Ground-Water Quality near an Inactive Landfill and Sludge-Spreading Area, Tallahassee, Florida

By Marian P. Berndt

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
acre	0.4047	hectare
cubic feet (ft^2)	0.0028	cubic meters
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
pound (lb)	0.453	kilogram
pound per acre (lb/acre)		kilograms per hectare
feet per day (ft/d)	0.3048	meter per day

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

ACRONYMS

MCL = maximum contaminant level
PVC = polyvinylchloride

ADDITIONAL ABBREVIATIONS

μmhos/m = micromhos per meter
μS/cm = microsiemens per centimeter at 25 degrees Celsius
μg/L = micrograms per liter
mg/L = milligrams per liter

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Abstract

Ground-water quality of a 120-acre area encompassing an inactive landfill southwest of Tallahassee, Florida, was assessed by installing and sampling 21 monitoring wells. Sludge from a municipal sewage-treatment plant was also applied to the land surface near the landfill site. Water samples were collected from the 21 monitoring wells from June 1987 through September 1990 and analyzed for concentrations of major ions, nitrogen species, trace metals, field measurements, and more than 140 organic constituents. Water quality in the Upper Floridan aquifer at the study site was compared to background water quality in other areas of Leon County. Ground-water quality of the study site was evaluated by the location of wells sampled in relation to the landfill and the sludge-spreading areas.

Results of nonparametric statistical analysis indicated that potassium and nitrite plus nitrate as nitrogen concentrations in water samples from wells completed in the Upper Floridan aquifer at the study site were significantly different at the 5 percent probability level from those in samples from background wells completed in this aquifer in Leon County. Median potassium concentrations were 0.4 mg/L (milligrams per liter) in water from wells at the study site and 0.7 mg/L in water from background wells in Leon County. Median nitrite plus nitrate concentrations were 6.48 mg/L in water samples from wells at the study site and 0.51 mg/L in water samples from background wells.

Graphical comparison of the water quality characteristics in water from six categories of wells; upgradient, landfill, adjacent to the landfill, downgradient onsite, downgradient offsite, and background Leon County, indicated that sodium, bicarbonate, sulfate, iron, manganese, and dissolved solids concentrations and specific conductance values were highest within the landfill. Upgradient and downgradient well categories include wells in areas affected by sludge spreading. Localized reducing conditions were indicated in a downgradient area by median iron concentrations of 930 and 30 μg/L (micrograms per liter) in samples from wells only 5 feet apart. Nitrite plus nitrate concentrations were lowest in water from wells in the landfill compared to water from the other categories. Concentrations of most trace elements and organic compounds were mostly below detection limits, although State maximum contaminant levels of 1 μg/L for benzene and vinyl chloride and 3 μg/L for tetrachloroethene were exceeded in 14 samples.

Concentrations of sodium, potassium, chloride, sulfate, nitrite plus nitrate, total organic and ammonia nitrogen, and ammonia nitrogen in ground water were statistically analyzed in areas affected by sludge-spreading and other areas. Only nitrite plus nitrate and chloride concentrations were significantly different between the two areas. Median nitrite plus nitrate and chloride concentrations in sludge-spreading areas were 6.9 mg/L and 2.9 mg/L, respectively, compared to 1.1 mg/L and 1.8 mg/L in other areas.

INTRODUCTION

The City of Tallahassee operated a municipal landfill at a site southwest of the city (fig. 1) from approximately 1959 to 1976. Other activities at the site include spreading of sludge from the municipal secondary sewage treatment plant and construction of a runway in 1976 for the Tallahassee Municipal Airport (now called the Tallahassee Regional Airport). The site is underlain by the unconfined surficial aquifer and the Upper Floridan aquifer of the Floridan aquifer system. The Upper Floridan aquifer is semiconfined in the area (Miller, 1986). The Upper Floridan aquifer is the primary source of drinking water for Leon County, so there is concern about possible contamination of this valuable water resource.

In 1986, the Florida Department of Environmental Regulation (FDER) installed seven monitoring wells (wells T-01 through T-07) around the perimeter of the landfill to determine the possible extent to which any landfill leachate may be causing ground-water contamination (fig. 1). Analysis of samples from the seven wells showed contamination of ground water (Hicks and others, 1986). Several constituents were detected at concentrations in excess of State primary and secondary maximum contaminant levels (MCL) for drinking water (Florida Department of Environmental Regulation, 1990), including sulfate, tetrachloroethene, sodium, nitrite plus nitrate, and manganese. In June 1987, the U.S. Geological Survey, in cooperation with the City of Tallahassee, began quarterly sampling of the seven wells analyzed by the City of Tallahassee Water Quality Laboratory. In October 1988, the U.S. Geological Survey (USGS) and the City of Tallahassee began an intensive cooperative study to better describe the extent and nature of the ground-water contamination at the study site. The study site includes areas near the landfill and sludge spreading. The results of the study are needed to assess the potential for contamination of the ground-water resources of the area. The study included installing additional wells and quarterly sampling of these and the previously installed monitoring wells at the study site.

Purpose and Scope

The purpose of this report is to describe the ground-water quality near an inactive landfill and a sludge-spreading area southwest of the City of Tallahassee. The hydrogeology near the site is also described. The study site included the area immediately surrounding and approximately 1,000 ft downgradient from the landfill. Various water quality data were evaluated, including 6 water-quality samples from 6 domestic wells located approximately 1 to 2 mi downgradient from the study site and 20 samples from 20 background water-quality sampling sites in Leon County (fig. 2).

Site Description

The inactive landfill is located southwest of Tallahassee near the Tallahasee Regional Airport (fig. 1). The 120-acre study site is on the southeast corner of the airport property and is bounded to the north by a cemetery and a highway. Another smaller cemetery is southeast of the landfill (fig. 1). The land surface slopes slightly to the southeast with elevations at the site ranging from approximately 60 ft above sea level on the north side of the site to approximately 30 ft above sea level on the southeast.

The landfill, which was known as the City of Tallahassee Dump when it was in operation, received mostly household trash from about 1959 (or earlier) until 1976. The landfill was filled beginning at the eastern end of the site boundary and progressed to the west. The trash was deposited in unlined, north-south oriented parallel trenches that were either about 20 ft deep and 45 ft across, or about 10 ft deep and 10 ft across (Hicks and others, 1986). A maximum estimated 30 million ft^3 of trash was deposited at the landfill during about 15 years of operation. The trenches were covered with native materials, consisting mostly of sand. An area covering approximately 20 acres on the south half of the landfill was excavated when an airport runway was constructed in 1976 (Hicks and others, 1986). The runway and approach lights were constructed on top of nonnative backfilled materials.

The City of Tallahassee currently deposits sludge at the study site from a secondary sewage-treatment plant across the road. Sludge has been spread at many locations at the study site (fig. 1, areas E, F, and G), including areas directly adjacent to the former landfill. Sludge was spread as early as the mid-1960's and continues to the present (1992).

Acknowledgments

The author thanks William G. Leseman and his staff of the City of Tallahassee Water Quality Laboratory for assistance in collecting and analyzing water-quality samples. The author also thanks the dispatchers at the Department of Public Works for providing access to the site and to Thomas P. Smith, former City Engineer for the City of Tallahassee, for providing historical accounts of the site and landfill operations.

METHODS OF INVESTIGATION

Several methods were used to assess the ground-water quality near the landfill and the sludge spreading and surrounding areas. Measurement of terrain conduc-

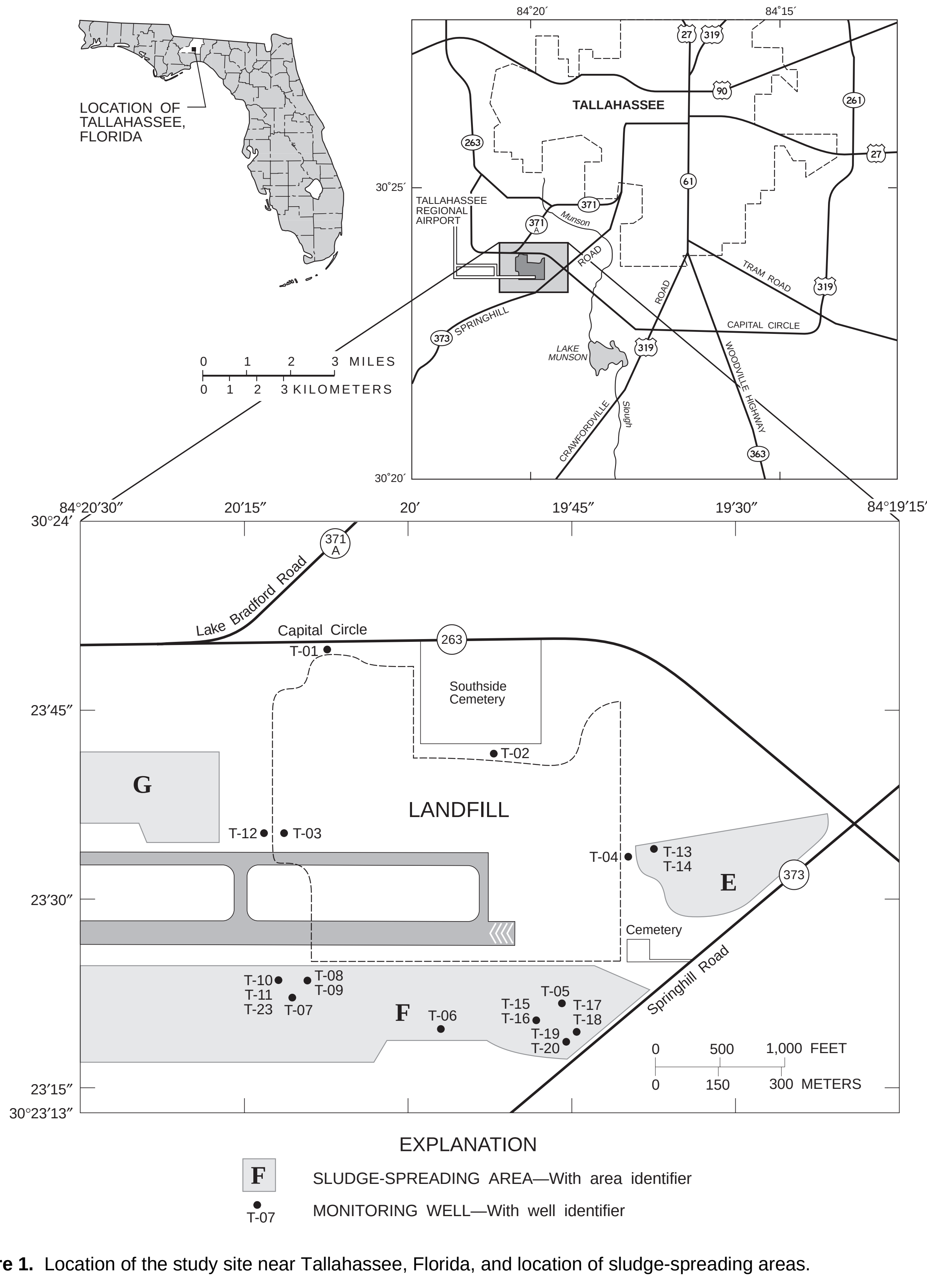

Figure 1. Location of the study site near Tallahassee, Florida, and location of sludge-spreading areas.

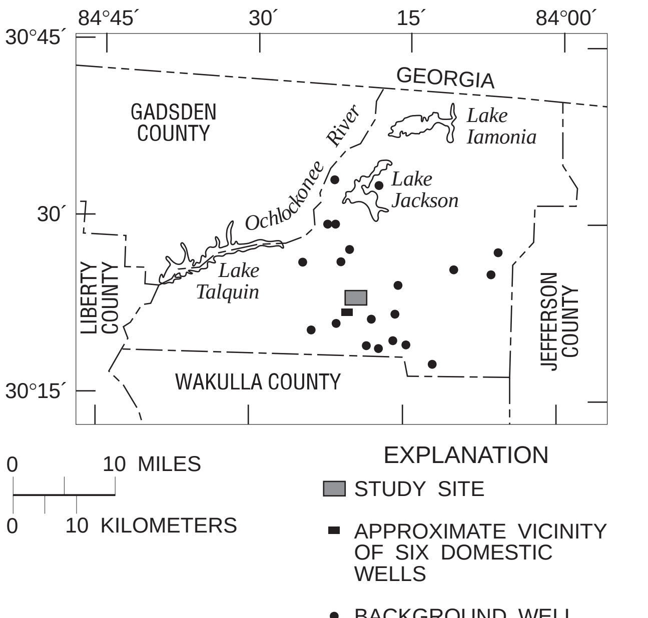

Figure 2. Locations of study site, domestic wells, and background wells in Leon County , Florida.

tivity was used as a reconnaissance tool to locate areas of possible ground-water contamination. Monitoring wells were installed and ground-water samples were collected. Water samples were analyzed for many inorganic and organic constituents in the laboratory and several measurements were made in the field.

Terrain Conductivity Survey

A surface geophysical survey was conducted at the landfill and surrounding area using electromagnetic terrain-conductivity equipment. Measurements were obtained using a Geonics EM34-3 Terrain Conductivity Meter. The purpose of the survey was to determine locations to install monitoring wells to sample contaminated ground water by identifying possible areas of ground-water contamination. Terrain-conductivity measurements can detect differences between saturated and unsaturated materials and some geologic materials. The measurements can sometimes be used to delineate between areas containing background ground-water quality and contaminated ground water in shallow aquifers.Conductivity values were obtained in the area of the landfill (fig. 1) at 111 stations using the 33-ft (10 m) coil spacing and the 66-ft (20 m) coil spacing in both the horizontal and vertical dipole configurations. The effective depth of exploration of terrain conductivity is dependent on both the coil spacing and the dipole configuration (McNeill, 1980, p. 6). The effective depth of exploration for the 33-ft coil spacing is 25 ft for the horizontal dipole configuration and 49 ft for the vertical dipole. The exploration depths for the 66-ft coil spacing are 49 and 98 ft for the horizontal and vertical dipoles.

The measurements of terrain-conductivity are presented in figures 3 and 4. The 33-ft coil spacing horizontal dipole configuration measurements were not used. This is because the measurements were made in October 1988 when water levels at the site ranged from 15 to 20 ft below land surface, and in some areas, were 30 ft below land surface; so a significant part of the explored thickness was unsaturated. Therefore, measurements recorded in this configuration would not indicate the presence or absence of possibly contaminated ground water. The 66-ft coil spacing horizontal dipole configuration was not used because the effective depth of exploration was equal to that of the 33-ft coil spacing vertical dipole configuration.

The locations of terrain-conductivity measurement stations were limited by a runway, taxiway and accompanying lighting and electrical wiring, and several small buildings in the vicinity of the airport. These features prevented the measurement of terrain-conductivity in the south half of the landfill.

Variable hydrogeology and lithology limit the ability to determine background terrain conductivities at this study site. Background terrain conductivities are only valid if there are no lithologic or depositional variations within the area of concern (Duran, 1984). Examination of well logs from a previous investigation at the site showed that clay layers were present on the south side of the landfill in thicknesses ranged from 15 to 30 ft; but at sites to the north, west, and east of the landfill, no clay layers were present (Hicks and others, 1986, p. 45-50). Comparison of values from the areas where clay is present to areas where clay is absent is not feasible. Terrain-conductivity values in the two areas have differing ranges (figs. 3 and 4). These differences are due, in part, to the absence or presence of clay in some areas and to the fact that some measurements were made on top of landfill materials.

Installation of Wells

Fourteen monitoring wells were installed at the site in 1989 and 1990. Two were 4-in. diameter wells, which were drilled using mud rotary, and twelve were 2-in. diameter wells, which were augered. Casing and screen material used in the wells is polyvinylchloride (PVC) with 5 to 10 ft of slotted screen, except for well T-08 which has 2 ft of open interval in the Upper Floridan

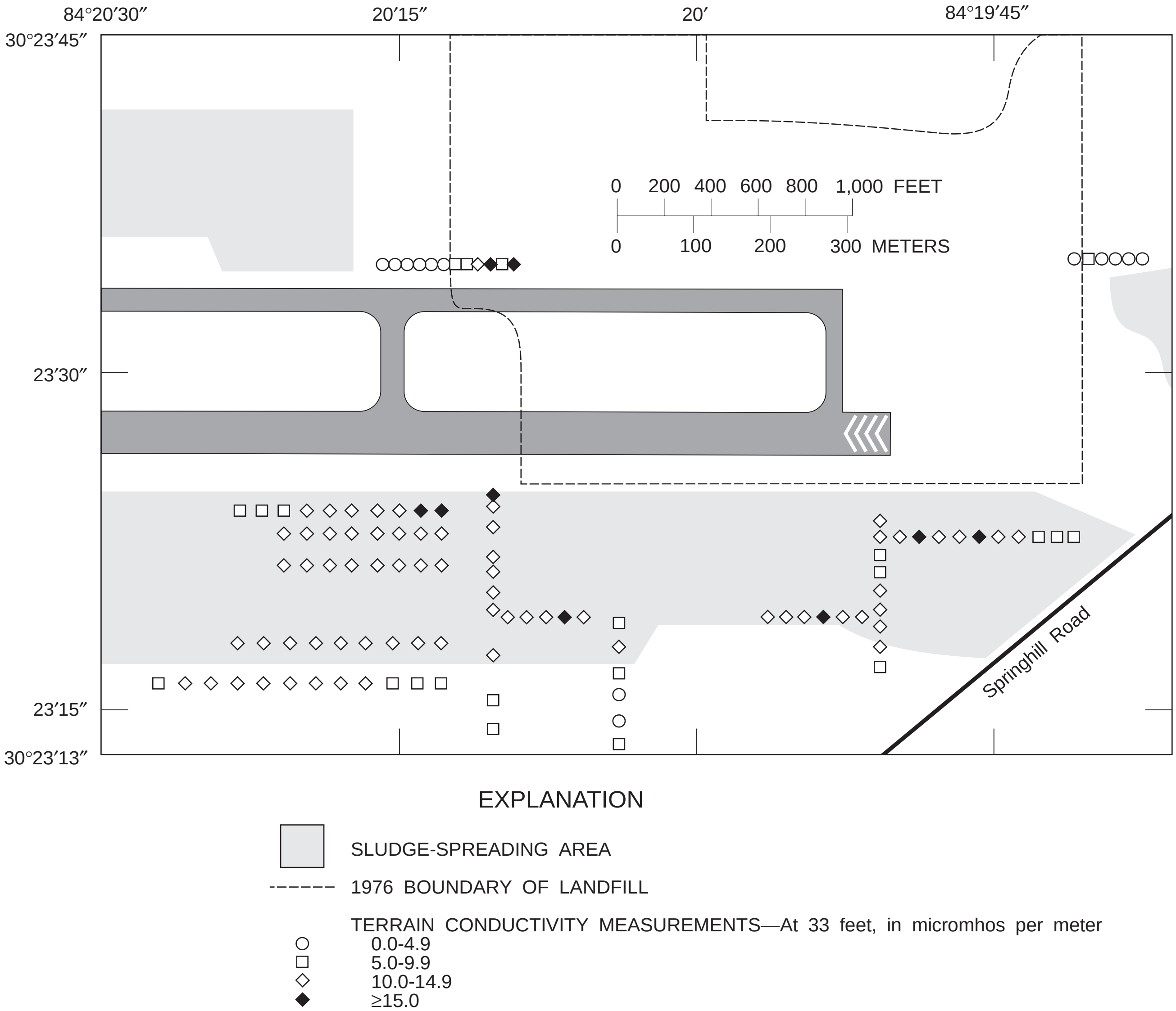

Figure 3. Measurements of electromagnetic terrain conductivity at the 33-foot vertical-dipole configuration.

Terrain-conductivity measurements were made in the area directly overlying the landfill and in areas adjacent to the landfill. Terrain conductivities directly over the landfill ranged from 10 to 56 µmhos/m (figs. 3 and 4). Conductivities decreased with distance from the landfill boundary with values as low as 2.5 µmhos/m several hundred feet from the landfill boundary (figs. 3 and 4).

Different ranges of terrain conductivity were measured downgradient from the landfill to the south. Conductivities ranged from 6 to 18 µmhos/m, with most values between 10 and 14.9 µmhos/m. Highest conductivities for both the 33-ft and 66-ft spaced vertical-dipole surveys south of the landfill were in two locations; one located directly southwest of the landfill and the other south of the southeast corner of the landfill (figs. 3 and 4). In these areas, values exceeded 15 µmhos/m. Because of the relatively high terrain conductivities on the south, downgradient side of the landfill and the predominant south to southeast flow paths in the Upper Floridan aquifer in the region (Rosenau and Meadows, 1986), these two areas were considered possible areas of ground-water contamination by the landfill leachate and several monitoring wells were installed in each of these areas (wells T8, T10, T11, and T23). The effects of landfill materials on ground-water quality in these and other downgradient areas are discussed in a subsequent section of this report.

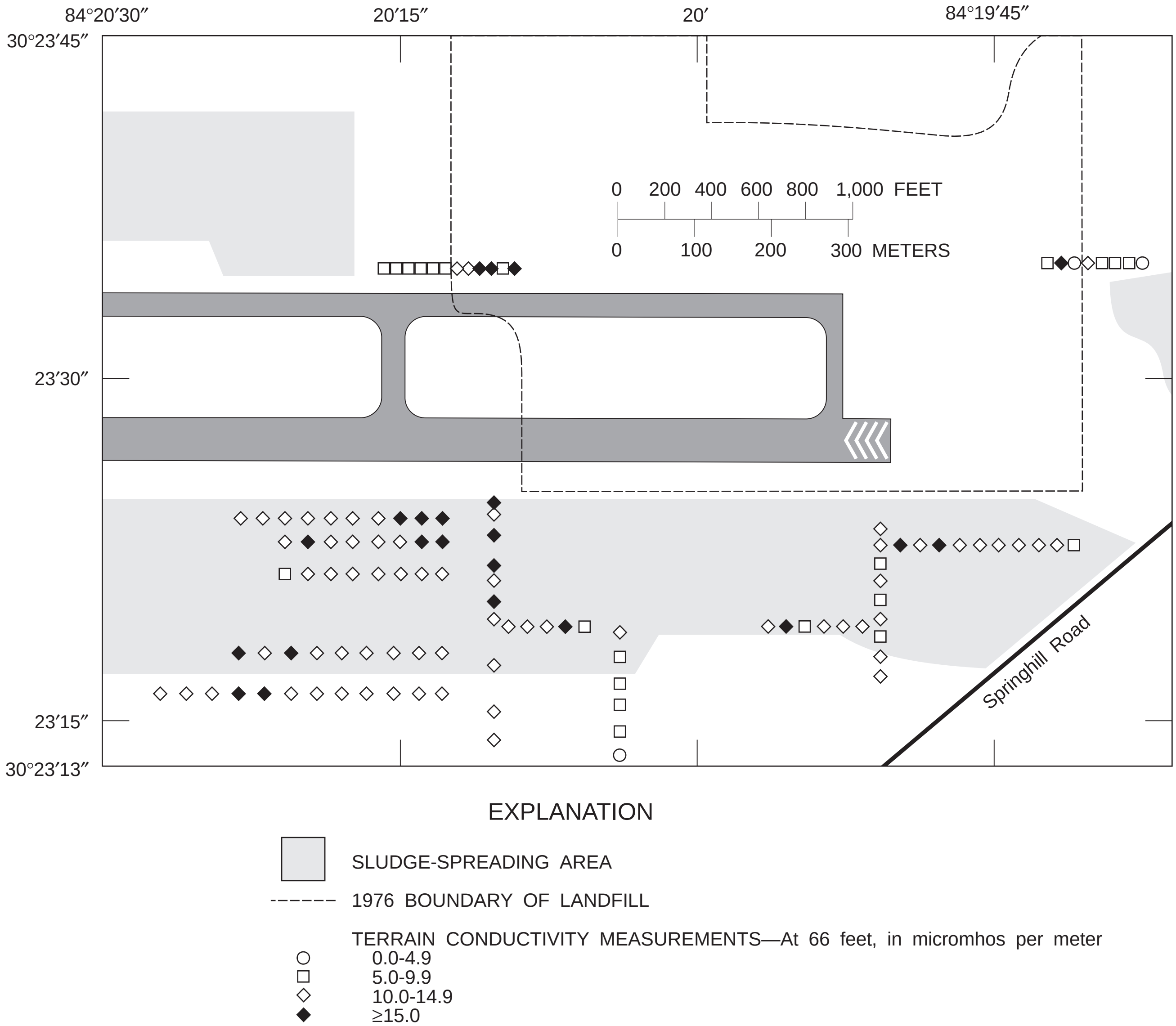

Figure 4. Measurements of electromagnetic terrain conductivity at the 66-foot vertical-dipole configuration.

aquifer. Depths of the wells range from 13 to 99 ft below land surface. Characteristics of the 14 wells installed as part of this study, and the 7 monitoring wells installed by previous investigators are presented in table 1. Locations of the monitoring wells at the site are shown in figure 1. Subsequent to drilling, wells were developed by forcing water out of the well with compressed air, by pumping with a submersible or positive-displacement pump, or by bailing water from the well until it was dry or a volume of water equivalent to the volume of the cased interval had been removed.

Sampling and Analysis of Ground Water

Measurements of temperature, pH, specific conductance, and alkalinity, were made in the field using standard USGS procedures (Wood, 1976). Chemical analyses of major ions, trace metals, and organic compounds, including volatile organic compounds, organochlorine pesticides, base-neutral and acid-fraction organic compounds, were provided by the City of Tallahassee Water Quality Laboratory using standard procedures (U.S. Environmental Protection Agency, 1979 1982, 1986; American Public Health Association, 1985; Fishman and Friedman, 1989).

Median concentrations for samples from a well or groups of wells were determined to compare water

Table 1. Characteristics of monitoring wells at the landfill

[FDER, Florida Department of Environmental Regulation; USGS, U.S. Geological Survey; UF, Upper Floridan; S, Surficial]

Well identifier	Aquifer	Diameter (inches)	Total depth (feet)	Screened or open hole interval (feet below land surface)
Installed by FDER				
T-01	UF	4	62.3	56.5 - 62.3 open
T-02	UF	4	79.3	35.0 - 79.3 open
T-03	S	2	30.8	15.8 - 30.8 screened
T-04	S	2	43.6	29.0 - 43.6 screened
T-05	UF	4	38.6	30.0 - 38.6 open
T-06	UF	4	39.7	25.0 - 39.7 open
T-07	UF	4	64.8	40.0 - 64.8 open
Installed by USGS				
T-08	UF	4	40.0	38.0 - 40.0 open
T-09	S	2	13.5	8.5 - 13.5 screened
T-10	UF	2	42.0	38.0 - 42.0 screened
T-11	S	2	17.5	12.5 - 17.5 screened
T-12	S	2	55.6	50.6 - 55.6 screened
T-13	S	2	50.0	45.0 - 50.0 screened
T-14	S	2	45.0	40.0 - 45.0 screened
T-15	UF	2	47.0	42.0 - 47.0 screened
T-16	S	2	28.9	23.9 - 28.9 screened
T-17	UF	2	28.5	23.5 - 28.5 screened
T-18	S	2	14.0	9.0 - 14.0 screened
T-19	UF	2	32.0	27.0 - 32.0 screened
T-20	S	2	11.5	6.5 - 11.5 screened
T-23	UF	4	99.0	84.0 - 94.0 screened

quality characteristics between areas. Wells were determined based on location in relation to the landfill and the direction of the shallow ground-water flow system. When analyses included results reported below analytical detection limits, the method of Helsel and Cohn (1988) was used to calculate median values using maximum likelihood estimates.

Analyses were performed on 136 samples of ground water collected from 18 wells from June 1987 through September 1990. Samples were collected from wells T-01 through T-07 from June 1987 through September 1990 with the exception of well T-03 which was sampled only from June 1987 through June 1988 because subsequent to June 1988 the well was either completely dry or had too little water to purge and then sample. Wells T-08 through T-19 were first sampled shortly after installation in either March, April, or June 1989, except for well T-18 which was first sampled in March 1990 (it was dry on other sampling attempts). Well T-23 was first sampled in April 1990, shortly after it was installed. Wells T-09, T-11, and T-20 remained dry during the course of this study and were not sampled.

HYDROGEOLOGY

The study site is underlain by a sandy surficial aquifer and by the Upper Floridan aquifer of the Floridan aquifer system. The hydrogeologic units present in the area southwest of Tallahassee and their general lithology are shown in figure 5.

Surficial Aquifer

The surficial aquifer ranges from 20- to 70-ft thick near the inactive landfill and consists of medium-grained sand and clayey sand with discontinuous clay layers. The clay layers range in thickness from 5- to 30-ft and are only present on the south side of the landfill. An east-west runway bisects the study site and restricts access to the middle part, so the location where the clay pinches out could not be determined. This aquifer is partly saturated and the potentiometric surface is slightly above the potentiometric surface of the

SERIES	STRATIGRAPHIC UNIT	GENERAL LITHOLOGY	THICKNESS	HYDROGEOLOGIC UNIT
Holocene to Pleistocene	Unnamed	Fine sand, clayey sand, and clay	20-70 Feet	Surficial aquifer
Miocene	St. Marks Formation	White to yellow-orange sandy limestone	Approximately 1,300 feet	Upper Floridan aquifer
Oligocene	Suwannee Limestone	Yellow-orange, fossiliferous, very porous and permeable limestone		
Eocene	Ocala Limestone	Pale orange to white, fossiliferous, very porous limestone		

Figure 5. Stratigraphic and hydrogeologic units near the inactive landfill, modified from Hendry and Sproul (1966) and Miller (1986).

Surficial Aquifer

The surficial aquifer ranges from 20- to 70-ft thick near the inactive landfill and consists of medium-grained sand and clayey sand with discontinuous clay layers. The clay layers range in thickness from 5- to 30-ft and are only present on the south side of the landfill. As eastwest runway bisects the study site and restricts access to the middle part, so the location where the clay pinches out could not be determined . This aquifer is partly saturated and the potentiometric surface is slightly above the potentiometric surface of the underlying Upper Floridan aquifer. A potentiometric-surface map could not be drawn because of the small number of wells, but measurements adjacent to the landfill indicates that flow in the surficial aquifer at the study site is outward from the landfill to the east, south, and west.

Slug tests are used to calculate properties of the aquifer such as hydraulic conductivity and transmissivity, properties which relate to the ability of an aquifer to transmit water. The tests were done only on surficial aquifer wells. The slug tests were conducted and results calculated according to the methods outlined by Bouwer (1989) and Bouwer and Rice (1976). Results of the slug tests are presented in table 2. Calculated hydrauic conductivity values ranged from 3.9 to 19.6 ft/d.

Upper Floridan Aquifer

Regionally, the Floridan aquifer system has been divided into the Upper Floridan and the Lower Floridan aquifers ; however, because of the absence of a middle confining unit in the vicinity of the study site, the aquifer is referred to as the Upper Floridan aquifer (Miller, 1986). The Upper Floridan aquifer is a sequence of highly permeable carbonate rocks and is the principal source of water in the area because of its high yield to wells. The aquifer is semiconfined. The confining layer is generally less than 100-ft thick and may be breached (Bush and Johnston, 1988). The Upper Floridan aquifer is approximately 1,300 ft thick in the study site (Miller 1986, pl. 28), and includes the St. Marks Formation, Suwannee Limestone, and Ocala Limestone (fig. 5) (Hendry and Sproul, 1966; Miller, 1986). The St. Marks Formation is a silty to sandy limestone as much as 200 ft thick (Hendry and Sproul, 1966). The Suwannee Limestone underlies the St. Marks Formation and contains numerous solution channels (Hendry and Sproul, 1966). Ground-water flow in the Tallahassee area gen-

Table 2. Results of slug tests on wells in the surficial aquifer

[ft/d, feet per day]

Well identifier	Hydraulic conductivity (ft/d)
T-12	10.8
T-12 (duplicate)	12.2
T-13	10.8
T-14	3.9
T-16	18.3
T-17	12.7
T-19	19.6

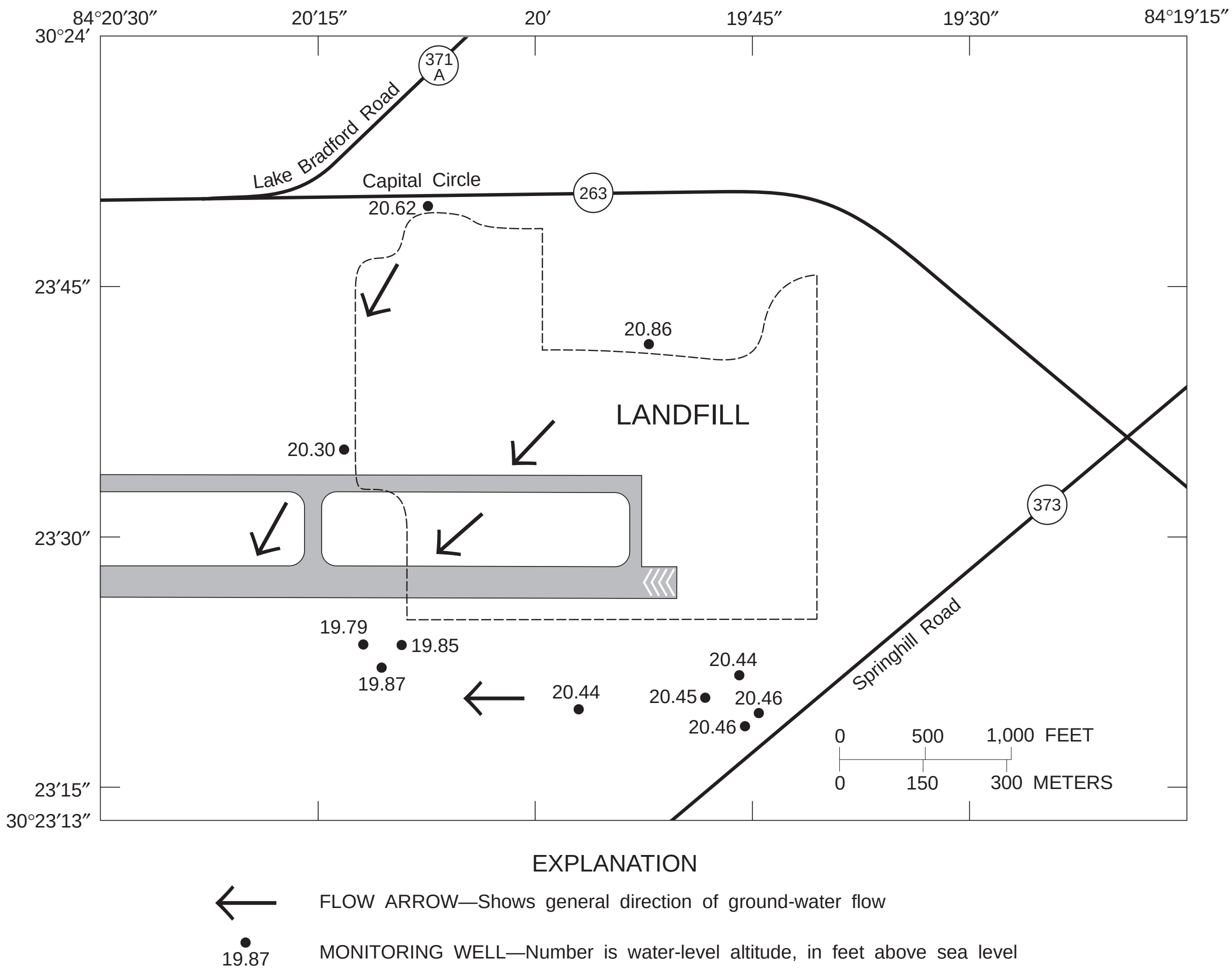

Figure 6. Water levels in wells tapping the Upper Floridan aquifer at the site.

erally is to the southeast (Rosenau and Meadows, 1986), but flow directions in the Upper Floridan aquifer in the vicinty of the study site are to the west and southwest (fig. 6).

Slug tests were not conducted on wells in the Upper Floridan aquifer due to high transmissivity values usually associated with this aquifer. It was expected that the response of that aquifer would be instantaneous and not detectable given the relatively small size of the slug withdrawn during the test.

GROUND-WATER QUALITY

The ground-water quality in the Upper Floridan aquifer near the study site was compared to the background water quality at 20 wells open to the Upper Floridan aquifer in other areas in Leon County. Comparisons were also made between the quality of water in the Upper Floridan aquifer and in the surficial aquifer at the study site. The 20 wells in the Upper Floridan aquifer in Leon County (fig. 2) that were used as background sites for comparison with the study site are part of a statewide set of background wells (Katz, 1992). Water-quality data from this set of background wells was only included for wells with depths less than 150 ft, because the deepest well at the landfill was 99 ft. Water-quality samples from two wells completed in the surficial aquifer at the study site were excluded from comparisons with samples from the Upper Floridan wells at the site because the wells were located within or along the border of the landfill.

The Wilcoxon rank-sum test (SAS Institute, Inc., 1988) is a nonparametric statistical test that was used in this report to determine if differences exist in water quality between selected groups of water quality data. The null hypothesis in each test was that there is no significant difference in two groups of water-quality data that are grouped by aquifer or by location. The level of significance that is used in the hypothesis tests in this report is 0.05. This value represents the maximum probability of rejecting the null hypothesis when it is actually true. For each water-quality characteristic tested, the p-value representing the attained significance level is presented. For these tests, a significant difference in the values of a water-quality characteristic between sample groups was assumed if the p-value is less than or equal to 0.05.

Ground-water quality in the Upper Floridan aquifer at the study site was similar to background ground-water quality in the Upper Floridan aquifer in Leon County (table 3). The pH, specific conductance and concentrations of most major ions in water from wells completed in the Upper Floridan aquifer at the site generally were within the ranges of values measured in the 20 samples from the background wells (table 3). Sulfate concentrations in some samples from wells in the Upper Floridan aquifer at the site exceeded the maximum concentrations measured in the water from the background wells, although the median sulfate concentration at the study site was lower than the median for the background sites.

Table 3. Summary of selected water-quality characteristics for samples from the Upper Floridan aquifer in Leon County and in the Upper Floridan aquifer and the surficial aquifer at the study site

[mg/L, milligrams per liter µg/L, micrograms per liter; Ranges represent all analyses in each category; Data from the surficial aquifer does not include data from well in the landfill (T-03) or well adjacent to the landfill (T-04); median s are considered significantly different if p-value is equal to or less than 0.05; <, less than; --, no data]

Water-quality and well characteristics	Value or concentration in water from aquifers in Leon County		Value or concentration in water from aquifers at the Study site				p-values for Wilcoxon rank-sum test	
	Upper Floridan aquifer wells (21 wells, 21 analyses)		Upper Floridan aquifer wells (12 wells[1], 98 analyses)		Surficial aquifer wells (4 wells[2], 14 analyses[3])			
	Median	Range	Median	Range	Median	Range	Upper Floridan aquifer in Leon County and at site	Upper Floridan and surficial aquifers at site
Calcium (mg/L)	38.0	21.4 - 88.4	35.3	13.3 - 86.3	6.5	1.8 - 38.7	0.07	<0.01
Magnesium (mg/L)	4.1	1.0 - 20.0	2.48	.81 - 20.1	1.2	.81 - 6.3	.13	.11
Sodium (mg/L)	3.7	2.1 - 3.7	2.22	.75 - 6.36	2.5	1.02 - 8.8	.01	.85
Potassium (mg/L)	.4	.3 - .8	.70	.05 - 2.98	.42	.07 - .84	.01	< .01
Bicarbonate (mg/L)	146	82.0 -266	87.5	39 -268	15	8 - 88	<.01	< .01
Chloride (mg/L)	4.0	2.4 - 8.9	2.38	.19 - 7.0	6.4	1.57 - 22.7	<.01	< .01
Sulfate (mg/L)	3.7	1.4 - 12.7	2.78	.23 - 27.9	10.3	86 - 52.5	.36	< .01
Nitrite +nitrate, as nitrogen (mg/L)	.51	.06 - 3.0	6.48	<.02 - 19	.17	< .02 - 7.25	< .01	< .01
Nitrogen, ammonia plus organic (mg/L)	--	--	.08	< .07 - 1.61	1.63	.19 - 15	--	< .01
Ammonia, as nitrogen (mg/L)	--	--	.01	< .02 - .20	.06	<.02 - .79	--	< .01
Iron, (µg/L)	--	--	25	<5.6 -690	34.7	<5.6 - 1127	--	.03
Manganese, (µg/L)	--	--	4.0	<1.2 -105	35.7	5 - 84	--	< .01
pH, standard units (µg/L)	7.8	7.0 - 8.6	7.8	6.8 - 10.0	6.0	5.5 - 6.9	. 20	< .01
Specific conductance, S/cm	230	142 -385	221	130 -430	36	10 - 263	.51	< .01
Well depth, in feet	100.0	55.0 -147.0	46.5	30.5 - 99	39.2	16.0 - 52.5		

[1]Wells T-01, T-02, T-05 through T-08, T-10, T-12, T-15 through T-17, T-19, and T-23.
[2]Wells T-12, T-14, T-16, and T-18.
[3]Only four of the seven wells tapping the surficial aquifer yielded samples during the sampling period.

Results of the Wilcoxon rank-sum test (SAS Institute, Inc., 1988), indicated that most major-ion and field measurements in the Upper Floridan aquifer background sites were not significantly different from the Upper Floridan aquifer at the study site. For the few major ions or field measurements whose concentrations or values were significantly different, the higher median concentrations or values were in samples from the background sites. Calcium, magnesium, and sulfate concentrations and pH and specific conductance values in the two groups of samples were not significantly different (table 3). Sodium, bicarbonate, and chloride concentrations in the two groups of samples were significantly different and median concentrations of these major ions were higher in the background samples (table 3). However, median sodium and chloride concentrations in the two groups of samples, differed by less than 2.0 mg/L; whereas the median bicarbonate concentration in the background samples, 146 mg/L, was nearly double the median bicarbonate concentration of 87.5 mg/L at the study site (table 3). The concentrations of these ions probably were higher in the background samples relative to the study site samples because the background wells were deeper on average than the wells at the landfill, so ground water from the background wells had greater residence time than the ground water at the study site. The median well depth for the Leon County wells was 100 ft, whereas the median well depth at the landfill site was 46.5 ft. The deepest well at the landfill site was 99 ft.

Nitrite plus nitrate as nitrogen and potassium concentrations in water from the Upper Floridan aquifer at the study site were significantly different from concentrations in water from the background sites. Median concentrations at the study site were higher than the background sites. The median nitrite plus nitrite plus nitrate concentration for samples from the study site was 6.48 mg/L, compared to 0.51 mg/L in the background samples. Potassium had a median concentration of 0.7 mg/L at the study site and 0.4 mg/L at the background sites (table 3). Nitrite plus nitrite plus nitrate and potassium are present in sewage sludge (Miller, 1980, p. 250), thus concentrations are probably higher overall at the study site as the result of sludge spreading. The effects of sludge spreading on water quality at the study site will be discussed in a subsequent section.

Differences in water quality were noted between the Upper Floridan and surficial aquifers at the study site. Results of the Wilcoxon rank-sum test of water quality in the Upper Floridan and surficial aquifers at the landfill site indicated that several values of physical and chemical characteristics of water from the two aquifers were significantly different. Of those that were significantly different, calcium, potassium, bicarbonate, nitrite plus nitrite plus nitrate, pH, and specific conductance had greater median concentrations or values in the Upper Floridan aquifer. Because the Upper Floridan aquifer consists predominantly of soluble limestone, higher concentrations of calcium and bicarbonate and higher values of pH and specific conductance in samples from this aquifer probably can be attributed to limestone dissolution.

The higher median potassium and nitrite plus nitrite plus nitrate concentrations in water from the Upper Floridan aquifer are probably related to the location of many of the sampled wells in the sludge spreading areas. Magnesium and sodium concentrations in water from the two aquifers were not significantly different.

Median ammonia plus organic nitrogen concentrations were higher in water from the surficial aquifer than in the Upper Floridan aquifer, whereas median nitrite plus nitrate concentrations (as nitrogen) were higher in water from the Upper Floridan aquifer (table 3). This indicates that nitrite plus nitrate concentration might be increasing with depth, but the number of samples from the surficial aquifer are fewer than the number of samples from the Upper Floridan aquifer and thus less representative. Data from the surficial aquifer includes 14 analyses of water from 4 wells, whereas the Upper Floridan aquifer data totals 97 analyses of water from 12 wells. Only 2 of the 4 wells completed in the surficial aquifer are in sludge-spreading areas (wells T-16 and T-18), compared to 10 of the 12 wells completed in the Upper Floridan aquifer.

Distribution of Selected Inorganic Characteristics

Ranges in values for selected water quality characteristics in water samples collected from wells located within and directly adjacent to the landfill were compared to those of samples from wells located upgradient and downgradient from the landfill, as well as to background wells in Leon County. Some wells located upgradient and downgradient from the landfill were also located in sludge-spreading areas. The effects of sludge spreading on ground-water quality will be discussed in the following section of the report. Analytical results were also available for water sampled from six domestic wells located approximately 1 to 2 mi downgradient from the study site. The chemical analyses for these samples were performed by the laboratory that analyzed the samples collected at the study site. Analytical results of samples from the following categories of wells were compared:

(1) Upgradient from the landfill and onsite (2 wells)

(2) Within the landfill (1 well)

(3) Adjacent to the landfill (1 well less than 15 ft from a trench)

(4) Downgradient from the landfill (14 wells)

(5) Downgradient from the landfill and offsite (6 wells)

(6) Background areas in Leon County (20 wells) (B.G. Katz, USGS, written commun., 1990)

Median values for selected water quality characteristics for each category of wells are given in table 4. Wells tapping the surficial and Upper Floridan aquifers were included in these categories.

Water samples from well T-03 located within the landfill had the highest median values for general physical and chemical characteristics including sodium, bicarbonate, sulfate, iron, manganese, dissolved solids, and specific conductance values (table 4). Only five water samples from well T-03 were available for analysis, because the well was dry or had too little water to sample after June 1988. Graphical summaries of sodium, bicarbonate, sulfate, iron, manganese, dissolved solids, and specific conductance values are shown in figures 7a-7g to illustrate the distribution among the categories. Concentrations below analytical detection limits were set equal to the constituent detection limit for the preparation of these graphical summaries. The highest values of these characteristics were measured in samples from well T-03 (in the landfill), and much lower concentrations were measured in samples from nearby wells, indicating that processes causing many constituents to have elevated concentrations in ground water in the landfill are not occurring downgradient from the landfill. In well T-04, adjacent to the landfill, values were either between the values for samples from the well in the landfill and values for samples from wells in other categories or similar to the ranges in samples from the upgradient, downgradient

Table 4. Median values for selected water-quality characteristics in water for six categories of wells

[Concentrations are in milligrams per liter, unless otherwise noted; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data]

Water-quality characteristics	Median value or concentration					
				Downgradient wells		
	Upgradient onsite wells[1] (2 wells, 28 analyses)	Landfill well[2] (1 well, 5 analyses)	Adjacent well[3] 1 well, 14 analyses)	Onsite[4] (14 wells, 84 analyses)	Offsite (6 wells, 6 analyses)	Background wells in Leon County (20 Wells, 20 analyses)
Calcium	23.9	14.8	82.7	34.0	28.6	38.0
Magnesium	9.1	4.2	7.2	1.9	6.4	4.1
Sodium	1.9	272	16.9	2.4	2.6	3.7
Bicarbonate	136	785	414	68	117	146
Chloride	1.7	3.7	1.6	2.9	3.7	4.0
Sulfate	2.1	142	7.2	4.8	3.6	3.6
Nitrite+ Nitrate as nitrogen	.54	.02	1.7	6.86	.23	.51
Iron, µg/L	26	1,750	24	25	140	86
Manganese, µg/L	4.6	355	134	4.7	3.4	--
pH, standard units	7.6	6.5	6.8	7.8	7.5	7.8
Specific conductance, µS/cm	250	1,310	582	216	--	220
Dissolved solids	152	778	348	157	106	150

[1]Wells T-01, T-02. [2]Well T-03. [3]Well T-04. [4]Wells T-05 through 08, T-10, T-12 through 19, T-23.

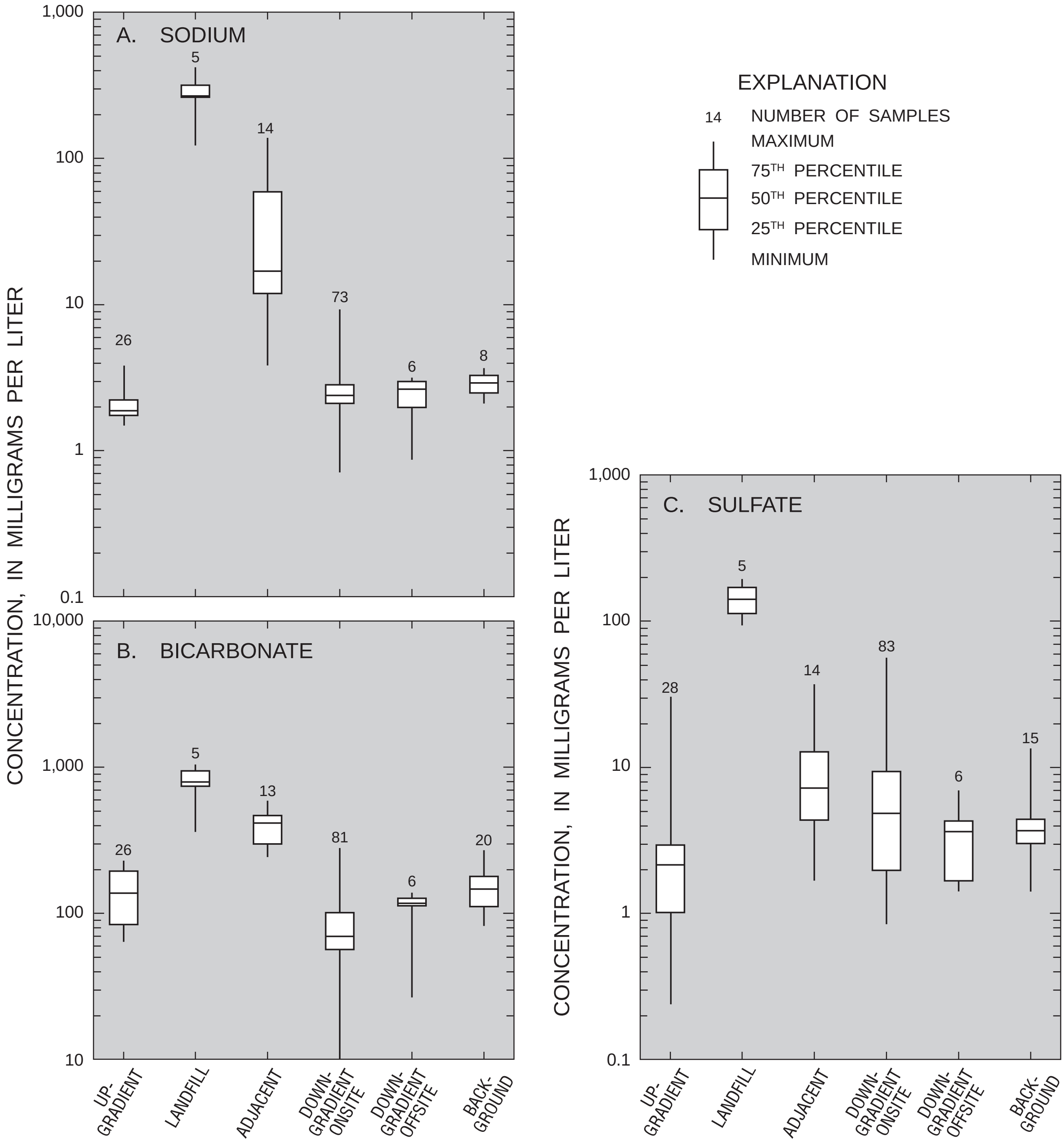

Figure 7. Summaries of water quality in samples from wells located upgradient from, in, adjacent to, and downgradient from the landfill, and from background wells in Leon County, Florida, showing distribution of concentrations of: (a) Sodium, (b) Bicarbonate, (c) Sulfate, (d) Iron, (e) Manganese, (f) Dissolved solids, and (g) Specific-conductance values.

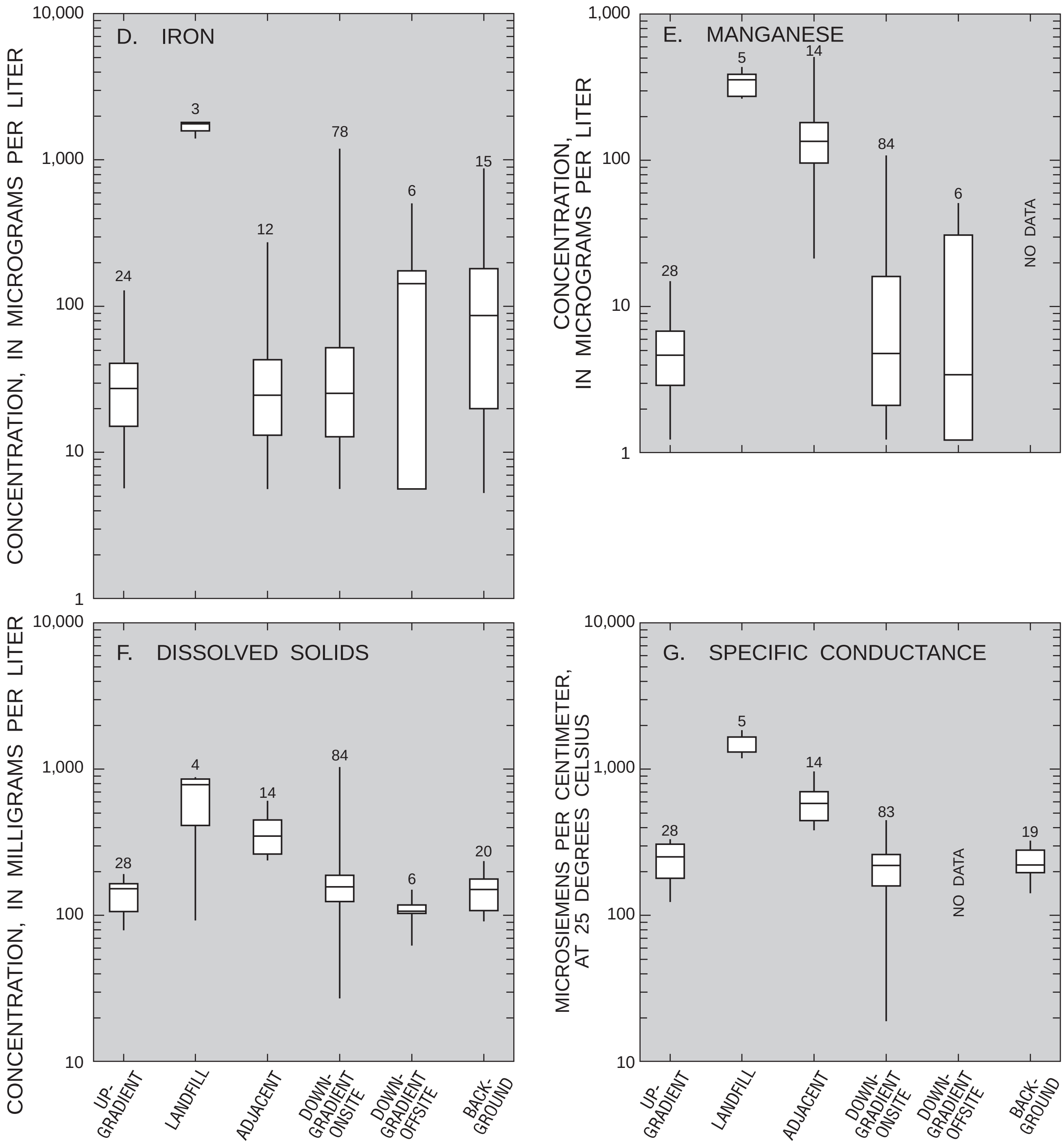

Figure 7. Summaries of water quality in samples from wells located upgradient from, in, adjacent to, and downgradient from the landfill, and from background wells in Leon County, Florida, showing distribution of concentrations of: (a) Sodium, (b) Bicarbonate, (c) Sulfate, (d) Iron, (e) Manganese, (f) Dissolved solids, and (g) Specific-conductance values--Continued.

onsite, downgradient offsite, and background well (table 4, figs. 7a-7g). The low values of most characteristics in water from wells in downgradient areas indicate that the effect of the landfill materials on ground-water quality is limited to local areas within the landfill and that contaminated water has not moved far from the landfill.

Iron and manganese concentrations in water samples from the well within the landfill exceeded State MCLs (500 and 300 µg/L, respectively) (Florida Department of Environmental Regulation, 1990). Iron and manganese have been measured in high concentrations in ground water adjacent to landfills where reducing conditions cause iron and manganese to be leached either from landfill materials or from aquifer sediments (Baedecker and Apgar, 1984). These reducing conditions seem to be localized at this landfill site, because samples from wells in downgradient areas (figs. 7d and 7e) had low iron and manganese concentrations.

Variability in iron, sulfate, nitrite plus nitrate, and total ammonia plus organic nitrogen concentrations in ground water near the landfill indicates reducing conditions were highly localized. Samples from the two wells closest to the landfill (wells T-14 and T-13) had different ranges in iron concentrations. Samples from well T-14 had a median iron concentration of 930 µg/L, whereas samples from well T-13, 5 ft deeper and approximately 5 ft away, had a median iron concentration of 30 µg/L (table 5). Median sulfate concentration was 30 mg/L in samples from well T-14 and 10 mg/L in samples from the deeper well T-13. Median nitrite plus nitrite plus nitrate concentrations in samples from both well T-13 and T-14 were less than 0.2 mg/L, whereas median total ammonia plus organic nitrogen in samples from wells T-13 and T-14 were 3.2 mg/L and 3.3 mg/L, respectively. The source of the nitrogen in ground water at these sites is probably the sewage-treatment plant sludge spread in this area. The presence of the reduced nitrogen species, total ammonia plus organic nitrogen, and the lack of the oxidized species, nitrite plus nitrate, as well as the differences in iron and sulfate concentrations in ground-water samples from wells T-14 and T-13 indicates that reducing conditions are highly localized in this particular area of the study site.

Nitrite plus nitrate concentrations at the study site were high in upgradient and downgradient areas but low in samples from wells T-03 and T-04, as shown in the graphical summary in figure 8. The lowest concentrations of nitrite plus nitrate at the study site were measured in samples from well T-03, indicating nitrite plus nitrate is being reduced within the landfill or that other sources of nitrite or nitrite plus nitrate are present at the study site. The spreading of sewage sludge at the study site is a probable source of nitrite plus nitrate and other nitrogen species.

Choride concentrations are commonly elevated in ground water downgradient from landfills (Baedecker and Back, 1979; Kimmel and Braids, 1980), but at this study site, chloride concentrations were lower than concentrations at other landfill study sites in northwest Florida.

Table 5. Median values or concentrations of selected water-quality characteristics in water from selected wells

[µS/cm, microseimens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; BDL, greater than 50 percent of all concentrations below detection limit]

Well identifer	Number of samples	Specific conductance, (µS/cm)	Chloride (mg/L)	Sulfate, (mg/L)	Iron, (µg/L)	Manganese, (µg/L)	Nitrite plus nitrate as nitrogen (mg/L)	Total ammonia plus organic nitrogen (mg/L)
T-05	13	257	2.7	9.1	26	4.4	11.4	0.12
T-06	14	206	2.5	1.4	29	2.2	11.0	BDL
T-07	14	150	1.7	2.4	28	2.5	6.9	.04
T-08	5	293	3.3	2.0	13	5.5	1.3	BDL
T-10	5	200	3.0	2.0	8.4	16	1.7	.22
T-12	4	294	2.2	6.0	64	40	BDL	.38
T-13	4	34	4.5	10.3	30	7.0	.16	3.2
T-14	5	33	4.4	3.0	926	38	.05	3.3
T-15	5	390	3.0	9.1	336	77	BDL	.28
T-16	4	246	8.8	17.7	21	83	6.2	.41
T-17	4	307	3.9	20.4	15	7.8	17.3	.39
T-18	1	230	10.3	52.5	51	9.0	4.3	8.8
T-19	4	187	3.2	3.8	13	3.3	10.3	.41
T-23	2	137	5.9	5.7	24	BDL	.13	BDL

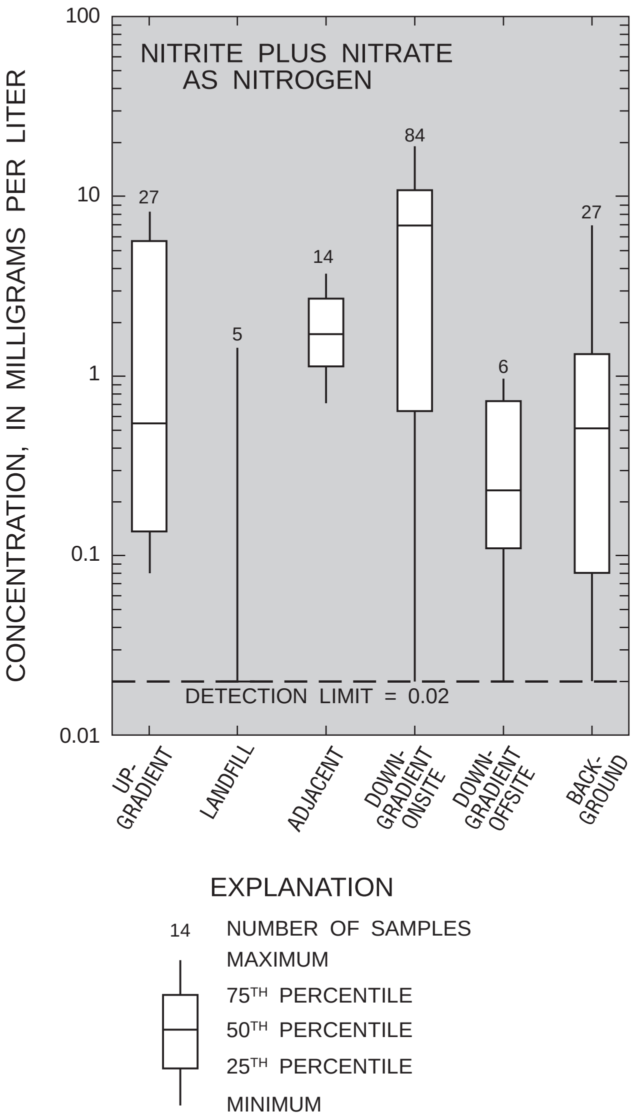

Figure 8. Graphical summaries of nitrate nitrogen concentrations in samples from wells located upgradient from, in adjacent to, and downgradient from the landfill, and from background wells in Leon County, Fla.

At five other landfills in northwest Florida, maximum chloride concentrations in samples from monitoring wells ranged from 35 to 172 mg/L (Bartel, 1986), whereas at this study site, the maximum chloride concentration was 22.7 mg/L. Chloride concentrations were similar in upgradient and downgradient areas near the landfill, and chloride concentrations were higher in samples from the background wells completed in the Upper Floridan aquifer in Leon County than in samples from the Upper Floridan aquifer at the study site (table 3).

Analysis of ground-water samples collected at the study site for trace-element concentrations indicated that many concentrations were below analytical detection limits. Trace element concentrations above detection limits generally had little difference in concentrations in samples from areas upgradient from the landfill, within and adjacent to the landfill, and downgradient from the landfill. Of the 13 trace elements analyzed, iron, copper, chromium, manganese, barium, and lead had less than 50 percent of the reported concentrations below detection limits (table 6). The occurrence and distribution of iron and manganese at the study site were discussed previously. Graphical summaries of barium, chromium, copper, and lead concentrations are shown in figures 9a-9d to illustrate the distribution among samples collected from wells in areas upgradient, within, adjacent to, and downgradient from the landfill. Concentrations below detection limits were set equal to the detection limit for the preparation of the graphical summaries. Median concentrations of copper and lead were greatest in samples from the landfill well, whereas the median concentrations of barium and chromium were highest in samples from the well adjacent to the landfill, although chromium concentrations varied little among the well categories (fig. 9b). The low concentrations of trace elements indicate that the landfill materials or aquifer sediments might not contain a source of trace elements or that the trace elements are being adsorbed by aquifer sediments. The low concentrations could also be related to dilution of ground water in the Upper Floridan aquifer.

Table 6. Trace elements analyzed at the study site and percent of concentrations below detection limit

[µg/L; micrograms per liter]

Trace element	Number of samples	Detection limit, (µg/L)	Percent below detection limit
Iron	117	5.6	11
Copper	131	.3	12
Chromium	131	.6	13
Manganese	131	1.2	21
Barium	131	12	32
Lead	131	.6	45
Cadmium	131	.4	68
Selenium	131	.3	75
Nickel	131	2.9	84
Arsenic	131	3.5	87
Silver	131	.7	92
Zinc	127	[1]61 [2]25	93
Mercury	131	.5	95

[1]Detection limit before August 1989.
[2]Detection limit from August 1989 until end of study.

Occurrence and Distribution of Organic Compounds

Only 27 of the more than 140 organic compounds analyzed in samples from the surficial and Upper Floridan aquifers at the site were present in concentrations above the detection limits. Constituents detected most frequently in the 136 samples included tetrachloroethene (PCE) (39 samples), toluene (22), benzene (19), xylene (14), naphthalene (13), bis(2-ethylhexyl) phthalate (13), chloroform (11), 124-trimethylbenzene (10), and 135-trimethylbenzene (7) (table 7). Most of these compounds detected had low concentrations (near analytical detection limits) and were detected in one or two samples per well from various wells at the site.

Only PCE, benzene, and vinyl chloride concentrations in samples collected at the study site exceeded State MCL's (Florida Department of Environmental Regulation, 1990). PCE was detected in 39 ground-water samples, 26 of which were from upgradient wells. PCE concentrations exceeded the State MCL of 3.0 μg/L in 13 samples from a well located upgradient from the landfill and in one sample from a well located downgradient from the landfill. Well T-02 is located

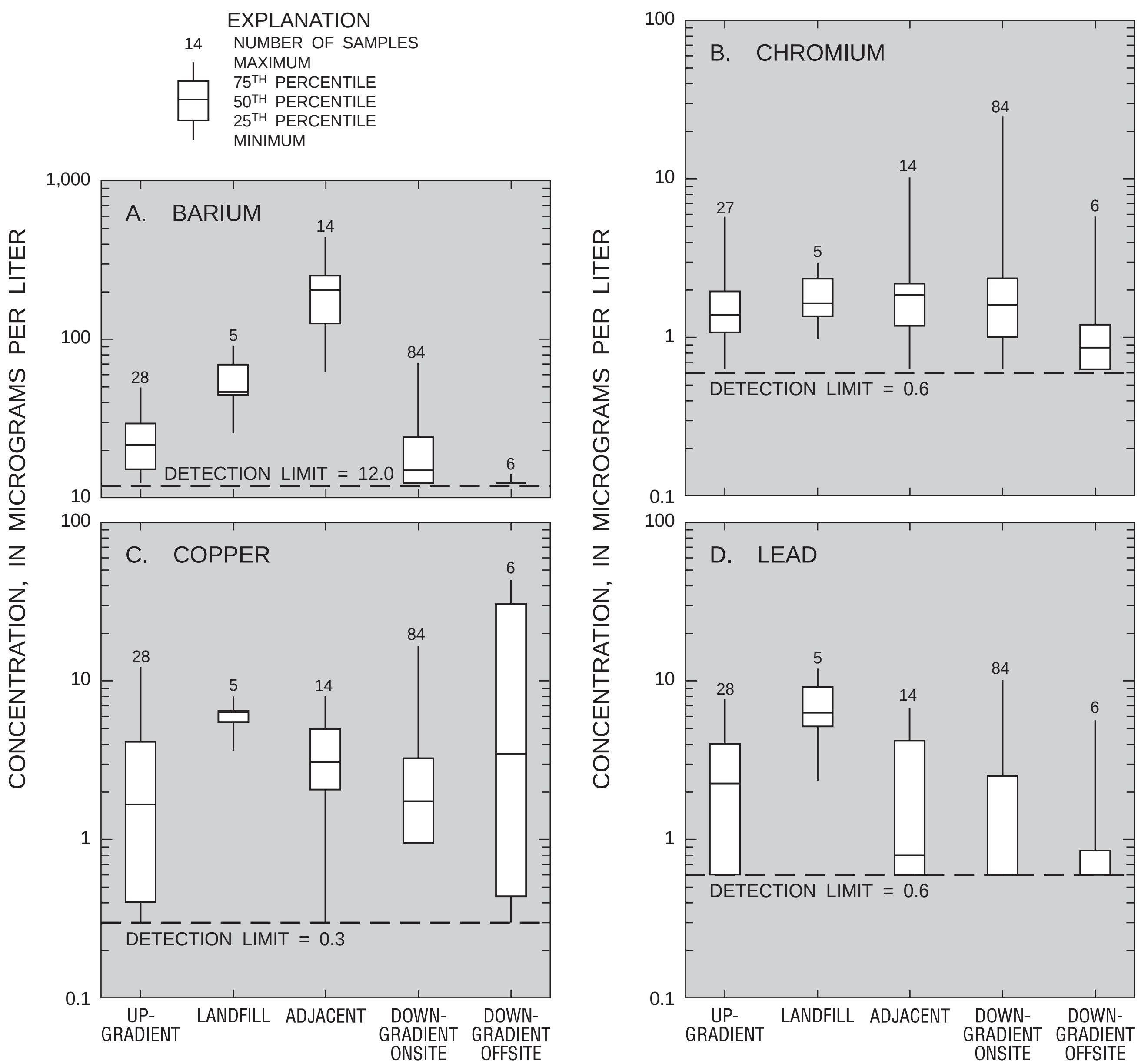

Figure 9. Summaries of water quality in samples from wells located upgradient from, in, adjacent to, and downgradient from the landfill showing concentrations of: (a) Barium, (b) Chromium, (c) Copper, and (d) Lead.

Table 7. Concentrations of organic compounds above analytical detection limits in samples collected from wells at the study site
[Concentrations are in micrograms per liter]

Compound	Well identifiers	Sample date	Concentration
Benzene	T-02	12-88	0.50
	T-03	6-88	1.56
		4-88	1.60
		12-87	3.0
		9-87	3.50
		6-87	1.46
	T-04	9-88	.25
	T-06	3-90	3.31
	T-07	3-90	.57
		12-88	.96
	T-10	9-89	5.80
	T-12	3-90	2.68
		9-89	.36
		5-89	4.68
	T-13	5-89	.17
	T-15	9-89	.74
		5-89	1.24
	T-16	9-89	5.82
	T-19	12-89	2.00
		9-89	8.53
bis (2-ethylhexyl) phthalate			
	T-01	3-89	12.5
	T-02	3-89	13.4
	T-04	12-88	38.1
	T-05	12-88	10.6
	T-07	9-90	12.3
		9-89	37.7
		6-89	13.2
		9-87	21.4
		6-87	13.9
	T-13	3-90	16.0
		5-89	30.6
	T-17	9-89	43.6
	T-19	9-89	11.2
Bromodichloromethane			
	T-15	5-89	1.17
	T-16	5-89	.32
n-Butylbenzene	T-02	12-88	.24
	T-04	9-88	.26
	T-06	12-88	.24
	T-07	9-90	4.40
s-Butylbenzene	T-01	12-88	.43
	T-07	12-88	.63
t-Butylbenzene	T-01	12-88	.20
		9-88	.12
	T-02	12-88	1.2
	T-04	9-88	.13
	T-05	12-88	.65
Chlorobenzene	T-03	6-88	3.21
		3-88	4.8
		12-87	4.48
		9-87	3.83
		6-87	2.74
Chloroform	T-01	9-90	1.14
		9-89	1.86
		3-89	.70
		9-88	.85
		6-88	1.14
		3-88	1.1
		12-87	1.77
	T-03	3-88	1.5
	T-04	9-88	.12
	T-15	5-89	1.16
	T-16	5-89	.49
Dibromochloromethane			
	T-15	5-89	.65
1,1-Dichloroethane	T-03	12-87	.07
		9-87	.10
cis-1,2-Dichloroethylene			
	T-01	9-90	1.75
		6-90	.84
	T-03	12-87	3.9
Ethylbenzene	T-02	12-88	2.13
	T-03	12-87	4.48
	T-04	9-88	.12
p-Isopropyltoluene	T-02	12-88	.31
	T-05	12-88	.18
	T-06	12-88	.14
	T-07	12-88	.17
Methylenechloride	T-02	6-87	1.53
Naphthalene	T-01	9-90	3.03
		12-88	1.0
		9-88	.38
	T-02	9-90	.83
		12-88	.70
	T-04	9-90	.88
		12-88	.27
		9-88	.25
	T-05	12-88	.58
	T-06	9-88	.25
	T-07	9-90	.90
		12-88	1.04
		9-88	.22
n-Propylbenzene	T-07	12-88	.29
Styrene	T-01	12-88	.16
	T-02	12-88	4.8
	T-05	12-88	.65
Tetrachloroethene (PCE)			
	T-01	9-90	1.34
		6-90	.86
		3-90	.61
		12-89	.68
		3-89	1.12
		12-88	.20

Table 7. Concentrations of organic compounds above analytical detection limits in samples collected from wells at the study site--Continued

Compound	Well identifiers	Sample date	Concentration
Tetrachloroethene (PCE)			
	T-01	9-88	.90
		6-88	.33
		3-88	.28
		12-87	.34
		9-87	.34
	T-02	9-90	14.5
		6-90	9.06
		3-90	10.8
		12-89	13.1
		9-89	.54
		9-89	8.72
		6-89	7.46
		3-89	7.41
		12-88	.84
		9-88	3.78
		6-88	3.52
		3-88	4.3
		12-87	5.42
		9-87	7.37
		6-87	8.67
	T-03	12-87	.08
		6-87	.08
	T-04	3-90	.14
		3-89	.11
		6-87	.86
	T-06	3-89	.21
		6-87	.10
	T-08	12-89	.16
	T-12	3-90	.18
	T-16	12-89	3.21
	T-17	3-90	.19
		12-89	1.23
	T-19	12-89	.45
Toluene	T-01	9-88	.40
	T-02	3-90	1.85
		12-88	3.57
	T-03	4-88	.85
		12-87	4.14
		9-87	1.52
		6-87	.64
	T-04	9-90	.92
		3-90	1.47
		9-88	.37
		9-87	.32
	T-05	3-90	1.49
		12-88	.58
		9-88	.20
	T-06	12-88	.56
		9-88	.20
	T-07	9-90	1.90
		6-90	.69
		12-88	.80
Trichlorethene	T-02	9-89	.27
		6-89	.53
	T-04	6-89	.56
	T-19	3-90	.13
1,1,1-Trichloroethane	T-01	3-88	.16
	T-03	3-88	.24
Trichloroflouromethane			
	T-02	9-90	4.72
		6-90	2.86
		9-89	21.4
		6-89	10.3
		9-88	.76
124-Trimethylbenzene			
	T-01	12-88	.50
		9-88	.25
	T-02	9-88	.10
	T-04	9-88	.15
	T-05	12-88	.32
		9-88	.13
	T-06	12-88	.35
		9-88	.16
	T-07	12-88	.49
		9-88	.11
135-Trimethylbenzene			
	T-01	12-88	.23
		9-88	.10
	T-02	12-88	.35
	T-04	9-88	.08
	T-05	12-88	.11
	T-06	12-88	.17
	T-07	12-88	.20
Vinyl Chloride	T-03	9-87	13.2
Xylene	T-01	12-88	.16
		9-88	.39
	T-02	12-88	6.06
		9-88	.18
	T-04	9-90	.92
		9-88	.36
	T-05	12-88	.59
		9-88	.13
	T-06	12-88	.57
		9-88	.20
	T-07	9-90	1.93
		6-90	.29
		12-88	.50
		9-88	.14

between the landfill and a cemetery, approximately 20 ft from the northern edge of the landfill (fig. 1). The proximity of this sampling location to the landfill may indicate that PCE is leaching directly from the landfill. The State MCL of 1.0 µg/L for benzene was exceeded in 13 of the 136 samples from wells located within the landfill (T-03), adjacent to the landfill (T-04), and in downgradient locations (table 7). On one occasion, benzene was detected in a sample from well T-02, an upgradient location. Vinyl chloride concentration exceeded the MCL of 1.0 µg/L once in a sample from the landfill well (T-03).

Ethylbenzene and styrene were detected in concentrations exceeding State guidance levels of 2.0 µg/L and 1.0 µg/L, respectively, in samples from some wells at the site. Guidance levels are nonenforceable standards established for drinking water (Florida Department of Environmental Regulation, 1990). Ethylbenzene was measured in concentrations greater than the guidance level in two samples, one from well upgradient from the landfill (T-02), and the other from well T-03 within the landfill. The concentration of styrene exceeded the State guidance level of 2.0 µg/L in one sample from upgradient well T-02.

A few organic compounds were detected in water samples from the landfill well T-03, including 1,1,1-trichloroethane, benzene, chloroform, ethylbenzene, PCE, toluene, and vinyl chloride. Of these compounds, only benzene and vinyl chloride concentrations exceeded State MCL's, and ethylbenzene exceeded the State guidance level (table 7). The presence of these compounds in samples from this well in the landfill (T-03) indicate that the household trash and other materials deposited in this part of the landfill probably contained some of these organic compounds.

Effects of Sludge Spreading on Ground-Water Quality

Sludge is the residue remaining after treatment of wastewater and consists of water, biological matter, and small quantities of metals and other chemicals (Miller, 1980). The sludge spread at this site is from a sewage-treatment plant that treats municipal wastewater for the City of Tallahassee and was applied as a liquid from a tank trunk. As a liquid, sludge typically contains 5 percent solids. The constituents in the sludge that most readily leaches to soils and ground water include sodium, potassium, chloride, sulfate and nitrite plus nitrate (Miller, 1980). Of these, nitrite plus nitrate is generally present in the highest concentrations in sludge (Miller, 1980). Estimates of nitrogen-loading rates were calculated from available data (William G. Leseman, City of Tallahassee, written commun., 1990). Records of total nitrogen content in sludge were available for the time period October 1985 through March 1990. Nitrite plus nitrate content was not available. The average loading rate for the three spreading areas adjacent to the landfill (fig. 1) was approximately 360 lb of nitrogen per acre per year. Annual loadings of this quantity of nitrogen have the potential to enrich the nitrogen concentration in ground water, especially when the water table is near land surface, and samples are collected near the water table.

Concentrations of sodium, potassium, chloride, sulfate, nitrite plus nitrate, total ammonia plus organic nitrogen, and ammonia in ground water from the surficial and Upper Floridan aquifers in sludge-spreading areas and other areas were compared to determine the effects of sludge spreading on ground-water quality. Nonparametric statistical analysis of constituent concentrations in the two areas using the Wilcoxon rank-sum test indicated that chloride and nitrite plus nitrate concentrations were significantly different in the two areas, with higher median concentrations in samples from wells in the sludge-spreading areas (table 8). Median chloride concentration was 2.9 mg/L in samples from wells in sludge-spreading areas and 1.8 mg/L in other areas. Median nitrite plus nitrate concentration in samples from wells in sludge spreading areas was 6.9 mg/L compared to 1.1 mg/L in other areas. The maximum nitrite plus nitrite plus nitrate concentration of 8.1 mg/L in the group of samples from other areas (table 8) may be due to a septic tank located at a nearby abandoned private residence. Potassium concentrations in ground water were significantly different in the two areas, but the median concentration was lower in the sludge-spreading areas and the difference in median concentration was only 0.3 mg/L (table 8). Sodium, total ammonia plus organic nitrogen and ammonia nitrogen concentrations were not significantly different in the two areas (table 8). Median total ammonia plus organic nitrogen and ammonia nitrogen were less than 0.50 mg/L in both areas (table 8).

SUMMARY

A 120-acre landfill located near the municipal airport served as the primary landfill for the City of Tallahassee, receiving mostly household trash from approximately 1959 to 1976. Sludge from a municipal sewage-treatment plant has been spread on land adjacent to the landfill since approximately the mid-1960's. In 1987, the USGS and the City of Tallahassee begain a cooperative study to determine the

Table 8. Summary of selected water quality characteristics for samples collected from wells in sludge-spreading and other areas at the study site

[<, less than; mg/L, milligrams per liter; N, nitrogen. Ranges represent all analyses in each category; data from the surficial aquifer does not include data from well in the landfill (T-03) or well adjacent to the landfill (T-04); Ranges represent all analyses in each category; Data from the surficial aquifer does not include data from well in the landfill (T-03) or well adjacent to the landfill (T-04); median s are considered significantly different if p-value is equal to or less than 0.05; <, less than]

	Constituent concentration in ground water from sludge-spreading areas (13 wells[1], 80 analyses)		Constituent concentration in ground water from other areas (5 wells[2], 50 analyses)		
Water-quality characteristic	Median (mg/L)	Range (mg/L)	Median (mg/L)	Range (mg/L)	p-value from Wilcoxon rank sum test
Sodium	2.4	0.75 - 8.8	2.5	1.5 - 404[3]	0.18
Potassium	.6	.05 - 3.0	.9	.07 - 17.3	< .01
Chloride	2.9	< .19 - 22.7	1.8	.80 - 4.4	< .01
Sulfate	4.4	1.0 - 52.5	3.8	<1.0 - 190	.40
Nitrite plus nitrate nitrogen	6.9	< .02 - 19.0	1.1	< .02 - 8.1[4]	< .01
Total ammonia plus organic nitrogen	.26	< .07 - 15.0	.07	< .07- 1.6	.24
Ammonia nitrogen	.02	< .02 - 0.79	.01	< .02- .73	.93

[1]Wells T-05 through T-08, T-10, T-13 through T-19, T-23
[2]Wells T-01 thorugh T-04, T-12
[3]High value from within landfill
[4]High value from well T-01, located adjacent to an abandoned private residence which might have a septic system on the property

extent and nature of ground-water contamination in the area. The site is underlain by a surficial aquifer and the Upper Floridan aquifer below. The surficial aquifer consists of sand and clayey sand with some clay layers, and is 20- to 70-ft thick at the study site. The Upper Floridan aquifer of the Floridan aquifer system is a sequence of highly permeable carbonate rocks with numerous open zones.

Seven monitoring wells were installed in the surficial and Upper Floridan aquifers by the Florida Department of Environmental Regulation (FDER) in 1986. Analyses of samples collected from these wells indicated that concentrations of some constituents exceeded the State maximum contaminant levels for drinking water. These constituents included iron, manganese, sulfate, nitrite plus nitrate, tetrachloroethene, benzene, and vinyl chloride. One of the wells, from which most of the samples that exceeded FDER MCLs were collected, was located within the boundaries of the landfill. Water-quality samples collected at this well were used to compare ground-water quality within the landfill to that in areas upgradient and downgradient from the landfill.

Fourteen additional monitoring wells were installed in 1989 and 1990 in suspected areas of contamination adjacent to the landfill and in an area identified by electromagnetic conductivity measurements. Chemical analysis of samples from these monitoring wells indicated some contamination. Comparison of the quality of water in the Upper Floridan aquifer at the site to that in the Upper Floridan aquifer at background sites in Leon County indicated that, of the major ions analyzed, only the concentrations of potassium and of nitrite plus nitrate were significantly different, with higher median concentrations at the study site. Median potassium and nitrite plus nitrate concentrations at the study site were 0.7 mg/L and 6.48 mg/L, respectively, compared to 0.4 mg/L and 0.51 mg/L in samples from the background wells. Concentrations of sodium, chloride, and bicarbonate were significantly different in samples from the background wells than in samples from wells at the study site and median concentrations of these ions were higher in samples from the background wells.

Specific conductance and concentrations of major ions and dissolved solids were evaluated for six well categories; upgradient, landfill, adjacent to landfill, downgradient onsite, downgradient offsite, and background. The downgradient offsite wells were domestic wells from 1-2 mi downgradient from the landfill. Concentrations of sodium, bicarbonate, sulfate, iron, manganese, and dissolved solids were highest in samples from a well located within the landfill. Nitrite plus nitrate concentrations were lowest in the landfill well, indicating that the nitrite plus nitrate was being reduced or that there was a source of nitrate other than from the landfill. Wide ranges in concentrations of iron, sulfate, nitrite plus nitrate, and total ammonia plus organic nitrogen in an area near the landfill indicated localized reducing conditions in ground water. Median iron concentrations of 930 μg/L and 30 μg/L were present in samples from wells less than 5 feet different in depth and located only 5 feet apart. In the same two wells, median sulfate concentrations were 30 mg/L and 10 mg/L, median nitrite plus nitrite plus nitrate concentrations were less than 0.2 mg/L, and median total ammonia plus organic nitrogen concentrations were 3.2 mg/L and 3.3 mg/L. Trace element concentrations generally were near or below detection limits. Other than iron and manganese, only barium, chromium, copper, and zinc were present in concentrations above detection limits in 50 percent or more of the samples. Median concentrations of copper and lead were highest in water from the landfill well.

Of the more than 140 organic compounds analyzed, only 27 compounds had concentrations above detection limits. State maximum contaminant levels were exceeded for benzene, tetrachlorethene, and vinyl chloride. The maximum contaminant level of 1.0 μg/L for benzene and vinyl chloride was exceeded in 13 samples for benzene and in 1 sample for vinyl chloride. The maximum contaminant level of 3.0 μg/L for tetrachloroethene was exceeded in 14 samples.

Sludge from the municipal sewage-treatment plant has been spread at the study site where many of the monitoring wells are located and is most likely responsible for the nitrite plus nitrate enrichment in ground-water samples because samples from the landfill well did not have high nitrite plus nitrate concentrations. Statistical comparison of ground water from sludge-spreading and other areas showed that chloride and nitrite plus nitrate concentrations were significantly different in the two areas. Median chloride concentrations in ground water from sludge-spreading areas was 2.9 mg/L compared to 1.8 mg/L in ground water from other areas. Median nitrite plus nitrate concentrations in ground water were 6.9 mg/L in sludge-spreading and 1.1 mg/L in other areas.

The effect of the landfill materials on ground-water quality at the site seems to be confined to an area immediately adjacent to the landfill. Low concentrations of water-quality constituents at the study site could be due to dilution by the large volumes of ground water flow in the Upper Floridan aquifer.

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