone formations, exhibits ground-water flow in a generally southwest direction across the spray field. The gradient within the Upper Floridan aquifer is generally upward in this part of north Florida, but a local downward gradient exists near the southern boundary of the spray field.

Three years of monthly water-level measurements from wells in various parts of the field showed significant correlation between water level and rainfall. There was also some correlation between water level and irrigation rate, but when the rainfall and irrigation rates were widely different, rainfall was the dominant control on ground-water levels.

Treated wastewater used for spray irrigation was found to have notably higher concentrations of chloride, all nitrogen species, phosphorus, organic carbon, and coliform bacteria than those found in ground water. Nevertheless, water-quality effects of the spray irrigation on ground water were generally limited to increases in chloride and nitrate at some wells. All effects observed by December 1982 occurred in the north central and south central areas of the field. Horizontal migration by this time was very limited.

As of December 1982, after more than 2 years of land treatment, the data clearly show that there are points where irrigation water has had some effect on ground-water quality. Nevertheless, the concentrations of all constituents in the ground water have remained below drinking water maximum levels set by the Florida Department of Environmental Regulation. Soil retention of constituents other than chloride and nitrate-nitrogen in the irrigated wastewater is apparently quite effective. There is no result of the investigation to date that suggests harmful degradation of ground-water quality due to wastewater application by spray irrigation. Steady-state conditions have not been reached, however, and it will be important to maintain a monitoring program at least as long as trends of concentration changes appear to be in effect.

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