

**EFFECTS OF LAND USE ON GROUND-WATER QUALITY IN CENTRAL FLORIDA--PRELIMINARY
RESULTS: U.S. GEOLOGICAL SURVEY TOXIC WASTE--GROUND-WATER CONTAMINATION PROGRAM**

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 86-4163

Prepared in cooperation with the
FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION



Tallahassee, Florida

1987

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**EFFECTS OF LAND USE ON GROUND-WATER QUALITY IN CENTRAL FLORIDA--
PRELIMINARY RESULTS: U.S. GEOLOGICAL SURVEY TOXIC WASTE--
GROUND-WATER CONTAMINATION PROGRAM**

By A.T. Rutledge

ABSTRACT

Ground water is the principal source of drinking water in central Florida. The most important hydrogeologic unit is the Floridan aquifer system, consisting of fractured limestone and dolomitic limestone. Above it in the southwestern part of central Florida is the intermediate aquifer whose permeable layers are mainly fractured limestone. Where the limestone is missing, only low permeability materials lie between the Floridan aquifer system and the surficial aquifer that immediately underlies the land surface throughout the area.

Activities of man in areas of recharge to the Floridan aquifer system that may be affecting ground-water quality include: (1) the use of drainage wells for stormwater disposal in urban areas, (2) the use of pesticides and fertilizers in citrus groves, and (3) the mining and processing of phosphate ore in mining areas. This report presents preliminary findings about the impacts of these land uses on ground-water quality by comparison with a fourth land use representing the absence of human activity in another area of recharge. It may be hypothesized that there are relations between land use and the prevailing trace element and organic compound composition of ground water, and that particular problems are associated with each land use.

Drainage wells convey excess urban stormwater directly to the Upper Floridan aquifer. Among the trace elements and organic compounds, the volatile organic compounds are the most common contaminants in ground water. These include chlorinated ethane compounds, chloroform, benzene, ethyl benzene, toluene, and methane. Other contaminants include nonvolatile organic compounds such as acenaphthene, silvex, and 2,4-D. Trace elements such as chromium and lead are entering the aquifer but their movement is apparently attenuated by precipitation reactions associated with high pH or by cation-exchange reactions.

Activities associated with citrus production include use of pesticides applied by spraying or direct application to the soil and trees. These chemicals can be transported downward to ground water by rainfall and irrigation water. Among the trace elements and organic chemicals, most ground-water contamination in citrus production areas is caused by pesticides, which include the organic compounds simazine, ametryne, chlordane, DDE, bromacil, aldicarb, EDB, trifluralin, and diazinon, and the trace elements zinc and copper; other contaminants include benzene, toluene, naphthalene, and indene compounds.

Activities associated with the phosphate industry include mining of the upper confining layer, use of interaquifer connector wells, and deposition of byproducts in gypsum stacks, clayey waste ponds, and sand tailings. Trace elements indigenous to the rocks in the mining area are mobilized in gypsum stack cooling ponds and in clayey waste ponds and may enter ground water from these sources. Mixtures of organic compounds are used to facilitate separation processes in phosphate processing plants. Components of these mixtures may enter ground water at sites of sand tailings and clay slime discharge. The potential for downward migration of contaminants to ground water is increased by the breaching of the confining layer and by interaquifer connector wells. In the phosphate mining area, the trace elements are the most common contaminants in ground water among trace elements and organic compounds. Constituents of concern are arsenic, selenium, and mercury, and secondarily are lead, chromium, cadmium, and others. Organic compounds such as fluorene, naphthalene, di-n-butyl phthalate, alkylated benzenes and naphthalenes, and indene compounds also are entering ground water.

INTRODUCTION

Background

Ground water is the principal source of drinking water in central Florida. The most important hydrogeologic unit for water supply is the Floridan aquifer system which consists of fractured limestone and dolomitic limestone of Paleocene to early Miocene age. An intermediate aquifer, consisting primarily of clayey sand, gravel, shell, and fractured limestones of Miocene age, and the surficial aquifer, consisting primarily of sand and shell beds of Pleistocene and Holocene age, generally play lesser roles in supplying water. However, these aquifers may locally be important because of the expense of drilling deep wells or because of local water-quality problems in the Floridan aquifer system.

Human activities at the land surface can affect the quality of water recharging these aquifers. Three major human activities, or land uses, in areas of recharge to the Floridan aquifer system in central Florida are: (1) urbanization in karstic terrane with accompanying stormwater disposal through drainage wells, (2) citrus growing with its application of fertilizers and pesticides, and (3) phosphate ore mining and processing with associated chemical use. The effects of these land uses may be evaluated by comparison with a land use representing the absence of human activity in another recharge area. Although a number of studies have dealt with ground-water quality in central Florida, most have not included organic compounds and trace elements. Thus, there is a need to assess the quality of ground water (trace elements and organic chemicals) particularly as it relates to these various land uses.

This study, 1 of 14 being made throughout the country as part of the Toxic Waste--Ground Water Contamination Program of the Geological Survey, seeks to relate land-use and associated activities to ground-water quality in central Florida. Collectively, the findings from all of these studies will be used to assess the present quality of the Nation's ground-water resource (Helsel and Ragone, 1984). A parallel study done as part of the cooperative program between the Florida Department of Environmental Regulation and the U.S. Geological Survey provided considerable supplemental information on water quality for the areas discussed herein.

The locations of the study areas, which range in size from 80 to 200 mi², are shown in figure 1. The urban area includes most, or all, of the cities of Orlando, Winter Park, and Maitland, where more than 300 drainage wells are located. The citrus growing area is about 15 miles west-southwest of downtown Orlando and is bounded on the east by the town of Windermere. The phosphate mining area, which includes the town of Bartow, is 25 miles east of Tampa and is one of the most active phosphate mining areas in the world. The undeveloped control area is 30 miles north-northwest of Orlando in the Ocala National Forest and is one of the least developed areas in central Florida.

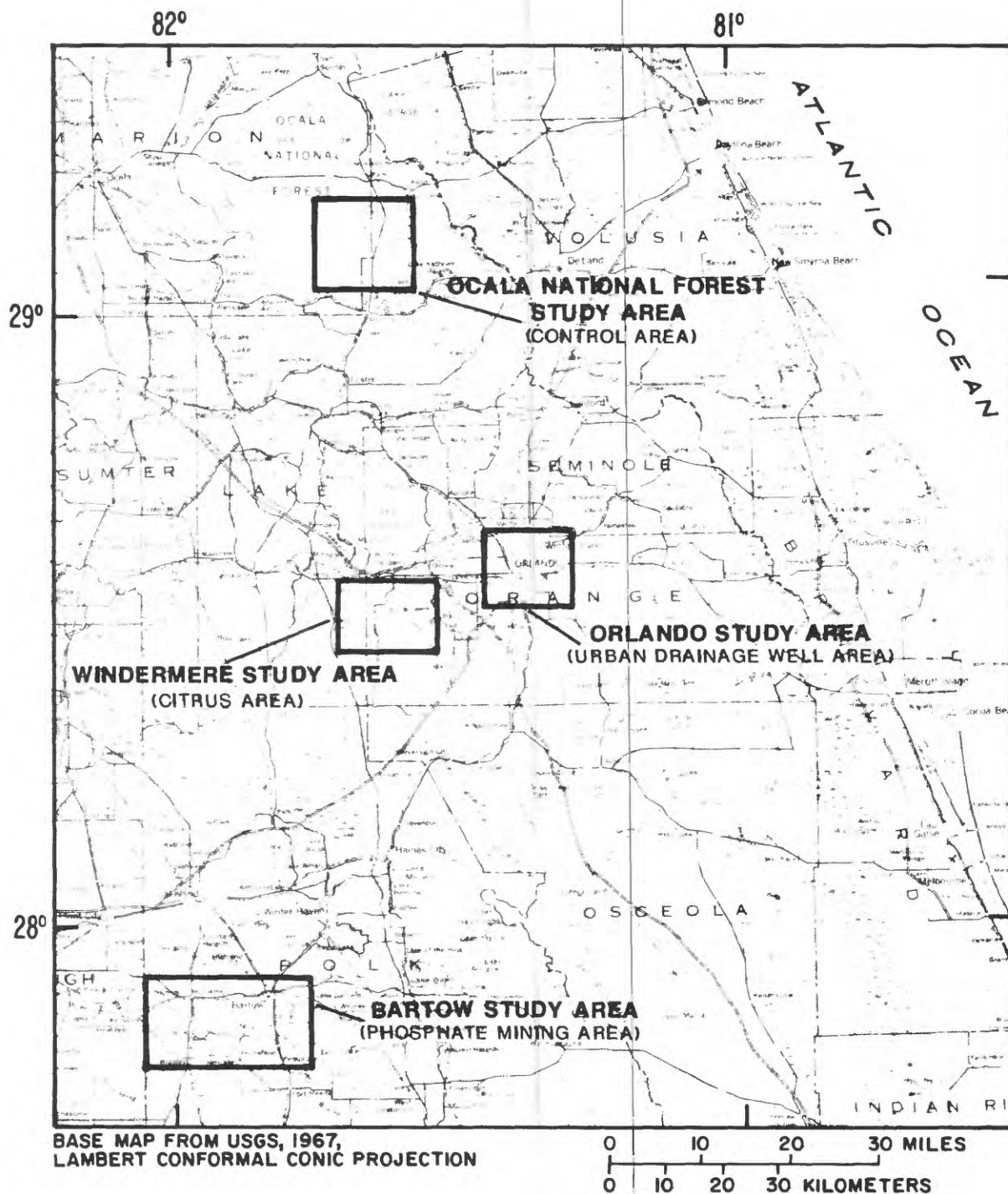


Figure 1.--Locations of study areas.

Purposes and Scope

This report describes the reconnaissance phase of study conducted from April 1984 to March 1985. The purpose of this investigation is to study the effect of land uses on ground-water quality. To accomplish this, the following approach is being used:

1. Identify chemicals used and chemical byproducts in each land-use type.
2. Indicate which chemicals are likely ground-water contaminants by describing the chemical characteristics of surface water and sediment that have been directly affected by development (source conditions).
3. Relate each land use to a characteristic ground-water quality, and statistically compare the similarities and differences in water quality among the four areas.

This preliminary report describes results of the first phase of the investigation, and information herein includes: maps showing the distribution of development of land use in each area, a summary of chemicals found in ground water during previous investigations, results of sampling of water and sediment near the source of contamination, results of sampling of water in aquifers, and hypotheses about the relation between land use and ground-water quality to be further tested.

Each of the three developed areas is representative of land use over a larger area so results of this investigation may be transferable. For instance, drainage wells are found in several urban areas in peninsular Florida. Citrus growing is a major Florida industry and groves are common in much of central and south Florida. Phosphate mining is expanding southward of the study area shown.

Most of each study area may be characterized as recharge areas to regional ground-water flow systems. Thus, in general, there is potential for movement of contaminants from the land surface into underlying aquifers in these areas.

The physical and chemical analyses made in this investigation include water from all aquifers in use. Water-quality analyses in this study generally are limited to organic compounds and trace elements.

LAND-USE TYPES AND POTENTIAL EFFECTS ON GROUND-WATER QUALITY

Control Area

The undeveloped control area is located in the southern part of the Ocala National Forest. Approximately 65 percent of the area is upland forest. The remainder consists of wetlands, water, and rangeland in approximately equal parts. Because of the scarcity of human activities, the ground-water quality should represent natural conditions.

Urban Area

Approximately 45 percent of the Orlando study area is residential, whereas the remaining land uses and their percentage of the area are: commercial and services, 15 percent; industrial and commercial complexes, 5 percent; transportation and other urban land uses, 10 percent; lakes, 5 percent; and others, 20 percent. The remainder includes varied land uses such as wetlands, citrus groves, and barren land.

Drainage wells are used in several urban areas in Florida. Drainage wells open to the Floridan aquifer system are commonly used to supplement surface drainage for urban areas in the karst terraces of central and north Florida, whereas drainage wells open to the Biscayne aquifer are used to dispose of stormwater runoff in southeast Florida (Kimrey and Fayard, 1984). Drainage wells in the Floridan aquifer system are the primary means of urban drainage for Orlando, Ocala, and Live Oak. Early use of drainage wells included disposal of domestic sewage and industrial wastewater, but their present use is mainly regulation of lake stages and disposal of stormwater.

Drainage wells, which are abundant in the study area (fig. 2), average about 4 wells per mi^2 throughout the study area and about 15 wells per mi^2 in the downtown Orlando area. These wells are open to the Upper Floridan aquifer and range in depth from about 120 to 1,050 feet; median depth is 400 feet. With the possible exception of the single deepest well, no drainage wells are known to penetrate the Lower Floridan aquifer. About 50 percent of the drainage wells are used to dispose of street and other impervious area runoff, 35 percent to regulate lake levels, and 15 percent to dispose of cooling, air conditioning, and other wastewaters (Schiner and German, 1983).

Possible ground-water contaminants in the Orlando study area include chemicals or groups of chemicals that are typical of urban runoff. A partial list includes lead, iron, zinc, organic solvents, petroleum compounds, herbicides, and insecticides. Highway runoff is characteristically rich in organic-compound and trace-element contamination. Average loads at six sites reported by Gupta and others (1981), in pounds per storm per acre, ranged from 0.96 to 3.83 for total organic carbon, 0.007 to 0.21 for total lead, and 0.006 to 0.05 for zinc. Other sources of contamination include service stations, private lawns, golf courses, and runoff from lakes where herbicides are used for aquatic weed control.

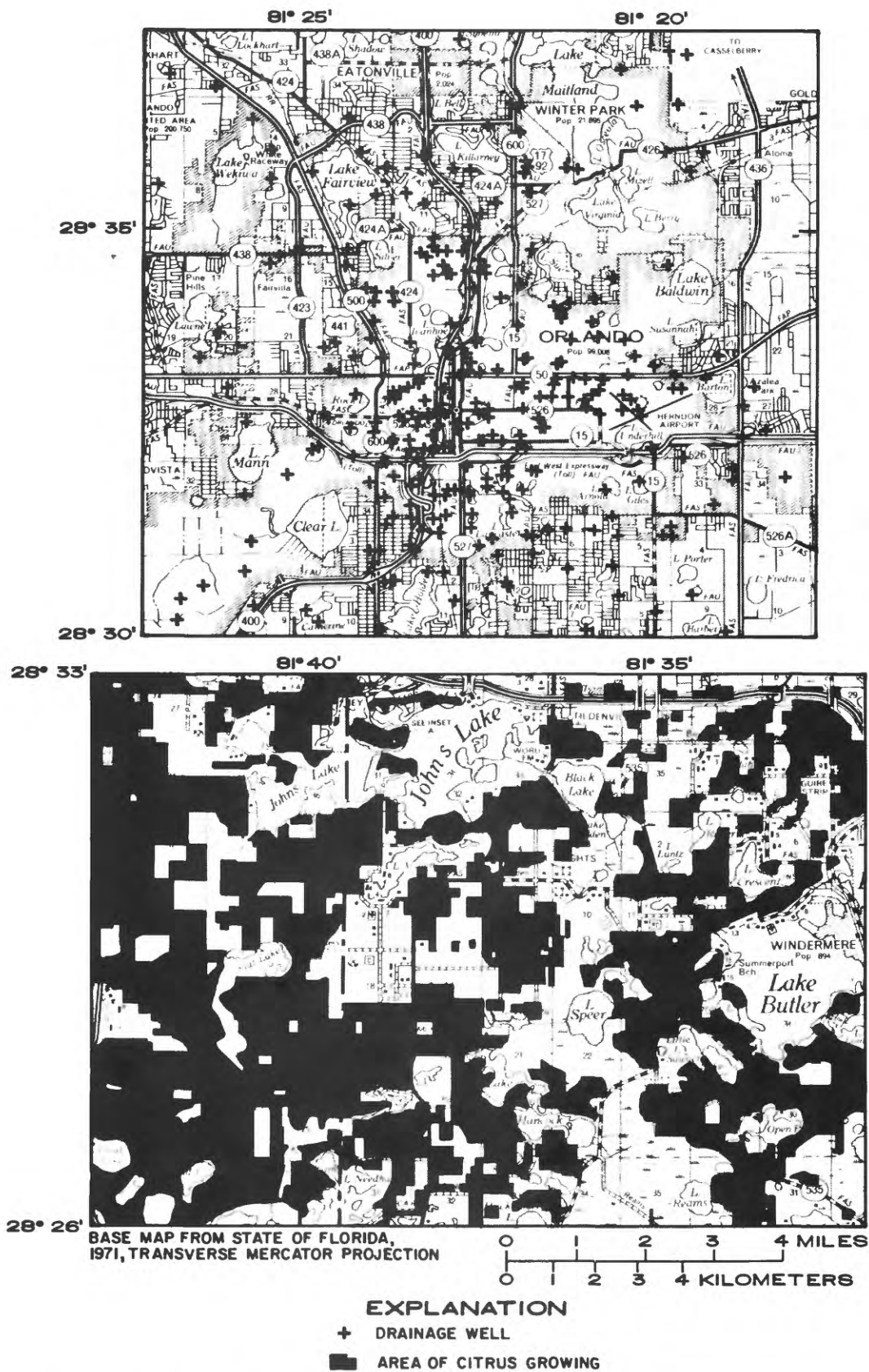


Figure 2.--Extent of development shown by (A) distribution of drainage wells in the urbanized Orlando study area, and (B) distribution of citrus in the Windermere study area.

Citrus Area

Citrus farming is one of the largest industries in Florida, and is particularly concentrated in areas of central Florida such as the Windermere area (fig. 2). Approximately 40 percent of this area is occupied by citrus groves. Other land-cover types in the study area include: cropland, pastures, and barren land, 25 percent; wetlands, 10 percent; lakes, 10 percent; and others, 15 percent. Optimal production of citrus in this area requires large water irrigational withdrawals from the Upper Floridan aquifer and the use of numerous chemicals, including fertilizers, insecticides, herbicides, fungicides, and others. Methods of application include spraying, direct application to the soil, and direct application to the trees. Organic-compound pesticides in use include benomyl, bromocil, diuron, dicofol, chlorobenzilate, and oils, which are each used on more than 100,000 acres in Florida. Additional organic-compound pesticides which have been used for citrus include ethylene dibromide (EDB) and aldicarb. Trace elements used as pesticides include copper and zinc (University of Florida, 1981). Trace elements applied to citrus as nutrients include copper, manganese, and zinc.

Ground-water contamination can occur by infiltration to the water table (in the surficial aquifer) and is accelerated by heavy rainfall and irrigation. Further downward movement to the Upper Floridan aquifer can occur by leakage through the confining layer or by percolation through breaches in the confining layer as a result of past sinkhole activity.

Mining Area

Approximately one-fifth of the phosphate production in the world occurs in central Florida. The Bartow area (fig. 3) is representative of heavily mined areas in central Florida. Land cover includes barren land, 40 percent; rangeland, 20 percent; industrial complexes, 10 percent; water and wetlands, 10 percent; and others, 20 percent. Most of the barren land and rangeland represent mined areas in various stages of reclamation.

Phosphate ore is found within the unconsolidated upper confining unit (fig. 4). Mining generally is accomplished by drag-line displacement of the overburden (the surficial aquifer) followed by removal of phosphate ore for processing.

Interaquifer connector wells are installed to remove water from the surficial aquifer during mining operations. These wells are open to the surficial aquifer and a deeper aquifer. Water flows from the surficial aquifer into the well, then downward into the intermediate aquifer or the Upper Floridan aquifer, or both, thereby lowering water levels in the surficial aquifer.

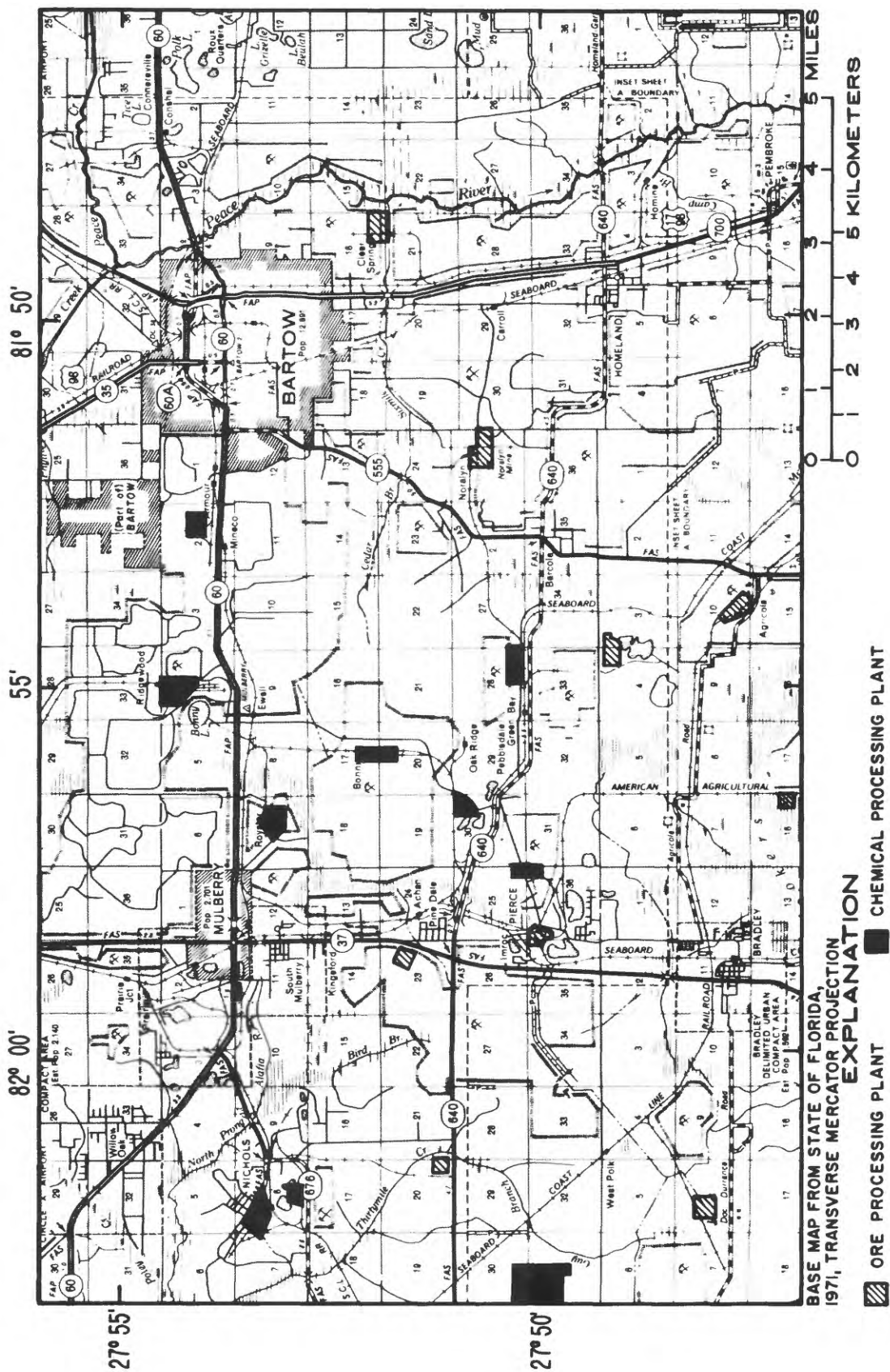


Figure 3.--Distribution of phosphate industry plants in the Bartow study area.

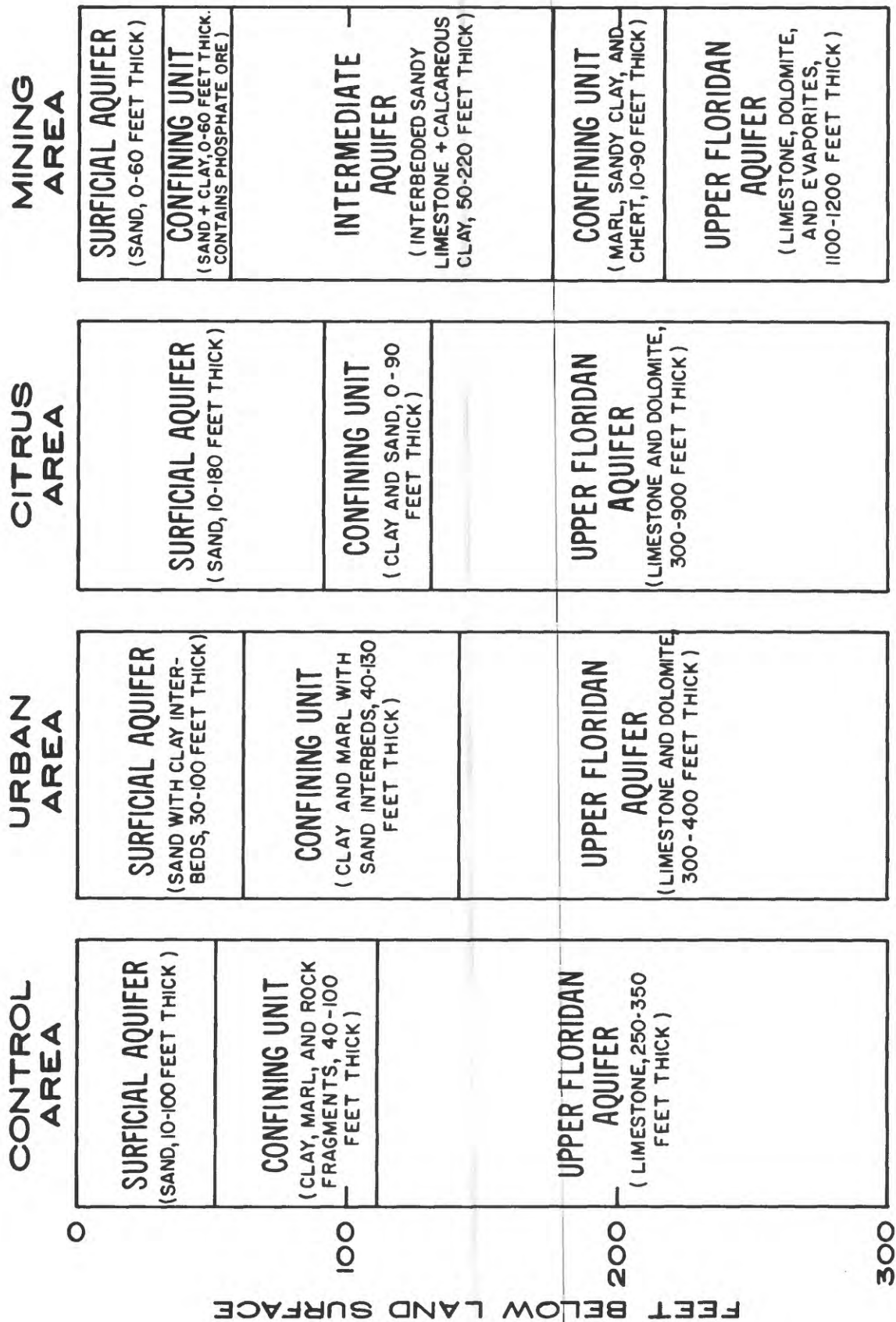


Figure 4.--Generalized geohydrologic columns. (Thickness of units other than the Upper Floridan aquifer, as drawn, indicate average thicknesses of units.)

Upon excavation, the ore is mixed with water and the resulting slurry is transported through pipes to an ore processing plant. The processing plant separates the phosphate particles, which make up approximately one-third of the ore, from the unwanted sands and clays, which each make up approximately one-third. The ore processing involves sieving and flotation and produces a sand slurry and a clay slurry, which are then disposed of in sand tailings and slime ponds, respectively. The water that is used for transport is recycled. There are nine ore processing plants in the area (fig. 3).

The phosphate extracted from the ore is transported to a chemical processing plant where it is reacted with sulfuric acid to produce phosphoric acid. A voluminous byproduct of this reaction is gypsum, which is transported, as a slurry, to gypsum stacks. Process water flows from the stacks into cooling ponds and is recycled for further use. There are 10 chemical processing plants in the Bartow area (fig. 3).

A potential for aquifer contamination arises because mixtures of organic chemicals, including kerosene and fuel oil, are used to facilitate separation processes in ore processing plants. Sand tailings may represent diffuse sources of organic-chemical contamination. Because of the acidity of process waters in chemical processing plants, some trace elements may have increased mobility in the hydrologic environment. Furthermore, mixtures of organic chemicals, including phenols, are used to facilitate separation processes in chemical processing plants. Gypsum stacks and cooling ponds may therefore represent potential sources of ground-water contamination. The surficial aquifer, which is the receiving aquifer in the phosphate mining area, can be contaminated by seepage from sand tailings, slime ponds, cooling ponds, and recirculation ditches. Contamination of deeper aquifers by downward seepage can be accelerated by breaching of the upper confining layer caused by mining. Downward movement of contaminants also can be facilitated by interaquifer connector wells.

PREVIOUS WORK AND WATER-QUALITY FINDINGS

Control Area

The control area has been studied to a limited extent in the past. A part of it was studied as a small segment of a Lake County investigation by Knochenmus and Hughes (1976). No data on trace elements and organic compounds in ground water existed before the present study.

Urban Area

The hydrology of the urban area has been studied extensively in the past, and in recent years emphasis has been placed on drainage wells. Reports by Unklesbay (1955) and Lichtler and others (1968) reviewed the physical aspects of drainage wells and the geohydrology of the Orange County area. A report by Kimrey (1978) contains data on hydraulics of drainage wells. Schiner and German (1983) studied the effects of drainage-well recharge on ground-water quality. A report by Kimrey and Fayard (1984) describes the history of drainage wells and explains the varied uses of these wells in Florida.

Analyses of samples for trace elements and organic compounds in the Orlando urban area involved comparisons of water from public-supply wells open to the Floridan aquifer system with water taken from drainage wells after prolonged pumping.

A few trace elements tend to occur at higher concentrations in water from drainage wells than in water from public-supply wells. Schiner and German (1983) found high concentrations for most inorganic constituents; among trace elements, this was especially evident for total recoverable iron. Dissolved trace elements that occur at higher levels in water from drainage wells than public-supply wells included manganese, iron, copper, and zinc. Kimrey and Fayard (1984) found that concentrations of lead and manganese for one sample from a drainage well exceeded the National Secondary Drinking Water Standards (USEPA, 1977), and that the standard for iron was exceeded in 8 of 10 drainage wells. Their data indicated that concentrations of trace elements in water from drainage wells are higher than those in water from public-supply wells.

Schiner and German (1983) found that of 25 pesticide compounds analyzed, 6 (2,4-D, silvex, diazinon, dieldrin, chlordane, and 2,4,5-T) were detected in water from 21 drainage wells, most of which were sampled once during their study. Polychlorinated biphenyls (PCBs) also were detected in three drainage wells. Of the 25 compounds, only silvex and dieldrin were detected in public-supply wells, and they were detected at lower concentrations and at lower frequencies of occurrence than they occurred in drainage wells. German (U.S. Geological Survey, written commun., 1985) noted that phthalates may be common in drainage well inflow in the Orlando area, and that polycyclic aromatic compounds could be present in areas of petroleum contamination.

Citrus Area

The citrus growing area, which includes parts of two counties, has only been studied as a small segment of county-wide investigations: Orange County, by Lichtler and others (1968); and Lake County, by Knochenmus and Hughes (1976). Little data on trace elements and organic compounds in ground water existed before the present study.

Information obtained by universities and State agencies give indications of the pesticides in use in citrus areas. Among the trace elements and the organic compounds, copper and zinc, and benomyl, bromacil, diuron, dicofol, chlorobenzilate, and oils apparently are used the most (University of Florida, 1981). Many other organic-compound pesticides are used. The Florida Department of Health and Rehabilitative Services has documented the widespread occurrence of EDB in ground water (S.H. King, written commun., 1983) and the Florida Department of Environmental Regulation has documented several occurrences of aldicarb in ground water (J.E. McNeal, written commun., 1983).

Mining Area

The physical hydrology of the phosphate mining area was described by Stewart (1966). A report by Robertson and Mills (1974) summarized water use in the area, and Hutchinson (1978) described the geohydrology of the shallow and intermediate aquifers in the area. Kimrey and Fayard (1984) described the use of connector wells in phosphate mining areas.

Two reports by Miller and Sutcliffe (1982; 1984) addressed water-quality effects of an ore processing plant and a chemical plant on the surficial aquifer and intermediate aquifer; trace elements were studied in detail and some reconnaissance samples for organic chemicals were analyzed. Samples of process waters at the chemical plant, clayey waste discharge waters at the ore-processing plant, and water from wells in the surficial aquifer and intermediate aquifer were collected and analyzed.

Clayey waste discharge to slime ponds was found to contain high concentrations of trace elements such as iron, manganese, aluminum, and zinc. These substances are associated with suspended-solid materials and are effectively retained in the slime ponds. Dissolved concentrations of health-related constituents are low in slime ponds. Consequently, Miller and Sutcliffe (1984, p. 177) concluded that the siting of slime ponds to control contamination of ground water should be less critical than siting of gypsum stacks and cooling ponds.

Process waters in chemical plants were found to have higher concentrations of most ions, including trace elements, than native waters. Water samples from wells in the surficial aquifer within a few hundred feet of gypsum stacks had high concentrations of most constituents, although these concentrations were significantly lower than those in process water. Trace elements that occur in high concentrations included cadmium, chromium, copper, zinc, arsenic, beryllium, cobalt, and lithium. Migration of trace elements in the surficial aquifer is believed to be controlled by acid neutralization, and

ground water more than 1,500 feet from stacks was found to be within water-quality standards set by Florida Department of Environmental Regulation (1983). One well in the intermediate aquifer close to a gypsum stack produced water that exceeded the maximum limit for arsenic concentration.

Maximum concentrations of total organic carbon (TOC) in water from wells in the surficial aquifer at chemical processing plants were markedly higher than concentrations from similar wells far from industrial plants. One well at a chemical plant yielded water with a TOC concentration of 370 mg/L (milligrams per liter) and total phenols of 1,300 μ g/L (micrograms per liter). Water from two other wells at the same plant had TOC and phenol concentrations slightly above background levels. These elevated concentrations of TOC and phenol probably were associated with a dump site at the chemical plant.

DATA COLLECTION

Water-level data were collected during this study to define the vertical and horizontal components of ground-water flow in each area. Water levels were measured in wells tapping the Upper Floridan aquifer and the surficial aquifer in all areas. Levels in the intermediate aquifer were monitored in the phosphate mining area, and levels in the Lower Floridan aquifer were monitored in the urbanized area.

In order that identifications could be made of chemicals most likely contaminating ground water in each area, the first sampling effort involved water and sediment close to the probable surface sources of contamination. In the urbanized area, this included surface-water inflow to drainage wells and stagnant water at the tops of water columns in unpumped drainage wells. In the citrus area this included grove soil and water and sediment in small ponds in citrus groves. In the phosphate mining area, this included water in cooling ponds and gypsum stacks at chemical plants, clayey waste discharge and sand tailings discharge from ore processing plants, and water in ditches near industrial plants. To identify chemicals that occur in the natural surface environment, water and sediment in ponds in the control area were sampled.

A second sampling effort was undertaken to determine prevailing chemical characteristics of ground water in the receiving aquifer in each study area. The receiving aquifer is the Upper Floridan aquifer in the drainage well area, but elsewhere it is the surficial aquifer. The Upper Floridan aquifer was sampled by pumping drainage wells with a portable submersible pump until the borehole volume had been evacuated several times. Samples representative of prevailing conditions in the aquifer were then obtained. Irrigation and public-supply wells open to the Upper Floridan aquifer in the drainage well area were pumped and sampled as were wells open to the Upper Floridan in the control area. Wells tapping the surficial aquifer were pumped and sampled in the control area, the citrus area, and the mining area. Additional samples of the surficial aquifer at locations where wells could not be found were obtained using a portable drive-point sampler. Evacuation of water from wells in the surficial aquifer was accomplished with a centrifugal pump, and final sampling from these wells and from the portable drive-point sampler was accomplished with a peristaltic pump.

Samples were analyzed by standard Geological Survey procedures as described by Skougstad and others (1979), and Wershaw and others (1983). In these procedures, trace elements are analyzed by atomic absorption flame spectrometry and organic compounds are extracted from the sample matrix into an organic solvent and analyzed by gas chromatography in combination with various types of detectors. Most of the 129 chemicals termed by the U.S. Environmental Protection Agency as "priority pollutants," and several additional pesticides, were identified using laboratory reference standards. Table 1 shows the constituents that were analyzed. Some organic compounds not compared with laboratory reference standards were tentatively identified using a National Bureau of Standards library of mass spectra of thousands of chemicals. Tentative identifications of these nontarget compounds are given in this report.

Table 1.--List of chemicals analyzed

[These were analyzed using laboratory standard solutions of known chemical composition. All concentrations are in micrograms per liter. Numbers in parentheses are water-quality standards from Florida Department of Environmental Regulation, 1983]

Type and name of chemical	Detection limit	Type and name of chemical	Detection limit	Type and name of chemical	Detection limit
Trace elements					
Arsenic	(50)	Acenaphthene	5.0	Acid extractables	
Barium	(1,000)	Acenaphthylene	5.0	4-Chloro-3-methylphenol	30.0
Cadmium	(10)	Anthracene	5.0	4-Chlorophenol	5.0
Chromium	(50)	Benz(a)anthracene	10.0	2,4-Dichlorophenol	5.0
Copper	(1,000)	Benz(a)pyrene	10.0	2,4-Dimethylphenol	5.0
Iron	(300)	Benzo(g,h,i)perylene	10.0	4,6-Dinitro-2-methylphenol	30.0
Lead	(50)	Benzo(k)fluoranthene	10.0	2,4-Dinitrophenol	20.0
Manganese	(50)	Benzo(b)fluoranthene	10.0	2-Nitrophenol	5.0
Silver	(50)	4-Bromophenyl phenyl ether	5.0	4-Nitrophenol	30.0
Zinc	(5,000)	N-Butylbenzyl phthalate	5.0	Pentachlorophenol	30.0
Selenium	(10)	bis(2-Chloroethoxy)methane	5.0	Phenol	5.0
Mercury	(2)	bis(2-Chloroethyl)ether	5.0	2,4,6-Trichlorophenol	20.0
		bis(2-Chloroisopropyl)ether	5.0		
Volatiles					
Benzene	(1)	2-Chloronaphthalene	5.0	Pesticides	
Bromofom	(3)	4-Chlorophenyl phenyl ether	5.0	Aldrin	0.01
Carbon tetrachloride	(3)	Chrysene	10.0	Ametryne	.1
Chlorobenzene	3.0	1,2,5,6-Dibenzo(a,h)anthracene	10.0	Atrazine	.1
Chlorodibromomethane	3.0	Di-n-butyl phthalate	5.0	Chlordane	.1
Chloroethane	3.0	1,3-Dichlorobenzene	5.0	Cyanazine	.1
Chloroethene	3.0	1,4-Dichlorobenzene	5.0	DDD	.01
2-Chloroethylvinyl ether	3.0	1,2-Dichlorobenzene	5.0	DDE	.01
Chloroform	3.0	Diethyl phthalate	5.0	DDT	.01
		Dimethyl phthalate	5.0	Dieldrin	.01
1,2-trans-Dichloroethylene	3.0	2,6-Dinitrotoluene	5.0	Diazinon	.01
Dichlorobromomethane	3.0	2,4-Dinitrotoluene	5.0	EDB	(.02)
Dichlorodifluoromethane	3.0	Di-n-octylphthalate	10.0	Endosulfan	.01
1,2-Dichloroethane	(3)	bis(2-Ethylhexyl)phthalate	5.0	Endrin	(.2)
1,1-Dichloroethylene	3.0	Fluoranthene	5.0	Ethion	.01
1,2-Dichloropropane	3.0	Fluorene	5.0	Heptachlor	.01
1,3-Dichloropropene	3.0	Hexachlorobenzene	5.0	Heptachlor epoxide	.01
Ethylbenzene	3.0	Hexachlorobutadiene	5.0	Lindane	(4)
Methyl bromide	3.0	Hexachlorocyclopentadiene	5.0	Malathion	.01
Methylene chloride	3.0	Hexachloroethane	5.0	Methoxychlor	.01
1,1,2-Tetrachloroethane	3.0	Indeno(1,2,3-cd)pyrene	10.0	Methyl parathion	.01
Tetrachloroethylene	(3)	Isophorone	5.0	Methyl trithion	.01
Toluene	3.0	Naphthalene	5.0	Mirex	.01
1,1,1-Trichloroethane	(200)	Nitrobenzene	5.0	Parathion	.01
1,1,2-Trichloroethane	3.0	N-Nitrosodi-N-propylamine	5.0	Perthane	.1
Trichloroethylene	(3)	N-Nitrosodimethylamine	5.0	Prometone	.1
Trichlorofluoromethane	3.0	N-Nitrosodiphenylamine	5.0	Prometryne	.1
Vinyl chloride	(1)	Phenanthrene	5.0	Propazine	.1
		Pyrene	5.0	Silvex	(10)
		1,2,4-Trichlorobenzene	5.0	Simazine	.01
Mixtures					
Polychlorinated naphthalenes	.1			Simetryne	.1
Polychlorinated biphenyls	.1			Toxaphene	1.0
				Trithion	.01
				2,4-D	.01
				2,4-DP	.01
				2,4,5-T	.01

GEOHYDROLOGIC SETTING

Climate

The climate in central Florida is classified as subtropical humid and is characterized by relatively wet summers and mild, relatively dry winters. The average annual temperature is about 71°F and average annual rainfall is about 53 inches. More than half of the yearly rainfall occurs during the humid summer months of June through September.

Topography

The topography in most of the undeveloped control area, the urban area, and the citrus growing area is characterized as karst. This is the name applied to the undulating, pitted land surface where sinkholes are numerous and drainage is primarily downward into deep aquifers instead of laterally into streams. The topography of the phosphate mining area is modified flatlands. Before disruption, streams played an important role in land drainage in the mining area. Now, because of mining, the confining layer that had prevented downward movement of ground water has been breached, so that vertical drainage probably has increased and streamflow probably has decreased. In addition, mining has increased topographic relief in the Bartow study area.

Geohydrologic Units

All four study areas are underlain first by the surficial aquifer, composed of sand and clay beds of Pleistocene and Holocene age, and at depth by the Floridan aquifer system, composed of fractured limestone and dolomitic limestone of Paleocene to early Miocene age. Between the surficial aquifer and the Floridan aquifer system lies a sequence of generally discontinuous beds of clay, marl, sand, and limestone of Miocene age. Where the limestone is thick and laterally extensive enough to constitute an aquifer, as it is in the phosphate mining area, the sequence is known as the intermediate aquifer (fig. 4). North and east of the mining area, limestone is missing, and the sequence is primarily a confining unit in the other three study areas. The intermediate aquifer, together with the Upper Floridan aquifer, is used in the phosphate mining area for domestic, industrial, and irrigation purposes. Use of water from the surficial aquifer probably accounts for less than 5 percent of total water use in each of the four areas.

The thickness of the surficial aquifer ranges from 0 to 180 feet and averages about 60 feet in the four study areas. The depth to the water table in the surficial aquifer ranges from 0 to 100 feet and averages close to 20 feet. The Floridan aquifer system, which is 1,500 to 3,500 feet thick in central Florida, is divided into an upper and lower aquifer. The aquifers are separated by a less permeable unit which acts as a semiconfining layer between the two. The Upper Floridan aquifer is the primary source of water in all study areas except the urban area, where more than half of the water pumped is from the Lower Floridan aquifer (not shown in fig. 4). All of the drainage wells route water into the Upper Floridan aquifer.

Ground-Water Flow

Direction and magnitude of ground-water flow are related to distribution of hydraulic head. Figures 5 through 8 show these distributions for each geohydrologic unit. A downward head gradient exists in each area; therefore, all are recharge areas for the regional ground-water system and the possibility exists for downward migration of contaminants. Most water that enters the surficial aquifer in these areas either moves laterally and discharges to local surface-water bodies or is lost to evapotranspiration where the water table is close to land surface. The remainder percolates downward to recharge the intermediate aquifer, where present, or the Upper Floridan aquifer, or both. When ground water enters the Upper Floridan aquifer, it becomes part of a regional flow system and flows toward areas of regional discharge.

Downward leakage into the Upper Floridan aquifer can be estimated using the formula

$$Q = H \times L \quad (1)$$

where

Q = rate of downward leakage, in inches per year;
H = head difference across the confining layer, in feet; and
L = leakance coefficient of the confining layer, in inches per year per foot of head difference.

Using the head difference between the aquifer above the Upper Floridan aquifer and the Upper Floridan from figures 5 through 8, and values of average leakance coefficient from Tibbals (1981) and Ryder (1982), the leakage inflow to the Upper Floridan may be estimated:

<u>Study area</u>	<u>Leakance coefficient [(in/yr)/ft]</u>	<u>Head difference (ft)</u>	<u>Leakage (in/yr)</u>
Urban area	0.35	35	12
Citrus area	.39	15	6
Mining area	.26	25	7
Control area	1.2	10	12

These values show that downward leakage is a significant part of the ground-water flow system in all four areas. The value for leakage in the phosphate mining area pertains to the Upper Floridan and is significantly less than the leakage to the intermediate aquifer system.

The total recharge rate in the urban area is equal to the leakage plus drainage-well recharge. One analysis (C.H. Tibbals, U.S. Geological Survey, written commun., 1983) suggests that drainage-well recharge is, on the average, about 30 to 35 Mgal/d in the Orlando metropolitan area. If it is assumed that this study area comprises 80 to 85 percent of all drainage wells in that area, then the average drainage-well recharge in the study area is approximately 7 in/yr, giving the urban area a total recharge of 19 in/yr.

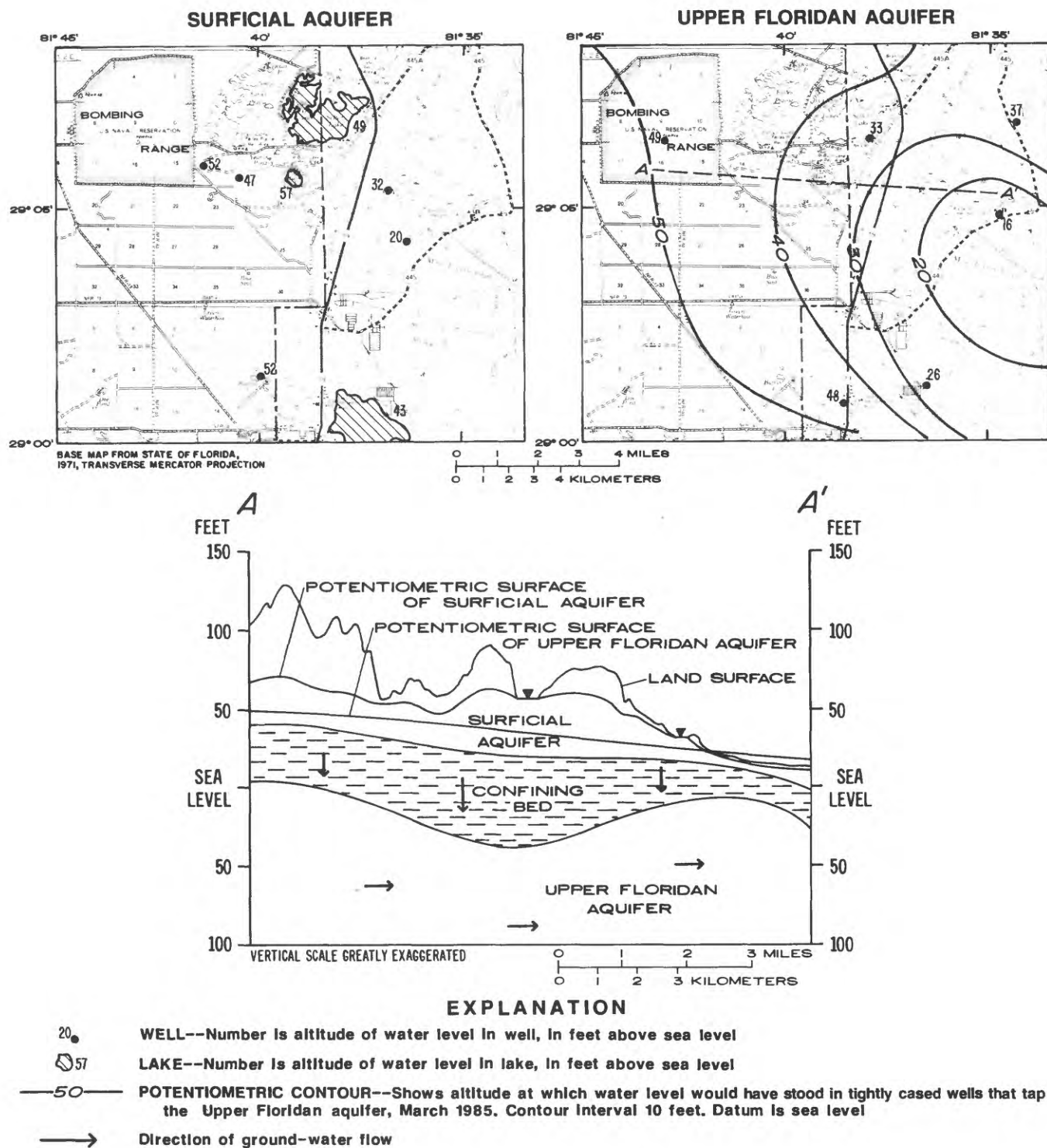
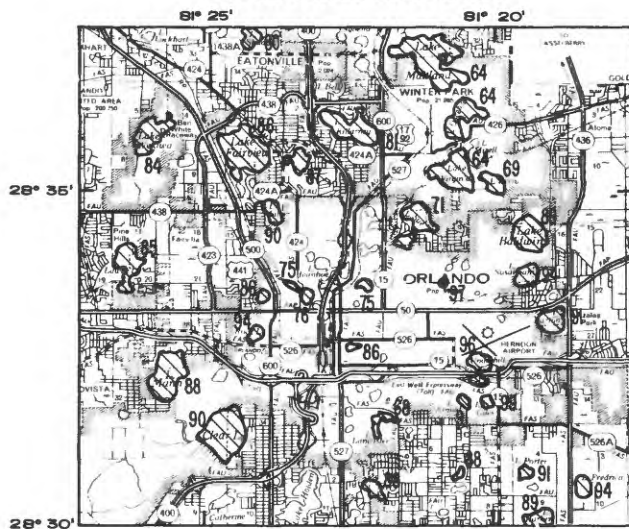
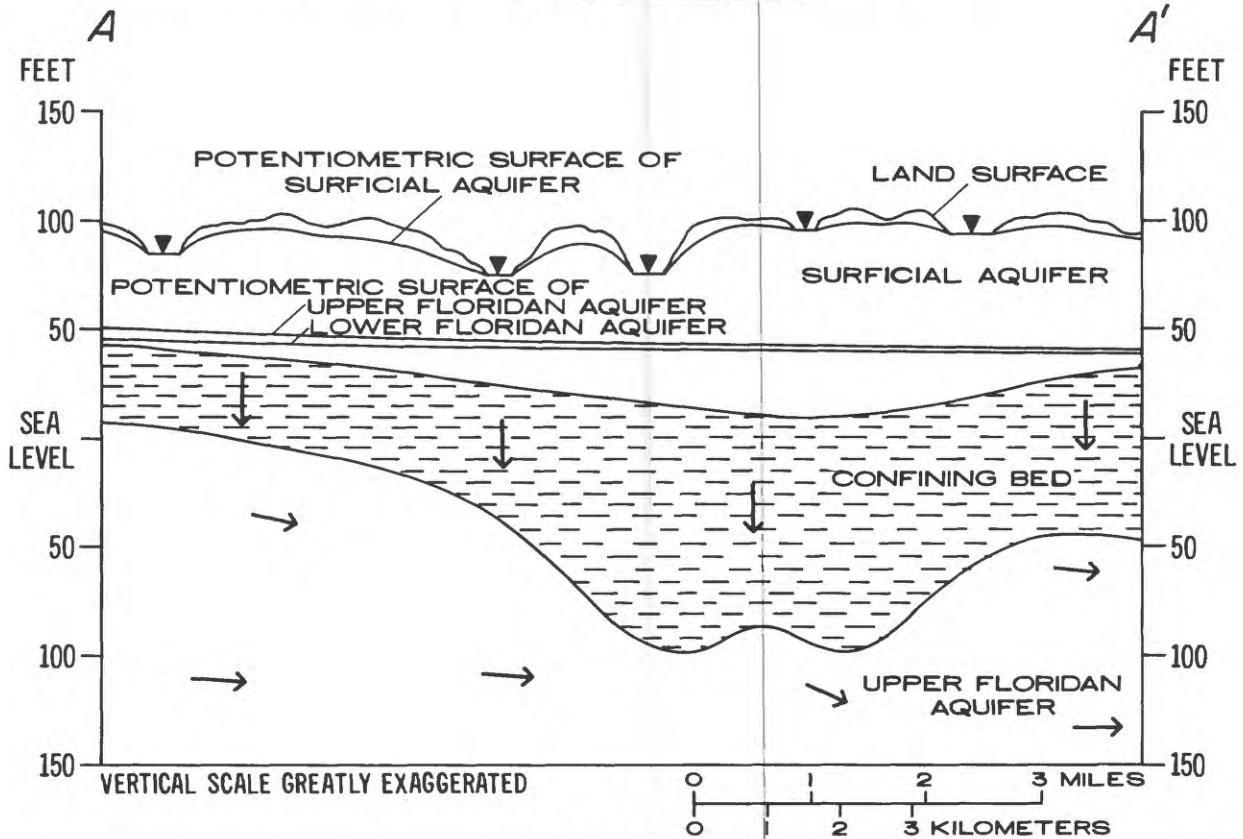
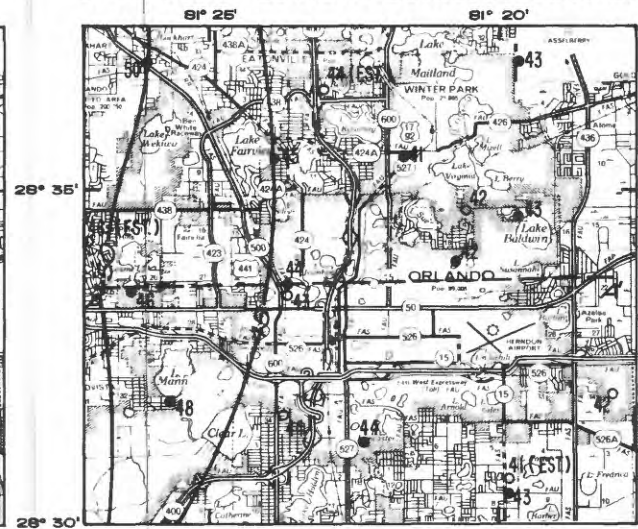


Figure 5.--The potentiometric surface of the surficial aquifer and the Upper Floridan aquifer in the control area, March 1985, and a generalized geohydrologic section through the area.

SURFICIAL AQUIFER



UPPER AND LOWER FLORIDAN AQUIFERS



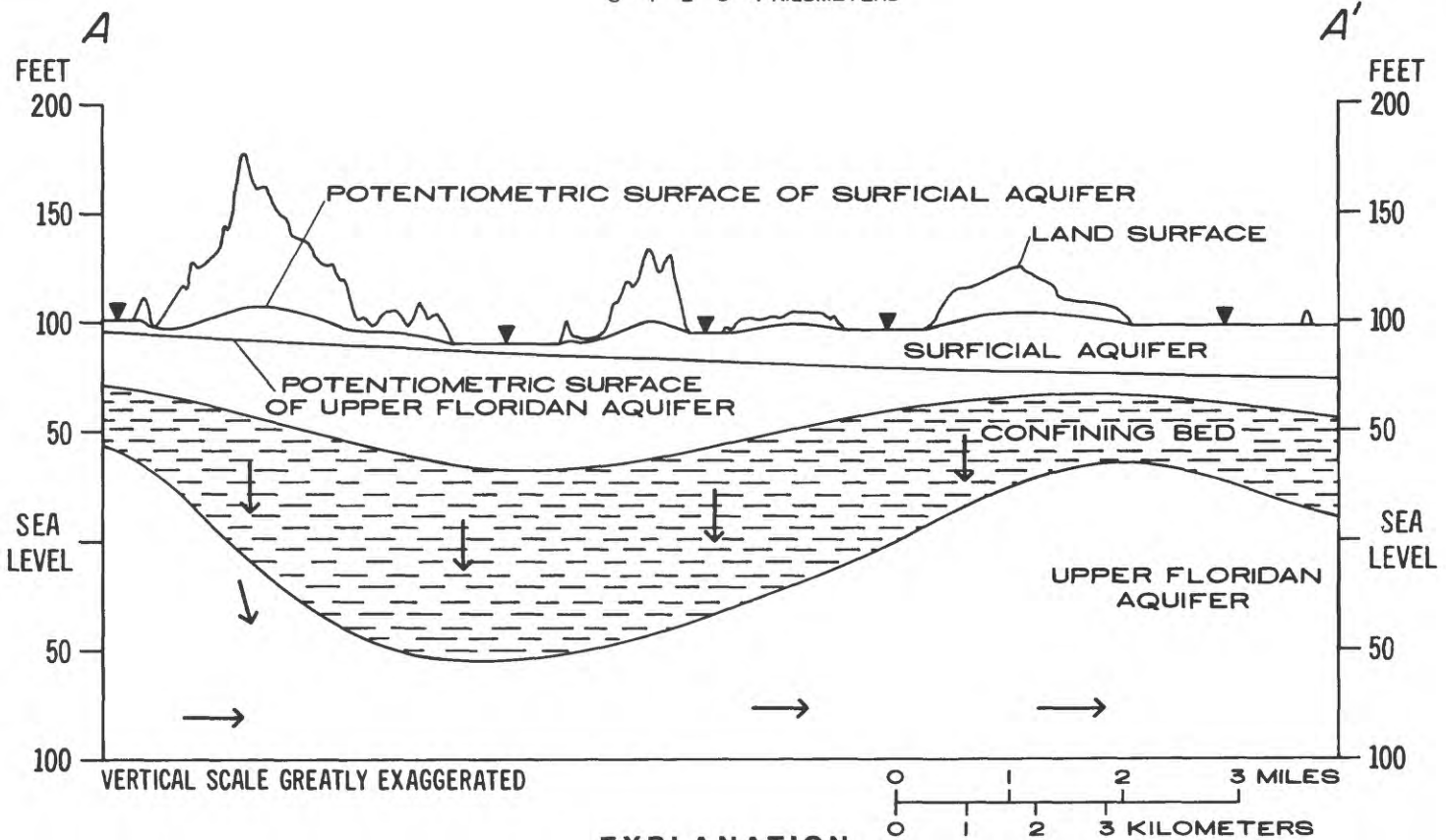
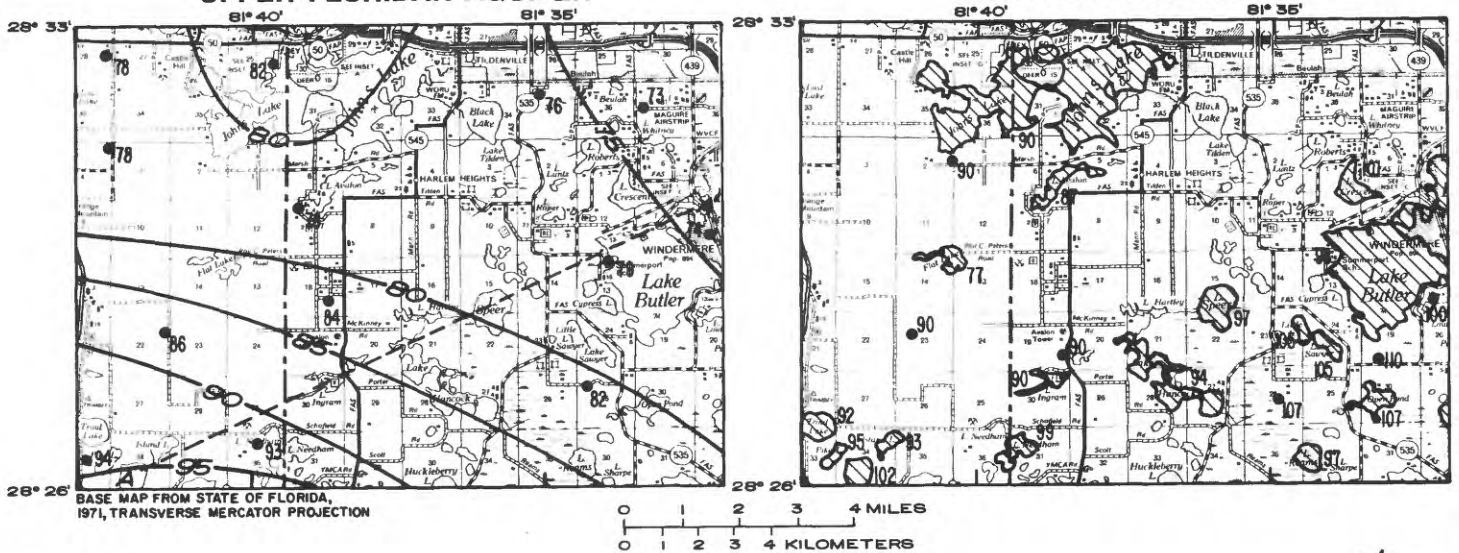
EXPLANATION

- LAKE--Number is altitude of water level in lake, in feet above sea level
- UPPER FLORIDAN AQUIFER WELL--Number is altitude of water level in well, in feet above sea level
- LOWER FLORIDAN AQUIFER WELL--Number is altitude of water level in well, in feet above sea level
- POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells that tap the Upper Floridan aquifer, May 1985. Contour interval 5 Feet. Datum is sea level
- Direction of ground-water flow

Figure 6.--The potentiometric surface of the surficial aquifer and the Upper and Lower Floridan aquifers in the urban area, May 1985, and a generalized geohydrologic section through the area.

UPPER FLORIDAN AQUIFER

SURFICIAL AQUIFER

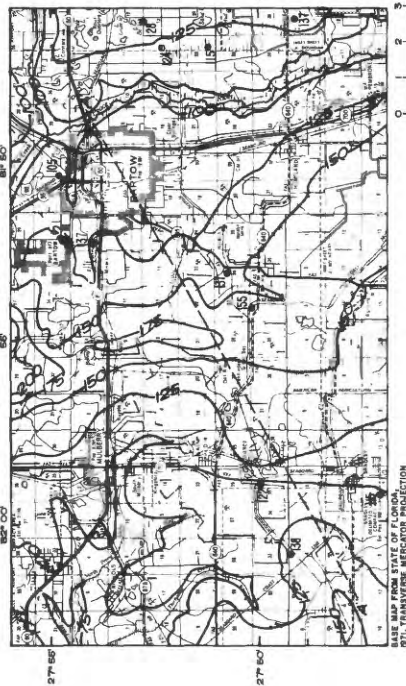


EXPLANATION

- 90 WELL--Number is altitude of water level in well, in feet above sea level
- 97 LAKE--Number is altitude of water level in lake, in feet above sea level
- 90 — POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells that tap the Upper Floridan aquifer, March 1985. Contour interval 10 feet. Datum is sea level
- Direction of ground-water flow

Figure 7.--The potentiometric surface of the surficial aquifer and the Upper Floridan aquifer in the citrus area, March 1985, and a generalized geohydrologic section through the area.

SURFICIAL AQUIFER



INTERMEDIATE AQUIFER AND UPPER FLORIDAN AQUIFER

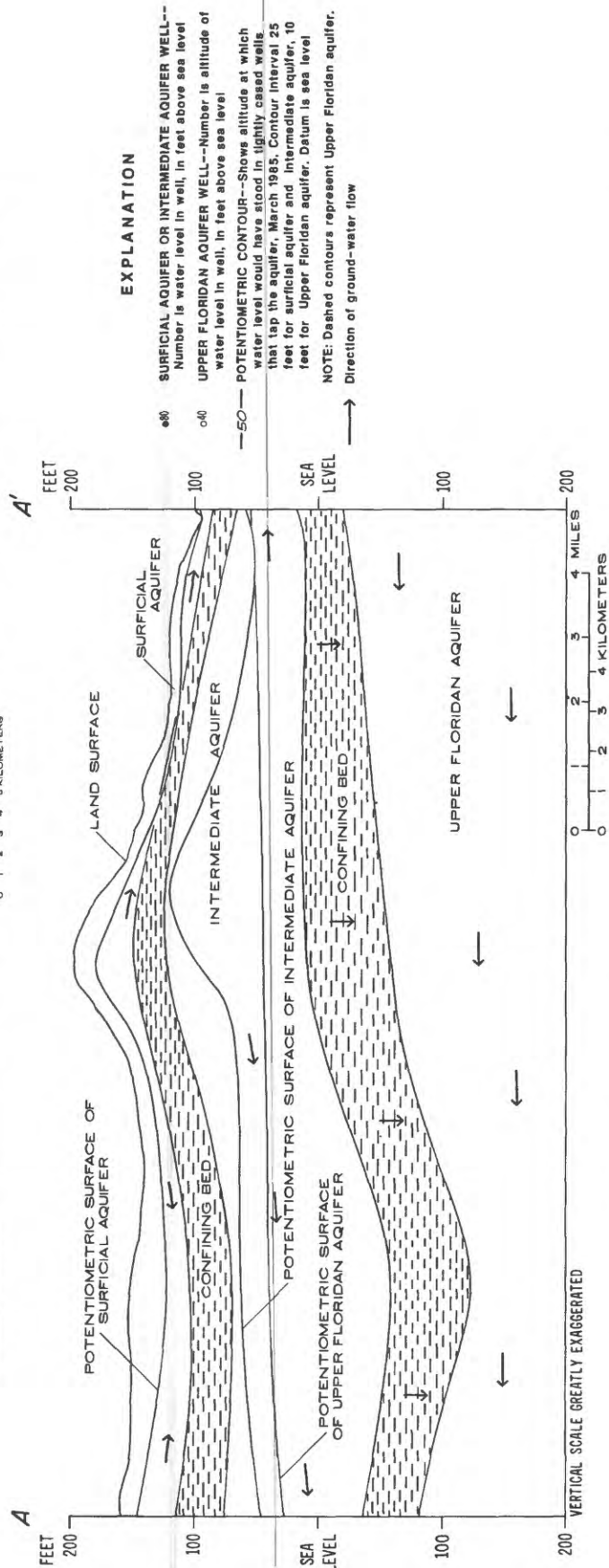
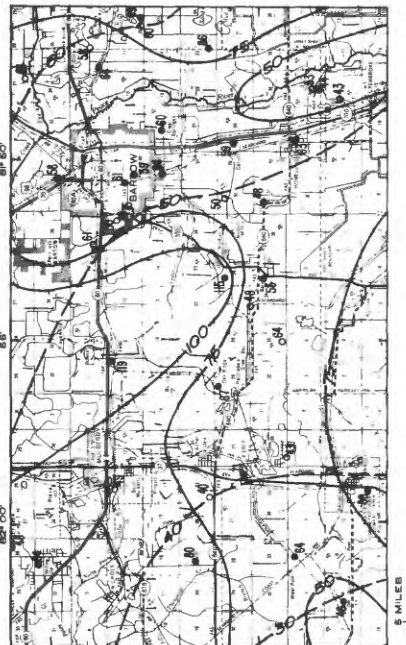


Figure 8.--The potentiometric surface of the surficial aquifer, the intermediate aquifer, and the Upper Floridan aquifer in the phosphate mining area, March 1985, and a generalized geologic section through the area.

The velocity at which a contaminant will move laterally is proportional to the ground-water velocity. If it is assumed that average properties of the surficial aquifer include transmissivity of 600 ft²/d, saturated thickness of 40 feet, porosity of 30 percent, and gradient of 10 ft/mi, then the average ground-water velocity in the surficial aquifer is 0.1 ft/d. The direction of flow in the surficial aquifer varies depending upon location and generally is toward surface sinks such as lakes, streams, and swamps. Most ground-water flow paths in the surficial aquifer in the four study areas are less than 3 miles in length. From the surface sinks, water moves outward by evapotranspiration and streamflow, or downward into a deeper aquifer.

Prevailing flow in the Upper Floridan aquifer is eastward in the urbanized area, northeastward in the citrus area, southwestward in the phosphate mining area, and eastward in the control area. The table below shows the quantities that determine ground-water velocity in the Upper Floridan aquifer for each study area. Transmissivities are from Tibbals (1981) and Ryder (1982), and aquifer thickness is from Miller (1982b). An estimate of porosity of 20 percent was used.

	Hydraulic gradient (ft/mi)	Transmis- sivity (ft ² /d)	Thickness of Upper Floridan aquifer (ft)	Veloc- ity (ft/d)
Urban area	0.8	280,000	330	0.6
Citrus area	1.4	160,000	350	.6
Mining area	2.0	130,000	1,100	.2
Control area	4.0	380,000	300	4.8

COMPARISONS BETWEEN LAND USE AND GROUND-WATER QUALITY CONDITIONS

The following are discussions about chemicals detected in each of the four areas during this study. First, the chemical nature of samples representing surface source conditions are compared with the nature of samples representing prevailing ground waters for each study area. Next is a section that compares prevailing water quality between the study areas. Last is a brief discussion of tentative identifications of additional organic compounds.

Table 1 shows the chemicals that were analyzed for, and the detection limit for each. Most of the organic compounds in table 1 do not occur, or occur only at very low concentrations, in the natural water environment. Tables 2 to 10 show results of chemical analyses. In each table, 12 trace elements are listed, whether detections were made or not. Only those organic compounds that were detected are listed. All 12 trace elements are found in the natural water environment, usually at concentrations low enough such that no health-related problems exist. Sampling sites used for all study areas are shown in figures 9, 10, and 11.

Control Area

Tables 2, 3, and 4 list chemicals found in ponds, in the surficial aquifer, and in the Upper Floridan aquifer, respectively. Iron concentration is slightly higher than the water-quality standard in one water sample from a pond, and iron and manganese are above standards in an Upper Floridan aquifer sample. Iron and manganese concentrations are elevated in the Upper Floridan in this area of little development, so their presence is indicative of natural geochemical processes and not of contamination. Barium, silver, and selenium were not detected in any samples from the control area, and most other trace elements occurred at concentrations near the detection limit.

The ubiquitous distribution of the widely used pesticide diazinon is indicated by its presence in the control area. Diazinon was detected in one well in the Upper Floridan aquifer and in two wells in the surficial aquifer at trace concentrations.

Urban Area

Table 5 shows chemical concentrations found in source waters to drainage wells and table 6 lists analyses for wells in the Upper Floridan aquifer. Among the trace elements, chromium, lead, iron, and manganese concentrations exceed water-quality standards in drainage-well source waters. In water from the aquifer, iron and manganese concentrations exceed standards. However, iron and manganese concentrations were shown to be high in the Upper Floridan aquifer in the control area, so this may not be related to land use. Neither chromium nor lead concentrations are elevated in the Upper Floridan. Although there is a significant influx of trace elements such as chromium and lead to drainage wells, concentrations of trace elements are apparently not exceeding background levels to a significant degree. A possible reason for this may be that the high pH of the water in this carbonate aquifer may cause precipitation of trace elements or that cation exchange between trace elements in the water and calcium ions in the aquifer is taking place.

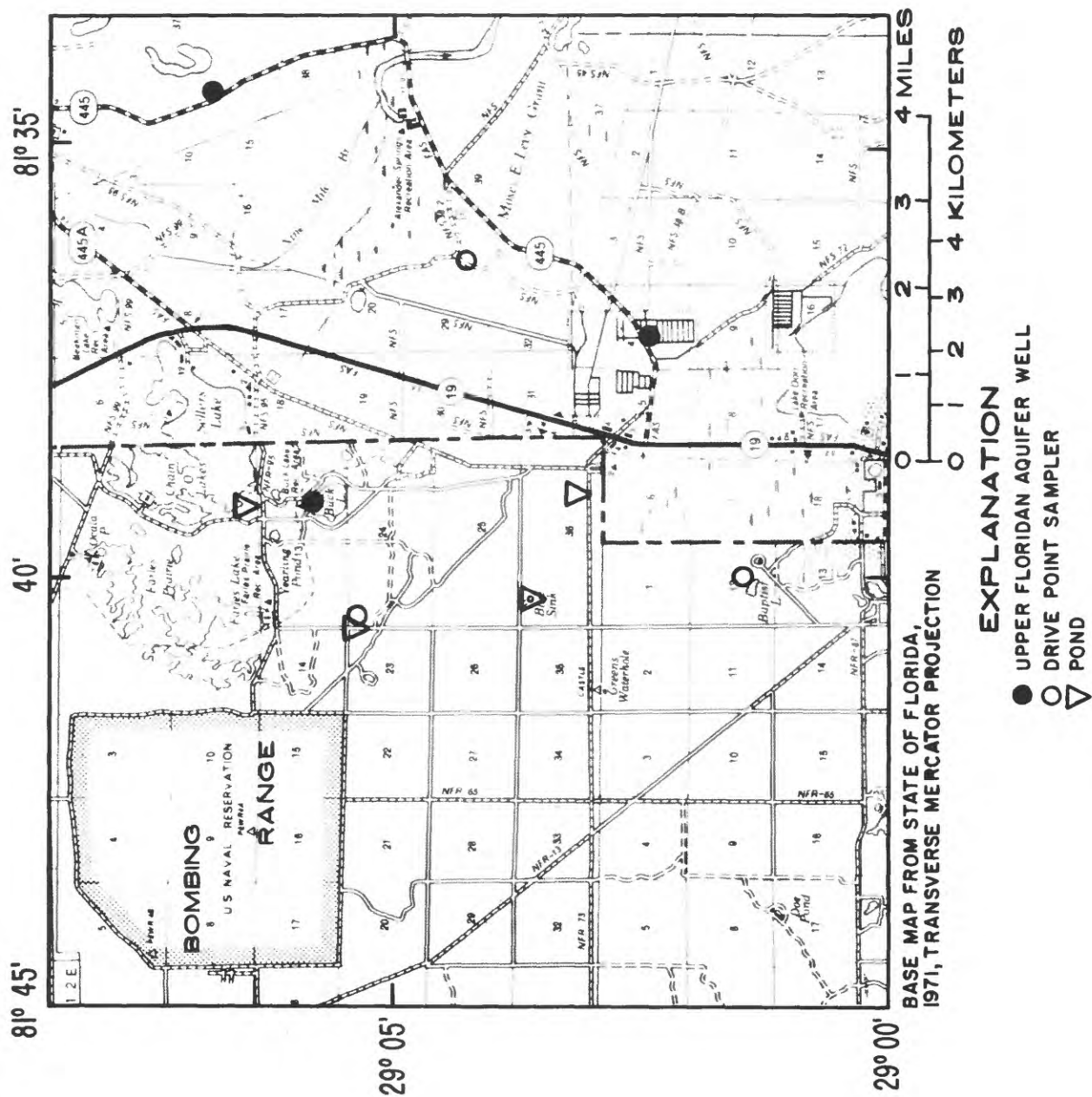


Figure 9.--Sampling sites in the control area.

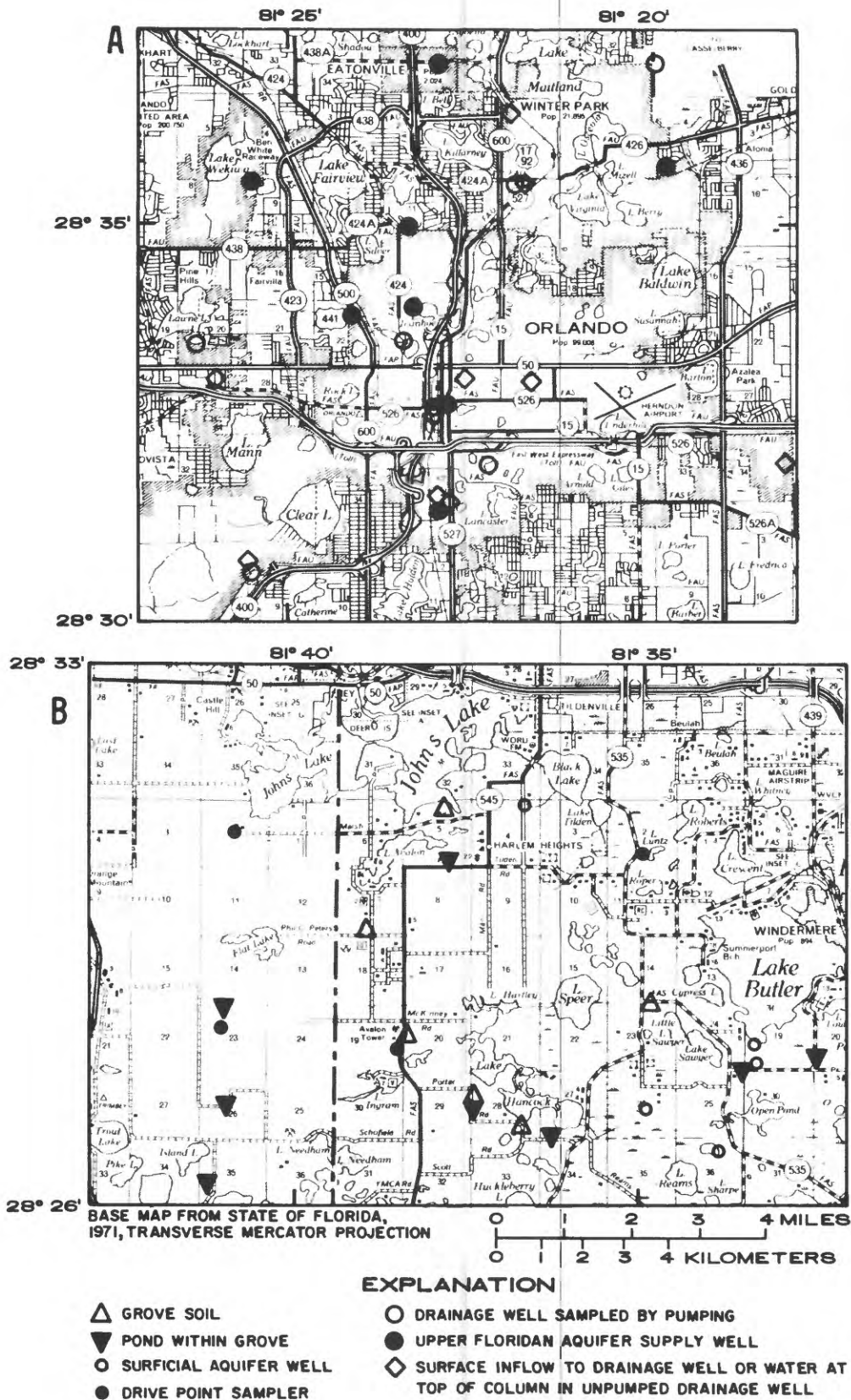


Figure 10.--Sampling sites in the (A) urban area, and (B) citrus area.

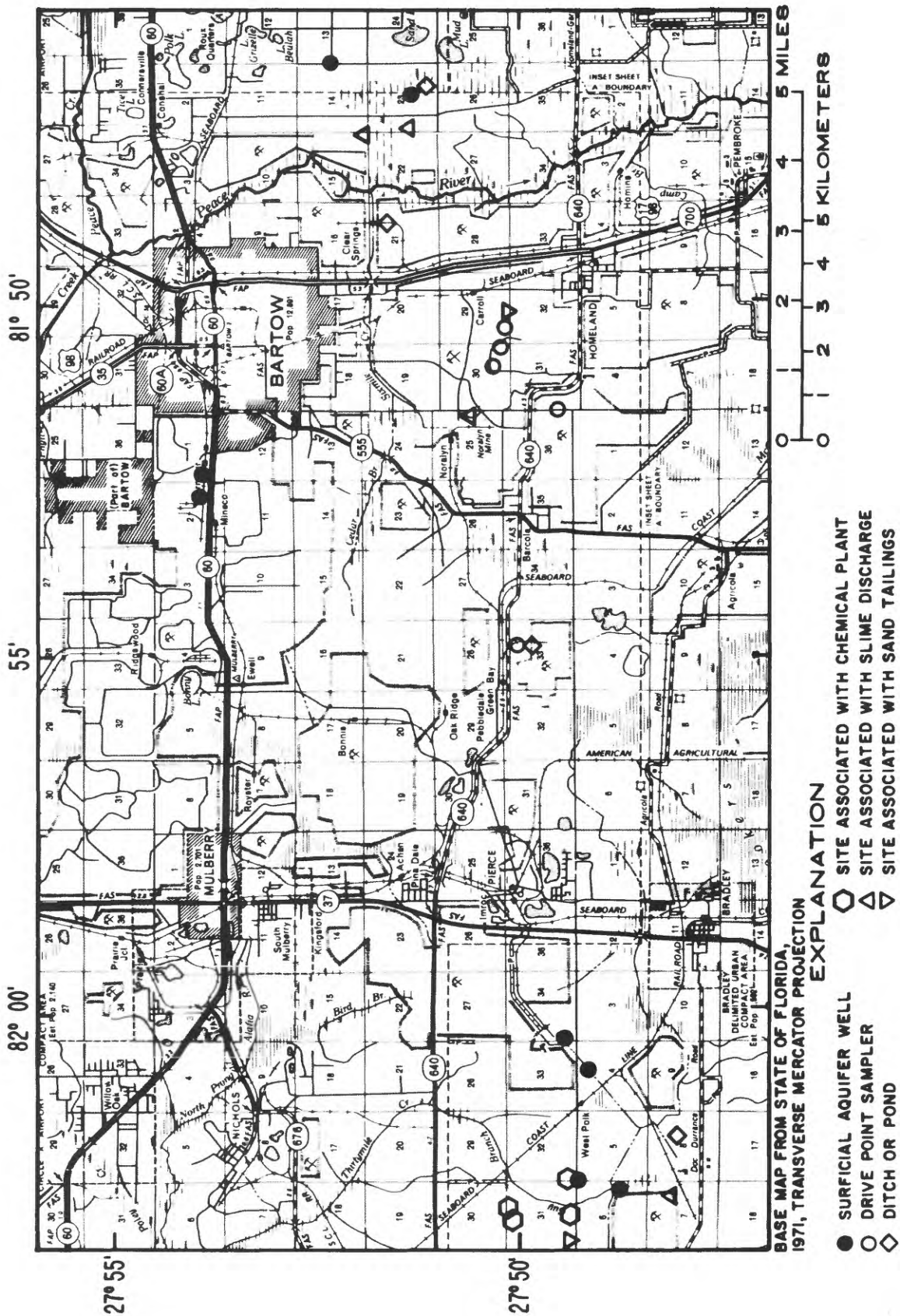


Figure 11.--Sampling sites in the phosphate mining area.

Table 2.--Trace elements in pond water and organic compounds in pond sediment in the control area

[Concentrations represent total recoverable concentrations, in micrograms per liter. For trace elements only, an asterisk indicates that the concentration exceeds water-quality standards of Florida Department of Environmental Regulation, 1983]

Trace element	Number of analyses	Number of detections	Concentration or range of concentration
Pond water:			
Arsenic	3	2	1
Barium	3	0	--
Cadmium	3	3	1
Chromium	3	3	10
Copper	3	2	1-2
Iron	3	3	130-490*
Lead	3	3	1-2
Manganese	3	1	20
Mercury	3	0	--
Selenium	3	0	--
Silver	3	0	--
Zinc	3	2	10-30

NOTE: Two pond sediment samples were analyzed for organic compounds. None was detected.

Among the organic compounds, volatile compounds are prevalent in both source waters and waters from the Upper Floridan aquifer. This includes benzene, chloroform, toluene, and methane, which were found in water pumped from the Upper Floridan aquifer, and trichloroethanes, dichloroethanes, dichloroethylenes, chloroethane, and ethylbenzene, which were found in source water. Of eight samples of water pumped from drainage wells, benzene was detected once, at 200 $\mu\text{g/L}$, and of eight analyses of supply wells open to the Upper Floridan aquifer, chloroform was detected once, at 11 $\mu\text{g/L}$, and toluene was detected once, at 8.0 $\mu\text{g/L}$. Of 11 samples of drainage-well source water, 1,1,1-trichloroethane was detected twice, at 340 and 550 $\mu\text{g/L}$, and 1,1-dichloroethane was detected twice, at 77 and 97 $\mu\text{g/L}$.

Numerous chlorinated and organophosphorus pesticides were found at low concentrations in both water types: this includes silvex, 2,4-D, dieldrin, diazinon, and malathion. Acenaphthene, a polycyclic aromatic compound derived from coal tar, is used as an insecticide and fungicide, and was detected in two samples of water from the Upper Floridan aquifer.

Table 3.--Trace elements and organic compounds in water from wells in the surficial aquifer in the control area

[Concentrations represent total recoverable concentrations, in micrograms per liter. For trace elements only, an asterisk indicates that the concentration exceeds water-quality standards of Florida Department of Environmental Regulation, 1983]

Constituent	Number of analyses	Number of detections	Concentration or range of concentration
Trace element:			
Arsenic	3	0	--
Barium	3	0	--
Cadmium	3	3	1
Chromium	3	3	10
Copper	3	3	1
Iron	3	3	40-50
Lead	3	0	--
Manganese	3	0	--
Mercury	3	0	--
Selenium	3	0	--
Silver	3	0	--
Zinc	3	3	10-20
Organic compound:			
Diazinon	3	2	0.03-0.04

Citrus Area

Table 7 lists chemicals found in pond waters, pond sediment, and grove soil. Table 8 lists analyses of water from wells tapping the surficial aquifer in the citrus-growing area. Most trace elements are detected at higher concentrations in the surficial aquifer than in ponds. Iron and manganese concentrations in the surficial aquifer exceed water-quality standards, and one selenium concentrations is equal to the water-quality standard (FDER, 1983). Zinc concentrations are close to the water-quality standard in the surficial aquifer. This could be related to the use of zinc sulfate as a pesticide. Although copper is widely used, concentrations of this element were below water-quality limits in ponds and in the surficial aquifer.

Phenol was detected in four samples of pond sediment and in one sample of pond water. The highest level was 340 $\mu\text{g/kg}$ (micrograms per kilogram) in sediment. Toluene was detected once in pond water and once in the surficial aquifer, and 2,6-dinitrotoluene was detected once in pond water. Benzene, toluene, ethylbenzene, and naphthalene were detected in water from the surficial aquifer at a site close to a fuel tank, so these may not be representative of prevailing conditions.

Table 4.--Trace elements and organic compounds in water from wells open to the Upper Floridan aquifer in the control area

[Concentrations represent total recoverable concentrations, in micrograms per liter. For trace elements only, an asterisk indicates that the concentration exceeds water-quality standards of Florida Department of Environmental Regulation, 1983]

Constituent	Number of analyses	Number of detections	Concentration or range of concentration
Trace element:			
Arsenic	3	2	1
Barium	3	0	--
Cadmium	3	2	1
Chromium	3	3	10
Copper	3	2	1-14
Iron	3	3	60-12,000*
Lead	3	3	1-2
Manganese	3	2	30-60*
Mercury	3	1	0.2
Selenium	3	0	--
Silver	3	0	--
Zinc	3	3	30-210
Organic compound:			
Diazinon	3	1	0.06

The pesticides chlordane, DDE, simazine, and ametryne were detected in grove soil or pond water while simazine and diazinon were detected in water from the surficial aquifer. Simazine was measured at 1,100 $\mu\text{g/L}$ in one grove soil sample. Diazinon was detected in water from four of seven wells in the surficial aquifer.

Mining Area

Table 9 shows chemicals found at sampling sites representing surface sources and table 10 shows chemicals found in water from wells in the surficial aquifer. Most trace elements occur at very high levels at source sites. In waters from the surficial aquifer, arsenic, iron, manganese, and selenium concentrations exceed water-quality standards. One value of mercury concentration exceeded the standard considerably. The well from which this sample was taken is 60 feet deep, and it might be open to the upper part of the intermediate aquifer. The well is located adjacent to a clayey waste disposal site. Of 11 water samples from the surficial aquifer, mercury and arsenic were each detected 10 times. The highest mercury concentration was 8.0 $\mu\text{g/L}$ and the highest arsenic concentration was 60 $\mu\text{g/L}$. These and other elements occur in very high concentrations in the surficial aquifer, but their movement may be attenuated by acid neutralization.

Table 5.--Trace elements and organic compounds in source waters
to drainage wells in the urban area

[Concentrations represent total recoverable concentrations, in micrograms per liter. Trace element data represent seven storm runoff samples (E.R.German U.S. Geological Survey, written commun., 1986) plus one sample obtained during this study by pumping a drainage well as it received runoff. For trace elements only, an asterisk indicates that the concentration exceeds water-quality standards of Florida Department of Environmental Regulation, 1983]

Constituent	Number of analyses	Number of detections	Concentration or range of concentration
Trace element:			
Arsenic	8	7	1
Barium	8	5	100
Cadmium	8	8	1-2
Chromium	8	6	10-610*
Copper	8	8	3-59
Iron	8	8	370-2,500*
Lead	8	7	24-430*
Manganese	8	8	10-60*
Mercury	8	2	0.1-0.2
Selenium	8	0	--
Silver	8	0	--
Zinc	8	8	10-360
Organic compound:			
Chlordane	11	1	0.1
Chloroethane	11	2	13-29
2,4-D	11	1	.03
DDD	11	1	.02
DDE	11	1	.01
Diazinon	11	1	.02
1,2-Dichloroethane	11	2	77-97
1,1-Dichloroethylene	11	1	7.2
Dieldrin	11	1	.01
Ethylbenzene	11	1	5.7
bis(2-Ethylhexyl)phthalate	11	2	2.0-14
Fluoranthene	11	2	1.0-2.0
Malathion	11	1	.01
Pyrene	11	1	1.0
Silvex	11	2	0.01-0.02
1,1,1-Trichloroethane	11	2	340-550

Table 6.--Trace elements and organic compounds in water from supply wells open to the Upper Floridan aquifer in the urban drainage well area and organic compounds in water pumped from drainage wells

[Concentrations represent total recoverable concentrations, in micrograms per liter. For trace elements only, an asterisk indicates that the concentration exceeds water-quality standards of Florida Department of Environmental Regulation, 1983]

Constituent	Water from supply wells			Water from drainage wells		
	Number of analyses	Number of detections	Concentration or range of concentration	Number of analyses	Number of detections	Concentration or range of concentration
Trace element:						
Arsenic	8	2	1-2	--	--	--
Barium	8	0	--	--	--	--
Cadmium	8	4	1-2	--	--	--
Chromium	8	7	10	--	--	--
Copper	8	7	1-54	--	--	--
Iron	8	8	80-1,400*	--	--	--
Lead	8	5	1-6	--	--	--
Manganese	8	5	30-50*	--	--	--
Mercury	8	3	0.1-0.2	--	--	--
Selenium	8	0	--	--	--	--
Silver	8	0	--	--	--	--
Zinc	8	8	10-450	--	--	--
Organic compound:						
Acenaphthene	8	1	9.0	8	1	14
Benzene	8	--	--	8	1	200
Chloroform	8	1	11	8	--	--
2,4-D	8	--	--	8	4	0.01-0.07
Diazinon	8	--	--	8	1	.04
Dieldrin	8	--	--	8	1	.01
Malathion	8	--	--	8	1	.06
Phenol	8	--	--	8	1	1.0
Silvex	8	1	.13	8	2	.01
Toluene	8	1	8.0	8	--	--

Many polycyclic aromatic compounds such as acenaphthene, fluorene, phenanthrene, and pyrene, are present in water and sediment in clayey-waste and sand-tailings discharges from ore-processing plants. Fluorene and naphthalene were detected in water samples from the surficial aquifer. Phenol and 2,4-dimethylphenol were detected in cooling ponds near chemical processing plants, but were not found in water from the surficial aquifer. The pesticide diazinon was detected at one source water site and at seven wells in the surficial aquifer in trace amounts (less than 10 times the detection limit).

Table 7.--Trace elements and organic compounds in pond water, pond sediment, and grove soil in the citrus area

[Concentrations represent total recoverable concentrations, in micrograms per liter, for water, and in micrograms per kilogram, for sediment. For trace elements only, an asterisk indicates that the concentration exceeds water-quality standards of Florida Department of Environmental Regulation, 1983]

Constituent	Number of analyses	Number of detections	Concentration or range of concentration
Trace element, in pond water:			
Arsenic	11	0	--
Barium	11	0	--
Cadmium	11	3	1
Chromium	11	8	10-20
Copper	11	11	1-19
Iron	11	11	40-890*
Lead	11	2	1-4
Manganese	11	9	10-560*
Mercury	11	6	0.1-0.3
Selenium	11	0	--
Silver	11	0	--
Zinc	11	9	10-50
Organic compound, in pond water:			
Ametryne	7	1	15
Diethylphthalate	7	1	12
2,6-Dinitrotoluene	7	1	5
Phenol	7	1	7
Toluene	7	1	21
Organic compound, in pond sediment:			
Phenol	6	4	40-340
Organic compound, in grove soil:			
Chlordane	5	1	21
DDE	5	1	52
Simazine	5	1	1,100

Table 8.--Trace elements and organic compounds in water from wells open to the surficial aquifer in the citrus area

[Concentrations represent total recoverable concentrations, in micrograms per liter. For trace elements only, an asterisk indicates that the concentration exceeds water-quality standards of Florida Department of Environmental Regulation, 1983]

Constituent	Number of analyses	Number of detections	Concentration or range of concentration
Trace element:			
Arsenic	8	1	4
Barium	8	5	100
Cadmium	8	6	1-2
Chromium	8	6	10-20
Copper	8	7	1-51
Iron	8	8	20-2,300*
Lead	8	5	1-18
Manganese	8	6	20-280*
Mercury	8	8	0.1-0.6
Selenium	8	4	1-10*
Silver	8	0	--
Zinc	8	5	10-4,000
Organic compound:			
Benzene	7	1	11
Diazinon	7	4	0.01-0.04
Ethylbenzene	7	1	5.0
Naphthalene	7	1	7.0
Simazine	7	1	0.20
Toluene	7	1	7.8

Comparisons of Ground Waters Between Study Areas

The following discussion and associated tables and figures relate to prevailing ground-water conditions in each study area. Source waters are not included. For the urban area, data from supply wells only are included--drainage-well data are excluded. For the citrus area, the organic chemical analysis of one well close to an underground gasoline tank is deleted because it is not representative of that land-use type.

Table 9.--Trace elements and organic compounds in water and sediment representing surface-source conditions in the phosphate mining area

[Concentrations represent total recoverable concentrations, in micrograms per liter for water, and in micrograms per kilogram for sediment. For trace elements only, an asterisk indicates that the concentration exceeds water-quality standards of Florida Department of Environmental Regulation, 1983]

Constituent	Water			Sediment		
	Number of analyses	Number of detections	Concentration or range of concentration	Number of analyses	Number of detections	Concentration or range of concentration
Trace element:						
Arsenic	9	8	2-960*	--	--	--
Barium	9	5	100-3,400*	--	--	--
Cadmium	9	6	1-440*	--	--	--
Chromium	9	9	10-2,000*	--	--	--
Copper	9	9	1-620	--	--	--
Iron	9	9	140-180,000*	--	--	--
Lead	9	8	1-400*	--	--	--
Manganese	9	9	20-10,000*	--	--	--
Mercury	9	5	0.2-8*	--	--	--
Selenium	9	4	2-14*	--	--	--
Silver	9	4	3-4	--	--	--
Zinc	9	8	10-4,500	--	--	--
Organic compound:						
Acenaphthene	12	2	1	--	--	--
Diazinon	12	1	.06	--	--	--
2,4-Dimethylphenol	12	1	2	--	--	--
Fluorene	12	2	1	3	1	10
Phenanthrene	12	3	3-4	3	2	21-68
Phenol	12	1	22	--	--	--
Pyrene	12	2	1-2	3	1	12
Toluene	12	1	3	--	--	--
1,1,1-Trichloroethane	12	1	3	--	--	--

Table 10.--Trace elements and organic compounds in water from wells open to the surficial aquifer in the phosphate mining area

[Concentrations represent total recoverable concentrations, in micrograms per liter. For trace elements only, an asterisk indicates that the concentration exceeds water-quality standards of Florida Department of Environmental Regulation, 1983]

Constituent	Number of analyses	Number of detections	Concentration or range of concentration
Trace element:			
Arsenic	11	10	1-60*
Barium	11	2	100
Cadmium	11	6	1-2
Chromium	11	9	10-20
Copper	11	10	1-16
Iron	11	11	280-48,000*
Lead	11	6	1-3
Manganese	11	10	10-1,400*
Mercury	11	10	0.1-8.0*
Selenium	11	1	61*
Silver	11	0	--
Zinc	11	11	10-40
Organic compound:			
Diazinon	11	7	0.04-0.08
Di-n-butyl phthalate	11	1	15
2,4-DP	11	2	0.01-0.05
Fluorene	11	1	1.0
Naphthalene	11	1	3.0
Prometone	11	1	.1

Figures 12 and 13 show that, although the ranges of concentrations of trace elements in ground water may be large as a result of land use, the median concentrations remain relatively unchanged. In the citrus area, water in the surficial aquifer can contain higher concentrations of copper, lead, or zinc than water in the surficial aquifer in the control area or the mining area (fig. 12). Copper and zinc concentrations could be high in citrus areas because of known use of these for pesticides and nutrients. Lead-based pesticides also may be in use. In the mining area, water from the surficial aquifer may have concentrations of arsenic, iron, manganese, mercury, and selenium that exceed concentrations in the control and the citrus area (fig. 12) because of mining activities such as acidification of process waters. Median concentrations in water pumped from the Upper Floridan aquifer differ only slightly between the urban area and the control area (fig. 13). The concentration ranges of copper, lead, and zinc may be slightly greater for the urban area than the control area.

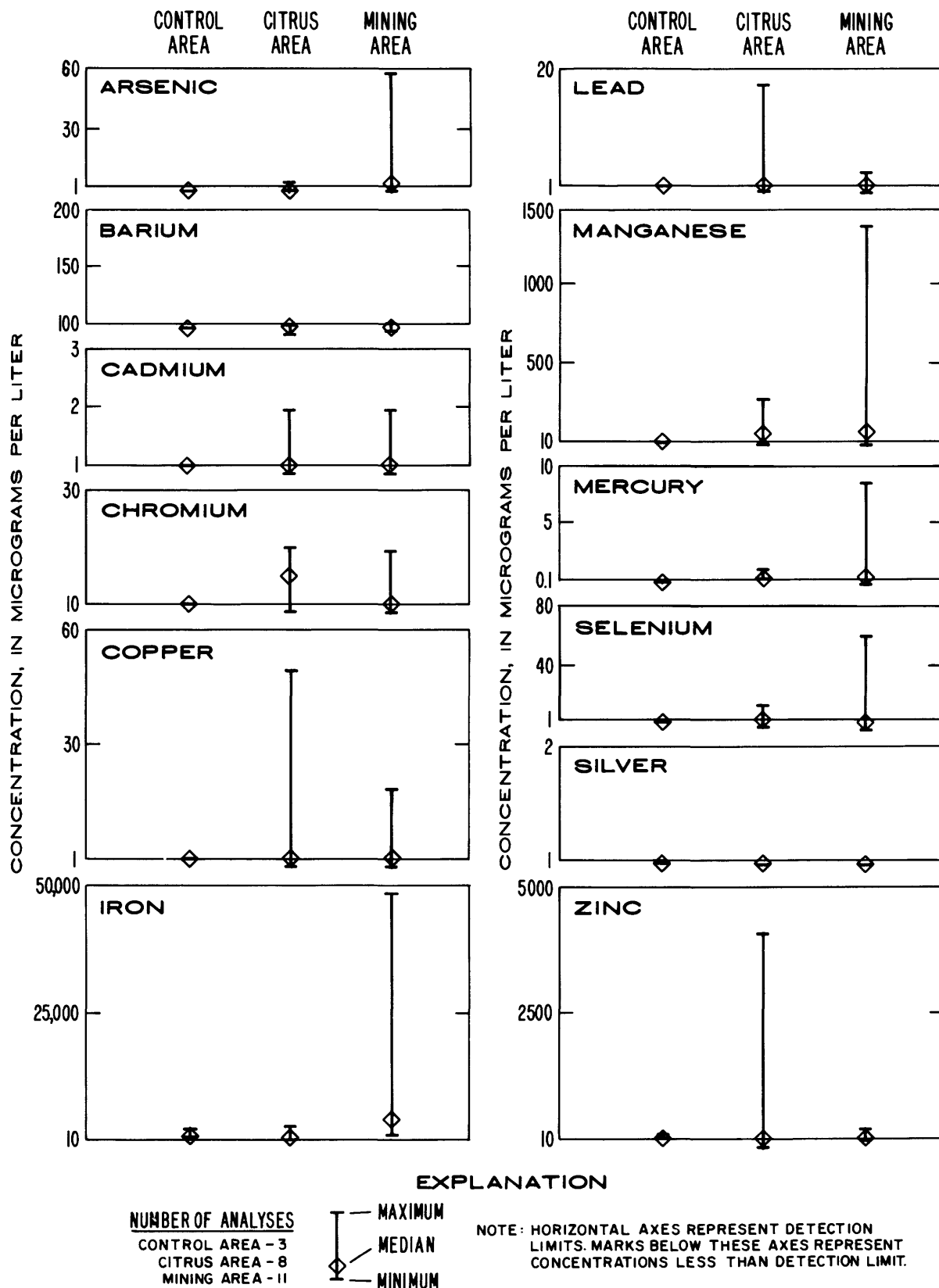


Figure 12.--Distributions of concentrations of trace elements in water pumped from wells completed in the surficial aquifer in the control area, the citrus area, and the mining area.

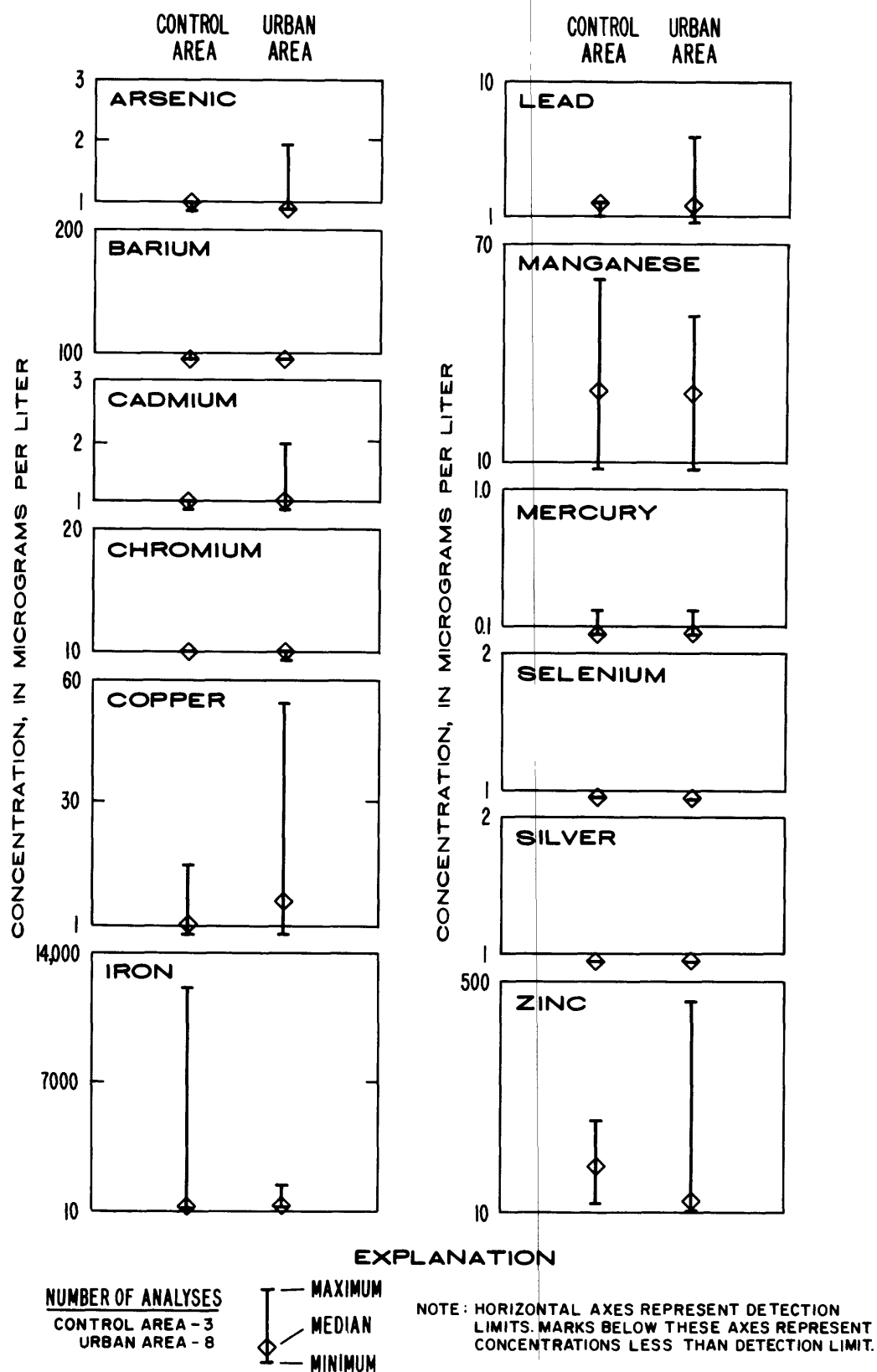


Figure 13.--Distributions of concentrations of trace elements in water pumped from wells completed in the Upper Floridan aquifer in the control area and the urban area. (For the urban area, only supply-well data are shown here; no drainage-well data.)

Table 11 shows the frequencies at which water-quality standards (FDER, 1983) for trace element concentrations are exceeded in each study area. Concentrations of iron, manganese, and selenium in the surficial aquifer exceeded water-quality standards in the citrus area more often than in the control area. The 12 percent exceedance rate of selenium for the citrus area may not be significant because it represents only one exceedance, and the concentration was equal to the water-quality standard. The frequencies at which water-quality standards for arsenic, iron, manganese, mercury, and selenium are exceeded in water pumped from the surficial aquifer in the phosphate mining area are greater than those in the control area. This may be related to increased mobility of elements caused by low pH in processed waters. The only exceedances in the control area are for iron and manganese concentrations in the Upper Floridan aquifer. The frequencies of exceedance for iron and manganese in the Upper Floridan in the urban area are not above those in the control area. These exceedances are apparently not due to land use, but are instead related to natural geochemical processes in the Upper Floridan aquifer. No other trace elements exceeded water-quality standards in water from the Upper Floridan aquifer. With few exceptions, the frequencies of exceedance of water-quality standards for trace elements were 50 percent or less.

Table 11.--Frequencies of exceedance of water-quality standards of trace element concentrations in water pumped from wells

[Numbers are in percents. In the urban area, only supply-well data are shown here (no drainage well data)]

Trace element	Water quality standard ($\mu\text{g/L}$) ¹	Surficial aquifer			Floridan aquifer	
		Control area (3 wells)	Citrus area (8 wells)	Phosphate mining (11 wells)	Control area (3 wells)	Urban area (8 wells)
Arsenic	50	--	--	9	--	--
Barium	1,000	--	--	--	--	--
Cadmium	10	--	--	--	--	--
Chromium	50	--	--	--	--	--
Copper	1,000	--	--	--	--	--
Iron	300	--	38	91	33	25
Lead	50	--	--	--	--	--
Manganese	50	--	50	55	33	25
Mercury	2	--	--	9	--	--
Selenium	10	--	12	9	--	--
Silver	50	--	--	--	--	--
Zinc	5,000	--	--	--	--	--

¹Florida Department of Environmental Regulation, 1983.

Table 12 shows the frequencies at which there were detections of organic compounds in ground waters in each area. The only chemicals listed here are those detected in samples representing prevailing ground waters. The data in table 12 may indicate that, among the organic chemicals, the volatiles are most common in the urban area and base-neutral extractables are most common in the mining area. Pesticides of one type or another are found in all areas, and diazinon in particular, is found in the control area. Analyses of a wider scope of pesticides in the future may reveal many more occurrences in the citrus area.

Table 12.--Frequencies of detections of organic compounds in water pumped from wells

[Numbers are in percents. For the citrus area, one well near a gasoline tank is excluded. For the urban area, only supply-well data are shown here (no drainage-well data). Analyses include all organic chemicals in table 1--any organic chemical in table 1 that is not listed here was analyzed for but not detected in samples representing prevailing ground waters]

Compound	Detection limit ($\mu\text{g/L}$)	<u>Surficial aquifer</u>			<u>Floridan aquifer</u>	
		Control	Citrus	Phosphate	Control	Urban
		area (3 wells)	area (8 wells)	mining (11 wells)	area (3 wells)	area (8 wells)
<u>Volatiles</u>						
Chloroform	3.0	--	--	--	--	12
Toluene	3.0	--	--	--	--	12
<u>Base-neutral extractables</u>						
Acenaphthene	5.0	--	--	--	--	12
Di-N-butylphthalate	5.0	--	--	9	--	--
Fluorene	5.0	--	--	9	--	--
Naphthalene	5.0	--	--	9	--	--
<u>Pesticides</u>						
Diazinon	.01	67	67	70	33	--
2,4-DP	.01	--	--	20	--	--
Prometone	.1	--	--	10	--	--
Simazine	.1	--	17	--	--	--
Silvex	.01	--	--	--	--	12

Data presented in figures 12 and 13 and in tables 11 and 12 indicate that the probability of unnaturally high concentrations of particular trace elements and organic compounds may be increased by the presence of a particular land use, but that the probability may nevertheless remain under 50 percent. Categorical methods of analysis may prove to be the most appropriate way of determining the statistical significance of this data (Helsel and Ragone, 1984). Contingency tables could be used during phase II of this study to compare each group's percentage of detections or percentage of exceedance of some arbitrary standard when more data are available.

Nontarget Chemicals

The tables of tentative identifications (tables 13, 14, 15, and 16) indicate that many additional organic compounds occur in each study area, and therefore, many are possible ground-water contaminants. These identifications are tentative because they were obtained without laboratory standard solutions, but were instead obtained using a National Bureau of Standards library of mass spectra for thousands of compounds.

Table 13.--Tentative identifications of additional organic compounds found in the control area

[These compounds were not specifically analyzed using laboratory standard solutions, but were identified, with less reliability, using a National Bureau of Standards library of mass spectra. X indicates tentative identification; -- indicates no detection]

	<u>Pond sediment</u>	<u>Surficial aquifer</u>	<u>Floridan aquifer</u>
Alkanes (various molecular weights)	X	--	--
Alkenes (various molecular weights)	X	--	--
Phenols (with various alkyl groups)	X	--	--
Benzenecetic acid	X	--	--
Benzenepropanoic acid	X	--	--
Benzenepropanoic acid, methyl ester	X	--	--
3-Hydroxybenzoic acid, methyl ester	X	--	--
3-Hydroxybutanoic acid, methyl ester	X	--	--
3-Pyridinecarboxylic acid, methyl ester	X	--	--
3-(3-Hydroxyphenyl)-2-propenoic acid, methyl ester	X	--	--
3-(4-Hydroxyphenyl)-2-propenoic acid, methyl ester	X	--	--
3-Ethyl-4-methyl-1H-pyrrole-2,5-dione	X	--	--
.beta.-Bisabolene	X	--	--
.beta.-Selinene	X	--	--

Table 14.--Tentative identifications of additional organic compounds found in the urban area

[These compounds were not specifically analyzed using laboratory standard solutions, but were identified, with less reliability, using a National Bureau of Standards library of mass spectra. X indicates tentative identification; -- indicates no detection]

	Drainage well source waters	Floridan aquifer
Alkanes (various molecular weights)	X	--
Benzoic acid	X	--
Butanoic acid	X	--
2,5-Dimethylbenzoic acid	X	--
Benzenepropanoic acid	X	--
Benzenoacetic acid	X	--
Benzenethanol	X	--
6-Methyl-3-octyne	X	--
Phenols, (with various alkyl groups)	X	--
Benzenes, (with various alkyl groups)	X	--
Cyclohexanes, (with various alkyl groups)	X	--
Decahydro-2-methylnaphthalene	X	--
Methane	--	X
2,3-Dihydro-4-methyl-1H-indene	--	X

Many chemicals in these tables are closely related to those that have been tested with laboratory standard solutions. For example, alkylated phenols are related to the parent phenol. Others, such as bromacil, are not closely related to chemicals previously reported. Many chemicals listed in these tables are probably components of complex hydrocarbon mixtures. These include alkanes, alkenes, alkylated naphthalenes, and alkylated anthracenes. Others are not hydrocarbons but are oxidized components of crude petroleum, such as the indene compounds. Several of the compounds tentatively identified include pesticides, such as bromacil, iridomyrmecin, trifluralin, and kelthane.

Table 15.--Tentative identifications of additional organic compounds found in the citrus area

[These compounds were not specifically analyzed using laboratory standard solutions, but were identified, with less reliability, using a National Bureau of Standards library of mass spectra. X indicates detection; -- indicates no detection]

	Pond sediment	Pond water	Grove soil	Surficial aquifer
Alkanes (various molecular weights)	X	X	X	--
Alkenes (various molecular weights)	X	--	X	--
Phenols (with various alkyl groups)	X	X	--	--
Benzenes (with various alkyl groups)	X	X	--	X
3-Methyl-1H-indole	X	X	--	--
1,3-Dihydro-2H-indol-2-one	X	X	--	--
2,3-Dihydro-1H-indene	--	--	--	X
2,3-Dihydro-1H-Inden-1-one	--	--	--	X
1H-Indole	--	X	--	--
Benzeneacetic acid	X	--	--	--
Benzenepropanoic acid	X	--	--	--
Benzenepropanoic acid, methyl ester	X	--	--	--
3-Hydroxybenzoic acid, methyl ester	X	--	--	--
3-(3-Hydroxyphenyl)-2-propenoic acid, methyl ester	--	X	--	--
13-Ethyl-3-hydroxy-Gona-1,3,5,7,9-pentane-17-one	--	X	--	--
1-(4-Hydroxy-3-methoxyphenyl)-ethanone	--	X	--	--
Benzaldehyde	--	X	--	--
4-Hydroxy-3-methoxybenzaldehyde	--	X	--	--
Bromacil	--	X	X	--
2,3-Dihydrobenzofuran	X	--	--	--
Iridomyrmecin	--	X	--	--
Alpha-Bergamoten	X	--	--	--
(Z)-Beta-farnesene	X	--	--	--
.beta.-Selinene	X	--	--	--
Trifluralin	--	--	X	--
bis(3-Chlorophenyl)methanone	--	--	X	--
bis(4-Chlorophenyl)methanone	--	--	X	--
Phosphotox E	--	--	X	--
Kelthane	--	--	X	--
Geyrene	--	--	X	--
Elemol	--	--	X	--
Seselin	--	--	X	--
Suberosin	--	--	X	--
Bravelin	--	--	X	--
Osthon	--	--	X	--
3,4'-Dichlorobenzophenone	--	--	X	--
2,2'-Oxybispropane	--	--	--	X
.alpha.-Methylbenzeneacetaldehyde	--	--	--	X
1,4-Dihydro-1,4-methanonaphthalene	--	--	--	X

Table 16.--Tentative identifications of additional organic compounds found in the phosphate mining area

[These compounds were not specifically analyzed using laboratory standard solutions, but were identified, with less reliability, using a National Bureau of Standards library of mass spectra. X indicates detection; -- indicates no detection]

	Sand tailings	Slime ponds	Cooling ponds	Surficial aquifer
Alkanes (various molecular weights)	X	X	X	--
Alkenes (various molecular weights)	X	X	X	--
Phenols (with various alkyl groups)	X	X	X	--
Benzenes (with various alkyl groups)	X	X	--	X
Naphthalenes (with various alkyl groups)	X	X	--	X
Naphthalenes (with various hydroxyl and alkyl groups)	X	X	--	X
Anthracenes (with various alkyl groups)	X	X	--	--
9H-Fluorenes (with various alkyl groups)	X	X	--	--
Phenanthrenes (with various alkyl groups)	X	X	--	--
Butylcyclohexane	X	--	--	--
.beta.-Ethenylbenzenethanol	X	--	--	--
Benzenemethanol	--	--	X	--
1,4-Dihydro-1,4-methanonaphthalen-9-ol	X	--	--	--
1,3-Isobenzofurandione	--	--	X	--
7-Ethyl-1,4-dimethylazulene	--	X	--	--
Benzaldehyde	--	--	X	--
2-Furancarboxaldehyde	--	--	X	--
Butanedioic acid, methyl ester	--	--	X	--
Benzoic acid	--	--	X	--
2,3-Dihydro-1H-indene	X	--	--	X
2,3-Dihydro-1-methyl-1H-indene	X	X	--	X
2,3-Dihydro-4-methyl-1H-indene	X	--	--	--
2,3-Dihydro-5-methyl-1H-indene	X	--	--	X
2,3-Dihydro-1,2-dimethyl-1H-indene	X	X	--	X
2,3-Dihydro-1,3-dimethyl-1H-indene	X	X	--	X
2,3-Dihydro-1,6-dimethyl-1H-indene	--	--	--	X
2,3-Dihydro-4,7-dimethyl-1H-indene	--	--	--	X
2,3-Dihydro-3,3-dimethyl-1H-indene -1-one	--	--	--	X
2,3-Dihydro-1,1,3-trimethyl-1H-indene	--	X	--	--
2,3-Dihydro-1,4,7-trimethyl-1H-indene	--	--	--	X
Dibenzothiophene	X	--	--	X
5-Methyl-benzo[b]thiophene	--	--	--	X
4-Methyl-benzo[b]thiophene	--	--	--	X
2,7-Dimethyl-benzo[b]thiophene	--	--	--	X
Fenchone	--	--	--	X
5-Methyl-1(3H)-isobenzofuranone	--	--	--	X
2-Methyl-1,1'-biphenyl	--	--	--	X
9H-Fluorene	--	--	--	X
9-Methyl-9H-fluorene	--	--	--	X

SUMMARY AND PRELIMINARY CONCLUSIONS

This study relates land use and associated activities to ground-water quality (trace elements and organic chemicals) in central Florida. The land uses included are: (1) urbanization in the Orlando study area where drainage wells convey surface water directly to the Upper Floridan aquifer, (2) citrus growing in the Windermere study area where many pesticides and fertilizers are in wide use, (3) mining and processing of phosphate ore in the Bartow study area where many processes may be increasing the potential of movement of contaminants to ground water, and (4) the absence of development in the Ocala National Forest study area where there is minimal human activity of any kind. Each of these land uses is representative of conditions which exist over larger areas, therefore, the results obtained from sampling in the four study areas, which range in size from only 80 to 200 square miles, may be transferable to many other locations.

Ground water is the principal source of drinking water in central Florida. The most important aquifer is part of the Floridan aquifer system which consists of fractured limestone and dolomitic limestone. The intermediate aquifer, which overlies the Upper Floridan aquifer in the phosphate mining area is used there as a secondary source of water. In the other areas, the Upper Floridan is separated from the surficial aquifer which immediately underlies the land surface in all the study areas, by mainly confining materials.

This first phase of the study consisted of reviewing available literature and data files, measuring water levels in wells, and sampling surface-water sources and water from wells. Samples were collected from representative surface sources such as surface runoff to drainage wells and stagnant water in drainage wells in the urban area; grove soil, pond sediment, and pond water in the citrus area; and process waters, sand tailings discharge, clay-slime discharge, and recirculation ditch water in the phosphate mining area. Water samples also were collected from wells that tapped receiving aquifers. The receiving aquifer in the urban area is the Upper Floridan aquifer and in the citrus and mining areas is the surficial aquifer. In the control area, water from both aquifers was sampled.

In the urban drainage well area, of the constituents of interest, the volatile organic compounds may exceed detection limits most frequently in the Upper Floridan aquifer. This includes benzene, chloroform, toluene, and methane, which were found in water pumped from the Upper Floridan, and trichloroethanes, dichloroethanes, dichloroethylenes, chloroethane, and ethylbenzene, which were found in source water. Of eight samples of water pumped from drainage wells, benzene was detected once at 200 $\mu\text{g/L}$, and of eight analyses of supply wells open to the Upper Floridan, chloroform was detected once at 11 $\mu\text{g/L}$, and toluene was detected once at 8.0 $\mu\text{g/L}$. Of 11 samples of drainage-well source water, 1,1,1-trichloroethene was detected twice at 340 and 550 $\mu\text{g/L}$, and 1,1-dichloroethane was detected twice at 77 and 97 $\mu\text{g/L}$. Present in lesser amounts are nonvolatile organics such as acenaphthene, silvex, and 2,4-D, detected in water pumped from the aquifer, and phthalates, fluoranthene, pyrene, and chlordane, in source water. Although there is a significant influx of trace elements such as chromium and lead to drainage wells, concentrations in water in the Upper Floridan aquifer

in the drainage well area apparently do not significantly exceed those in the Upper Floridan aquifer in the control area. A possible reason for this may be that the high pH of the water in this carbonate aquifer may cause precipitation of trace elements or that cation exchange between trace elements in the water and calcium ions in the aquifer is taking place.

In the citrus area, most ground-water contamination apparently is related to pesticides. This includes chemicals such as simazine and diazinon, which were found in water from the surficial aquifer; bromacil, ametryne, chlordane, DDE, trifluralin, iridomyrmecin, kelthane, phosphotox E, and bis(4-chlorophenyl)methanone, which were found at surface-source sites; and benomyl, diuron, dicofol, glyphosate, chlorobenzilate, and aldicarb, which are pesticides known to be in use in citrus-growing areas but not detected in ground water. The widespread occurrence of EDB in central Florida has been documented by the Florida Department of Environmental Regulation. Trace elements associated with pesticide and fertilizer use include zinc, copper, and manganese. These elements, in addition to iron, lead, and selenium, occur at higher concentrations in the citrus area surficial aquifer than in the control area surficial aquifer. Other contaminants that may be entering ground water are chemicals related to petroleum such as benzene, toluene, naphthalene, and indene compounds.

In the phosphate mining area, the most abundant ground-water contaminants among the constituents of interest, are trace elements. Selenium, mercury, arsenic, manganese, and iron concentrations frequently were greater than those in the control area. Mercury and arsenic were each detected in 10 of 11 samples of water from the surficial aquifer. The highest mercury concentration was 8.0 $\mu\text{g/L}$ and the highest arsenic concentration was 60 $\mu\text{g/L}$. These and other trace elements have been shown to occur in high concentrations in the surficial aquifer, but their movement may be attenuated by acid neutralization. Organic compounds such as fluorene, di-n-butyl phthalate, naphthalene, alkylated benzenes and naphthalenes, and indene compounds with hydroxyl and alkyl groups attached were detected.

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* GOVERNMENT PRINTING OFFICE: 1987 - 730135 / 40021