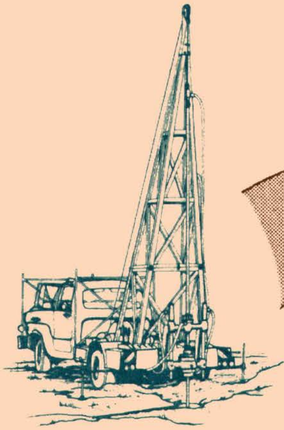
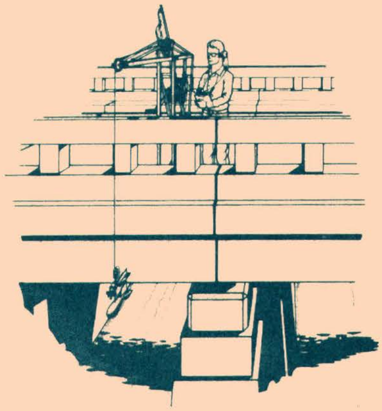
EFFECTS ON GROUND-WATER QUALITY FROM IRRIGATING PASTURE WITH SEWAGE EFFLUENT NEAR LAKELAND, FLORIDA





U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 76-108

Prepared in cooperation with the
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

WRI 76-108 EFFECTS ON GROUND-WATER QUALITY FROM IRRIGATING PASTURE WITH SEWAGE EFFLUENT NEAR LAKELAND, FLORIDA WRI 76-108

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16. Abstracts Since 1969 an average of 25,000 gal/d of domestic secondary-treated effluent has been used to supplement irrigation of 30 acres of grazed pasture north of Lakeland, Fl. Monitor wells were constructed near the effluent-irrigated pasture. The water table in the surficial aquifer under the pasture varied from 1.0 to 3.3 feet below land surface. Total nitrogen was less than 20 percent of the effluent content after percolating 8 feet; no increase in nitrogen was detected 20 feet below the surface, or in down-gradient ground water. There was no evidence of phosphorus or carbon contamination of ground water. Low numbers of bacteria (generally coliform) were noted in some samples from nine wells. Four wells sampled contained bacteria of probable fecal origin. Low-rate application of the effluent to the pasture apparently has had little effect on the soil and ground water.

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By R. C. Reichenbaugh

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Water-Resources Investigations 76-108

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Factors for converting English units to metric units are shown to four significant figures. However, in the text, the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

Multiply English units	By	To obtain Metric units
	Length	
in (inches)	2.54×10^{1}	mm (millimeters)
ft (feet)	3.048×10^{-1}	m (meters)
mi (miles)	1.609	km (kilometers)
	Area	
acres	4.047×10^{-3}	km^2 (square kilometers)
acres	4.047×10^{-1}	ha (hectares)
mi^2 (square miles)	2.590	km^2 (square kilometers)
	Volume	
gal (gallons)	3.785	L (liters)
	Rate	
ft/d (feet per day) hydraulic conductivity (feet per day per square foot)	.3048	m/d (meters per day)

EFFECTS ON GROUND-WATER QUALITY FROM IRRIGATING PASTURE WITH SEWAGE EFFLUENT NEAR LAKELAND, FLORIDA

By

R. C. Reichenbaugh

ABSTRACT

Since 1969, on the average, 25,000 gallons (94,600 liters per day) of domestic secondary-treated effluent has been used each day to supplement irrigation of 30 acres (12 hectares) of grazed pasture north of Lakeland, in west-central Florida. The U. S. Geological Survey began a study of the site several months after sprinkler application of the effluent to the Myakka sands (well-sorted, fine, acid) was started. The site, on the south shore of Lake Gibson, is underlain by as much as 60 feet (18 meters) of sand, sandy clay, and clay, containing the water-table aquifer, and two relatively unimportant confined aquifers, which in turn are underlain by the confined Floridan aquifer.

Monitor-wells were constructed to various depths in clusters near the effluent-irrigated pasture. The water table in the surficial aquifer varied from 1 to 3.3 feet (0.3 to 1.0 meters) below the land surface. Ground-water quality was evaluated by analysis of water samples collected three times over a 1-year period.

Ground-water beneath the irrigated pasture showed slight increases in cations and anions which are attributed to irrigation with the effluent. The concentration of total nitrogen (predominantly ammonia and organic nitrogen) was reduced to less than 20 percent of that in the upper 8 feet (2.4 meters) of pasture soils, and there was no increase in concentration below 20 feet (6.1 meters), or in downgradient ground water. There was no evidence of phosphorus or carbon contamination of ground water at the site. Though small numbers of bacteria were noted in some samples from nine wells, most were of the coliform group. Only four wells yielded samples containing bacteria of probable fecal origin--one colony per 100 milliliters in each sample.

There was no detected accumulation of solids at the soil surface. Organic carbon, pH, and kjeldahl nitrogen concentrations of the soil in the irrigated pasture were only slightly higher when compared to soil outside the pasture. As of 1972, the low-rate application of the effluent to the pasture apparently has had little effect on the soil and ground water.

INTRODUCTION

During the last 10 years, Florida's mild and agreeable climate has made it one of the fastest growing states in the nation. A large number of people have immigrated to Florida for retirement, to enjoy the mild climate, or to earn their livelihood in the thriving tourism industry. Many problems, such as those associated with the disposal of solid and liquid wastes, are undesirable byproducts of such rapid growth. As the population increases, the problems associated with waste disposal become more acute, and the effects of inadequate waste treatment become more pervasive. Coincident with waste disposal problems is the problem of protecting water resources.

Efforts are underway in many places to develop a suitable means of treating human waste, to renovate the waste water, and to introduce the renovated effluent into the hydrologic cycle. One of the oldest of such practices, and one now receiving renewed attention, is the practice of returning the wastes directly to the land, relying on the natural processes of chemical and physical sorption, organic decomposition, and nutrient uptake by vegetation to accomplish waste treatment. Modern practices attempt to combine the present techniques of secondary waste treatment and disinfection with land disposal, hoping to achieve the ultimate in waste treatment: an environmentally acceptable effluent at a cost that is acceptable to the public.

At several sites in Florida (Tallahassee, Tampa, and near Tarpon Springs) land disposal of agricultural and human wastes has been practiced. This report details the study of a site near Lakeland in central Florida (fig. 1), where domestic-waste-treatment-plant effluent is being applied to a grazed pasture.

In September 1969, the managers of the retirement home owned by the United Brotherhood of Carpenters and Joiners (Carpenters' Home) began irrigating about 30 acres (12 ha) of pasture at the home with effluent from its secondary treatment plant. Earlier, the effluent had been routed to nearby Lake Gibson. As bacteria counts in the lake increased, concerned local health authorities urged the home's operators to develop an alternate means of effluent disposal. Irrigation and crop experts of the U. S. Department of Agriculture suggested the disposal of effluent by pasture irrigation and assisted in the design of the present operating system.

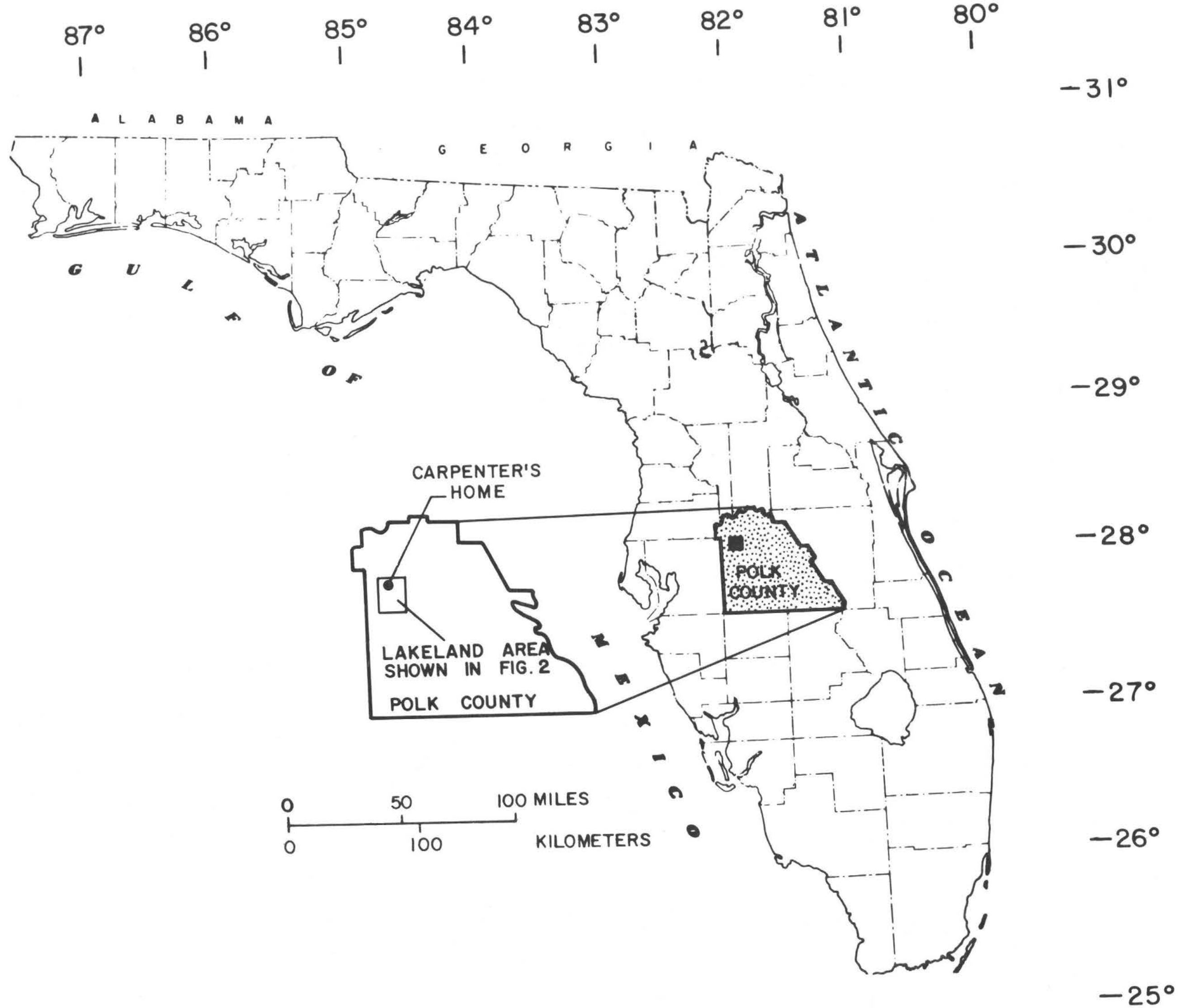


FIGURE 1.--Location of the Carpenter's Home near Lakeland
Polk County, Florida

Objectives

In 1970, the U. S. Geological Survey, in cooperation with the Southwest Florida Water Management District, undertook the study of the effluent disposal site at the Carpenters' Home. The Southwest Florida Water Management District officials deemed the site ideal for initiation of studies of land disposal of treated human wastes in west-central Florida.

The objectives of the study were: (1) to determine the effectiveness of the pasture vegetation and the soil and sub-soil material in assimilating the wastes discharged by the secondary treatment plant, and (2) to provide insight into the nature of changes taking place in the soils and shallow ground water as a result of the continued application of the effluent.

Water-management officials recognized that knowledge gained from such studies would aid them in identifying the environmental factors important to the success of such practices. They foresaw that even though land developers and municipalities might tend to use potentially undesirable tracts of land for waste disposal by land spreading, nonetheless, if the proper safeguards were employed in system designs and operations, that means of disposal could prove beneficial.

Pasture irrigation using the treated sewage effluent provides an opportunity for nutrient removal by soil, vegetation, and microorganisms. The nutrients, if allowed to enter surface-water bodies, are potentially harmful. They cause enrichment and accelerate the process of eutrophication. The soils also provide a filtering medium, removing suspended solids and bacteria. The water irrigates the pasture, thus offsetting the need to pump an equal amount of potable water from aquifers. Finally, the irrigation could be a means of recharging an aquifer.

Acknowledgments

The author acknowledges the full cooperation of Don Feaster, Executive Director, Southwest Florida Water Management District, during the course of this investigation. The study also received cooperation of the management of the Carpenters' Home, agents of the Soil Conservation Service of the U. S. Department of Agriculture, and Polk County officials. The author acknowledges the assistance rendered by Joseph Sandford, Chief Engineer at the Carpenters' Home, and his staff, including Leamon Starling and Frank Pritchard, who operate the disposal system, and John Reed, District Conservationist, of the USDA (U. S. Department of Agriculture), SCS (Soil Conservation Service) at Bartow.

Methods of Investigation

The approach to the evaluation of the effects of irrigation using the treated wastes from the home was to install and maintain a network of small diameter PVC (polyvinylchloride) cased wells finished with 2 ft (0.6 m) of metal screen in and around the sprayed acreage to monitor the depth to the water table and the chemical quality of the shallow ground water. The study commenced several months after sewage-effluent irrigation had started, so data regarding pre-spray water quality and soil characteristics were not available. A meter was installed to measure the daily and total volume of effluent applied to the 30 acres (12 ha) irrigated by sewage effluent. Water samples for comprehensive analysis were collected in February 1971, October 1971, and February 1972. Soil samples were collected in June 1972 to compare the chemical and physical character of the soils under irrigation to similar soils not receiving wastes.

LOCATION

The United Brotherhood of Carpenters and Joiners Home is located in northwestern Polk County on a 2,000-acre (809-ha) site adjoining the south shore of the 477-acre (193-ha) Lake Gibson about 2 mi (3.2 km) north of Lakeland on U. S. Route 98 (fig. 2). At the home are buildings housing 200-250 persons, an 18-hole public golf course, citrus groves, and 285 acres (115 ha) of grassed pasture, about 30 acres (12 ha) of which are being irrigated with sewage effluent from the home. Details of land use near the effluent-irrigated pasture are shown in figure 3.

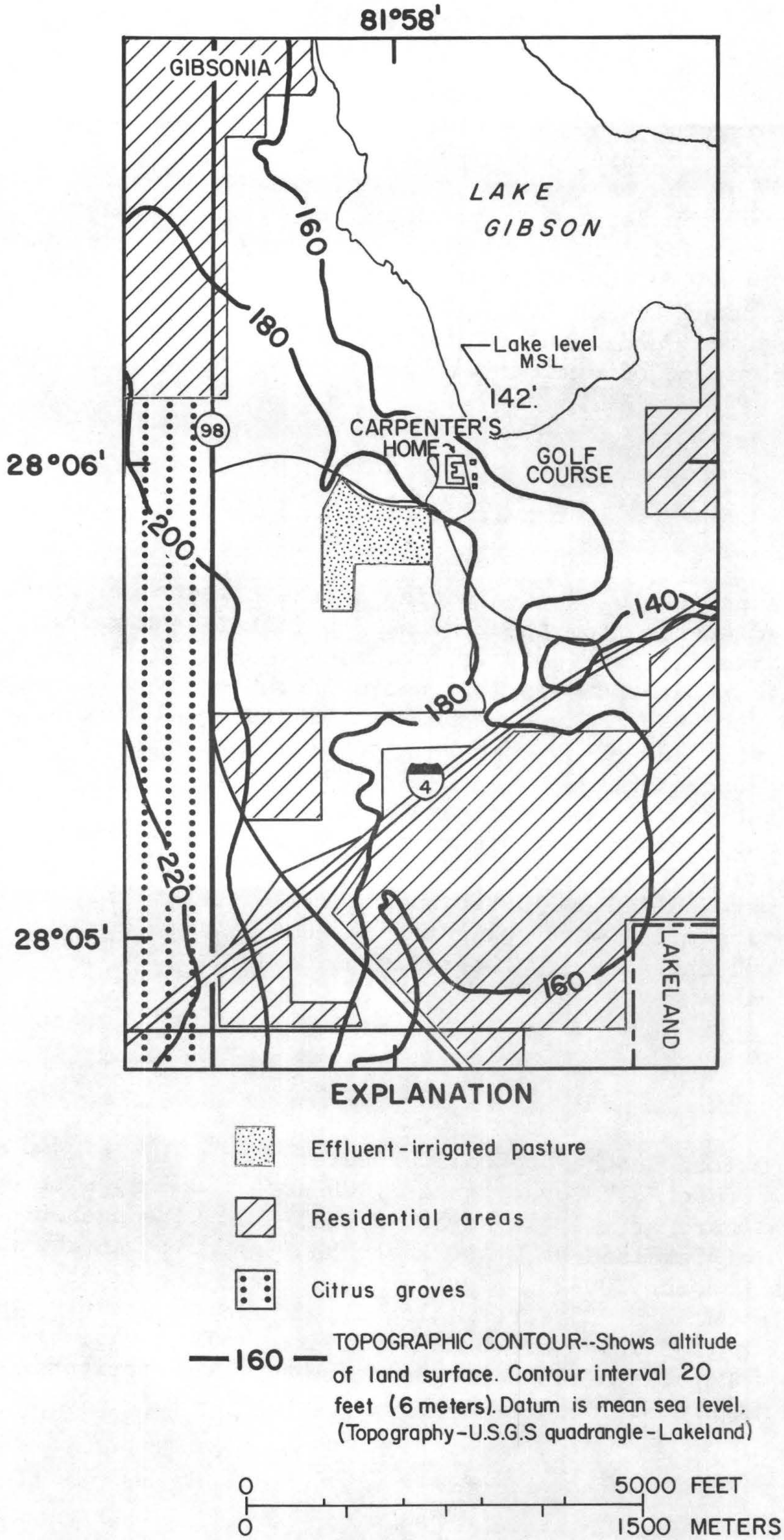


FIGURE 2.--Location of the Carpenter's Home and nearby land use.

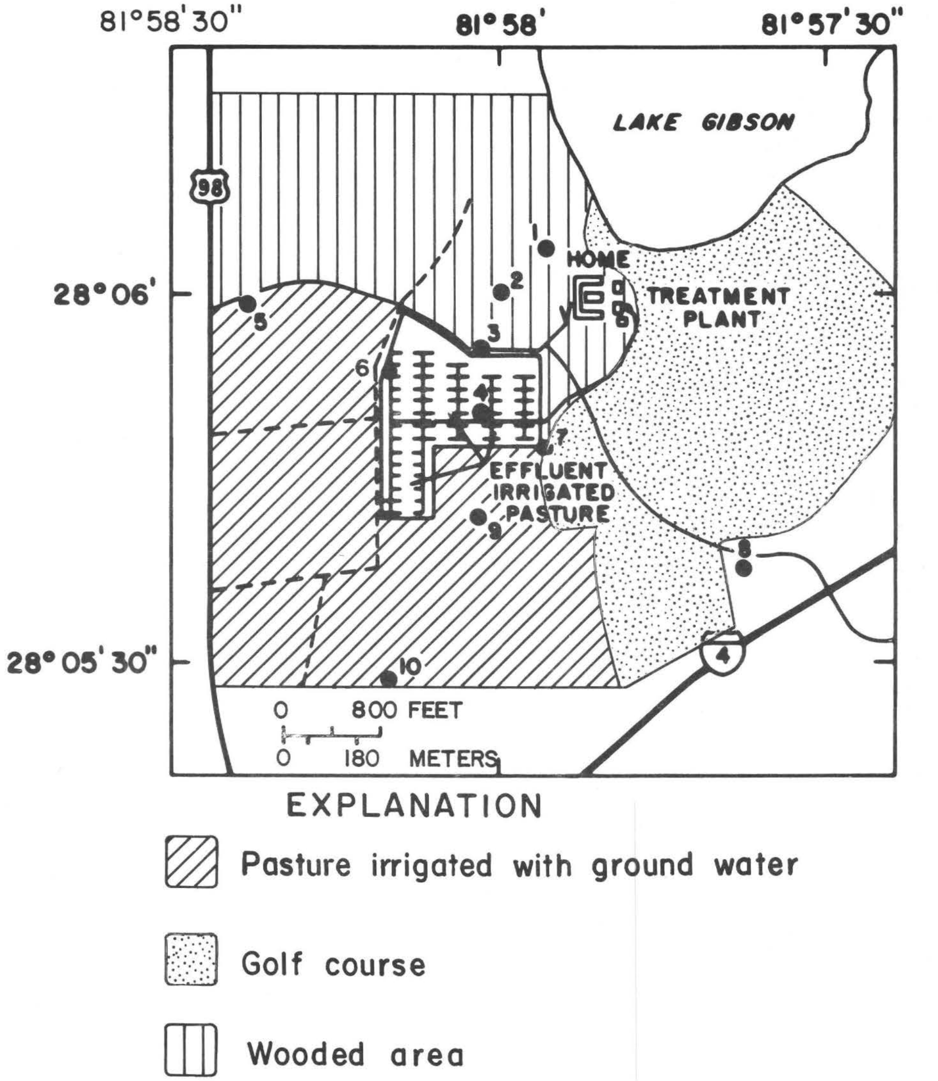


FIGURE 3.--Land use in the vicinity of the effluent-irrigated pasture at the Carpenter's Home.

The average annual temperature in Lakeland is 72°F (22°C); the monthly average in January is 62°F (16°C) and in August, 82°F (28°C). Winters are characterized by bright, warm days, cool nights, and light to moderate rainfall. Although winter weather is seldom severe, major cold waves occur, and minimum temperatures are in the mid-twenties to low thirties. Lakeland's summers are long; maximum temperatures generally range from the high eighties to mid-nineties. Minimum temperatures in summer usually are in the low seventies.

The average annual rainfall is about 51 in (1,300 mm), of which more than half occurs from June to September in the form of thundershowers. Heavy showers are known to produce 3 in (76 mm) or more of rain over a small area in an hour. Tropical disturbances (storms and hurricanes) with their associated widespread heavy rains, although infrequent, occur in the summer and fall. In June, July, and August the average monthly rainfall is more than 7 in (178 mm); in November, the driest month, the average rainfall is less than 2 in (51 mm). Rainfall during the late fall, winter and early spring is usually associated with large-scale weather systems and their accompanying frontal activity, and is more general in nature and occurrence (Butson and Prine, 1968).

A National Weather Service observation station is located in Lakeland, about 4 mi (6.4 km) south of the Carpenters' Home, and 214 ft (65 m) above mean sea level. The normals, means and extremes of temperature, precipitation and related meteorological parameters are summarized in table 1.

Table 1.--Normals, means, and extremes of temperature, precipitation, and other climatological data at Lakeland.
(From U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Services, 1972)

Month	Temperature (°F) Normal Daily maximum	Temperature (°F) Normal Daily Minimum	Temperature (°F) Normal Monthly	Temperature (°F) Extremes Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)[1]	Precipitation (inches) Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Wind (mi/hr) Mean speed (mi/hr) $	Prevailing direction #	Pct. of possible sunshine	Mean sky cover sunrise to sunset[2]	Mean number of days: Sunrise to Sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms %	Heavy fog %	Temperature Max. 90° and above	Max. 32° and below	Min. 32° and below	Min. 0° and below
(a)	(b)	(b)	(b)	32		32		(b)	(b)	32		32		32		13	18	19	23	32	32	32	32	32	24	24	32	32	32	32
J	71.2	52.2	61.7	85	1947+	25	1970	195	2.05	8.74	1948	0.12	1950	3.88	1945	7.3	NE	61	5.1	10	12	9	6	0	1	4	0	0	1	0
F	72.8	53.3	63.1	88	1962+	28	1970+	146	2.51	6.59	1963	0.17	1945	3.92	1971	7.8	NE	63	5.3	10	9	9	7	0	2	3	0	0	*	0
M	76.7	56.3	66.5	91	1949	30	1943	99	4.25	12.94	1960	0.78	1949	6.96	1960	7.8	W	65	5.3	10	11	10	8	0	4	2	*	0	*	0
A	81.3	61.7	71.5	95	1968	40	1950	0	3.51	8.48	1959	0.00	1967	4.41	1941	7.7	E	72	4.8	11	12	7	6	0	4	1	1	0	0	0
M	86.8	66.9	76.9	99	1945	54	1971+	0	3.54	9.68	1957	0.13	1953	4.36	1968	6.9	E	72	5.1	10	14	7	9	0	9	*	8	0	0	0
J	89.9	71.2	80.6	100	1945	63	1949	0	7.20	14.86	1968	1.87	1948	10.12	1945	6.2	E	63	6.3	4	16	10	14	0	18	*	17	0	0	0
J	90.5	72.6	81.6	101	1942	66	1947+	0	8.30	15.67	1960	3.09	1961	6.66	1960	5.7	S	60	6.6	2	18	11	18	0	23	*	21	0	0	0
A	90.6	73.3	81.9	98	1961+	63	1957	0	7.08	15.57	1948	3.40	1942	6.20	1949	5.5	NE	60	6.3	3	18	10	18	0	22	*	21	0	0	0
S	88.1	72.2	80.2	97	1944	61	1947	0	6.55	11.68	1947	0.81	1972	6.34	1960	6.6	NE	58	6.1	5	15	10	14	0	12	*	11	0	0	0
O	82.8	66.1	74.5	94	1959+	43	1957	0	2.93	6.72	1952	0.25	1942	4.99	1944	7.2	NE	64	5.1	12	11	8	8	0	3	1	2	0	0	0
N	75.9	57.8	66.9	89	1946+	28	1970	57	1.59	5.94	1941	T	1960	3.97	1963	6.9	NE	66	4.5	12	11	7	6	0	1	3	0	0	*	0
D	71.7	53.1	62.4	85	1971+	20	1962	164	1.86	5.33	1941	0.09	1944	4.08	1949	6.9	NE	64	4.9	11	11	9	6	0	1	5	0	0	*	0
YR	81.5	63.1	72.3	101	JUL. 1942	20	DEC. 1962	661	51.37	15.67	JUL. 1960	0.00	APR. 1967	10.12	JUN. 1945	6.9	NE	64	5.5	100	158	107	120	0	100	19	82	0	2	0

1 Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F.
2 Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.
(a) Length of record in years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-60).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
% Through 1964. The station did not operate 24 hours daily. Data may be incomplete.
$ Through 1964.
\# To eight compass points only. From records through 1958.

GENERAL GEOHYDROLOGY OF THE LAKE GIBSON AREA

Physiography

Polk County is in the central, or mid-peninsular zone, one of the three major geomorphic divisions of the Florida peninsula (White, 1970). The zone is characterized by discontinuous highlands in the form of nearly-parallel ridges separated by broad valleys. In general, the ridges of the central zone are well drained and are above the potentiometric surface of the upper part of the underlying Floridan aquifer. Broad shallow lakes are common on the low-lying, level, poorly-drained expanse of valleys; smaller, deep, nearly-circular sinkhole lakes dot the ridges (Cathcart, 1964, p. G6). The Carpenters' Home adjoins Lake Gibson on the east side of the northern end of the Lakeland Ridge (Robertson, 1973). The land at the home ranges in altitude from 142 ft (43 m) at the shore of Lake Gibson to about 200 ft (60 m) near the southwest part of the grounds. Lake Gibson is one of several large lakes in the county whose irregular or complex arcuate shorelines result from the coalescing of the small sinkholes (Stewart, 1966, p. 69).

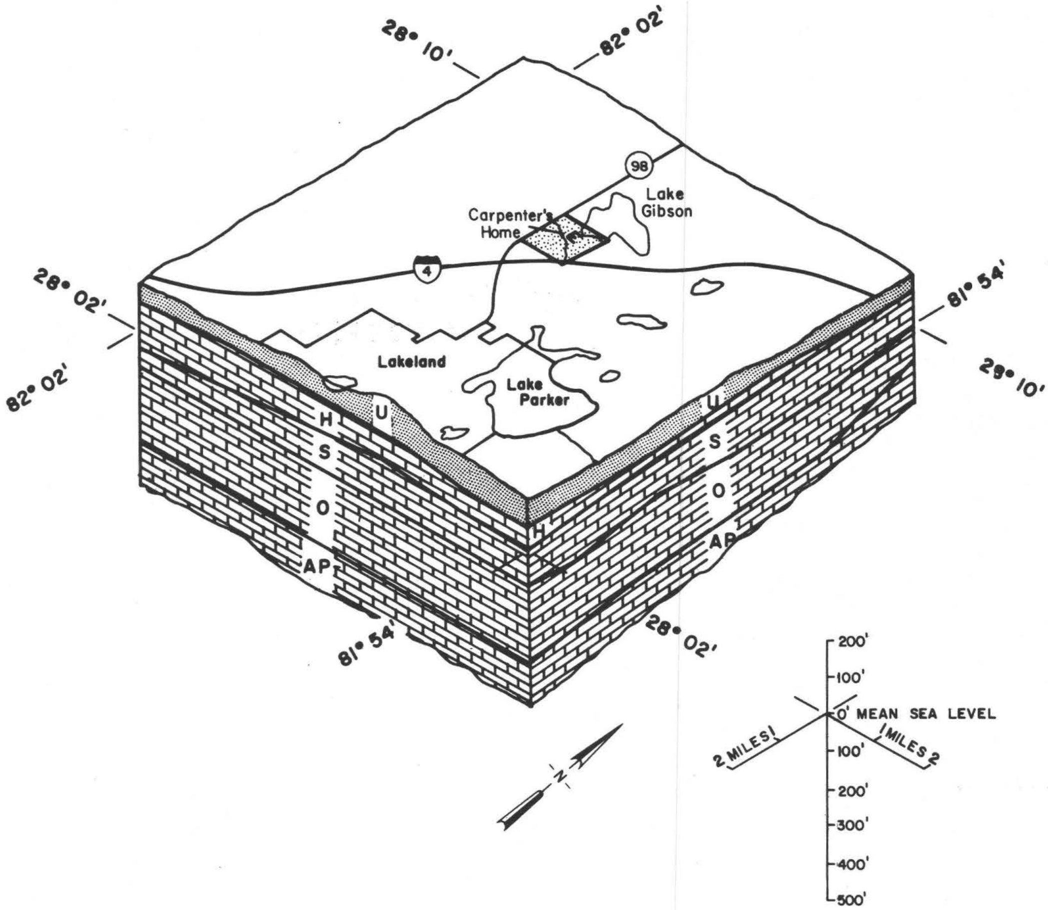
Geology

Stewart (1966) and Robertson (1973) described the geology of the region in sufficient detail to provide insight into the geohydrology of the Lake Gibson and Carpenter Home area.

The generalized geology of the Lakeland Ridge area is shown in figure 4. The limestones of the confined Floridan aquifer are composed of the Avon Park and Ocala Limestones (Eocene), the Suwannee Limestone (Oligocene) and limestone of the Tampa Formation (Miocene) where sufficiently connected hydraulically with the underlying rocks. The Floridan aquifer is overlain by limestone and clay of the Hawthorn Formation (Miocene). The Hawthorn Formation is overlain by phosphatic sand and clay of the Bone Valley Formation (Pliocene) which, in turn, are overlain by surficial deposits of sand and clay.

The Hawthorn Formation is about 60 ft (18 m) thick in the Lake Gibson area. The upper part is extensively eroded forming an irregular karst surface into which overlying sediments have collapsed, creating a land surface with many small irregular depressions and hills (Cathcart, 1964).

The Bone Valley Formation is divided into a phosphatic lower unit and a clay-sand upper unit. The lower unit is predominantly clayey sand or sandy clay, but beds of loose phosphatic sand are common; beds



EXPLANATION

GEOLOGIC UNIT	HYDROLOGIC UNIT	SYMBOL
Undifferentiated surficial deposits (Sands, clays, and pebble phosphate zone; Bone Valley Formation)	Water-table aquifer / Uppermost artesian aquifer	U
Hawthorn Formation and Tampa Formation, undivided	Secondary artesian aquifer	H
Suwannee Limestone	Floridan aquifer	S
Ocala Limestone		O
Avon Park Limestone		AP

FIGURE 4.--Generalized geohydrology of the Lake Gibson-Carpenter's Home area.

of clay, though present, are rare. The lower unit ranges in thickness from 0 to 35 ft (11 m) and averages about 10 ft (3 m) thick.

The upper unit consists of clayey sand or sandy clay and some beds almost entirely of sand, and includes all of the clayey sand that contains traces of phosphate. The upper unit ranges in thickness from 0 to 25 ft (7.6 m) and averages about 8 ft (2.4 m) thick.

The Bone Valley Formation is overlain by loose quartz sand of Pleistocene and Holocene age. The sand ranges in thickness from 0 to 58 ft (18 m); the contact between the two is selected on the basis of a change from clayey sand to loose sand. The loose sand is thickest on the ridges and thin or absent in the swampy lowlands and, at the home, is about 20 ft (6 m) thick. The sand is well sorted and consists of fine-to-medium-grained quartz. The grains are clear or milky and are commonly stained black or brown with organic material or iron oxide. Hardpan, sand cemented by iron oxide (limonite), is sparingly present, and then only at higher elevations at the site; the hardpan is usually found at the contact between the loose sand of the Pleistocene and Holocene and the clayey sand of the upper unit of the Bone Valley Formation (Cathcart, 1964, p. G 30, 31).

Soils

The soils in the vicinity of the Carpenters' Home were mapped and surveyed by the SCS (USDA). Soil names used conform to the most recent (1976) soil survey of Polk County (John Reed, USDA, SCS, Bartow, Florida, written communication, October 1976). Soil distributions are shown on figure 5.

The SCS classified the pastures at the Carpenters' Home into land capability class IV. The soils are highly permeable, generally poorly drained (excluding the moderately-drained Pomello), have a low moisture-retention capacity (generally 1.5 to 3.0 in (3.8 to 76 mm) total in the upper 3 ft (1 m) of soil) and a low organic content, the soils are most suited to improved pasture requiring water management. The Myakka soils have a shallow root zone which causes the soils to be dry during periods of low rainfall. The Myakka soils are also subject to rapid leaching and to periodic wetness in the vicinity of a widely fluctuating water table.

To supplement existing general descriptions of the soil as provided by the SCS, soil samples were collected at several locations in and near the sprayed pastures in June 1972. Sections of the pasture were designated A, B, C, D, and E (fig. 5).

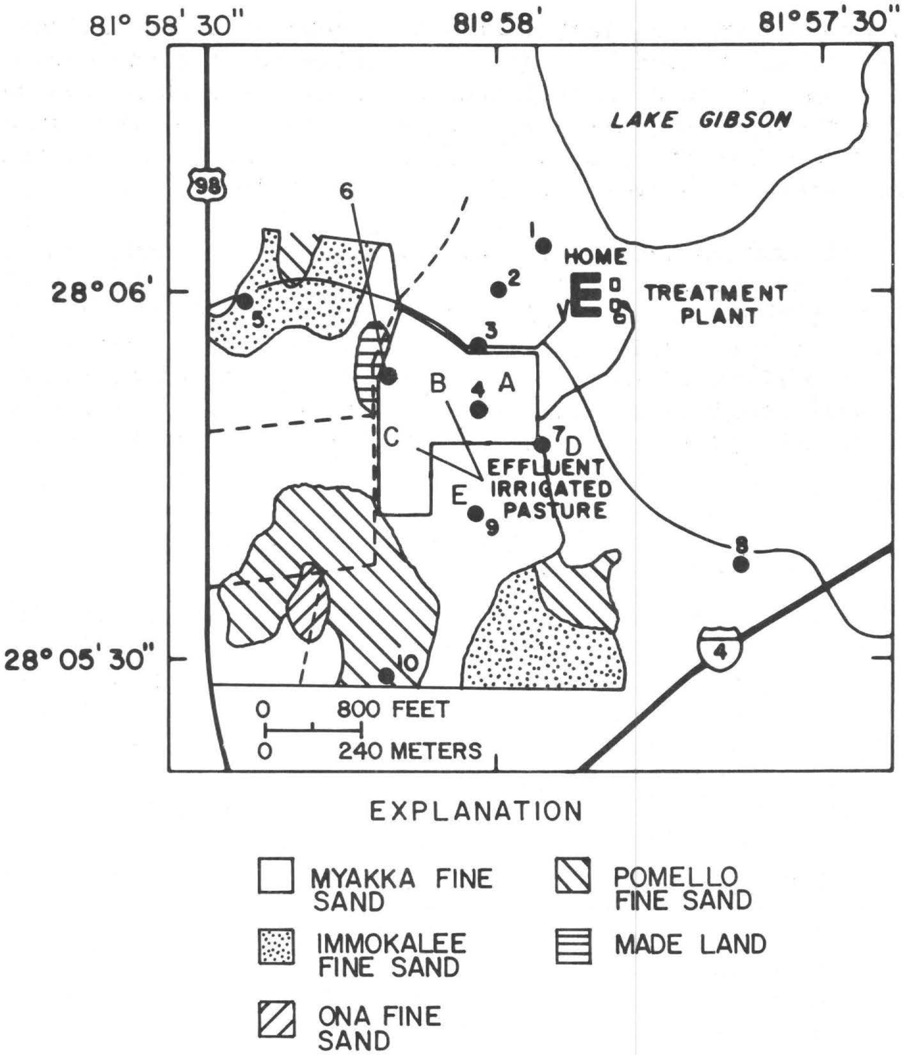


FIGURE 5.--Distribution of soil types and soil-sampling locations in and near the irrigated pasture.

Soil samples were collected with an "orchard" or bucket sampler of the type normally used by the SCS. Samples for a given depth were collected from four randomly-selected sites within each of the pasture sections, composited and mixed thoroughly; a portion of the mixed sample was frozen in dry ice and transported to the U. S. Geological Survey Laboratory in Denver, Colorado for analysis.

The soil samples were integrated to represent typical soil conditions at (1) the surface 1 to 6 in (25 to 152 mm); (2) the top of the water table at the time of sample collection; and (3) the top of the organic stain layer (spodic horizon). In addition, one sample was collected from 14 to 20 in (356 to 508 mm) below the water table to represent soil conditions there. Sampling depths and soil characteristics determined at each sampling site are shown in table 2.

Hydrology

According to Robertson (1973, p. 11), the Lakeland Ridge area (Lake Gibson area) is underlain by four aquifers. As shown in figure 4 these are: (1) the water-table aquifer, in permeable zones in the sandy and clayey surficial materials, (2) the uppermost artesian aquifer, in the pebble-phosphate deposits underlying the surficial sediments, (3) the secondary artesian aquifer, in limestone of the Hawthorn Formation, confined by clay of the Hawthorn Formation above and Tampa Formation below, and (4) the Floridan aquifer. The first three of these aquifers are relatively unimportant, generally used for domestic and small volume irrigation supplies.

The Floridan aquifer comprises limestones of Eocene to Miocene age. The Suwannee Limestone, which underlies most of the Lakeland Ridge area, constitutes the upper part of the Floridan aquifer. Locally, limestone of the Tampa Formation has sufficient hydraulic connection with the underlying Suwannee to be included as part of the aquifer. At places in the county where the Tampa and Suwannee are absent, the Ocala Limestone constitutes the upper part of the aquifer.

The base of the Avon Park Limestone is generally considered the base of the Floridan aquifer in Polk County. Most deep wells in the county terminate in the Avon Park Limestone, but a few penetrate the full thickness. Stewart (1966) described the Avon Park as the greatest water-producing unit in the Floridan aquifer in the county.

The four operating supply wells at the Carpenters' Home tap the Floridan aquifer. They are used for water supply to the home, and to irrigate the pastures and groves on the grounds. The confining clays of the unconsolidated sediments overlying the Floridan aquifer prevent local recharge to the aquifer from the surface.

Table 2. -- Soil characteristics at different depths below the effluent-irrigated pasture.

Composite sample location (fig. 5)	Depth interval sampled (inches)	Soil-water pH	Organic carbon (percent by weight)	Kjeldahl nitrogen (percent by weight)	Carbon exchange capacity (meq/100g)	Percent base saturation	Interstitial water carbon concentration (mg/L)		
							Organic carbon	Inorganic carbon	Total carbon
				Surficial Soil					
A	0-6	6.5	0.83	0.07	3.36	81.8			
B	0-6	6.8	1.11	0.09	3.52	97.0			
C	0-6	5.8	1.47	.07	7.72	43.6			
D	0-6	3.8	0.91	.05	3.76	17.8			
E	0-6	5.8	1.09	.04	1.60	84.4			
				Top of Water Table					
A	15-18	5.0	1.26	.05	7.72	12.8			
B	20-60	4.8	0.99	.03	7.40	7.3			
C	10-13	4.8	1.41	.08	14.4	6.5			
D	15-18	4.1	0.95	.04	4.76	8.8			
E	15-18	4.8	0.26	.02	1.74	14.4	45.7	1.6	47.3
				Top of Organic Stain Layer (Spodic Horizon)					
A	29-66	6.0	0.15	.01	1.06	24.3	4.7	4.8	9.5
B	30-72	4.8	0.26	.02	2.13	12.7			
C	30-76	4.6	0.35	.02	2.66	8.6	16.2	4.7	20.9
D	40-44	6.2	0.10	.02	1.26	19.1	47.0	1.2	48.2
E	20-36	4.4	1.82	.07	8.60	6.5			
				Below Water Table					
A	54-60	5.6	0.11	.08	1.36	18.9	94.2	2.2	96.4

The Lakeland Ridge is underlain by aquifers that generally supply water of good quality that requires only treatment by aeration and chlorination where used for public supply. To depths of about 500 ft (150 m) below land surface, the quality of water in the Floridan aquifer is generally uniform, at least since the 1950's. The chemical quality of the water from one of the home's irrigation wells is shown in table 3 (11F, Fig. 7).

A generalized north-south section across the pasture is shown in figure 6. Almost everywhere the pasture is underlain by the water-table aquifer. Generally the aquifer--a layer of sand--extends to about 10 ft (3 m), and the silty-sand hardpan about 10 to 12 ft (3.0 to 3.7 m), below the surface. Elsewhere, water-table aquifer depth extends to as much as 19 ft (5.8 m) below pasture surface.

Below the hardpan, the base of which is the contact with the upper unit of the Bone Valley Formation, lies the uppermost artesian aquifer, which is composed of sand with increasing clay content to about 18 ft (5.5 m), and undifferentiated layers of sand, clayey sand, and clay to more than 40 ft (12 m), the maximum depth penetrated at all but one monitor site.

The water-table aquifer in the vicinity of the pastures at the home is composed of a well-sorted fine sand having sorting coefficients less than 1.67; the median grain size of the sand ranges from 0.150 to 0.170 mm.

Hydraulic conductivity (formerly field coefficient of permeability) is a measure of the volume of water at the existing kinematic viscosity that will move in a unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. The measurement assumes the porous medium to be isotropic and the fluid homogeneous. The vertical hydraulic conductivity has been determined and reported in table 4.

Values in table 4 show that, in the area of the effluent-irrigated pasture, the vertical hydraulic conductivity is greatest near the surface and becomes progressively less with depth as the relative proportions of finer-sized particles increase. The lower values at depth indicate that vertical flow of water becomes less with depth. Water applied to the field will generally move laterally downgradient and away from the pasture.

Table 3. -- Chemical quality of water from an irrigation well tapping the Floridan aquifer at the Carpenters' Home.

(Concentrations in mg/L except as noted)

Well Number	Well Location Latitude/ Longitude	Date Sampled	Specific Conductance (micromhos/cm at 25°C)	pH at time of collection	Calcium (Ca)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate Nitrogen (NO_3-N)
11F	28°05'59"N/81°57'48"	2/29/72	305	7.2	110	6.6	0.4	145.	5.6	12	0.26

Nitrite Nitrogen (NO_2-N)	Ammonia Nitrogen (NH_3, N)	Organic Nitrogen (N)	Total Nirtogen (N)	Orthophosphate (PO_4)	Total Phosphorus (P)	Organic Carbon (C)	Inorganic Carbon (C)	Aluminum (Al, ug/l)	Iron (Fe, ug/l)	Zinc (An, ug/l)
0	0.06	0.37	0.69	0	0	1	32	0	0	1400

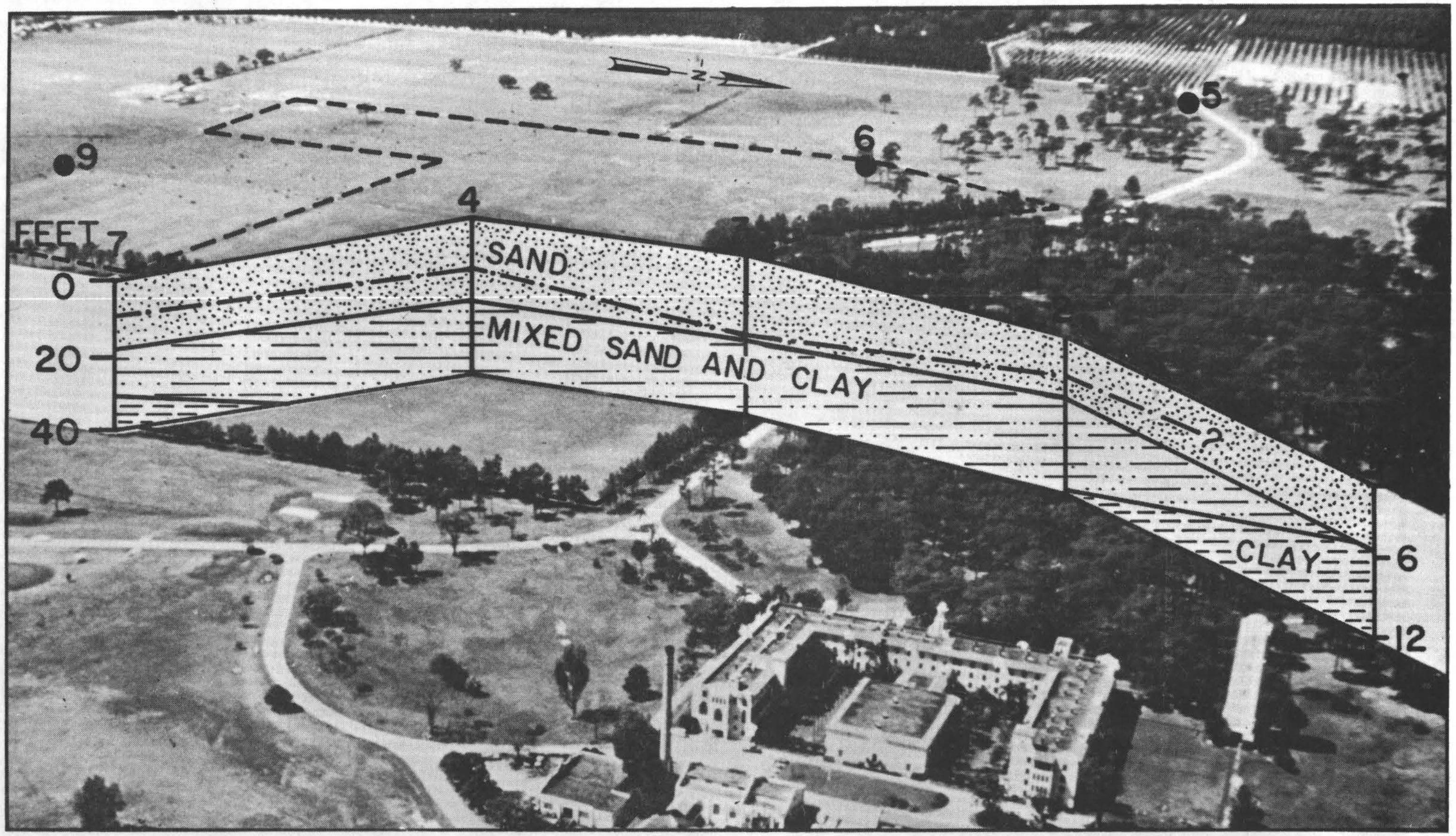


FIGURE 6.--Generalized relations of the unconsolidated surficial sediments at the study site. (Dashed line through section represents hardpan. Well sites are shown by number.)

Table 4.-- Hydrologic characteristics of the surficial sediments at the study site

Well site number	Depth sampled (feet below surface)	Vertical hydraulic conductivity (metres per day)	Effective size (mm)	Median grain size (mm)	Uniformity coefficient	Sorting coefficient	Skewness (Log_{10})	Percent in size range: Sand 0.062 mm to 2.0 mm	Percent in size range: Silt 4 microns to 0.062 mm	Percent in size range: Clay less than 4 microns	Specific gravity of solids grams/cc	Specific retention (percent)	Specific yield (percent)	Total porosity (percent)	Clay mineral identification by differential thermal analysis
2	5	--	0.070	0.165	2.64	1.29	0.01141	94.4	2.8	2.8	2.66				
2	10	0.25	.068	.165	2.65	1.29	.05475	94.6	0.6	4.7	2.64				
2	15	--	.070	.180	2.71	1.29	.02802	93.7	3.5	2.8	2.61				
3	2	--	.062	.165	2.90	1.47	.10252	90.0	5.1	4.9	2.55				
3	4	1.2	.078	.175	2.37	1.29	.03969	95.4	1.1	3.5	2.62				Illite
3	6	--	.068	.170	2.72	1.32	.05949	93.9	3.7	2.4	2.65				
3	8	0.6	.070	.165	2.57	1.31	.02284	94.3	3.2	2.6	2.65				Illite
3	10	0.8	.068	.170	2.65	1.41	.15936	94.4	4.1	1.5	2.62				
4	5	(a)	.070	.170	2.64	1.24	.01766	95.1	2.3	2.6	2.61	5.2	37.3	42.5	Illite
4	10	3.4×10^{-2}	.070	.165	2.57	1.32	.03356	94.2	3.4	2.5	2.63	3.8	38.8	42.6	Illite
4	15	4.7×10^{-3}	.017	.150	10.0	1.67	.21704	80.8	13.2	6.0	2.63				
6	5	--	.065	.160	2.77	1.45	.08602	93.7	3.1	3.2	2.61				
6	10	--	.002	.125	75	1.66	.12563	76.1	11.0	12.8	2.62				
6	15	--	.008	.125	18.75	1.50	.03545	89.3	2.0	8.7	2.64				
7	5	0.6	.070	.165	2.57	1.43	.12533	94.5	3.7	1.8	2.64				
7	10	12.9×10^{-3}	.008	.145	20.6	1.65	.19888	83.1	9.7	7.2	2.61				
9	5	--	.078	.180	2.44	1.27	.01223	94.3	3.5	2.1	2.62				
9	10	--	.072	.175	2.64	1.30	.02971	--	--						
9	15	--	.072	.170	2.57	1.31	.03154	--							

[a]disturbed sample - no value.

Monitor-well Network

Studies at the Carpenters' Home concentrated on evaluating the quality of the water in the depth range of 3 ft (0.9 m) to 29 ft (8.8 m) below land surface in the water-table and uppermost artesian aquifer. The underlying aquifers are well isolated from the shallower aquifers by clay and clayey sands which inhibit local recharge to them. Some monitor wells constructed to greater depths penetrated clay or clay lenses and yielded little or no water.

The monitor wells were constructed using 2-in (57-mm) diameter PVC (polyvinylchloride) pipe placed into an augered 6-in (152-mm) diameter open hole. Except in well 3-29, the PVC pipe was attached to screened well points, either of galvanized iron or stainless steel. Well 3-29 was constructed using 22 ft (6.7 m) of slotted PVC screen. Table 5 shows the location, elevation, and depth interval open to the aquifer at each site.

The monitor wells were constructed at 10 sites in and near the effluent-irrigated pastures at the home. At each site (locations shown in fig. 7) is a cluster of 2 to 6 wells open to different depths in the shallow aquifer. The wells are designated by a composite number. The first number is the site; the numerals after the hyphen represent the depth, in feet, to the top of the screen. The well numbered 3-27, for example, is at site 3 and is cased to 27 ft (8.2 m). Reference to table 5 shows that the well is open to the aquifer in the interval 27 to 29 ft (8.2 to 8.8 m) below land surface.

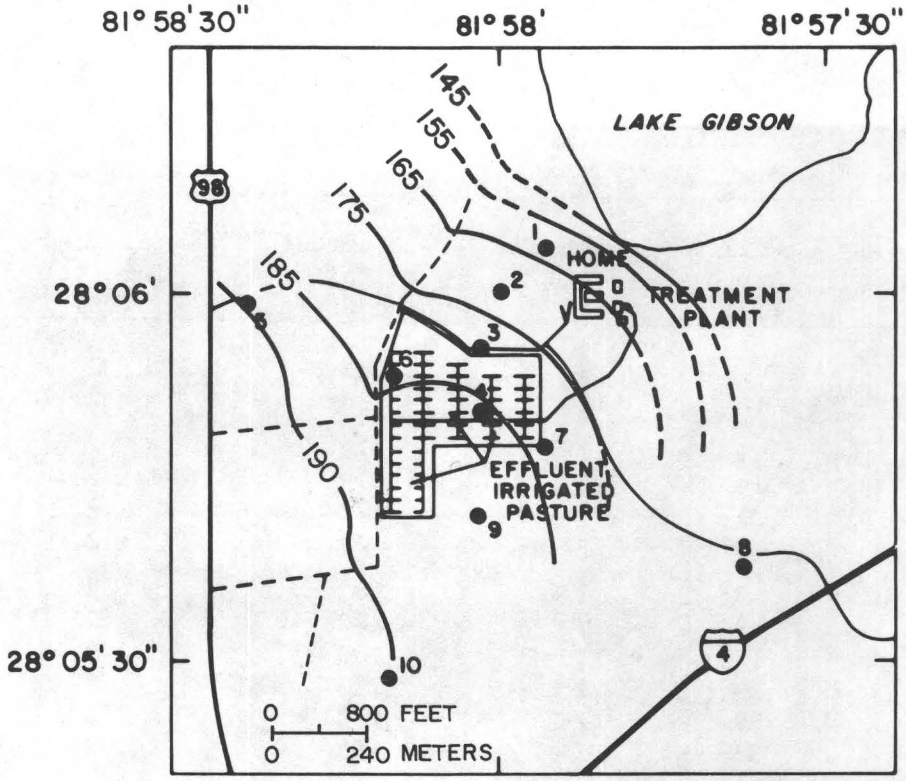
Water Levels in the Shallow Aquifer

Periodically during the study, water levels were measured at all wells in the monitoring network shown in figure 7. Except for well 4-74, all are open to the water-table aquifer or the uppermost artesian aquifer within the interval 3 - 40 ft (0.9 - 12 m) below land surface. Well 4-74 is open to the limey clay of the secondary-artesian aquifer in the Hawthorn Formation 74 ft (22.6 m) below land surface. The potentiometric surfaces in the secondary artesian aquifer and the underlying Floridan aquifer were several feet lower than the elevation of the water table, thus showing the potential for recharge of these aquifers should the confining clays be breached or absent, or by downward leakage through the clayey material.

Table 5. -- Description of 2-inch wells in the surficial aquifers at the study site.

(Depths are in feet below land surface; locations of wells are shown on fig. 7.)

Well Number	Well Depth (ft)	Casing Depth (ft)	Altitude of Land Surface	Length of Screened Interval (ft)
1-5	7	5	164	2
1-12	14	12	164	2
2-7	9	7	179	2
2-14	16	14	179	2
2-19	21	19	179	2
2-27	29	27	179	2
3-3	5	3	183	2
3-7	9	7	183	2
3-13	15	13	183	2
3-27	29	27	183	2
3-29	29	7	183	22
3-33	35	33	183	2
4-4	6	4	188	2
4-8	10	8	188	2
4-19	21	19	188	2
4-32	34	32	188	2
4-74	76	74	188	2
5-9	11	9	196	2
5-19	21	19	196	2
6-4	6	4	190	2
6-7	9	7	190	2
6-17	19	17	190	2
6-26	28	26	190	2
6-38	40	38	190	2
7-4	7	4	186	2
7-8	10	8	186	2
7-17	19	17	186	2
7-24	26	24	186	2
8-7	9	7	142	2
8-17	19	17	142	2
9-4	6	4	190	2
9-8	11	8	190	2
9-20	22	20	190	2
10-7	9	7	193	2
10-18	21	18	193	2



EXPLANATION

——175— — — WATER-TABLE CONTOUR--Shows altitude of water table, February 1972. Contour interval 5 and 10 feet (1.5 and 3 meters). Datum is mean sea level. Dashed where approximately located

●3 Well site and number

- - - - - - - - - - - - Ditch

+++++++++++ Irrigation pipe

Mean lake altitude 142.45 feet (43.45 meters), February 1972

FIGURE 7.--Locations of wells in the network and elevations of the water table at the study site, February 1972.

In the water-table aquifer water levels fluctuate in response to recharge by rainfall and irrigation, to discharge by gravity flow to lakes and streams, to evapotranspiration, to leakage to the underlying aquifers, and to discharge to wells. The confining clays of the unconsolidated sediments overlying the Floridan aquifer prevent local recharge to the aquifer from the surface. The general configuration of the water table in February 1972 is shown on figure 7. During this study the water table fluctuated less than 4 ft (1.2 m), chiefly in response to variations in seasonal rainfall and irrigation applications. Depth to the water table varied from 1 to 3.3 ft (0.3 to 1.0 m) below land surface in the sewage irrigated pasture (site 4) and from less than 1 to about 9 ft (0.3 to 2.7 m) in wells outside and in the vicinity of the pastures (table 6).

EFFLUENT IRRIGATION AND TOTAL WASTE LOAD AT THE STUDY SITE

The sewage-treatment facility at the Carpenters' Home was constructed about 1947. The facility consists of an Imhoff tank, which combines solids sedimentation with anaerobic decomposition, two trickling filters, and a secondary clarifier. Provisions are made to pump sediment from the secondary clarifier back to the Imhoff tank. Sludge is periodically removed from the tank and deposited elsewhere on the property. The plant has a design capacity of 50,000 gal (190 m^3) per day.

The effluent is chlorinated with sodium hypochlorite solution to meet Florida's disinfection criterion. Florida Department of Pollution Control interim guidelines require the effluent be disposed on agricultural land not directly accessible to the public, to have a free-chlorine residual of 0.5 mg/L after 15 minutes of contact time at some stage in the final treatment (Bruce Carter, Florida Department of Pollution Control, Winter Haven, Florida, oral commun., January 21, 1974).

Until 1969, the treated effluent was discharged to Lake Gibson through a submerged outfall near the south shore about 700 ft (215 m) north of the treatment plant. This practice continued until concern by regional pollution control officials regarding bacteria and nutrients entering the lake led the home's managers to seek an alternate means of effluent disposal.

Table 6. -- Altitude of the water table in wells that tap the water-table aquifer at the study site, during the period from October 1970 to May 1972.

(Depths shown are feet below land surface datum.)

Well number	Altitude of land surface (ft)	Altitude of water table, February 1971	Altitude of water table, October 1971	Altitude of water table, February 1972	Range of depths to water table (ft) (numerous measurements 10/70-5/72)
2-7	179	171	171	171	7.5 - 9.4
3-7	183	179	178	179	3.3 - 6.4
4-8	187	185	184	186	1.0 - 3.3
5-9	196	-	-	190	5.1 - 8.0
6-7	190	184	183	184	6.1 - 7.3
7-8	186	183	182	184	1.2 - 4.3
8-7	142	-	-	142	0.4 - 2.8
9-4	190	188	186	187	0.7 - 3.9
10-7	193	-	-	190	2.1 - 5.2

During 1969, the operators of the home consulted with officials of the USDA, SCS and were advised how to design an irrigation system. The holding tank, buried irrigation pipelines, and rotating sprinklers were installed to dispose of the home's treated effluent. The Florida Department of Air and Water Pollution Control approved operation of the disposal system in September 1969. Sprinkler irrigation of the pasture started soon thereafter.

The raw sewage influent to the plant and the treated sewage effluent were sampled monthly between August 1971 and March 1973, except for 4 months. The samples were analyzed by personnel of the Sewer Division of the City of Lakeland to determine the effectiveness of the treatment plant to reduce BOD, total solids, total suspended solids, and fixed suspended solids. The analyses are listed in table 7. BOD removal averaged 86 percent during the study, total solids removal averages 23 percent, suspended solids removal averaged 66 percent, and fixed suspended solids removal averaged 60 percent. Free chlorine residual data are not available.

The final effluent from the treatment plant was sampled periodically from March 1971 into February 1972. Analyses of the samples are listed in tables 8 and 9.

The chlorinated treated effluent from the home's treatment facility is held in a 3,000 gal (11 m^3) tank until pumped by a 200 gal/min (13 L/s) capacity pump through a metered 5-in (127-mm) buried pipeline about 1,300 ft (400 m) to the pasture (fig. 7). From this line, a network of main and lateral pipelines and valves was constructed to enable the operators to irrigate selected parts of the 30-acre (12 ha) section of pasture.

Rotating sprinklers are mounted on 6-ft (1.8-m) galvanized pipe risers in the pasture. The sprinklers are an "insect proof" design with a 50 lb/in^2 (3.52 kg/cm^2) nozzle pressure capable of wetting a 120-ft (37-m) diameter circle, delivering 11.3 gal/min (0.7 L/s). The sprinklers are spaced about 90 ft (27 m) apart in rows. Different 5- to 6-acre (2- to 2.4-ha) parts of the pastures are sprayed daily (on a nonscheduled routine) with 25,000 gal (95 m^3) of treated effluent on the average.

Table 7. -- Biochemical oxygen demand and solids in raw sewage and treated effluent from the Carpenters' Home (analyses by Sewer Division, City of Lakeland).

(milligrams per Liter)

Month Sampled	BOD		Total Solids		Total Suspended Solids		Fixed Suspended Solids	
	Raw	Final	Raw	Final	Raw	Final	Raw	Final
August 1971	280	57	742	760	170	94	28	20
September	180	56	783	638	180	66	--	--
October	--	--	--	--	--	--	--	--
November	200	28	642	590	108	38	0	0
December	275	32	830	686	174	48	28	10
January 1972	270	30	--	--	184	44	0	0
February	360	40	1042	568	233	67	4	0
March	280	47	734	566	124	102	0	0
April	265	30	620	496	172	60	22	10
May	270	18	674	538	70	12	0	0
June	--	--	--	--	--	--	--	--
July	--	--	--	--	--	--	--	--
August	--	--	--	--	--	--	--	--
September	380	80	672	464	202	74	20	12
October	210	30	772	536	104	26	4	0
November	120	14	512	352	108	42	0	0
December	210	31	562	344	90	20	3	0
January 1973	245	35	626	482	130	34	8	0
February	370	44	690	618	151	38	19	2
March	195	15	580	422	100	16	16	0
AVERAGE	257	37	699	537	144	49	10	4

Table 8.--Inorganic and inorganic constituents, and nutrients in whole-water samples of the treated sewage effluent from the Carpenter's Home. (Concentrations in milligrams per liter, except as indicated.)

Date Sampled	Specific Conductance (micromhos/cm)	pH (at time of collection)	Calcium (Ca)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3) as N	Nitrite (NO_2) as N	Ammonia (NH_3, NH_4) as N	Organic Nitrogen (N)	Total Nitrogen (N)	Orthophosphate, as P	Total phosphorus, as P	Organic Carbon (C)	Inorganic Carbon (C)
March 25, 1971	650	-	20	110	11	249	23	33	-	-	-	-	-	-	-	-	-
October 1, 1971	650	-	23	120	13	182	22	53	-	-	-	-	-	-	-	51	32
February 24, 1972	595	8.1	48	100	12	225	19	48	7.6	0.16	0.90	3.7	12.36	6.0	6.2	46	41
February 25, 1972	615	7.5	53	100	11	220	15	55	6.0	0.01	0.33	3.2	9.54	6.5	6.8	38	38
February 28, 1972	580	7.4	20	96	14	218	16	44	8.5	0.20	0.92	5.8	15.42	7.0	8.4	97	27
February 29, 1972	649	-	40	94	6	240	19	50	8.4	0.16	0.35	5.9	14.81	7.1	6.7	57	39
AVERAGE	623	7.7	34	103	11	222	19	47	7.6	0.13	0.62	4.6	13.	6.6	7.0	58	35

Table 9. -- Concentration of dissolved metals in filtered water samples of the treated sewage effluent from the Carpenters' Home.

(Concentrations in micrograms per liter.)

Date	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Strontium (Sr)	Zinc (Zn)
March 25, 1971	–	0	20	–	4	–	–	130
October 1, 1971	1	–	30	110	–	10	–	60
February 24, 1972	0	–	20	80	3	10	80	110
February 25, 1972	0	0	10	130	2	10	80	70
February 28, 1972	0	0	10	60	3	10	80	50
February 29, 1972	0	0	20	80	1	10	80	90
AVERAGE	1	0	20	90	3	10	80	85

The average daily output of treated effluent is insufficient to meet the crop-water requirements for the grasses in the pasture. For bermuda grass pasture, the water demand is at least 0.20 in (5.1 mm) per day, with a desirable irrigation frequency of every 4 days (U. S. Department of Agriculture, Soil Conservation Service, 1963). This totals more than 1.4 in (36 mm) of water per week, yet the effluent provides only about 0.21 in (5.3 mm) per week or 1/7 of the pasture water needs.

Supplemental irrigation from the Carpenters' Home irrigation well tapping the Floridan aquifer is distributed through the same network of sprinklers. During extended dry periods, additional water from the Floridan aquifer is pumped into the holding tank, and after being mixed with the sewage effluent, is sprayed onto the pasture. Table 3 shows the chemical characteristics of water from the irrigation well (11F, fig. 7).

Chemical analyses of the treated sewage effluent from the home are shown on tables 7, 8, and 9. Using these data, average daily solids, BOD, nitrogen, and organic carbon loads were calculated for the irrigated pasture. Total daily loads applied were:

Dissolved solids	112 lb
BOD	7.7 lb
Total nitrogen	2.65 lb
Total kjeldahl nitrogen	0.31 lb
Phosphorus	1.46 lb
Organic carbon	12.1 lb
Potassium	2.29 lb

Concurrent with the daily application of sewage effluent on the pasture, dairy cattle are grazed on all parts of the pasture. Estimates place the number of grazing dairy cattle at about 1 cow per acre. Research indicates that cattle grazing an area return 75 to 80 percent of the nitrogen, phosphorus, and potassium in their forage to the soil in their excrement (Burton, 1954). The bovine waste load thus imposed is significant when compared to the domestic sewage load applied to the pasture. Goldberg (1970, p. 111) presented data showing that dairy cattle wastes average 1 lb (0.45 kg) of BOD_5 (5-day biochemical oxygen demand) per animal per day, which is about 8 human equivalents. Dairy cattle also produce about 10 lb (4.5 kg) of total dry solids per animal per day (18 human equivalents) and 0.4 lb (0.18 kg) of total (kjeldahl) nitrogen per animal per day (about 12 human equivalents). The bovine waste data, compared to the actual sewage effluent at the home, show that the estimated 30 cattle grazing the field contribute about 4 times the BOD_5 and 40 times the total kjeldahl nitrogen contained in the treated effluent. These data are approximate, but they do lend perspective to the magnitude of the bovine waste load on the pasture, and the relative size of the applied human waste load.

Burton (1954) recommends that each acre of coastal bermuda-grass be fertilized annually with about 100 lb (45 kg) of nitrogen, about 5.5 lb (2.5 kg) phosphorus and about 21 lb (9.5 kg) potassium. The treated effluent from the home annually contributes, per acre, about 32 lb (14.5 kg) of nitrogen, 18 lb (8 kg) of phosphorus, and about 28 lb (13 kg) of potassium. Thus the sewage effluent satisfies the crop requirements for phosphorus and potassium, and about one-third the crop nitrogen requirements. The additional required nitrogen has been supplied by commercial fertilizers.

In the past, the 30-acre (12-ha) study pasture was limed. The soils data show evidence of the liming of the field (table 2): calcium and magnesium ions predominate and percent base saturation (a measure of the degree to which sodium, potassium, calcium, and magnesium cations have sorbed onto exchange sites) is highest at the soil surface (as much as 97 percent) and is less than 15 percent at depths of 10 to 15 in (254 to 381 mm), near the top of the stain layer.

INVESTIGATION OF WATER QUALITY OF THE SHALLOW AQUIFERS

Methods of Investigation

The quality of the ground water in the vicinity of the sewage effluent-irrigated pasture at the Carpenters' Home was evaluated by analysis of water samples from part of the network of 35 monitoring wells in and around the pasture (fig. 7). Ground-water samples were first collected in February 1971 after about 16 months of irrigation with sewage effluent. Samples were again collected in October 1971 and February 1972.

Water samples collected from the wells in the monitoring network were analyzed for a variety of parameters, including carbon, inorganic constituents, trace elements, and bacteria. Constituent concentrations reported herein are from analysis of unfiltered (whole water) samples, unless otherwise noted. Principal problems encountered in planning and executing the sampling program for the well network included avoiding containimation of the wells or the samples during sampling.

A peristaltic pump was used to sample the wells, thereby eliminating contamination associated with the pumping and sampling procedure. To prevent cross-contamination of samples, tubing in the peristaltic pump was flushed with several gallons of water from a well before the sample was collected. To further prevent cross-contamination of wells, a 1-in (25.4-mm) diameter PVC pipe was left standing in each well casing. The flexible PVC tubing in the pump was easily attached to a coupling at the top of the drop-pipe, thereby eliminating the hazard of contamination associated with placing intake tubing into each well during each sampling effort. The samples of water collected during the study were analyzed in laboratories of the U. S. Geological Survey.

Samples collected for the determination of species of N are especially subject to the action of oxidation, reduction, and biodegradation, which have the effect of altering relative concentrations of each form of nitrogen present in the sample. The timely analysis of samples collected during this study improved data reliability, especially on unstable nitrogen species.

Analyses are shown in tables 10 and 11. The cations, anions, nitrogen species, carbon, and specific conductance are shown graphically in figures 8, 9, 10, 11, and 13.

The wells that were sampled were divided into two groups, those less than 11 ft (3.4 m) deep, and those greater than 11 ft (3.4 m) deep. The shallowest well sampled was 6 ft (1.8 m) and the deepest sampled was 29 ft (8.8 m). This grouping was made for convenience in illustrating and interpreting results.

The wells at sites 2, 3, 4, 6, 7, and 9 (fig. 7) in the network were selected for chemical sampling. The data collected were categorized as follows: physical characteristics, major inorganic constituents, macronutrients and related constituents, and bacteria enumeration.

The well sites were chosen to provide data relating to the movement of water in the shallow aquifers, thus permitting the identification of contaminants and their movement, if any, in the shallow aquifers. Site 2 was about 1,000 ft (320 m) north of, and downgradient from, the middle of the effluent-irrigated pasture. Site 3 was about 560 ft (170 m) north of, and downgradient from well site 4. Site 4 was located in the center of the sewage-irrigated pasture. Site 6, at the west boundary of the sewage-irrigated pasture, was selected to sample ground water moving from the pastures toward the drainage ditch. Site 7, on the golf course, east of the pasture, provided data from a site not expected to be contaminated by sewage applied to the pasture or by grazing. Site 9, upgradient from the sewage-irrigated pasture, is on grazed pasture, irrigated only with water from the Floridan aquifer. Grazing dairy cattle frequent the area because of nearby watering troughs. Data from site 9 provide grazed-pasture control of background water quality for comparison with data from downgradient samples.

Table 10. -- Chemical analyses of water from wells less than 11 feet deep that tap the shallow aquifer in or near the effluent irrigated pasture, Carpenters' Home.

Well Number	Well No. 2-7			Well No. 3-7			Well No. 4-4		
Date of Collection / Water-quality Constituent	Feb. 1971	Oct. 1971	Feb. 1972	Feb. 1971	Oct. 1971	Feb. 1972	Feb. 1971	Oct. 1971	Feb. 1972
Specific conductance (micromhos at 25°C)	50	63	84	139	137	157	205	208	193
Water temperature	20	27	-	20	24	19	19	26	18
pH	5.9	-	5.6	5.7	-	5.5	6.2	-	6.6
Dissolved oxygen (DO)	-	-	-	-	-	2.4	-	-	1.8
Calcium (Ca), dissolved	1.6	2.2	3.9	8.7	7.0	7.2	2.6	1.7	-
Magnesium (Mg), dissolved	0.8	-	-	1.2	-	-	0.4	-	-
Sodium (Na), dissolved	3.5	6.0	9.2	6.6	5.8	16	26	30	36
Potassium (K) dissolved	0	-	0	5.9	-	9.5	13	-	6.4
Bicarbonate (HCO_3)	6	-	4	2.0	-	13	12	-	30
Sulfate (SO_4)	7.2	6.8	6.8	14	15	18	13	12	17
Chloride (Cl), dissolved	5.5	12	16	23	20	24	44	38	19
Fluoride (F), dissolved	0.1	-	-	0.2	-	-	0.3	-	-
Dissolved solids, residue at 180°C	48	-	-	86	-	-	318	-	-
Silica (SiO_2), dissolved	2.5	2.6	-	2.7	5.2	-	8.5	10	-
Nitrate, total as N	0	0	0	0	0	0	0	0.02	0.0
Nitrite, total as N	0	0	0	0	0	0	0	0.01	0
Nitrogen, ammonia, total as N	0.02	0	0.03	0.07	0.05	0.41	1.4	3.11	1.9
Phosphorus, total ortho as P	0	0.01	0	0.013	0.08	0.10	0.01	0.07	0.0
Phosphorus, total as P	0.02	0.02	0	0.030	0.08	0.04	0.01	0.07	0
Carbon, organic, dissolved	-	1	1	-	2	4	-	40	92
Carbon, organic, total	6	2	1	2	5	5	57	71	95
Carbon, inorganic, dissolved	-	1	5	-	4	24	-	30	10
Carbon, inorganic, total	0	0	6	17	5	28	7	0	10

Table 10 (Continued). -- Chemical analyses of water from wells less than 11 feet deep that tap the shallow aquifer in or near the effluent irrigated pasture, Carpenters' Home.

Well Number	Well No. 4-8			Well No. 6-7			Well No. 7-4		
Date of Collection / Water-quality Constituent	Feb. 1971	Oct. 1971	Feb. 1972	Feb. 1971	Oct. 1971	Feb. 1972	Feb. 1971	Oct. 1971	Feb. 1972
Specific conductance (micromhos at 25°C)	120	129	140	85	85	97	130	206	179
Water temperature	20	24	20	24	28.5	-	22	26	-
pH	5.4	-	5.3	6.4	-	6.5	5.7	-	6.0
Dissolved oxygen (DO)	-	-	0.4	-	-	-	-	-	-
Calcium (Ca), dissolved	7.9	6.2	5.2	4.8	4.2	5.8	7.9	3.1	4.0
Magnesium (Mg), dissolved	0.7	-	-	0.6	-	-	1.3	-	-
Sodium (Na), dissolved	5.3	7.0	15	8.0	8.9	8.0	9.0	16	13
Potassium (K), dissolved	6.6	-	9.1	2.2	-	3.6	4.8	-	20
Bicarbonate (HCO_3)	10	-	4	3	-	7	6	-	16
Sulfate (SO_4)	11	12	15	15	13	14	15	24	27
Chloride (Cl), dissolved	17	24	25	9.8	12	11	23	30	13
Fluoride (F), dissolved	0.1	-	-	0.1	-	-	0.1	-	-
Dissolved solids, residue at 180°C	70	-	-	64	-	-	90	-	-
Silica (SiO_2), dissolved	3.8	4.0	-	1.2	1.4	-	1.3	1.5	-
Nitrate, total as N	0	0	0	0	0	0	0	0.86	0.01
Nitrite, total as N	0	0	0	0	0	0	0	0.07	0
Nitrogen, ammonia, total as N	0.27	1.09	1.0	0.03	0	0.02	0.14	0.30	0.26
Phosphorus, total ortho as P	0	0.02	0	0	0.01	0	0	0.03	0
Phosphorus, total as P	0	0.02	0	0	0.02	0	0	0.03	0
Carbon, organic, dissolved	-	0	7	-	1	0	-	5	4
Carbon, organic, total	7	5	4	1	2	2	0	7	2
Carbon, inorganic, dissolved	-	5	34	-	3	2	-	13	18
Carbon, inorganic, total	17	8	45	0	3	2	4	14	22

Table 10 (Continued). -- Chemical analyses of water from wells less than 11 feet deep that tap the shallow aquifer in or near the effluent irrigated pasture, Carpenters' Home.

Well Number	Well No. 7-8			Well No. 9-6			Well No. 9-8		
Date of Collection / Water-quality Constituent	Feb. 1971	Oct. 1971	Feb. 1972	Feb. 1971	Oct. 1971	Feb. 1972	Feb. 1971	Oct. 1971	Feb. 1972
Specific conductance (micromhos at 25°C)	110	105	150	186	295	290	-	161	228
Water temperature	22.5	25	18.5	26	26	-	-	26	17
pH	5.5	-	5.6	6.5	-	8.1	-	0	7.0
Dissolved oxygen (DO)	-	3.7	1.1	-	-	-	-	2.2	1.8
Calcium (Ca), dissolved	4.2	3.8	2.6	12	13	15	-	7.5	8.5
Magnesium (Mg), dissolved	1.7	-	-	1.4	-	-	-	-	-
Sodium (Na), dissolved	7.0	7.9	9.4	12	12	18	-	9.4	16
Potassium (K), dissolved	3.1	-	9.4	9	-	6.9	-	-	8.8
Bicarbonate (HCO_3)	6	-	10	38	-	62	-	-	40
Sulfate (SO_4)	8.8	15	14	0.4	36	18	-	10	9.8
Chloride (Cl), dissolved	20	16	20	35	30	44	-	26	41
Fluoride (F), dissolved	0.1	-	-	0.3	-	-	-	-	-
Dissolved solids, residue at 180°C	70	-	-	138	-	-	-	-	-
Silica (SiO_2), dissolved	2.5	3.0	-	5.4	5.5	-	-	2.4	-
Nitrate, total as N	0	0	0.01	0	0	0.01	-	0	0
Nitrite, total as N	0	0	0	0.02	0	0	-	0.01	0
Nitrogen, ammonia, total as N	0.07	0.10	0.16	0.48	0.62	2.4	-	0.55	1.1
Phosphorus, total ortho as P	0	0.02	0	0.04	0.02	0.067	-	0.02	0
Phosphorus, total as P	0	0.02	0	0.08	0.03	0.031	-	0.03	0.21
Carbon, organic, dissolved	-	1	1	-	20	26	-	4	3
Carbon, organic, total	2	5	0	24	16	28	-	5	14
Carbon, inorganic, dissolved	-	6	20	-	8	18	-	6	15
Carbon, inorganic, total	8	16	32	8	10	18	-	15	15

Table 11. -- Chemical analyses of water from wells greater than 11 feet deep that tap the shallow aquifer in or near the effluent-irrigated pasture, Carpenters' Home.

Well Number	Well No. 2-14			Well No. 2-19			Well No. 3-13		
Date of Collection / Water-quality Constituent	Feb. 1971	Oct. 1971	Feb. 1972	Feb. 1971	Oct. 1971	Feb. 1972	Feb. 1971	Oct. 1971	Feb. 1972
Specific conductance (micromhos at 25°C)	115	120	107	100	112	115	73	85	101
Water temperature	21	24	21	22	27	21	22	23	20.5
pH	5.9	-	5.7	6.0	-	6.0	6.0	-	4.8
Dissolved oxygen (DO)	-	1.1	0.4	-	-	0.4	-	-	0.4
Calcium (Ca), dissolved	5.4	4.0	6.2	3.7	2.8	6.1	2.2	2.9	4.0
Magnesium (Mg), dissolved	2.1	-	-	2.0	-	-	1.4	-	-
Sodium (Na), dissolved	11	13	15	6.8	12	14	4.0	4.1	6.2
Potassium (K), dissolved	0	-	0	0.2	-	0	1.3	-	3.8
Bicarbonate (HCO_3)	2	-	4	18	-	8	0	-	1
Sulfate (SO_4)	15	8.0	17	4.0	6.0	7.6	9.2	16	13
Chloride (Cl), dissolved	24	26	16	12	26	23	10	9.2	13
Fluoride (F), dissolved	0.2	-	-	0	-	-	0.1	-	-
Dissolved solids, residue at 180°C	68	-	-	86	-	-	35	-	-
Silica (SiO_2)	2.4	3.0	-	3.1	3.0	-	4.4	4.0	-
Nitrate, total as N	0	0	0	0	0	0	0	0	0
Nitrite, total as N	0	0	0	0	0	0.01	0	0	0
Nitrogen, ammonia, total as N	0.08	0.06	0.08	0.08	0.05	0.14	-	0.10	0.14
Phosphorus, total ortho as P	0.01	0.03	0.02	0.02	0.24	0.31	0	0.01	0
Phosphorus, total as P	0.01	0.03	0	0.08	0.24	0.22	0.06	0.02	0
Carbon, organic, dissolved	-	0	1	-	3	5	-	0	2
Carbon, organic, total	5	0	1	10	8	7	7	0	3
Carbon, inorganic, dissolved	-	10	15	-	10	15	-	12	20
Carbon, inorganic, total	14	13	17	5	14	18	15	12	25

Table 11 (Continued). -- Chemical analyses of water from wells greater than 11 feet deep that tap the shallow aquifer in or near the effluent-irrigated pasture, Carpenters' Home.

Well Number	Well No. 3-27			Well No. 4-19			Well No. 6-17		
Date of Collection / Water-quality Constituent	Feb. 1971	Oct. 1971	Feb. 1972	Feb. 1971	Oct. 1971	Feb. 1972	Feb. 1971	Oct. 1971	Feb. 1972
Specific conductance (micromhos at 25°C)	47	46	64	45	41	57	35	30	41
Water temperature	22	23	22.5	23	23	21	24	26	22
pH	5.9	-	6.6	5.6	-	5.9	5.9	-	5.7
Dissolved oxygen (DO)	-	-	0.6	-	-	0.3	-	-	0.45
Calcium (Ca), dissolved	1.3	1.1	1.4	0.4	0.4	1.2	0.3	0.3	0.3
Magnesium (Mg), dissolved	0.8	-	-	0.4	-	-	0.5	-	-
Sodium (Na), dissolved	3.1	2.7	4.5	4.4	5.0	6.8	2.6	2.8	4.0
Potassium (K), dissolved	0.1	-	0.4	0.1	-	0	0	-	0
Bicarbonate (HCO_3)	15	-	20	2.0	-	2	4	-	1
Sulfate (SO_4)	0.2	0.4	1.4	0	0	0	0	0	0
Chloride (Cl), dissolved	7.0	6.8	7.8	8.0	10	12	7.5	7.0	9.2
Fluoride (F), dissolved	0.1	-	-	0.1	-	-	0.1	-	-
Dissolved solids, residue at 180°C	40	-	-	32	-	-	48	-	-
Silica (SiO_2)	5.4	3.0	-	3.6	3.8	-	4.2	4.7	-
Nitrate, total as N	0	0	0	0	0	0	0	0	0
Nitrite, total as N	0.01	0	0	0.01	0	0	0.01	0	0
Nitrogen, ammonia, total as N	0.08	0.24	3.4	0.08	0.19	0.13	0.18	0.06	0.20
Phosphorus, total ortho as P	0.09	0.06	3.6	0.02	0.02	0	0.03	0.02	0
Phosphorus, total as P	0.12	0.07	4.5	0.04	0.02	0	0.06	0.02	0.02
Carbon, organic, dissolved	-	0	0	-	0	3	-	0	2
Carbon, organic, total	1	0	3	2	2	16	2	2	2
Carbon, inorganic, dissolved	-	10	13	-	8	17	-	6	6
Carbon, inorganic, total	14	14	18	16	0	19	0	4	5

Table 11 (Continued). -- Chemical analyses of water from wells greater than 11 feet deep that tap the shallow aquifer in or near the effluent-irrigated pasture, Carpenters' Home.

Well Number	Well No. 7-17			Well No. 7-24			Well No. 9-20		
Date of Collection / Water-quality Constituent	Feb. 1971	Oct. 1971	Feb. 1972	Feb. 1971	Oct. 1971	Feb. 1972	Feb. 1971	Oct. 1971	Feb. 1972
Specific conductance (micromhos at 25°C)	51	55	65	52	64	68	-	38	34
Water temperature	24	28	19	25	24	21.5	-	24	19
pH	6.1	-	5.5	6.1	-	6.0	-	-	6.6
Dissolved oxygen (DO)	-	-	0.8	-	-	0	-	-	0.7
Calcium (Ca), dissolved	0.2	0.2	1.1	1.6	1.6	1.4	-	2.0	1.6
Magnesium (Mg), dissolved	0.3	-	-	0.7	-	-	-	-	-
Sodium (Na), dissolved	4.0	4.6	6.4	2.5	2.6	4.4	-	3.0	7.3
Potassium (K), dissolved	0	-	0	0.2	-	0.3	-	-	0
Bicarbonate (HCO_3)	20	-	20	19	-	29	-	-	7
Sulfate (SO_4)	0	0	0	0	0.4	1.4	-	0.8	0
Chloride (Cl), dissolved	6.0	7.5	8.6	5.8	4.8	4.4	-	5.2	1.2
Fluoride (F), dissolved	0.1	-	-	0.1	-	-	-	-	-
Dissolved solids, residue at 180°C	46	-	-	50	-	-	-	-	-
Silica (SiO_2)	3.1	3.2	-	6.2	7.0	-	-	3.4	-
Nitrate, total as N	0	0	0	0	0	0	-	0	0
Nitrite, total as N	0	0	0	0.02	0.01	0	-	0.01	0
Nitrogen, ammonia, total as N	0.3	0.11	0.05	0.12	0.02	0.03	-	0.04	0.09
Phosphorus, total ortho as P	0.01	0.04	0	0.08[a]	0.22	0.10[a]	-	0.33	0.06
Phosphorus, total as P	0.03	0.04	0	0.11[a]	0.22	0[a]	-	0.33	0.02
Carbon, organic, dissolved	-	2	0	-	2	2	-	0	6
Carbon, organic, total	0	1	0	3	2	10	-	5	1
Carbon, inorganic, dissolved	-	4	14	-	8	10	-	10	11
Carbon, inorganic, total	1	5	15	1	16	14	-	1	14

[a]dissolved value from filtered sample

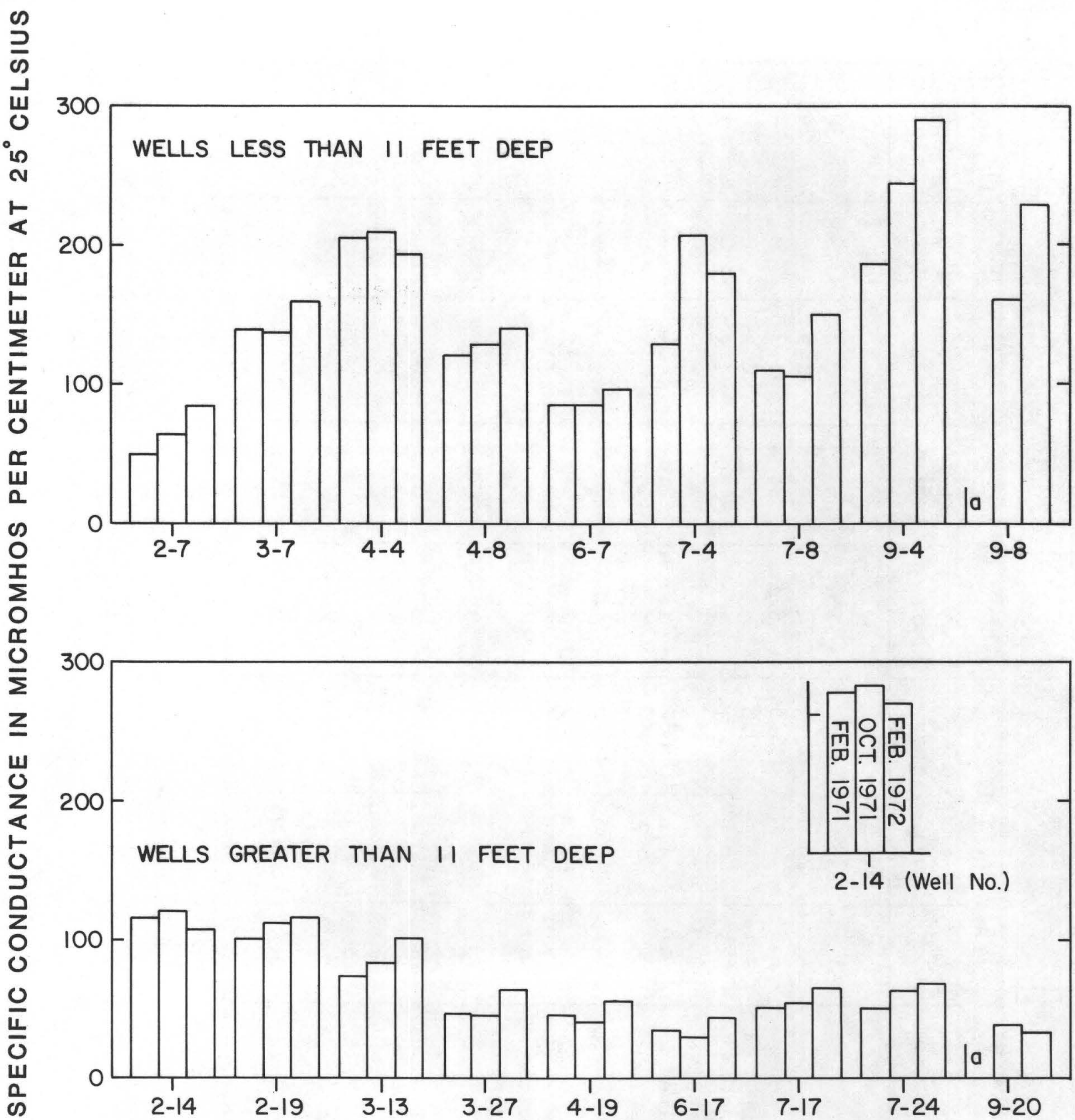


FIGURE 8.--Specific conductance of water from wells that tap the shallow aquifer at the study site, February 1971 to February 1972.

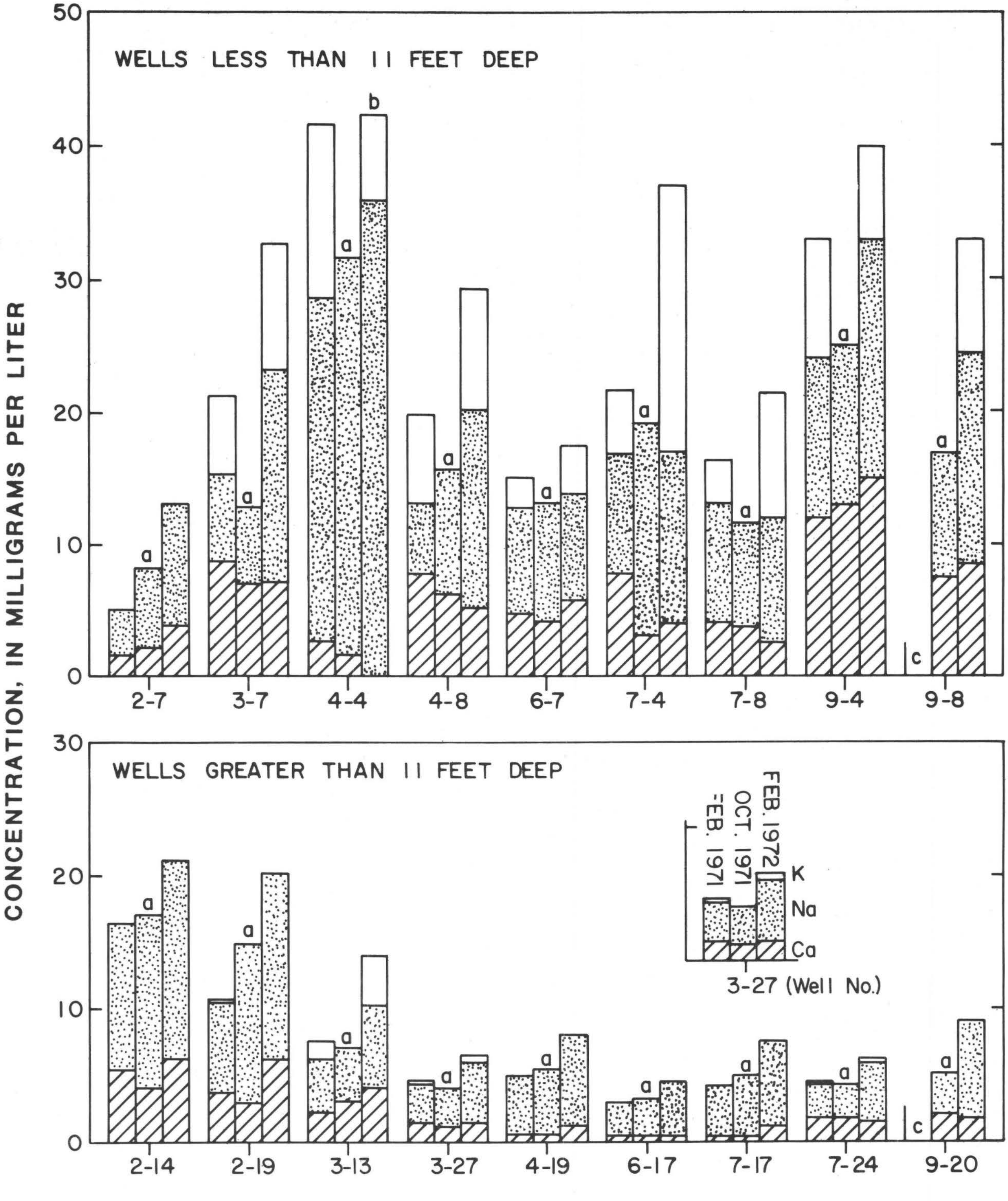


FIGURE 9.--Major inorganic cations in water from wells that tap the shallow aquifer at the study site, February 1971 to February 1972.

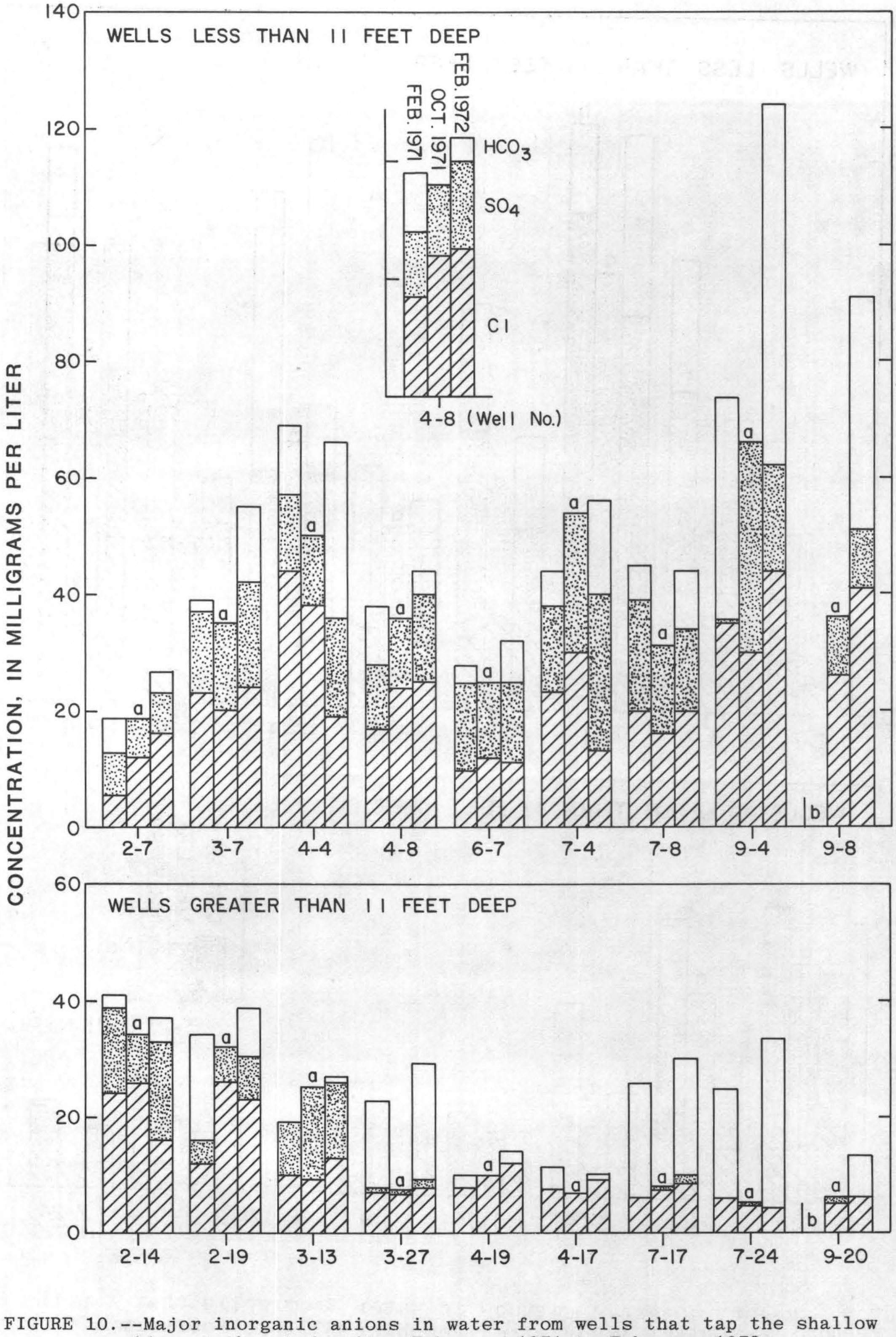


FIGURE 10.--Major inorganic anions in water from wells that tap the shallow aquifer at the study site, February 1971 to February 1972.

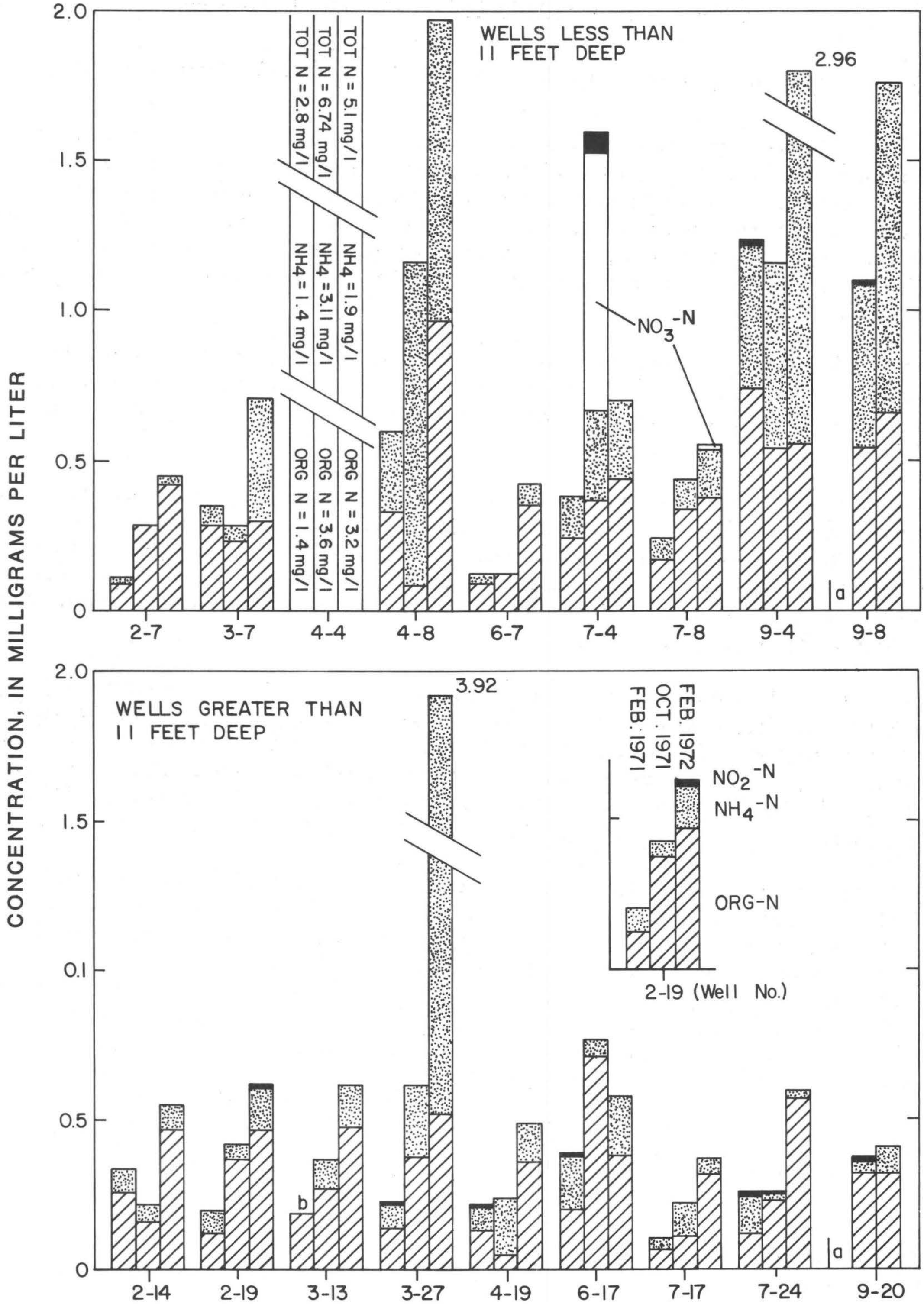


FIGURE 11.--Nitrogen compounds as N and total nitrogen in water from wells that tap the shallow aquifer at the study site, February 1971 to February 1972.

Results of the Water-Quality Investigation

Physical Characteristics and Major Inorganic Constituents

DO (dissolved oxygen) was measured at several of the wells in February 1972, after they had been pumped and sampled. Probes lowered into the wells showed that DO was generally less than 1 mg/L in all wells except the shallow wells at sites 3, 4, 7, and 9; in these, the DO was as much as 2.4 mg/L. The low DO values were expected, as a result of oxygen consumption by oxidation and biodegradation of organic matter.

Ground-water temperatures ranged from 21° to 24°C through the year in wells deeper than 20 ft (6.1 m). Temperatures in shallower wells varied over a wider range, from 18°C in 1972 to 26°C in September 1971.

Ground water was slightly acid at all sites in the shallow aquifer and at all depths. The pH ranged from 4.8 to 6.6 (at most sites from 5.5 to 6.5) except one measurement of 8.1, 4 ft (1.2 m) below land surface at site 9. Previous measurements at that site at all depths ranged from 6.5 to 7.0. The pH data showed no other significant departure during the tests.

Specific conductance generally decreased with increasing depth at all sites except site 2 (fig. 8). Highest conductance, indicating the highest degree of mineralization, was measured in the sewage-irrigated pasture, and in the fresh-water-irrigated pasture up gradient (site 9). The conductance data from deeper wells show that the applied effluent apparently is not affecting the ground water below 17 ft (5.2 m).

At site 2, both the conductance and temperature are higher in the deeper wells 2-14 and 2-19, indicating that inadequate sealing of the casings of the 14 and 19 ft (4.3 and 5.8 m) deep wells may have allowed ground water from nearer land surface to infiltrate the disturbed sediments in the augered holes and to enter the well-screens (fig. 8). Higher concentrations of cations and anions also occurred in water from wells 2-14 and 2-19 at the site (figs. 9 and 10). Apparently the water from these wells is not representative of water in the aquifer at that depth.

Concentrations of the cations of calcium, sodium and potassium are shown in figure 9. Generally, the cations were present in low concentrations in the ground water, and decreased in concentration with depth. Cation concentrations in the shallow ground water were highest at sites 4 and 9. Calcium and sodium were present in similar concentrations in most samples. At the top of the water table, beneath the sprayed fields, sodium was the principal cation. Sodium was the principal cation in the sewage effluent applied to the field.

Cation exchange was occurring in the sprayed field as a result of the occasional liming of the pasture and the application of the treated effluent. Analysis of surficial soil samples to determine base saturation (table 2) shows that base saturation ranged from about 44 to 97 percent in samples from sites A, B, C and E (fig. 5) in the irrigated and limed pasture. Base saturation was only about 18 percent in a sample from site D outside the pasture. Calcium, magnesium and sodium ions added in the liming and in the treated effluent were exchanged for hydrogen ions in the soil, thereby increasing soil-water pH slightly.

Concentrations of the major anions, bicarbonate, sulfate and chloride, are shown in figure 10. In general, the anion concentrations in the shallow wells were highest at sites 4 and 9 and they decreased with depth except at site 2. The concentration of these anions decreased downgradient from the sprayed field. Some of the reduction in sulfate may be attributable to conversion of sulfate to hydrogen sulfide by anaerobic sulfate-reducing bacteria. Idenfification of the bacteria was not done in this study; however, the odor of hydrogen sulfide was detected when some wells were sampled.

Macronutrients

Nitrogen

Total nitrogen concentration in the sewage effluent (table 8) averaged 13 mg/L, predominantly in the form of nitrate (7.6 mg/L) and organic nitrogen (4.6 mg/L). However, ground water from the monitor wells in and near the pasture, with the exception of well 4-4, contained less than 4 mg/L total nitrogen, predominantly in the forms of ammonia and organic nitrogen. Nitrate concentration, with one exception, was less than 0.02 mg/L in all ground water samples collected. Samples collected from wells and the sewage effluent were analyzed to determine concentrations of nitrate, nitrite, ammonia and organic nitrogen. Analyses are shown in figure 11; concentrations are expressed in mg/L as N.

Nitrite is an intermediate step in nitrification, the biochemical conversion of ammonia and organic nitrogen to nitrate, and is normally present only in very small amounts in the shallow ground water. Nitrite concentrations greater than 0.02 mg/L were detected in only one sample, from 4 ft (1.2 m) below land surface at site 7, in October 1971; the concentration was very low-0.07 mg/L. At all other sites, nitrite was absent or less than 0.02 mg/L.

Nitrate is the end product of the aerobic decomposition of organic nitrogen. Usually it is the most prevalent form of inorganic N in water containing dissolved oxygen and is the most soluble and easily leached form. A notable concentration of nitrate nitrogen (NO_3-N) was present in only one sample, again from 4 ft (1.2 m) below land surface at the water table at site 7, in October 1971. The presence of 0.86 mg/L nitrate and 0.07 mg/L nitrite at this site may be attributed to golf-course fertilization near the time of sampling. At other sampling sites, nitrate was less than 0.02 mg/L.

The absence of appreciable amounts of nitrate in the shallow ground water indicates that nitrate uptake by plants or conversion to elemental nitrogen (gas) by denitrification were effective before the applied waste water left the root zone.

Ammonia nitrogen was present in greatest concentrations at the water table in the effluent-irrigated field (site 4) and in the fresh-water-irrigated pasture near the water troughs (site 9). Ammonia concentrations were low, less than 0.2 mg/L, at depths greater than 11 ft (3.4 m) below land surface, except for well 3-27 (fig. 11).

In one sample collected in February 1972 from well 3-27, the concentration of ammonia was high. It is possible that sample contamination could account for the 3.4 mg/L of ammonia present, the highest concentration of ammonia noted during the study as concentrations of other nitrogen species in the sample were comparable to the concentration in water from wells deeper than 11 ft (3.4 m). Therefore, contamination or an analytical error is likely.

Organic-nitrogen concentration was highest at the water table under both the effluent-irrigated field (3.6 mg/L at well 4-4 in October, 1971), and in the freshwater-irrigated pasture, near the watering troughs (0.66 mg/L at well 9-8 in February, 1972). Organic nitrogen concentrations were less in downgradient wells, though concentrations increased throughout the study at most depths, as shown in figure 11. The increase was most pronounced in the deeper wells at sites 2 and 3. The greatest concentration of organic nitrogen in samples from wells deeper than 11 feet (3.4 m) outside the irrigated site was 0.71 mg/L in well 6-17 in October 1971.

The total nitrogen concentration in water is the sum of the concentrations of the individual forms of nitrogen: ammonia, nitrate, nitrite, and organic nitrogen. The effectiveness of the vegetation and soil processes in removing nitrogen from the applied waste water may be assessed by determining total nitrogen concentrations in ground water at various depths. Dilution by ground water lower in nitrogen concentration reduces total nitrogen concentrations. The extent of dilution effects on nitrogen (or any other chemical constituent) can be approximated by determining the changes of concentration of chloride or some other constituent relatively unaffected by processes other than dilution.

Chloride concentrations were used to approximate the effects of dilution of the percolating effluent by shallow-ground water. The chloride concentration of the effluent averaged 47 mg/L. The chloride concentration of water 8 feet below the surface of the effluent-irrigated pasture was generally 40 to 60 percent less than the chloride concentration of the effluent, except in well 9-8 in February 1972.

By comparison, the total nitrogen in ground water sampled on the same three dates showed over 80 percent reduction in concentration, evidence that nitrogen had been removed.

The total nitrogen concentration in the effluent applied to the pastures averaged 13 mg/L. Total N in wells at site 4 in the sprayed area was highest at the water table, ranging from 2.8 to 6.7 mg/L during the year. Total N was also high at site 9, ranging from 1.2 to 3.0 mg/L during the year. Total N had been reduced to less than 20 percent of its concentration in the effluent in samples from 8 ft (2.4 m) below land surface at sites 4 and 9, though at these sites, total N was still higher than at corresponding depths at other sites. The anomalously high ammonia concentration of water from well 3-27 causes the high total nitrogen value from the same well.

Lines of equal concentration of total nitrogen in ground water under the irrigated pasture were drawn (fig. 12) representing data collected at the start of testing, and at the end of testing. Lines of equal net increase in total nitrogen during the period were also drawn. The figures show total nitrogen concentration and net increase in nitrogen in the ground water 7 to 8 ft (2.1 to 2.4 m) below land surface (in the water-table aquifer) and 13 to 20 ft (4 to 6 m) below land surface (in the uppermost artesian aquifer) are shown in figure 12.

Data from the water-table aquifer (fig. 12 a,b,c) show the nitrogen to be highest near the water troughs (site 9) in the early samples, and near the center of the effluent-irrigated pasture by the end of the sampling period in 1972. The impact on the water table of irrigation

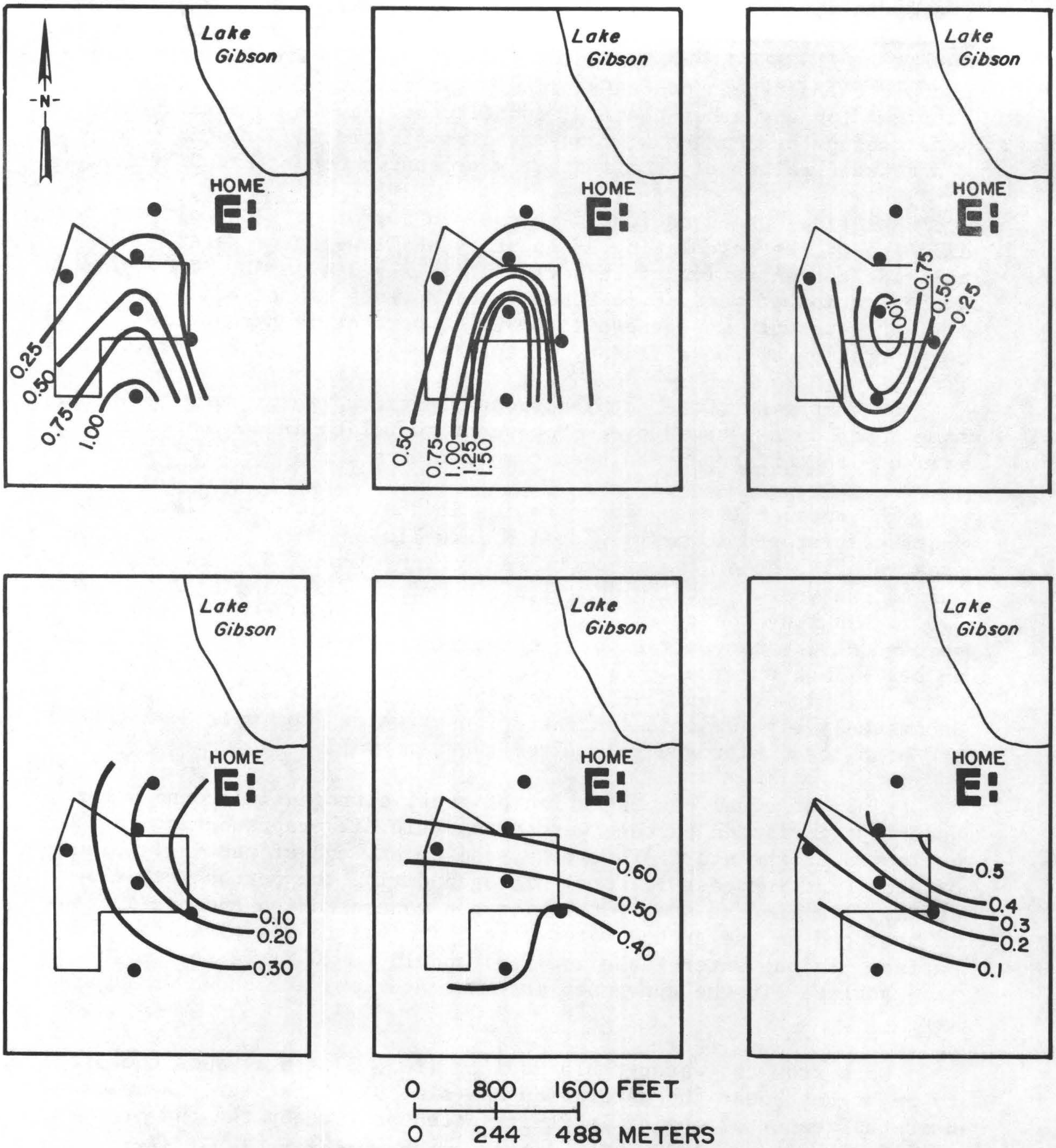


FIGURE 12.--Lines of equal concentration of total nitrogen in ground water, in milligrams per liter as N, and lines of equal net increase in total nitrogen at the effluent-irrigated pasture. (Wells are identified in figure 7 and the data are listed in tables 11 and 12.)

with the effluent was greatest beneath the pasture, and diminished outward with some downgradient movement of reduced levels of total nitrogen.

Data from the uppermost artesian aquifer (fig. 12 d,e,f) show lower concentration of total nitrogen in this deeper aquifer. The pattern of isolines in figure 12e indicates that nitrogen was moving downgradient away from the pasture. The greatest increases in total nitrogen in the uppermost artesian aquifer were in the downgradient wells, indicating some vertical movement of nitrogen from the water-table aquifer perhaps as a response to recharge (rainfall).

Phosphorus

Phosphorus occurs in nature both in the organic and inorganic form. Because of its role in metabolism, phosphorus is a cyclic element, similar to nitrogen, in that the combined form may be changed by decomposition and synthesis, particularly in aquatic systems. Phosphorus is present in several common minerals, but the concentration in water is limited by the relative insolubility of these minerals. Both organic and inorganic phosphorus may occur in water resulting from leaching of soil and rocks, and from fertilizer, normal decomposition of plants and animals, sewage, and industrial effluents. Waters that have undergone phosphate treatment for removal of hardness (not done at the home) can also increase in phosphorus concentration.

In concentrations normally found in water, phosphorus is not known to be toxic to man, animals or fish. However, the element does stimulate the growth of algae, which may degrade the water resource.

Ground-water samples were analyzed to determine concentration of orthophosphate and total phosphorus. The difference between the two in a given sample is an approximation of organic phosphorus concentration, but may be an inflated value. Particulate and sorbed orthophosphate present in the unfiltered samples may be included in the difference.

Normally, phophorus is not very mobile in acid soils such as the Myakka at the site. The phosphorus forms sparingly soluble phosphates, in combination with hydrated iron and aluminum oxides present in the soil (Olsen and Fried, 1957). Clay minerals in the soils are also known to adsorb phosphorus. Data from other ground-water samples from the site reflect these processes.

Nearly all of the phosphorus in the sewage plant effluent used to irrigate the pastures was held in the soil. The organic phosphorus concentration in the sewage plant effluent at the Carpenters' Home was low, averaging about 0.4 mg/L; total phosphorus in the effluent averaged 7.0 mg/L; however, total phosphorus was less than 0.08 mg/d in ground water from all wells less than 11 ft (3.4 m) deep.

In samples from wells greater than 11 ft (3.4 m), total phosphorus concentrations were less than 0.24 mg/L except for 0.33 mg/L at well 9-20, and an anomalously high 4.5 mg/L from well 3-27; the latter possibly resulting from the same error in sampling or analysis that was apparent in the nitrogen values from the sample.

Carbon

Carbon occurs in ground water in both organic and inorganic compounds. Inorganic carbon compounds are chiefly carbonate, bicarbonate, and carbon dioxide, derived mainly from dolomite, limestone, and the atmosphere. Organic carbon is derived from organic materials such as domestic waste, leaf litter, decomposing vegetation and soil organisms, and animal wastes.

Both unfiltered and filtered samples were analyzed to determine organic and inorganic carbon. In most samples, the difference between the values of total carbon and dissolved carbon was negligible. Organic carbon in the sewage effluent averaged 58 mg/L and inorganic carbon averaged 35 mg/L, though both varied greatly. Organic carbon in the monitor wells (site 4) was highest at the water table in the effluent-irrigated pasture, ranging from 57 to 95 mg/L (fig. 13). Inorganic carbon ranged from 0 to 10 mg/L at that site. Organic carbon was also relatively high at site 9. Organic carbon concentrations were 16 mg/L or less at depths greater than 7 ft (2.1 m) at all sites, an indication that the organic carbon in waste water did not percolate to that depth.

Bacteria

Secondary effluent typically contains many viable enteric bacteria and viruses, though proper chlorination will inactivate more than 99 percent of the bacteria in an effluent (U. S. Department of the Interior, Federal Water Pollution Control Administration, 1969). Bacteria types most commonly quantified in sewage effluents are the coliforms and streptococci. The total coliform group of bacteria includes coliform bacteria capable of growth outside the body, and fecal coliform, which are indicators of fecal contamination.

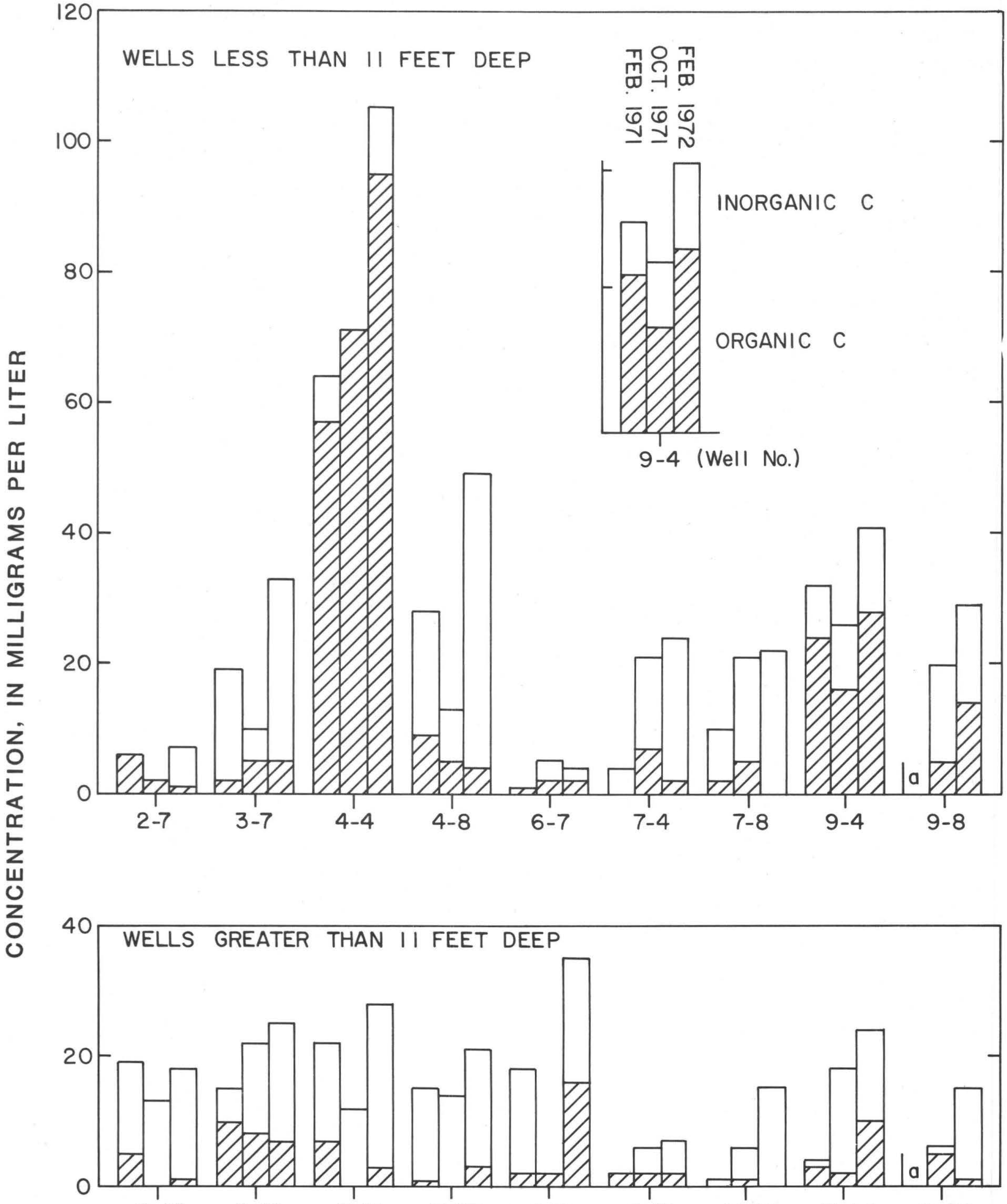


FIGURE 13.--Organic carbon, inorganic carbon and total carbon in water from wells that tap the shallow aquifer at the study site, February 1971 to February 1972.

The total coliform group of organisms has a long history of use as indicator organisms in water-quality assessments. Because they are part of the normal flora of the human intestine, are nonpathogenic, and are readily detectable by relatively unsophisticated bacteriological procedures, the coliforms have become the organism of choice for indicating possible fecal contamination of water. The presence of fecal coliforms is an indicator of fecal contamination of water, and the possible presence of pathogens.

Fecal streptococci are being used increasingly as indicators of fecal contamination because the normal habitat of these organisms is the warm-blooded animal intestine. Fecal streptococci data verify fecal pollution, and in combination with data on coliform bacteria, are used in sanitary evaluation as a supplement to fecal coliforms (Slack and others, 1973, p. 50). Because of uncertainties in die-off rates, the absence of fecal streptococci in water does not necessarily mean that the water is bacteriologically potable.

Treated sewage effluent intended for use in agricultural, industrial or recreational activities generally is not required to meet drinking water standards. However, research indicates that, as a preventative measure and good public health practice, designs for land disposal of effluent should include chlorination of the effluent after secondary treatment (Benarde, 1973), as is the practice in Florida.

Water samples collected from wells at sites 2, 3, 4, 6, 7, and 9 were analyzed by the membrane-filter method to determine the numbers of total coliform, fecal coliform and fecal streptococci. The coliform bacteria determinations were made on samples collected in all three sampling periods--February 1971, October 1971, and February 1972. Fecal streptococci were determined from samples collected in October 1971 and February 1972 only. Data from only the wells in which bacteria were detected are shown in table 12.

The Carpenters' Home sewage-treatment-plant effluent was sampled four times in February 1972. The effluent averaged 770 col/100 ml (colonies per 100 milliliters) for total coliform, 99 col/100 ml for fecal coliform and 260 col/100 ml for fecal streptococci.

No fecal streptococci were detected in samples from wells in the pasture (site 4). Outside the pasture, fecal streptococci were present in one sample from well 9-4, upgradient from the pasture and from well 2-7, downgradient from the pasture. In each sample, the concentration was very low, 1 col/100 ml of sample. From these data, there was no evidence of fecal streptococci contamination of the ground water from irrigation using the sewage-treatment plant effluent.

Table 12. -- Wells from which ground-water samples contained numbers of coliforms and/or fecal streptococci.[a] Numbers are colonies per 100 ml of sample. Locations are shown on figure 7.

		February 1971			October 1971			February 1972		
Well Number	Depth (ft)	Total Coliform	Fecal Coliform	Fecal Strep.	Total Coliform	Fecal Coliform	Fecal Strep.	Total Coliform	Fecal Coliform	Fecal Strep.
2-14	14	0/200[b]	0	-	0	0	0	7	0	0
2-19	19	7/300[b]	-	-	89	0	0	14	0	0
2-7	7	0	0	-	0	0	0	0	0	1
3-7	7	0	0	-	0/7[b]	0	0	0	0	0
3-27	27	0	0	-	6/3[b]	0	0	0	0	0
4-4	4	-	-	-	2	0	0	31	0	0
4-19	19	0	0	-	0	0	0	0	1	0
9-4	4	10	0	-	0	0	0	0	0	1

[a]by membrane - filter techniques

[b]two samples collected

Fecal coliform bacteria were absent from all ground-water samples except those collected from wells directly beneath the effluent-irrigated pasture (site 4). At this site, one sample from each, the 4-ft (1.2-m) deep well and the 19-ft (5.8-m) deep well contained one col/100 ml. From these data is is reasonable to conclude that there col/100 ml. From these data it is reasonable to conclude that there was no evidence or pattern of fecal-bacterial contamination of the ground water from irrigation using the sewage-treatment-plant effluent.

Total coliforms were detected in water samples from some wells at sites 2, 3, 4 and 9. Total coliforms were detected in all three samples from well 2-19, downgradient from the pasture. Coliforms were also detected in two of three samples from well 2-14. As previously noted there is some indication of the ease of movement of water from near land surface directly down through the disturbed soil along the casings of these two wells at site 2. Therefore, bacteria in these two wells may be an unreliable indication of their presence in the deeper ground water.

Coliforms also were detected in all three samplings of well 4-4 in the effluent-irrigated pasture, but none were detected in samples from well 4-8. Total coliforms also were detected at least once in samples from wells 3-7 and 3-27, and well 9-4. Most of the counts were low, ranging from 3 to 300 col/100 ml. Because bacteria in the total coliform group may be present naturally in soil, their presence in the ground water does not necessarily indicate contamination resulting from irrigation using the treated effluent.

CONCLUSIONS

At the Carpenters' Home, the treated secondary effluent, averaging 25,000 gal/d (1.1 L/s) has been used to irrigate about 30 acres (12 ha) of Coastal bermuda grass since late 1969. The effluent, applied daily to different parts of the pasture, is far less than the crop water requirement, and thus is supplemented by rainfall and irrigation with water from the Floridan aquifer.

The rate of application of sewage at this site is low compared to that which would make maximum use of the infiltration and permeability characteristics of a given soil. Because the rate of application of the effluent is low, the soil and grass are afforded ample time to assimilate the applied wastewater. At the Carpenters' Home, the natural processes of dilution, filtration, sorption, nutrient uptake, biodegradation, nitrification and denitrification, and other soil biochemical processes combine to effectively reduce the total nitrogen and phosphorus, remove suspended solids and bacteria, and reduce the dissolved solids concentration in the applied wastewater. Data collected from wells at various depths and locations near the pasture indicate that the renovation is achieved in the upper 14 ft (4.3 m) of soil (most likely in the first few feet of the soil). Analyses of water samples collected in the pasture indicate total nitrogen was reduced about 80 percent in the upper 8 ft (2.4 m) of the soil, and total phosphorus was reduced to background levels in the top 4 ft (1.2 m) of soil. Some downgradient migration of total nitrogen was demonstrated, though migration of other constituents was not demonstrated in the waste water.

The pasture benefits from the nutrients contained in the effluent; the phosphorus and potassium load satisfies the crop requirement. The nitrogen load is about one-third of the crop requirement. Cattle graze the pastures concurrently with the application of the effluent. The BOD, total solids, and total kjeldahl nitrogen load in bovine waste was estimated to be in excess of the human waste load applied to the pasture.

Bacteriological data failed to indicate a definite pattern of fecal contamination of shallow ground water below the site. Though isolated incidences of the presence of pathogen-indicator bacteria were noted in samples from nine wells, most were in small numbers of the coliform group. Only four wells yielded water samples containing bacteria of probable fecal origin, (one col/100mls in each sample).

Soil data collected after 2.5 years of irrigation with the effluent show the soil to be relatively unaffected by the practice. The pH in the upper few feet of soil in the pasture was higher than outside the pasture, due chiefly to liming, an agricultural practice recommended to increase soil pH. Organic carbon and Kjeldahl nitrogen were only slightly higher in samples from the upper 2 ft (0.6 m) of pasture soil, compared to their concentrations in soil from a like depth outside the pasture.

After 2.5 years of low-rate sewage application, there was no detectable accumulation of solids clogging the soil surface. The infiltration rate for the pasture is relatively high, and the water-table gradient is away from the pasture, encouraging lateral movement of percolating water, generally toward Lake Gibson. Vertical hydraulic conductivity is between 0.7 and 3.9 ft/d (0.2 and 1.2 m/d) in the upper 10 ft (3 m), and is less in the clayey sand lenses deeper than 10 ft. The water table in the pasture ranged from 1 to 3.3 ft (0.3 to 1 m) below land surface during the 2.5-year period. Thus, a zone of aeration 1 to 3 ft (0.3 to 1 m) thick was main tained throughout the study.

The sewage at the Carpenters' Home is typical domestic sewage, with an absence of industrial wastes. The 200 to 220 persons, with commissary, laundry, and medical clinic, are the waste contributors at the home.

In summary, the low-rate application of chlorinated secondary-treated waste water to grazed pastures at the Carpenters' Home is apparently beneficial to the ground-water and surface-water resources and to the water environment of the area for a number of reasons. These include (1) conservation of fresh water, (2) recharge to the shallow aquifer, (3) elimination of direct discharge of the effluent containing nutrients, other dissolved and suspended solids, and bacteria into surface water, (4) distribution of the nutrients onto cultivated land, and (5) filtration of bacteria by the soil.

REFERENCES CITED

Benarde, Melvin, A., 1973, Land disposal and sewage effluent-Appraisal of health effects of pathogenic organisms: Jour. Am. Water Works Assoc., June 1973, p. 432-440.

Brown, Eugene, Skougstad, M.W. and Fishman, M.J , 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geol. Survey Techniques Water-Resources Inv., chap. A1, book 5, 160 p.

Burton, G.W., 1964, Coastal (Bermuda) covers more than six million acres: Livestock Breeder Jour., March 1964, 3 p.

Burton, G.W., 1954, Coastal Bermuda grass: Georgia Agriculture Experiment Stations Bull. N.S. 2, University of Georgia, 31 p.

Butson, K.D., and Prine, G.M., 1968, Weekly rainfall frequencies in Florida: Institute of Food and Agricultural Sciences, Exp. Sta., U. of Florida, Gainesville, 41 p.

Cathcart, J.B., 1964, Economic geology of the Lakeland quadrangle, Florida: U.S. Geol. Survey Bull. 1162-G, p. G1-128.

Goldberg, M.C., 1970, Sources of nitrogen in water supplies: Willrich, T.L., and Smith, G.E., eds., Agriculture practices and water quality, result of a conference, the Role of Agriculture in clean water, Ames, Iowa, November 18-20, 1969: Iowa State Univ. Press, p. 94-124.

Olsen, S.R. and Fried, M., 1957, Soil phosphorus and fertility, in U.S. Dept. of Agriculture, 1957, the Yearbook of Agriculture 1957: Washington, U.S. Govt. Printing Office.

Pride, R.W., Meyer, J.W., and Cherry, R.N., 1966, Hydrology of Green Swamp area in Central Florida: Florida Geol. Survey Rept. Inv. 42, 137 p.

Robertson, A.F., 1973, Hydrologic conditions in the Lakeland Ridge area of Polk County, Florida: Florida Bur. Geol. Rept. Inv. 64, 54 p.

Slack, K.V., Averett, R.C., Greeson, P.E., and Lipscomb, R.G., 1973, Methods for collection and analysis of aquatic biological and microbiological samples: U.S. Geol. Survey Techniques Water-Resources Inv., chap. A 4, book 5, 165 p.

Stewart, H.G., Jr., 1966, Ground-water resources of Polk County, Florida: Florida Geol. Survey Rept. Inv. 44, 170 p.

U.S. Dept. of Agriculture, Soil Cons. Ser., 1963, Conservation irrigation guide for design of sprinkler irrigation system for Florida: Univ. of Florida, Agr. Ext. Ser. and Agr. Exp. Sta., 13 p.

U.S. Dept. of Commerce, Nat. Oceanic and Atmospheric Admin., Environmental Data Service, 1972, Local Climatological Data Annual Summary-Lakeland, Florida: Washington, U.S. Govt. Printing Office.

U.S. Dept. of Interior, Fed. Water Pollution Control Admin., 1969, A primer on waste water treatment: Washington, U.S. Govt. Printing Office.
White, W.A., 1970, the geomorphology of the Florida peninsula: Florida Bur. of Geol. Bull. 51, p. 1-164.

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