# EFFECTS OF DRIED WASTEWATER-TREATMENT SLUDGE APPLICATION ON GROUND-WATER QUALITY IN SOUTH DADE COUNTY, FLORIDA

By Barbara Howie

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 91-4135

Prepared in cooperation with the

SOUTH DADE SOIL AND WATER CONSERVATION DISTRICT,
FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION,
and the
DADE COUNTY WATER AND SEWER AUTHORITY DEPARTMENT

Tallahassee, Florida
1992

U.S. DEPARTMENT OF THE INTERIOR
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U.S. GEOLOGICAL SURVEY
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## CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS, AND ACRONYMS

| Multiply | By | To obtain |
|---|---|---|
| inch (in.) | 25.4 | millimeter |
| foot (ft) | 0.3048 | meter |
| foot per day (ft/d) | 0.3048 | meter per day |
| foot squared per day (ft2/d) | 0.09290 | meter squared per day |
| mile (mi) | 1.609 | kilometer |
| acre | 0.4047 | hectare |
| quart (qt) | 0.9463 | liter |
| gallon per minute (gal/min) | 0.00006309 | cubic meter per second |
| gallon per day (gal/d) | 0.0038 | cubic meter per day |
| pound (lb) | 0.4536 | kilogram |
| ton, short | 907.2 | kilogram |
| ton per acre (ton/acre) | 2,242 | kilogram per hectare |
| ton per acre per year (ton/acre/yr) | 2,242 | kilogram per hectare per year |

*Sea level*: In this report, "sea level" refers to the National Geodetic Vertical Datum 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.

Abbreviations used in report:

µg/L = micrograms per liter
µS/cm = microsiemens per centimeter at 25 degrees Celsius
mg/L = milligrams per liter
MPN/g = most probable number per gram
PFU/g = plaque forming unit per gram
Pt-Co = platinum-cobalt

Acronyms used in report:

DOC = dissolved organic carbon
EPA = U.S. Environmental Protection Agency
FDER = Florida Department of Environmental Regulation
MCL = primary maximum contaminant level
NWS = National Weather Service
PVC = polyvinyl chloride
SFWMD = South Florida Water Management District
SMCL = secondary maximum contaminant level
SWCD = South Dade Soil and Water Conservation District
TOC = total organic carbon
USGS = U.S. Geological Survey
WSA = Dade County Water and Sewer Authority Department
WSRT = Wilcoxon signed ranks test

# EFFECTS OF DRIED WASTEWATER-TREATMENT SLUDGE APPLICATION ON GROUND-WATER QUALITY IN SOUTH DADE COUNTY, FLORIDA

*By* Barbara Howie

**ABSTRACT**

*Four test fields in the south Dade agricultural area were studied to determine the effects of sludge application on ground-water quality. Two fields had been cultivated for 30 years or more, and two had not been farmed for at least 10 years. The fields were representative of the area's two soil types (Rockdale and Perrine marl) and two major crop types (row crops and groves). Before the application of sludge, wells upgradient of, within, and downgradient of each field were sampled for possible sludge contaminants at the end of wet and dry seasons. Municipal wastewater-treatment sludge from the Dade County Water and Sewer Authority Department was then applied to the fields at varying application rates. The wells at each field were sampled over a 2-year period under different hydrologic conditions for possible sludge-related constituents (specific conductance, pH, alkalinity, nitrogen, phosphorus, total organic carbon, copper, iron, magnesium, manganese, potassium, zinc, arsenic, cadmium, chloride, chromium, lead, mercury, nickel, and sodium). Comparisons were made between presludge and postsludge water quality, between water quality in the vicinity of the test fields and Florida Department of Environmental Regulation primary and secondary drinking-water regulations, and between water quality upgradient of, beneath, and downgradient of the fields.*

*Comparisons between presludge and postsludge water quality did not indicate any improvement because of retention of agrichemicals by the sludge nor did they indicate any deterioration because of leaching from the sludge. Comparisons of water quality upgradient of the fields to water quality beneath and downgradient of the fields also did not indicate any changes related to sludge.*

*Florida Department of Environmental Regulation primary and secondary drinking-water regulations were exceeded at the Rockdale maximum-application field by mercury (9.5 μg/L [micrograms per liter]), at the Perrine marl maximum-application field by manganese (60 μg/L) and lead (85 μg/L), and at the Perrine marl row-crop field by mercury (5.2 μg/L). All other exceedances were either in presludge or upgradient samples, or they were for constituents or properties, such as iron and color, which typically exceed standards in native ground water.*

*Acid-extractable and base-neutral compounds, volatile organic compounds, chlorophenoxy herbicides, organophosphorus insecticides, and organochlorine compounds were analyzed for one shallow well at each field twice annually. Those compounds that equaled or exceeded the detection limit after sludge was applied included benzene (0.3 and 1.2 μg/L), chloroform (0.2 and 0.3 μg/L), bis(2-Ethylhexyl)phthalate (29 and 42 μg/L), methylene chloride (14 μg/L), toluene (0.2, 0.4, 0.4, 0.5, 1.3, and 4.4 μg/L), 1,1,1-trichloroethane (0.6 μg/L), trichloroethylene (0.3 μg/L), 2,4-D (0.01 μg/L), and xylene (0.3 μg/L). It was not possible to ascertain the origin of these compounds because they are available from sources other than sludge.*

## INTRODUCTION

Agriculture in Dade County is a $200 million a year business, encompassing 80,000 acres and producing 50 percent of the Nation's winter vegetables. The south Dade agricultural area (fig. 1) includes about 10,000 acres of low-permeable Perrine marl soil planted in row crops and 70,000 acres of highly permeable Rockdale soil planted in groves and row crops. Rockdale soil is actually the top 6 in. of oolitic limestone-rock and soil complex that has been ground into a "soil" suitable for cultivation. Because water soluble nutrients used in agriculture are rapidly lost by leaching from the Rockdale soils and by runoff from Perrine marl soils, growers apply organic nitrogen, which makes nitrogen available more slowly, and inorganic micronutrients. To this end, local growers applied commercially available domestic wastewater-treatment sludge, henceforth referred to as sludge, from industrial cities in the Midwest. However, in the 10 years before this study, a shortage of available sludge had forced them to use commercially prepared mixes of fertilizer and 10 percent sludge or, in the absence of sludge, synthetic organic nitrogen (sulfur-coated urea) and manufactured organic or inorganic micronutrients.

Growers would like to return to the use of sludge, which is now available locally from the Dade County Water and Sewer Authority Department (WSA). This sludge has

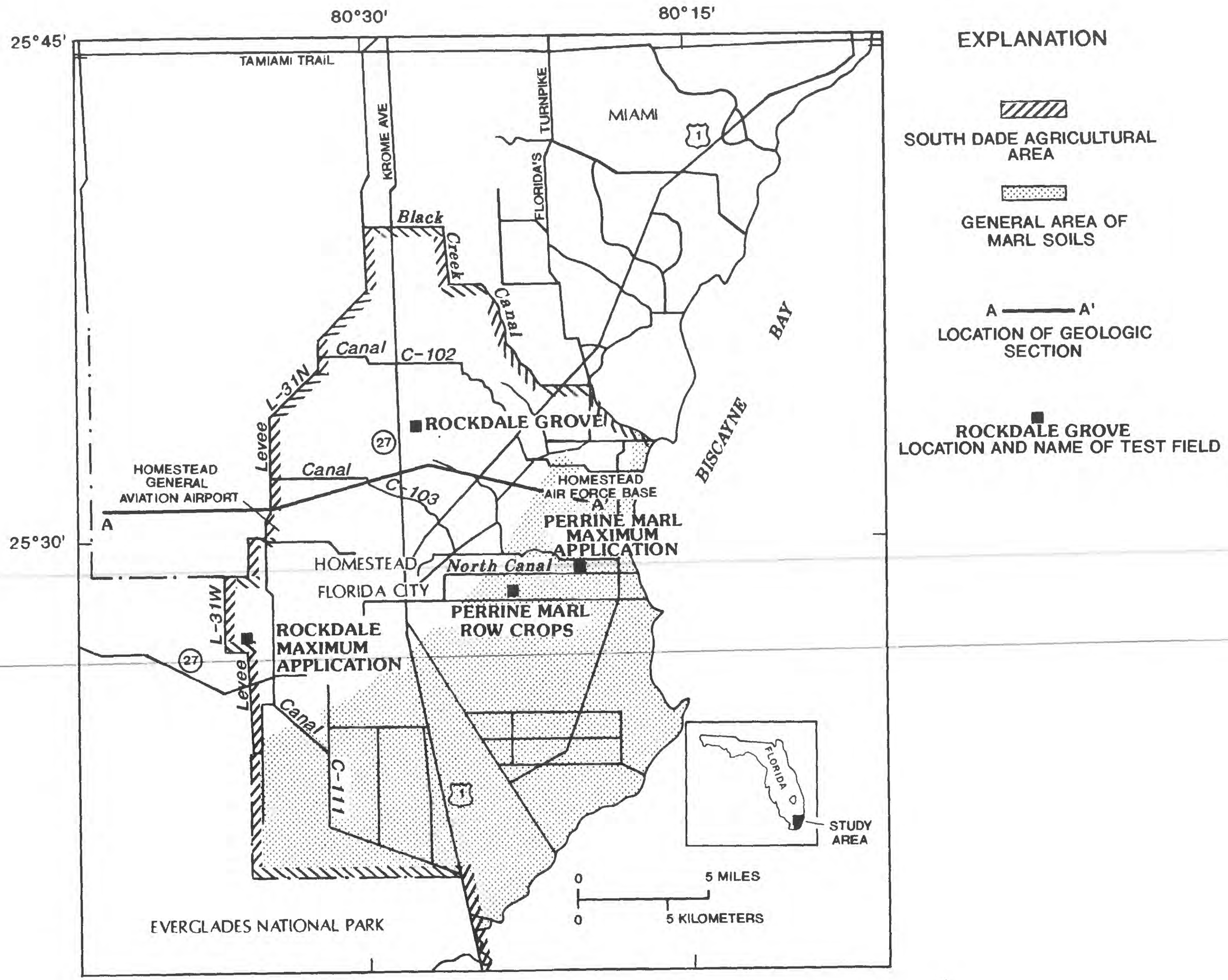


**Figure 1.** The south Dade agricultural area showing location of the test fields and geologic section A-A'.

lower concentrations of trace metals than other municipal sludges because there is no heavy industry in the area, and it is less expensive than currently used sources of organic nitrogen. Also, because the organic nitrogen in sludge is released slowly, the use of other fertilizers can be reduced, lowering the growers' cost and possibly decreasing the quantity of nitrates leached into the ground water. At present (1989), sludge application from local sources is limited by Dade County because the agricultural area overlies the Biscayne aquifer, a shallow water-table aquifer that has been designated a sole-source aquifer by the U.S. Environmental Protection Agency (EPA). The problem for both farmer and regulator is a lack of data documenting the effects of sludge application on ground water and no data documenting the effects of sludge application on ground water in the Biscayne aquifer.

To address this problem, the U.S. Geological Survey (USGS), in cooperation with the South Dade Soil and Water Conservation District (SWCD), Florida Department of Environmental Regulation (FDER), and WSA, studied four test sites in south Dade County from October 1984 through September 1988. Two sites had been under continuous cultivation for 30 years or more and two had not been farmed for at least 10 years.

## Purpose and Scope

This report evaluates the effects on ground-water quality caused by the application of Dade County's domestic wastewater-treatment sludge to farmland. The evaluation is based on onsite field measurements and on the analysis of nutrients, selected major ions, trace elements, and organic priority pollutants sampled at the four test sites from 1985 to 1988. These data were interpreted by: (1) the quantitative comparison of presludge and postsludge concentrations; (2) the statistical comparison of upgradient, center-field, and downgradient concentrations; and (3) an assessment of the results in terms of what is known about chemical attenuation processes. This report discusses results related to sludge application only. It does not consider water-quality changes related to other agricultural practices, as discussed in Howie (1986), nor does it discuss changes related to preexisting trends, such as increasing salinity.

## Acknowledgments

The author thanks Court Greenfield, former SWCD Conservationist, for technical advice and operational assistance during the investigation. Similar help was provided by the SWCD's Board of Supervisors, Chairman Jack Campbell and members Richard Alger and the late Norman Sutton. Thanks is also extended to the land owners for permitting wells to be installed in their fields.

# DESCRIPTION OF STUDY AREA

In this report, the south Dade agricultural area (fig. 1) is defined as the area south of Black Creek Canal and east of Levee L-31. Some farming occurs north of Black Creek Canal, but it is gradually giving way to urban development, and since the beginning of this study, there has been increased cultivation of the area west of Levee L-31. Within the agricultural area are Homestead and Florida City, the Homestead Air Force Base, and the Homestead General Aviation Airport. Farms range from several acres to hundreds of acres and are interspaced with residential and commercial areas of various sizes. The land devoted to groves, some of which are 30 to 40 years old, remains relatively constant from year to year, but the acreage devoted to row crops varies each growing season as does the proportion planted in a particular crop. Groves and row crops are both grown in the Rockdale area and are frequently intermingled. Perrine marl supports only row crops.

In a planar view of the study area, the most predominant feature is the Atlantic Coastal Ridge (fig. 2). It is 2 to 8 mi wide and is the area of highest land-surface altitude, 8 to 12 ft above sea level. The Atlantic Coastal Ridge is a natural barrier to drainage from the interior, except where it is transversed by canals or natural sloughs. Most of the development in the study area occurs along the ridge, and the agriculture that exists there (mostly groves) is gradually giving way to development. Coastward from the Atlantic Coastal Ridge are marshland and mangrove swamps. The marshland area has an altitude of 0 to 3 ft above sea level and is the area where the Perrine marl soil is found. West of the Atlantic Coastal Ridge is the East Everglades, which has an altitude of 5 to 9 ft above sea level, good drainage, and most of the farmable land in the south Dade agricultural area.

Under predevelopment conditions, flow east and south of the Atlantic Coastal Ridge was coastward, and flow west of the ridge was to the south or southwest. Although the regional ground-water gradient is still seaward, the construction of an extensive system of levees, canals, and water-control structures has caused local variations in ground-water gradients, especially at shallow depths. The effect of the canal system on ground-water gradients is shown in figure 3 modified from Fish and Stewart (1991, figs. 18 and 19). The Levee L-31 system that forms the western boundary of the study area helps maintain high water levels in Everglades National Park.

During the wet season, as represented by the average September water-table configuration, canals are used to drain the area east of the Levee L-31 system, and local gradients are generally toward the canals.

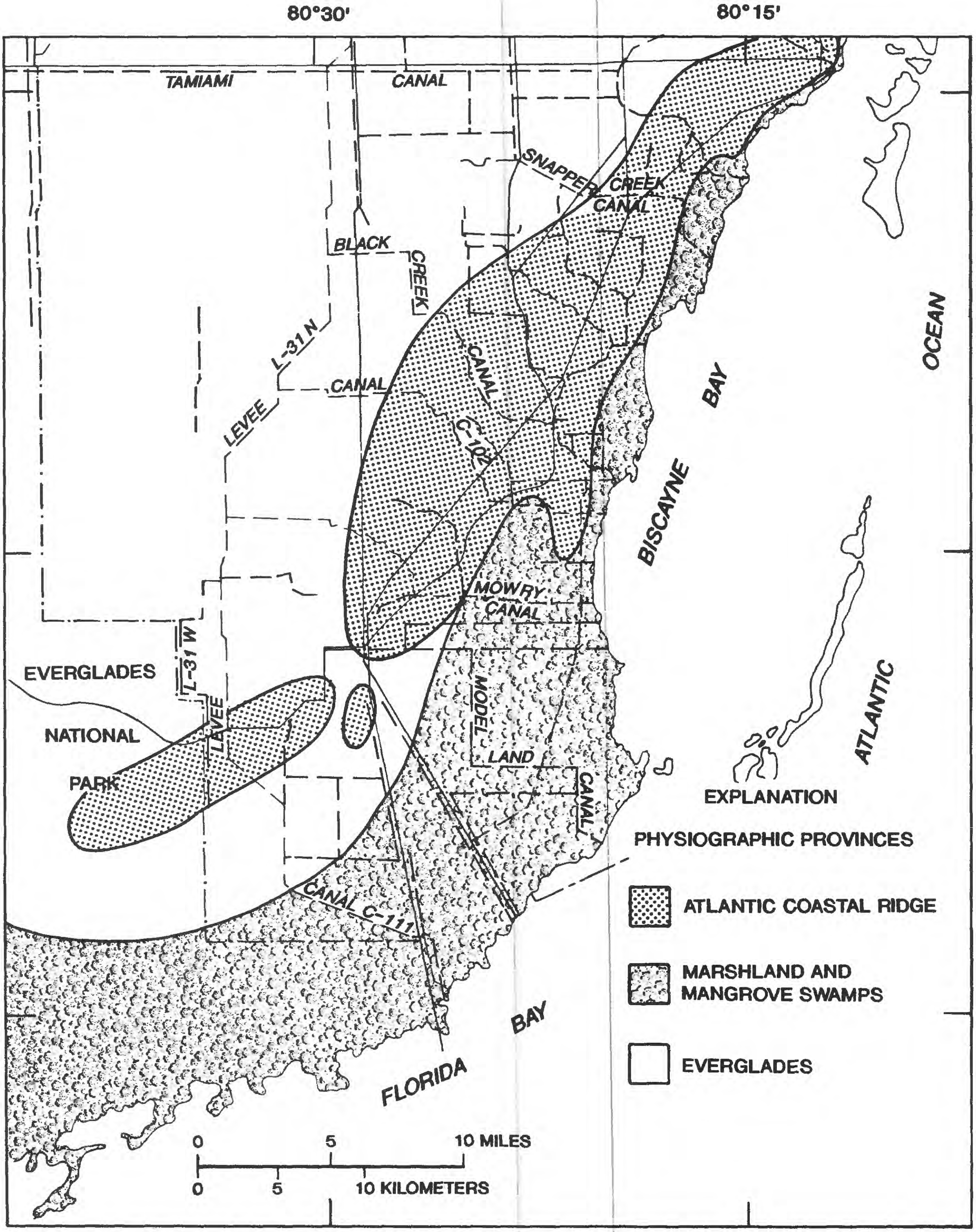


**Figure 2.** Physiographic and hydrologic features of the south Dade agricultural area (modified from Klein and others, 1975, p. 8).

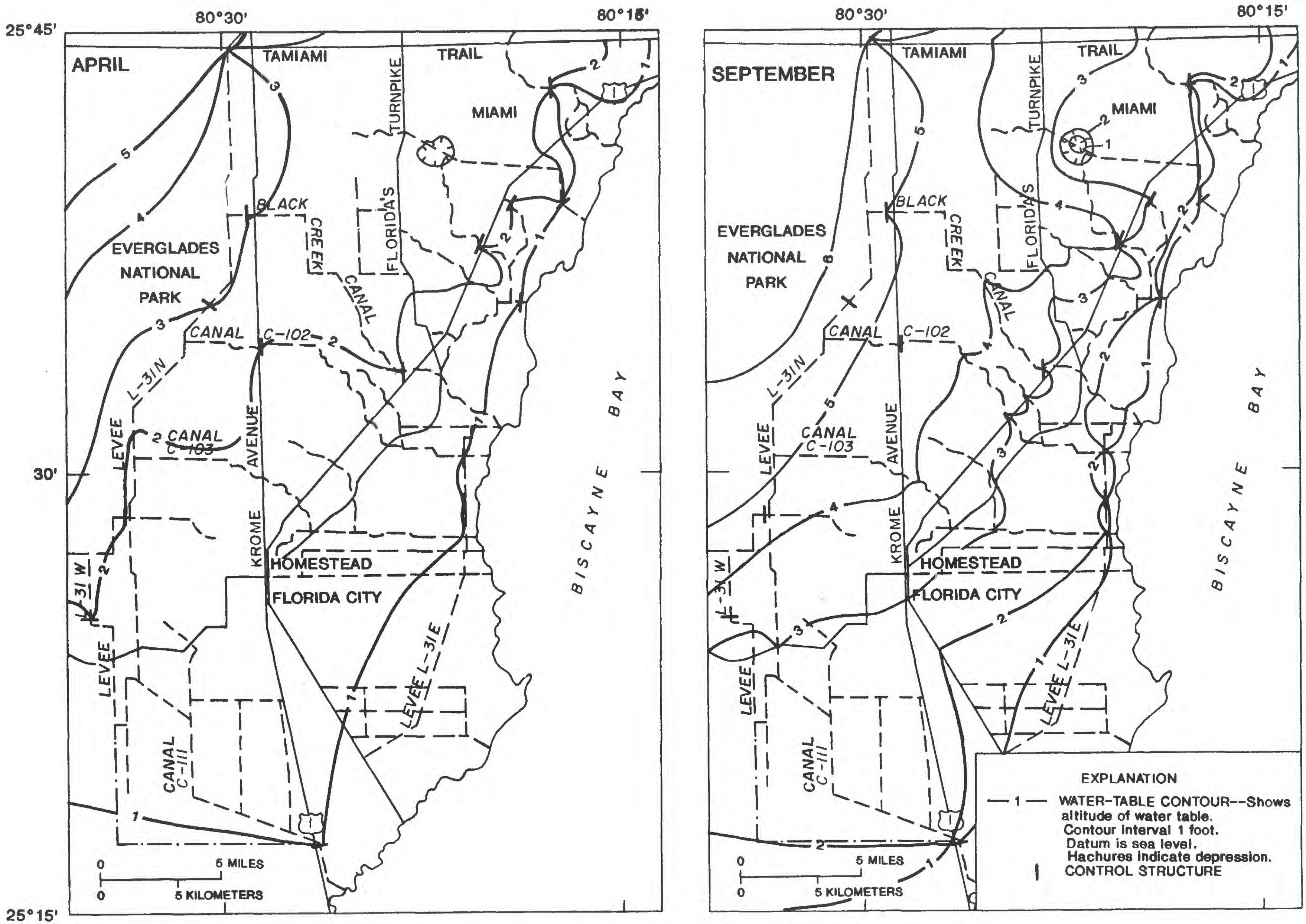


**Figure 3.** Average configurations of the water table in the study area in April and September based on the 1974-82 period (modified from Fish and Stewart, 1991).

During dry periods, as represented by the average April water-table configuration, the canal system is used to convey water into the study area to replenish the Biscayne aquifer and retard saltwater intrusion; thus, ground-water gradients are away from the canals or are less steep toward the canals. The water-table configurations in figure 3 represent average conditions for the period from 1974 to 1982. The effects of the canals are more pronounced during periods of heavy rainfall.

Water levels in the canals are controlled by the South Florida Water Management District (SFWMD) by means of pumping stations and control structures. The operation of the canal system and maintenance of stages in the individual canals are implemented by a complex system of operation rules that are beyond the scope of this report. The reader is referred to Cooper and Lane (1987) for a discussion of the system operations, to Klein and others (1975) for a discussion of the history and operation of water management in south Florida, and to Leach and others (1972) for a discussion of the effects of the canal system on the hydrology of southeast Florida.

Southeast Florida is underlain by the Biscayne aquifer, defined by Fish and Stewart (1991) as follows:

> "that part of the surficial aquifer system in southeast Florida composed of (from land surface downward) the Pamlico Sand, Miami Oolite, Anastasia Formation, Key Largo Limestone, and Fort Thompson Formation (all of Pleistocene age), and contiguous, highly permeable beds of the Tamiami Formation of Pliocene and late Miocene age where at least 10 ft of the section is very highly permeable (a horizontal hydraulic conductivity of about 1,000 ft/d or more)."

The formations comprising the Biscayne aquifer are illustrated in the representative cross section (fig. 4) from Causaras (1987). The Biscayne aquifer extends 30 to 110 ft below sea level beneath the study area (Fish and Stewart, 1991). It is composed chiefly of permeable limestone and sandstone and has good vertical and horizontal permeability. Although the aquifer is relatively thin in south Dade County, transmissivities were estimated by Fish and Stewart to be 300,000 to 1,000,000 ft$^2$/d and may exceed 2,000,000 ft$^2$/d near Homestead. The unsaturated zone is between 0 and 11 ft thick (on the basis of historical high and low water levels at the USGS water-level recorders in the study area). It is composed chiefly of porous limestone, or, in the Perrine marl areas, of marl or marl overlying limestone. Water quality in the Biscayne aquifer varies areally and with depth. Shallow ground water also varies with time because of land use and infiltration from rainfall. Table 1, compiled from data stored in the USGS computer data base, gives the ranges of selected constituents that have been found in two recent studies of the Biscayne aquifer (Howie, 1986; Sonntag, 1987).

**Table 1.** *Water quality in the Biscayne aquifer beneath the south Dade agricultural area*

[Primary and secondary maximum contaminant levels for drinking water were established by the Florida Department of Environmental Regulation (1982). Primary maximum contaminant levels (MCLs) are enforceable limits established for contaminants that can adversely affect human health. Secondary maximum contaminant levels (SMCLs) are nonenforceable limits established for contaminants that can adversely affect the odor or appearance of water. If a constituent was not detected in a sample, that constituent is reported as less than the detection limit (for example, <100). Asterisk denotes field-filtered sample. Abbreviations: N, nitrogen; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; >, greater than; --, no data]

| Constituent | 1983-84 | | 1984-85 | | Maximum contaminant level |
|---|---|---|---|---|---|
| | No. of samples | Range | No. of samples | Range | |
| Alkalinity (mg/L) | 19 | 157-296 | 45 | 167-387 | |
| pH (units) | 19 | 6.8-7.8 | 44 | 6.9-7.8 | <6.5 or >8.5 SMCL |
| Specific conductance (µS/cm) | 19 | 320-1,265 | 46 | 360-4,600 | |
| Kjeldahl nitrogen (mg/L) | 17 | 0.12-0.96* | 47 | <0.6-3.0 | |
| Nitrite + nitrate nitrogen (mg/L) | 17 | <0.02-3.6* | 47 | <0.01-11 | 10 MCL, nitrate as N |
| Total organic carbon (mg/L) | -- | -- | 7 | 1-24 | |
| Dissolved organic carbon (mg/L) | 17 | 1.0-9.4 | -- | -- | |
| Total phosphorus (mg/L) | 17 | 0.01-0.03* | 47 | <0.01-0.04 | |
| Chloride (mg/L) | 19 | 13-350 | 46 | 4.4-1,280 | 250 SMCL |
| Arsenic (µg/L) | 7 | 1-2* | 47 | <1-18 | 50 MCL |
| Cadmium (µg/L) | 7 | <1-1* | 47 | <1-2 | 10 MCL |
| Chromium (µg/L) | 7 | <10-10* | 47 | <1-13 | 50 MCL |
| Copper (µg/L) | -- | -- | 47 | <1-8 | 1,000 SMCL |
| Iron (µg/L) | 19 | <10-650* | 47 | 10-3,000 | 300 SMCL |
| Lead (µg/L) | 7 | <1-6* | 47 | <1-16 | 50 MCL |
| Magnesium (mg/L) | 19 | 2.5-9.2 | 47 | 1.2-68 | |
| Manganese (µg/L) | 19 | <10-20* | 47 | <10-100 | 50 SMCL |
| Mercury (µg/L) | 7 | <0.1-0.3 | 46 | <0.1-1.0 | 2 MCL |
| Nickel (µg/L) | -- | -- | 46 | <1-37 | |
| Potassium (mg/L) | 19 | 1.0-7.3 | 47 | 1.7-30 | |
| Sodium (mg/L) | 19 | 8.4-170 | 47 | 1.5-720 | 160 MCL |
| Zinc (µg/L) | 9 | <10.0-40.0* | 47 | <10-30 | 5,000 SMCL |

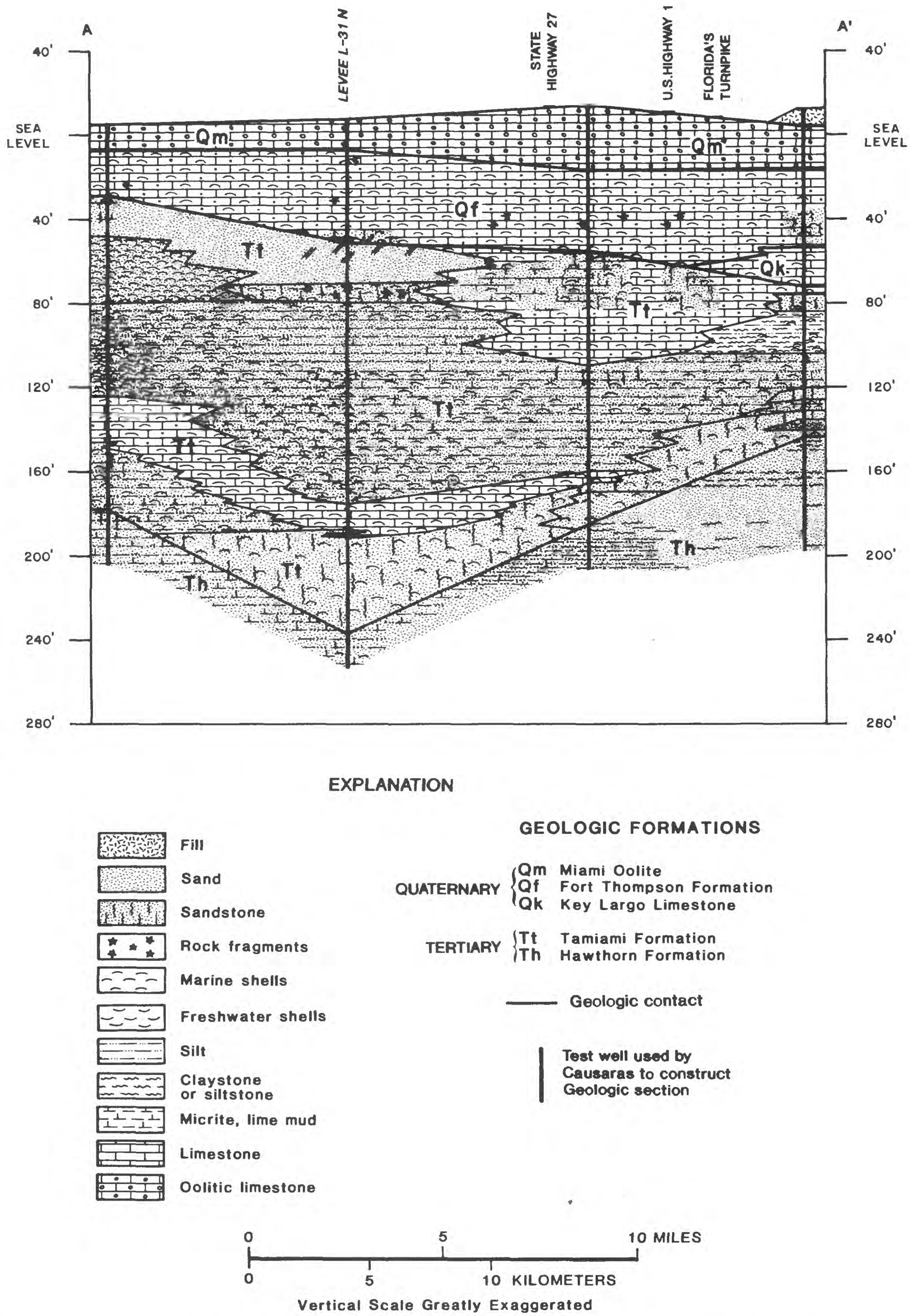


**Figure 4.** Geologic section (west-east) of the south Dade agricultural area (from Causaras, 1987; location of section is shown in figure 1).

Thorough discussions of the geology, hydrochemistry, and hydrology of the Biscayne aquifer are presented by Causaras (1987), Sonntag (1987), and Fish and Stewart (1991).

## Climate

South Dade County is in a subtropical marine climatological regime with generally hot, wet summers and mild, dry winters. This is illustrated by figure 5, which shows the normal and actual monthly temperature and the normal and actual monthly rainfall before and during the period of study using a long-term National Weather Service (NWS) station in Homestead (fig. 1). Normal is a NWS term defined as the average from 1951 to 1980. The south Dade growing season for row crops (September-May) corresponds to the cooler dry season. The close correlation between rainfall and water-table fluctuations using a hydrograph of USGS well S-196A at the NWS station in Homestead is also shown in figure 5.

## Soil

The south Dade agricultural area includes two soil series, Perrine marl and Rockdale, and one miscellaneous land type, Rockland. For the purpose of this study, Rockland is considered a Rockdale soil because it has similar characteristics to the latter after it is prepared for cultivation (rock plowed).

Rockdale is generally a coarse, light-orange to brown calcium carbonate soil derived from outcrops of soft limestone with some fine calcareous sand. It is well drained with little potential for surface runoff. Rockdale is a mineral soil with very small quantities of organic material--4 percent or less organic carbon (Carol Wettstein, U.S. Soil Conservation Service, written commun., 1984). All of the study area not defined as Perrine marl below is Rockdale, which overlies the Miami Oolite, and ranges from a few inches to 1 ft thick. About 70,000 acres in the Rockdale area were under cultivation at the beginning of this study.

Perrine marl is a light-gray (when dry), silty, calcareous marl. Because of its silty texture, the marl is poorly drained and is prone to surface runoff and ponding. Like Rockdale, Perrine marl is primarily calcium carbonate with generally less than 4 percent organic carbon (Carol Wettstein, U.S. Soil Conservation Service, written commun., 1984). For the purpose of this study, the Perrine marl soil area is defined as being generally east of U.S. Highway 1 or south of State Highway 27 (fig. 1) and having several inches to several feet of marl over the limestone of the Miami Oolite formation. About 10,000 acres of Perrine marl were under cultivation at the beginning of this study.

Soil characteristics of Rockdale soil and Perrine marl that influence the migration and attenuation of surface contaminants, such as sludge constituents, are listed in table 2. A more detailed discussion of Dade County soils and soil properties is given in the U.S. Department of Agriculture (1958) and Caldwell and Johnson (1982).

**Table 2.** *General characteristics of soils in the south Dade agricultural area*

[Sources: 1, from U.S. Department of Agriculture (1958); 2, from Caldwell and Johnson (1982); and 3, from Paul Orth, U.S. Soil Conservation Service, oral commun. (1989). Depth to bedrock data for Perrine marl from U.S. Department of Agriculture (1958) and data for Rockdale from Caldwell and Johnson (1982)]

| Characteristic | Rockdale | Perrine marl | Source |
|---|---|---|---|
| Parent material | Small pockets of fine sand or fine sandy loam in soft limestone. | Unconsolidated finely divided, highly calcareous sediments; mainly of freshwater origin. | 1 |
| Surface color | Dark-grayish-brown to brown | Light-brownish-gray to dark-grayish-brown. | 1 |
| Surface texture | Fine sand to fine sandy loam | Marl of silt loam texture | 1 |
| Depth to high water table. | 1 to 6 feet | 0 to 1 foot | 2 |
| Depth to bedrock | 4 to 12 inches | 6 to 60 inches | 1,2 |
| Vertical permeability | Moderately rapid | Moderate | 3 |
| Runoff potential | Low | High | 2 |
| Acidity | Neutral to alkaline | Strongly alkaline | 1 |
| Suitability for agriculture. | Severe limitations because soil is shallow, droughty or stoney. | Severe limitations on the type of crops due to wetness. | 2 |
| Relief | Nearly level with some gentle slopes. | Nearly level with slight depressions. | 1 |

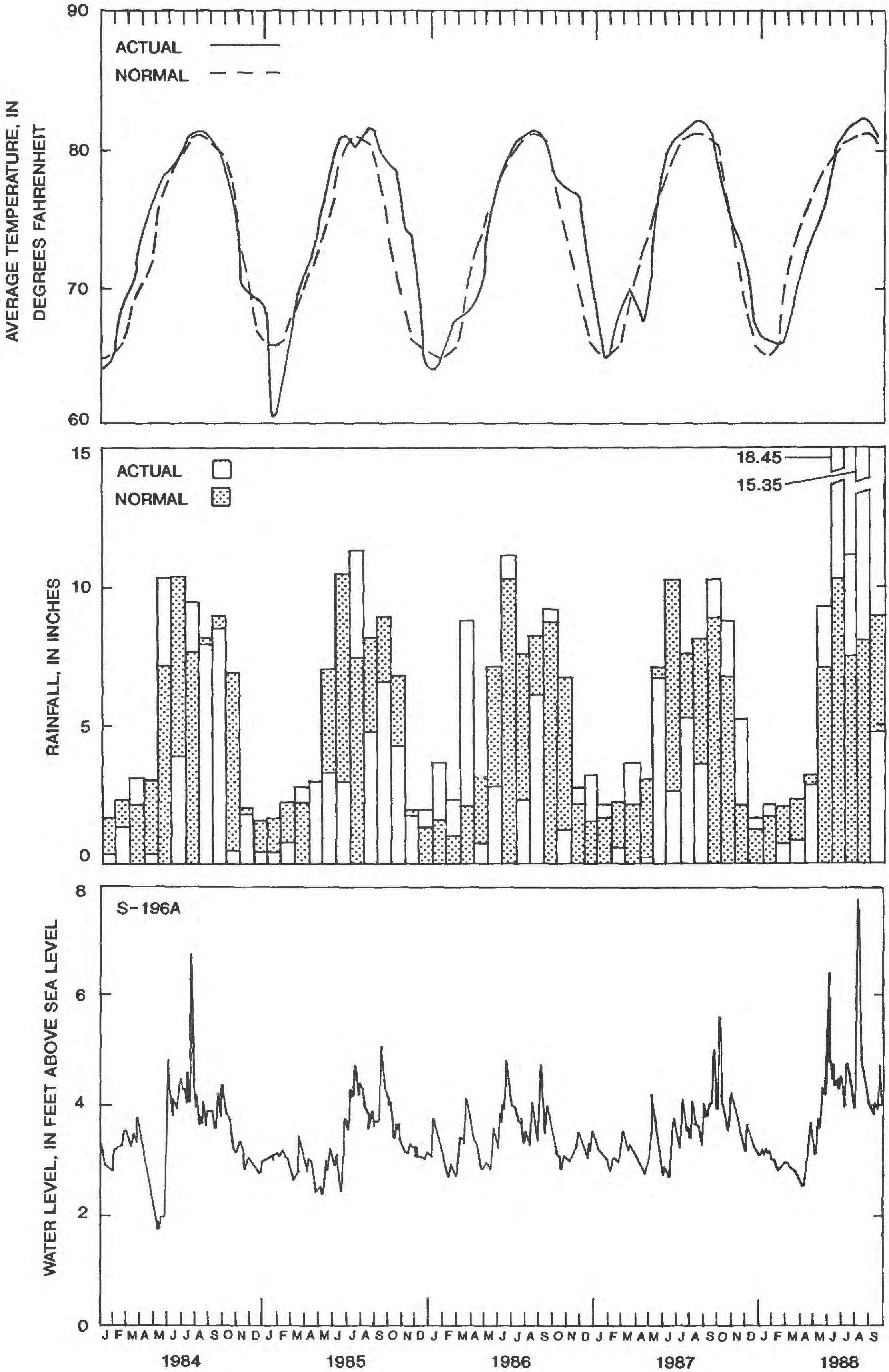


**Figure 5.** Average and normal monthly temperatures, total and normal monthly rainfall, and water-table altitude at the National Weather Service station in Homestead, January 1984 to September 1988 (climatological data from National Oceanic and Atmospheric Administration, 1984-88; water-level data from U.S. Geological Survey computerized data files).

## Agriculture

South Florida's soils and unique climate favor a wide variety of crops and dictate that agricultural practices are sometimes different than in other parts of the country. It is estimated that 51 different crops are grown commercially in south Dade County. This report is concerned with sludge use on food crops that are grown as row crops or as groves. Ornamental plants, grown in tree farms or containerized in nurseries, are a third type of agriculture that is burgeoning in south Dade County and that may use substantial quantities of sludge in the future.

Row crops are grown from September to May in both Perrine marl and Rockdale soil. Field preparation usually begins in August when fields are cleared and fumigated and fertilizer is applied. Crops are planted from September to November. Sludge is applied to fields at the beginning or the end of the growing season at an approximate rate of 2 dry tons/acre and then disked into the soil. The Florida Department of Environmental Regulation (1984) rules for sludge application prohibit the use of sludge on root crops or vegetables eaten raw. As a result, sludge cannot be applied to some of south Dade County's major crops, such as potatoes and tomatoes (which, although botanically a fruit, is considered a vegetable under these rules).

Irrigation for row crops is usually by gun-type rigs on an "as needed" basis rather than by schedule. These rigs can pump up to 1,000 gal/min and generally remain at each location for a sufficient period (about 30 minutes) to wet the root zone but have little effect on the water table. The Perrine marl soils are usually wet enough not to need irrigation. Thus, the most likely medium for contaminant infiltration during the winter dry season is occasional heavy rainfall associated with cold fronts moving across the area.

Groves are planted only in the Rockdale soil area, and fertilizer and pesticides are applied several times during the year. Accordingly, sludge is applied three times annually at a rate of 2 dry tons/acre, which equals the maximum allowable rate of 6 tons/acre/yr. Groves do not usually need irrigation because of the deeper root system of the trees, but some groves are equipped with overhead sprinklers or drip lines for extended dry periods. Results of an earlier study of the south Dade agricultural area (Howie, 1986) indicated a greater buildup of nitrate and potassium in water under groves than under row crops. This is probably because of the application rates and year-round application, and it may be indicative of the behavior of some sludge contaminants.

Fertilizers and pesticides contain some of the same constituents as sludge, and there may be some chemical interaction between these agrichemicals and sludge. The climate and crop variety in the south Dade agricultural area provide an ideal habitat for many species of insects, weeds, and fungi, and consequently the need for a wide variety of pesticides. The West Well Field Agricultural Subcommittee (written commun., 1988) identified 70 pesticides as currently being used. Similarly, fertilizer is used in large quantities because it tends to run off the Perrine marl soils and to rapidly leach from the Rockdale soils. It has been suggested that the organic material in sludge will retain nitrate and trace elements from fertilizer for uptake by crops and thereby reduce heavy fertilizer use.

# METHODS OF INVESTIGATION

This section includes a brief discussion of the methods and techniques used during the study. References are provided when a thorough explanation of the method is beyond the scope of this report.

## Site Selection and Well Locations

The investigation involved four test fields (fig. 1), two in each soil type (Rockdale and Perrine marl). One field in each soil type was an unused field, which was to receive sludge at the maximum allowable application rate (6 tons/acre). These fields represented the effects of maximum sludge use because of the application rate and because there was no crop uptake. The other field in each soil type was an actively farmed field, which was to receive sludge at the recommended rate for the field's crop. These fields represented the real-world scenario in terms of the effects of the land application of sludge. The active field in Perrine marl soil was planted in row crops and the active field in Rockdale soil was a grove in order to observe both major crop types.

There were also several practical considerations that had to be taken into account in selecting the four test fields. The selection was limited to those fields where the owner's cooperation was assured, to fields with year-round accessibility, and, in the case of maximum-application fields, to fields that had not been farmed for an extended period of time. The selection for maximum-application fields was severely restricted because there is limited farmland in the south Dade agricultural area, and where land was suitable for agriculture, it was already in use or had been within the last few years.

At each field, clusters of three wells, completed at different depths in the Biscayne aquifer, were located upgradient and downgradient of the field (fig. 6). At the Rockdale maximum-application field, the Perrine marl maximum-application field, and the Rockdale grove, an additional cluster was located in the middle of the field. The Perrine marl row-crop field did not have an additional well cluster because row-crop farming practices prohibited the placement of a well cluster in the center of the field. The upgradient and downgradient well clusters are located immediately within the test field borders, except at the row-crop field where some wells were just outside the borders.

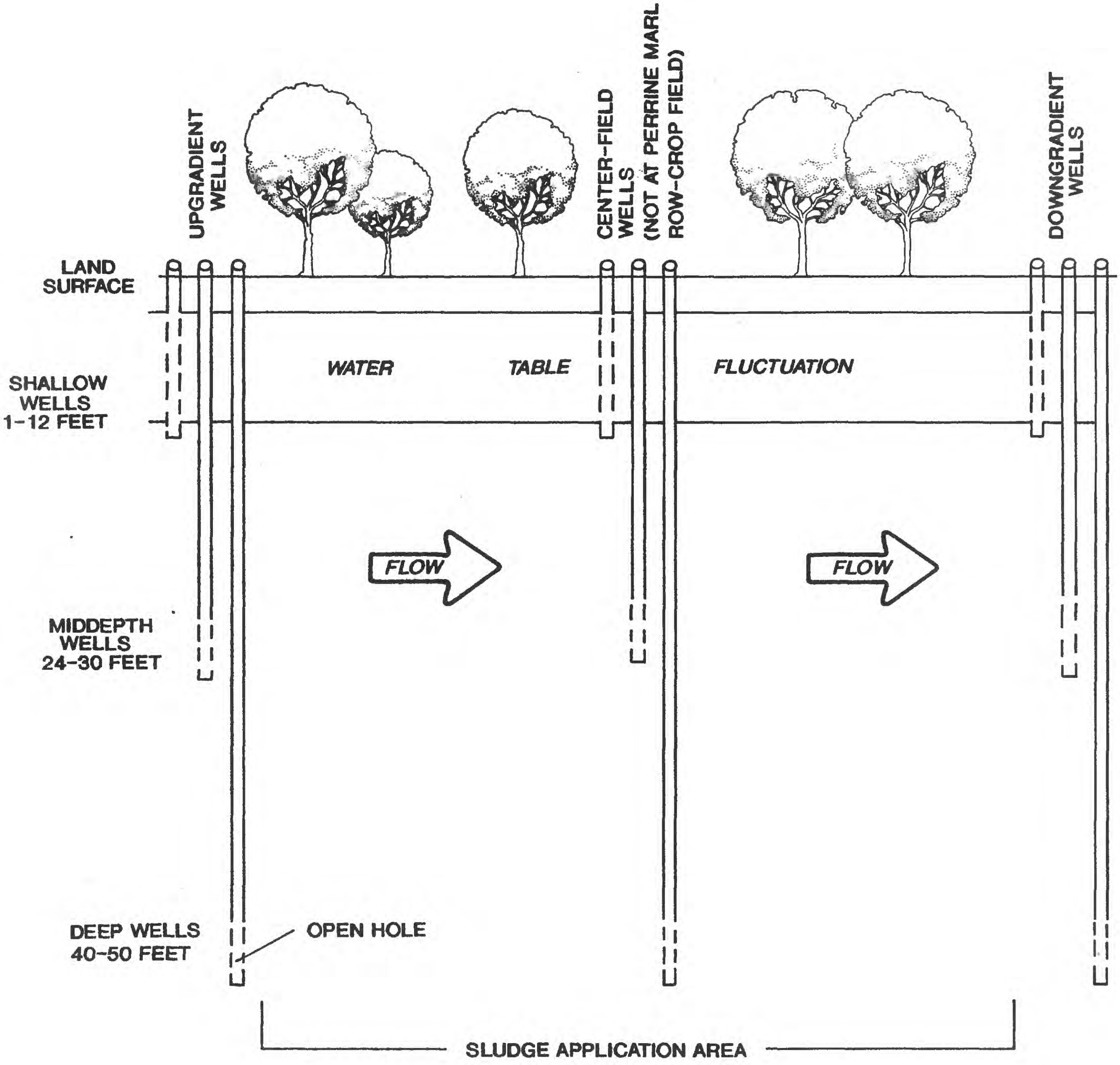


**Figure 6.** Generalized well placement at the test fields.

Water from the upgradient wells represented the water quality of inflow to the field and temporal variations not related to sludge application. Ground water beneath the sludge-applied area of the field, represented by the shallow well in the center-field well cluster, was expected to show the earliest and greatest effects (if they occurred) because of the land application of sludge. The other two wells in the center-field well cluster were to be used to examine the vertical movement of any contaminants detected in the shallow well. Finally, water from the downgradient well cluster represented ground water leaving the field, and these well samples were to be used to determine if any contaminants reaching the water table beneath the field were moving offsite.

Sludge was applied between and to within 10 to 20 ft of the upgradient and downgradient well clusters. The shallow well in each cluster tapped the water table, where the effects of the land application of sludge were most likely to be evident. The depths of the remaining wells in each cluster were determined from a geologic test hole drilled at or near each field. The middepth wells were installed at 24 to 30 ft, just below the first hard layer that marks the boundary between the oolitic limestone and the limestone of the Fort Thompson Formation (fig. 4). This is the producing zone for most domestic and irrigation wells, and water from this zone was sampled to determine if there was vertical migration below the hard layer of any contaminants detected in the shallow wells. The deep wells were installed 40 to 50 ft deep. This depth represents the next producing zone and also the deepest extent of the Biscayne aquifer beneath the westernmost field that has the thinnest aquifer of the four fields.

Well numbers, station identification numbers and depths of all the wells at the test fields are listed in appendix I. The station identification numbers can be used to access data in the USGS computer data bases.

The Rockdale maximum-application field is shown in figure 7. Although this 40-acre field has not been farmed, it is in an area between Canal C-111 and Levee L-31W that has been farmed since 1974. The test site was first cleared a few years prior to the study and has been rock plowed several times since then but has never been planted. When the study began, the areas north, northeast, and south of the test field had not been farmed, and the remaining adjacent land was planted in tomatoes. The soil layer is composed of 3 to 5 in. of pulverized oolitic limestone and marl with very little organic material. The Miami Oolite is about 9 ft thick beneath this field. The ground-water gradient is to the south or southeast, depending on water levels in Canal C-111 and Levee L-31W Canal. During the period of study, the unsaturated zone extended from 1.5 to 2.7 ft below land surface.

The Rockdale grove is shown in figure 8. This 30-acre avocado grove is about 30 years old. There is a lime grove to the north, a commercial nursery to the east, a two-lane street and row crops to the south, and an old mixed citrus grove and an area of low-density homes to the west. When this grove was established, holes were drilled or dynamited into the oolitic limestone, and the trees were placed in the holes. Thus, there is no real soil at this site, but there is 2 to 4 in. of accumulated leaf litter. The Miami Oolite extends 23 ft below land surface at this site, which is on the western edge of the Atlantic Coastal Ridge. The ground-water gradient is to the southeast, and during the period of study, the unsaturated zone was 4 to 8 ft thick.

The Perrine marl maximum-application field is shown in figure 9. This 8-acre field is owned by the University of Florida and has been used by its Institute of Food and Agricultural Sciences for agricultural research. It had not been used for at least 10 years prior to this study. West of the field is an ornamental tree farm; to the north, potatoes are grown; to the east are 10.5 acres (also belonging to the University) that have not been used for about 10 years; and to the south are North Canal and North Canal Drive. The soil layer consists of about 2.2 ft of Perrine marl. The Miami Oolite at this site is approximately 14 ft thick. The regional ground-water gradient is to the south-southeast; however, water-level data from the shallow wells during this study indicated a variable gradient for shallow ground water beneath the field (which diminished the value of this field for determining contamination of the aquifer). During the period of investigation, the unsaturated zone was 0 to 1.5 ft thick. This field is in an area underlain by brackish water with a chloride concentration that ranged from 160 to 1,300 mg/L in shallow well samples collected during the study.

The Perrine marl row-crop field is shown in figure 10. This 36-acre field has been cultivated 30 years or more. It was planted with sweet corn during the study period and had previously been used to grow potatoes. Potatoes were grown in fields to the north, west, and east; the area to the south was forested. The underlying material at this site consists of 14 in. of Perrine marl and 12 ft of Miami Oolite. The ground-water gradient is north toward the North Canal. During the period of study, the unsaturated zone was 0.3 to 2.5 ft thick. Row-crop farming practices, coupled with the need for installing wells within the field and on farm roads, resulted in damage to five of six wells during the study. These wells were repaired or redrilled as needed, but some samples were missed at damaged wells before repair.

## Drilling and Well Construction

Drilling methods and well construction were planned so the completed wells would be suitable for sampling both inorganic and organic constituents. Holes were drilled by a reverse-air, dual-wall, drill-pipe method. The rig, drill stem, and other drilling equipment were steam cleaned before and periodically during drilling.

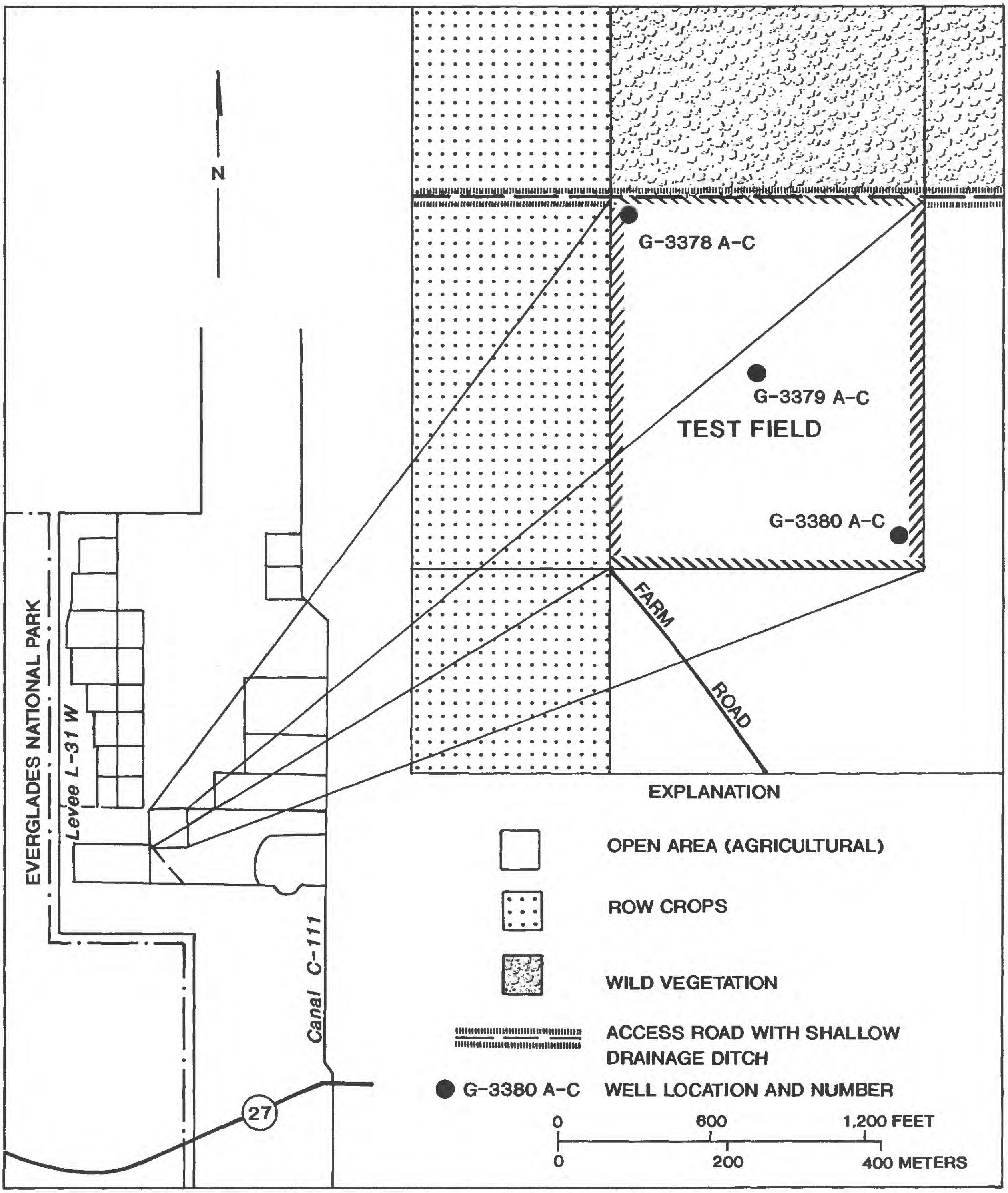


**Figure 7.** Rockdale maximum-application field and well locations.

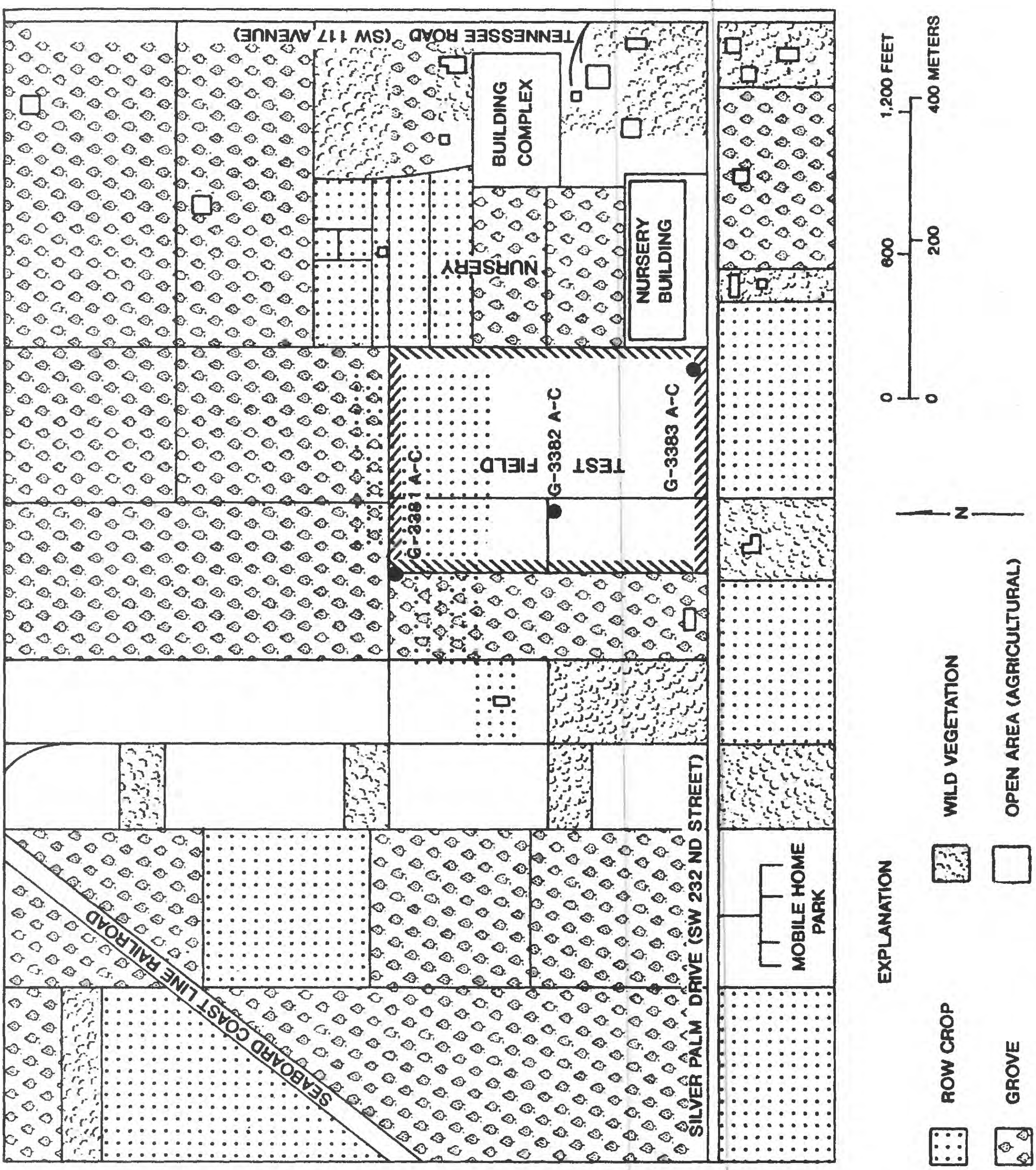


**Figure 8.** Rockdale grove and well locations.


**Figure 9.** Perrine marl maximum-application field and well locations.

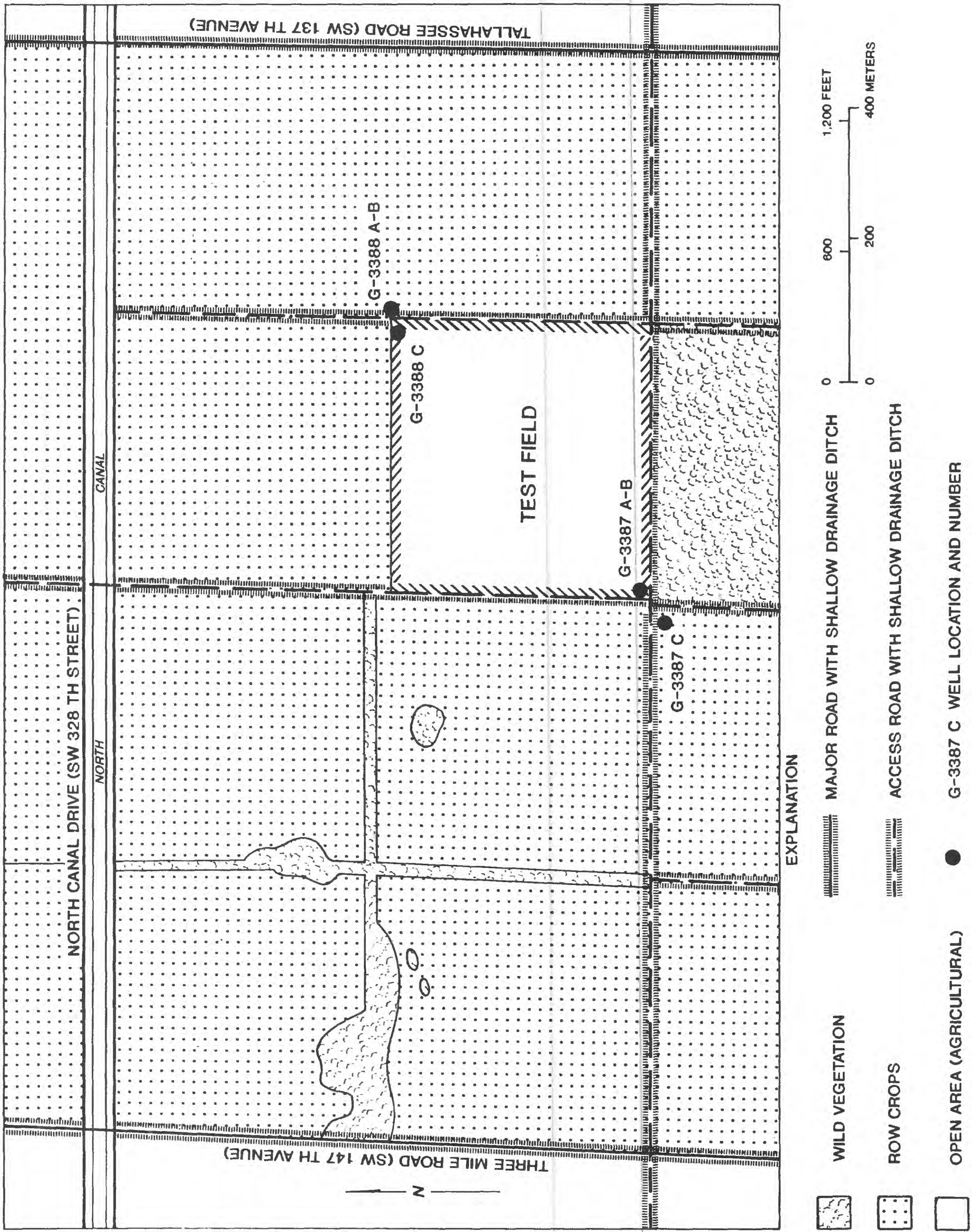


**Figure 10.** Perrine marl row-crop field and well locations.

To construct the well, the 6-in. borehole was filled with clean silica sand to the top of the interval to be sampled, 2-in. threaded polyvinyl chloride (PVC) casing was set 6 in. into the sand, and the annulus above the sand between the casing and borehole was grouted. After several days, the sand was pumped out leaving an open hole in the 4- to 5-ft sampling interval, which allowed for minimal contact between the PVC casing and ground water during sampling. The wells that tap the water table are open hole for an interval representing the historical fluctuation of the water table at each well site as estimated from nearby wells.

## Water-Quality Sampling

Most constituents were selected for analysis on the basis of their history of occurrence in WSA or other municipal sludges and on their potential for infiltrating to the water table. The insecticides and organic priority pollutants were sampled as an auxiliary study at the request of FDER because baseline data for these compounds were needed for south Dade County. Some additional constituents that are necessary for chemical verification of analyses were also analyzed, but these constituents are not included in the discussion, except on rare occasions when they seem relevant to sludge application. The physical properties and chemical constituents included in this study are as follows:

- *Physical properties--Specific conductance, alkalinity, and pH.*
- *Nutrients--Nitrogen, phosphorus, and total organic carbon.* In this report, the term nutrients is used in the context of water quality and refers to organic carbon, the species of nitrogen, and the species of phosphorus. This is different from the agricultural context which refers to nitrogen, phosphorus, and potassium.
- *Micronutrients--Copper, iron, magnesium, manganese, potassium, and zinc.*
- *Sludge-derived contaminants--Arsenic, cadmium, chloride, chromium, lead, mercury, nickel, and sodium.*
- *Synthetic organic constituents--Acid-extractable and base-neutral compounds, volatile organic compounds, chlorophenoxy herbicides, organophosphorus insecticides, and organochlorine compounds.*

Sampling methodology depended on the constituents to be analyzed. Prior to sampling, 10 casing volumes were pumped from the well using a centrifugal pump and reinforced Tygon[1] tubing. The same pump and tubing were used to collect samples for the measurement of the physical properties and for the analysis of nutrients, trace metals, potassium, sodium, and chloride. A Teflon bailer rinsed with methanol and organic-free water was used for sampling all organic constituents. A quality-assurance program was conducted to ensure confidence in sampling techniques and analytical results. Ten to 20 percent of all samples were reference samples, duplicates, or field blanks. Quality-assurance measures in the laboratory consisted of surrogate samples, internal standards, and blanks. Organic constituent analyses were performed by the USGS National Water Quality Laboratory in Denver, Colo. All other chemical analyses were performed by the USGS Quality of Water Service Unit in Ocala, Fla. The analytical techniques used for the determinations are described by Goerlitz and Brown (1972), Fishman and Brown (1976), and Skougstad and others (1979).

The sampling schedule was changed from the initial project design, which called for sludge application and water sampling at the same time for all four fields to allow statistical comparisons to be made between fields. A hard freeze in January 1985 required replanting of the Perrine marl row-crop field, delaying the end of the growing season and subsequently delaying drilling in the field. Another delay was caused when, because of frequent rainfall, there was insufficient dry sludge for field application at the Rockdale maximum-application field. As a result of these changes, the fields were sampled on different schedules (described later). The overall sampling schedule was to sample all shallow wells and the middepth well in the center or downgradient of the field at the end of wet and dry seasons before applying sludge. Only the shallow well in the center of the field (downgradient shallow well for the row-crop field) was sampled for organic constituents because of the prohibitive cost of these analyses. Sludge was then applied to the field, and all wells were sampled after the first rainfall large enough to affect water levels. Samples were collected from all wells once during the growing (dry) season, at the end of the growing season, once during the wet season after heavy rainfall, and at the end of the wet season. This schedule was continued until the data-collection phase of the study was completed at each field. Water samples for organic constituent analysis were collected from the shallow well in the center of the field at the end of the wet and dry seasons.

## Data-Interpretation Techniques

This report compares the quality of ground water upgradient of, beneath the center of, and downgradient of each field using a signed ranks test and compares all data to drinking-water standards. Prior to these comparisons, each constituent sampled in the shallow wells was plotted against time to determine if there were any time trends in the data. Although some constituent concentrations increased or decreased, these trends were evident in all of the shallow wells, including the upgradient well (fig. 11A), or they were already evident in the first year of the study before sludge was applied (fig. 11B). These preexisting trends are not relevant to the land application of sludge.

[1]Any use of brand names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

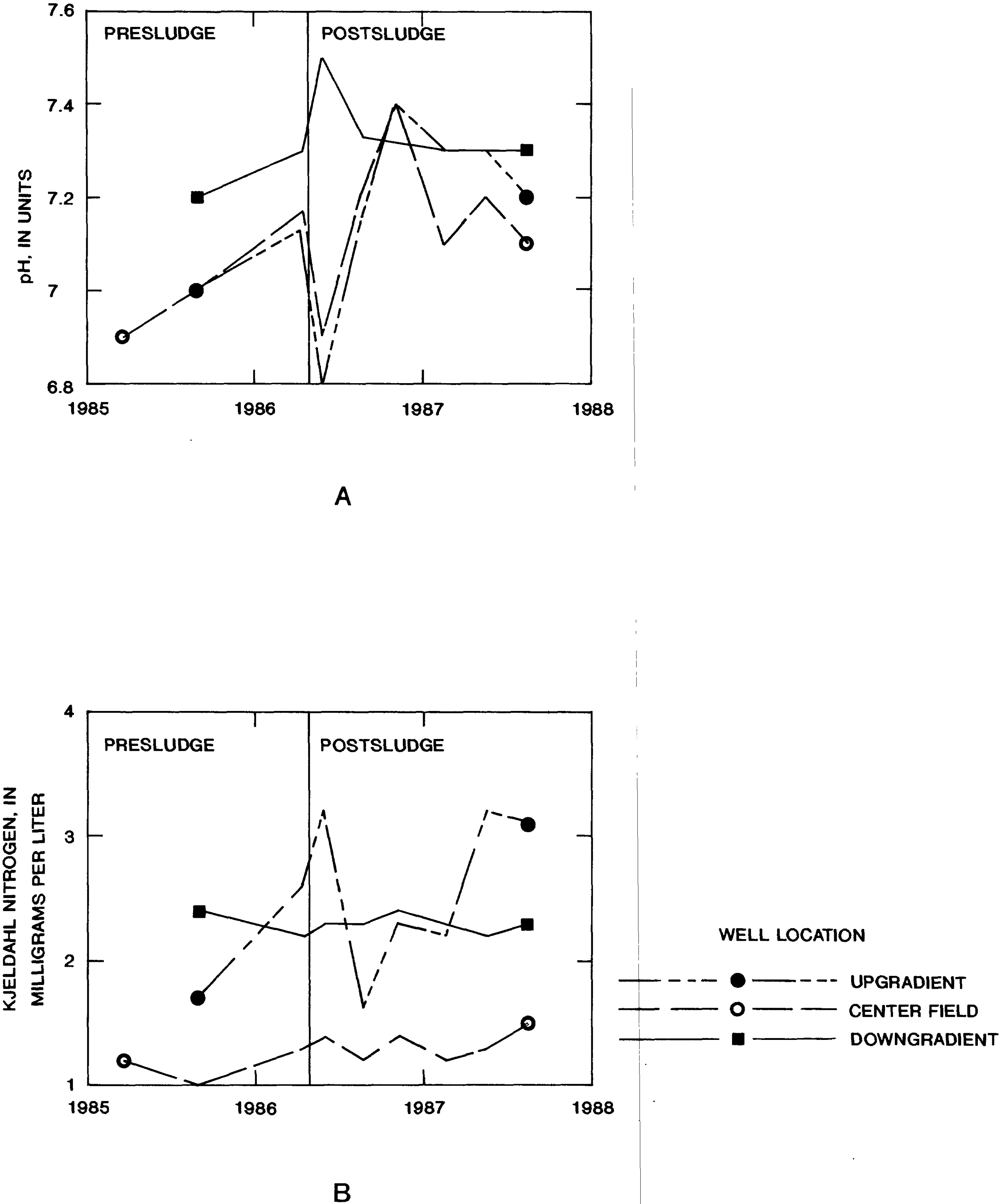


**Figure 11.** Examples of preexisting trends at the Perrine marl maximum-application field: (A) trend toward increasing pH, and (B) trend toward lower Kjeldahl nitrogen beneath the center of the field.

The quality of ground water upgradient of, beneath, and downgradient of each field was compared using a two-tailed Wilcoxon signed ranks test (WSRT) as described in Iman and Conover (1983, p. 256-260). For a WSRT, the absolute values of the differences in concentration between two wells being compared are ranked by size. Each rank is assigned a negative sign if the original difference was negative and a positive sign otherwise. The standardized average rank is then compared to the student's t distribution to see if it is larger or smaller than would be expected if the concentrations in the two wells were statistically the same. The WSRT was used because the small sample sizes for each well do not allow for the verification of normalcy as required for parametric tests. A two-tailed test was used to determine if concentrations beneath or downgradient of the field were less than concentrations upgradient, as would be the case if the trace metals used as micronutrients on the actively farmed fields were retained by the organic material in the sludge.

For the Rockdale maximum-application field, the Rockdale grove, and the Perrine marl row-crop field, these tests were comparisons of ground water entering the field, passing under the field, and leaving the field. Because of the changes in ground-water gradient at the Perrine marl maximum-application field, the tests may only be considered comparisons of ground water beneath the sludge-applied area to ground water outside of the sludge-applied area.

The WSRT, like all hypothesis tests, only indicates which differences are statistically significant. It does not indicate why the differences occur, specifically, if they occur because of sludge application. For this reason, differences in water quality between areas upgradient of, beneath, and downgradient of the fields that were indicated by the WSRT were further examined using the time-trend plots and the first-year (presludge) data. Statistically significant differences were often detected between wells because of one or two higher concentrations in samples from one well. When the variability of the first-year data for the constituent was considered, it became evident that the higher concentrations were the probable result of natural variability and not sludge application. Preexisting trends (fig. 11) also often accounted for the statistically significant differences between wells, either because samples from one well had higher concentrations of the constituent before sludge was applied or because concentrations in one well were increasing or decreasing before sludge was applied.

Data collected for this investigation were compared to Florida Department of Environmental Regulation (1982) primary and secondary drinking-water regulations (table 1) to determine if there are any temporary effects from sludge application that are not long term enough to test statistically significant. Concentrations of constituents that exceeded drinking-water regulations were compared to concentrations found in a baseline study of the agricultural area during the first year of this investigation (Howie, 1986) and to concentrations found in background wells for an earlier investigation of land use in south Dade County (Waller, 1983). Comparing the data from the sludge investigation to data for the agricultural area provides indications of which constituents are naturally high, which constituents may be high because of agricultural activity other than sludge application, and which constituents may be high because of sludge.

## DADE COUNTY WATER AND SEWER AUTHORITY DEPARTMENT SLUDGE TREATMENT AND CHARACTERISTICS

Dade County produces 20,000 tons of dry sludge per year at its Central and South District Wastewater Treatment Plants (Robert Fergen, Dade County Water and Sewer Authority Department, oral commun., 1984). At the beginning of this study, there were another 200,000 tons of sludge stockpiled at the central district facility. The stockpiled sludge was from a few weeks to 3 years old and had a low nitrogen content (about 1 percent) because of biochemical degradation within the stockpile. Sludge from the stockpile and from drying beds at both plants was used for field application.

Steps in the process used by WSA to convert raw sewage to sludge are described in figure 12. The chemical and biological reactions during each step of the treatment process are beyond the scope of this report; however, a few generalities may be noted. These sewage constituents, which are readily soluble or which degrade into soluble products, are removed with the effluent from the final settling tanks and from the centrifuge. Most of those constituents which are volatile, or which degrade to volatile products, would be expected to be released during aeration, mechanical agitation, digestion, and by exposure to heat and mechanical turning in the drying beds. The volatile fraction of sewage may include volatile organics, nitrogen gas, and chlorine gas among others. Those constituents of sewage that are neither soluble nor volatile are concentrated during the treatment process; thus, a unit volume of sludge has a higher concentration of these constituents than a unit volume of sewage influent. This fraction of sludge may include metals, nonmetallic elements, and heavy organic compounds.

Both Dade County treatment plants are Type I Facilities (designed to process 500,000 gal/d or more of sewage) that produced a Grade I sludge during the sludge application phase of this study (Robert Fergen, Dade County Water and Sewer Authority Department, oral commun., 1988). To be classified as Grade I, sludge must be stabilized and meet the following metals criteria:

| Metal | Maximum allowable concentration (milligrams per kilogram) |
|---|---|
| Cadmium | 30 |
| Copper | 900 |
| Lead | 1,000 |
| Nickel | 100 |
| Zinc | 1,800 |

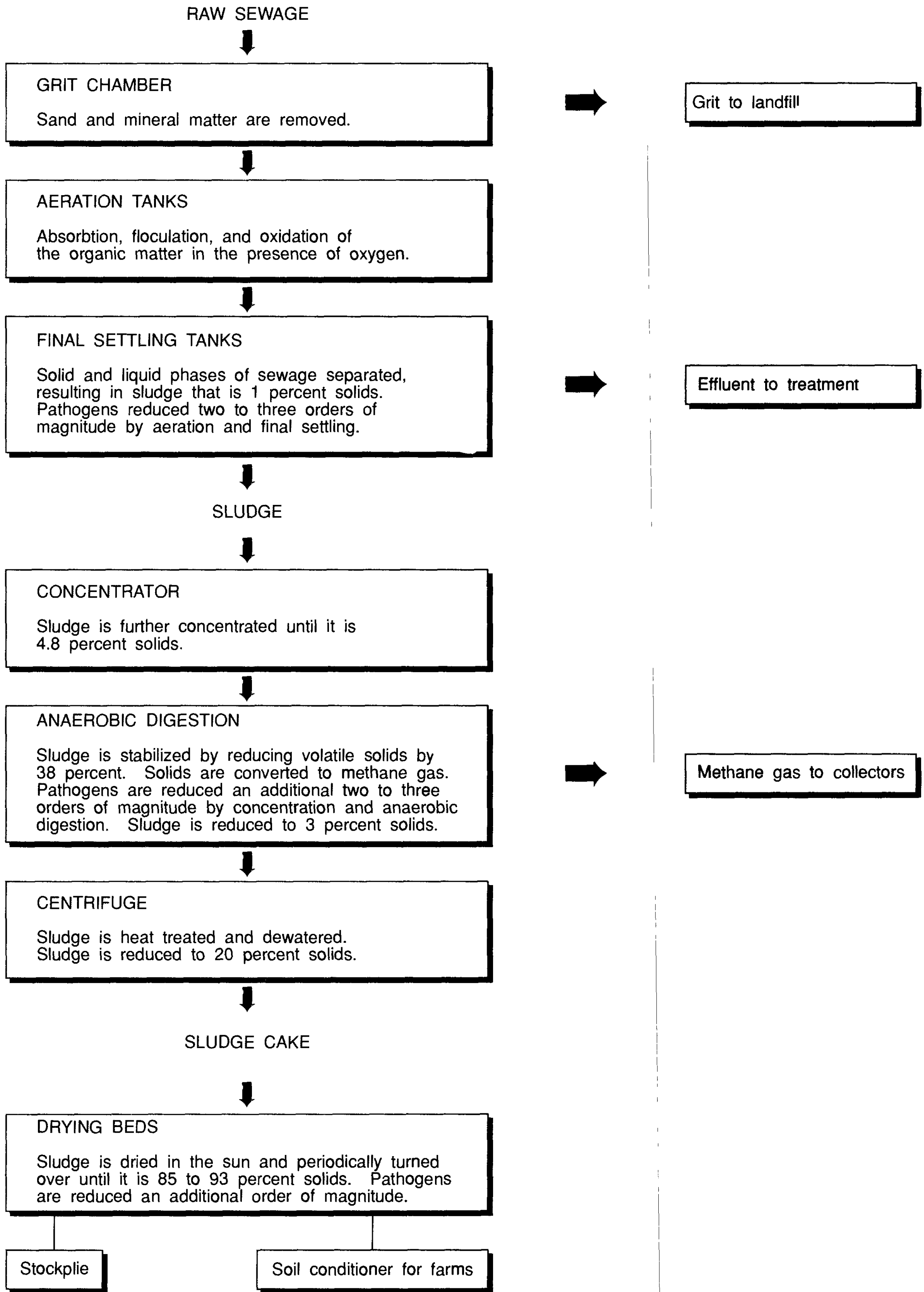


**Figure 12.** Steps in the Dade County Water and Sewer Authority Department sewage-treatment process.

Plant permits require monthly samples for metallic priority pollutants and annual samples for organic priority pollutants. Priority pollutants that have been detected in sludge from the drying beds during the period of study are listed in table 3 along with levels in sludges from other cities. WSA sludge is generally low in both metallic and organic priority pollutants, as would be expected for a community with no heavy industry.

Pathogens in sludge are a concern when applying sludge to agricultural lands, although more for their possible deleterious effects on farm workers and harvest than for their effect on ground water. Pathogens were not investigated as part of this study for two reasons.

First, when the study was designed, WSA was installing an experimental 4-megarad, high-energy electron beam to eradiate the sludge before it entered the centrifuge. It was thought that this process would produce a pathogen-free sludge, making pathogen testing of ground water unnecessary. EPA later determined that only a 1-megarad beam was necessary to disinfect sludge so WSA discontinued its use of the more powerful 4-megarad system.

The second reason for not investigating pathogens was that when the study began, two pathogen studies were already in progress at the WSA plants and one had been recently completed. These studies are briefly summarized below.

- The Florida Department of Health and Rehabilitation Service, Epidemiology Research Center, sampled viruses at each stage of the treatment process in WSA's Central District Plant from September 1983 to April 1984. There were no detections in the four monthly samples of sludge collected from the drying beds and from the stockpile (Flora Mae Wellings, 1984, Study to determine the virus inactivation efficiency of high energy electron treatment, an unpublished report contracted by WSA).
- The University of Florida conducted a microbiological study involving both plants in 1985. A sample of the dry sludge yielded the following: no coliform or fecal streptococci bacteria, enteroviruses, or helminth ova were detected; there was one detection of salmonella at 0.2 MPN/g, and bacteriophage were detected at 91 PFU/g (Samuel R. Farrah, University of Florida Institute of Food and Agricultural Sciences, written commun., transmitting data to Robert Fergen of WSA, 1985).
- The Los Angeles County Sanitation District began an EPA sponsored study of 26 wastewater facilities in 1985. A single sample of the stockpiled sludge collected in 1986 found no viruses, salmonella, nor helminth ova (Robert Fergen, Dade County Water and Sewer Authority Department, written commun., 1988).

It should be noted that pathogens are reduced by long-term storage in the stockpile, so those results that are from the stockpiled sludge may not be representative of sludge taken directly from the drying beds to the fields.

## EFFECTS OF SLUDGE APPLICATION ON GROUND-WATER QUALITY

The following discussion of results is arranged to describe the effects of sludge application on ground-water quality at the Rockdale maximum-application field,

**Table 3.** *Priority pollutents in Dade County Water and Sewer Authority Department (WSA) sludge during the period of study and in municipal sludges sampled by the U.S. Environmental Protection Agency*

[Concentrations shown in milligrams per kilogram; WSA data from Bertha Goldenberg (written commun., 1989) and the WSA ranges are for yearly priority pollutant analyses; municipal sludge data from Feiler (1980); <, less than; ND, no detection]

| Priority pollutant | Sludge | |
|---|---|---|
| | WSA | Municipal |
| **Metals** | | |
| Cadmium | 9-22.5 | 1.1-59 |
| Chromium | 6.3-153 | 63-1,762 |
| Copper | 29-626 | 100-1,427 |
| Lead | 82-169 | 39-1,169 |
| Mercury | <1-12 | 0.037-78 |
| Nickel | 18-107 | 12-803 |
| Zinc | 400-1,500 | 420-8,468 |
| **Synthetic organic compounds** | | |
| Anthracene | ND | 0.89-44 |
| Benzene | 0.015-0.098 | 0.053-11.3 |
| Butylbenzyl phthalate | 0.070 | 0.52-210 |
| Carbon tetrachloride | ND | 4.2 |
| Chlordane | 0.110-0.320 | ND |
| Chloroethane | ND | 14.5-24 |
| Chloroform | 2.0-2.938 | ND |
| 2-Chloronaphthalene | ND | 4.7 |
| Chrysene | ND | 0.25-13 |
| 4,4' DDD | 0.010-0.018 | ND |
| 4,4' DDE | 0.024-0.046 | ND |
| **Synthetic organic compounds--Continued** | | |
| Dibenzo(a,h)anthracene | ND | 13 |
| 1,2-trans Dichloroethylene | ND | 0.72-865 |
| Dieldrin | 0.018 | ND |
| Di-n-butyl phthalate | ND | 0.32-17 |
| Ethylbenzene | ND | 1.0-51 |
| bis(2-Ethylhexyl)phthalate | 14-73 | 4.1-273 |
| Fluoranthene | ND | 0.35-7.1 |
| Hexachlorobutadiene | ND | 0.52-8 |
| Methylene chloride | 0.021 | 0.06-30 |
| Naphthalene | ND | 0.9-70 |
| Polychlorinated biphenyl | 0.040-0.160 | ND |
| 1260. | ND | 0.89-44 |
| Phenanthrene | ND | 0.89-44 |
| Phenol | ND | 0.9-113 |
| Pyrene | ND | 0.33-18 |
| Tetrachloroethylene | ND | 0.024-42 |
| Toluene | 0.0096 | 1.4-705 |
| 1,1,1-Trichloroethane | 0.016 | ND |
| 1,1,2-Trichloroethane | ND | 0.036-6.9 |
| Trichloroethylene | ND | 0.048-44 |
| Trichlorofluormethane | 0.0047 | ND |
| Vinyl chloride | ND | 3-110 |

Rockdale grove, Perrine marl maximum-application field, and Perrine marl row-crop field in the south Dade agricultural area. Comparisons are made between water quality before and after sludge application, between water quality upgradient of, beneath, and downgradient of the fields, and between water quality in the vicinity of the test fields and Florida Department of Environmental Regulation (1982) primary and secondary drinking-water regulations.

## Rockdale Maximum-Application Field

Sludge was applied to the Rockdale maximum-application field at the rate of 6 tons/acre on March 30, 1987. The first postsludge water-quality samples were collected on May 19, 1987, after 0.75 in. of rainfall. Subsequent samples were collected according to the previously described schedule on August 20, 1987, November 12, 1987, February 22, 1988, and May 23, 1988. The deep well downgradient of the field was destroyed after the November 1987 sampling period so data for this well were not available for the last two sampling periods. There was no other chemical application to this field, and the only other potential contaminant sources are atmospheric deposition, which was not quantified, and ground-water inflow, which was quantified by sampling the upgradient wells. This field was not farmed so the only plant uptake (unquantified) was by weeds.

### Comparison of Water Quality Before and After Sludge Application

The shallow wells upgradient of, within, and downgradient of the field and the middepth well in the center of the field were sampled before sludge was applied. Wells at all depths and locations in the field were sampled after sludge was applied. The summary data for each well are listed in table 4, which gives the concentration range for each constituent in samples collected before sludge was applied and the concentration range, median, and mean for samples collected after sludge was applied.

Presludge and postsludge measurements and concentrations for the shallow well samples were examined before any formal analysis of the data was done as described in "Data-Interpretation Techniques." Two postsludge dissolved organic carbon (DOC) samples from beneath the center of the field, which were analyzed at this well in addition to the scheduled constituents, were significantly higher than the presludge samples (8.5 and 6.5 mg/L contrasted with 2.5 and 4.0 mg/L). Copper in one sample from the downgradient well (9 μg/L) in addition to being higher than presludge samples from this field exceeded the maximum concentration for the agricultural area found by Howie (1986) in the first year of this study (8 μg/L) and the maximum concentration found by Waller (1983, p. 14) for background wells (2 μg/L). The other four postsludge samples for copper from this well were similar to presludge concentrations for this field.

### Statistical Interpretation of Water-Quality Data

The WSRT was used to examine possible differences in the quality of ground water entering, beneath, and leaving the field. The constituents studied are listed in table 4. Those tests that indicated statistically significant (0.05 significance level) differences in water-quality constituents between areas of the field are listed in appendix II. Most significant differences in physical properties and constituent concentrations were the result of trends that existed before sludge application or because of only one or two higher concentrations as discussed in "Data-Interpretation Techniques." Differences not readily explained by these factors were found for the following properties and constituents (dashes indicate not enough samples from the downgradient well to make a comparison; none indicates that constituents were either not significantly different or significantly different but explained by preexisting trends or high concentrations).

| | Areas compared | | |
|---|---|---|---|
| Well depth | Upgradient to center | Upgradient to downgradient | Center to downgradient |
| Shallow | None | None | Arsenic |
| Middepth | None | None | Specific conductance<br>Potassium<br>Copper |
| Deep | None | -- | -- |

In shallow ground water, arsenic concentrations were higher beneath the center of the field than leaving the field. Arsenic concentrations were the same beneath and leaving the field before sludge application. The WSRT indicated a difference in arsenic because the concentrations increased slightly beneath the field after sludge was applied. However, the increase, although observed in four of five samples, was slight (less than 2 μg/L), and the concentrations did not exceed levels found upgradient before sludge application.

In middepth ground water, specific conductance was lower and potassium and copper concentrations were higher beneath the field than leaving the field. Because no decrease in specific conductance was observed in shallow ground water, the lower measurements for underflow (467-488 μS/cm) than for outflow (474-526 μS/cm) indicated by the WSRT for middepth ground water probably represent the natural variation in ground water. The differences in potassium and copper concentrations between underflow and outflow did not appear to be of consequence.

**Table 4.** *Summary data for ground-water quality from wells at the Rockdale maximum-application field before and after sludge application*

[Samples below the detection limit (DL) are not included in the mean and median calculations. If a constituent was not detected in a sample, the constituent is reported as less than (<) the detection limit (for example, <100). When the presludge and postsludge detection limits are different, it is because other constituents in a sample may interfere with an analysis, necessitating the use of alternative methods of analysis with higher or lower detection limits. The analytical methods for some constituents (Kjeldhal nitrogen, nitrite + nitrate nitrogen, total phosphorus, and lead) and, therefore, their detection limits were changed permanently during the period of study. Abbreviations: mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NM, statistic has "no meaning" given number of detections (median and mean do not apply for pH), NS, no samplings were made]

| Constituent | Presludge | | Postsludge | | | | |
|---|---|---|---|---|---|---|---|
| | No. of samples | Range | No. of samples | Range | Median | Mean | No. below DL |
| | **Upgradient shallow well G-3378C** | | | | | | |
| Alkalinity (mg/L) | 1 | 202 | 5 | 192-202 | 197 | 197 | 0 |
| pH (units) | 3 | 6.9-7.4 | 1 | 7.4 | | | 0 |
| Specific conductance (µS/cm) | 3 | 464-637 | 5 | 459-521 | 472 | 481 | 0 |
| Kjeldahl nitrogen (mg/L) | 3 | 0.62-1.00 | 5 | 0.30-0.73 | .53 | .53 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | 3 | <0.02-0.04 | 5 | <0.02-0.03 | .02 | .02 | 3 |
| Total organic carbon (mg/L) | 1 | 5.5 | 5 | 2.6-10 | 6.10 | 5.88 | 0 |
| Total phosphorus (mg/L) | 3 | 0.01-0.02 | 5 | <0.02-<0.02 | NM | NM | 5 |
| Chloride (mg/L) | 3 | 23-73 | 5 | 20-43 | 24.0 | 26.6 | 0 |
| Arsenic (µg/L) | 3 | 1-3 | 5 | <1-2 | 1.0 | 1.3 | 2 |
| Cadmium (µg/L) | 3 | <1-1 | 5 | <1-1 | 1.0 | 1.0 | 3 |
| Chromium (µg/L) | 3 | <1-1 | 5 | <1-2 | NM | NM | 4 |
| Copper (µg/L) | 3 | <1-1 | 5 | <1-2 | 1.5 | 1.5 | 1 |
| Iron (µg/L) | 3 | 90-280 | 5 | 260-400 | 360 | 346 | 0 |
| Lead (µg/L) | 3 | <5-2 | 5 | <5-<5 | NM | NM | 5 |
| Magnesium (mg/L) | 3 | 4.5-12 | 5 | 3.8-7.0 | 4.10 | 4.66 | 0 |
| Manganese (µg/L) | 3 | <10-10 | 5 | <10-10 | 10.0 | 10.0 | 3 |
| Mercury (µg/L) | 2 | <0.1-<0.1 | 5 | <0.1-<0.1 | NM | NM | 5 |
| Nickel (µg/L) | 3 | 1-2 | 5 | <1-3 | NM | NM | 4 |
| Potassium (mg/L) | 3 | 2.3-4.9 | 5 | 2.5-5.3 | 3.60 | 3.68 | 0 |
| Sodium (mg/L) | 3 | 13-47 | 5 | 11-35 | 14.0 | 17.2 | 0 |
| Zinc (µg/L) | 3 | <10-10 | 5 | <10-20 | 15.0 | 15.0 | 1 |
| | **Upgradient middepth well G-3378B** | | | | | | |
| Alkalinity (mg/L) | NS | | 5 | 191-198 | 194 | 194 | 0 |
| pH (units) | NS | | 1 | 7.4 | | | 0 |
| Specific conductance (µS/cm) | NS | | 5 | 445-566 | 449 | 472 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 5 | 0.44-0.90 | .58 | .61 | 0 |
| Nitrite + nitrate nitrogen (mg/L ) | NS | | 5 | <0.02-0.02 | NM | NM | 4 |
| Total organic carbon (mg/L) | NS | | 5 | 4.2-24.0 | 5.50 | 10.98 | 0 |
| Total phosphorus (mg/L) | NS | | 5 | <0.02-0.06 | .04 | .04 | 3 |
| Chloride (mg/L) | NS | | 5 | 18-57 | 21.0 | 27.8 | 0 |
| Arsenic (µg/L) | NS | | 5 | <1-1 | NM | NM | 4 |
| Cadmium (µg/L) | NS | | 5 | <1-2 | 1.0 | 1.3 | 2 |
| Chromium (µg/L) | NS | | 5 | <1-3 | NM | NM | 4 |
| Copper (µg/L) | NS | | 5 | <1-3 | 2.0 | 2.3 | 2 |
| Iron (µg/L) | NS | | 5 | 340-490 | 360 | 386 | 0 |
| Lead (µg/L) | NS | | 5 | <5-<5 | NM | NM | 5 |
| Magnesium (mg/L) | NS | | 5 | 3.5-4.4 | 3.50 | 3.70 | 0 |
| Manganese (µg/L) | NS | | 5 | <10-10 | 10.0 | 10.0 | 2 |
| Mercury (µg/L) | NS | | 5 | <0.1-0.3 | NM | NM | 4 |
| Nickel (µg/L) | NS | | 5 | <1-4 | NM | NM | 4 |
| Potassium (mg/L) | NS | | 5 | 2.5-2.9 | 2.70 | 2.70 | 0 |
| Sodium (mg/L) | NS | | 5 | 10-26 | 12.0 | 14.2 | 0 |
| Zinc (µg/L) | NS | | 5 | <10-10 | 10.0 | 10.0 | 2 |
| | **Upgradient deep well G-3378A** | | | | | | |
| Alkalinity (mg/L) | NS | | 5 | 189-200 | 191 | 193 | 0 |
| pH (units) | NS | | 1 | 7.4 | | | 0 |
| Specific conductance (µS/cm) | NS | | 5 | 43-572 | 445 | 479 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 5 | 0.50-0.95 | .56 | .64 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 5 | <0.02-<0.02 | NM | NM | 5 |
| Total organic carbon (mg/L) | NS | | 5 | 4.3-18.0 | 7.00 | 8.16 | 0 |
| Total phosphorus (mg/L) | NS | | 5 | <0.02-<0.02 | NM | NM | 5 |
| Chloride (mg/L) | NS | | 4 | 19-58 | 23.5 | 31.0 | 0 |
| Arsenic (µg/L) | NS | | 5 | <1-<1 | NM | NM | 5 |
| Cadmium (µg/L) | NS | | 5 | <1-<1 | NM | NM | 5 |
| Chromium (µg/L) | NS | | 5 | <1-2 | 2.0 | 2.0 | 3 |
| Copper (µg/L) | NS | | 5 | <1-2 | 1.5 | 1.5 | 1 |
| Iron (µg/L) | NS | | 5 | 290-430 | 380 | 364 | 0 |
| Lead (µg/L) | NS | | 5 | <5-9 | NM | NM | 4 |
| Magnesium (mg/L) | NS | | 5 | 3.7-9.0 | 3.80 | 4.98 | 0 |
| Manganese (µg/L) | NS | | 5 | <10-20 | 10.0 | 12.5 | 1 |
| Mercury (µg/L) | NS | | 5 | <0.1-0.1 | NM | NM | 4 |
| Nickel (µg/L) | NS | | 5 | <1-8 | 4.5 | 4.5 | 3 |
| Potassium (mg/L) | NS | | 5 | 2.4-4.4 | 2.60 | 2.90 | 0 |
| Sodium (mg/L) | NS | | 5 | 12-37 | 13.0 | 18.0 | 0 |
| Zinc (µg/L) | NS | | 5 | <10-30 | 10.0 | 16.7 | 2 |

**Table 4.** *Summary data for ground-water quality from wells at the Rockdale maximum-application field before and after sludge application*–Continued

| Constituent | Presludge No. of samples | Presludge Range | Postsludge No. of samples | Postsludge Range | Median | Mean | No. below DL |
|---|---|---|---|---|---|---|---|
| | | | **Center-field shallow well G-3379C** | | | | |
| Alkalinity (mg/L) | 1 | 222 | 5 | 206-217 | 208 | 210 | 0 |
| pH (units) | 3 | 6.9-7.8 | 1 | 7.2 | | | 0 |
| Specific conductance (μS/m) | 3 | 444-473 | 5 | 477-501 | 489 | 490 | 0 |
| Kjeldahl nitrogen (mg/L) | 3 | 0.44-0.73 | 5 | 0.37-0.70 | .45 | .51 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | 3 | <0.20-<0.20 | 5 | <0.02-0.03 | NM | NM | 4 |
| Total organic carbon (mg/L) | 1 | 4.0 | 5 | 3.6-5.8 | 4.50 | 4.48 | 0 |
| Total phosphorus (mg/L) | 3 | 0.01-0.02 | 5 | <0.02-0.02 | NM | NM | 4 |
| Chloride (mg/L) | 3 | 15-19 | 5 | 18-21 | 20.0 | 19.6 | 0 |
| Arsenic (μg/L) | 3 | <1-1 | 5 | 1-3 | 1.0 | 1.8 | 0 |
| Cadmium (μg/L) | 3 | <1-1 | 5 | <1-2 | NM | NM | 4 |
| Chromium (μg/L) | 3 | <1-<1 | 5 | <1-4 | 2.5 | 2.5 | 3 |
| Copper (μg/L) | 3 | 1-2 | 5 | <1-2 | 2.0 | 1.8 | 1 |
| Iron (μg/L) | 3 | 350-410 | 5 | 310-400 | 350 | 358 | 0 |
| Lead (μg/L) | 3 | <5-1 | 5 | <5-<5 | NM | NM | 5 |
| Magnesium (mg/L) | 3 | 2.7-3.3 | 5 | 3.1-3.3 | 3.20 | 3.18 | 0 |
| Manganese (μg/L) | 3 | <10-20 | 5 | 10-10 | 10.0 | 10.0 | 0 |
| Mercury (μg/L) | 3 | <0.1-0.2 | 5 | <0.1-0.1 | NM | NM | 4 |
| Nickel (μg/L) | 3 | <1-4 | 5 | <1-2 | NM | NM | 4 |
| Potassium (mg/L) | 3 | 1.7-2.5 | 5 | 2.2-3.2 | 2.60 | 2.64 | 0 |
| Sodium (mg/L) | 3 | 9.2-11.0 | 5 | 11-11 | 11.0 | 11.0 | 0 |
| Zinc (μg/L) | 3 | <10-10 | 5 | <10-20 | 10.0 | 12.5 | 1 |
| | | | **Center-field middepth well G-3379B** | | | | |
| Alkalinity (mg/L) | 1 | 202 | 5 | 199-207 | 200 | 201 | 0 |
| pH (units) | 3 | 7.0-7.7 | 1 | 7.3 | | | 0 |
| Specific conductance (μS/cm) | 3 | 442-485 | 5 | 467-488 | 477 | 479 | 0 |
| Kjeldahl nitrogen (mg/L) | 3 | 0.52-0.68 | 5 | 0.50-0.74 | .62 | .62 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | 3 | <0.02-<0.02 | 5 | <0.02-0.50 | NM | NM | 4 |
| Total organic carbon (mg/L) | 1 | 5 | 5 | 4.3-5.3 | 4.80 | 4.80 | 0 |
| Total phosphorus (mg/L) | 3 | 0.01-0.02 | 5 | <0.02-<0.02 | NM | NM | 5 |
| Chloride (mg/L) | 3 | 18-26 | 5 | 19-23 | 22.0 | 21.8 | 0 |
| Arsenic (μg/L) | 3 | <1-2 | 5 | <1-<1 | NM | NM | 5 |
| Cadmium (μg/L) | 3 | <1-1 | 5 | <1-1 | 1.0 | 1.0 | 3 |
| Chromium (μg/L) | 3 | <1-1 | 5 | <1-4 | 2.5 | 2.5 | 3 |
| Copper (μg/L) | 3 | 1-1 | 5 | 1-2 | 2.0 | 1.6 | 0 |
| Iron (μg/L) | 3 | 370-410 | 5 | 360-440 | 420 | 410 | 0 |
| Lead (μg/L) | 3 | <5-3 | 5 | <5-<5 | NM | NM | 5 |
| Magnesium (mg/L) | 3 | 3.2-3.7 | 5 | 3.4-3.6 | 3.50 | 3.50 | 0 |
| Manganese (μg/L) | 3 | <10-10 | 5 | <10-10 | 10.0 | 10.0 | 1 |
| Mercury (μg/L) | 3 | <0.1-0.2 | 5 | <0.1-<0.1 | NM | NM | 5 |
| Nickel (μg/L) | 3 | <1-4 | 5 | <1-4 | NM | NM | 4 |
| Potassium (mg/L) | 3 | 2.2-3.0 | 5 | 2.5-3.4 | 3.00 | 3.00 | 0 |
| Sodium (mg/L) | 3 | 10-16 | 5 | 12-13 | 12.0 | 12.2 | 0 |
| Zinc (μg/L) | 3 | <10-<10 | 5 | <10-20 | 10.0 | 13.3 | 2 |
| | | | **Center-field deep well G-3379A** | | | | |
| Alkalinity (mg/L) | NS | | 5 | 200-203 | 202 | 202 | 0 |
| pH (units) | NS | | 1 | 7.3 | | | 0 |
| Specific conductance (μS/cm) | NS | | 5 | 470-488 | 477 | 478 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 5 | 0.50-0.73 | .65 | .61 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 5 | <0.02-0.38 | NM | NM | 4 |
| Total organic carbon (mg/L) | NS | | 5 | 3.8-5.5 | 5.00 | 4.78 | 0 |
| Total phosphorus (mg/L) | NS | | 5 | <0.02-0.02 | NM | NM | 4 |
| Chloride (mg/L) | NS | | 5 | 20-23 | 22.0 | 21.6 | 0 |
| Arsenic (μS/cm) | NS | | 5 | <1-1 | 1.0 | 1.0 | 3 |
| Cadmium (μg/L) | NS | | 5 | <1-1 | 1.0 | 1.0 | 3 |
| Chromium (μg/L) | NS | | 5 | <1-3 | 1.0 | 1.7 | 2 |
| Copper (μg/L) | NS | | 5 | <1-3 | 1.0 | 1.7 | 2 |
| Iron (μg/L) | NS | | 5 | 430-560 | 440 | 472 | 0 |
| Lead (μg/L) | NS | | 5 | <5-5 | NM | NM | 4 |
| Magnesium (mg/L) | NS | | 5 | 3.4-3.6 | 3.50 | 3.50 | 0 |
| Manganese (μg/L) | NS | | 5 | <10-10 | 10.0 | 10.0 | 1 |
| Mercury (μg/L) | NS | | 5 | <0.1-9.5 | 4.85 | 4.85 | 3 |
| Nickel (μg/L) | NS | | 5 | <1-5 | 3.0 | 3.3 | 2 |
| Potassium (mg/L) | NS | | 5 | 2.3-2.8 | 2.60 | 2.58 | 0 |
| Sodium (mg/L) | NS | | 5 | 11-13 | 12.0 | 12.0 | 0 |
| Zinc (μg/L) | NS | | 5 | <10-10 | 10.0 | 10.0 | 1 |

**Table 4.** *Summary data for ground-water quality from wells at the Rockdale maximum-application field before and after sludge application*--Continued

| Constituent | Presludge | | Postsludge | | | | |
|---|---|---|---|---|---|---|---|
| | No. of samples | Range | No. of samples | Range | Median | Mean | No. below DL |
| **Downgradient shallow well G-3380C** | | | | | | | |
| Alkalinity (mg/L) | 1 | 215 | 4 | 202-210 | 206 | 206 | 0 |
| pH (units) | 3 | 6.7-7.3 | 1 | 7.3 | | | 0 |
| Specific conductance (μS/cm) | 3 | 460-476 | 5 | 472-494 | 489 | 484 | 0 |
| Kjeldahl nitrogen (mg/L) | 3 | 0.61-0.66 | 5 | 0.48-0.73 | .55 | .58 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | 3 | <0.02-0.01 | 5 | <0.02-<0.02 | NM | NM | 5 |
| Total organic carbon (mg/L) | 1 | 4.5 | 5 | 3.6-12 | 4.50 | 6.20 | 0 |
| Total phosphorus (mg/L) | 3 | 0.01-0.02 | 5 | <0.02-<0.02 | NM | NM | 5 |
| Chloride (mg/L) | 3 | 15-19 | 5 | 18-22 | 19.0 | 19.4 | 0 |
| Arsenic (μg/L) | 3 | <1-2 | 5 | <1-1 | 1.0 | 1.0 | 3 |
| Cadmium (μg/L) | 3 | <1-1 | 5 | <1-3 | 1.0 | 1.5 | 1 |
| Chromium (μg/L) | 3 | <1-<1 | 5 | <1-4 | 2.0 | 2.3 | 2 |
| Copper (μg/L) | 3 | 1-1 | 5 | 1-9 | 2.0 | 3.0 | 0 |
| Iron (μg/L) | 3 | 380-460 | 5 | 380-1,000 | 440 | 550 | 0 |
| Lead (μg/L) | 3 | <5-6 | 5 | <5-20 | NM | NM | 4 |
| Magnesium (mg/L) | 3 | 2.7-3.2 | 5 | 2.9-3.7 | 3.20 | 3.24 | 0 |
| Manganese (μg/L) | 3 | <10-20 | 5 | <10-20 | 10.0 | 12.5 | 1 |
| Mercury (μg/L) | 3 | <0.1-0.4 | 5 | <0.1-<0.1 | NM | NM | 5 |
| Nickel (μg/L) | 3 | 1-1 | 5 | <1-3 | 2.0 | 2.0 | 3 |
| Potassium (mg/L) | 3 | 1.8-2.3 | 5 | 2.0-2.7 | 2.40 | 2.34 | 0 |
| Sodium (mg/L) | 3 | 9.3-11.0 | 5 | 10-12 | 11.0 | 11.0 | 0 |
| Zinc (μg/L) | 3 | <10-10 | 5 | <10-10 | 10.0 | 10.0 | 2 |
| **Downgradient middepth well G-3380B** | | | | | | | |
| Alkalinity (mg/L) | NS | | 5 | 200-207 | 205 | 204 | 0 |
| pH (units) | NS | | 2 | 7.0-7.3 | | | 0 |
| Specific conductance (μS/cm) | NS | | 5 | 474-526 | 485 | 492 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 5 | 0.58-0.80 | .72 | .70 | 0 |
| Nitrite + nitrate nitoogen (mg/L) | NS | | 5 | <0.02-<0.02 | NM | NM | 5 |
| Total organic carbon (mg/L) | NS | | 5 | 3.3-5.8 | 4.80 | 4.74 | 0 |
| Total phosphorus (mg/L) | NS | | 5 | <0.02-<0.02 | NM | NM | 5 |
| Chloride (mg/L) | NS | | 5 | 19-24 | 22.0 | 21.8 | 0 |
| Arsenic (μg/L) | NS | | 5 | <1-<1 | NM | NM | 5 |
| Cadmium (μg/L) | NS | | 5 | <1-1 | NM | NM | 4 |
| Chromium (μg/L) | NS | | 5 | <1-5 | 3.5 | 3.5 | 3 |
| Copper (μg/L) | NS | | 5 | <1-2 | 1.5 | 1.5 | 3 |
| Iron (μg/L) | NS | | 5 | 350-430 | 420 | 398 | 0 |
| Lead (μg/L) | NS | | 5 | <5-<5 | NM | NM | 5 |
| Magnesium (mg/L) | NS | | 5 | 3.3-3.6 | 3.40 | 3.42 | 0 |
| Manganese (μg/L) | NS | | 5 | <10-10 | 10.0 | 10.0 | 2 |
| Mercury (μg/L) | NS | | 5 | <0.1-0.1 | NM | NM | 4 |
| Nickel (μg/L) | NS | | 5 | <1-3 | 3.0 | 2.3 | 2 |
| Potassium (mg/L) | NS | | 5 | 2.0-3.0 | 2.60 | 2.52 | 0 |
| Sodium (mg/L) | NS | | 5 | 12-13 | 12.0 | 12.2 | 0 |
| Zinc (μg/L) | NS | | 5 | <10-10 | 10.0 | 10.0 | 1 |
| **Downgradient deep well G-3380A** | | | | | | | |
| Alkalinity (mg/L) | NS | | 3 | 200-206 | 205 | 204 | 0 |
| pH (units) | NS | | 2 | 7.3-7.4 | | | 0 |
| Specific conductance (μS/cm) | NS | | 3 | 474-488 | 477 | 480 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 3 | 0.72-0.77 | .74 | .74 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 3 | <0.02-<0.02 | NM | NM | 3 |
| Total organic carbon (mg/L) | NS | | 3 | 4.5-5.5 | 5.00 | 5.00 | 0 |
| Total phosphorus (mg/L) | NS | | 3 | <0.02-<0.02 | NM | NM | 3 |
| Chloride (mg/L) | NS | | 3 | 20-22 | 21.0 | 21.0 | 0 |
| Arsenic (μg/L) | NS | | 3 | <1-<1 | NM | NM | 3 |
| Cadmium (μg/L) | NS | | 3 | <1-1 | 1.0 | 1.0 | 1 |
| Chromium (μg/L) | NS | | 3 | <1-4 | NM | NM | 2 |
| Copper (μg/L) | NS | | 3 | 1-3 | 2.0 | 2.0 | 0 |
| Iron (μg/L) | NS | | 3 | 380-440 | 420 | 413 | 0 |
| Lead (μg/L) | NS | | 3 | <5-<5 | NM | NM | 3 |
| Magnesium (mg/L) | NS | | 3 | 3.3-3.5 | 3.40 | 3.40 | 0 |
| Manganese (μg/L) | NS | | 3 | <10-20 | 15.0 | 15.0 | 1 |
| Mercury (μg/L) | NS | | 3 | <0.1-<0.1 | NM | NM | 3 |
| Nickel (μg/L) | NS | | 3 | <1-3 | NM | NM | 2 |
| Potassium (mg/L) | NS | | 3 | 1.5-2.2 | 1.80 | 1.83 | 0 |
| Sodium (mg/L) | NS | | 3 | 12-13 | 12.0 | 12.3 | 0 |
| Zinc (μg/L) | NS | | 3 | <10-10 | 10.0 | 10.0 | 1 |

Three of five center-field samples had higher concentrations of copper (2, 1, 2, 2, and 1 µg/L) than the downgradient samples (less than 1, 1, 2, less than 1, and less than 1 µg/L). The differences are so small that they have no real importance in terms of the application of sludge. The high concentration of potassium beneath the center of the field reflects the pattern of occurrence observed in shallow ground water, which was evident in the February sample before sludge was applied.

## Rockdale Grove

Sludge was spread beneath the grove's tree canopy three times annually, beginning on February 24, 1986, at the rate of 2 tons/acre for each application. Initial water-quality samples were collected March 27, 1986, after 0.14 in. of rainfall. Subsequent samples were collected according to schedule on May 27, 1986, August 19, 1986, November 7, 1986, February 9, 1987, May 20, 1987, and August 19, 1987. The upgradient middepth well was destroyed soon after installation. Problems occurred in taking the drill rig between rows of trees a second time, and it was not replaced; therefore, this well was never sampled. The Rockdale grove was operated normally during the study and had chemical loading from fertilizers, minor nutrients, and pesticides in addition to the loading from sludge. This loading is summarized in the following table (Norman Sutton, Grove Manager, oral commun., 1985):

| Compound | Quantity per acre per year (lb) | Annual loading (lb) |
|---|---|---|
| Copper sulfate | 60 | 1,800 |
| Wetable sulfur | 45-60 | 1,350-1,800 |
| Manganese | 20 | 600 |
| Zinc | 20 | 600 |
| Fertilizer (12-2-12) | 3,200 | 96,000 |
| Nitrogen | 384 | 11,520 |
| Potassium | 53 | 1,590 |
| Phosphate | 169 | 5,070 |
| Sevin (Carbaryl) | 5-12 | 150-360 |

These constituents and some constituents of the applied sludge are used as nutrients by the avocado trees and, to a lesser extent, by weeds.

### Comparison of Water Quality Before and After Sludge Application

The shallow wells upgradient of, within, and downgradient of the field and the center-field middepth and deep wells were sampled before sludge was applied. Wells at all depths and areas of the field were sampled after sludge was applied. The summary data for each well are listed in table 5, which gives the concentration range for each constituent in samples collected before sludge was applied and the concentration range, median, and mean in samples collected after sludge was applied.

Presludge and postsludge measurements and concentrations for samples from the shallow wells were examined before any formal analysis of the data as described in "Data-Interpretation Techniques." There were frequent changes occurring over time at this grove; however, they reflected changes that also occurred in inflow (upgradient ground water). DOC, which was sampled in the shallow center-field well when organic compounds were sampled, was an order of magnitude lower in the three postsludge samples than in the two presludge samples.

### Statistical Interpretation of Water-Quality Data

The WSRT was used to examine changes in the quality of ground water flowing into, beneath, and from the grove. Those tests that indicated a statistically significant difference (0.05 significance level) are listed in appendix II. Most differences were the result of preexisting trends (or of one or two higher concentrations) and are not related to sludge application as was explained in "Data-Interpretation Techniques." Differences not explained by these factors were found for the following constituents (dashes indicate the upgradient well was destroyed soon after drilling; none indicates that constituents are either not significantly different or significantly different but explained by preexisting trends or high concentrations).

| Well depth | Areas compared: Upgradient to center | Upgradient to downgradient | Center to downgradient |
|---|---|---|---|
| Shallow | None | Zinc<br>Mercury | Chloride<br>Zinc<br>Mercury |
| Middepth | -- | -- | Chloride |
| Deep | Iron | None | Nitrite + nitrate nitrogen<br>Sodium |

**Table 5.** *Summary data for ground-water quality from wells at the Rockdale grove before and after sludge application*

[Samples below the detection limit (DL) are not included in the mean and median calculations. If a constituent was not detected in a sample, the constituent is reported as less than (<) the detection limit (for example, <100). When the presludge and postsludge detection limits are different, it is because other constituents in a sample may interfere with an analysis, necessitating the use of alternative methods of analysis with higher or lower detection limits. The analytical methods for some constituents (Kjeldhal nitrogen, nitrite + nitrate nitrogen, total phosphorus, and lead) and, therefore, there detection limits were changed permanently duiring the period of study. Abbreviations: mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NM, statistic has "no meaning" given number of detections (median and mean do not apply for pH); NS, no samplings were made]

| Constituent | Presludge | | Postsludge | | | | |
|---|---|---|---|---|---|---|---|
| | No. of samples | Range | No. of samples | Range | Median | Mean | No. below DL |
| | | | **Upgradient shallow well G-3381C** | | | | |
| Alkalinity (mg/L) | 0 | NM | 5 | 176-219 | 211 | 205 | 0 |
| pH (units) | 2 | 6.9-7.2 | 5 | 7.3-7.5 | | | 0 |
| Specific conductance (µS/cm) | 2 | 649-676 | 8 | 580-667 | 644 | 640 | 0 |
| Kjeldahl nitrogen (mg/L) | 2 | 0.08-0.29 | 8 | <0.20-0.25 | .23 | .23 | 3 |
| Nitrite + nitrate nitrogen (mg/L) | 2 | 5.5-6.0 | 8 | 3.3-5.0 | 3.85 | 3.99 | 0 |
| Total organic carbon (mg/L) | 0 | NM | 6 | 1.5-2.0 | 2.00 | 1.88 | 0 |
| Total phosphorus (mg/L) | 2 | 0.01-0.02 | 8 | <0.02-0.02 | .01 | .01 | 3 |
| Chloride (mg/L) | 2 | 37-37 | 8 | 37-51 | 43.5 | 43.0 | 0 |
| Arsenic (µg/L) | 2 | 1-1 | 8 | <1-<1 | NM | NM | 8 |
| Cadmium (µg/L) | 2 | <1-1 | 8 | <1-1 | NM | NM | 7 |
| Chromium (µg/L) | 2 | <1-<1 | 8 | <1-4 | 1.0 | 2.0 | 5 |
| Copper (µg/L) | 2 | 1-2 | 8 | <1-3 | 2.0 | 2.0 | 1 |
| Iron (µg/L) | 2 | 20-60 | 8 | <10-100 | 50.0 | 55.0 | 2 |
| Lead (µg/L) | 2 | <5-6 | 8 | <5-<5 | NM | NM | 8 |
| Magnesium (mg/L) | 2 | 3.5-4.1 | 8 | 3.1-3.4 | 3.25 | 3.22 | 0 |
| Manganese (µg/L) | 2 | 10-10 | 8 | <10-20 | 20.0 | 16.7 | 5 |
| Mercury (µg/L) | 2 | <0.1-0.2 | 8 | <0.1-2.3 | 1.05 | 1.12 | 4 |
| Nickel (µg/L) | 2 | 1-3 | 8 | <1-8 | 2.0 | 3.0 | 3 |
| Potassium (mg/L) | 2 | 9.4-9.4 | 8 | 7.2-8.7 | 7.70 | 7.87 | 0 |
| Sodium (mg/L) | 2 | 19-19 | 8 | 21-28 | 24.5 | 24.4 | 0 |
| Zinc (µg/L) | 2 | <10-10 | 8 | <10-60 | 15.0 | 25.0 | 4 |
| | | | **Upgradient deep well G-3381A** | | | | |
| Alkalinity (mg/L) | NS | | 5 | 204-216 | 210 | 210.0 | 0 |
| pH (units) | NS | | 5 | 7.3-7.7 | | | 0 |
| Specific conductance (µS/cm) | NS | | 8 | 626-661 | 642 | 644 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 8 | <0.2-0.34 | .31 | .28 | 4 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 8 | 3.40-5.00 | 3.90 | 4.00 | 0 |
| Total organic carbon (mg/L) | NS | | 6 | 1.5-3.0 | 2.00 | 2.02 | 0 |
| Total phosphorus (mg/L) | NS | | 8 | <0.01-0.03 | .01 | .02 | 2 |
| Chloride (mg/L) | NS | | 8 | 36-51 | 44.5 | 43.1 | 0 |
| Arsenic (µg/L) | NS | | 8 | <1-<1 | NM | NM | 8 |
| Cadmium (µg/L) | NS | | 8 | <1-2 | 1.5 | 1.5 | 6 |
| Chromium (µg/L | NS | | 8 | <1-4 | 4.0 | 3.0 | 5 |
| Copper (µg/L) | NS | | 8 | 1-4 | 2.0 | 2.0 | 0 |
| Iron (µg/L) | NS | | 8 | 20-180 | 40.0 | 77.5 | 0 |
| Lead (µg/L) | NS | | 8 | <5-<5 | NM | NM | 8 |
| Magnesium (mg/L) | NS | | 8 | 3.1-3.4 | 3.25 | 3.24 | 0 |
| Manganese (µg/L) | NS | | 8 | <10-20 | 20.0 | 16.7 | 5 |
| Mercury (µg/L) | NS | | 7 | <0.1-1.4 | .55 | .65 | 3 |
| Nickel (µg/L) | NS | | 8 | <1-3 | 1.5 | 1.8 | 4 |
| Potassium (mg/L) | NS | | 8 | 7.3-8.8 | 7.85 | 7.95 | 0 |
| Sodium (mg/L) | NS | | 8 | 21-29 | 24.0 | 24.3 | 0 |
| Zinc (µg/L) | NS | | 8 | <10-20 | 10.0 | 12.5 | 4 |

**Table 5.** *Summary data for ground-water quality from wells at the Rockdale grove before and after sludge application*–Continued

| Constituent | Presludge No. of samples | Presludge Range | Postsludge No. of samples | Postsludge Range | Postsludge Median | Postsludge Mean | Postsludge No. below DL |
|---|---|---|---|---|---|---|---|
| **Center-field shallow well G-3382C** | | | | | | | |
| Alkalinity (mg/L) | 0 | NM | 5 | 200-217 | 212 | 210 | 0 |
| pH (units) | 2 | 7.0-7.2 | 4 | 7.2-7.3 | | | 0 |
| Specific conductance (μS/cm) | 2 | 639-701 | 7 | 644-664 | 655 | 654 | 0 |
| Kjeldahl nitrogen (mg/L) | 2 | 0.2-0.3 | 7 | <0.20-0.28 | .25 | .25 | 3 |
| Nitrite + nitrate nitrogen (mg/L) | 2 | 5.4-10.0 | 7 | 3.7-5.9 | 4.20 | 4.39 | 0 |
| Total organic carbon (mg/L) | 0 | NM | 5 | 1.5-3.0 | 2.00 | 2.20 | 0 |
| Total phosphorus (mg/L) | 2 | 0.01-0.02 | 7 | <0.01-0.02 | .01 | .01 | 4 |
| Chloride (mg/L) | 2 | 33-34 | 7 | 36-50 | 41.0 | 41.9 | 0 |
| Arsenic (μg/L) | 2 | <1-1 | 7 | <1-<1 | NM | NM | 7 |
| Cadmium (μg/L) | 2 | <1-1 | 7 | <1-1 | 1.0 | 1.0 | 5 |
| Chromium (μg/L) | 2 | <1-<1 | 7 | <1-5 | 3.0 | 3.0 | 3 |
| Copper (μg/L) | 2 | 2-2 | 7 | <1-7 | 2.5 | 3.0 | 1 |
| Iron (μg/L) | 2 | 70-70 | 7 | <10-100 | 35.0 | 45.0 | 1 |
| Lead (μg/L) | 2 | <1-1 | 7 | <5-3 | NM | NM | 6 |
| Magnesium (mg/L) | 2 | 3.6-4.1 | 7 | 3.2-3.5 | 3.40 | 3.36 | 0 |
| Manganese (μg/L) | 2 | <10-10 | 7 | <10-10 | 10.0 | 10.0 | 4 |
| Mercury (μg/L) | 2 | 0.1-0.3 | 7 | <0.1-1.2 | .45 | .57 | 3 |
| Nickel (μg/L) | 2 | 1-2 | 7 | <1-3 | 1.0 | 1.6 | 2 |
| Potassium (mg/L) | 2 | 9.6-13.0 | 7 | 7.5-9.1 | 8.20 | 8.21 | 0 |
| Sodium (mg/L) | 2 | 17-18 | 7 | 20-26 | 23.0 | 23.1 | 0 |
| Zinc (μg/L) | 2 | <10-10 | 7 | <10-40 | 10.0 | 20.0 | 4 |
| **Center-field middepth well G-3382B** | | | | | | | |
| Alkalinity (mg/L) | 0 | NM | 5 | 199-209 | 203 | 204 | 0 |
| pH (units) | 2 | 6.9-7.4 | 4 | 7.26-7.40 | | | 0 |
| Specific conductance (μS/cm) | 2 | 619-631 | 7 | 633-656 | 644 | 643 | 0 |
| Kjeldahl nitrogen (mg/L) | 2 | <0.05-0.52 | 7 | <0.20-0.24 | .21 | .21 | 3 |
| Nitrite + nitrate nitrogen (mg/L) | 2 | 5.4-5.4 | 7 | 3.8-5.6 | 4.20 | 4.39 | 0 |
| Total organic carbon (mg/L) | 0 | NM | 6 | 1.5-5.5 | 1.75 | 2.33 | 0 |
| Total phosphorus (mg/L) | 2 | 0.01-0.02 | 7 | <0.01-0.02 | .01 | .01 | 4 |
| Chloride (mg/L) | 2 | 35-35 | 7 | 36-49 | 42.0 | 41.9 | 0 |
| Arsenic (μg/L) | 2 | 1.0-1.0 | 7 | <1-<1 | NM | NM | 7 |
| Cadmium (μg/L) | 2 | <1-1 | 6 | <1-2 | NM | NM | 5 |
| Chromium (μg/L) | 2 | <1-1 | 6 | <1-5 | 2.0 | 2.4 | 1 |
| Copper (μg/L) | 2 | 1-2 | 6 | 1-7 | 2.5 | 3.0 | 0 |
| Iron (μg/L) | 2 | 20-60 | 6 | <10-70 | 20.0 | 30.0 | 1 |
| Lead (μg/L) | 2 | <5-9 | 6 | <5-<5 | NM | NM | 6 |
| Magnesium (mg/L) | 2 | 3.1-3.5 | 7 | 3.1-3.4 | 3.20 | 3.21 | 0 |
| Manganese (μg/L) | 2 | <10-10 | 6 | <10-20 | 15.0 | 15.0 | 4 |
| Mercury (μg/L) | 2 | <0.1-0.3 | 7 | <0.1-0.8 | .60 | .60 | 5 |
| Nickel (μg/L) | 2 | 2-3 | 6 | <1-14 | 2.5 | 5.0 | 2 |
| Potassium (mg/L) | 2 | 8.6-9.4 | 7 | 7.7-9.0 | 8.20 | 8.13 | 0 |
| Sodium (mg/L) | 2 | 18-19 | 7 | 20-25 | 22.0 | 22.7 | 0 |
| Zinc (μg/L) | 2 | <10-10 | 6 | <10-20 | 15.0 | 15.0 | 4 |
| **Center-field deep well G-3382A** | | | | | | | |
| Alkalinity (mg/L) | 0 | NM | 5 | 207-213 | 207 | 209 | 0 |
| pH (units) | 1 | 7.2 | 4 | 7.25-7.31 | | | 0 |
| Specific conductance (μS/cm) | 1 | 646 | 7 | 626-659 | 649 | 649 | 0 |
| Kjeldahl nitrogen (mg/L) | 1 | .08 | 7 | <0.2-1.90 | .23 | .65 | 3 |
| Nitrite + nitrate nitrogen (mg/L) | 1 | 5.4 | 7 | 3.8-5.6 | 4.20 | 4.40 | 0 |
| Total organic carbon (mg/L) | 0 | NM | 6 | 1.5-4.0 | 1.90 | 2.30 | 0 |
| Total phosphorus (mg/L) | 1 | .02 | 7 | <0.01-0.02 | .01 | .01 | 4 |
| Chloride (mg/L) | 1 | 35 | 7 | 37-49 | 40.0 | 41.7 | 0 |
| Arsenic (μg/L) | 1 | 2 | 7 | <1-<1 | NM | NM | 7 |
| Cadmium (μg/L) | 1 | 1 | 7 | <1-4 | NM | NM | 6 |
| Chromium (μg/L) | 1 | <1 | 7 | <1-1 | 1.0 | 1.0 | 4 |
| Copper (μg/L) | 1 | 1 | 7 | <1-2 | 2.0 | 1.7 | 1 |
| Iron (μg/L) | 1 | 30 | 7 | <10-100 | 20.0 | 36.0 | 2 |
| Lead (μg/L) | 1 | 6 | 7 | <1-<5 | NM | NM | 7 |
| Magnesium (mg/L) | 1 | 3.5 | 7 | 3.1-3.4 | 3.30 | 3.29 | 0 |
| Manganese (μg/L) | 1 | 10 | 7 | <10-20 | 20.0 | 16.7 | 4 |
| Mercury (μg/L) | 1 | .10 | 7 | <0.1-0.6 | .20 | .30 | 4 |
| Nickel (μg/L) | 1 | 2 | 7 | <1-1 | 1.0 | 1.0 | 5 |
| Potassium (mg/L) | 1 | 9.3 | 7 | 7.6-9.0 | 8.10 | 8.13 | 0 |
| Sodium (mg/L) | 1 | 19 | 7 | 20-25 | 22.0 | 22.7 | 0 |
| Zinc (μg/L) | 1 | <10 | 7 | <10-20 | 15.0 | 15.0 | 5 |

**Table 5.** *Summary data for ground-water quality from wells at the Rockdale grove before and after sludge application*--Continued

| Constituent | Presludge | | Postsludge | | | | |
|---|---|---|---|---|---|---|---|
| | No. of samples | Range | No. of samples | Range | Median | Mean | No. below DL |
| | | | **Downgradient shallow well G-3383C** | | | | |
| Alkalinity (mg/L) | 0 | 226-236 | 5 | 194-222 | 213 | 210 | 0 |
| pH (units) | 2 | 6.8-7.3 | 4 | 7.2-7.3 | | | 0 |
| Specific conductance (µS/cm) | 2 | 660-694 | 7 | 625-678 | 674 | 659 | 0 |
| Kjeldahl nitrogen (mg/L) | 2 | 0.08-0.28 | 7 | <0.20-0.40 | .23 | .26 | 2 |
| Nitrite + nitrate nitrogen (mg/L) | 2 | 6.0-7.3 | 7 | 3.6-6.5 | 5.10 | 4.86 | 0 |
| Total organic carbon (mg/L) | 0 | NM | 6 | 1.0-3.0 | 2.00 | 1.92 | 0 |
| Total phosphorus (mg/L) | 2 | 0.01-0.02 | 7 | <0.01-0.04 | .01 | .02 | 3 |
| Chloride (mg/L) | 2 | 33-37 | 7 | 35-48 | 40.0 | 40.7 | 0 |
| Arsenic (µg/L) | 2 | 1-1 | 7 | <1-<1 | NM | NM | 7 |
| Cadmium (µg/L) | 2 | 1-1 | 7 | <1-<1 | NM | NM | 7 |
| Chromium (µg/L) | 2 | <1-<1 | 7 | <1-6 | 2.0 | 3.3 | 4 |
| Copper (µg/L) | 2 | 3-3 | 7 | <1-3 | 3.0 | 2.7 | 1 |
| Iron (µg/L) | 2 | 30-80 | 7 | <10-140 | 25.0 | 45.0 | 1 |
| Lead (µg/L) | 2 | <1-1 | 7 | <5-2 | NM | NM | 6 |
| Magnesium (mg/L) | 2 | 3.8-4.2 | 7 | 3.3-3.8 | 3.70 | 3.60 | 0 |
| Manganese (µg/L) | 2 | 10-10 | 7 | <10-10 | NM | NM | 5 |
| Mercury (µg/L) | 2 | <0.1-0.4 | 7 | <0.1-<0.1 | NM | NM | 7 |
| Nickel (µg/L) | 2 | 3-3 | 7 | <1-4 | 1.0 | 1.8 | 2 |
| Potassium (mg/L) | 2 | 10-10 | 7 | 7.9-10.0 | 9.00 | 8.76 | 0 |
| Sodium (mg/L) | 2 | 17-18 | 7 | 19-25 | 22.0 | 21.9 | 0 |
| Zinc (µg/L) | 2 | <10-<10 | 7 | <10-10 | 10.0 | 10.0 | 5 |
| | | | **Downgradient middepth well G-3383B** | | | | |
| Alkalinity (mg/L) | NS | | 5 | 197-215 | 210 | 209 | 0 |
| pH (units) | NS | | 4 | 7.26-7.40 | | | 0 |
| Specific conductance (µS/cm) | NS | | 7 | 646-660 | 654 | 655 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 7 | 0.20-0.62 | .25 | .32 | 2 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 7 | 3.4-5.7 | 4.30 | 4.27 | 0 |
| Total organic carbon (mg/L) | NS | | 6 | 1.5-5.5 | 2.15 | 2.60 | 0 |
| Total phosphorus (mg/L) | NS | | 7 | < 0.01-0.01 | .01 | .01 | 4 |
| Chloride (mg/L) | NS | | 7 | 36-49 | 40.0 | 41.3 | 0 |
| Arsenic (µg/L) | NS | | 7 | <1-<1 | NM | NM | 7 |
| Cadmium (µg/L) | NS | | 7 | <1-2 | 1.0 | 1.3 | 4 |
| Chromium (µg/L) | NS | | 7 | <1-4 | 3.0 | 2.8 | 3 |
| Copper (µg/L) | NS | | 7 | 1-4 | 2.0 | 2.3 | 0 |
| Iron (µg/L) | NS | | 7 | <10-140 | 30.0 | 45.0 | 1 |
| Lead (µg/L) | NS | | 7 | <1-20 | NM | NM | 6 |
| Magnesium (mg/L) | NS | | 7 | 3.2-3.6 | 3.40 | 3.40 | 0 |
| Manganese (µg/L) | NS | | 7 | <10-20 | 10.0 | 13.3 | 4 |
| Mercury (µg/L) | NS | | 7 | <0.1-0.5 | .50 | .50 | 5 |
| Nickel (µg/L) | NS | | 7 | <1-3 | 1.0 | 1.7 | 4 |
| Potassium (mg/L) | NS | | 7 | 7.7-9.4 | 8.30 | 8.36 | 0 |
| Sodium (mg/L) | NS | | 7 | 20-26 | 22.0 | 22.9 | 0 |
| Zinc (µg/L) | NS | | 7 | <10-10 | 10.0 | 10.0 | 3 |
| | | | **Downgradient deep well G-3383A** | | | | |
| Alkalinity (mg/L) | NS | | 5 | 195-212 | 207 | 204 | 0 |
| pH (units) | NS | | 4 | 7.25-7.36 | | | 0 |
| Specific conductance (µS/cm) | NS | | 7 | 625-654 | 646 | 643 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 7 | 0.20-0.40 | .22 | .26 | 2 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 7 | 3.3-5.2 | 3.90 | 4.01 | 0 |
| Total organic carbon (mg/L) | NS | | 6 | 1.0-2.0 | 1.25 | 1.42 | 0 |
| Total phosphorus (mg/L) | NS | | 7 | <0.01-0.02 | .01 | .02 | 3 |
| Chloride (mg/L) | NS | | 7 | 36-50 | 42.0 | 42.1 | 0 |
| Arsenic (µg/L) | NS | | 7 | <1-<1 | NM | NM | 7 |
| Cadmium (µg/L) | NS | | 7 | <1-<1 | NM | NM | 7 |
| Chromium (µg/L) | NS | | 7 | <1-5 | 3.5 | 3.5 | 5 |
| Copper (µg/L) | NS | | 7 | <1-4 | 2.0 | 2.0 | 1 |
| Iron (µg/L) | NS | | 7 | <10-110 | 25.0 | 36.7 | 1 |
| Lead (µg/L) | NS | | 7 | <1-<5 | NM | NM | 7 |
| Magnesium (mg/L) | NS | | 7 | 3.2-3.5 | 3.30 | 3.30 | 0 |
| Manganese (µg/L) | NS | | 7 | <10-10 | 10.0 | 10.0 | 5 |
| Mercury (µg/L) | NS | | 7 | <0.1-0.5 | .30 | .30 | 4 |
| Nickel (µg/L) | NS | | 7 | <1-4 | 1.5 | 2.0 | 3 |
| Potassium (mg/L) | NS | | 7 | 7.5-11.0 | 8.10 | 8.50 | 0 |
| Sodium (mg/L) | NS | | 7 | 20-26 | 23.0 | 23.4 | 0 |
| Zinc (µg/L) | NS | | 7 | <10-10 | 10.0 | 10.0 | 5 |

In the shallow wells, zinc and mercury concentrations were lower in outflow than in inflow or underflow. Zinc concentrations were 20 and 60 μg/L in the upgradient well on days when they were 10 μg/L and less than 10 μg/L in the downgradient well, and zinc was found in the center-field well at 40 μg/L on a day when it was less than 10 μg/L in the downgradient well. Concentrations were the same in all wells for the other five samples. Zinc concentrations of 20, 40, and 60 μg/L were higher than the maximum concentration found in presludge samples for this grove (10 μg/L). Concentrations were also high compared to the maximum concentration for the agricultural area found by Howie (1986) in the first year of this study (30 μg/L) and in background wells (60 μg/L) sampled by Waller (1983, p. 14). Mercury was found in the upgradient shallow well at concentrations of 0.2, 0.1, and 2.3 μg/L in three successive samples, and it was found in the center-field shallow well at concentrations of 0.3, 0.6, and 0.2 μg/L. There were no other detections of mercury in the three shallow wells. The concentration of 2.3 μg/L exceeds the maximum contaminant level (MCL) for mercury, and 0.6 μg/L is slightly higher than the concentrations found by Howie (1986) (less than 0.1 to 0.5 μg/L) or the concentration found by Waller (1983, p. 14) in background wells (0.5 μg/L). The fact that high zinc and mercury concentrations were found in inflow (upgradient) suggests the high concentrations are from a source other than sludge.

For both shallow and middepth well samples, chloride concentrations were higher in the center-field wells than in the downgradient wells. The maximum difference for wells at both depths was 2 mg/L, and chloride in the shallow wells tended to decrease from upgradient to downgradient so the difference probably is due to natural variation.

For deep wells, iron was lower for underflow than for inflow, nitrite plus nitrate nitrogen was higher for underflow than for outflow, and sodium was lower for underflow than for outflow. The differences in iron probably reflect the natural variability of iron in south Florida ground water, and the differences in sodium were only 1 mg/L. Neither of these test results seems to be sludge related. All of the postsludge samples for nitrite plus nitrate nitrogen in the center-field well had higher concentrations than the downgradient well by differences of 0.1 to 0.6 mg/L. There was no evidence of nitrite plus nitrate nitrogen leaching from the sludge in the shallow wells (in fact, it decreased in all three wells), and this is an active grove to which fertilizer has been applied for many years so this test result probably is an effect of loading other than sludge.

## Perrine Marl Maximum-Application Field

Sludge was applied to the Perrine marl maximum-application field on May 2, 1986. Twelve tons/acre were applied instead of 6 tons/acre because of a delivery error. The first ground-water samples were collected May 29, 1986, after a 0.8-in. rainfall, and subsequent samples were collected according to schedule on August 20, 1986, November 6, 1986, February 17, 1987, May 18, 1987, and August 17, 1987. There was no other chemical loading to this field during the study, except for atmospheric deposition (unquantified) and ground-water inflow.

### Comparison of Water Quality Before and After Sludge Application

The shallow wells upgradient of, within, and downgradient of the field and the middepth well in the center of the field were sampled before sludge was applied. (There was a variable shallow ground-water gradient at this field during the period of study, so the terms upgradient and downgradient refer to regional flow and do not necessarily represent conditions at the water table.) Wells at all depths and areas of the field were sampled after sludge was applied. The summary data for each well are listed in table 6, which gives the concentration range for each constituent in samples collected before sludge was applied and the concentration range, mean, and median for samples collected after sludge was applied. The sample for the upgradient shallow well collected February 17, 1987, was less brackish than other samples from this well, a result not observed in the other shallow wells.

Presludge and postsludge measurements and concentrations were examined for the shallow-well depth prior to statistical analysis as previously described in "Data-Interpretation Techniques." Postsludge samples from beneath the center of the field often had higher Kjeldahl nitrogen concentrations, a trend also observed in the upgradient well. Sodium concentrations were often higher and alkalinity concentrations were lower after sludge application but neither indicated a trend with time. Iron concentrations increased during the postsludge application period (from 550-1,200 μg/L before sludge to 860-1,600 μg/L after sludge). Iron concentrations varied widely before and after sludge application at this field.

### Statistical Interpretation of Water-Quality Data

The WSRT was used to examine differences in the quality of ground water beneath the field and outside the field. Those tests that indicate statistically significant differences (0.05 significant level) in water-quality constituents between areas of the field are given in appendix II. Most differences in water quality can be attributed to trends that existed before sludge was applied or to one or two higher concentrations as discussed in "Data-Interpretation Techniques." The tests for this site were also affected by a preexisting decrease in the brackishness of ground water from upgradient to downgradient, which influenced the measurement of specific conductance and concentrations of sodium, chloride, potassium, magnesium, and sulfate. These constituents were also higher in the center-field middepth

**Table 6.** *Summary data for ground-water quality from wells at the Perrine marl maximum-application field before and after sludge application*

[Samples below the detection limit (DL) are not included in the mean and median calculations. If a constituent was not detected in a sample, the constituent is reported as less than (<) the detection limit (for example, <100). When the presludge and postsludge detection limits are different, it is because other constituents in a sample may interfere with an analysis, necessitating the use of alternative methods of analysis with higher or lower detection limits. The analytical methods for some constituents (Kjeldhal nitrogen, nitrite + nitrate nitrogen, total phosphorus, and lead) and, therefore, their detection limits were changed permanently during the period of study. Abbreviations: mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NM, statistic has "no meaning" given number of detections (median and mean do not apply for pH); NS, no samplings were made]

| Constituent | Presludge | | Postsludge | | | | |
|---|---|---|---|---|---|---|---|
| | No. of samples | Range | No. of samples | Range | Median | Mean | No. below DL |
| **Upgradient shallow well G-3384C** | | | | | | | |
| Alkalinity (mg/L) | 1 | 312 | 5 | 223-325 | 253 | 273 | 0 |
| pH (units) | 2 | 7.0-7.1 | 6 | 6.8-7.4 | | | 0 |
| Specific conductance (µS/cm) | 2 | 3,180-3,450 | 6 | 2,080-4,460 | 3,330 | 3,235 | 0 |
| Kjeldahl nitrogen (mg/L) | 2 | 1.7-2.6 | 6 | 1.6-3.2 | 2.70 | 2.60 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | 2 | <0.01-0.26 | 6 | <0.01-0.02 | NM | NM | 5 |
| Total organic carbon (mg/L) | 1 | 10 | 5 | 8.5-29.0 | 10.0 | 17.1 | 0 |
| Total phosphorus (mg/L) | 2 | 0.02-0.07 | 6 | <0.02-0.16 | .07 | .07 | 1 |
| Chloride (mg/L) | 2 | 790-870 | 6 | 480-1,300 | 855 | 855 | 0 |
| Arsenic (µg/L) | 2 | 15-16 | 6 | 8-15 | 11.0 | 11.5 | 0 |
| Cadmium (µg/L) | 2 | 2-2 | 6 | <1-2 | 1.0 | 1.3 | 3 |
| Chromium (µg/L) | 2 | <1-4 | 6 | <1-5 | 4.0 | 4.3 | 3 |
| Copper (µg/L) | 2 | <1-2 | 6 | <1-20 | 7.0 | 8.8 | 1 |
| Iron (µg/L) | 2 | 960-1,800 | 6 | 580-1,700 | 1,035 | 1,035 | 0 |
| Lead (µg/L) | 2 | 7-12 | 6 | <5-10 | NM | NM | 5 |
| Magnesium (mg/L) | 2 | 46-50 | 6 | 30-65 | 45.5 | 45.7 | 0 |
| Manganese (µg/L) | 2 | 20-90 | 6 | 20-120 | 85.0 | 76.7 | 0 |
| Mercury (µg/L) | 2 | <0.5-0.1 | 6 | <0.1-0.3 | NM | NM | 5 |
| Nickel (µg/L) | 2 | 3-7 | 6 | <1-2 | 2.0 | 2.0 | 4 |
| Potassium (mg/L) | 2 | 20-24 | 6 | 12-21 | 17.0 | 16.8 | 0 |
| Sodium (mg/L) | 2 | 440-480 | 6 | 270-640 | 460 | 450 | 0 |
| Zinc (µg/L) | 2 | 10-30 | 6 | <10-50 | 20.0 | 26.0 | 1 |
| **Upgradient middepth well G-3384B** | | | | | | | |
| Alkalinity (mg/L) | NS | | 4 | 276-296 | 290 | 288 | 0 |
| pH (units) | NS | | 6 | 7.15-7.60 | | | 0 |
| Specific conductance (µS/cm) | NS | | 6 | 3,790-4,260 | 4,005 | 4,012 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 6 | 1.3-1.4 | 1.30 | 1.32 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 6 | <0.01-0.02 | .01 | .02 | 4 |
| Total organic carbon (mg/L) | NS | | 5 | 5.0-7.4 | 6.50 | 6.24 | 0 |
| Total phosphorus (mg/L) | NS | | 6 | <0.01-0.02 | .02 | .02 | 1 |
| Chloride (mg/L) | NS | | 6 | 960-1,200 | 1,050 | 1,060 | 0 |
| Arsenic (µg/L) | NS | | 6 | 7-8 | 7.5 | 7.5 | 0 |
| Cadmium (µg/L) | NS | | 6 | <1-2 | 1.0 | 1.3 | 3 |
| Chromium (µg/L) | NS | | 6 | <1-11 | 3.0 | 5.0 | 3 |
| Copper (µg/L) | NS | | 6 | <1-3 | 2.0 | 1.8 | 1 |
| Iron (µg/L) | NS | | 6 | 490-630 | 545 | 545 | 0 |
| Lead (µg/L) | NS | | 6 | <5-7 | NM | NM | 5 |
| Magnesium (mg/L) | NS | | 6 | 54-61 | 56.5 | 57.5 | 0 |
| Manganese (µg/L) | NS | | 6 | <10-20 | 10.0 | 13.3 | 3 |
| Mercury (µg/L) | NS | | 6 | <0.1-0.2 | NM | NM | 5 |
| Nickel (µg/L) | NS | | 6 | <1-2 | NM | NM | 5 |
| Potassium (mg/L) | NS | | 6 | 18-22 | 21.0 | 20.5 | 0 |
| Sodium (mg/L) | NS | | 6 | 540-610 | 595 | 587 | 0 |
| Zinc (µg/L) | NS | | 6 | <10-30 | 20.0 | 18.0 | 1 |
| **Upgradient deep well G-3389A** | | | | | | | |
| Alkalinity (mg/L) | NS | | 4 | 302-317 | 308 | 309 | 0 |
| pH (units) | NS | | 6 | 6.8-7.5 | | | 0 |
| Specific conductance (µS/cm) | NS | | 6 | 6,170-8,580 | 7,695 | 7,460 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 6 | 1.3-1.6 | 1.40 | 1.42 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 6 | <0.02-0.02 | .01 | .02 | 4 |
| Total organic carbon (mg/L) | NS | | 6 | 4.5-8.0 | 5.00 | 5.47 | 0 |
| Total phosphorus (mg/L) | NS | | 6 | <0.01-0.03 | .02 | .02 | 2 |
| Chloride (mg/L) | NS | | 6 | 1,800-2,600 | 2,300 | 2,250 | 0 |
| Arsenic (µg/L) | NS | | 6 | 5-7 | 6.0 | 5.8 | 0 |
| Cadmium (µg/L) | NS | | 6 | <1-1 | 1.0 | 1.0 | 4 |
| Chromium (µg/L) | NS | | 6 | <1-3 | NM | NM | 5 |
| Copper (µg/L) | NS | | 6 | 1-2 | 1.5 | 1.5 | 0 |
| Iron (µg/L) | NS | | 6 | 430-640 | 450 | 485 | 0 |
| Lead (µg/L) | NS | | 6 | <5-7 | NM | NM | 5 |
| Magnesium (mg/L) | NS | | 6 | 110-150 | 135.0 | 131.7 | 0 |
| Manganese (µg/L) | NS | | 6 | 10-20 | 20.0 | 16.7 | 0 |
| Mercury (µg/L) | NS | | 6 | <0.1-2.0 | .30 | .67 | 2 |
| Nickel (µg/L) | NS | | 6 | <1-2 | 1.0 | 1.3 | 3 |
| Potassium (mg/L) | NS | | 6 | 16-47 | 36.0 | 34.2 | 0 |
| Sodium (mg/L) | NS | | 6 | 980-1,400 | 1,200 | 1,197 | 0 |
| Zinc (µg/L) | NS | | 6 | 10-40 | 15.0 | 20.7 | 0 |

**Table 6.** *Summary data for ground-water quality from wells at the Perrine marl maximum-application field before and after sludge application*--Continued

| Constituent | Presludge: No. of samples | Presludge: Range | Postsludge: No. of samples | Postsludge: Range | Postsludge: Median | Postsludge: Mean | Postsludge: No. below DL |
|---|---|---|---|---|---|---|---|
| Center-field shallow well G-3385C | | | | | | | |
| Alkalinity (mg/L) | 1 | 355 | 5 | 329-367 | 349 | 346 | 0 |
| pH (units) | 3 | 6.9-7.2 | 6 | 6.9-7.4 | | | 0 |
| Specific conductance (µS/cm) | 3 | 1,960-2,380 | 6 | 2,090-2,620 | 2,170 | 2,250 | 0 |
| Kjeldahl nitrogen (mg/L) | 3 | 1.0-1.3 | 6 | 1.2-1.5 | 1.35 | 1.33 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | 3 | <0.01-0.01 | 6 | <0.0-0.04 | NM | NM | 5 |
| Total organic carbon (mg/L) | 1 | 11 | 6 | 5.0-8.0 | 6.00 | 6.18 | 0 |
| Total phosphorus (mg/L) | 3 | <0.01-0.03 | 6 | <0.01-0.02 | .02 | .02 | 2 |
| Chloride (mg/L) | 3 | 380-520 | 6 | 410-630 | 490 | 502 | 0 |
| Arsenic (µg/L) | 3 | 13-24 | 6 | 14-21 | 16.0 | 16.4 | 0 |
| Cadmium (µg/L) | 3 | <1-2 | 6 | <1-10 | 1.0 | 4.0 | 3 |
| Chromium (µg/L) | 3 | <1-3 | 6 | <1-2 | 1.0 | 1.3 | 3 |
| Copper (µg/L) | 3 | <1-2 | 6 | <1-3 | 2.0 | 2.2 | 1 |
| Iron (µg/L) | 3 | 550-1,200 | 6 | 860-1,600 | 1,200 | 1,210 | 0 |
| Lead (µg/L) | 3 | <1-8 | 6 | <5-8 | NM | NM | 5 |
| Magnesium (mg/L) | 3 | 36-40 | 6 | 36-41 | 38.5 | 38.7 | 0 |
| Manganese (µg/L) | 3 | 10-20 | 6 | <10-20 | 10.0 | 14.0 | 1 |
| Mercury (µg/L) | 3 | <0.1-0.4 | 6 | <0.1-0.3 | .25 | .25 | 4 |
| Nickel (µg/L) | 3 | <1-6 | 6 | <1-1 | NM | NM | 5 |
| Potassium (mg/L) | 3 | 14-20 | 6 | 14-16 | 14.5 | 14.7 | 0 |
| Sodium (mg/L) | 3 | 230-280 | 6 | 240-320 | 280 | 282 | 0 |
| Zinc (µg/L) | 3 | <10-20 | 6 | <10-20 | 10.0 | 13.3 | 3 |
| Center-field middepth well G-3385B | | | | | | | |
| Alkalinity (mg/L) | 1 | 271 | 5 | 266-295 | 269 | 279 | 0 |
| pH (units) | 2 | 7.0-7.2 | 6 | 6.9-7.4 | | | 0 |
| Specific conductance (µS/cm) | 1 | 4,590 | 6 | 4,420-4,710 | 4,570 | 4,560 | 0 |
| Kjeldahl nitrogen (mg/L) | 2 | 1.0-1.2 | 6 | 1.2-1.4 | 1.25 | 1.27 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | 2 | <0.02-0.01 | 6 | <0.01-<0.02 | NM | NM | 6 |
| Total organic carbon (mg/L) | 1 | 7.9 | 6 | 3.8-5.0 | 4.35 | 4.45 | 0 |
| Total phosphorus (mg/L) | 2 | 0.01-0.02 | 6 | <0.01-0.02 | .02 | .02 | 2 |
| Chloride (mg/L) | 2 | 1,200-1,300 | 6 | 1,200-1,300 | 1,250 | 1,250 | 0 |
| Arsenic (µg/L) | 2 | 2-2 | 6 | 2-4 | 3.5 | 3.3 | 0 |
| Cadmium (µg/L) | 2 | 1-2 | 6 | <1-1 | 1.0 | 1.0 | 4 |
| Chromium (µg/L) | 2 | <1-2 | 6 | <1-2 | 1.0 | 1.3 | 3 |
| Copper (µg/L) | 2 | <1-1 | 6 | <1-2 | 1.0 | 1.4 | 1 |
| Iron (µg/L) | 2 | 130-260 | 6 | 180-300 | 250 | 245 | 0 |
| Lead (µg/L) | 2 | 1-11 | 6 | <5-<5 | NM | NM | 6 |
| Magnesium (mg/L) | 2 | 68-68 | 6 | 65-82 | 70.5 | 71.3 | 0 |
| Manganese (µg/L) | 2 | 10-20 | 6 | <10-10 | 10.0 | 10.0 | 2 |
| Mercury (µg/L) | 2 | 0.4-0.5 | 6 | <0.1-2.0 | .25 | .65 | 2 |
| Nickel (µg/L) | 2 | 3-6 | 6 | <1-1 | 1.0 | 1.0 | 4 |
| Potassium (mg/L) | 2 | 26-30 | 6 | 16-29 | 27.0 | 25.2 | 0 |
| Sodium (mg/L) | 2 | 700-720 | 6 | 690-770 | 720 | 723 | 0 |
| Zinc (µg/L) | 2 | 10-30 | 6 | <10-20 | 20.0 | 17.5 | 2 |
| Center-field deep well G-3385A | | | | | | | |
| Alkalinity (mg/L) | NS | | 5 | 251-264 | 258 | 257 | 0 |
| pH (units) | NS | | 6 | 6.9-7.2 | | | 0 |
| Specific conductance (µS/cm) | NS | | 6 | 27,700-28,300 | 28,000 | 28,000 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 6 | 0.9-1.1 | 1.00 | .99 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 6 | <0.01-0.01 | NM | NM | 5 |
| Total organic carbon (mg/L) | NS | | 6 | 3.0-9.5 | 4.40 | 5.15 | 0 |
| Total phosphorus (mg/L) | NS | | 6 | 0.02-0.22 | .03 | .06 | 0 |
| Chloride (mg/L) | NS | | 6 | 9,800-10,000 | 9,950 | 9,917 | 0 |
| Arsenic (µg/L) | NS | | 6 | 4-6 | 5.0 | 5.0 | 0 |
| Cadmium (µg/L) | NS | | 6 | <1-1 | 1.0 | 1.0 | 3 |
| Chromium (µg/L) | NS | | 6 | <1-3 | 1.0 | 1.5 | 2 |
| Copper (µg/L) | NS | | 6 | <1-3 | 2.0 | 1.8 | 1 |
| Iron (µg/L) | NS | | 6 | 280-410 | 380 | 358 | 0 |
| Lead (µg/L) | NS | | 6 | <5-8 | NM | NM | 5 |
| Magnesium (mg/L) | NS | | 6 | 600-680 | 600.0 | 615.0 | 0 |
| Manganese (µg/L) | NS | | 6 | 40-60 | 45.0 | 46.7 | 0 |
| Mercury (µg/L) | NS | | 6 | <0.1-0.8 | .45 | .47 | 2 |
| Nickel (µg/L) | NS | | 6 | <1-1 | NM | NM | 5 |
| Potassium (mg/L) | NS | | 6 | 160-200 | 170.0 | 178.3 | 0 |
| Sodium (mg/L) | NS | | 6 | 5,100-5,500 | 5,200 | 5,250 | 0 |
| Zinc (µg/L) | NS | | 6 | 20-80 | 30.0 | 38.3 | 0 |

**Table 6.** *Summary data for ground-water quality from wells at the Perrine marl maximum-application field before and after sludge application*–Continued

| Constituent | Presludge | | Poststludge | | | | |
|---|---|---|---|---|---|---|---|
| | No. of samples | Range | No. of samples | Range | Median | Mean | No. below DL |
| | | | **Downgradient shallow well G-3386C** | | | | |
| Alkalinity (mg/L) | 1 | 257 | 5 | 259-278 | 275 | 271 | 0 |
| pH (units) | 2 | 7.2-7.3 | 5 | 7.3-7.5 | | | 0 |
| Specific conductance (μS/cm) | 2 | 1,060-1,140 | 6 | 1,080-1,630 | 1,130 | 1,223 | 0 |
| Kjeldahl nitrogen (mg/L) | 2 | 2.2-2.4 | 6 | 2.2-2.4 | 2.30 | 2.30 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | 2 | 0.01-0.02 | 6 | <0.01-0.04 | NM | NM | 5 |
| Total organic carbon (mg/L) | 1 | NM-9.6 | 6 | 2.2-12.0 | 3.55 | 4.72 | 0 |
| Total phosphorus (mg/L) | 2 | 0.01-0.14 | 6 | <0.01-0.02 | .02 | .02 | 3 |
| Chloride (mg/L) | 2 | 160-180 | 6 | 170-330 | 190 | 212 | 0 |
| Arsenic (μg/L) | 2 | 4-5 | 6 | 2-3 | 3.0 | 2.8 | 0 |
| Cadmium (μg/L) | 2 | 1-2 | 6 | <1-8 | 1.0 | 3.3 | 3 |
| Chromium (μg/L) | 2 | <1-3 | 6 | <1-2 | 1.5 | 1.5 | 4 |
| Copper (μg/L) | 2 | 1-7 | 6 | 1-3 | 2.0 | 1.8 | 0 |
| Iron (μg/L) | 2 | 280-330 | 6 | 200-240 | 220 | 220 | 0 |
| Lead (μg/L) | 2 | 6-10 | 6 | <5-<5 | NM | NM | 6 |
| Magnesium (mg/L) | 2 | 15-16 | 6 | 15-20 | 17.5 | 17.5 | 0 |
| Manganese (μg/L) | 2 | 10-20 | 6 | <10-20 | 10.0 | 13.3 | 3 |
| Mercury (μg/L) | 2 | 0.7-0.9 | 6 | <0.1-0.5 | .30 | .30 | 4 |
| Nickel (μg/L) | 2 | 1-3 | 6 | <1-7 | NM | NM | 5 |
| Potassium (mg/L) | 2 | 8.8-8.9 | 6 | 8.4-10 | 8.9 | 9.0 | 0 |
| Sodium (mg/L) | 2 | 96-100 | 6 | 110-180 | 115 | 127 | 0 |
| Zinc (μg/L) | 2 | 10-30 | 6 | <10-10 | NM | NM | 5 |
| | | | **Downgradient middepth well G-3386B** | | | | |
| Alkalinity (mg/L) | NS | | 5 | 318-333 | 324 | 324 | 0 |
| pH (units) | NS | | 5 | 7.2-7.5 | | | 0 |
| Specific conductance (μS/cm) | NS | | 6 | 4,270-4,520 | 4,420 | 4,397 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 6 | 1.2-1.4 | 1.30 | 1.32 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 6 | <0.01-0.08 | NM | NM | 5 |
| Total organic carbon (mg/L) | NS | | 6 | 3.3-7.5 | 4.35 | 4.67 | 0 |
| Total phosphorus (mg/L) | NS | | 6 | <0.02-0.02 | .02 | .02 | 2 |
| Chloride (mg/L) | NS | | 6 | 1,200-1,200 | 1,200 | 1,200 | 0 |
| Arsenic (μg/L) | NS | | 6 | 4-6 | 5.0 | 5.0 | 0 |
| Cadmium (μg/L) | NS | | 6 | <1-1 | 1.0 | 1.0 | 4 |
| Chromium (μg/L) | NS | | 6 | <1-1 | 1.0 | 1.0 | 4 |
| Copper (μg/L) | NS | | 6 | 1-3 | 1.5 | 1.7 | 0 |
| Iron (μg/L) | NS | | 6 | 430-690 | 655 | 617 | 0 |
| Lead (μg/L) | NS | | 6 | <5-6 | NM | NM | 5 |
| Magnesium (mg/L) | NS | | 6 | 70-76 | 72.0 | 72.5 | 0 |
| Manganese (μg/L) | NS | | 6 | <10-20 | 10.0 | 14.0 | 1 |
| Mercury (μg/L) | NS | | 6 | <0.1-0.5 | .20 | .27 | 3 |
| Nickel (μg/L) | NS | | 6 | <1-2 | NM | NM | 5 |
| Potassium (mg/L) | NS | | 6 | 22-27 | 24.5 | 24.3 | 0 |
| Sodium (mg/L) | NS | | 6 | 610-670 | 645 | 645 | 0 |
| Zinc (μg/L) | NS | | 6 | <10-20 | 20.0 | 16.0 | 1 |
| | | | **Downgradient deep well G-3386A** | | | | |
| Alkalinity (mg/L) | NS | | 4 | 315-331 | 326 | 325 | 0 |
| pH (units) | NS | | 5 | 7.1-7.5 | | | 0 |
| Specific conductance (μS/cm) | NS | | 6 | 4,550-6,090 | 4,950 | 5,138 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 6 | 1.3-1.4 | 1.30 | 1.32 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 6 | <0.01-0.01 | NM | NM | 5 |
| Total organic carbon (mg/L) | NS | | 6 | 4.0-9.5 | 4.90 | 5.47 | 0 |
| Total phosphorus (mg/L) | NS | | 6 | <0.02-0.05 | .02 | .02 | 1 |
| Chloride (mg/L) | NS | | 6 | 1,200-1,700 | 1,400 | 1,417 | 0 |
| Arsenic (μg/L) | NS | | 6 | 2-6 | 5.0 | 4.5 | 0 |
| Cadmium (μg/L) | NS | | 6 | <1-8 | 4.5 | 4.5 | 4 |
| Chromium (μg/L) | NS | | 6 | <1-2 | 1.0 | 1.3 | 3 |
| Copper (μg/L) | NS | | 6 | 1-3 | 2.0 | 1.8 | 0 |
| Iron (μg/L) | NS | | 6 | 460-720 | 700 | 655 | 0 |
| Lead (μg/L) | NS | | 6 | <5-85 | 46.0 | 46.0 | 4 |
| Magnesium (mg/L) | NS | | 6 | 78-100 | 81.5 | 85.3 | 0 |
| Manganese (μg/L) | NS | | 6 | <10-20 | 20.0 | 16.0 | 1 |
| Mercury (μg/L) | NS | | 5 | <0.1-0.2 | .15 | .15 | 3 |
| Nickel (μg/L) | NS | | 6 | <1-2 | 2.0 | 2.0 | 4 |
| Potassium (mg/L) | NS | | 6 | 26-30 | 27.5 | 28.0 | 0 |
| Sodium (mg/L) | NS | | 6 | 680-890 | 750 | 768 | 0 |
| Zinc (μg/L) | NS | | 6 | <10-50 | 20.0 | 25.0 | 2 |

well and, to a greater degree, the deep well. Both wells were installed deeper than the upgradient and downgradient wells representing their equivalent depths because of the lithologic features of the subsurface. This 3- to 9-ft difference in depth made a difference in the above measurements and constituents because the field is underlain by intruded saltwater. Differences in water quality beneath areas of the field that are not immediately explained by these factors were found for the following constituents (none indicates that constituents are either not significantly different or significantly different but explained by preexisting trends or high concentrations).

| | Areas compared | |
|---|---|---|
| Well depth | Upgradient to center | Center to downgradient |
| Shallow | Total organic carbon<br>Copper<br>Zinc | None |
| Middepth | Alkalinity<br>Total organic carbon<br>Arsenic | Alkalinity<br>Arsenic<br>Iron |
| Deep | Alkalinity<br>Total phosphorus<br>Arsenic<br>Iron<br>Manganese<br>Zinc<br>Ammonia | Alkalinity<br>Iron<br>Manganese<br>Mercury<br>Ammonia |

In shallow ground water, total organic carbon (TOC), copper, and zinc concentrations were lower beneath the field than they were upgradient. TOC concentrations were lower beneath the field after sludge was applied than in the one presludge sample. The WSRT result for TOC is the result of an increase in concentration in the upgradient well in 1987 rather than the effects of sludge application. An increase in copper and zinc concentrations in the upgradient well also caused the difference indicated by their respective WSRT.

In middepth ground water, the WSRT indicated lowest alkalinity and arsenic concentrations beneath the field, lower TOC concentrations beneath the field than upgradient, and lower iron concentrations beneath the field than downgradient. The concentrations of alkalinity, arsenic, and iron beneath the field are similar to those in presludge samples, and there was no evidence of these constituents being attenuated by sludge in the shallow well samples; the lower concentrations probably are due to natural variation. TOC concentrations followed the pattern observed in shallow ground water, decreasing after sludge was applied and usually being lower under the field than upgradient. The range of variation for TOC and the increased concentrations for shallow upgradient water mask any subtle changes that might be caused by sludge.

In deep ground water, alkalinity, ammonia (included in the Kjeldahl nitrogen analysis in table 6), and iron concentrations were lowest beneath the center of the field, and arsenic concentrations were lower beneath the center of the field than upgradient. Total phosphorus, manganese, and zinc concentrations were highest beneath the center of the field, and mercury concentrations were higher there than downgradient. Most of these patterns of occurrence were not observed in shallow ground water where effects from sludge application should be most evident. Only ammonia had the same pattern of occurrence (lowest concentration beneath the field) in shallow and middepth water; this pattern was observed in the presludge samples as well, so it is not related to sludge.

## Perrine Marl Row-Crop Field

Sludge was applied to the Perrine marl row-crop field at the rate of 2 tons/acre/yr, starting on April 30, 1986. The first water samples were collected May 27, 1986, after an 0.8-in. rain. Subsequent samples were collected August 21, 1986, November 3, 1986, February 17, 1987, May 21, 1987, and August 18, 1987, according to schedule. The field was farmed using normal operating procedures for sweet corn and had nutrient and pesticide loading in addition to loading from sludge. This loading is summarized in the following table (John Alger, Alger Farms, oral commun., 1985):

| Compound | Quantity per acre per year | Annual loading |
|---|---|---|
| Fertilizer (8-16-8 and 13-0-10) | 850 and 1,700 lb | 91,800 lb |
| Nitrogen | 289 lb | 10,404 lb |
| Potassium | 113 lb | 4,060 lb |
| Phosphate | 105 lb | 3,770 lb |
| Nitrogen (urea) | as needed | |
| Sutan (Butylate) | 2 qt | 72 qt |
| Atrazine | 2 qt | 72 qt |
| Methomyl | 12.5 qt | 450 qt |
| Parathion | 2.5-4 qt | 90-144 qt |
| Counter (Terbufos) | 12 lb | 432 lb |
| Maneb | 25 lb | 900 lb |

Some of these constituents and some sludge constituents are used as nutrients by the corn and by weeds that grow between growing seasons.

### Comparison of Water Quality Before and After Sludge Application

The shallow wells upgradient and downgradient of the field and the middepth well downgradient of the field were sampled before sludge application. Wells at all locations in the field were sampled after sludge was applied. The summary data for each well are listed in table 7, which gives the concentration range for each constituent in samples collected before sludge was applied and the concentration range, median, and mean for samples collected after sludge was applied.

Presludge and postsludge measurements and concentrations were examined as described in "Data-Interpretation Techniques." Changes in water quality that were evident downgradient of the field reflected changes that were occurring upgradient as well.

#### Statistical Interpretation of Water-Quality Data

The WSRT was used to examine changes in the quality of ground water entering and leaving the field for middepth and deep wells. It was not used for shallow ground water. The shallow wells were only sampled on the same day three times during the postsludge period because of damage or destruction as previously discussed. Data from the shallow wells were compared to determine if there were any differences in water quality between the upgradient and downgradient areas of the field.

Comparison of the shallow wells indicates that: (1) specific conductance measurements and concentrations of nitrite plus nitrate nitrogen, magnesium, sodium, potassium, chloride, and sulfate were generally equal or higher in water leaving the field; (2) pH measurements and concentrations of alkalinity, Kjeldahl nitrogen, arsenic, iron, manganese, and zinc were generally equal or lower in water leaving the field; and (3) total phosphorus, TOC, cadmium, copper, nickel, and mercury indicated no difference between water entering and leaving the field. All differences were evident in the presludge period so they were not related to sludge application. Chromium concentrations were equal or higher (by 1 μg/L) in the downgradient well samples before sludge was applied, but after sludge application they were lower (by 1 μg/L) or equal in the downgradient samples. The size of the difference makes it insignificant.

The results of the WSRT for middepth and deep ground water, which were significant (0.05 significance level), are given in appendix II. All differences in upgradient and downgradient water quality were explained by trends that existed before sludge application as discussed in "Data-Interpretation Techniques."

## Exceedance of Water-Quality Standards

All data collected as part of this investigation were compared to the Florida Department of Environmental Regulation (1982) primary and secondary drinking-water regulations (table 1). This comparison was made to determine if there were potential problems related to the land application of sludge that were too temporary to show up as time trends or to cause a rejection of the null hypothesis using the WSRT. The secondary maximum contaminant levels (SMCLs) for iron (300 μg/L) and color (15 Pt-Co units) are routinely exceeded in south Florida ground water, and their exceedance here was not related to the land application of sludge.

At the Rockdale maximum-application field, the SMCL for iron was exceeded at all wells, and the SMCL for color (not included in table 4) was exceeded at the upgradient, middepth, and deep wells and at the downgradient shallow well. The MCL for mercury (2 μg/L) was exceeded in the first sample collected at the center-field deep well after sludge was applied (9.5 μg/L).

At the Rockdale grove, the MCL for mercury was exceeded at the upgradient shallow well on February 9, 1987, when the mercury concentration was 2.3 μg/L. This well represents inflow to the field and variations in water quality that are not related to sludge application, so the exceedance of the standard does not represent a sludge effect.

At the Perrine marl maximum-application field, MCLs for sodium (160 μg/L) and chloride (250 mg/L) at all wells and the SMCL for sulfate (250 μg/L, not included in table 6) at the deep wells were exceeded because of brackish water underlying the field. The SMCL for iron was exceeded in samples from all wells, except for the center-field middepth well where it was equaled. In the upgradient shallow well, the SMCL for color (not included in table 6) was exceeded in the three samples for 1987 when it measured 30, 100, and 80 Pt-Co units, and the SMCL for manganese (50 μg/L) was exceeded by all but two samples, with concentrations of 20, 90, 90, 20, 60, 80, 120 and 90 μg/L. The SMCL for manganese was also exceeded at the center-field deep well on November 4, 1986, when it was 60 μg/L. The MCL for lead (50 μg/L) was exceeded when it was 85 μg/L in water from the downgradient deep well on May 29, 1986, the first sample after sludge was applied.

At the Perrine marl row-crop field, SMCLs for iron and manganese were exceeded in the upgradient shallow well. Arsenic, which has been part of pesticide formulations, exceeded the MCL (10 μg/L) in the first presludge samples from the downgradient shallow well when the concentration was 11 μg/L. The MCL for mercury was exceeded in the February 1987 sample from the downgradient middepth well when the concentration was 5.2 μg/L. This concentration is higher than that found by Howie (1986) at the agricultural area during the first year of this study (less than 0.1 to 0.5 mg/L) or found by Waller (1983) in background wells (less than 0.5 to 0.5 μg/L).

**Table 7.** *Summary data for ground-water quality from wells at the Perrine marl row-crop field before and after sludge application*

[Samples below the detection limit (DL) are not included in the mean and median calculations. If a constituent was not detected in a sample, the constituent is reported as less than (<) the detection limit (for example, <100). When the presludge and postsludge detection limits are different, it is because other constituents in a sample may interfere with an analysis, necessitating the use of alternative methods of analysis with higher or lower detection limits. The analytical methods for some constituents (Kjeldhal nitrogen, nitrite + nitrate nitrogen, total phosphorus, and lead) and, therefore, their detection limits were changed permanently during the period of study. Abbreviations: mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NM, statistic has "no meaning" given number of detections (median and mean do not apply for pH); NS, no samplings were made]

| Constituent | Presludge | | Postsludge | | | | |
|---|---|---|---|---|---|---|---|
| | No. of samples | Range | No. of samples | Range | Median | Mean | No. below DL |
| | Upgradient shallow well G-3387C | | | | | | |
| Alkalinity (mg/L) | 1 | 192 | 2 | 220-227 | 224 | 224 | 0 |
| pH (units) | 2 | 7.1-7.5 | 3 | 7.3-7.4 | | | 0 |
| Specific conductance (µS/cm) | 2 | 552-575 | 4 | 562-580 | 572 | 571 | 0 |
| Kjeldahl nitrogen (mg/L) | 2 | 0.23-0.68 | 4 | 0.33-1.20 | .65 | .71 | 0 |
| Nitrite + nitrate nitrogen (mg/L) | 2 | 0.68-1.30 | 4 | 1.2-1.5 | 1.40 | 1.37 | 0 |
| Total organic carbon (mg/L) | 0 | NM | 4 | 1.0-1.5 | 1.25 | 1.25 | 0 |
| Total phosphorus (mg/L) | 2 | 0.02-0.02 | 4 | <0.01-0.06 | .05 | .05 | 2 |
| Chloride (mg/L) | 2 | 27-27 | 4 | 29-30 | 29.0 | 29.3 | 0 |
| Arsenic (µg/L) | 2 | 7-10 | 4 | 6-10 | 8.0 | 8.0 | 0 |
| Cadmium (µg/L) | 2 | 1-2 | 4 | <1-2 | NM | NM | 3 |
| Chromium (µg/L) | 2 | <1-1 | 4 | <1-7 | 3.0 | 4.3 | 1 |
| Copper (µg/L) | 2 | 1-4 | 4 | <1-3 | 3.0 | 2.7 | 1 |
| Iron (µg/L) | 2 | 120-410 | 4 | 190-1,000 | 390 | 493 | 0 |
| Lead (µg/L) | 2 | 2-13 | 4 | <5-<5 | NM | NM | 4 |
| Magnesium (mg/L) | 2 | 2.9-3.0 | 4 | 2.8-3.0 | 2.95 | 2.92 | 0 |
| Manganese (µg/L) | 2 | 20-50 | 4 | 20-110 | 35.0 | 50.0 | 0 |
| Mercury (µg/L) | 2 | <0.5-0.6 | 4 | <0.1-<0.1 | NM | NM | 4 |
| Nickel (µg/L) | 2 | 1-2 | 4 | <1-2 | 1.0 | 1.3 | 1 |
| Potassium (mg/L) | 2 | 4.7-6.2 | 4 | 4.3-5.5 | 4.70 | 4.80 | 0 |
| Sodium (mg/L) | 2 | 16-16 | 4 | 15-17 | 16.0 | 16.0 | 0 |
| Zinc (µg/L) | 2 | 10-30 | 4 | <10-40 | 30.0 | 26.7 | 1 |
| | Upgradient middepth well G-3387B | | | | | | |
| Alkalinity (mg/L) | NS | | 3 | 196-203 | 200 | 200 | 0 |
| pH (units) | NS | | 4 | 7.2-7.8 | | | 0 |
| Specific conductance (µS/cm) | NS | | 5 | 549-567 | 562 | 559 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 5 | <0.2-<0.2 | NM | NM | 5 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 5 | 2.0-2.7 | 2.60 | 2.46 | 0 |
| Total organic carbon (mg/L) | NS | | 5 | 0.5-2.5 | .80 | 1.06 | 0 |
| Total phosphorus (mg/L) | NS | | 5 | <0.02-0.02 | .01 | .02 | 3 |
| Chloride (mg/L) | NS | | 5 | 28-32 | 30.0 | 29.6 | 0 |
| Arsenic (µg/L) | NS | | 5 | <1-<1 | NM | NM | 5 |
| Cadmium (µg/L) | NS | | 5 | <1-1 | NM | NM | 4 |
| Chromium (µg/L) | NS | | 5 | <1-1 | NM | NM | 4 |
| Copper (µg/L) | NS | | 5 | 1-3 | 2.0 | 2.0 | 0 |
| Iron (µg/L) | NS | | 5 | <10-50 | 25 | 30 | 1 |
| Lead (µg/L) | NS | | 5 | <5-<5 | NM | NM | 5 |
| Magnesium (mg/L) | NS | | 5 | 2.7-2.9 | 2.80 | 2.82 | 0 |
| Manganese (µg/L) | NS | | 5 | <10-20 | NM | NM | 4 |
| Mercury (µg/L) | NS | | 5 | <0.1-0.4 | NM | NM | 4 |
| Nickel (µg/L) | NS | | 5 | <1-1 | 1.0 | 1.0 | 3 |
| Potassium (mg/L) | NS | | 5 | 4.0-4.3 | 4.2 | 4.2 | 0 |
| Sodium (mg/L) | NS | | 5 | 15-17 | 16.0 | 16.0 | 0 |
| Zinc (µg/L) | NS | | 5 | <10-10 | NM | NM | 4 |
| | Upgradient deep well G-3387A | | | | | | |
| Alkalinity (mg/L) | NS | | 4 | 201-204 | 202 | 202 | 0 |
| pH (units) | NS | | 4 | 7.3-8.1 | | | 0 |
| Specific conductance (µS/cm) | NS | | 5 | 554-581 | 565 | 566 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 5 | <0.20-0.24 | NM | NM | 4 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 5 | 2.2-2.6 | 2.40 | 2.44 | 0 |
| Total organic carbon (mg/L) | NS | | 5 | 0.5-1.0 | .80 | .76 | 0 |
| Total phosphorus (mg/L) | NS | | 5 | <0.02-0.02 | .01 | .02 | 3 |
| Chloride (mg/L) | NS | | 5 | 29-35 | 30.0 | 31.2 | 0 |
| Arsenic (µg/L) | NS | | 5 | <1-<1 | NM | NM | 5 |
| Cadmium (µg/L) | NS | | 5 | <1-1 | NM | NM | 4 |
| Chromium (µg/L) | NS | | 5 | <1-1 | 1.0 | 1.0 | 3 |
| Copper (µg/L) | NS | | 5 | 1-6 | 2.0 | 2.4 | 0 |
| Iron (µg/L) | NS | | 5 | 10-60 | 20 | 32 | 0 |
| Lead (µg/L) | NS | | 5 | <5-<5 | NM | NM | 5 |
| Magnesium (mg/L) | NS | | 5 | 2.8-3.0 | 2.90 | 2.90 | 0 |
| Manganese (µg/L) | NS | | 5 | <10-10 | NM | NM | 4 |
| Mercury (µg/L) | NS | | 5 | <0.1-0.3 | NM | NM | 4 |
| Nickel (µg/L) | NS | | 5 | <1-1 | NM | NM | 4 |
| Potassium (mg/L) | NS | | 5 | 4.2-4.5 | 4.40 | 4.34 | 0 |
| Sodium (mg/L) | NS | | 5 | 16-18 | 17.0 | 16.8 | 0 |
| Zinc (µg/L) | NS | | 5 | <10-10 | 10.0 | 10.0 | 3 |

**Table 7.** *Summary data for ground-water quality from wells at the Perrine marl row-crop field before and after sludge application*--Continued

| Constituent | Presludge: No. of samples | Presludge: Range | Postsludge: No. of samples | Postsludge: Range | Median | Mean | No. below DL |
|---|---|---|---|---|---|---|---|
| **Downgradient shallow well G-3388C** | | | | | | | |
| Alkalinity (mg/L) | 1 | 211 | 5 | 197-218 | 212 | 210 | 0 |
| pH (units) | 2 | 7.0-7.3 | 3 | 7.2-7.3 | | | 0 |
| Specific conductance (μS/cm) | 1 | 657 | 6 | 625-714 | 666 | 671 | 0 |
| Kjeldahl nitrogen (mg/L) | 2 | 0.07-0.18 | 6 | <0.20-0.54 | .28 | .31 | 2 |
| Nitrite + nitrate nitrogen (mg/L) | 2 | 2.0-4.6 | 6 | 3.6-7.9 | 4.55 | 4.85 | 0 |
| Total organic carbon (mg/L) | 1 | 3.1 | 6 | 0.5-10.0 | 1.85 | 3.07 | 0 |
| Total phosphorus (mg/L) | 2 | 0.01-0.02 | 6 | <0.02-0.03 | .02 | .02 | 1 |
| Chloride (mg/L) | 2 | 36-39 | 6 | 32-48 | 39.0 | 39.0 | 0 |
| Arsenic (μg/L) | 2 | 3-11 | 6 | 2-4 | 3.0 | 3.0 | 0 |
| Cadmium (μg/L) | 2 | 1-2 | 6 | <1-1 | NM | NM | 5 |
| Chromium (μg/L) | 2 | <1-2 | 5 | <1-2 | 2.0 | 2.0 | 4 |
| Copper (μg/L) | 2 | 2-4 | 6 | <1-3 | 2.0 | 2.2 | 1 |
| Iron (μg/L) | 2 | 40-50 | 6 | <10-60 | 50 | 40 | 1 |
| Lead (μg/L) | 2 | 4-13 | 6 | <5-<5 | NM | NM | 6 |
| Magnesium (mg/L) | 2 | 4.2-5.1 | 6 | 4.0-4.7 | 4.10 | 4.25 | 0 |
| Manganese (μg/L) | 2 | 10-40 | 6 | <10-20 | 20.0 | 17.5 | 2 |
| Mercury (μg/L) | 2 | <0.5-0.6 | 6 | <0.1-0.3 | NM | NM | 5 |
| Nickel (μg/L) | 2 | <1-1 | 6 | <1-4 | 2.5 | 2.5 | 4 |
| Potassium (mg/L) | 2 | 12-22 | 6 | 10.0-25.0 | 14.00 | 15.50 | 0 |
| Sodium (mg/L) | 2 | 19-19 | 6 | 17-21 | 18.5 | 18.8 | 0 |
| Zinc (μg/L) | 2 | <10-30 | 6 | <10-20 | 10.0 | 13.3 | 3 |
| **Downgradient middepth well G-3388B** | | | | | | | |
| Alkalinity (mg/L) | 1 | 201 | 4 | 200-205 | 203 | 203 | 0 |
| pH (units) | 2 | 7.0-7.3 | 4 | 7.2-7.4 | | | 0 |
| Specific conductance (μS/cm) | 2 | 577-581 | 5 | 566-588 | 580 | 578 | 0 |
| Kjeldahl nitrogen (mg/L) | 2 | <0.05-<0.05 | 5 | <0.2-<0.2 | NM | NM | 5 |
| Nitrite + nitrate nitrogen (mg/L) | 2 | 2.2-3.0 | 5 | 2.5-3.4 | 3.00 | 2.92 | 0 |
| Total organic carbon (mg/L) | 1 | NM-16 | 5 | 0.5-2.0 | .80 | .96 | 0 |
| Total phosphorus (mg/L) | 2 | 0.01-0.02 | 5 | <0.02-0.02 | .02 | .02 | 3 |
| Chloride (mg/L) | 2 | 27-29 | 5 | 28-33 | 30.0 | 30.4 | 0 |
| Arsenic (μg/L) | 2 | <1-1 | 5 | <1-<1 | NM | NM | 5 |
| Cadmium (μg/L) | 2 | 1-1 | 5 | <1-1 | NM | NM | 4 |
| Chromium (μg/L) | 2 | <1-1 | 5 | <1-<1 | NM | NM | 5 |
| Copper (μg/L) | 2 | 1-3 | 5 | 1-3 | 3.0 | 2.2 | 0 |
| Iron (μg/L) | 2 | 50-70 | 5 | 30-50 | 30 | 36 | 0 |
| Lead (μg/L) | 2 | 5-11 | 5 | <5-5 | NM | NM | 4 |
| Magnesium (mg/L) | 2 | 3.1-3.2 | 5 | 3.1-3.2 | 3.10 | 3.12 | 0 |
| Manganese (μg/L) | 2 | 10-10 | 5 | <10-10 | NM | NM | 4 |
| Mercury (μg/L) | 2 | <0.5-0.1 | 5 | <0.1-5.2 | 2.70 | 2.70 | 3 |
| Nickel (μg/L) | 2 | <1-4 | 5 | <1-1 | 1.0 | 1.0 | 3 |
| Potassium (mg/L) | 2 | 5.4-5.8 | 5 | 5.0-5.5 | 5.40 | 5.32 | 0 |
| Sodium (mg/L) | 2 | 16-17 | 5 | 16-17 | 17.0 | 16.8 | 0 |
| Zinc (μg/L) | 2 | 10-30 | 5 | <10-10 | NM | NM | 4 |
| **Downgradient deep well G-3388A** | | | | | | | |
| Alkalinity (mg/L) | NS | | 5 | 196-205 | 204 | 203 | 0 |
| pH (units) | NS | | 4 | 7.1-7.5 | | | 0 |
| Specific conductance (μS/cm) | NS | | 5 | 570-589 | 579 | 579 | 0 |
| Kjeldahl nitrogen (mg/L) | NS | | 5 | <0.20-0.24 | NM | NM | 4 |
| Nitrite + nitrate nitrogen (mg/L) | NS | | 5 | 2.7-3.2 | 3.00 | 2.98 | 0 |
| Total organic carbon (mg/L) | NS | | 5 | 0.5-3.0 | 2.00 | 1.80 | 0 |
| Total phosphorus (mg/L) | NS | | 5 | <0.02-0.02 | .02 | .02 | 3 |
| Chloride (mg/L) | NS | | 5 | 29-32 | 31.0 | 30.8 | 0 |
| Arsenic (μg/L) | NS | | 5 | <1-<1 | NM | NM | 5 |
| Cadmium (μg/L) | NS | | 5 | <1-1 | NM | NM | 4 |
| Chromium (μg/L) | NS | | 5 | <1-<1 | NM | NM | 5 |
| Copper (μg/L) | NS | | 5 | 1-2 | 2.0 | 1.8 | 0 |
| Iron (μg/L) | NS | | 5 | 10-80 | 40 | 42 | 0 |
| Lead (μg/L) | NS | | 5 | <5-<5 | NM | NM | 5 |
| Magnesium (mg/L) | NS | | 5 | 3.1-3.3 | 3.20 | 3.18 | 0 |
| Manganese (μg/L) | NS | | 5 | <10-20 | NM | NM | 4 |
| Mercury (μg/L) | NS | | 5 | <0.1-1.0 | NM | NM | 4 |
| Nickel (μg/L) | NS | | 5 | <1-1 | NM | NM | 4 |
| Potassium (mg/L) | NS | | 5 | 5.3-5.8 | 5.50 | 5.50 | 0 |
| Sodium (mg/L) | NS | | 5 | 16-17 | 17.0 | 16.6 | 0 |
| Zinc (μg/L) | NS | | 5 | <10-10 | 10.0 | 10.0 | 3 |

## Pesticide and Organic Priority Pollutant Analyses

The pesticides and organic priority pollutants analyzed for this study and their detection limits are shown in appendix III. Concentrations of these compounds were determined for shallow ground water from the center of the field (downgradient for the Perrine marl row-crop field). Water samples were collected at the end of each wet and dry season before and after sludge was applied and continued on that schedule for the period of study at each field. Those compounds that were found at or above the detection limits are listed in table 8.

It is not possible to ascertain the source of the organic compounds that were detected. Most of these compounds have been detected in WSA sludge at least once (table 3), and chloroform (0.2 µg/L), toluene (1.3 and 0.2 µg/L), and bis(2-Ethylhexyl)phthalate (42 µg/L) were found at sites that were not farmed. Also, the detected compounds were not detected in trip or laboratory blanks for their respective samples. However, most are common volatile compounds, making samples susceptible to contamination if any compound exists in the atmosphere during sampling or analysis.

For example, toluene, xylene, and benzene are found in gasoline, and atmospheric residuals of these compounds could be left from the field vehicle or from the pump initially used to purge the wells. Methylene chloride is used for chemical extractions so residual methylene chloride could remain in the laboratory atmosphere. Similarly, bis(2-Ethylhexyl)phthalate is used to produce plastics and is almost ubiquitous in any human environment. The pesticide 2,4-D (not volatile) obviously has potential sources in an agricultural area other than sludge. Detections of chlorobenzene (4.1 µg/L), ethylbenzene (3.0 µg/L), and tetrachloroethylene (5.5 µg/L) at the Rockdale maximum-application field before sludge was applied indicate there are nonsludge-related sources for these compounds. This discussion is not meant to imply that the detected compounds were not the result of sludge but to reinforce the initial premise that their origin cannot be ascertained.

## Factors Affecting the Occurrence of Sludge Contaminants During the Period of Study

The application of sludge did not seem to have had much, if any, effect on ground-water quality beneath the four test fields to which it was applied. This is in spite of the fact that dried municipal wastewater-treatment sludge is known to contain trace metals, major ions, and organic compounds (natural and synthetic), which either by their very occurrence or by their increased concentrations are considered potential ground-water contaminants. Whether these constituents of sludge contaminate ground water depends not only on the composition of the sludge (table 3) but also on the extent potential contaminants are attenuated between land surface and an aquifer. The environmental and human factors that may be influencing the results of this study are examined in the following discussion.

In the study area, temperature and rainfall are the primary climatic concerns in the attenuation of sludge contaminants. Warm, humid environments can speed chemical and biological processes, such as volatilization, chemical breakdown to metabolites, and biological decay. Rainfall is

**Table 8.** *Pesticides and organic priority pollutants results*

[Values shown in micrograms per liter. ND, samples were analyzed on this date for organics, and there were no detections. NS, field was not sampled for organic compounds on this date. Dashes indicatee constituent was sampled but not detected]

| Sampling date | Pesticide/pollutant | Rockdale maximum-application field | Rockdale grove | Perrine marl maximum-application field | Perrine marl row crop field |
|---|---|---|---|---|---|
| March and April 1985 | | ND | ND | NS | NS |
| August 1985 | Chlorobenzene | 4.1 | -- | -- | -- |
| | Ethylbenzene | 3.0 | -- | -- | -- |
| | Tetrachloroethylene | 5.5 | -- | -- | -- |
| May 1986 | | NS | ND | ND | ND |
| November and December 1986 | Benzene | -- | 1.2 | -- | 0.3 |
| | Chloroform | -- | .3 | 0.2 | -- |
| | bis(2-Ethylhexyl)phthalate | -- | -- | -- | 29 |
| | Methylene chloride | -- | 14 | -- | -- |
| | Toluene | -- | 4.4 | 1.3 | .4 |
| | 1,1,1-Trichloroethane | -- | -- | -- | .6 |
| | Trichloroethylene | -- | .3 | -- | -- |
| | 2,4-D | -- | -- | -- | .01 |
| May 1987 | bis(2-Ethylhexyl)phthalate | -- | -- | 42 | -- |
| August 1987 | Toluene | .2 | .5 | -- | .4 |
| | Xylene | -- | .3 | -- | -- |

also the primary transport mechanism for the migration of contaminants from land surface to the water table. During the period of study, it was generally warmer and drier than normal (fig. 5). This could have resulted in a higher degree of chemical and biological attenuation of the sludge at the surface and less-rapid transport of the sludge contaminants to the aquifer than in more typical years. It is also possible that the 43 to 65 in. of annual rainfall during the period of study were enough to substantially dilute contaminants in the dried sludge.

The mineral and organic content of soil affects sorption and ionic replacement of sludge constituents. Physical properties of soil, such as thickness, texture, and consistency (table 2), help determine the rate that sludge-enriched rainfall or irrigation water percolates through the soil and, therefore, the time available for sorption and ionic replacement reactions to occur. A recent study in Broward County (just north of Dade County) found that significant amounts of metals, carbon, nitrogen, and phosphorus contained in highway runoff were retained in the top 0.05 ft of organic soil within swales (Howie and Waller, 1986, p. 9-10). However, in south Dade County, the thin calcium carbonate soils with a smaller organic fraction are probably less effective in attenuating surface contaminants than soils in Broward County. Contaminants leaching through the soil layer are not likely to be retained by the limestone components of the unsaturated zone, which has limited potential for the sorption and ionic replacement of contaminants because of its calcium carbonate composition and because it allows rapid infiltration of recharge to the aquifer.

In the south Dade agricultural area, the growing season for most row crops starts near the end of the wet season when water levels are high. For this reason, the SFWMD lowers water levels in some canals on October 15 to drain the agricultural area. In many areas, row-crop fields are rimmed by shallow borrow canals that feed into the SFWMD canals to facilitate drainage. The canal system strongly influences local ground-water flow patterns (fig. 3) and, therefore, the direction and rate of contaminant transport from fields to which sludge is applied. Lowering water levels beneath the south Dade agricultural area, coupled with ground-water gradients toward the canals, may result in some flushing of contaminated ground water from the highly permeable aquifer beneath the fields. Lowering water levels may also facilitate the oxidation and volatilization of some components of sludge.

## SUMMARY

Four test fields in the south Dade agricultural area were studied. Two had been cultivated 30 years or more, and two had not been farmed for at least 10 years. The fields were representative of the area's two soil types (Perrine marl and Rockdale) and two major crop types (row crops and groves). Wells upgradient of, within, and downgradient of each field were sampled in 1985 and 1986 at the end of the wet and dry seasons to establish ground-water-quality characteristics before the test application of sludge. Municipal wastewater-treatment sludge from WSA was then applied to the fields at varying rates. The wells at each field were then sampled over a 2-year period under different hydrologic conditions for possible sludge-related contaminants.

Most of the differences in water quality between presludge and postsludge samples or between areas of the test fields were explained by preexisting trends or were evident in upgradient samples. These differences could, therefore, not be attributed to sludge application. Differences in water quality that were not explained by factors other than sludge are discussed.

The Rockdale maximum-application field received 6 tons/acre of sludge. Concentrations of DOC in shallow ground water beneath the field increased from 2.5 to 4.0 mg/L before sludge application to 6.5 and 8.5 mg/L after sludge application. Copper was detected in one postsludge sample from beneath the field at a concentration of 9 μg/L. A comparison of water quality upgradient, center-field, and downgradient indicated that arsenic was higher in shallow ground water beneath the field than in water leaving the field by a maximum concentration of 2 μg/L. The FDER MCL for mercury was exceeded in one postsludge sample from the center-field deep well (9.5 μg/L).

The Rockdale grove received 2 tons/acre of sludge, three times annually. DOC concentrations in shallow ground water beneath the center of the field were an order of magnitude lower in postsludge samples than in presludge samples. Although there were some changes in water quality resulting from farming at this grove, the differences in water quality indicated by the WSRT do not appear to be related to sludge. FDER primary and secondary drinking-water regulations were not exceeded beneath or downgradient of this field.

The Perrine marl maximum-application field received 12 tons/acre of sludge. Iron and sodium concentrations increased and alkalinity decreased in postsludge samples for shallow center-field ground water. None of the differences in ground-water quality between sludge-applied and nonsludge-applied areas of the field indicated by the WSRT appears to be the result of applied sludge. Manganese exceeded the FDER SMCL in one sample from the center-field deep well (60 μg/L), as it had in shallow ground water upgradient before and after sludge application. The MCL for lead was exceeded by one sample from the downgradient deep well (85 μg/L) after sludge was applied. All other exceedances of FDER regulations were explained by the brackish water underlying the field or by naturally high iron and color. A variable shallow ground-water gradient and brackish water beneath the center of the field diminished the value of this field for tracking contaminant movement.

The Perrine marl row-crop field received 2 tons/acre of sludge annually. There was no center-field well cluster at this field because it would have interfered with farming operations. Chromium concentrations were slightly lower in shallow downgradient water than in upgradient water after sludge application. The FDER MCL for mercury was exceeded in one sample from the downgradient middepth well when the concentration was 5.2 µg/L. All other exceedances were either in presludge or upgradient samples.

Selected pesticides and organic priority pollutants were analyzed for samples collected from the shallow center-field or downgradient wells at the end of each wet and dry season. Most organic compounds were not detected. Those that equaled or exceeded the detection limit were benzene, chlorobenzene, chloroform, ethylbenzene, bis(2-Ethylhexyl)phthalate, methylene chloride, tetrachloroethylene, toluene, 1,1,1-trichloroethane, trichloroethylene, 2,4-D, and xylene. Detections of chlorobenzene, ethylbenzene, and tetrachloroethylene only occurred before the application of sludge. None of the postsludge detections were above MCLs. It was not possible to ascertain the origin of these compounds because they are available from other sources as well as sludge.

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# APPENDIXES

Appendix I.--Well numbers, station identification numbers, and well depths at the test fields

| Location | Well number | Station identification number | Well depth (feet) |
|---|---|---|---|
| | | *Rockdale maximum-application field* | |
| Upgradient | G-3378A | 252555080345501 | 40 |
| | G-3378B | 252555080345502 | 26 |
| | G-3378C | 252555080345503 | 10 |
| Center field | G-3379A | 252550080344801 | 40 |
| | G-3379B | 252550080344802 | 26 |
| | G-3379C | 252550080344803 | 10 |
| Downgradient | G-3380A | 252543080344201 | 40 |
| | G-3380B | 252543080344202 | 27 |
| | G-3380C | 252543080344203 | 10 |
| | | *Rockdale grove* | |
| Upgradient | G-3381A | 253312080281001 | 41 |
| | G-3381B | 253312080281002 | 30 |
| | G-3381C | 253312080281003 | 15 |
| Center field | G-3382A | 253307080280501 | 41 |
| | G-3382B | 253307080280502 | 28 |
| | G-3382C | 253307080280503 | 15 |
| Downgradient | G-3383A | 253302080280001 | 41 |
| | G-3383B | 253302080280002 | 28.5 |
| | G-3383C | 253302080280003 | 15 |
| | | *Perrine marl maximum-application field* | |
| Upgradient | G-3384A | 252755080222901 | 41 |
| | G-3384B | 252755080222902 | 24 |
| | G-3384C | 252755080222903 | 10 |
| Center field | G-3385A | 252750080222701 | 50 |
| | G-3385B | 252750080222702 | 30 |
| | G-3385C | 252750080222703 | 10 |
| Downgradient | G-3386A | 252746080222501 | 41 |
| | G-3386B | 252746080222502 | 27 |
| | G-3386C | 252746080222503 | 10 |
| | | *Perrine marl row-crop field* | |
| Upgradient | G-3387A | 252719080251201 | 43 |
| | G-3387B | 252719080251202 | 27.5 |
| | G-3387C | 252719080251301 | 12 |
| Downgradient | G-3388A | 252732080245801 | 43.5 |
| | G-3388B | 252732080245802 | 28.5 |
| | G-3388C | 252732080245803 | 13 |

Appendix II.--Wilcoxon signed ranks tests that indicate a statistically significant difference in water quality between areas of the fields (0.05 significance level)

[Positive test statistics indicate the first well in the column heading was higher; negative test statistics indicate the second well in the column heading was higher. Where values are given, except as noted by an asterisk, the relation indicated by the test is explained by preexisting conditions or by one or two high values as discussed in the "Data Interpretation" section. Dashes indicate the test was not significant at the 0.05 significant level. An asterisk next to a given value denotes that the relation, indicated by the test, is discussed in the text]

| Constituent | Well | Test statistics: Upgradient/ center field | Test statistics: Upgradient/ downgradient | Test statistics: Center field/ downgradient |
|---|---|---|---|---|
| | Rockdale maximum-application field[1] | | | |
| Alkalinity | Shallow | -4.35 | -4.03 | -- |
| | Middepth | -4.24 | -4.24 | -- |
| | Deep | -4.35 | | |
| Specific conductance | Shallow | -- | -- | -- |
| | Middepth | -- | -- | -4.24* |
| | Deep | -- | | |
| Ammonia | Shallow | -- | -- | -4.24 |
| | Middepth | -4.35 | -4.24 | -4.90 |
| | Deep | -4.24 | | |
| Nitrite + nitrate nitrogen | Shallow | 6.00 | 4.74 | 6.00 |
| | Middepth | -- | 6.00 | 6.00 |
| | Deep | -- | | |
| Total organic carbon | Shallow | -- | -- | -- |
| | Middepth | -- | -- | -- |
| | Deep | 4.24 | | |
| Total phosphorus | Shallow | -- | -- | 6.00 |
| | Middepth | 4.74 | 4.74 | -- |
| | Deep | -- | | |
| Arsenic | Shallow | -- | -- | 4.35* |
| | Middepth | 6.00 | 6.00 | -- |
| | Deep | -- | | |
| Cadmium | Shallow | -- | -- | -- |
| | Middepth | 6.00 | 4.74 | 6.00 |
| | Deep | -- | | |
| Copper | Shallow | -- | -- | -- |
| | Middepth | -- | -- | 4.47* |
| | Deep | -- | | |
| Iron | Shallow | -- | -- | -- |
| | Middepth | -- | -- | -- |
| | Deep | -4.35 | | |
| Lead | Shallow | -- | -- | -- |
| | Middepth | -- | -- | -- |
| | Deep | 6.00 | | |
| Manganese | Shallow | -- | -- | -- |
| | Middepth | -- | -- | 6.00 |
| | Deep | -- | | |
| Mercury | Shallow | -- | -- | 6.00 |
| | Middepth | 6.00 | 5.00 | -- |
| | Deep | -- | | |
| Nickel | Shallow | 6.00 | -- | -- |
| | Middepth | -- | -- | -- |
| | Deep | -- | | |
| Potassium | Shallow | 4.24 | 4.35 | -- |
| | Middepth | -- | -- | 4.35* |
| | Deep | -- | | |
| Sodium | Shallow | 4.35 | -- | -- |
| | Middepth | -- | -- | -- |
| | Deep | 4.74 | | |
| Zinc | Shallow | -- | 4.74 | 4.90 |
| | Middepth | -- | -- | -- |
| | Deep | -- | | |

Appendix II.--Wilcoxon signed ranks tests that indicate a statistically significant difference in water quality between areas of the fields (0.05 significance level)--Continued

| Constituent | Well | Test statistics: Upgradient/ center field | Test statistics: Upgradient/ downgradient | Test statistics: Center field/ downgradient |
|---|---|---|---|---|
| | | **Rockdale grove[2]** | | |
| Specific conductance | Shallow | -- | -- | -- |
| | Middepth | | | -3.67 |
| | Deep | -- | -- | -- |
| Ammonia | Shallow | -- | -- | 8.00 |
| | Middepth | | | -- |
| | Deep | -- | -- | -- |
| Nitrite + nitrate nitrogen | Shallow | -4.99 | -4.94 | -3.27 |
| | Middepth | | | -- |
| | Deep | -5.08 | -- | 4.94* |
| Total phosphorus | Shallow | 8.00 | -- | -- |
| | Middepth | | | 8.00 |
| | Deep | 6.11 | 6.11 | -- |
| Chloride | Shallow | 2.99 | 3.70 | 5.47* |
| | Middepth | | | 5.47* |
| | Deep | 2.65 | 4.99 | -- |
| Cadmium | Shallow | -- | 8.00 | 6.20 |
| | Middepth | | | -- |
| | Deep | -- | 6.11 | 8.00 |
| Copper | Shallow | -- | -- | -- |
| | Middepth | | | -- |
| | Deep | 6.20 | -- | -- |
| Iron | Shallow | -- | -- | -- |
| | Middepth | | | -- |
| | Deep | 4.99* | -- | -- |
| Lead | Shallow | -- | -- | 8.00 |
| | Middepth | | | -- |
| | Deep | -- | -- | -- |
| Manganese | Shallow | 6.20 | 6.11 | 8.00 |
| | Middepth | | | -- |
| | Deep | -- | 6.11 | 6.11 |
| Mercury | Shallow | -- | 5.41* | 5.41* |
| | Middepth | | | -- |
| | Deep | -- | -- | -- |
| Potassium | Shallow | 3.28 | -4.99 | -4.94 |
| | Middepth | | | -3.74 |
| | Deep | -5.13 | -2.99 | -- |
| Sodium | Shallow | 5.29 | 5.13 | 6.20 |
| | Middepth | | | -- |
| | Deep | 5.13 | 5.18 | -2.62* |
| Zinc | Shallow | -- | 6.11* | 8.00* |
| | Middepth | | | -- |
| | Deep | 8.00 | 6.20 | 8.00 |
| | | **Perrine marl maximum-application field** | | |
| Alkalinity | Shallow | -4.24 | -- | 4.24 |
| | Middepth | 3.87* | -3.87* | -4.24* |
| | Deep | 3.87* | -3.87* | -3.87* |
| Specific conductance | Shallow | 3.12 | 4.65 | 4.65 |
| | Middepth | -4.58 | -4.58 | 3.12 |
| | Deep | -4.65 | 4.58 | 4.58 |
| Ammonia | Shallow | -- | -4.58 | -4.58 |
| | Middepth | -- | -- | 4.87 |
| | Deep | 4.58* | 4.87* | -4.65* |
| Kjeldahl nitrogen | Shallow | 4.58 | -- | -4.72 |
| | Middepth | -- | -- | -- |
| | Deep | 4.72 | 4.96 | -5.42 |

Appendix II.--Wilcoxon signed ranks tests that indicate a statistically significant difference in water quality between areas of the fields (0.05 significance level)--Continued

| Constituent | Well | Test statistics: Upgradient/ center field | Test statistics: Upgradient/ downgradient | Test statistics: Center field/ downgradient |
|---|---|---|---|---|
| **Perrine marl maximum-application field--Continued** | | | | |
| Total organic carbon | Shallow | 4.24* | -- | -- |
| | Middepth | 4.24* | -- | -- |
| | Deep | -- | -- | -- |
| Total phosphorus | Shallow | -- | 4.65 | 7.00 |
| | Middepth | -- | -- | -- |
| | Deep | -4.95* | -- | -- |
| Chloride | Shallow | 4.58 | 4.58 | 4.95 |
| | Middepth | -4.72 | -3.18 | 5.22 |
| | Deep | -4.65 | 4.95 | 4.72 |
| Arsenic | Shallow | -- | 4.58 | 4.74 |
| | Middepth | 5.42* | 5.22 | -4.95* |
| | Deep | 4.95* | 4.95* | -- |
| Cadmium | Shallow | -- | -- | -- |
| | Middepth | 5.53 | 5.53 | -- |
| | Deep | -- | -- | -- |
| Chromium | Shallow | -- | 4.87 | -- |
| | Middepth | -- | 5.42 | 5.53 |
| | Deep | -- | -- | -- |
| Copper | Shallow | 4.65* | -- | -- |
| | Middepth | 5.53 | -- | -- |
| | Deep | -- | -- | -- |
| Iron | Shallow | -- | 4.58 | 4.58 |
| | Middepth | 4.58 | -- | -4.65* |
| | Deep | 4.58* | -4.65* | -4.58* |
| Lead | Shallow | 7.00 | 7.00 | 7.00 |
| | Middepth | 7.00 | 7.00 | -- |
| | Deep | -- | -- | -- |
| Manganese | Shallow | 4.58 | 4.65 | -- |
| | Middepth | -- | -- | -- |
| | Deep | -5.42* | 5.53 | 4.95* |
| Mercury | Shallow | -- | -- | -- |
| | Middepth | -- | -- | -- |
| | Deep | -- | -- | 4.24* |
| Nickel | Shallow | 5.42 | -- | -- |
| | Middepth | -- | -- | -- |
| | Deep | 5.42 | -- | -- |
| Potassium | Shallow | -- | 4.58 | 4.65 |
| | Middepth | -- | -4.65 | -- |
| | Deep | -4.58 | -- | 4.58 |
| Sodium | Shallow | 4.65 | 4.65 | 4.65 |
| | Middepth | -4.95 | -4.65 | 4.65 |
| | Deep | -4.65 | 4.65 | 4.58 |
| Zinc | Shallow | 4.72* | 4.65* | 5.24 |
| | Middepth | -- | -- | -- |
| | Deep | -5.42* | -- | -- |
| **Perrine marl row-crop field[4]** | | | | |
| Specific conductance | Middepth | | 4.24 | |
| | Deep | | -- | |
| Ammonia | Middepth | | 4.90 | |
| | Deep | | -- | |
| Nitrite + nitrate nitrogen | Middepth | | -4.24 | |
| | Deep | | -4.35 | |
| Total organic carbon | Middepth | | 6.00 | |
| | Deep | | -- | |

Appendix II.--Wilcoxon signed ranks tests that indicate a statistically significant difference in water quality between areas of the fields (0.05 significance level)--Continued

| Constituent | Well | Test statistics: Upgradient/ center field | Test statistics: Upgradient/ downgradient | Test statistics: Center field/ downgradient |
|---|---|---|---|---|
| | Perrine marl row-crop field[4]--Continued | | | |
| Chromium | Middepth | | 6.00 | |
| | Deep | | 4.90 | |
| Manganese | Middepth | | 6.00 | |
| | Deep | | -- | |
| Potassium | Middepth | | -4.35 | |
| | Deep | | -4.35 | |
| Sodium | Middepth | | -2.89 | |
| | Deep | | -- | |

[1] Blank values for the deep wells because there were not enough samples from downgradient well to make comparison.
[2] Blank values for the middepth wells because the upgradient well was destroyed soon after drilling.
[3] Relation indicated by the test is explained by a naturally occurring decrease in brackishness at the field or by the difference in well depth (both described in the text).
[4] Blank values because there was no center-field well cluster.

Appendix III.--Pesticides and organic priority pollutants analyzed for the study

[Detection limits shown in micrograms per liter]

| Storet code | Compound | Detection limits |
|---|---|---|
| **Acid-extractable compounds** | | |
| 34452 | 4-Chloro-3-methylphenol | 1, 5, 30 |
| 34586 | 2-Chlorophenol | 1, 5, 6 |
| 34601 | 2,4-Dichlorophenol | 1, 5, 6 |
| 34606 | 2,4-Dimethylphenol | 1, 5, 6 |
| 34657 | 4,6-Dinitro-2-methylphenol | 1, 30 |
| 34616 | 2,4-Dinitrophenol | 1, 20 |
| 34591 | 2-Nitrophenol | 1, 5, 6 |
| 34646 | 4-Nitrophenol | 1, 30 |
| 39032 | Pentachlorophenol | 1, 30 |
| 34694 | Phenol | 1, 5, 6 |
| 34621 | 2,4,6-Trichlorophenol | 1, 5, 20 |
| **Base/neutral-extractable compounds** | | |
| 34205 | Acenaphthene | 1, 5 |
| 34200 | Acenaphthylene | 1, 5 |
| 34220 | Anthracene | 1, 5 |
| 34526 | Benz (a) anthracene | 1, 5, 10 |
| 34230 | Benzo (b) fluoranthene | 1, 10 |
| 34242 | Benzo (k) fluoranthene | 1, 10 |
| 34521 | Benzo (g,h,i) perylene | 1, 10 |
| 34247 | Benzo (a) pyrene | 1, 10 |
| 34636 | 4-Bromophenyl phenyl ether | 1, 5 |
| 34292 | Butyl benzyl phthalate | 1, 5 |
| 34278 | bis (2-Chloroethoxy) methane | 1, 5 |
| 34273 | bis (2-Chloroethyl) ether | 1, 5 |
| 34283 | bis (2-Chloroisopropyl) ether | 1, 5 |
| 34581 | 2-Chloronaphthalene | 1, 5 |
| 34641 | 4-Chlorophenyl phenyl ether | 1, 5 |
| 34320 | Chrysene | 1, 10 |
| 34556 | Dibenzo (a,h) anthracene | 1, 10 |
| 34536 | 1,2-Dichlorobenzene | 1, 5 |
| 34566 | 1,3-Dichlorobenzene | 1, 5 |
| 34571 | 1,4-Dichlorobenzene | 1, 5 |
| 34336 | Diethyl phthalate | 1, 5 |
| 34341 | Dimethyl phthalate | 1, 5 |
| 39110 | Di-n-butyl phthalate | 1, 5 |
| 34611 | 2,4-Dinitrotoluene | 1, 5 |
| 34626 | 2,6-Dinitrotoluene | 1, 5 |
| 34596 | Di-n-octylphthalate | 1, 5 |
| 39100 | bis (2-Ethylhexyl) phthalate | 1, 5 |
| 34376 | Fluoranthene | 1, 5 |
| 34381 | Fluorene | 1, 5 |
| 39700 | Hexachlorobenzene | 1, 5 |
| 39702 | Hexachlorobutadiene | 1, 5 |
| 34386 | Hexachlorocyclopentadiene | 1, 5 |
| 34396 | Hexachloroethane | 1, 5 |
| 34403 | Indeno (1,2,3-cd) pyrene | 1, 10 |
| 34408 | Isophorone | 1, 5 |
| 34696 | Naphthalene | 1, 5 |
| 34447 | Nitrobenzene | 1, 5 |
| 34438 | n-Nitrosodimethylamine | 1, 5 |
| 34428 | n-Nitrosodi-n-propylamine | 1, 5 |
| 34433 | n-Nitrosodiphenylamine | 1, 5 |
| 34461 | Phenanthrene | 1, 5 |
| 34469 | Pyrene | 1, 5 |
| 34551 | 1,2,4-Trichlorobenzene | 1, 5 |
| **Volatile organic compounds** | | |
| 34030 | Benzene | 3, 0.2 |
| 32104 | Bromoform | 3, .2 |
| 32102 | Carbon tetrachloride | 3, .2 |
| 34301 | Chlorobenzene | 3, .2 |
| 34311 | Chloroethane | 3, .2 |
| 34576 | 2-Chlorethyl vinyl ether | 3, .2 |
| 32106 | Chloroform | 3, .2 |
| 32105 | Dibromochloromethane | 3, .2 |
| 32101 | Dichlorobromomethane | 3, .2 |
| 34496 | 1,1-Dichloroethane | 3, .2 |
| 32103 | 1,2-Dichloroethane | 3, .2 |
| 34501 | 1,1-Dichloroethylene | 3, .2 |
| 34546 | 1,2-trans-Dichloroethylene | 3, .2 |
| 34541 | 1,2-Dichloropropane | 3, .2 |
| 34561 | 1,3-Dichloropropene | 3, .2 |
| 34371 | Ethylbenzene | 3, .2 |
| 34413 | Methylbromide | 3, .2 |
| 34423 | Methylene chloride | 3, .2 |
| 34516 | 1,1,2,2-Tetrachloroethane | 3, .2 |
| 34475 | Tetrachloroethylene | 3, .2 |
| 34010 | Toluene | 3, .2 |
| 34506 | 1,1,1-Trichloroethane | 3, .2 |
| 34511 | 1,1,2-Trichloroethane | 3, .2 |
| 39180 | Trichloroethylene | 3, .2 |
| 39175 | Vinyl chloride | 3, .2 |
| **Organochlorine compounds** | | |
| 39330 | Aldrin | 0.01 |
| 39350 | Chlordane | .1 |
| 39360 | DDD | .01 |
| 39365 | DDE | .01 |
| 39370 | DDT | .01 |
| 39570 | Diazinon | .01 |
| 39380 | Dieldrin | .01 |
| 39388 | Endosulfan | .01 |
| 39390 | Endrin | .01 |
| 39398 | Ethion | .01 |
| 39516 | Gross polychlorinated biphenyls | .1 |
| 39250 | Gross polychlorinated naphthalenes | .1 |
| 39410 | Heptachlor | .01 |
| 39420 | Heptachlor epoxide | .01 |
| 39340 | Lindane | .01 |
| 39530 | Malathion | .01 |
| 39480 | Methoxychlor | .01 |
| 39600 | Methyl parathion | .01 |
| 39790 | Methyl trithion | .01 |
| 39755 | Mirex | .01 |
| 39540 | Parathion | .01 |
| 39034 | Perthane | .1 |
| 39400 | Toxaphene | 1.0 |
| 39786 | Trithion | .01 |
| **Chlorophenoxy acid herbicides** | | |
| 39730 | 2,4-D | 0.01 |
| 82183 | 2,4-DP | .01 |
| 39760 | Silvex | .01 |
| 39740 | 2,4,5-T | .01 |



*U.S. Government Printing Office: 1992— 631-117/40013