Analysis of Nonpoint-Source Ground-Water Contamination in Relation to Land Use: Assessment of Nonpoint-Source Contamination in Central Florida

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By E.R. German

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CONVERSION FACTORS, ABBREVIATED WATER-QUALITY UNITS, AND ACRONYMS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meters
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow	
inch per year (in/yr)	25.4	millimeter per year
	Transmissivity	
foot squared per day (ft^2/d)	0.0929	meter squared per day
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day
	Hydraulic gradient	
foot per mile (ft/mi)	0.1786	meter per kilometer
	Application rate	
pounds per acre per year [lb/acre)/yr]	1.121	kilograms per hectare per year
	Leakance	
inch per year per foot [(in/yr)/ft]	83.33	millimeter per year per meter

Equations for temperature conversion between degrees Celsius (°C) and degrees Fahrenheit (°F):

$$°C = 5/9\ (°F - 32)$$
$$°F = (9/5\ °C) + 32$$

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.

Altitude, as used in this report, refers to distance above or below sea level.

Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness $[(ft^3/d)/ft^2]ft$. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Abbreviated water-quality units

μg/L	micrograms per liter
mg/L	milligrams per liter

Acronyms

CSTR	constantly stirred tank reactor
DBCP	dibromochloropropane
DDE	dichlorodiphenyldichloroethylene
DDT	dichloro diphenyl trichlorethane
EDB	ethylene dibromide
FDACS	Florida Department of Agriculture and Consumer Services
FDEP	Florida Department of Environmental Protection
FID	flame-ionization detector
GC	gas chromatography
MS	mass spectrography
NURP	Nationwide Urban Runoff Program
PVC	polyvinylchloride
RUPS	restricted-use pesticides
TIOC	tentatively identified organic compounds
TOC	total organic carbon
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Analysis of Nonpoint-Source Ground-Water Contamination in Relation to Land Use: Assessment of Nonpoint-Source Contamination in Central Florida

By Edward R. German

Abstract

Ground-water quality in central Florida is affected by land-use practices, such as the urbanization of karstic terrain with accompanying stormwater disposal through drainage wells, citrus cultivation with accompanying application of large quantities of fertilizers and pesticides, and mining and processing of phosphate ores into fertilizers. Stormwater entering drainage wells in urban areas can directly affect the Upper Floridian aquifer, the upper part of the Floridan aquifer system, which is used as a source of potable water throughout the area. Leachate from fertilizers and pesticides, and activities associated with phosphate mining are most likely to affect the surficial aquifer system. Although water from the surficial aquifer system is not used extensively as a source of public water supply, it does ultimately recharge the Floridan aquifer system.

Ground-water quality in three developed areas with different land uses was compared to ground-water quality in an undeveloped control area. Statistical tests were used to determine if differences in ground-water quality among the areas were significant. A probability level of 5 percent was used to indicate significant differences.

The primary study areas were an undeveloped area referred to as the control area, an urban area, a citrus production area, and a phosphate-mining area. The control area is an undeveloped part of the Ocala National Forest, where only low-density recreational activities and periodic logging occur. The urban area is in Orlando, where hundreds of drainage wells convey stormwater to the Upper Floridan aquifer. The citrus area is near Windermere, west of Orlando, where citrus has been cultivated for at least 25 years. The mining area is near Bartow, Fla., in an area that supplies as much as one-fifth of the phosphate used in manufacturing fertilizer worldwide. In addition to the primary study areas, two other areas were studied to test transferability of the findings from the primary urban and citrus study areas. These were a citrus area near Lake Wales and an urban area in Ocala.

Concentrations of most of the major constituents, nitrogen species, phosphorus, and organic compounds in water from the Upper Floridan aquifer underlying the urban area were significantly greater than concentrations in water from this aquifer in the control area, possibly as the result of drainage-well inflow. Trace elements and volatile organics were detected in ground water in the control area as frequently as in ground water in the urban area.

Most major constituents and nitrogen species were present in greater concentrations in water from the surficial aquifer system underlying the citrus area than in water from the surficial aquifer system in the control area. Nitrate-nitrogen concentrations exceeded the U.S. Environmental Protection Agency primary maximum-contaminant level for drinking water (10 milligrams per liter) in water from more than half the 33 wells sampled in the citrus area. The pesticide bromacil was detected in water from more than

half of the 19 wells in the citrus area sampled for pesticide analysis. Concentrations of bromacil exceeded 20 micrograms per liter in water from some wells in the citrus area.

Study results indicate that the most mineralized ground water is in the mining area. Concentrations of all major constituents, nitrogen species, and phosphorus were significantly greater in water from the surficial aquifer system underlying the mining area than in ground water from the control area. The numbers and concentrations of organic compounds detected in ground water also were greater in the mining area than in the control area. Arsenic was more commonly detected in ground water in the mining area than in the control area and was the only trace element that was detected significantly more frequently in any developed area than in the control area.

Ground-water quality was determined in a second urban area (the Ocala area) to test the transferability of the study results to other urban areas. Ground-water quality in the Upper Floridan aquifer beneath the Ocala area differed from that in the undeveloped area as did ground-water quality in the Orlando urban area. In both of these urban areas, stormwater is disposed of in drainage wells or sinkholes. However, the specific effects of stormwater on ground-water quality may not be consistent from one urban area to another.

Ground-water quality also was determined in a second citrus area to test the transferability of study results to other citrus areas. A comparison of the water-quality data for the two areas indicated that citrus cultivation had affected the quality of water in the surficial aquifer system in both areas. Nitrate concentrations in water from the surficial aquifer system in both citrus areas generally exceeded the maximum-contaminant level for drinking water. Also, bromacil was detected in concentrations exceeding 20 micrograms per liter in ground-water samples from several wells in each of the two citrus areas.

INTRODUCTION

Three aquifer systems (the Floridan aquifer system, the intermediate aquifer system, and the surficial aquifer system) supply most of the drinking water in central Florida. The major source of water supply is the Floridan aquifer system, which consists of fractured limestone and dolomitic limestone of Paleocene to early Miocene age. The intermediate aquifer system lies above the Floridan aquifer system and consists primarily of clayey sand, gravel, shell, and fractured limestones of Miocene age. Overlying the intermediate aquifer system is the surficial aquifer system, which consists primarily of sand and shellbeds of Pleistocene and Holocene age. Although the intermediate and surficial aquifer systems are less productive sources of water than the Floridan aquifer system, they are locally important sources of water because of the expense of drilling deep wells or because of local water-quality problems in the Floridan aquifer system. The intermediate and surficial aquifer systems are sources of recharge to the Floridan aquifer system.

Land use can affect the quality of ground water, including water deep in the Floridan aquifer system. The three major types of land use or development in areas of recharge to the Floridan aquifer system in central Florida are (l) urbanization in karstic terrain with accompanying stormwater disposal through drainage wells, (2) citrus cultivation with associated application of fertilizers and pesticides, and (3) phosphate-ore mining and processing with associated chemical use. The effects of these land uses on underlying ground water can be evaluated by comparing hydrologic data collected from these areas with data collected from a geohydrologically similar area that is relatively unaffected by man’s activities.

The U.S. Geological Survey (USGS) began appraising the ground-water quality in selected areas of the Nation for the Toxic Waste--Ground-Water Contamination Program in 1984. The central Florida study area (fig. l) was 1 of 14 study areas throughout the United States selected for investigation of a variety of hydrologic, climatic, soil, and land-use characteristics. The studies were intended to develop methods to evaluate the extent of ground-water contamination and to determine the effects of human activities and land-use practices on ground-water quality (Helsel and Ragone, 1984). The central Florida study was conducted by the USGS in cooperation with the Florida Department of Environmental Protection (FDEP) (formerly the Florida Department of Environmental Regulation).

Some of the 14 studies were conducted in two phases: a preliminary phase and a final phase. Central Florida was one of seven areas selected for additional study in the final phase. The scope of the two phases varied among the studies depending on available data

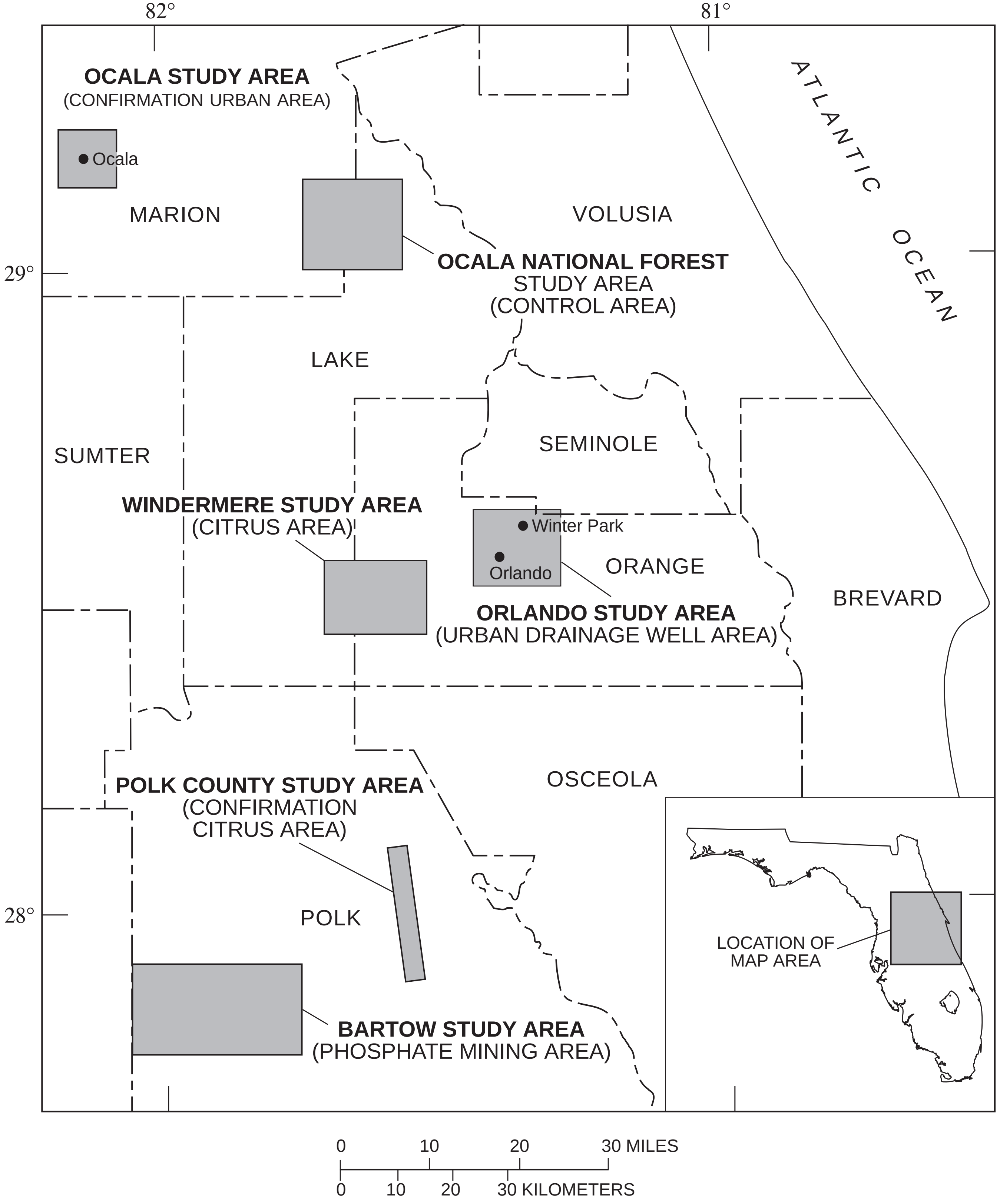


Figure 1. Locations of study areas.

and specific study objectives. Results of the preliminary phase in central Florida indicated that relatively little data on ground-water quality were available and that little was known about the possible effects on ground water from potential surface sources of contamination, especially with respect to organic compounds. The preliminary phase of the central Florida study had three principal objectives: (1) identify chemicals used in each major land-use type that could affect ground-water quality; (2) indicate which chemicals could be in the path of water recharging the aquifer; and (3) provide preliminary characterization of ground-water quality for each major land use and compare the similarities and differences in ground-water quality among the land-use categories.

Data were collected from April 1984 to March 1985 for the preliminary phase of the central Florida study, and a report presenting the data and conclusions of that phase of the study was published in 1987 (Rutledge, 1987). A study plan for the final phase of the study, which was designed to determine the effect of land use on ground-water quality, was then prepared and work on this phase of the study was begun. This report presents the results of the final phase of the central Florida study.

The effects of urban, citrus cultivation, and phosphate mining land-use on ground-water quality are evaluated in this report. The potential for contamination is discussed and ground-water quality in each developed area is individually compared to that in an undeveloped control area. Also, the transferability of study results for urban and citrus areas to other areas of similar land use was evaluated using data from other urban and citrus areas. The transferability of the identified land-use effects associated with the mining area was not investigated because there is such a variety of mining-related activities that a transferability study was beyond project resources.

All chemical data collected during preliminary and final phases of this study (April 1984-September 1989) are summarized in this report. Some data from earlier studies also are included. Chemical data summarized in this report include concentrations of dissolved major constituents, macronutrients (nitrogen and phosphorus species), trace elements, organic compounds of several classes, and radiochemicals. Analyses of the organic compounds included gas chromatography screening scans and quantitative analyses of volatile compounds, pesticides of several classes, and base-neutral and acid-extractable priority pollutants. Radioisotope analyses were used for dating ground water.

DESCRIPTION OF THE STUDY AREAS

Ground-water quality was determined in three areas in Florida with different land uses (urban, citrus, and phosphate mining) and in an undeveloped control area. The control area is located in the Ocala National Forest. The urban area is in Orlando, the citrus area is near Windermere, and the phosphate-mining area is near Bartow. Additional sampling of ground water to study transferability of identified land-use effects was conducted in an urban area in Ocala and in a citrus area near Lake Wales (fig. 1).

All the study areas have similar climate, topography, and underlying geohydrologic units. The Upper Floridan aquifer is the unit of primary interest in the urban areas, whereas the surficial aquifer system is the unit of primary interest in the citrus and mining areas. Both aquifers were investigated in the control area.

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 the average annual rainfall is about 53 in. More than half the annual rainfall occurs from June through September.

Topography

The topography in most of the study areas is classified as karst. This is the name applied to the undulating, pitted land surface where sinkholes are numerous and drainage is primarily downward into underlying limestone aquifers rather than laterally into streams. The topography of the phosphate-mining area is typically flatlands that have been modified by surface mining. Streams drained the area prior to the commencement of mining activities. Because of the use of connector wells (wells connecting the surficial and Upper Floridan aquifer), vertical drainage probably has increased and streamflow probably has decreased. Additionally, mining has increased topographic relief in the area.

Geohydrologic Units

All four study areas are underlain by the surficial aquifer system, which is composed of sand and clay beds of Pleistocene and Holocene age, and the Floridan aquifer system, composed of fractured limestone and dolomitic limestone of Paleocene to early Miocene age (fig. 2). Between the surficial aquifer system and the Floridan aquifer system lies a sequence of discontinuous beds of clay, marl, sand, and limestone of early Miocene age. Where the limestone beds are thick and laterally extensive enough to constitute aquifers, as they are in the phosphate-mining area, the sequence is referred to as the intermediate aquifer system. In the other three study areas, the limestone layers are absent and the sequence primarily is a confining unit. The intermediate aquifer system, together with the Upper Floridan aquifer, is used in the phosphate mining area as a source of water for domestic, industrial, and irrigation uses.

The thickness of the surficial aquifer system in the four study areas ranges from 0 to about 200 ft and averages about 60 ft. The thickness of the intermediate aquifer system in the mining study area ranges from about 50 to 350 ft. The Floridan aquifer system, which is 1,500 to 3,500 ft thick in central Florida, is divided into an upper and lower aquifer. These aquifers, referred to as the Upper Floridan aquifer and the Lower Floridan aquifer, are separated by a less permeable unit of limestone.

The Floridan aquifer system is the source of most ground-water withdrawals in the four study areas although some water is withdrawn from the surficial and intermediate aquifer systems. The Upper Floridan aquifer is the major source of water in all study areas except the urban area, where more than half of the ground water is withdrawn from the Lower Floridan aquifer. The surficial aquifer system probably supplies less than 5 percent of the ground water withdrawn in each of the four areas. The intermediate aquifer system is a significant source of water only in the mining area.

Control Area

The 110 mi^2 undeveloped control area is located in the southern part of the Ocala National Forest (fig. l).

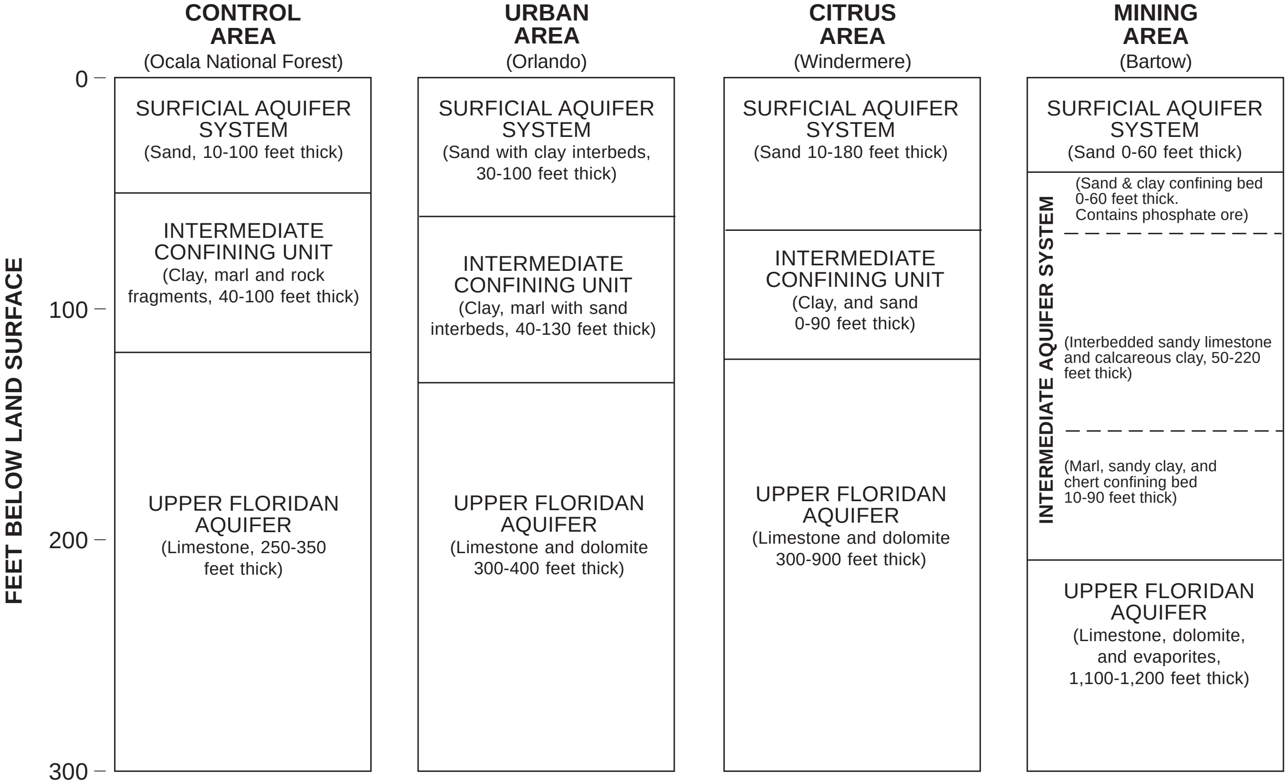


Figure 2. Generalized geohydrologic columns in the four study areas in central Florida. (Thickness of units other than the Upper Floridan aquifer, as drawn, indicate average thickness of units. Modified from Rutledge, 1987.)

Ground water from wells tapping either the Upper Floridan aquifer or the surficial aquifer system in the control area was sampled for comparison with ground water in one or more of the developed land-use areas. About 65 percent of the control area is upland forest and about 35 percent consists of wetlands, surface-water bodies, and grasslands in approximately equal parts (fig. 3). The upland forest sections of the area are subject to periodic logging. A bombing range used for training U.S. Navy air crews is located in the northwestern part of the control area and, as a result of the training activity, the control area is subject to frequent low-altitude overflights.

The sandy soils in the control area provide rapid infiltration of water and soils in the higher-altitude areas are subject to excessive drainage which limits moisture in the soil zone. Because of relatively low soil moisture, plants in the control area are limited to those that can tolerate relatively dry conditions. The depth to the water table in some places within the control area is as much as 100 ft. Because the altitude of the water table is greater than the potentiometric surface of the underlying Upper Floridan aquifer (fig. 4), the surficial aquifer system recharges the underlying Floridan aquifer system.

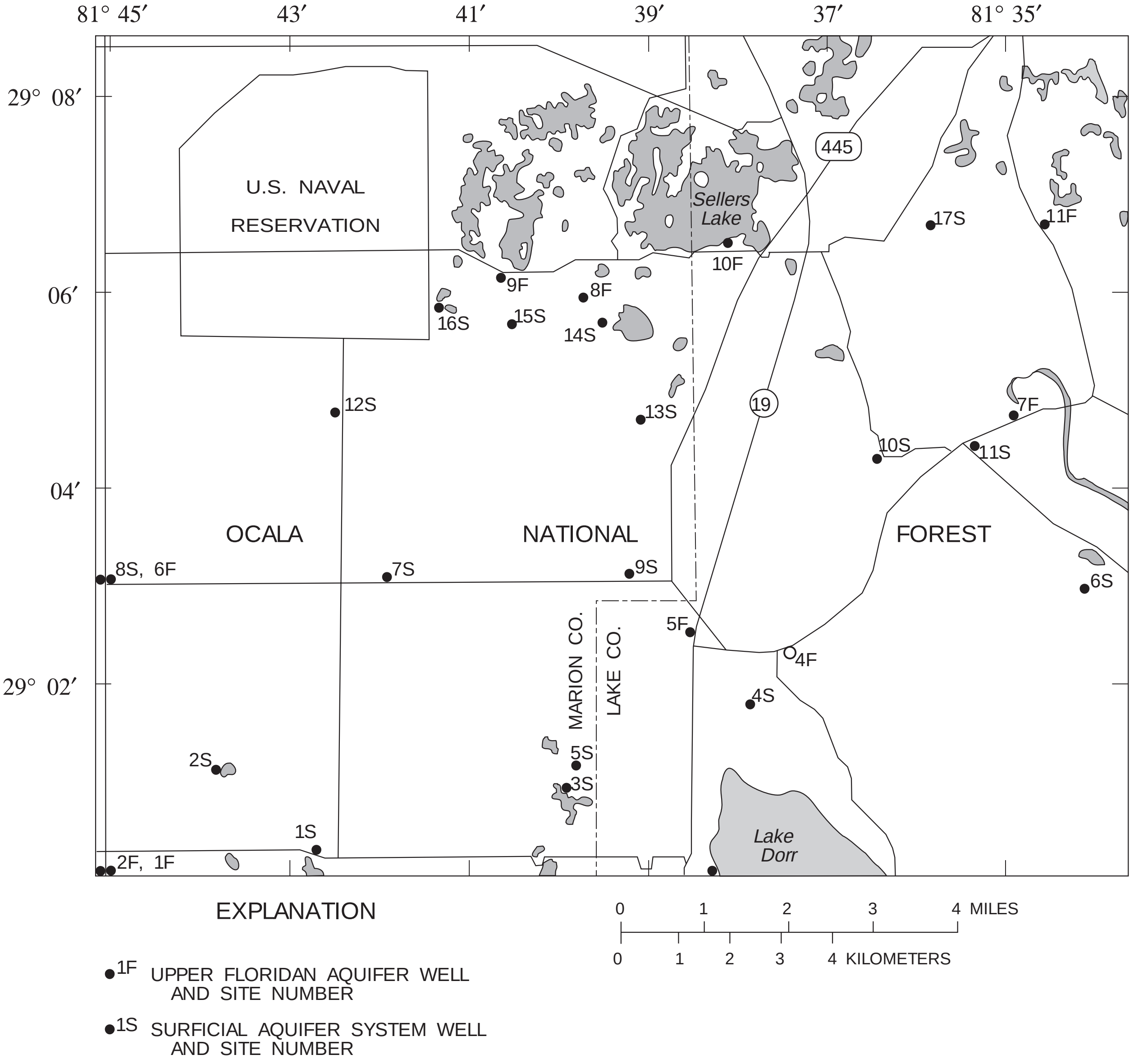


Figure 3. Control area and locations of sampled wells.

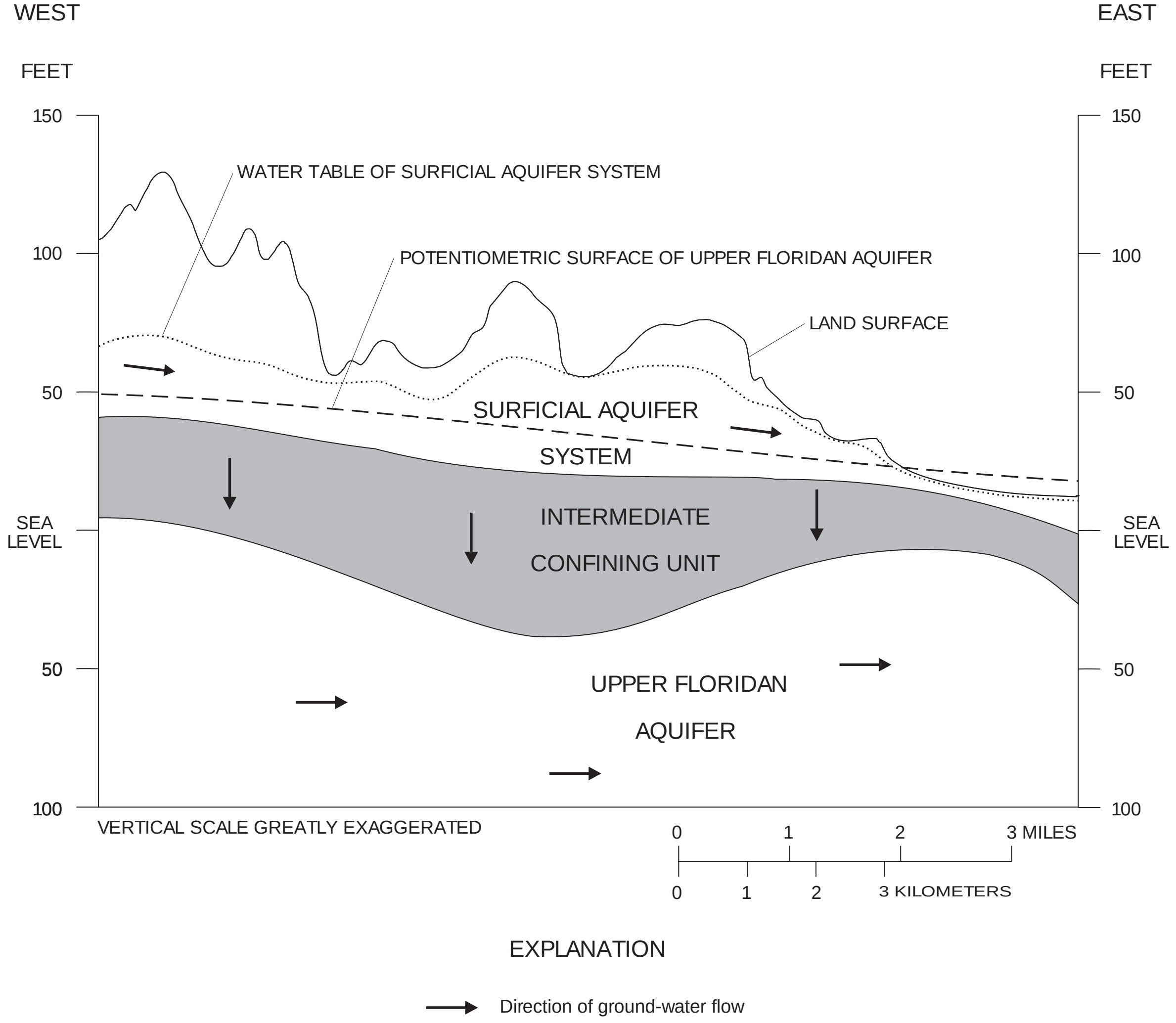


Figure 4. Generalized geohydrologic section through the control area in the Ocala National Forest (modified from Rutledge, 1987).

The rate of movement of water from the surficial aquifer system to the Upper Floridan aquifer in the control area can be estimated from the head difference across the intermediate confining unit between the two aquifers and the leakance coefficient of the confining unit. Using a typical head difference of 10 ft. and a leakance of 1.2 (in/yr)/ft, Tibbals (1981) and Ryder (1982) estimated that recharge to the Upper Floridan aquifer by leakage through the confining unit averaged about 12 in/yr.

The prevailing direction of water movement in the Upper Floridan aquifer is eastward (fig. 4). Rutledge (1987) estimated the rate of ground-water movement in this aquifer to be 4.8 ft/d, based on a hydraulic gradient of 4 ft/mi; a transmissivity of 380,000 ft^2/d; an aquifer thickness of 300 ft; and an aquifer porosity of 20 percent.

Urban Area

The urban study area covers about 90 mi^2 in central Orlando (fig. l). Land-cover percentages in the urban study area are residential, 45 percent; commercial and services, 15 percent; industrial and commercial complexes, 5 percent; transportation and other urban uses, 10 percent; lakes, 5 percent; and nonurban, 20 percent. The nonurban usage includes wetlands, small areas of pine forest, citrus groves, and barren land.

In the urban study area, natural drainage is supplemented by the use of drainage wells. There are more than 400 drainage wells in the greater Orlando area. About 330 of these are within the area selected for study (fig. 5). The wells are open to the Upper Floridan aquifer and typically are about 120 to 600 ft

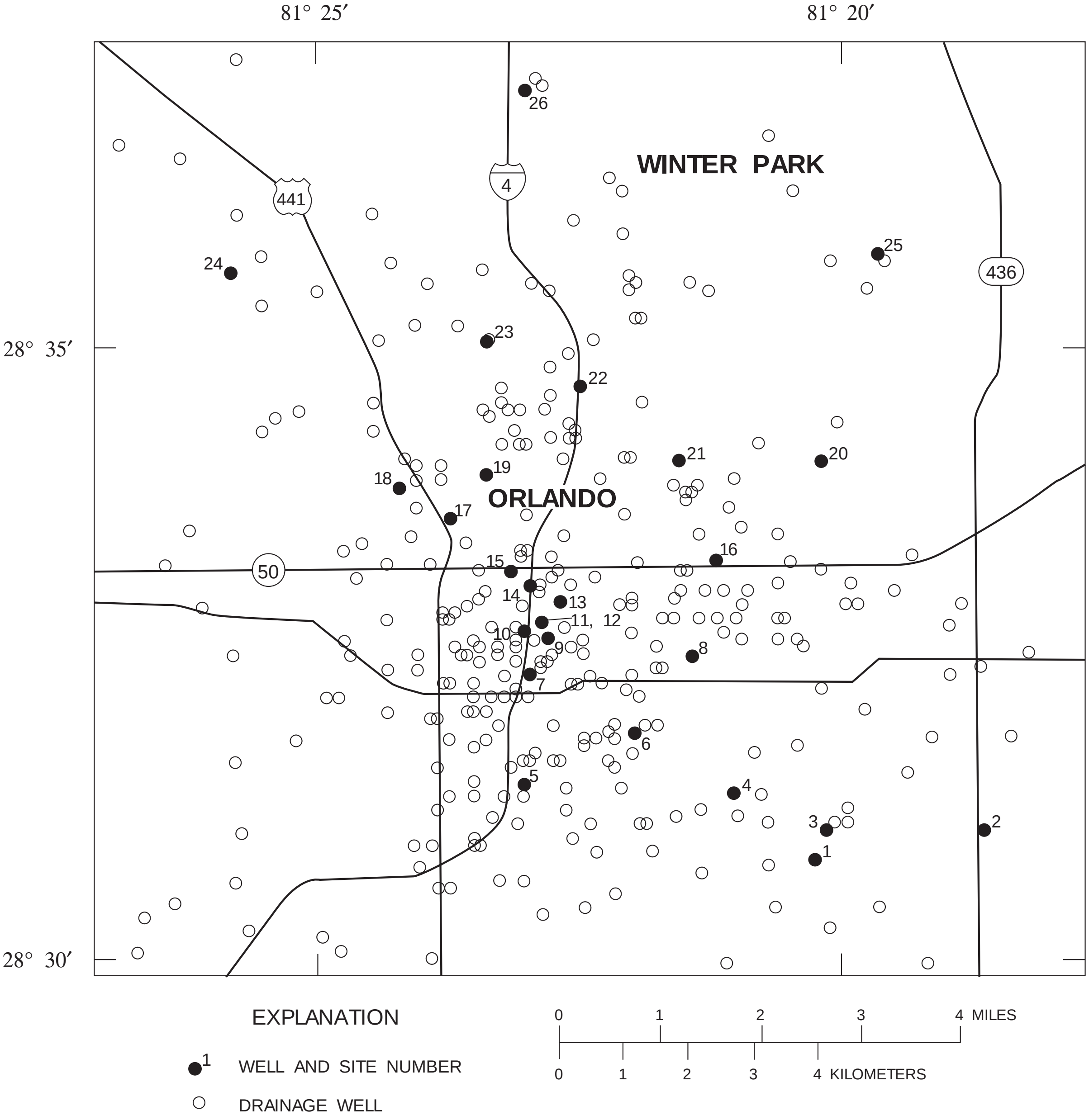


Figure 5. Urban study area in Orlando, Fla., and locations of sampled wells and drainage wells.

deep; median depth is 400 ft. One well is thought to be 1,050 ft deep. These drainage wells are used to dispose of runoff from streets and other impervious areas (about 50 percent of the wells); to regulate lake levels (35 percent); and to dispose of cooling, air conditioning, and other wastewater (15 percent) (Schiner and German, 1983). Early use of drainage wells included disposal of domestic sewage and industrial wastewater, but this usage is not known to have occurred during the last 30 years.

The quantity of drainage-well recharge in the urban study area is not insignificant in comparison to natural recharge. Rutledge (1987) estimated that natural recharge to the Upper Floridan aquifer from the surficial aquifer system is 12 in/yr in the urban study area and that recharge through drainage wells is 7 in/yr.

A generalized geohydrologic section of the urban area is shown in figure 6. The water table is 30 to 50 ft above the potentiometric surface of the Upper Floridan aquifer; thus, movement of water in

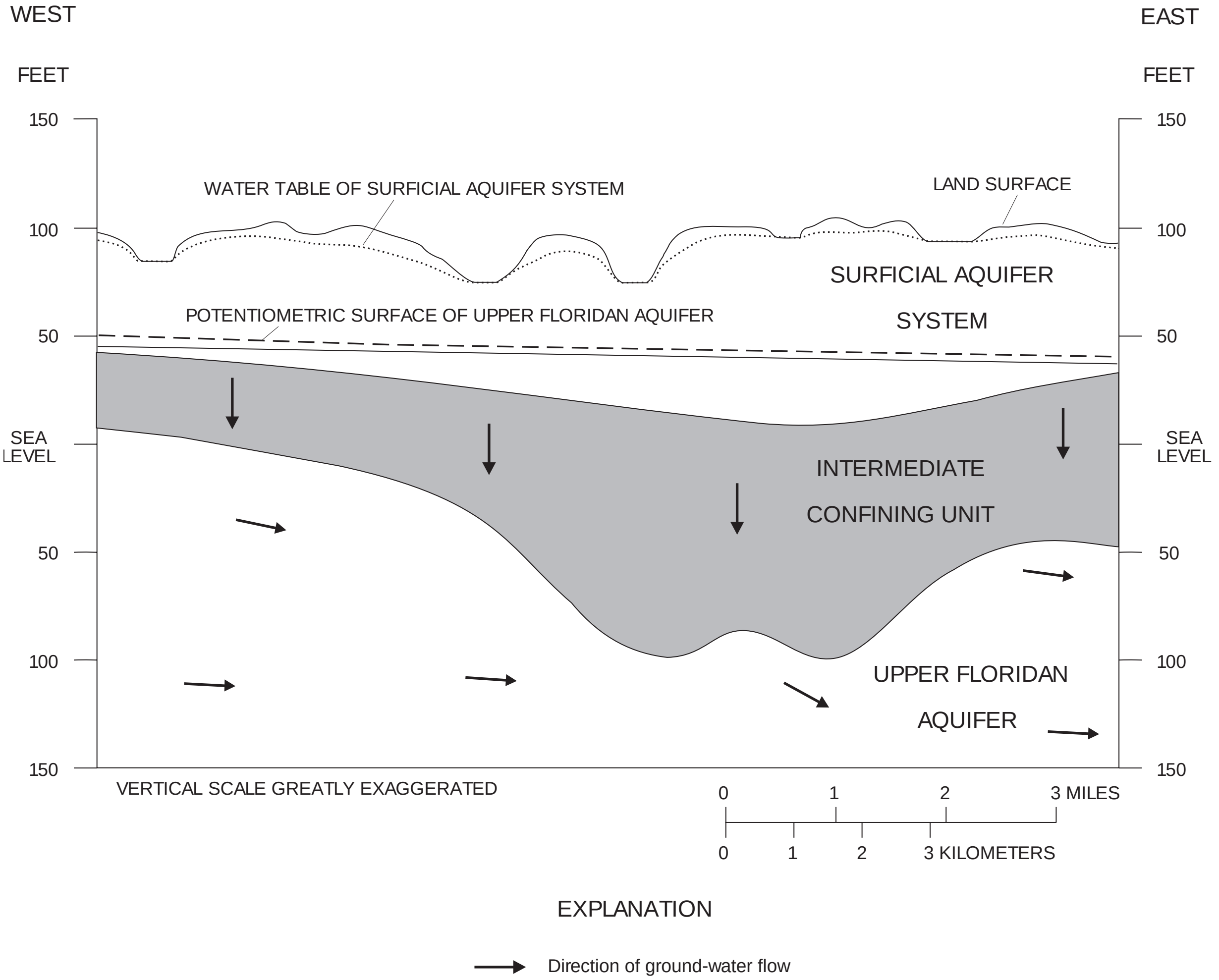


Figure 6. Generalized geohydrologic section through the urban study area in Orlando, Fla.

the vertical direction is downward from the surficial aquifer system to the Upper Floridan aquifer. Some of the water is lost to evapotranspiration or moves laterally and discharges to surface-water bodies.

The lateral direction of regional ground-water movement in the Floridan aquifer system generally is from west to east in the Orlando urban area (fig. 6) and the velocity of flow through the aquifer is estimated to be about 0.6 ft/d (Rutledge, 1987). Mounding of the potentiometric surface as a result of recharge through drainage wells may have disrupted regional flow patterns. A ground-water flow model has indicated that a sustained potentiometric high equivalent to as much as 4 ft of head (water pressure) could exist in the Orlando urban study area because of drainage-well recharge to the Upper Floridan aquifer (Tibbals, 1990).

Citrus Area

The study area near Windermere (fig. 1) is typical of citrus farming areas throughout central Florida. About 40 percent of the 90 mi^2 study area (fig. 7) was in citrus cultivation prior to devastating freezes in December 1983 and January l985. Other land-cover types in the study area include cropland, pastures, and barren land, 25 percent; wetlands, 10 percent; lakes, 10 percent; and other types, l5 percent. Citrus cultivation in the study area at all locations where wells were sampled had been ongoing for at least 25 years according to aerial photographs and topographic map coverage.

A generalized geohydrologic section of the citrus study area is shown in figure 8. The altitude of the water table generally reflects the topography and probably averages about 15 ft higher than the altitude of the potentiometric surface of the Upper Floridan

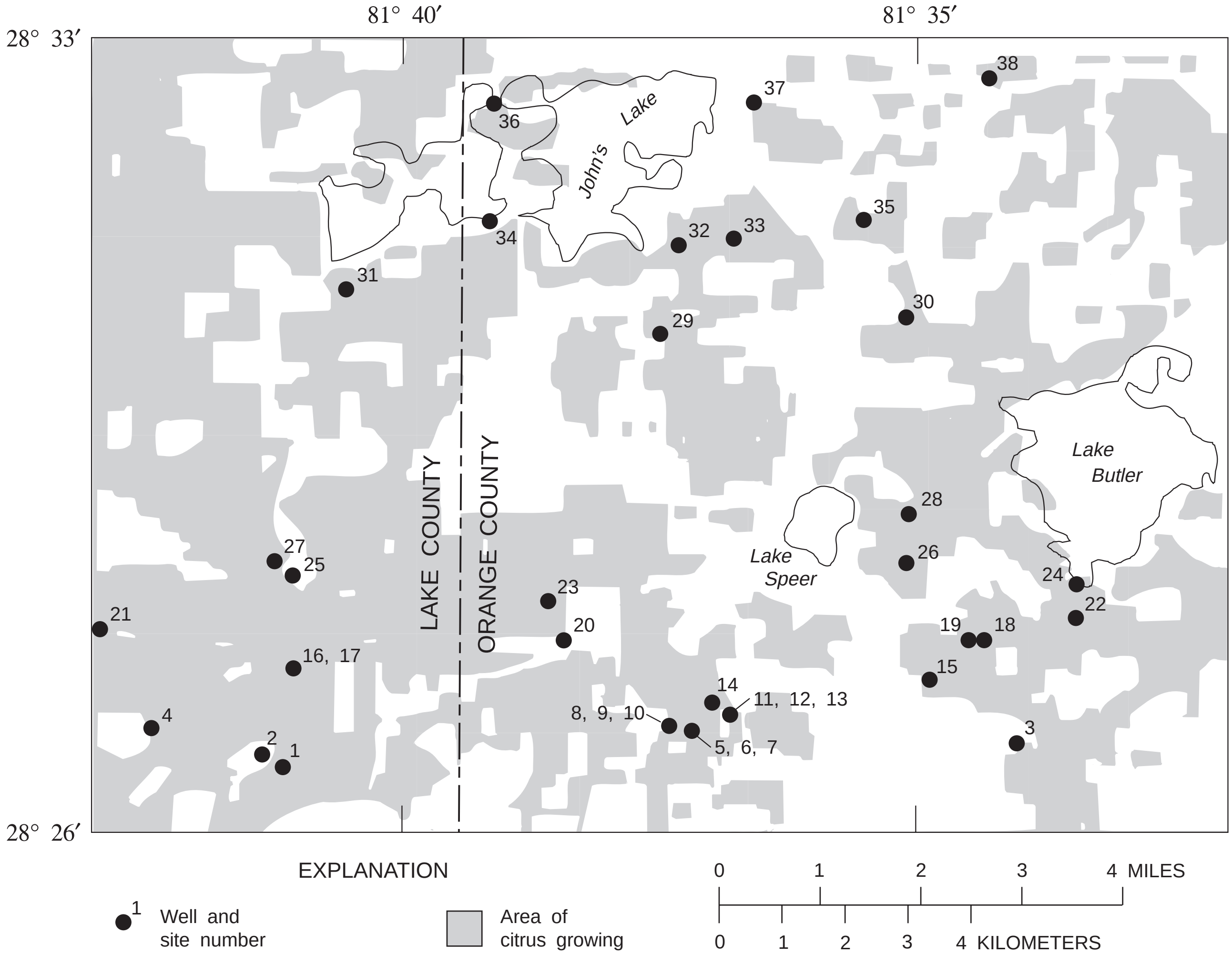


Figure 7. Citrus study area near Windermere, Fla., and locations of sampled wells.

aquifer (Rutledge, 1987). Water in the surficial aquifer system percolates downward to the Upper Floridan aquifer or moves laterally to surface-water bodies. Some water probably is lost to evapotranspiration in areas where the water table is near land surface. Rutledge (1987) estimated a recharge rate of 6 in/yr from the surficial aquifer system to the Upper Floridan aquifer in the citrus study area.

Mining Area

The mining area selected for study is a 190 mi^2 area near Bartow (fig. 1) where phosphate ore is mined. Within this area are several industrial complexes for processing phosphate ore into fertilizer (fig. 9). Land cover in this study area includes barren land, 40 percent; rangeland, 20 percent; industrial complexes, 10 percent; water and wetlands, l0 percent; and other types, 20 percent. Most of the barren land, rangeland, and some of the water and wetlands represent mined areas in various stages of reclamation.

Phosphate ore is present within the unconsolidated upper part of the intermediate aquifer system (fig. 2). Mining usually is accomplished by dragline displacement of the overburden (containing the surficial aquifer system) followed by removal of phosphate ore for processing.

Interaquifer connector wells are installed as part of the mining process to remove water from the surficial aquifer system by draining it to the intermediate or Upper Floridan aquifers. Water flows from the surficial aquifer system into the well, then downward into the intermediate aquifer system or the Upper Floridan aquifer, or both, thereby lowering water levels in the surficial aquifer system.

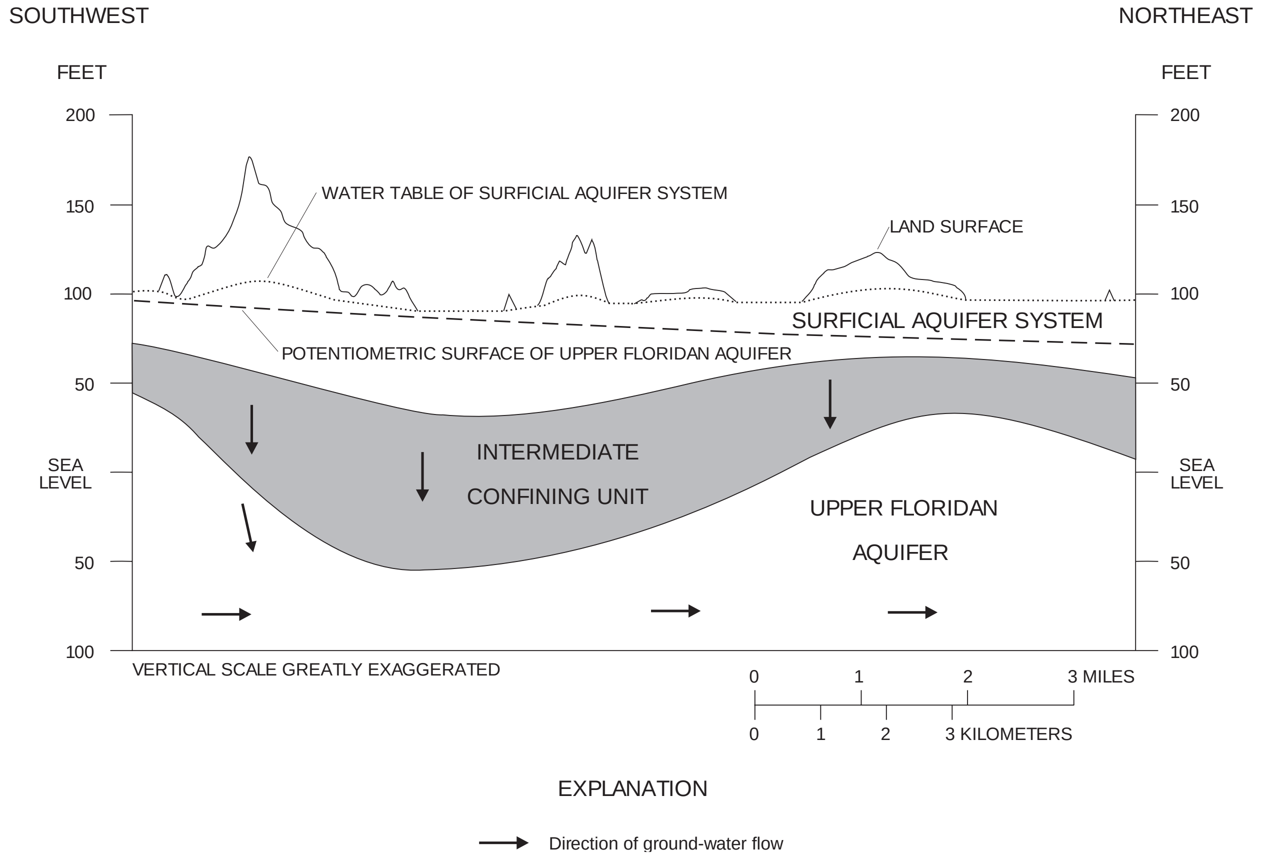


Figure 8. Generalized geohydrologic section through the citrus study area near Windermere, Fla. (modified from Rutledge, 1987).

Following excavation, the ore is mixed with water and the resulting slurry is transported through pipes to 1 of 9 ore-processing plants in the study area (fig. 9). The processing plant separates the phosphate particles from the unwanted sands and clays, which constitute about two-thirds of the ore. The separation involves washing the ore to remove clay particles, and then physically separating the phosphatic rock from the remaining sand using a flotation process. A clay slurry generated as a waste product is pumped into settling ponds, commonly called slime ponds, where the clay is allowed to settle. Water is drawn from the top of the slime ponds and reused. Slime ponds eventually become filled with the clay, which is allowed to dry, and commonly are covered with soil or overburden as part of a land-reclamation process. The sand, often referred to as tailings, is mixed with water and pumped back into mined-out cuts and used for fill as part of the reclamation process. The fill is then covered with overburden and revegetated.

There are 10 phosphate-processing plants in the Bartow area (fig. 9), where sulfuric acid is added to the phosphate extracted from the ore to produce phosphoric acid. A voluminous by-product of this process is gypsum (hydrated calcium sulfate), which is transported as a slurry to residual piles called gypsum stacks. Process water flows from the stacks into cooling ponds and is recycled for further use.

A generalized geohydrologic section of the mining area is shown in figure 10. The water table in the mining area is about 25 ft higher than the potentiometric surface in the Upper Floridan aquifer. As in the other study areas, water in the surficial aquifer system moves laterally to surface-water bodies, is lost to evapotranspiration, or moves downward to recharge the intermediate aquifer system and the Upper Floridan aquifer. Rutledge (1987) estimated leakage of water from the surficial aquifer system to the Upper Floridan aquifer to be 7 in/yr within the mining area.

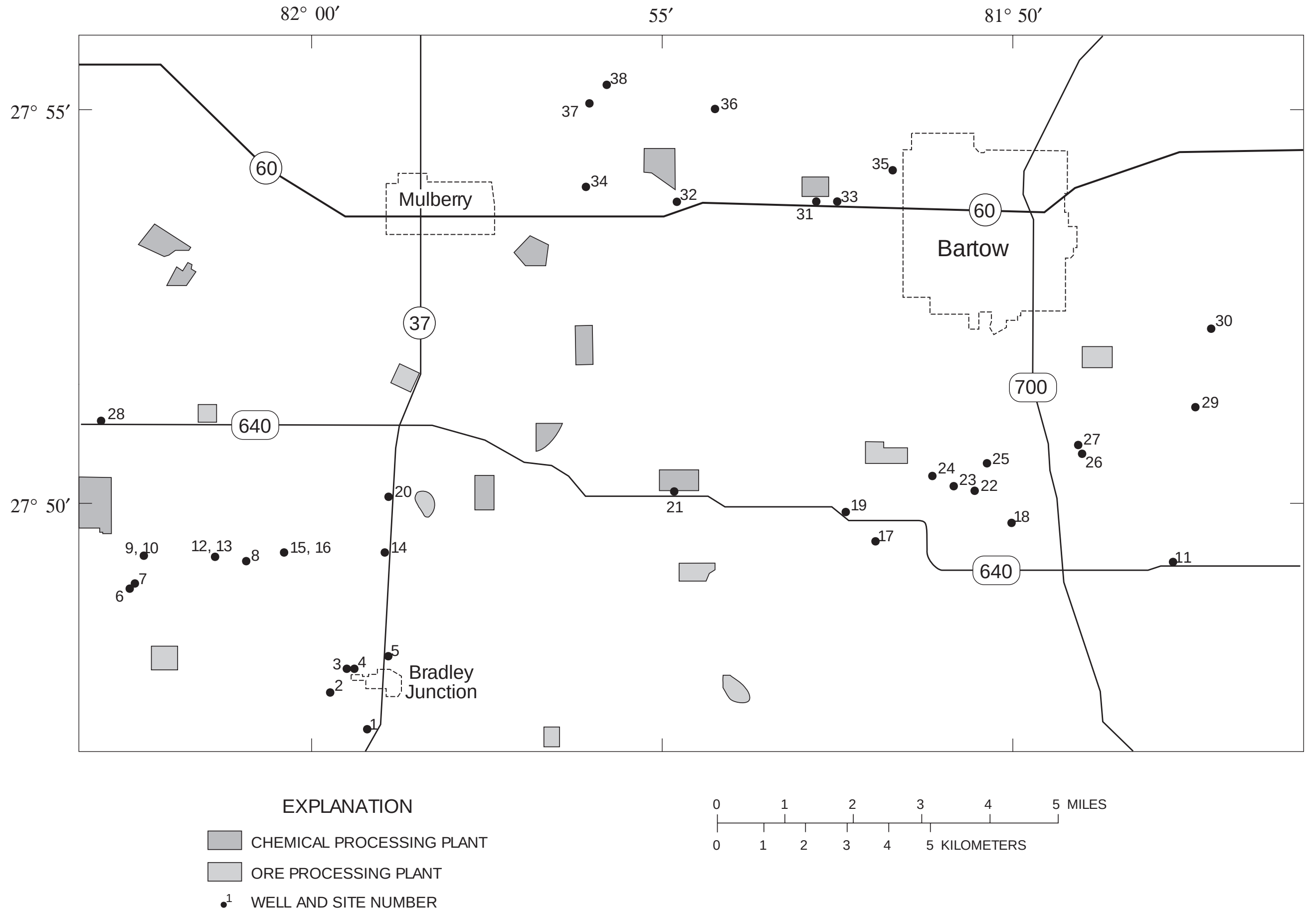


Figure 9. The phosphate mining study area near Bartow, Fla., and locations of sampled wells.

Areas Selected for Assessment of Transferability of Study Results

Two additional study areas were selected to test the transferability of study results related to land-use effects on ground-water quality identified in the Orlando urban and Windermere citrus study areas to other areas of similar land use. The transferability testing was limited to urban and citrus land uses because of the complexity associated with determination of water-quality characteristics in phosphate-mining areas.

Urban Area

The area selected for the test of transferability of identified land-use effects associated with urban stormwater recharge is located in Ocala, about 60 mi north of the primary urban study area in Orlando (fig. 1). Ocala, like Orlando, utilizes drainage wells open to the Upper Floridan aquifer to augment natural drainage (fig. 11). There are 42 drainage wells known to be active in the Ocala area (Kimrey and Fayard, 1984), far fewer than the 400-plus drainage wells in the Orlando area.

The Upper Floridan aquifer is at a higher altitude in the Ocala area than in the Orlando area and is at or near land surface throughout most of the area where land-surface altitudes are less than 100 ft above sea level. Many natural sinkholes and detention ponds receiving urban stormwater in the Ocala area incise the top of the Upper Floridan aquifer, thereby emplacing the urban stormwater directly into the Upper Floridan aquifer. With the combination of drainage wells, sinkholes, and detention ponds in the Ocala area, the process of emplacing urban stormwater into the Upper Floridan aquifer is similar to that occurring in Orlando.

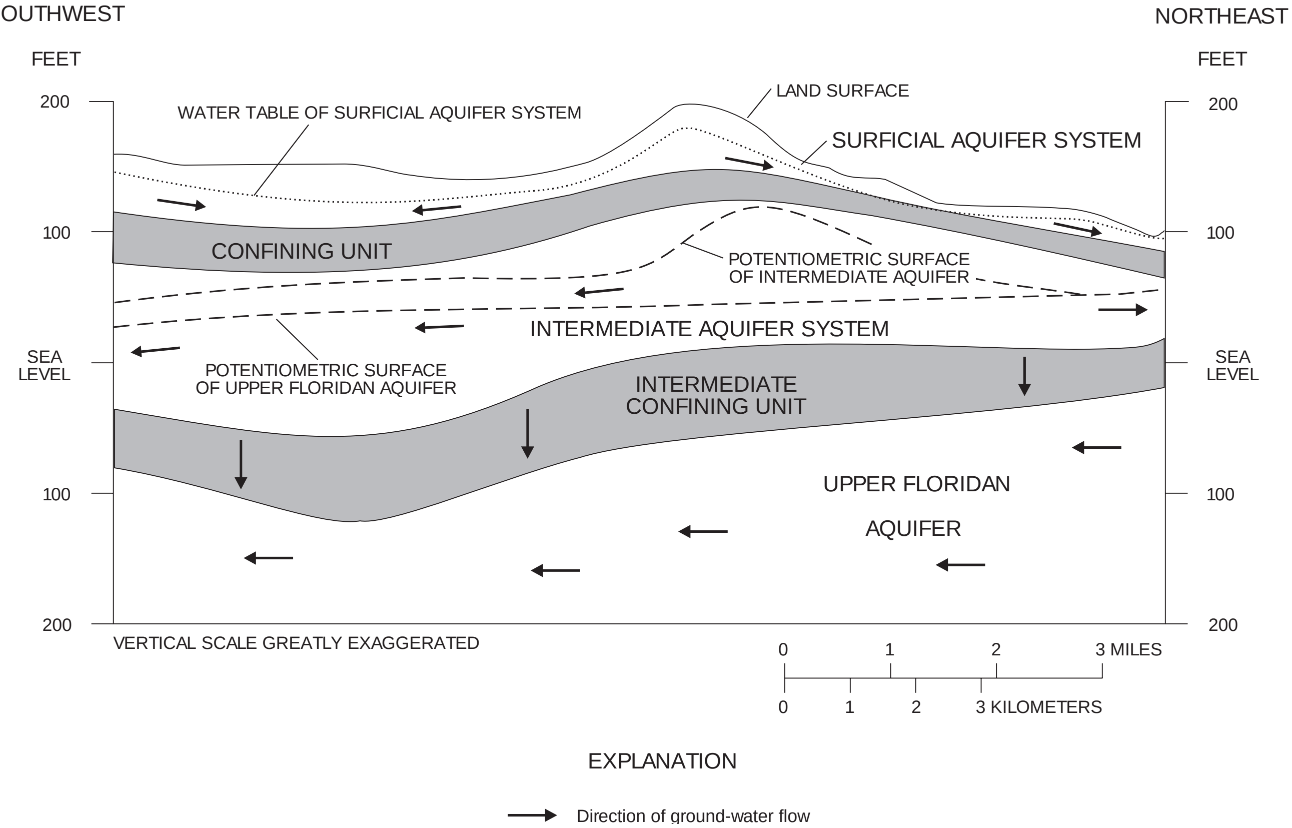


Figure 10. Generalized geohydrologic section through the mining study area near Bartow, Fla. (modified from Rutledge, 1987).

Citrus Area

The citrus area selected to evaluate the transferability of findings in the primary citrus area to other areas of similar land use is in Polk County near Lake Wales (fig. 1), about 30 mi south of the primary citrus study area near Windermere. The Lake Wales study area is a long-term, intensively farmed citrus area (fig. 12) similar to the Windermere area, with citrus cultivation taking place in well-drained sandy soils. Polk County was ranked first in Florida in the production of citrus fruits, according to the 1954 Agricultural Census (U.S. Bureau of Census, 1957, p. 149).

The Lake Wales study area is underlain by the surficial aquifer system and is similar to the Windermere citrus area. This aquifer is generally 3 to 20 ft thick in low areas, and as much as 250 ft or more thick in higher areas. It is the only source of recharge to the underlying intermediate and Floridan aquifer systems (Stewart, 1966).

PREVIOUS WORK

Information and data used in this study was collected as part of previous investigations conducted in central Florida. The amount of previously collected data varies widely among the study areas; the control area had the least available information and the urban and mining areas had the most available information. The available data included results of analyses of major dissolved constituents, nutrients, and some trace elements and pesticides. None of the previous investigations included the collection of data for the entire list of organic compounds analyzed in this study; however methods for determining some of the compounds have just recently become available. The work of Rutledge (1987), the preliminary phase of this study, provided considerable data for determination of land-use effects on ground-water quality in all the study areas.

In the control area, Rutledge (1987) collected and analyzed surface-water samples and sediments to determine which contaminants were present at the land surface and could conceivably reach the ground water. Also, Rutledge collected water samples from three surficial aquifer system wells and three Upper Floridan aquifer wells for chemical analysis. Available data for the control area also included some geologic

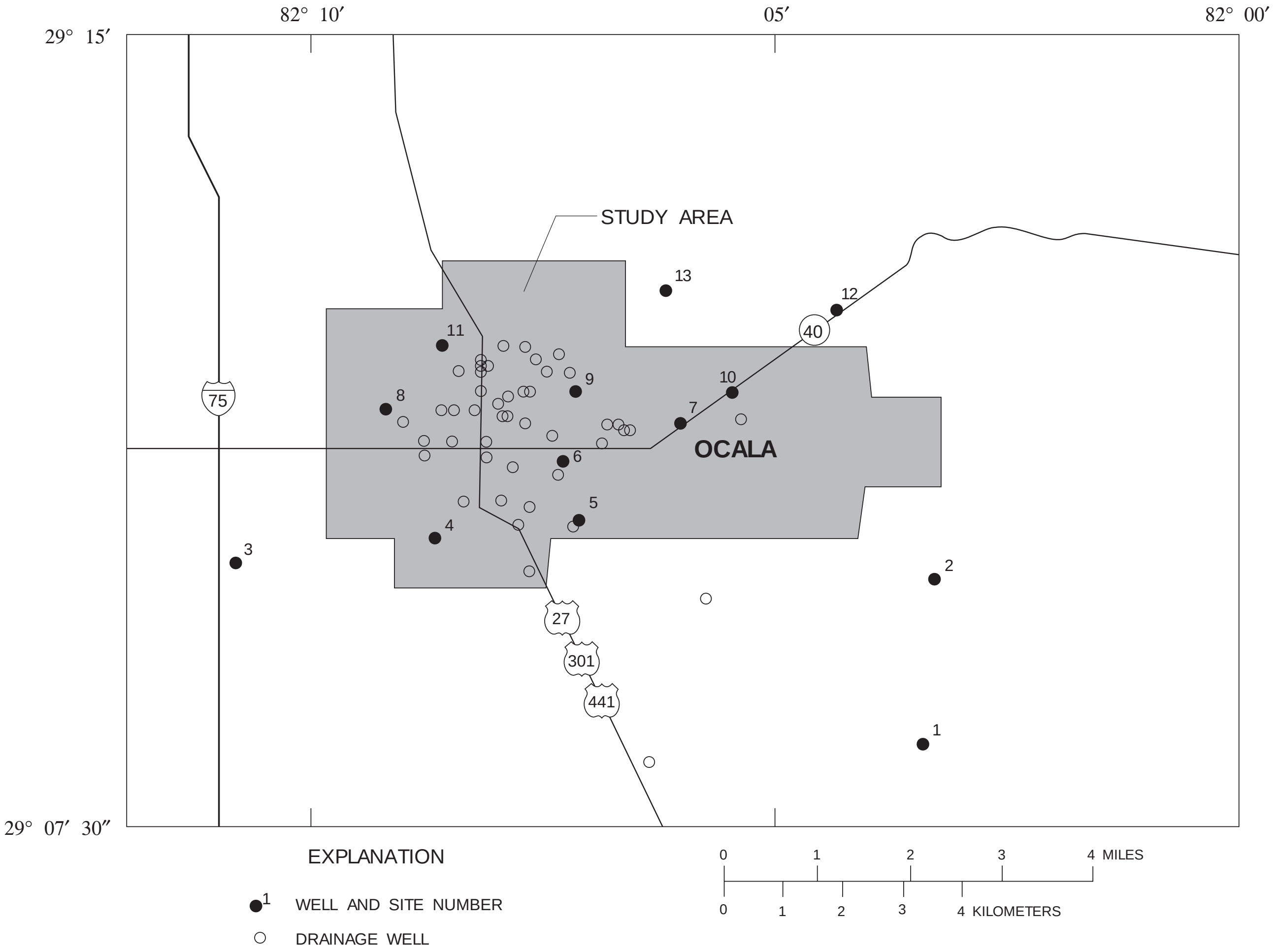


Figure 11. Urban study area in Ocala, Fla., and locations of sampled wells.

and hydrologic data collected as part of an investigation of Lake County by Knochenmus and Hughes (1976).

The Orlando urban area has been extensively studied in the past, particularly with regard to recharge from drainage wells. Reports by Stringfield (1933), Unklesbay (1944), and Telfair (1948) documented the history of drainage wells in the Orlando area, and included some data on drainage-well inflow quantities, water levels, and results of bacteriological analyses of water from supply wells near drainage wells. Concern over potential effects of drainage-well recharge on ground-water quality resulted in additional areal investigations during the 1970's and 1980's. Reports containing water-quality data for water pumped from drainage wells published during this period included those by Kimrey (1978); Schiner and German (1983); and Kimrey and Fayard (1984). Rutledge (1987) sampled source waters to several drainage wells in the Orlando area (either stormwater or water contained in the well casing between storms). German (1989) reported on the quantity and quality of drainage-well recharge during a one-year period at two drainage wells that receive relatively large quantities of water. Bradner (1991) documented a plume of organic compounds in the Upper Floridan aquifer in central Orlando that probably was the result of the operation of a former manufactured-gas plant. Bradner (1991) also documented the quality of water in the Upper Floridan aquifer in the immediate vicinity of a drainage well accepting large quantities of water.

Prior to the work of Rutledge (1987), the citrus area near Windermere had been studied only as part of countywide investigations in Orange County (Lichtler and others, 1968) and Lake County (Knochenmus and Hughes, 1976). Pfischner (1968) related land use to surface lake-water quality in a part of Orange County that included the citrus study area.

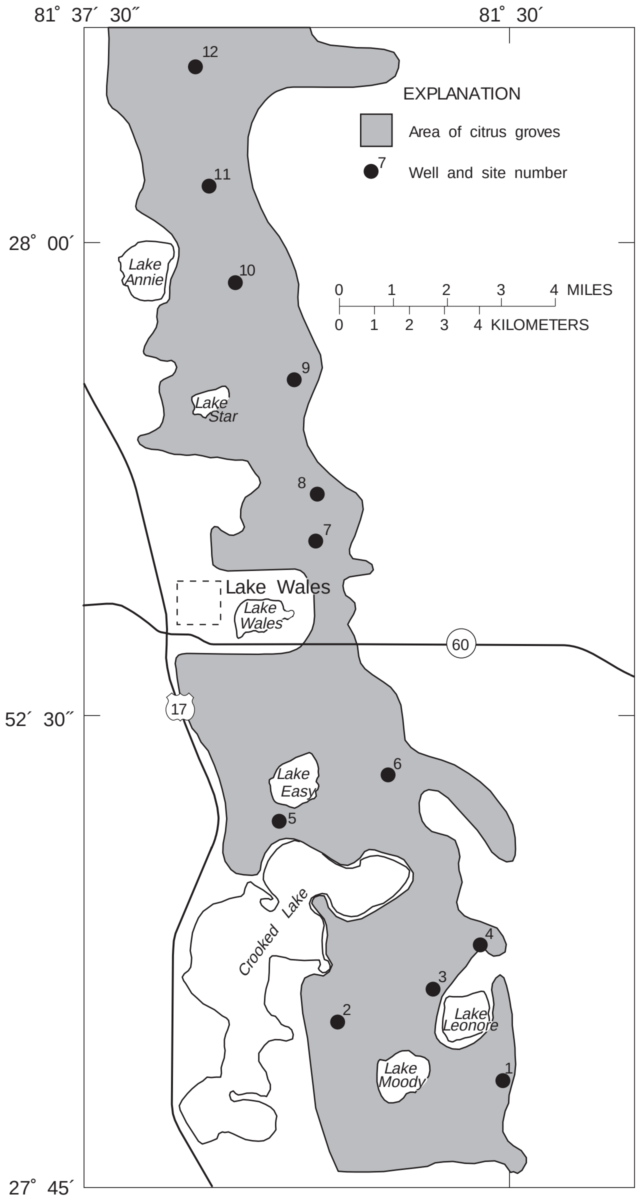


Figure 12. Citrus study area near Lake Wales, Fla., and locations of sampled wells.

During the preliminary phase of this study, Rutledge (1987) collected samples of ground water, water in ponds, pond sediment, and orange grove soils for chemical analysis to identify potential ground-water contaminants.

The phosphate-mining area near Bartow has been studied by several investigators. Stewart (1966) described the hydrology of the mining area. Robertson and Mills (1974) summarized water use in the area, and Hutchinson (1978) described the geohydrology of the surficial and intermediate aquifer systems in the area. Kimrey and Fayard (1984) described the use of inter-aquifer connector wells in the phosphate-mining areas. Miller and Sutcliffe (1982, 1984) described the effects of ore processing and fertilizer production on the quality of water in the surficial and intermediate aquifer systems; they also reported on concentrations of trace elements and some organic chemicals in ground water in the area. Rutledge (1987) reported on potential sources of contaminants to the ground water, including clayey wastes and sand-tailing discharges from ore-processing plants, and process water from cooling ponds at chemical processing plants. Rutledge also documented the quality of water from the surficial aquifer system at 11 sites in the vicinity of those sources.

METHOD OF INVESTIGATION

The method of investigation used in this study involved the following steps:

1. Selection of study areas: Each study area was selected on the basis of having a predominant land-use activity and known geohydrological features. One of the selected areas was undeveloped, so that baseline (predevelopment) ground-water conditions could be evaluated. The selection of the study areas was done in phase I.
2. Characterization of ground-water quality: Ground water in each study area was sampled at multiple locations selected to represent the study areas. Selection of sampling sties, details of monitoring well construction, and sampling schedules are described in this section.
3. Formulation of hypotheses of relation of land use to water quality: Hypotheses of land-use effects on ground-water quality were tested by comparison of water-quality data for the developed areas with data for the undeveloped control areas. The statistical techniques used for testing the hypothesis are described in this section.
4. Testing the transferability of identified land-use effects on ground-water quality of the primary study sites to other areas of similar land use: Hypotheses regarding effects of urban and citrus land use on ground-water quality, formulated at the initial study areas, were further tested by collecting ground-water samples at another urban and another citrus area. Data from these additional areas were compared with data from the control area to determine whether land-use effects observed in the initial areas and the additional areas were consistent.

Sampling-Site Selection

Sampling locations were selected to represent the various features of land use thought to be related to ground-water quality. Because the most important land-use characteristics (related to water quality) are not the same within each of the four study areas, different criteria were used for selection of sampling locations in each area.

Control Area: Surficial Aquifer System

Seventeen sampling sites in the control area (fig. 3, and table 1) were selected to represent natural (not affected by man) conditions in the surficial aquifer; sites were located in forested or wetland areas and not in rangeland, campgrounds, or other areas affected by man’s activities. Within the natural areas, the factor most likely to affect water quality in the surficial aquifer system is the depth to the water table because it relates to the oxygenic state of the ground water (Freeze and Cherry, 1979 p. 245), a condition that in turn could have a considerable effect on water quality.

The surficial aquifer system sampling sites in the control area were distributed among the upland and lowland forested areas; the depth to water at the well sites ranged from about 3 to nearly 60 ft. The median depth to water at the surficial aquifer system sampling sites was 11 ft.

Control Area: Upper Floridan Aquifer System

The Upper Floridan is not as subject to the direct effects of local land-surface conditions as is the surficial aquifer system because the Upper Floridan aquifer is separated from the land surface by the surficial aquifer system and the intermediate confining unit. Because the water sampled is a mixture of local recharge and water moving along regional flow paths from distant points of recharge, the origin of water sampled at any point in the Upper Floridan aquifer can not be determined. Therefore, for this study, 11 wells (fig. 3 and table 2) were selected for sampling so as to achieve a uniform geographic coverage of the area.

Table 1. Surficial aquifer system wells sampled in the control area

[Site numbers refer to figure 3. Type of well: DPS, temporary drive-point sampler removed after sampling; PVC, 2-inch diameter polyvinyl chloride casing with stainless-steel well point. Depth is feet below land surface]

Site number	Station identifier	Type of well	Depth of well	Depth to water
1S	290013081424901	DPS	16	13
2S	290105081435801	DPS	14	11
3S	290119081400101	DPS	12	10
4S	290137081373601	DPS	10	6
5S	290144081394701	DPS	12	6
6S	290256081341001	DPS	11	6
7S	290300081420901	PVC	70	57
8S	290300081471701	PVC	27	18
9S	290301081391801	PVC	68	42
10S	290418081361801	DPS	10	8
11S	290424081350701	PVC	25	16
12S	290439081423501	PVC	58	36
13S	290448081390801	DPS	14	11
14S	290528081391201	DPS	15	12
15S	290539081402601	DPS	12	9
16S	290547081411701	DPS	20	8
17S	290640081354201	DPS	10	3

Table 2. Upper Floridan aquifer wells sampled in the control area

[Site numbers refer to figure 3. All wells are used for potable supply and are constructed with steel casing. Depth is feet below land surface. --, depth not known]

Site number	Station identifier	Depth of well
1F	285907081451701	--
2F	285908081470101	198
3F	290000081380001	200
4F	290222081371601	240
5F	290228081382301	200
6F	290300081452001	--
7F	290445081344001	100
8F	290550081393001	175
9F	290612081402901	--
10F	290633081375201	--
11F	290647081342101	190

Urban Areas

In the Orlando urban area, 26 irrigation wells or air-conditioning supply wells that are known to be cased into the Upper Floridan aquifer were sampled. These types of wells were selected because they are not required to produce water that meets water-quality standards, and thus are likely to provide an unbiased picture of water quality in the area. Wells were selected to provide uniform coverage of the down-gradient (east) side of the urban study area (fig. 5). A list of the 26 wells selected for sampling is given in table 3.

Table 3. Wells sampled in the urban area in Orlando

[Site numbers refer to figure 5. Most wells are used for lawn irrigation or cooling-water supply and are constructed with steel casing, 4 inches or greater in diameter. Depth is feet below land surface. --, depth not known]

Site number	Station identifier	Depth of well
1	283046081200401	--
2	283101081182601	300
3	283103081195501	--
4	283121081205101	270
5	283122081225001	227
6	283147081214701	428
7	283218081224801	--
8	283223081211501	214
9	283235081223801	325
10	283240081225001	248
11	283242081224201	--
12	283243081224101	290
13	283252081223101	275
14	283300081224701	--
15	283309081230001	300
16	283310081205901	--
17	283333081233502	400
18	283348081240201	200
19	283354081231501	157
20	283401081195901	--
21	283401081212101	350
22	283437081221901	400
23	283458081231401	280
24	283531081254201	365
25	283542081192701	400
26	283703081225001	371

Table 4. Wells sampled in the urban area in Ocala

[Site numbers refer to figure 11. Monitoring wells are 4-inch diameter polyvinyl chloride casing grouted from top of Upper Floridan aquifer to land surface. Irrigation and drinking-water supply wells generally are iron casing with submersible pumps. Depth is feet below land surface. --, depth not known]

Site number	Station identifier	Well use	Depth
1	290820082032001	Monitoring	72
2	290953082031301	Monitoring	86
3	291002082104901	Irrigation	--
4	291015082084001	Drinking-water supply	--
5	291025082070401	Monitoring	60
6	291058082071701	Irrigation	--
7	291120082060001	Drinking-water supply	140
8	291126082091101	Irrigation	--
9	291139082070801	Irrigation	--
10	291140082052701	Monitoring	90
11	291204082083601	Monitoring	54
12	291226082042001	Irrigation	--
13	291235082061001	Irrigation	--

Thirteen wells were sampled in the Ocala urban area. The wells sampled (fig. 11, table 4) were private irrigation or drinking-water supply wells, or monitoring wells installed by the USGS or the St. Johns River Water Management District. Wells were selected to provide a uniform coverage of the area drained by drainage wells or sinkholes and detention ponds.

In the Ocala area as in the Orlando area, public-supply wells and drainage wells were not sampled. A common deficiency in most of the previous studies of the urban areas is that drainage wells or public-supply wells were used for sampling. Data from drainage wells might not be representative of water in the aquifer because the well bores and cavities intersected by the borehole could be filled with storm-water inflow and accumulated debris. Public-supply wells typically are installed in parts of the aquifer where there is no indication of water-quality problems. New public-supply wells failing to meet bacteria standards during testing commonly are abandoned or deepened until water of acceptable quality is reached. Thus, sampling of public-supply wells could give a biased representation of water quality.

Citrus Areas

Thirty-eight wells were selected for sampling in the Windermere citrus area (fig. 7). All well sites were located in (or within a few feet of) the downgradient side of active groves. The selection of these wells primarily was based on soil type and depth to water estimated from the altitude of land surface. The depth to water at sampling sites ranged from 3 to 40 ft (table 5), with a median of 10 ft. Of the 38 wells selected for sampling, 16 were in areas underlain by the Candler soil series, 13 by the Tavares series, and 9 by other soil series, including the Basinger and the Smyrna Series (U.S. Department of Agriculture, 1989).

Twelve wells were sampled in the Lake Wales citrus area (fig. 12 and table 6). These wells were constructed during 1988-89 by the Southwest Florida Water Management District (SWFWMD) as part of a ground water-quality monitoring network. The well locations were selected by the SWFWMD to represent citrus-cultivation land use in the Lake Wales vicinity. All wells are located in citrus groves or along roads through groves.

Table 5. Wells sampled in the citrus area near Windermere

[Site numbers refer to figure 7. Well types: DPS, temporary drive-point sampler removed after sampling; 0TH, domestic-supply or irrigation well constructed with iron casing and details of screen unknown; PVC1, 2-inch polyvinylchloride well casing with stainless-steel well point; PVC2, 2-inch polyvinylchloride well casing with slotted polyvinylchloride screen. Depth is feet below land surface. Soil type: C, Candler series; T, Tavares series; B, Basinger series; O, other series; and S, Smyrna series (U.S. Department of Agriculture, 1989). --, depth not known]

Site number	Station identifier	Well type	Depth of well (feet)	Soil type	Depth to water (feet)
1	282633081410901	DPS	16	C	11
2	282640081412101	DPS	15	C	--
3	282643081335601	0TH	29	T	7
4	282653081422401	DPS	13	B	10
5	282654081370901	PVC1	35	C	26
6	282654081370902	PVC1	44	C	26
7	282654081370903	PVC1	52	C	26
8	282654081372301	PVC1	53	C	39
9	282654081372302	PVC1	63	C	39
10	282654081372303	PVC1	74	C	40
11	282701081364701	PVC1	17	T	12
12	282701081364702	PVC1	26	T	12
13	282701081364703	PVC1	32	T	11
14	282706081365901	DPS	8	C	5
15	282719081344801	0TH	19	C	--
16	282727081410101	DPS	11	O	8
17	282727081410102	DPS	21	O	18
18	282738081341402	DPS	6	T	4
19	282738081342201	PVC1	19	T	7
20	282741081382501	DPS	12	C	9
21	282748081425601	PVC1	38	C	23
22	282752081332301	PVC2	19	T	9
23	282800081383001	DPS	20	C	17
24	282811081332101	PVC2	19	S	7
25	282815081410401	DPS	14	S	11
26	282819081350101	DPS	8	C	4
27	282822081411301	DPS	12	S	9
28	282849081345901	PVC1	19	T	9
29	283024081372701	PVC1	33	C	19
30	283034081350101	DPS	12	T	9
31	283052081403001	DPS	8	B	5
32	283112081371601	PVC1	19	T	6
33	283116081364401	PVC2	13	T	4
34	283125081390601	DPS	16	C	9
35	283127081352901	DPS	9	T	4
36	283226081390501	DPS	16	T	14
37	283229081363101	DPS	6	B	3
38	283243081341201	DPS	5	S	3

Table 6. Wells sampled in the citrus area near Lake Wales

[Site numbers refer to figure 12. All wells were installed by the Southwest Florida Water Management District. Wells are constructed of 4-inch polyvinyl chloride casing with 20 feet of slotted polyvinylchloride screen; annulus was grouted from top of screen to land surface. Depth is feet below land surface. Depth to water was recorded at time of sampling, May 31 through July 13, 1989]

Site number	Station identifier	Depth of well	Depth to water
1	274625081300901	39	7.37
2	274732081325001	105	76.26
3	274806081311401	55	29.44
4	274850081302401	21	4.50
s	275050081335401	90	62.27
6	275127081315201	65	42.21
7	275513081331601	87	70.24
8	275558081331601	60	30.00
9	275742081334401	70	58.40
10	275857081344400	79	59.49
11	280120081351401	97	61.96
12	280252081354301	89	42.10

Mining Area

A total of 37 wells were sampled in the mining area (fig. 9). The wells were selected to represent six types of mining land use (table 7): reclaimed land (19 wells), undisturbed land adjacent to mined areas (2 wells), ore-processing or chemical-processing industrial areas (7 wells), active mining excavation (1 well), slime ponds (3 wells), and fresh sand tailings (5 wells).

Well Construction

Wells sampled as part of this investigation included existing wells of various types and sizes and wells installed specifically for the study. In the control and urban areas, all of the Upper Floridan aquifer wells sampled were existing wells being used for irrigation, potable supply, observation of water levels, or water-quality sampling. The wells were constructed with 4-in. diameter (or larger) iron casings extending into the Upper Floridan aquifer. These wells were not screened.

Some of the surficial aquifer system wells sampled in the control area, the Windermere citrus area, and the mining area were existing wells constructed with 2-in. diameter (or larger) iron or PVC casing and screened with galvanized screen or slotted PVC casing, but most were installed specifically for the study. Wells installed for this study were constructed of 2-in. diameter PVC casing attached to a 5-ft length of 2-in. diameter stainless-steel casing, which was attached to a 3-ft length of stainless-steel screen. The wells were installed using a hollow-core auger.

Table 7. Wells sampled in the mining area near Bartow

[Site numbers refer to figure 9. Well type: PVC2, 2-inch polyvinyl chloride casing with slotted polyvinyl chloride screen; PVC1, 2-inch polyvinyl or greater, iron casing with slotted screens in surficial aquifer system and one or more underlying aquifers; DPS, temporary drive point sampler removed after sampling; OTH, iron casing and details of construction unknown. Depth is feet below land surface. --, depth not known. Type of activity: R, reclaimed area; U, unmined area; ST, sand tailings; I, industrial area (ore processing or chemical processing); SP, clayey-wastes disposal (slime ponds); MI, mining (excavation area)]

Site number	Station identifier	Well type	Depth	Type of activity
1	274702081590501	PVC2	--	R
2	274732081593701	PVC1	33	R
3	274751081591801	PVC1	13	U
4	274751081592301	PVC1	13	R
5	274732081593701	PVC1	7	U
6	274851082023101	CON	255	R
7	274855082022701	DPS	17	ST
8	274911082005202	OTH	38	R
9	274915082022001	OTH	26	I
10	274915082022002	OTH	39	I
11	274916081472601	PVC1	13	R
12	274917082012002	PVC2	28	I
13	274917082012003	PVC2	16	I
14	274920081585201	DPS	12	SP
15	274920082001801	CON	261	R
16	274920082001802	OTH	34	R
17	274929081514601	DPS	8	ST
18	274944081494901	OTH	29	MI
19	274951081521601	OTH	30	R
20	275002081584901	PVC2	--	R
21	275007081544602	DPS	--	R
22	275009081501901	DPS	--	ST
23	275014081503901	DPS	--	ST
24	275022081505501	DPS	--	ST
25	275030081501001	PVC1	23	R
26	275037081484601	PVC1	23	R
27	275045081484901	DPS	--	R
28	275101082025501	PVC2	17	I
29	275114081471001	OTH	22	SP
30	275216081465701	OTH	60	SP
31	275352081524201	DPS	--	I
32	275352081543801	PVC1	15	R
33	275353081522411	PVC2	--	I
34	275405081555801	PVC1	22	R
35	275419081513301	DPS	11	R
36	275509081555601	PVC1	23	R
37	275524081554201	PVC1	18	R

The annulus was filled with native material from the bottom of the hole to about 2 ft above the screen, at which point the annulus was sealed with several inches of bentonite pellets. Native material was used to fill from the seal to within about 10 ft of land surface. The top 10 ft of the annulus was filled with Portland-cement grout. Where the water table was near the land surface, a temporary stainless-steel drive-point sampler was sometimes used and no wells were installed.

The wells installed by the SWFWMD in the Lake Wales citrus area were installed using mud-rotary drilling. These wells were cased with 4-in. diameter, threaded PVC pipe and finished with 20 ft of slotted PVC screen. No glues or solvents were used to construct these wells.

Sampling and Analytical Procedures

The collection of samples from most of the Floridan aquifer wells (control and urban areas) was accomplished using existing submersible pumps in the irrigation or water-supply wells. These wells were sampled after pumping for a period of time sufficient to remove at least three casing volumes of water and after specific conductance, temperature, and pH had stabilized. Samples from irrigation-well systems were collected from hose bibs or sprinkler nozzles using a brass connector and tetrafluoroethylene polymer tubing. Sampling points were located near the well.

Most surficial aquifer system wells in the control area, the citrus area, and the mining area were sampled using a peristaltic pump or a 2-in. diameter stainless-steel submersible pump with a tetrafluoroethylene polymer discharge line. A few wells in the control area were sampled using a bailer constructed of inert fluorocarbon polymer. All newly constructed wells were pumped for several hours or until the pump discharge contained no visible suspended solids, before water samples were collected.

Field blanks and duplicate samples were used as quality-assurance measures for sampling and sample-handling methods, and for analytical methods. Water for field blanks, analyzed for organic compounds, was prepared by passing distilled water through activated carbon filters. This water was taken into the field and poured into bottles in the same manner as actual samples. Duplicate samples were analyzed for major constituents, nutrients, and trace elements by filling duplicate sets of bottles from the pump discharge.

Samples for analysis of nutrients and organics were chilled to 4 °C immediately after collection and shipped to the laboratories within 3 days of collection. All samples were treated according to USGS procedures and, except for some pesticides, analyzed at USGS laboratories using methods described by

Thatcher and others (1977), Wershaw and others (1987), and Fishman and Friedman (1989). Some pesticides were analyzed by the Tennessee Valley Authority in Chattanooga, Tenn., using standard methods recommended by the U.S. Environmental Protection Agency (USEPA).

Constituents Analyzed

The chemical constituents for which ground-water samples were analyzed for each type of land use were selected to include ground-water contaminants identified in previous studies or known to be present in the area. The chemical constituents analyzed in water samples from the Ocala and Lake Wales areas (selected for evaluation of transferability) were modified from those originally analyzed for the Orlando and Windermere areas and included only the constituents affected by the land-use. The types of constituents analyzed in ground water and the number of wells sampled in each study area are presented in table 8.

Gas chromatography using a flame-ionization detector (FID scan) was used qualitatively to assess organic compound content and to screen samples to be analyzed for specific organic compounds. The FID scan does not provide any identification of the compounds detected, but does make it possible to estimate both the number of different compounds in a sample and the total concentration of all detected compounds relative to an internal standard (compounds of known identity added by the laboratory before analysis for instrument calibration). The FID scan does not detect all compounds and the detection limit of the scan varies according to the type of organic compound. Generally, the FID scan is a carbon detector and is relatively insensitive to hydrocarbons that contain halogens or other noncarbon groups. Additionally, the most volatile organic compounds may not be detected by the FID scan, or if detected, may not be resolved into individual peaks if several are present.

The organic compounds included in volatile-organic, base-neutral, and acid-extractable analytical schedules are listed in table 9. Some additional organic compounds, not included in table 9, were only tentatively identified by the gas chromatography and mass spectrography spectra from the base-neutral-extractable and acid-extractable analyses. These data, referred to as tentatively identified organic compounds (TIOCs), are based on computer comparisons of sample spectra with library spectra followed by visual examination of the gas chromatography and mass spectrography spectra. TIOC data have not been confirmed by direct comparison with reference standards; therefore, TIOC identification is tentative and reported concentrations are semiquantitative.

The pesticides for which ground-water samples were analyzed are listed in table 10. Ground-water samples from all study areas were analyzed for some general-use pesticides and water samples from the control and citrus areas were analyzed for other pesticides not likely to be used in the urban and mining areas.

Table 8. Types of analyses performed on ground-water samples

Type of analysis	Control Area		Urban Area		Citrus Area		Mining area
	Upper Floridan aquifer	Surficial aquifer system	Orlando area	Ocala area	Windermere area	Lake Wales area	
Major constituents, properties, nitrogen species, phosphorus	9	10	22	13	27	12	27
Bromide, Iodide	0	7	0	0	0	0	8
Trace elements	10	17	23	3	26	2	34
Gross alpha and beta	0	10	0	0	0	0	13
Tritium	4	3	11	0	3	0	0
Gas chromatography scans	9	8	15	13	20	12	23
Volatile organics	9	9	16	13	16	11	12
Base-neutral extractable organics	3	3	11	0	7	0	15
Acid-extractable organics	3	3	11	0	7	0	15
Pesticides, general use	10	10	20	3	19	2	11
Pesticides, citrus use	0	8	0	0	19	12	0

Table 9. Analytical schedules for volatile, base-neutral-extractable and acid-extractable organic compound

[Compounds were analyzed using laboratory standard solutions of known chemical composition. All concentrations are in micrograms per liter. Numbers in parentheses are drinking-water standards from Florida Department of Environmental Regulation, 1989]

Type and name of chemical		Detection limit	Type and name of chemical	Detection limit
Volatiles			**Base-neutral extractables**	
Benzene	(1.0)	3.0	Acenaphthe	5.0
Bromoform		3.0	Acenaphyhylene	5.0
carbon tetrachloride	(3.0)	3.0	Anthracene	5.0
Chlorobenzene		3.0	Benz(a)anthracene	10.0
Clorodibromomethane		3.0	Benzo(a)pyrene	10.0
Chloroethane		3.0	Benzo(g,h,i)perylene	10.0
2-Chloroethylvinyl ether		3.0	Benzo(k)fluoranthene	10.0
Chloroform		3.0	Benzo(b)fluoranthene	10.0
1,2-trans-Dichlorethylene		3.0	4-Bromophenyl phenyl ether	5.0
Dichlorobromomethane		3.0	NoButylbensyl phthalate	5.0
Dichlorodifluoromethane		3.0	bis(2-Chloroethoxy)methane	5.0
1,2-Dichloroethane	(3.0)	3.0	bis(2-Chloroethyl)ether	5.0
1,1-Dichloroethylene		3.0	bis(2-Chloroisopropyl)ether	5.0
1,2-Dichloropropane		3.0	2-Chloronaphthalene	5.0
1,3-Dichloropropene		3.0	4-Chlorophenyl phenyl ether	5.0
Ethylbenzene		3.0	Chrysene	10.0
Methyl bromide		3.0	l,2,5,6-Dibenzo(a,h)anthracene	10.0
Methylene chloride		3.0	Di-n-butyl phthalate	5.0
1,1,2,2-Tetrachloroethane	(3.0)	3.0	1,3-Dichlorobenzene	5.0
Toluene		3.0	l,4-Dichlorobenzene	5.0
1,1,1-Trichloroethane	(200.0)	3.0	1,2-Dichlorobenzene	5.0
1,l,2-Trichloroethane		3.0	Diethyl phthalate	5.0
Trichloroethylene	(3.0)	3.0	Dimethyl phthalate	5.0
Trichlorofluoromethane		3.0	2.6-Dinitrotoluene	5.0
Vinyl chloride (1.0)	(1.0)	3.0	2,4-Dinitrotoluene	5.0
			Di-n-octylphthalate	10.0
Mixtures			bis(2-Ethylhexyl)phthalate	5.0
			Fluoranthene	5.0
Polychlorinated naphthalenes		.1	Fluorine	5.0
Polychlorinated biphenyls		.1	Hexachlorobenzene	5.0
			Hexachlorobutdiene	5.0
Acid extractables			Hexachlorocyclopentadiene	5.0
			Hexachloroethane	5.0
4-Chloro-3-methylphenol		30.0	Indeno(l,2,3-cd)pyrene	10.0
2-Chlorophenol		5.0	Isophorone	5.0
2,4-Dichlorophenol		5.0	Naphthalene	5.0
2,4-Dimethylphenol		5.0	Nitrobenzene	5.0
4,6-Dinitro-2-methylphenol		30.0	N-Nitrosodi-N-propylamine	5.0
2,4-Dinitrophenol		20.0	N-Nitrosodimethylamine	5.0
2-Nitrophenol		5.0	N-Nitrosodiphenylamine	5.0
4-Nitropheno1		30.0	Phenanthrene	5.0
Pentachlorophenol		30.0	Pyrene	5.0
Phenol		5.0	l,2,4-Trichlorobenzene	5.0
2,4,6-Trichlorophenol		20.0		

Data Analysis

Statistical procedures were used to determine if there are significant effects of land use on water-quality. Water quality data for each developed area are compared to data for the control area. The application of the procedures used for this analysis is discussed in a report by Helsel and Ragone (1984). One of two test procedures was applied depending on the type of data being tested: the Mann-Whitney test and a contingency table test. The null hypothesis for both tests is the same: that there is no difference in water quality

Table 10. Analytical schedule for pesticide compounds

[Pesticides were analyzed using laboratory standard solutions of known chemical composition. Detection limits are in micrograms per liter. The following compounds were analyzed by the Tennessee Valley Authority: bromacil, dicofol, fenamiphos, DBCP, chlorpyrifos, ethoprop, molinate, propanil, and thiobencarb. All other compounds were analyzed by USGS]

Pesticide	Detection limit	Pesticide	Detection limit
Aldicarb [1]	0.5	Lindane	.01
Aldrin	.01	Malathion	.01
Bromacil [1]	.1	Methomyl [1]	.5
Ametryne	.1	Methoxychlor	.01
Atrazine	.1	Methyl parathion	.01
Carbaryl [1]	.5	Methyl trithion	.01
Carbofuran [1]	.5	Mirex	.01
Chlordane	.1	Molinate	.1
Chlorpyrifos [1]	.05	l-naphthol [1]	.5
Cyanazine	.l	Oxamyl [1]	.5
DBGP [1]	.01	Parathion	.01
DDD	.01	Perthane	.1
DDE	.01	Prometone	.1
DDT	.01	Propanil [1]	.1
Dicofol [1]	.01	Propazine	.1
Dieldrin	.01	Propham [1]	.5
Diazinon	.01	Silvex	.01
EDB	.2	Simazine	.1
Endosulfan	.01	Simetryne	.1
Endrin	.01	Thiobencarb [1]	.1
Ethion	.01	Toxaphene	1.0
Ethoprop [1]	.05	Trithion	.01
Fenamiphos [1]	.05	2,4-D	.01
Heptachlor	.01	2,4-DP	.01
Heptachlor epoxide	.01	2,4,5-TP	.01
3-hydroxycarbofuran	.5		

[1] Compounds analyzed only in the citrus and control areas.

between each developed area and the control area. A probability is computed from these procedures that differences in water quality between a developed area and the control area could be due to chance alone, rather than some effect of development. The null hypothesis is rejected if the probability that water-quality differences could be due to chance is 5 percent or less. Although this probability of 5 percent is commonly used for rejection of a null hypothesis, it is somewhat arbitrary. Therefore, the calculated probability levels computed from the statistical tests are listed in the appendix; from this list the test can be evaluated at different probability levels.

The Mann-Whitney test (Conover, 1980) was used to test the null hypothesis for water-quality characteristics that had no or few values that were less than the analytical detection limits (censored values). The test is not appropriate if more than about 20 percent of the data are censored (Helsel and Ragone, 1984). The test is nonparametric and is analogous to the parametric two-population t-test. Data from the control area and the developed area being tested are combined and the data are ranked. The ranked values are summed by area and these sums are compared. If there is a difference in water quality between the two areas, the sum of the ranks from the two areas will be different. Data that were tested using the Mann-Whitney test included major constituents, properties, and some nutrient species and trace elements.

For those water-quality characteristics with highly censored data (more than 20 percent of values less than detection limit), the Mann-Whitney test was not applicable. These water-quality characteristics included all organic compounds, most of the trace elements, and some of the nutrient species. For these heavily-censored data, a contingency-table analysis was used.

Contingency-table testing (Conner, 1980) is based on frequency of detection rather than concentration of a water-quality characteristic. The type of contingency table used in this study to assess effects of development on ground-water quality is known as a 2 x 2 table. For each developed area and water-quality characteristic tested, a table such as the one shown below is constructed. N1 and N2 are the number of locations at which the characteristic was detected, and N3 and N4 are the number of locations where the characteristic was not detected.

Number of locations where:	Control area	Developed areas
Detected	N1	N2
Not detected	N3	N4

If all of the N values in the contingency table are greater than 5, the probability that the frequency of detections in both areas are equal is evaluated assuming the test statistic (a function of the N values) has a chi-square distribution (Conover, 1980). Otherwise, the probability is estimated assuming the test statistic has a distribution known as an exact distribution. Because of the relatively small numbers of locations sampled in this study, most of the contingency table analyses were evaluated using the exact distribution.

POTENTIAL FOR CONTAMINATION OF GROUND WATER FROM NONPOINT SOURCES

The occurrence of tritium in ground water in most study areas is discussed in this section. Tritium is an indicator of recent recharge in ground water. The presence of tritium indicates that recharge was recent enough to have been affected by man's activities. Possible contaminant sources and contaminants detected in previous studies also are discussed in the following sections for each study area.

Age of Ground Water as an Indication of Contamination Potential

The testing of thermonuclear weapons in the early 1960's injected large quantities of tritium into the atmosphere. Tritium concentrations in rainfall have been determined in Ocala, Fla., (about 30 mi west of the control are) since 1961 and are assumed to be representative of concentrations in the central Florida area. Recharge that entered the ground-water system in the early 1960's could today contain tritium concentrations as high as 100 tritium units (fig. 13). Tritium concentrations in more recent recharge (late 1980's) probably ranges from about 3 to 15 tritium units. The absence of tritium in ground water would indicate that the water predates the atmospheric testing in the early 1960's and could possibly predate man's activities.

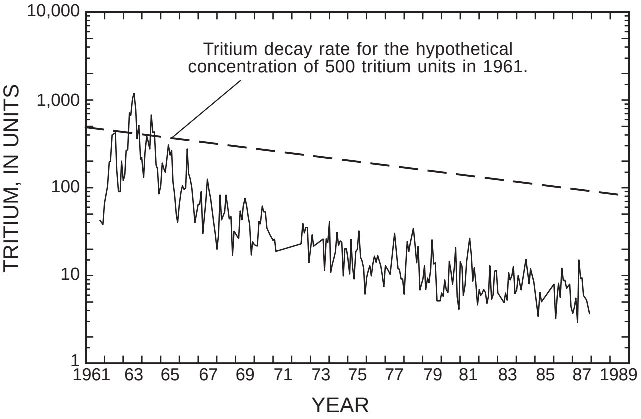


Figure 13. Tritium concentration in rainfall at Ocala, Fla., 1961-87.

Tritium concentrations in water from three relatively deep surficial aquifer wells in the control area (7S, 8S, and 9S) ranged from 5.44 to 9.04 tritium units (table 11) and were similar to concentrations of tritium in recent precipitation at Ocala. The tritium concentration in precipitation ranged from 2.9 to 15.0, and averaged 7.5 tritium units in January-July 1987. This is an indication that at least some of the water in the surficial aquifer system is of relatively recent origin.

Tritium analyses of water from four Upper Floridan aquifer wells in the control area (2F, 5F, 6F, and 11F) indicate that the age of the water is variable and ranges from relatively recent to relatively old (table 11). The tritium concentration at site 2F was 0.35 tritium units, indicating a predominance of water that originated as recharge prior to the 1960's. The concentration at site 11F was 4.94, indicating that some of the water originated as recharge since the early 1960's.

In the urban area, analysis of tritium in water samples from 11 wells sampled in June 1987 indicates that the Upper Floridan aquifer may contain significant amounts of direct recharge water received

Table 11. Tritium concentration in water from wells in the control, urban, and citrus areas

[Tritium concentrations are expressed in tritium units, where one tritium unit indicates a tritium to hydrogen ratio of 10^{-18}; --, depth is not known]

Site number	Tritium concentrations, in units	Well depth (feet)
Control area, June-August 1987		
7S	6.49	70
8S	5.44	27
9S	9.04	68
2F	0.35	198
5F	1.34	200
6F	3.15	---
11F	4.94	190
Urban area, June 1987		
2	4.62	300
4	1.34	270
6	6.34	428
8	9.40	--
11	4.69	--
12	4.77	290
15	6.81	300
16	3.16	--
21	4.85	350
22	5.45	400
23	5.98	280
Citrus area, June 1988		
21	5.25	38
28	4.63	19
29	5.25	33

through drainage wells. Tritium concentrations ranged from 1.34 to 9.40 tritium units; excluding the lowest concentration, the range was from 3.16 to 9.40 tritium units (table 11). Tritium concentrations in precipitation at Ocala ranged from 2.9 to 15.0 and averaged 7.7 tritium units during January-June 1987 (fig. 13). These data indicate that at most locations in the urban study area, ground water within the sampled interval is of relatively recent origin and possibly originated as recharge a few months or years prior to the sampling date.

In the citrus area, tritium concentrations in water from three relatively deep surficial aquifer wells ranged from 4.63 to 5.25 tritium units (table 11). These concentrations are well within the range of concentrations in recent rainfall.

Tritium determinations were not made in the mining area because tritium concentrations in water at the control and citrus sites had indicated the presence of relatively recent water in the surficial aquifer system. Therefore, surficial aquifer systems in other areas (including the mining area) probably contain water of relatively recent origin.

Potential Contaminant Sources and Contaminants

Previous studies, including the preliminary phase of the present study described by Rutledge (1987), have identified potential sources of ground-water contamination in the central Florida area. The potential for ground-water contamination and possible contaminants are discussed in the following sections.

Control Area

The potential for ground-water contamination in the control area is much less than that in any of the developed study areas. However, the possibility exists for contamination from the limited human activities in the area, or from airborne transport of contaminants to the control area from developed areas.

Rutledge (1987) did reconnaissance sampling of ground water, pond water, and pond sediments in the control area. Trace-element concentrations in pond water were near detection limits (with the exception of iron) and were well below drinking-water standards. Pond-sediment samples were analyzed for organic compounds, but none were detected. Diazinon was detected in water from one of three Upper Floridan aquifer wells and in water from two of three surficial aquifer wells, indicating that Diazinon may be common in the ground water of central Florida. The maximum Diazinon concentration was 0.06 μg/L

Urban Area

The most probable contaminants in the Orlando urban study area are those associated with urban stormwater, which is emplaced into the Floridan aquifer through drainage wells. Stormwater can contain a wide variety of contaminants, including organic compounds and trace elements.

German (1989) used a simple conceptual model to show that the quantities of drainage-well recharge to the Upper Floridan aquifer are not insignificant compared to natural recharge and lateral inflow to the aquifer. His model treated the aquifer as a constantly-stirred tank reactor into which water from drainage wells and other sources (lateral inflow and natural recharge) is added at known rates. According to this model, about 20 percent of the water in the Upper Floridan aquifer underlying the study area at the end of 1988 could have originated from drainage-well recharge. The model also indicated that the maximum content of drainage-well water (about 30 percent) would not be present in the Upper Floridan aquifer for several decades.

The presence of traffic-related trace elements in stormwater has been extensively documented in other reports. Helsel and others (1979) reported that motor vehicles could be a major source of lead, zinc, and copper in storm runoff in northern Virginia. Kobriger and others (1981) reported average lead concentrations of 960 µg/L and zinc concentrations of 410 µg/L at six highway-runoff monitoring sites. Rutledge (1987) determined that source waters to drainage wells (either stormwater or water retained in the casing between storms) contained concentrations of chromium, lead, iron, and manganese that exceeded drinking-water standards. German (1989) reported median total-recoverable lead and zinc concentrations of 120 µg/L in seven samples of stormwater inflow to lakes in the Orlando area.

A wide variety of organic compounds have been reported in stormwater. Whipple and Hunter (1979) detected several of the polynuclear aromatic priority pollutants in petroleum-bearing stormwater in the Delaware River Estuary area. Malmquist and Hard (1981) reported high concentrations of polynuclear aromatics in stormwater and a significant increase in these compounds in ground water downgradient from a highway. Cole and others (1984), summarizing data from the USEPA Nationwide Urban Runoff Program (NURP), reported that 11 compounds (including 3 pesticides, 2 volatiles, 5 base-neutral extractables, and 1 acid-extractable compound) were present in 10 to 20 percent of the 86 samples of stormwater runoff analyzed prior to July 1982. Rutledge (1987) determined that volatile organic compounds, including benzene, chloroform, toluene, trichloroethanes, dichloroethanes, and others, were present in some source waters to drainage wells and in water from some wells completed in the Upper Floridan aquifer. German (1989) identified 24 organic compounds in stormwater or drainage-well inflow in the Orlando area. These compounds were mostly pesticides, phthalates, or polynuclear aromatics.

Citrus Area

The potential effect of citrus cultivation on underlying ground water primarily is due to the application of fertilizer and pesticides. Both are needed in large quantities in Florida’s nutrient-poor, sandy soils and warm, humid climate. The ground-water contamination potential is high because the soils in citrus-producing areas tend to be excessively well-drained and have relatively little capacity to retain chemicals applied to them.

Citrus fertilizers typically contain relatively large (and equal) amounts of nitrogen and potassium; about half as much magnesium; about a tenth or less phosphorus; and smaller amounts of the micronutrients boron, copper, iron, manganese, molybdenum, and zinc. Recommended application rates for nitrogen generally are at least 80 (lb/acre)/yr (Ziegler and Wolfe, 1981). The chemical composition of the fertilizers also may include large amounts of calcium, chloride, and sulfate. Thus, leachate from fertilizers could potentially contribute substantial amounts of a wide variety of constituents to the underlying aquifers.

A wide variety of pesticide compounds are applied to citrus groves (Knapp and others, 1986). Because of the large number of pesticides commercially available, the variation in practice among growers, and the continual development of new products, it is difficult to compile a complete and accurate history of the type and quantity of pesticide usage.

The USGS sponsored the compilation of a county-based nonurban, nonpoint-source inventory of the quantity of pesticides used for citrus production in Florida during 1977 (Gianessi and others, 1986). This inventory was based, in part, on data from the USEPA and the U.S. Department of Agriculture (USDA). The application-rate data included in this inventory were extrapolated from limited data and probably are useful only in a general, semiquantitative manner. The University of Florida compiled a similar inventory based on interviews with about 10 percent of the citrus growers in Florida during 1978-79 (University of Florida, 1981). The Florida Department of Agriculture and Consumer Services (FDACS) has conducted three annual random-sample surveys of restricted-use pesticides (RUPS). These surveys were compiled from records required of commercial applicators under State law and, therefore, probably are more reliable than the other surveys mentioned in this report.

However, most pesticides used in citrus cultivation are not RUPS and would not be included in the RUPS survey.

Because the pesticide-usage estimates are from different sources, they do not include the same pesticides (table 12). Many pesticides included in the Lake County tabulation by Gianessi and others (1986) do not appear on the University of Florida (1981) list. Because the list for Lake County is not restricted to citrus cultivation, some of the pesticides listed may be used only on noncitrus crops. However, citrus was the predominant crop in Lake County prior to the freeze of January 1985.

Two pesticides that have often been detected in ground water, EDB (l,2-dibromoethane, commonly called ethylene dibromide, or EDB) and aldicarb, were not included in either inventory of pesticide usage (table 12). These pesticides have been used in parts of the citrus growing area in the State, though not necessarily in the study area. The absence of these pesticides from the surveys indicates the limitations of the existing pesticide-usage surveys. However, the surveys still give an indication of some of the pesticides heavily used in Florida citrus production.

The ground-water contamination potential for pesticides varies widely among the different compounds and is a function of the physical and chemical properties of the compounds. Rao and others (1985) ranked 41 commonly used pesticides according to estimates of traveltime through the root zone and the vadose zone to the water table. According to their estimates, the five pesticides with the greatest ground-water contamination potential (smallest traveltimes) are EDB, bromacil, picloram, dibromochloropropane, and diuron. With the possible exception of picloram, all of these probably have been used in the citrus area. Malathion, used in citrus cultivation, was ranked as having the least contamination potential.

Ground-water contamination in Florida resulting from pesticide applications in citrus groves has been documented for at least three pesticides: aldicarb, EDB, and bromacil. Aldicarb, in use since about 1962, was first detected in ground water at an experimental agricultural area in 1982. Aldicarb is now a restricted-use pesticide in Florida and can be applied only under specific conditions.

Table 12. Inventory of pesticide usage

[Usage, in pounds of active ingredient per year; --, no data]

Chemical	Lake County[1] (1977)	Statewide[2] (1978-79)
Maneb	21	--
Acephate	38	9,131
Atrazine	55	--
Parathion	154	--
Chloramben	251	--
Carbaryl	413	1,431
Trifluralin	602	--
2,4-D	692	--
Diazinon	1,569	2,147
Methidathion	1,782	--
Ametryn	1,789	--
Dalapon	1,864	--
Ferbam	2,525	--
Propargite	3,656	--
Dioxathion	3,769	--
Azinphosmethyl	3,801	--
Gaptan	5,217	--
Glyphosate	7,960	113,503
Paraquat	26,300	22,388
Simazine	40,100	11,305
Zineb	41,464	--
Dicofol	50,358	139,664
Captafol	52,811	10,174
Carbophenothion	60,080	2,336
Benomyl	62,531	690,968
Terbacil	99,041	60,293
Diuron	139,720	647,952
Bromacil	152,481	1,020,832
Ethion	157,805	62,319
Chlorobenzilate	186,732	1,265,221
Chlordane	--	11,342
Copper	--	697,332
Dimetholate	--	304
Fenbutatin-oxide	--	1,507
Malathion	--	64,295
Mancozeb	--	11,757
Zinc sulfate	--	12,538,870

[1] Gianessi and others, 1986.

[2] University of Florida, 1981.

EDB was first introduced as an agricultural fumigant in 1954 and has been used widely in Florida citrus-producing areas as a soil-fumigant nematicide. EDB contamination of grains, grain products, and ground water in Florida and several other states was documented by Cohen and others (1984). As a result, agricultural use of EDB was banned. Two years after the ban, the FDER reported EDB concentrations in ground water ranging from 0.02 µg/L to about 600 µg/L (Weintraub and others, 1986). EDB was still being detected in ground water in Florida 4 years after its last known usage (Katz and Choquette, 1988).

Bromacil, a herbicide used for control of a wide range of grasses, broadleaf weeds, and some woody species, was detected in ground water 3 months after application in a forest in Florida (Hebb and Wheeler, 1978). Although this bromacil application was not citrus related, the detection indicates bromacil is mobile in the sandy soils that are typical of citrus cultivation areas.

In the preliminary phase of this study, Rutledge (1987) sampled ground water, water in ponds, pond sediment, and grove soil in the citrus study area to determine what compounds or constituents were present and, therefore, potentially available for ground-water contamination. With the exception of iron and manganese, trace-element concentrations in pond water or ground water did not exceed drinking-water standards (U.S. Environmental Protection Agency, l988a,b,c). The pesticides chlordane, DDE, and simazine were present in one of five samples of grove soil. Several other organic compounds (not pesticides) were detected in pond water or grove soils. Of seven surficial aquifer wells sampled, diazinon was detected in samples from four wells, and simazine was detected in a sample from one well. In water from one well, four nonpesticide volatile organic compounds (benzene, ethylbenzene, naphthalene, and toluene) were present in concentrations exceeding 4 µg/L. The presence of these volatiles was thought to be the result of a fuel spill.

Analyses of samples collected during the preliminary phase did not include analyses for many of the pesticides (such as bromacil) that have a high usage rate and high potential for ground-water contamination. This is because analytical methods for many of these compounds were not routinely available at that time. An additional limitation of the organics data from the preliminary phase of the study was that detection limits on volatiles such as EDB were relatively high (3 µg/L) and considerably above the limits considered to be of concern in ground water.

Mining Area

The potential for contamination of ground water in the mining area primarily is associated with two aspects of the mining and processing operation: ore separation and chemical processing. Contamination associated with byproducts from the ore-separation process could be much more widespread than contamination from the chemical plant because the sand and clay wastes are used as fill in reclamation. Conversely, the chemical plants occupy a relatively small area with a fixed location where the handling of products and by-products is closely controlled.

Large quantities of chemicals are used in the ore-separation process. The following estimates of chemical usage are based on production of 7.4 million tons of ore in Polk County in 1982 (Gordon F. Palm and Associates, 1983):

Usage during 1982

Chemical compound	Usage (tons)
Caustic soda	1,100
Ammonia	800
Tall oil	8,900
Fuel oil	10,400
Kerosene	600
Sulfuric acid	16,000
Amines	2,000
Surfactants	140

Residuals of some of these chemicals could be contained in sand and clay slurries discharged to the storage and reclamation areas. Some concern has been expressed over the possibility that the oils used as flotation agents could be contaminated by organic priority pollutants (Gordon F. Palm and Associates, 1983). Oil residues containing these pollutants would most likely be associated with disposal of sand tailings and could migrate to the ground water under areas reclaimed using sand tailings.

Overburden and wastes from the ore-separation process used as reclamation fill could cause relatively high levels of radiochemical activity in these reclaimed areas. This is because the material can contain radioactive minerals, such as uranium and its associated daughter products, which occur naturally in the same part of the aquifer as phosphate ore.

Slime ponds containing clay-slurry wastes can have high concentrations of phosphorus, trace elements, and radioisotopes associated with waste solids. These are effectively trapped in the slime ponds, but some material can solubilize after settling and infiltrate through the bottom of the pond into the underlying ground water (Miller and Sutcliffe, 1984).

The most concentrated sources of contamination probably are at the chemical plants where the phosphate ore is processed into phosphoric acid. This process produces residuals of acidic water and voluminous quantities of gypsum. The acidity of the water increases the solubility of trace metals as it percolates through the unsaturated zone and the surficial aquifer system. Ground water near gypsum stacks can contain high concentrations of arsenic, beryllium, cadmium, chromium, cobalt, copper, lithium, and zinc (Miller and Sutcliffe, 1982; 1984).

Rutledge (1987) reported high trace-element concentrations in samples of clayey waste, sand-tailing discharge, and cooling-pond water. However, contamination of ground water by process water probably is restricted to the vicinity of the sources because the solubility of most constituents, including radioactive isotopes and trace elements, is reduced after acids contained in the process water are neutralized by reaction with aquifer materials. The solubilities of bromide and iodide compounds from process water are, however, unaffected by neutralization and these compounds, therefore, probably are mobile in ground-water systems. Miller and Sutcliffe (1984) reported that water samples from wells 1,500 ft or more from sources of process water generally met all drinking-water standards, as did water from most wells located closer to the source.

Miller and Sutcliffe (1984) reported that concentrations of total organic carbon (TOC) in water from wells in the surficial aquifer system at chemical processing plants were markedly higher than concentrations in water from similar wells located far from industrial plants. One well at a chemical plant yielded water with a TOC concentration of 370 mg/L and a total phenol concentration of 1,300 μg/L.

Rutledge (1987) reported many polynuclear organic compounds in samples of clayey waste and sand-tailing discharges. These compounds included phenanthrene (detected in 3 of 12 samples) and acenaphthene, fluorene, and pyrene (detected in 2 of 12 samples).

EFFECTS OF LAND USE ON GROUND-WATER QUALITY

The effects of land use on ground-water quality were evaluated in this study by individually comparing water-quality data between the three land-use types, and the control area. The quality of water from the Upper Floridan aquifer in the Orlando urban area was compared to the quality of water from the same aquifer in the control area. The quality of water from the surficial aquifer system in the Windermere citrus area and the Bartow mining area was compared to the quality of water in the same aquifer in the control area. The comparisons were made using graphical presentations of water-quality data and summary tables presenting results of statistical tests and are described in this section of the report. Detailed summaries of water-quality data in the study area are included in Appendix I through IV.

In this section of the report, box plots are used to show the statistical distribution of selected properties and constituents by land use; each well is represented as a single observation in the distribution. Data from the latest sample are shown where multiple samples were collected from a well. The box plots are sometimes truncated on the low end at the analytical detection limits.

Major Constituents, Properties, Nitrogen Species, Phosphorus, and Unidentified Organic Compounds

Concentrations of major constituents and nitrogen and phosphorus species in ground water generally are higher and more variable in the developed land-use areas than in the control area, as shown in box plots of specific conductance, selected major constituents (fig. 14), and selected nitrogen and phosphorus species (fig. 15). Constituents and properties that are significantly related to land use at a probability level of 5 percent or less are listed in table 13. The specific conductance and concentrations of calcium, sodium, potassium, chloride, and ammonia are significantly higher in all three developed areas than in the control area.

The higher concentrations of calcium, sodium, and chloride in the urban area probably are not the result of drainage-well inflow, because concentrations of these constituents are lower in stormwater and lake overflow into drainage wells than in water from the Upper Floridan aquifer (table 14). Rather, the differences for these constituents probably reflect differences in the period of time the water is in contact with aquifer materials or the quality of water recharging the Upper Floridan aquifer through the surficial aquifer system.

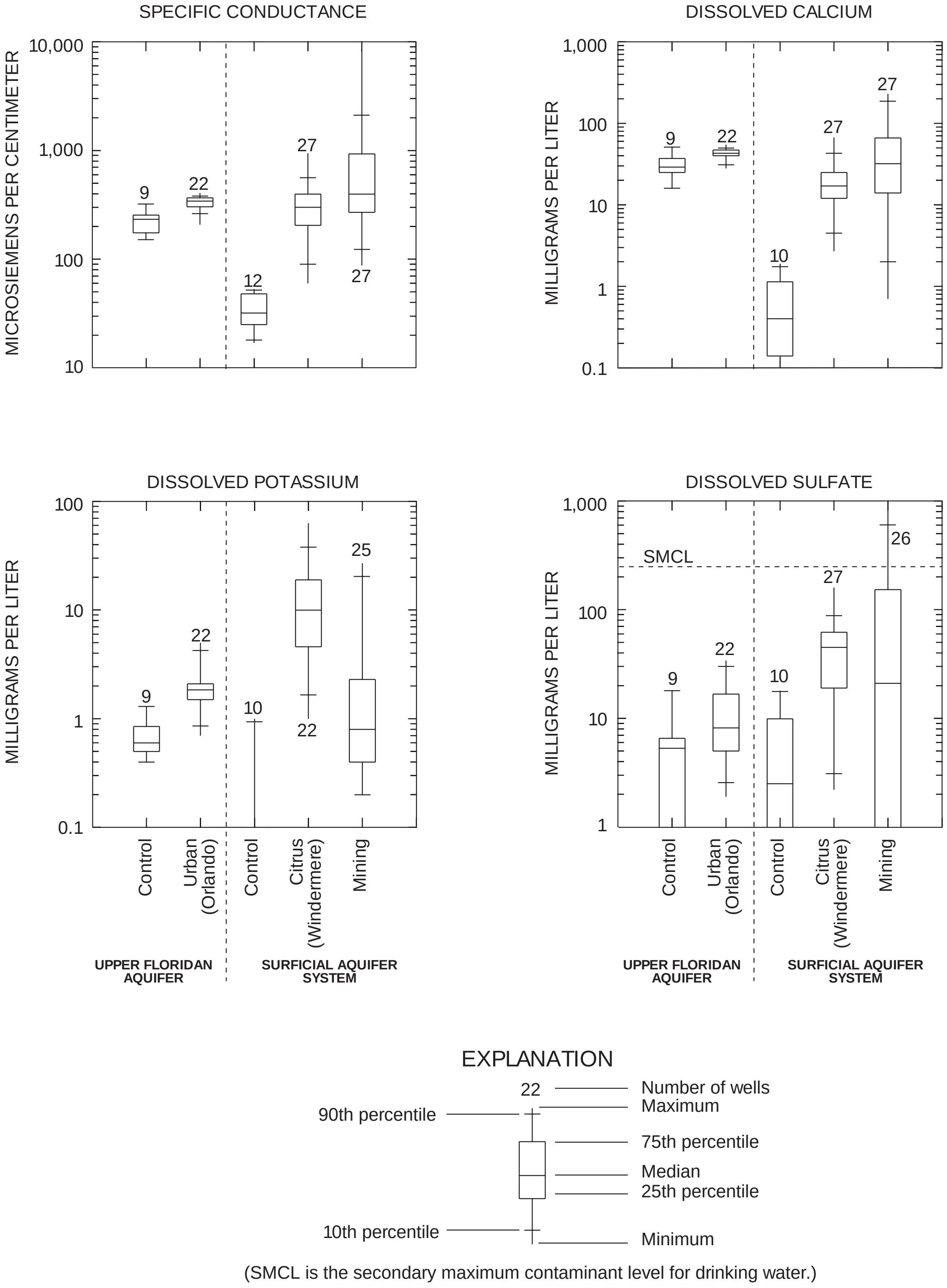
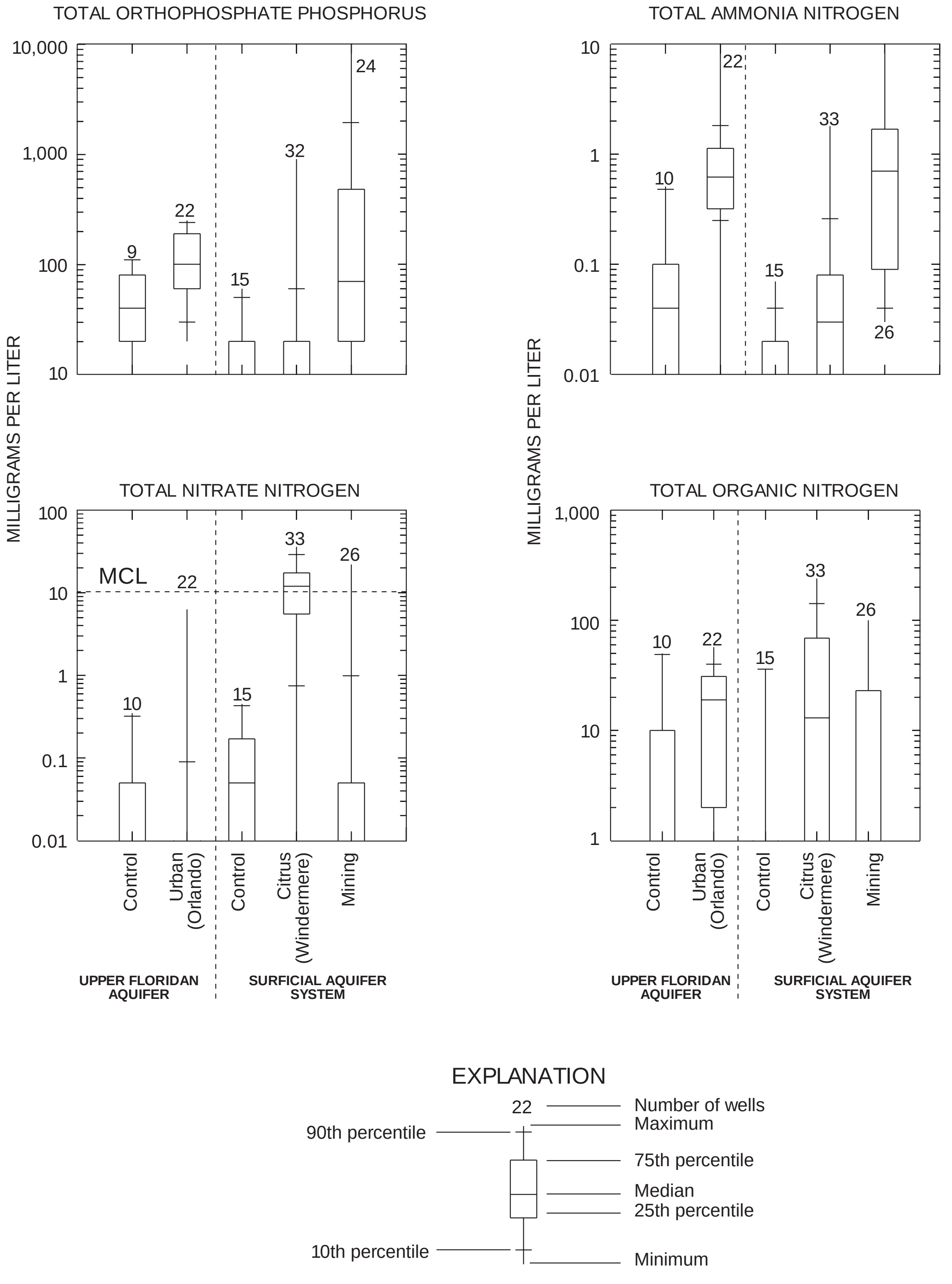


Figure 14. Specific conductance and calcium, potassium, and sulfate concentrations in ground water in the study areas, April 1984 through September 1989.



(MCL is the maximum contaminant contaminant level for drinking water.)

Figure 15. Nitrogen and phosphorus species concentrations in ground water in the study areas, April 1984 through September 1989.

However, other constituents that are present in higher concentrations in the urban area than in the control area (potassium, sulfate, nitrogen species, total organic carbon, phosphorus, and unidentified organic compounds) could result, at least in part, from drainage-well recharge, because stormwater and lake overflow contain similar or greater concentrations than does the water in the Upper Floridan aquifer (table 14). The higher concentrations of organic nitrogen, ammonia, phosphorus, and organic compounds in the urban area are most likely the result of drainage-well recharge. These constituents do not have a geochemical origin but are present in relatively high concentrations in source water entering drainage wells.

The constituents in ground water most affected by citrus-farming activities, as indicated by an increase in median concentrations between the control and citrus areas by a factor of ten or more, are listed below:

Constituent	Median concentrations (milligrams per liter, unless otherwise noted)	
	Control area	Citrus area
Calcium	0.4	17
Magnesium	.5	9.4
Potassium	<0.1	10
Sulfate	2.5	45
Organic nitrogen	<.01	0.44
Nitrate (as nitrogen)	0.05	12

Of these, the higher median nitrate concentration in the citrus area is especially significant because it exceeds the maximum-contaminant level for drinking water of 10 mg/L (U.S. Environmental Protection Agency, 1988a). The nitrate concentration exceeded the maximum-contaminant level for drinking water at more than half of the 33 sites sampled.

The most highly mineralized ground water in any of the study areas was in the mining area, as shown by the summary of specific conductance (fig. l4). Concentrations of all the major dissolved constituents (except sulfate), bromide, iodide, ammonia, nitrite, and phosphorus, and gross alpha and beta radioactivity in ground water were significantly higher in the mining area than in the control area (table 13). Although sulfate concentrations are not significantly higher in the mining area than in the control area (at a probability level of 0.05), the highest sulfate concentrations were observed in the mining area (fig. 14); at some locations, sulfate exceeded the secondary maximum-contaminant level for drinking water of 250 mg/L (U.S. Environmental Protection Agency, l988c).

Table 13. Summary of statistically significant land-use effects on ground-water quality

[Upper Floridan aquifer water quality in the urban area is compared to that in the control area. Surficial aquifer system water quality in the citrus and mining areas is compared to that in the control area. Water-quality characteristics are listed only if there is a significant difference between at least one area and the control area. UOCs, Unidentified Organic Compounds from gas chromatography analysis; >, value of water-quality characteristic is greater in the developed area than in the control area; <, value of water-quality characteristic is less in the developed area than in the control area; > or <, the probability that a difference is due to chance rather than a land-use effect is 0.05 or less and is regarded as significant; =, the probability that a difference is due to chance rather than a land-use effect is greater than 0.05; --, no comparison made]

Water-quality characteristics	Significance of water-quality differences between developed areas and control area		
	Urban area	Citrus area	Mining area
Specific conductance	>	>	>
pH	<	=	>
Calcium	>	>	>
Magnesium	=	>	>
Sodium	>	>	>
Potassium	>	>	>
Alkalinity	=	=	>
Chloride	>	>	>
Sulfate	>	>	=
Bromide	--	--	>
Iodide	--	--	>
Organic nitrogen	>	=	=
Ammonia	>	>	>
Nitrite	=	=	>
Nitrate	=	>	=
Total organic carbon	>	--	--
Orthophosphorus	>	=	>
Total phosphorus	>	=	>
UOCs, number of compounds.	=	=	>
UOCs, total concentration	>	=	>
Radioactivity, gross alpha	- -	- -	>
Radioactivity, gross beta	- -	- -	>
Arsenic	=	=	>
Iron	=	=	>
Manganese	=	>	>
Silver	=	<	<
Zinc	=	=	>
Toluene	=	=	>
Bromacil	--	>	--

The constituents in or properties of ground water most affected by mining, as indicated by an increase in median values between the control and mining areas by a factor of ten or more, follow:

Constituents or property	Median concentrations (milligrams per liter, unless otherwise noted)	
	Control area	Mining area
Calcium	0.4	32
Magnesium	.5	15
Sodium	2.2	19
Alkalinity	.8	66
Organic nitrogen	<.01	.25
Ammonia	.01	.7
Iodide	.003	.06
Total phosphorus	.08	.97
Gross alpha radioactivity (picocuries per liter)	.5	5.2

Trace Elements

Trace element concentrations generally were less than detection limits in all study areas, with the exception of copper, iron, manganese, and zinc. High concentrations of trace elements occurred sporadically in most study areas and exceeded standards for drinking water in water from a few wells (figs. 16 and 17).

The mining area was the most affected of the three developed areas with respect to trace elements in ground water; arsenic, iron, manganese, and zinc were detected at a significantly higher frequency or were present in ground water in significantly higher concentrations in the mining area than in the control area (table 13). Manganese was detected more frequently in ground water in the citrus area than in ground water in the control area. Detection frequency or concentrations of trace elements in ground water in the urban area were not significantly higher than those in ground water in the control area.

Silver was detected in ground water more frequently in the control area than in the citrus and mining areas (table 13). The source of silver in the control area is not known but high concentrations of silver could be due to sample contamination. The detection of silver only in water from newly-installed wells with stainless-steel well points indicates that the silver could have originated from the well screen.

Volatile, Base-Neutral-Extractable, and Acid-Extractable Compounds

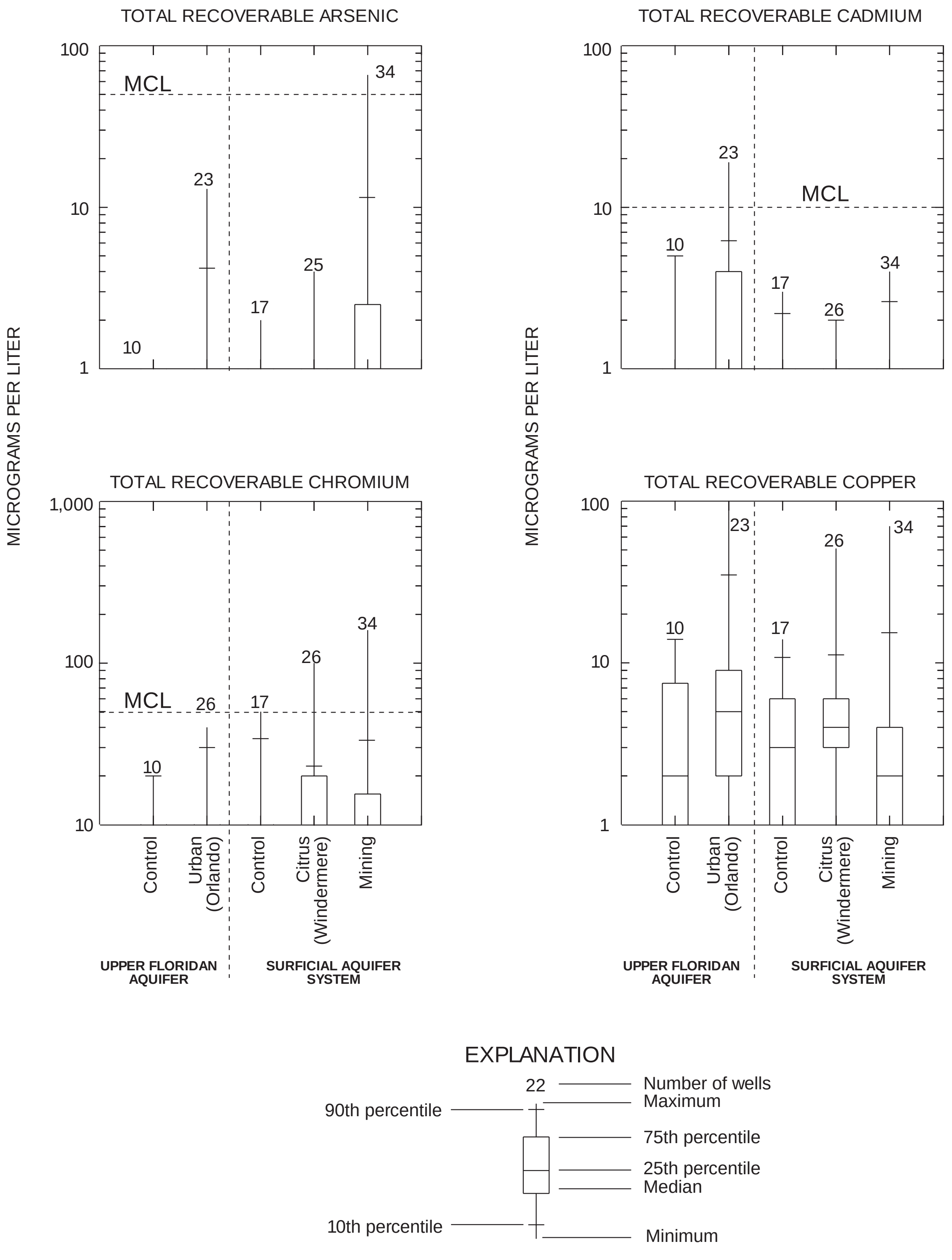
Of the 25 volatile organic compounds analyzed, 16 were detected in ground water from at least one well. Toluene was the only volatile organic compound that was detected in ground water at a significantly

Table 14. Median concentrations of selected constituents in stormwater, lake overflow, and Upper Floridan aquifer water in the urban area

[Concentrations are in milligrams per liter, except as noted; µg/L, micrograms per liter; - -, no data; <, less than specified value]

	Storm water			Lake overflow			Ground water
	Lakes Faith, Hope, & Charity[1]	Lake Midget[2]	Park Lake[2]	Lake Underhill[3]	Lake Midget	Park Lake	Upper Floridan aquifer
Number of samples	91	4	3	4	7	7	22
Constituent	**Median concentrations**						
Calcium	16	--	--	20	20	22	43
Magnesium	1.3	--	--	2.2	6	3.0	8.6
Sodium	3.6	--	--	5.4	1.5	4.1	10.5
Potassium	3.3	--	--	2.0	I.l	1.5	1.8
Alkalinity	44	--	--	46	55	66	132
Chloride	7.6	--	--	9.4	2.2	6.8	15
Sulfate	8	--	--	15	4.0	6.0	8.2
Total nitrogen	3.6	1.4	2.4	1.0	.82	.53	.81
Total phosphorus	58	28	37	.08	.13	.04	16
Total organic carbon	45	--	--	6.8	--	--	--
Lead, µg/L	200	120	170	<5	18	10	<5
Zinc, µg/L	120	80	140	15	30	20	25

[1] German, 1983. [2] German, 1989. [3] Bradner, 1991.



(MCL is the maximum contaminant level for drinking water.)

Figure 16. Arsenic, cadmium, chromium, and copper concentrations in the study areas, April 1984 through September 1989.

higher frequency in a developed area (the mining area) than in the control area (table 13). The compounds that were detected at more than two wells in a study area are listed below:

Volatile organic compound	Study area	Aquifer	Number of wells with detections/ total wells sampled
Chloroform	Control	Surficial	3/9
Toluene	Control	Upper Floridan	3/9
Toluene	Mining	Surficial	5/12
Benzene	Urban	Upper Floridan	6/16
Trichloroethylene	Mining	Surficial	3/12

The six wells in which benzene was detected in ground water in the urban area were not widely distributed over the area. Four of the six locations at which benzene was detected (in concentrations as high as 86 µg/L) are thought to be within the area of a hydrocarbon plume existing as a result of a coal gasification plant that had previously operated in the area. At three of these sites, several base-neutral-extractable organic compounds, probably originating from the coal gasification plant were also detected (Bradner, 1991). Samples from wells at seven other sites in the Orlando urban area (sites 5, 18, 19, 23, 24, 25, and 26) not in the vicinity of the suspected hydrocarbon plume, did not have detectable concentrations of the base-neutral-extractable compounds.

Low concentrations of base-neutral-extractable aromatic and polycyclic compounds were present in ground water at two sites in the mining area (table 15, sites 2 and 25). Both sites are in reclaimed areas underlain by backfill sands and clays from the ore-separation process: site 2 is in an area with sand-tailing fill and site 25 is in an area that is a reclaimed slime pond.

Relatively high concentrations of some acid-extractable or base-neutral-extractable TIOCs were detected in ground water at sites 2, 11, and 25 (table 16), particularly at site 11, which is a recently mined area backfilled with sand and clay overburden. The cause of the high TIOC concentrations in ground water at site 11 is unknown and is considered to be unusual because process wastes were not used as fill at this site. Some of the TIOCs could have originated from fuel spills and some, such as camphor, might occur naturally.

Table 15. Base-neutral-extractable compounds detected in water from the surficial aquifer system in the mining area

[Number is concentration in micrograms per liter; - -, compound was not detected]

Compound name	Site 2	Site 25
Acenaphthene	1.27	0.54
Anthracene	.38	.38
Fluorene	--	1.01
Fluoranthene	.77	--
Phenanthrene	--	.35
Pyrene	.72	.65
1,2 dichlorobenzene	--	.23
1,4 dichlorobenzene	--	.60
Naphthalene	--	.43

Pesticides

A total of 14 pesticide compounds were detected in ground water from at least one well. Bromacil was the only pesticide that was detected at a significantly higher frequency in a developed area (the citrus area) than in the control area (table 13). It was detected in water from 12 of 19 wells in the citrus area in concentrations as high as 22 µg/L. Most of the other pesticides detected were also in ground water from the citrus area. The pesticides that were detected at more than two wells are listed below:

Pesticide	Study area	Aquifer	Number of wells with detections/ total wells sampled
Bromacil	Citrus	Surficial	12/19
Diazinon	Control	Surficial	5/8
	Citrus	Surficial	7/17
	Mining	Surficial	7/11
Simazine	Citrus	Surficial	5/24
Fenamiphos	Citrus	Surficial	3/19
Aldicarb derivatives	Citrus	Surficial	3/18
1,2-Dibromo-3 chloropropane (DBCP)	Citrus	Surficial	3/19
DDT	Citrus	Surficial	3/19

ASSESSMENT OF TRANSFERABILITY OF STUDY RESULTS

Ground-water quality in two areas, the Ocala urban area and the Lake Wales citrus area, was

Table 16. Tentatively identified organic compounds in water from wells in the mining area

[The concentration, in micrograms per liter, generally is accurate to one order of magnitude. The CAS number, assigned by the Chemical Abstracts Service, Inc., is a computer file key that may be used to access information about the compounds; - -, no CAS number assigned]

Concentration	CAS number	Compound
Site 2		
l	4706905	1,3-dimethyl-5-(1-methylethyl)-benzene
l	1127760	l-ethyl-naphthalene
l	573988	l,2-dimethyl-naphthalene
1	569415	l,8-dimethyl-naphthalene
1	1730376	1-methyl-9H-fluorene
2	582161	2,7-dimethyl-naphthalene
2	2245387	l,6,7-trimethyl-naphthalene
(Ten other compounds were reported at concentrations of less than l microgram per liter)		
Site 11		
l	108394	3-methyl phenol
l	1632731	D-fenchyl alcohol
l	89805	p-Menthone
2	464459	l-Borneol
2	499752	2-methyl-5-(l-methylethyl)-phenol
2	536607	p-cymen-8-ol
2	5153924	8,13-epoxy-15,16-dinorlab-12-ene
3	1678826	8,13-epoxy-15,16-dinorlab-12-ene trans-cyclohexane
3	1124272	1-methyl-4-(l-methylethylidene)-cyclohexane
3	498817	p-Menthan-8-ol
3	89781	Menthol
4	5256655	3-methyl 6-(1-methylethylidene)-cyclohexane
6	--	2,5-dione-bornane
8	98544	4-(1,l-dimethylethyl)-phenol
10	108883	Methyl benzene
10	644359	2-propyl-phenol
20	122009	1-(4-methylphenyl)-ethanone
23	1195795	Fenchone
30	33675761	3-(2-phenylethyl)-phenol
38	76222	Camphor
98	6069983	1-methyl-4-(1-methylethyl) cis-cyclohexane
200	99876	1-methyl-4-(1-methylethyl)-benzene
(Eight other compounds were reported at concentrations of less than l microgram per liter)		
Site 25		
1	939275	2-ethyl-naphthalene
1	575417	1,3-dimethyl-naphthaIene
1	87854	hexamethyl benzene
1	16587443	7-ethyl-2-methyl-benzo(b)thiophene
1	2131411	l,4,5-trimethyl-naphthalene
2	767588	2,3-dihydro-1-methyl-1H-indene
2	4175535	2,3-dihydro-l,3-dimethyl-1H-indene
2	571584	1,4-dimethyl-naphthaIene
2	573988	1,2-dimethyl-naphthalene
2	581408	2,3-dimethyl-naphthalene
2	569415	1,8-dimethyl-naphthalene
2	829265	2,3,6-trimethyl-naphthalene
2	2245387	1,6,7-otrimethyl-naphthalene
2	2131422	1,4,6-trimethyl-onaphthalene
2	2523377	9-methyl-9H-fluorene
3	90120	1-methyl-naphthalene
4	91576	2-methyl-naphthalene
4	575371	I,7-dimethyl-naphthalene
5	99876	1-methyl-4-(lmethylethyl)-benzene
5	- -	alkenes / cycloalkanes
5	10544500	Molecular sulfur
8	98544	4-(1,1-dimethylethyl)-phenol
(Thirty other tentatively identified organic compounds were reported at concentrations of less than l microgram per liter)		

determined to evaluate the transferability of study results at the primary urban and citrus study areas (the Orlando urban area and the Lake Windermere citrus area) to other areas of similar land use.

Urban Areas

Statistical comparison of water-quality data for the Ocala area with that for the control area tends to confirm the general conclusion from the Orlando area; that differences exist in ground-water quality between undeveloped areas and areas where urban stormwater is emplaced into the Upper Floridan aquifer. However, there is little agreement on specific effects between the two urban areas (table 17).

In both the Orlando and Ocala urban areas, specific conductance and concentrations of calcium, sodium, and sulfate in ground water were significantly higher than specific conductance and concentrations of those ions in ground water in the control area. Also, pH was significantly lower in both urban areas than in the control area. Calcium and sodium are not present in high concentrations in stormwater, relative to

Table 17. Summary of statistically significant land-use effects on ground-water quality in urban areas

[Water quality characteristics are listed only if there is a significant difference between the Orlando urban area and the control area or between the Ocala urban area and the control area. UOCs, Unidentified Organic Compounds from gas chromatography analysis; >, value of water-quality characteristic is greater in the developed area than in the control area; <, value of water-quality characteristic is less in the developed area than in the control area; > or <, the probability that a difference is due to chance rather than a land-use effect is 0.05 or less and is regarded as significant; =, the probability that a difference is due to chance rather than a land-use effect is greater than 0.05]

Water-quality characteristic	Orlando urban area	Ocala urban area
Specific conductance	>	>
pH	<	<
Calcium	>	>
Sodium	>	>
Potassium	>	=
Alkalinity	=	>
Chloride	>	=
Sulfate	>	>
Organic nitrogen	>	=
Ammonia	>	<
Nitrate	=	>
Total organic carbon	>	=
Total phosphorus	>	=
Orthophosphorus	>	=
UOCs, number of compounds	=	<
UOCs, total concentration	>	<

ground water in the study areas; thus, sulfate and perhaps pH are the most likely water-quality characteristics to be affected by urban stormwater.

Many constituents that were significantly higher in concentration or frequency of detection in the Orlando urban area than in the control area did not differ significantly between the Ocala urban area and the control area. These included potassium, chloride, organic nitrogen, total organic carbon, total phosphorus, and orthophosphorus. Additionally, the frequency of detection of ammonia and total concentrations of unidentified organic compounds in ground water were significantly higher in the Orlando area than in the control area, but were significantly lower in the Ocala area than in the control area.

Some properties or constituents in ground water that differed significantly between the Ocala urban area and the control area did not differ significantly between the Orlando urban area and the control area. Alkalinity and the frequency of nitrate detection were higher and the number of unidentified organic compounds was lower in the Ocala area than in the control area.

Some of the differences noted between the two urban areas in specific land-use effects from urban stormwater disposal might be related to differences in the mechanics of stormwater recharge between the two urban areas. Orlando and Ocala both use drainage wells for stormwater disposal, but Ocala also uses retention ponds and sinkholes for an undetermined (but probably significant) amount of stormwater recharge. Retention ponds and sinkholes often contain a layer of sand that can function as a filter through which stormwater must pass before reaching the Upper Floridan aquifer. This filtering of stormwater could remove leaves and other debris that would otherwise be transported into the aquifer. In Orlando, where drainage wells are the sole means of stormwater recharge to the Upper Floridan aquifer, debris deposits in the aquifer could be more extensive than in Ocala. Leaching of these debris deposits could result in the higher concentrations of organic nitrogen, ammonia, organic carbon, and phosphorus that were observed in ground water in the Orlando area. Median concentrations for these constituents in ground water in the two areas are listed below:

Constituent	Median total-recoverable concentrations (milligrams per liter)	
	Ocala	Orlando
Organic nitrogen	<0.01	0.19
Ammonia	<0.01	.62
Total organic carbon	.4	3.1
Total phosphorus	.06	.16

Some differences in ground-water quality between the urban areas could be due to differences in dissolved-oxygen concentrations. Dissolved-oxygen concentrations were not determined in either area; however, the limestone in the Ocala area, being much closer to the land surface than in Orlando, could contain water with relatively higher dissolved-oxygen concentrations. Higher dissolved-oxygen concentrations would favor the presence of nitrate nitrogen rather than ammonia nitrogen in the Ocala area. Median nitrate concentration in ground water was 1.2 mg/L in the Ocala area and less than 0.01 mg/L in the Orlando area.

As in the Orlando area (excluding the area of the hydrocarbon plume in downtown Orlando), there were few detections of volatile organic compounds in ground water in Ocala. Chloroform was detected in water from three of the nine wells sampled and two other volatile organic compounds (toluene and tetrachloroethylene) were detected in water from one well. None of the volatile organic compounds were detected more frequently in ground water in the Ocala area than in ground water in the control area.

Three wells in the Ocala area were sampled in either June or August 1989 to determine if there was any evidence of elevated trace-element concentrations. Results of analyses of these samples, listed below, do not indicate elevated concentrations of trace elements.

Trace element	Total-recoverable concentrations (micrograms per liter)		
	Site 3	Site 12	Site l
Arsenic	<l	<1	<I
Cadmium	<1	<1	<1
Chromium	<10	<10	<10
Copper	3	1	2
Iron	30	150	50
Lead	<5	<5	<5
Manganese	l0	<I0	<l0
Mercury	.3	<.1	<.1
Selenium	<1	<1	<1
Zinc	230	90	160

Citrus Areas

All of the significant land-use effects on water quality in the surficial aquifer noted in the Windermere citrus area were also noted in the Lake Wales area (table 18), except for differences in manganese concentration and frequency of silver detection. (Manganese and silver were not determined in water from all wells in the Lake Wales area). As in the Windermere citrus area, the median nitrate concentration (12 mg/L) for ground-water samples in the Lake Wales citrus area exceeded the primary maximum-contaminant level (10 mg/L) for drinking water. Also, bromacil was detected in more than half the ground-water samples analyzed (in concentrations exceeding 20 pg/L) for both study areas.

Some significant ground-water quality differences observed between the Lake Wales citrus area and the control area were not observed between the Windermere citrus area and the control area. These include a significantly higher pH and alkalinity, a higher frequency of nitrite detection, higher concentrations of phosphorus, a higher frequency of detection of volatile organic compounds, and a lower frequency of detection of diazinon (table 18).

Table 18. Summary of statistically significant land-use effects on ground-water quality in the citrus areas

[Water-quality characteristics are listed only if there is a significant difference between the Windermere citrus area and the control area or between the Lake Wales citrus area and the control area. >, value of water- quality characteristic is greater in the developed area than in the control area; <, value of water-quality characteristic is less in the developed area than in the control area; > or <, the probability that a difference is due to chance rather than a land-use effect is 0.05 or less and is regarded as significant; =, the probability that a difference is due to chance rather than a land-use effect is greater than 0.05; --, no comparison made]

Water-quality characteristic	Significance of water-quality differences between citrus areas and the control area	
	Windermere citrus area	Lake Wales citrus area
Specific conductance	>	>
pH	=	>
Calcium	>	>
Magnesium	>	>
Sodium	>	>
Potassium	>	>
Alkalinity	=	>
Chloride	>	>
Sulfate	>	>
Ammonia	>	>
Nitrite	=	>
Nitrate	>	>
Total phosphorus	=	=
Orthophosphorus	=	>
Manganese	>	--
Silver	<	--
Chlorodibromomethane	=	>
Chloroform	=	>
Dichlorobromomethane	=	>
Diazinon	=	<
Bromacil	>	>

Differences in ground-water quality between the two citrus areas are exemplified by the following median values for selected water-quality characteristics:

Constituent or property	Median total-recoverable concentrations [milligrams per liter, unless otherwise noted]	
	Lake Wales	Windermere
pH (units)	7.3	4.8
Alkalinity	56	2.1
Sodium	43	3.8
Total phosphorus	.16	.02

The relatively high median pH, alkalinity, and concentrations of phosphorus in water from the Lake Wales area might be caused by the grout used in well construction. Grout contains limestone materials known to affect the pH and alkalinity of water in contact with the grout and may contain traces of phosphatic material.

Three volatile organic compounds were detected in ground water at a significantly higher frequency in the Lake Wales area than in the control area. These compounds and number of detections are listed below:

Volatile organic compound	Number of detections/number of samples	
	Control area	Lake Wales area
Chlorodibromomethane	0/9	5/11
Chloroform...........	3/9	10/11
Dichlorobromomethane	0/9	8/11

This detection frequency of volatile organics was not observed in the Windermere citrus area, although chloroform and dichlorobromomethane were detected in 2 of 16 samples of ground water from the Windermere area. The presence of chloroform was detected in all but one ground-water sample from the Lake Wales area in concentrations as high as 17 µg/L.

The reason for the high detection frequency of volatile organic compounds in ground water in the Lake Wales area has not been determined. Because no glues or solvents were used during well construction and because no volatiles were detected in the field blanks prepared at two of the sites, there is no indication of well or sample contamination. Degradation of pesticides containing chlorine could be a possible source of some volatiles; however, this type of decomposition requires specific bacteria and an anaerobic environment and is not considered a likely source of volatile organic compounds in the study area (T.R. Steinheimer, U.S. Geological Survey, oral commun., 1990).

Two wells in the Lake Wales area (at sites 4 and 6) were sampled for analysis of trace elements in ground water. Results of the analyses of these samples, listed in the next column, do not indicate elevated concentrations of most trace elements.

Iron and manganese concentrations were slightly elevated in the ground-water sample from site 4 and arsenic and copper concentrations were slightly elevated in the sample from site 6. Iron and manganese occur naturally, and elevated concentrations of these elements in ground water are not uncommon.

Trace element	Total-recoverable concentrations [micrograms per liter]	
	Site 4	Site 6
Arsenic	1	7
Cadmium.............	<1	<1
Chromium	<10	<10
Copper.................	8	30
Iron......................	130	60
Lead	<5	<5
Manganese	2l0	<I0
Mercury...............	<0.1	<0.1
Selenium	<1	<1
Zinc	<10	<10

Arsenic and copper are not commonly associated with the sandy soils in central Florida, and slightly elevated concentrations of these trace elements in ground water could be related to the application of agricultural chemicals to the citrus crops.

SUMMARY AND CONCLUSIONS

This report presents the findings of a study to determine the effects of three different land uses on ground-water quality. In this report, quality of ground water in each of three developed areas, an urban area in Orlando, a citrus farming area near Windermere, and a mining area near Bartow, is compared to that of an undeveloped principal control area. The land-use activities associated with the three developed areas are (l) urban stormwater disposal through drainage wells, (2) citrus cultivation with the associated application of fertilizers and pesticides, and (3) mining and processing of phosphate ore into fertilizers. Transferability of conclusions from sampling and analyzing ground water in the urban area and the Windermere citrus area was tested in additional urban and citrus areas of similar hydrology and land use. No evaluation of the transferability of study results related to the mining area was made because of the large variety of activities that exists in mining areas.

The control area is in an undeveloped area of the Ocala National Forest, where human activity is limited to low-density recreational activities and periodic logging. Ground-water samples from both the surficial aquifer system and the Upper Floridan aquifer were collected in the control area. The urban study area is in Orlando, where more than 400 drainage wells are used to drain stormwater runoff to the Upper Floridan aquifer. The citrus study area is located near Windermere, west of Orlando, where citrus has been cultivated for at least 25 years. Fertilizers and pesticides applied to this area have the potential to leach into the surficial aquifer system. The mining study area, near Bartow, is in an area of central Florida that produces nearly one-fifth of the phosphate fertilizer in the world. Various activities associated with mining and processing phosphate ore have the potential to affect water quality in the surficial aquifer system.

The area selected for transferability testing for urban land use is in Ocala, about 60 miles north of the Orlando area. Drainage wells, sinkholes, and detention ponds with direct connection to the Upper Floridan aquifer are used in Ocala to dispose of stormwater runoff. The area selected for transferability testing for citrus land use is near Lake Wales, an area that was once the leading producer of citrus fruit in the State.

Several constituents in stormwater runoff could degrade water quality in the Upper Floridan aquifer underlying the urban area at Orlando. These include traffic-related metals, particularly lead and zinc, as well as a wide variety of organic compounds.

Large amounts of fertilizers and pesticides are applied annually in areas used to grow citrus. Citrus fertilizers contain large amounts of nitrogen and other constituents. Application rates for these fertilizers are on the order of 80 pounds of nitrogen per acre per year because the soils typical of citrus-growing areas generally are low in nitrogen content. A wide variety of pesticides is used for weed and pest control in the production of citrus crops.

The ground-water contamination potential associated with phosphate mining is most likely related to two aspects of the operation: ore-separation and chemical processing. Because the disposal of sand-and-clay waste produced by the ore-separation process is widely distributed, the contamination potential associated with ore processing could be the most widespread. In addition, some chemical reagents used in the ore-separation process could be discharged to storage and reclamation areas along with the sand-and-clay wastes.

Statistical tests were used to compare water-quality data in the developed areas with data from the control area. Water-quality data for the two areas were considered to be significantly different at the 5-percent level.

Concentrations of major constituents and nitrogen and phosphorus species generally were higher and more variable in ground water in the developed land-use areas than in ground water in the control areas, probably as the result of land-use activities. In the urban area, the higher concentrations of calcium, sodium, and chloride in ground water probably were not the result of stormwater recharged through drainage wells. Relatively high concentrations of potassium, sulfate, nitrogen species, phosphorus, total organic carbon, and unidentified organic compounds in ground water in the urban area could be caused by drainage-well recharge, however. In the citrus area, high nitrate concentrations in ground water (from fertilizer usage) were especially significant because they exceeded the maximum contaminant level of 10 milligrams per liter for drinking water at more than half of the 33 sites sampled. The most highly mineralized ground water in any of the study areas was in the mining area.

Concentrations of trace elements in ground water generally were less than detection limits in all study areas, with the exception of copper, iron, manganese, and zinc. However, high concentrations of trace elements occurred sporadically in most areas and in some instances exceeded maximum contaminant levels for drinking water. Significantly higher concentrations or detection frequencies of arsenic, iron, manganese, and zinc were observed for ground water in the mining area than in water from the control area, and manganese concentrations were significantly higher in the citrus area than in the control area.

Toluene was the only organic compound detected more frequently in ground water in a developed area (the mining area) than in the control area. Low concentrations of base-neutral-extractable aromatic and polycyclic compounds, and high concentrations of tentatively identified organic compounds were detected in ground water from reclaimed parts of the mining area.

Bromacil was the only pesticide detected more frequently in ground water from a developed area (the citrus area) than in the control area. Bromacil was detected in water from 12 of 19 wells in the citrus area at concentrations as high as 22 micrograms per liter.

Sampling in the Ocala urban area to test transferability of identified land-use effects supported the general conclusion (based on the study of the Orlando urban area) that stormwater runoff from urban areas (emplaced in the Upper Floridan aquifer through drainage wells, sinkholes, or retention ponds) could affect ground-water quality. However, the specific effects differed somewhat between the two urban areas.

Sampling in the Lake Wales citrus area supported the conclusion based on the study of the Windermere citrus area, that citrus cultivation could affect ground-water quality. The most important observed effects of citrus cultivation on water quality in the surficial aquifer probably are increased nitrate concentrations and occurrence of the herbicide bromacil. Median nitrate concentrations in ground water from wells in both citrus areas exceeded the maximum contaminate level for drinking water of 10 milligrams per liter (as nitrogen). Bromacil was detected in ground water at more than half the sites sampled and concentrations exceeded 20 micrograms per liter in water from some wells.

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APPENDIXES

Appendix I. Summary of water-quality characteristics for ground water beneath various land-use areas in central Florida

[W is the number of wells sampled. ND is the number of wells in which the constituent was detected. Minimum, median, and maximum are in milligrams per liter except as indicated. The p-value is the probability that water-quality differences between the developed area and the control area could be due to chance, rather than a land-use effect. The p-values are from Mann-Whitney analysis, unless more than 20 percent of the sample values are censored; then the p-values are from contingency-table analysis and are in parentheses. FC, Upper Floridan aquifer in the control area; OR, Upper Floridan aquifer in the Orlando urban area; OC, Upper Floridan aquifer in the Ocala urban area; SC, surficial aquifer system in the control area; WM, surficial aquifer system in the Windermere citrus area; LW, surficial aquifer system in the Lake Wales citrus area; BT, surficial aquifer system in the Bartow mining area. <, less than specified value; --, control area - test for differences not applicable]

Water quality characteristic	Study area	W	ND	Minimum	Maximum	Median	Significance of water-quality differences: p-value
Specific conductance (microsiemens per centimeter)							
	FC	9	9	151	325	228	--
	OR	22	22	221	450	332	<0.01
	OC	13	13	250	565	430	<.01
	SC	12	12	18	62	32	--
	WM	27	27	60	920	265	<.01
	LW	l2	12	99	728	476	<.01
	BT	27	27	88	8,500	405	<.0l
pH (units)							
	FC	8	8	7.9	8. l	8	--
	OR	14	14	7	8.1	7.5	<.01
	OC	11	11	7.2	8	7.4	.01
	SC	15	l5	4.2	5.6	4.8	--
	WM	33	33	4	7.3	4.8	.72
	LW	11	11	6.1	8.8	7.3	<.01
	BT	24	24	4.3	7.4	6.2	<.0l
Color (platinum-cobalt units)							
	FC	10	1	<5	5.l	<5	--
	OR	l3	l	<5	10	<5	(.99)
	OC	8	l	<5	5.1	<5	(.99)
Calcium							
	FC	9	9	16	51	29	--
	OR	22	22	28	55	43	<.0l
	OC	10	10	56	100	74	<.0l
	SC	12	11	<.1	1.9	.4	--
	WM	27	27	2.7	67	17	<.0l
	LW	12	12	11	43	18	<.0l
	BT	27	27	.7	230	32	<.01
Magnesium							
	FC	9	9	4	9.5	6.7	--
	OR	22	22	3	11	8.6	.17
	OC	10	10	2	14	7.2	.60
	SC	12	11	<.1	1.2	.5	--
	WM	27	27	.5	36	9.4	<.01
	LW	12	12	.8	15	7	<.01
	BT	27	27	.5	240	15	<.01

Appendix I. Summary of water-quality characteristics for ground water beneath various land-use areas in central Florida—Continued

[W is the number of wells sampled. ND is the number of wells in which the constituent was detected. Minimum, median, and maximum are in milligrams per liter except as indicated. The p-value is the probability that water-quality differences between the developed area and the control area could be due to chance, rather than a land-use effect. The p-values are from Mann-Whitney analysis, unless more than 20 percent of the sample values are censored; then the p-values are from contingency-table analysis and are in parentheses. FC, Upper Floridan aquifer in the control area; OR, Upper Floridan aquifer in the Orlando urban area; OC, Upper Floridan aquifer in the Ocala urban area; SC, surficial aquifer system in the control area; WM, surficial aquifer system in the Windermere citrus area; LW, surficial aquifer system in the Lake Wales citrus area; BT, surficial aquifer system in the Bartow mining area. <, less than specified value; --, control area - test for differences not applicable]

Water quality characteristic	Study area	W	ND	Minimum	Maximum	Median	Significance of water-quality differences: p-value
Sodium							
	FC	9	9	2.3	5.3	3.4	--
	OR	22	22	7.4	20	10.5	<.0l
	OC	l0	10	4.2	l6	7.2	<.01
	SC	12	12	1.3	5.8	2.2	--
	WM	27	26	<.1	40	3.8	.05
	LW	12	12	11	150	43	<.01
	BT	27	27	1.9	1,200	19	<.0l
Potassium							
	FC	9	9	.4	1.3	.6	--
	OR	22	22	.7	5	1.8	<.01
	OC	10	10	.2	3	.8	.51
	SC	12	6	<.1	l	<.1	--
	WM	27	27	l	63	10	<.01
	LW	12	12	2.5	22	9.8	<.01
	BT	27	27	.2	27	.8	<.01
Alkalinity							
	FC	9	9	60	163	92	--
	OR	22	22	3.4	174	132	.07
	OC	10	10	120	230	160	<.01
	SC	9	6	<.1	13	.8	--
	WM	22	18	<.1	93	2.1	.08
	LW	12	12	3.4	210	56	<.01
	BT	25	24	<.1	536	66	<.01
Chloride							
	FC	8	8	4.5	13	6.7	--
	OR	22	22	8	21	15	<.01
	OC	13	13	2.3	17	11	.12
	SC	12	12	2.7	9.6	4.1	--
	WM	27	27	2.5	75	19	<.01
	LW	12	12	13	45	24	<.01
	BT	27	27	3.3	520	13	<.01
Sulfate							
	FC	9	8	<l	18	5.3	--
	OR	22	22	1.9	34	8.2	.04
	OC	10	10	12	100	47	<.0l
	SC	12	11	<l	18	2.5	--

Appendix I. Summary of water-quality characteristics for ground water beneath various land-use areas in central Florida—Continued

[W is the number of wells sampled. ND is the number of wells in which the constituent was detected. Minimum, median, and maximum are in milligrams per liter except as indicated. The p-value is the probability that water-quality differences between the developed area and the control area could be due to chance, rather than a land-use effect. The p-values are from Mann-Whitney analysis, unless more than 20 percent of the sample values are censored; then the p-values are from contingency-table analysis and are in parentheses. FC, Upper Floridan aquifer in the control area; OR, Upper Floridan aquifer in the Orlando urban area; OC, Upper Floridan aquifer in the Ocala urban area; SC, surficial aquifer system in the control area; WM, surficial aquifer system in the Windermere citrus area; LW, surficial aquifer system in the Lake Wales citrus area; BT, surficial aquifer system in the Bartow mining area. <, less than specified value; --, control area - test for differences not applicable]

Water quality characteristic	Study area	W	ND	Minimum	Maximum	Median	Significance of water-quality differences: p-value
	WM	27	27	2.2	160	45	<.01
	LW	12	12	7.3	100	64	<.0l
	BT	26	21	<l	1,100	20	.08
Bromide							
	SC	7	6	<.0l	.17	.03	--
	BT	12	12	.02	.40	.12	.04
Iodide							
	SC	7	4	<.001	.008	.003	--
	BT	8	8	.015	.07	.060	<.01
Total organic nitrogen. as N							
	FC	10	2	<.01	.50	<.01	--
	OR	22	17	<.01	.57	.19	(<.01)
	OC	13	2	<.01	.62	<.01	(.99)
	SC	15	3	<.01	.36	<.01	--
	WM	33	17	<.01	2.4	.44	(.06)
	LW	12	8	<.01	.49	.l9	(.02)
	BT	26	11	<.01	1	.25	(.19)
Total ammonia as N							
	FC	10	10	.01	.51	.04	--
	OR	22	22	.01	10	.62	<.01
	OC	13	4	<.01	.15	<.01	(<.01)
	SC	15	15	.01	.07	.01	--
	WM	33	33	.01	1.8	.03	.02
	LW	11	10	<.0l	.64	.05	<.01
	BT	26	26	.03	370	.70	<.01
Total nitrite. as N							
	FC	10	1	<.01	.04	<.01	--
	OR	22	0	<.01	<.01	<.01	(.31)
	OC	13	l	<.01	.01	<.01	(.99)
	SC	15	3	<.0l	.02	<.01	--
	WM	33	13	<.0l	.18	<.01	(.32)
	LW	11	10	<.0l	.23	.05	(<.01)
	BT	26	14	<.01	.07	.01	(.05)
Total nitrate. as N							
	FC	10	4	<.01	.35	<.01	--
	OR	22	5	<.01	6.3	<.01	(.41)
	OC	l3	13	.02	3.6	1.2	(<.01)

Appendix I. Summary of water-quality characteristics for ground water beneath various land-use areas in central Florida—Continued

[W is the number of wells sampled. ND is the number of wells in which the constituent was detected. Minimum, median, and maximum are in milligrams per liter except as indicated. The p-value is the probability that water-quality differences between the developed area and the control area could be due to chance, rather than a land-use effect. The p-values are from Mann-Whitney analysis, unless more than 20 percent of the sample values are censored; then the p-values are from contingency-table analysis and are in parentheses. FC, Upper Floridan aquifer in the control area; OR, Upper Floridan aquifer in the Orlando urban area; OC, Upper Floridan aquifer in the Ocala urban area; SC, surficial aquifer system in the control area; WM, surficial aquifer system in the Windermere citrus area; LW, surficial aquifer system in the Lake Wales citrus area; BT, surficial aquifer system in the Bartow mining area. <, less than specified value; --, control area - test for differences not applicable]

Water quality characteristic	Study area	W	ND	Minimum	Maximum	Median	Significance of water-quality differences: p-value
	SC	15	12	<.01	.45	.05	--
	WM	33	32	<.01	36	12	<.01
	LW	12	10	<.01	32	12	<.01
	BT	26	18	<.01	22	.01	.24
Total organic carbon							
	FC	9	8	<.1	2.5	.8	--
	OR	18	18	1.2	5.1	3.1	<.01
	OC	13	12	<.1	2	.4	.42
Total orthophosphorus, as P							
	FC	9	8	<.01	.11	.04	--
	OR	22	22	.02	.25	.10	<.01
	OC	13	13	.01	.12	.05	.38
	SC	15	13	<.01	.06	.01	--
	WM	32	27	<.01	.90	.01	.86
	LW	11	11	.01	1.2	.l4	<.01
	BT	24	24	.01	485	.07	<.01
Total phosphorus, as P							
	FC	9	9	.02	.23	.05	--
	OR	19	19	.02	.47	.16	.02
	OC	13	12	<.01	.15	.06	.76
	SC	10	9	<.01	.26	.01	--
	WM	25	24	<.01	.94	.02	.18
	LW	11	11	.02	1.2	.l6	.10
	BT	12	12	.08	7.7	.97	<.01
Gross alpha, picocuries per liter							
	SC	10	7	<.l	3.8	.8	--
	BT	13	13	2.1	65	7.7	<.01
Gross beta, picocuries her liter							
	SC	10	8	<.1	4.2	.8	--
	BT	13	13	.9	17	5	<.01

Appendix I. Summary of water-quality characteristics for ground water beneath various land-use areas in central Florida—Continued

[W is the number of wells sampled. ND is the number of wells in which the constituent was detected. Minimum, median, and maximum are in milligrams per liter except as indicated. The p-value is the probability that water-quality differences between the developed area and the control area could be due to chance, rather than a land-use effect. The p-values are from Mann-Whitney analysis, unless more than 20 percent of the sample values are censored; then the p-values are from contingency-table analysis and are in parentheses. FC, Upper Floridan aquifer in the control area; OR, Upper Floridan aquifer in the Orlando urban area; OC, Upper Floridan aquifer in the Ocala urban area; SC, surficial aquifer system in the control area; WM, surficial aquifer system in the Windermere citrus area; LW, surficial aquifer system in the Lake Wales citrus area; BT, surficial aquifer system in the Bartow mining area. <, less than specified value; --, control area - test for differences not applicable]

Water quality characteristic	Study area	W	ND	Minimum	Maximum	Median	Significance of water-quality differences: p-value
Unidentified oceanic compounds:							
Number of compounds:							
	FC	9	9	3	16	5	--
	OR	15	15	2	126	6	.52
	OC	8	7	0	3	1	<.01
	SC	10	10	3	22	9	--
	WM	20	20	4	50	10	.48
	BT	23	23	6	320	23	<.01
Total concentration: (micrograms per liter)							
	FC	9	9	3	160	4	--
	OR	15	15	5	230	8	<.01
	OC	8	7	<.1	1.3	.3	<.01
	SC	10	10	3.5	23	9.6	--
	WM	20	20	5	268	15	.06
	BT	15	15	5	12,000	54	<.01

Appendix II. Summary of water quality data: volatile organic compounds in ground-water beneath various land-use areas in central Florida

[W is the number of wells sampled. ND is the number of wells in which the constituent was detected. Concentrations are in micrograms per liter. The p-value is the probability that water-quality differences between the developed area and the control area could be due to chance, rather than a land-use effect. The p-values are from contingency-table analysis. FC, Upper Floridan aquifer in the control area; OR, Upper Floridan aquifer in the Orlando urban area; OC, Upper Floridan aquifer in the Ocala urban area; SC, surficial aquifer system in the control area; WM, surficial aquifer system in the Windermere citrus area; LW, surficial aquifer system in the Lake Wales citrus area; BT, surficial aquifer system in the Bartow mining area. <, less than specified value; --, control area - test for differences not applicable]

Compound	Study area	W	ND	Maximum concentration	Significance of water-quality differences: p-value
Benzene					
	FC	9	0	<.2	--
	OR	16	6	86	..06
	OC	9	0	<.2	.99
	SC	10	0	<.2	
	WM	16	0	<.2	.99
	LW	11	0	<.2	.99
	BT	12	2	3.3	.48
Chlorobenzene					
	FC	9	0	<.2	--
	OR	16	2	.7	.52
	OC	9	0	<.2	.99
	SC	10	0	<.2	--
	WM	16	0	<.2	.99
	LW	11	0	<.2	.99
	BT	12	l	1.3	.99
Chloroform					
	FC	9	2	2	--
	OR	16	0	<.2	.12
	OC	9	3	.5	.99
	SC	10	3	3.1	--
	WM	16	2	1.4	.34
	LW	11	10	17	<.01
	BT	12	0	<.2	.08
Chlorodibromomethane					
	FC	9	0	<.2	--
	OR	16	0	<.2	.99
	OC	9	0	<.2	.99
	SC	l0	0	<.2	--
	WM	16	0	<.2	.99
	LW	11	5	.9	.04
	BT	12	0	<.2	.99
Dichlorobromomethane					
	FC	9	0	<0.2	--
	OR	16	0	<.2	0.99
	OC	9	0	<.2	.99
	SC	10	0	<.2	--
	WM	16	2	.9	.51
	LW	11	8	2.7	<.01
	BT	12	0	<.2	.99

Appendix II. Summary of water quality data: volatile organic compounds in ground-water beneath various land-use areas in central Florida—Continued

[W is the number of wells sampled. ND is the number of wells in which the constituent was detected. Concentrations are in micrograms per liter. The p-value is the probability that water-quality differences between the developed area and the control area could be due to chance, rather than a land-use effect. The p-values are from contingency-table analysis. FC, Upper Floridan aquifer in the control area; OR, Upper Floridan aquifer in the Orlando urban area; OC, Upper Floridan aquifer in the Ocala urban area; SC, surficial aquifer system in the control area; WM, surficial aquifer system in the Windermere citrus area; LW, surficial aquifer system in the Lake Wales citrus area; BT, surficial aquifer system in the Bartow mining area. <, less than specified value; --, control area - test for differences not applicable]

Compound	Study area	W	ND	Maximum concentration	Significance of water-quality differences: p-value
l, 2-Dichloroethane					
	FC	9	0	<.2	--
	OR	16	0	<.2	.99
	OC	9	0	<.2	.99
	SC	10	0	<.2	--
	WM	16	0	<.2	.99
	LW	11	0	<.2	.99
	BT	12	1	.2	.99
1,.4-Dichlorobenzene					
	FC	9	0	<.2	--
	OR	16	l	5.7	.99
	OC	9	0	<.2	.99
	SC	10	0	<.2	--
	WM	16	0	<.2	.99
	LW	11	0	<.2	.99
	BT	12	1	.8	.99
Dichlorodifluoromethane					
	FC	9	0	<.2	--
	OR	16	1	.5	.99
	OC	9	0	<.2	.99
	SC	10	1	.2	--
	WM	16	0	<.2	.99
	LW	11	0	<.2	.99
	BT	12	0	<.2	.99
Tetrachloroethylene					
	FC	9	0	<.2	--
	OR	16	0	<.2	.99
	OC	9	1	.2	.99
	SC	10	0	<.2	--
	WM	16	0	<.2	.99
	LW	11	0	<.2	.99
	BT	12	0	<.2	.99
1.1.1-Trichloroethane					
	FC	9	0	<.2	--
	OR	16	l	.2	.99
	OC	9	0	<.2	.99
	SC	10	0	<.2	--
	WM	16	0	<.2	.99
	LK	11	0	<.2	.99
	BT	12	0	<.2	.99

Appendix II. Summary of water quality data: volatile organic compounds in ground-water beneath various land-use areas in central Florida—Continued

[W is the number of wells sampled. ND is the number of wells in which the constituent was detected. Concentrations are in micrograms per liter. The p-value is the probability that water-quality differences between the developed area and the control area could be due to chance, rather than a land-use effect. The p-values are from contingency-table analysis. FC, Upper Floridan aquifer in the control area; OR, Upper Floridan aquifer in the Orlando urban area; OC, Upper Floridan aquifer in the Ocala urban area; SC, surficial aquifer system in the control area; WM, surficial aquifer system in the Windermere citrus area; LW, surficial aquifer system in the Lake Wales citrus area; BT, surficial aquifer system in the Bartow mining area. <, less than specified value; --, control area - test for differences not applicable]

Compound	Study area	W	ND	Maximum concentration	Significance of water-quality differences: p-value
1. 2-trans-Dich1oroethene					
	FC	9	0	<.2	--
	OR	16	2	1.0	.52
	OC	9	0	<.2	.99
	SC	10	0	<.2	--
	WM	16	0	<.2	.99
	LW	11	0	<.2	.99
	BT	12	1	.3	.99
Trichloroethylene					
	FC	9	l	.9	--
	OR	16	1	.2	.99
	OC	9	0	<.2	.99
	SC	10	0	<.2	--
	WM	16	0	<.2	.99
	LW	11	0	<.2	.99
	BT	12	3	.3	.22
Toluene					
	FC	9	3	3.9	--
	OR	16	l	.2	.12
	OC	9	1	.2	.58
	SC	10	0	<.2	--
	WM	16	1	.3	.99
	LW	11	0	<.2	.99
	BT	12	5	5.5	.04
Trichlorofluoromethane					
	FC	9	2	1.0	--
	OR	16	0	<.2	.12
	OC	9	0	<.2	.47
	SC	10	1	.6	--
	WM	16	0	<.2	.38
	LW	11	0	<.2	.48
	BT	12	0	<.2	.45
Vinyl chloride					
	FC	9	0	<.2	--
	OR	16	1	3.6	.99
	OC	9	0	<.2	.99
	SC	10	0	<.2	--
	WM	16	0	<.2	.99
	LW	11	2	.3	.48
	BT	12	2	1.6	.48

Appendix III. Summary of pesticides concentrations in ground water beneath various land-use areas in central Florida

[W is the number of wells sampled. ND is the number of wells in which the constituent was detected. Concentrations are in micrograms per liter. The p-value is the probability that water-quality differences between the developed area and the control area could be due to chance, rather than a land-use effect. The p-values are from contingency-table analysis. FC, Upper Floridan aquifer in the control area; OR, Upper Floridan aquifer in the Orlando urban area; OC, Upper Floridan aquifer in the Ocala urban area; SC, surficial aquifer system in the control area; WM, surficial aquifer system in the Windermere citrus area; LW, surficial aquifer system in the Lake Wales citrus area; BT, surficial aquifer system in the Bartow mining area. <, less than specified value; --, control area - test for differences not applicable]

Compound	Study area	W	ND	Maximum concentration	Significance of water-quality differences: p-value
Diazinon					
	FC	10	0	<0.01	--
	OR	20	2	.01	.54
	OC	11	1	.02	.99
	SC	8	5	.04	--
	WM	17	7	.05	.41
	LW	12	0	<.01	<.01
	BT	11	7	.08	.99
Chloypyrifos					
	SC	8	0	<.01	--
	WM	19	1	.05	.99
	LW	12	1	.12	.99
Simazine					
	FC	3	0	<.01	--
	OR	8	2	.1	.99
	SC	10	0	<.01	--
	WM	24	5	.87	.29
	LW	12	1	.34	.99
	BT	10	0	<.01	.99
Prometryne					
	SC	8	0	<.1	--
	WM	18	1	.1	.99
	LW	12	0	<.1	.99
	BT	10	0	<.1	.99
Prometone					
	SC	8	0	<.1	--
	WM	18	0	<.1	.99
	BT	10	1	.1	.99
Bromacil					
	SC	8	0	<.1	--
	WM	19	12	22	<.0l
	LW	12	8	25	<.01
Fenamiphos					
	SC	8	0	<.01	--
	WM	19	3	.05	.53
	LW	12	0	<.0l	.99
Endrin aldehyde					
	SC	8	0	<.01	--
	WM	19	1	.02	.99
	LW	12	0	<.01	.99

Appendix III. Summary of pesticides concentrations in ground water beneath various land-use areas in central Florida—Continued

[W is the number of wells sampled. ND is the number of wells in which the constituent was detected. Concentrations are in micrograms per liter. The p-value is the probability that water-quality differences between the developed area and the control area could be due to chance, rather than a land-use effect. The p-values are from contingency-table analysis. FC, Upper Floridan aquifer in the control area; OR, Upper Floridan aquifer in the Orlando urban area; OC, Upper Floridan aquifer in the Ocala urban area; SC, surficial aquifer system in the control area; WM, surficial aquifer system in the Windermere citrus area; LW, surficial aquifer system in the Lake Wales citrus area; BT, surficial aquifer system in the Bartow mining area. <, less than specified value; --, control area - test for differences not applicable]

Compound	Study area	W	ND	Maximum concentration	Significance of water-quality differences: p-value
1,2-dibromo-3-chloro-propane (DBCP)					
	SC	8	0	<.01	--
	WM	19	3	.14	.53
	LW	12	0	<.01	.99
Dichloro-diphenyl-trichloroethane (DDT)					
	SC	8	0	<.0l	--
	WM	19	3	.2	.53
	LW	12	0	<.01	.99
2.4-DP					
	SC	10	0	<.01	--
	WM	9	0	<.01	.99
	BT	11	2	<.05	.48
Aldicarb sulfoxide					
	SC	9	0	<.5	--
	WM	18	3	l. 6	.53
	LW	l2	0	<.5	.99
Aldicarb sulfone					
	SC	9	0	<.5	--
	WM	18	3	4.l	.53
	LW	12	4	1.7	.10
Silvex					
	FC	10	0	<.01	--
	OR	20	2	.15	.54

Appendix IV. Summary of trace element concentrations in ground water beneath various land-use areas in central Florida

[W is the number of wells sampled. ND is the number of wells in which the constituent was detected. Minimum, median, and maximum are in micrograms per liter. The p-value is the probability that water-quality differences between the developed area and the control area could be due to chance, rather than a land-use effect. The p-values are from contingency-table analysis, unless less than 20 percent of the sample values are censored; then the p-values are from Mann-Whitney analysis and are in parentheses. FC, Upper Floridan aquifer in the control area; OR, Upper Floridan aquifer in the Orlando urban area; OC, Upper Floridan aquifer in the Ocala urban area; SC, surficial aquifer system in the control area; WM, surficial aquifer system in the Windermere citrus area; LW, surficial aquifer system in the Lake Wales citrus area; BT, surficial aquifer system in the Bartow mining area. <, less than specified value; - -, control area - test for differences not applicable]

Trace element	Study area	W	ND	Minimum	Maximum	Median	Significance of water-quality differences: p-value
Arsenic							
	FC	10	0	<l	<1	<l	--
	OR	23	6	<l	13	<l	.14
	SC	17	1	<l	2	<l	--
	WM	25	1	<l	4	<l	.99
	BT	34	18	<l	66	1	<.01
Cadmium							
	FC	10	3	<1	5	<l	--
	OR	23	11	<1	19	<1	.45
	SC	17	6	<l	2	<l	--
	WM	26	10	<1	2	<1	.99
	BT	34	12	<1	4	<l	.99
Chromium							
	FC	10	4	<10	20	<10	--
	OR	26	9	<10	40	<10	.99
	SC	17	5	<10	50	<10	--
	WM	26	10	<10	100	<l0	.75
	BT	34	17	<10	160	<10	.23
Copper							
	FC	10	8	<l	14	2	--
	OR	23	22	<1	90	5	(.19)
	SC	17	17	1	14	3	--
	WM	26	25	<l	51	4	(.22)
	BT	34	31	<l	70	2	(.50)
Iron							
	FC	10	10	30	1,300	250	--
	OR	26	26	30	17,000	160	(.65)
	SC	17	17	10	3,800	50	--
	WM	26	26	20	3,800	120	(.84)
	BT	34	34	60	105,000	6,700	(<.01)
Lead							
	FC	11	2	<5	10	<5	--
	OR	26	10	<5	43	<5	.28
	SC	16	1	<5	6	<5	--
	WM	26	5	<5	21	<5	.38
	BT	34	6	<5	70	<5	.41

Appendix IV. Summary of trace element concentrations in ground water beneath various land-use areas in central Florida—Continued

[W is the number of wells sampled. ND is the number of wells in which the constituent was detected. Minimum, median, and maximum are in micrograms per liter. The p-value is the probability that water-quality differences between the developed area and the control area could be due to chance, rather than a land-use effect. The p-values are from contingency-table analysis, unless less than 20 percent of the sample values are censored; then the p-values are from Mann-Whitney analysis and are in parentheses. FC, Upper Floridan aquifer in the control area; OR, Upper Floridan aquifer in the Orlando urban area; OC, Upper Floridan aquifer in the Ocala urban area; SC, surficial aquifer system in the control area; WM, surficial aquifer system in the Windermere citrus area; LW, surficial aquifer system in the Lake Wales citrus area; BT, surficial aquifer system in the Bartow mining area. <, less than specified value; - -, control area - test for differences not applicable]

Trace element	Study area	W	ND	Minimum	Maximum	Median	Significance of water-quality differences: p-value
Manganese							
	FC	10	7	<10	20	--	--
	OR	26	17	<10	40	10	.99
	SC	17	7	<l0	30	<0	--
	WM	26	21	<10	280	20	.01
	BT	34	33	<10	2,500	75	<.01
Silver							
	FC	8	0	<1	<l	<l	--
	OR	16	3	<1	9	<1	.53
	SC	8	5	<1	l	1	--
	WM	15	l	<l	l	<l	<.01
	BT	23	1	<l	2	<l	<.01
Selenium							
	FC	10	0	<1	<l	<1	--
	OR	23	1	<1	2	<l	.99
	SC	17	1l	<1	l	<l	--
	WM	26	4	<1	9	<l	.63
	BT	34	1	<l	l	<l	.99
Zinc							
	FC	10	9	<10	26	25	--
	OR	26	18	<10	49	20	.39
	SC	17	13	<10	0	10	--
	WM	26	22	<10	1000	15	(.10)
	BT	34	31	<10	11	20	(<.01)