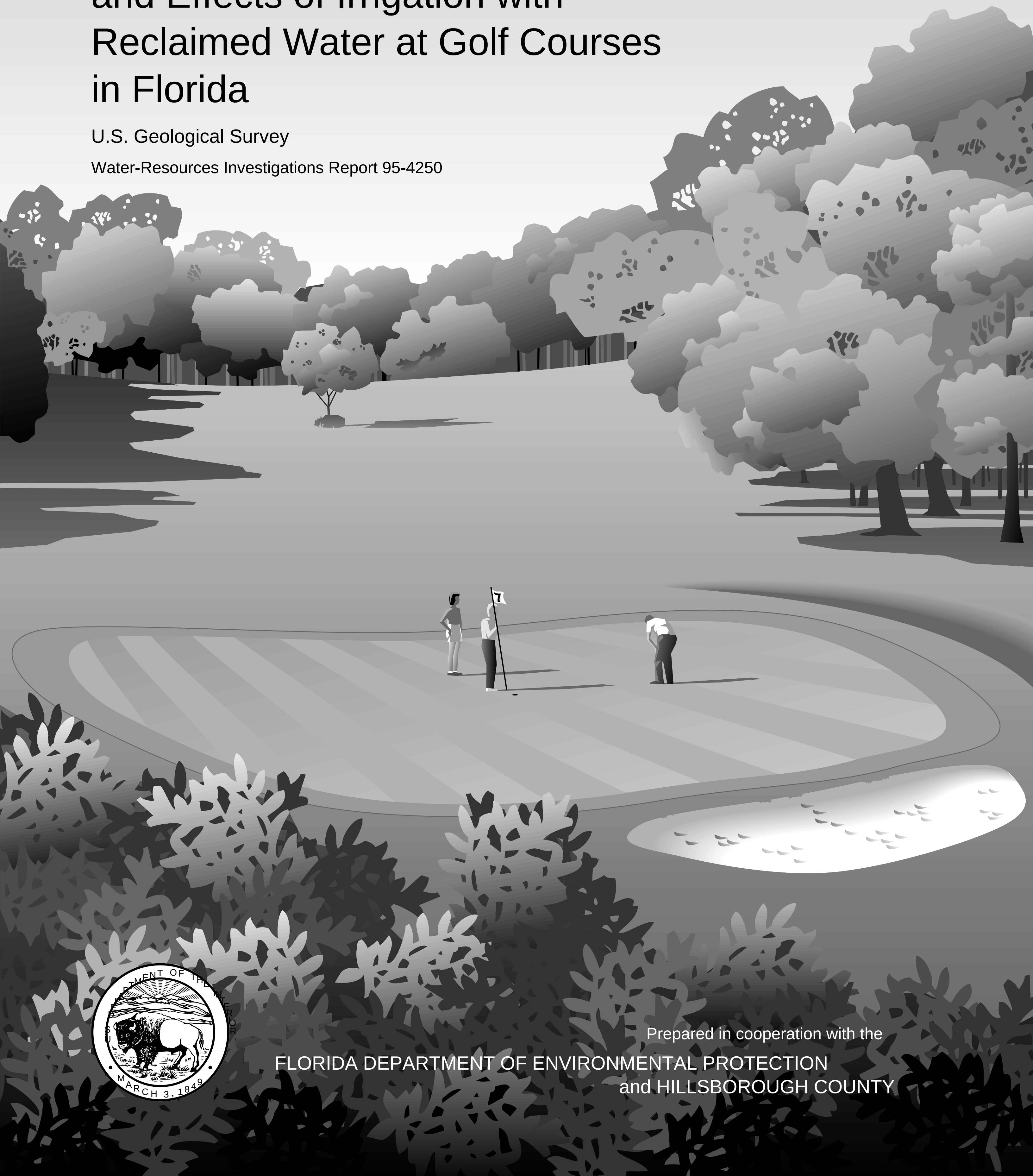
Water Quality, Pesticide Occurrence, and Effects of Irrigation with Reclaimed Water at Golf Courses in Florida

U.S. Geological Survey

Water-Resources Investigations Report 95-4250



Prepared in cooperation with the

FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION
and HILLSBOROUGH COUNTY

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Tallahassee, Florida
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ABBREVIATED WATER-QUALITY UNITS

µS/cm	microsiemens per centimeter at 25 degrees Celsius
mg/L	milligrams per liter
µg/L	micrograms per liter

ACRONYMS

DO	Dissolved oxygen
DOC	Dissolved organic carbon
FDEP	Florida Department of Environmental Protection
GC	Guidance concentration
IFAS	Institute of Food and Agricultural Sciences
MBAS	Methylene blue active substances
MCL	Maximum contaminant level
MDL	Method detection limit
MSMA	Monosodium methanearsonate
NAS	Naval Air Station
NTU	Nephelometric turbidity unit
PQL	Practical quantitation limit
TDS	Total dissolved solids
USGS	U.S. Geological Survey
WTP	Wastewater treatment plant

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Abstract

Reuse of treated wastewater for golf course irrigation is an increasingly popular water management option in Florida, where growth has put stress on potable water supplies. Surface water, ground water, and irrigation water were sampled at three pairs of golf courses quarterly for one year to determine if pesticides were present, and the effect of irrigation with treated effluent on ground-water quality, with an emphasis on interactions of effluent with pesticides. In addition to the six paired golf courses, which were in central Florida, ground water was sampled for pesticides and other constituents at three more golf courses in other parts of the State. This study was the first to analyze water samples from Florida golf courses for a broad range of pesticides.

Statistical methods based on the percentage of data above detection limits were used to determine the effects of irrigation with reclaimed water on ground-water quality. Shallow ground water at golf courses irrigated with treated effluent has higher concentrations of chloride, lower concentrations of bicarbonate, and lower pH than ground water at golf courses irrigated with water from carbonate aquifers. There were no statistically significant differences in nutrient concentrations in ground water between paired golf courses grouped by irrigation water type at a 95 percent confidence level. The number of wells where pesticides occurred was significantly higher at the paired golf courses using ground water for irrigation than at ones using reclaimed water. However, the limited occurrences of individual pesticides in ground water make it difficult to correlate differences in irrigation-water quality with pesticide migration to the water table. At some of the golf courses, increased pesticide occurrences may be associated with higher irrigation rates, the presence of well-drained soils, and shallow depths to the surficial aquifer.

Pesticides used by golf courses for turf grass maintenance were detected in ground water on seven of nine golf courses studied and in 52 percent of ground-water samples. Concentrations of pesticides in ground water at golf courses were generally low relative to regulatory guidelines, with 45 percent of all occurrences at trace levels and 92 percent under the maximum contaminant level or guidance concentration. Two of the nine golf courses had no pesticides detected in ground water, and a third had only two occurrences, which were at trace levels. There were six occurrences of concentrations of arsenic, bentazon, or acephate in ground water above the maximum contaminant level or guidance concentration. Additionally, the following pesticides were detected in ground water from at least one site: atrazine, bromacil, diazinon, diuron, fenamiphos, metalaxyl, oxydiazon, and simazine. The fenamiphos metabolites, fenamiphos sulfoxide and fenamiphos sulfone, also were detected in ground water.

Samples from wastewater treatment plants contained trace levels of atrazine, bromacil, and gamma-BHC (Lindane). Concentrations of pesticides in golf course ponds were generally low,

with 60 percent of all occurrences at trace levels. All but one of the pond samples collected during the study contained at least one pesticide. The most commonly occurring pesticides in golf course ponds were: atrazine, fenamiphos and fenamiphos sulfoxide, and diuron.

INTRODUCTION

Because of the increasing population of Florida and a period of deficit rainfall over many parts of the state during the 1980's and early 1990's, locating new sources of potable water has become a growing concern. Conservation and reuse are becoming critical components of water-management strategies. Reuse of treated wastewater for irrigation is one practical way to reduce the need for new sources.

In 1993, there were more than 1,000 golf courses in Florida. Water use at golf courses is highly variable, but it is not unusual for a golf course having 50 irrigated acres in central Florida to use an average of over 100,000 gallons of water each day for irrigation. The consistently high year-round water use and proximity to urban areas make golf courses excellent potential users of reclaimed water. Secondarily treated wastewater also provides a source of nitrogen-rich irrigation water to golf courses, reducing the need to apply additional fertilizer, and also reducing potential nutrient loading to receiving streams and estuaries.

The interaction of effluent and pesticides used on golf courses has not been previously evaluated. However, evidence from studies in related areas indicates that the effluent could either reduce pesticide leaching by increasing the retention and degradation, or it could increase leaching by increasing mobility. The particulate fraction of the effluent may decrease leaching potential by increasing soil microbial populations (Seaker and Sopper, 1988, a, b), but the presence of dissolved humic acids, fulvic acids, and surfactants may increase solubility and lead to increased leaching potential (Chiou and others, 1987, Lee and Farmer, 1989). The chemistry of a particular pesticide determines which process occurs.

The leaching potential of pesticides is partly controlled by the environment in which the pesticides are applied. Soil characteristics that enhance leaching potential include sandy soil, relatively shallow zone of maximum biological activity, low average water content, and high drainage rate (Jury and others, 1987). These soil characteristics describe the general conditions in many parts of Florida.

Pesticide leaching on golf courses also may be enhanced by management practices. To maintain year-round favorable appearance and playing conditions, turf grass is likely to receive a greater amount and variety of pesticides than most agricultural crops. To protect water resources, water managers need information on pesticide occurrence in water at golf courses using both potable and reclaimed water for irrigation.

Purpose and Scope

This report describes the results of a 4 1/2-year study of pesticide occurrence in ground water, surface water, and irrigation water on golf courses in Florida. The specific objectives of this study were to: 1) determine if pesticides used for turf-grass management at golf courses in Florida are migrating to shallow ground water, and 2) evaluate the effect of municipal reclaimed water on leaching potential by examining mechanisms of interaction between effluent and selected pesticides.

The report describes water quality at nine golf courses, in a total of 39 shallow wells or drive points, three irrigation systems, six golf course ponds, two reclaimed water-storage ponds and three wastewater-treatment plants. Types of analyses include pesticides, major ions, nutrients, and trace elements. Information on hydrogeology, pesticide use and water use also are presented. This report contains a statistical analysis of the effects of irrigation with reclaimed water on ground-water quality and pesticide occurrence.

Previous Studies

Previous research on the agricultural implications of land application of effluent has concentrated in three areas: the influence of the effluent on the plant nutrient supply, the addition of heavy metals to the plant-soil system, and the addition of pathogens to the environment (Foster and Engelbrecht, 1973; Kardos and Sopper, 1973; Hossner and others, 1978; Weaver and others, 1978; Sheikh and others, 1985; Fitzpatrick and others, 1986).

The particulate organic compounds present in effluent can decrease leaching potential by stabilizing soil microbial populations. Seaker and Sopper (1988a, 1988b) monitored surface-mine spoil which had been amended previously with sewage sludge during one season; they reported changes in the numbers and types of microorganisms and increases in soil organic carbon.

Leaching potential of pesticides can be decreased by adsorption to particulate organic compounds. Houzim and others (1986) listed adsorption by soil organic matter as a key factor in the evaluation of the leaching potential of pesticides. They concluded that adsorption by organic matter occurred in 13 major groups of pesticides.

The soluble components of the effluent could increase leaching potential by contributing to increased aqueous solubility of pesticides in the soil system. Sewage effluent contains a variety of soluble compounds, including humic and fulvic acids, and surfactants (Hunter and Kotalik, 1973). Several researchers have concluded that soluble humic and fulvic acids derived from soil organic matter bind to pesticides, thus increasing solubility, although the chemistry of the binding was unclear (Chiou and others, 1986; Madhun and others, 1986; Chiou and others, 1987; Lee and Farmer, 1989). Humic and fulvic acids present in effluent could also bind pesticides which would result in an increased potential for mobility of the pesticide in the soil. Other compounds in the effluent might also cause an increase in pesticide solubility. Kile and Chiou (1989) noted an increase in the water solubility of DDT in the presence of three industrial surfactants.

Jury and others (1987) selected soil criteria that represent a potentially high leaching condition to be used in a qualitative model for screening pesticides. Other attempts to determine the fate of pesticides in the environment using available data on chemical and soil properties include the PRZM model (Carsel and others, 1984), its upgraded version, RUSTIC (Dean and others, 1989), the CREAMS/GLEAMS model developed by the U.S. Department of Agriculture (Leonard and others, 1987), and the GUS screening technique (Gustafson, 1993).

The leaching of pesticides that were applied to four golf courses in Cape Cod was described by Cohen and others (1990). They detected eight pesticides and pesticide metabolites as well as two pesticide impurities in the ground water; however, only chlordane/heptachlor was present in toxicologically significant levels. In the Cape Cod study, Cohen and others (1990) found more pesticides in water from monitor wells associated with greens and tees than fairways. They concluded that for the hydrologic conditions at their study sites, the use of turf pesticides applied in the Cape Cod area had minimal impact on ground-water quality. Cohen and others (1990) also recommended that this type of study be repeated in other areas, especially in southern climates where more nematicides are applied to turf.

The United States Golf Association funds studies on turf management and pesticide mobility at universities around the country. Recent publications related to pesticides include those by Watschke amd Mumma (1989), Branham and others (1993), and Smith and Tillotson (1993).

Turf grass research done at the University of Florida’s Institute of Food and Agricultural Sciences (IFAS) is critical to understanding the behavior of pesticides in the unique environment of Florida. Although the majority of this work is done at controlled experimental sites, researchers at the University of Florida are conducting field-scale experiments on the mobility of pesticides on a golf course green in south Florida (Snyder and Cisar, 1993).

Unpublished data collected by the Florida Department of Environmental Protection at a golf course in West Palm Beach indicated no instances of ground water contamination by pesticides, but a smaller number of pesticides was analyzed compared to this study, and wells were installed at greater depths (D. Tterlikkis, FDEP, oral commun., 1994).

Other related publications in Florida include an investigation of potential water-quality effects of golf course maintenance in the basin contributing to Sarasota Bay (Camp Dresser and McKee, 1992). U.S. Geological Survey reports describing the effects of land application systems on water quality in Florida include those by Pruitt and others (1985), Yurewicz and Rosenau (1986), and Trommer (1992). Statistical methods were used by German (in press) to determine the effects of different land-uses on ground-water quality.

Acknowledgments

This project would not have been possible without the assistance of the golf course superintendents and owners who were willing to participate in the study. Special thanks to Bill Moore of Buckhorn Springs Golf and Country Club in Valrico, Joe Sittinger of Pebble Creek Golf and Country Club in Tampa, Gary Smitter and Larry Edwards of Meadows

Golf and Country Club in Sarasota, Joe Ondo of Winter Pines Golf Course in Winter Park, Don McCommon and Lou Dolan of Ventura Country Club in Orlando, Damien Loughran of Bonaventure Country Club in Fort Lauderdale, Chuck Rettew and Jim Cain of Pensacola Naval Air Station Golf Course, and Pierre Grimm of Skiing Paradise/Swiss Fairways in Clermont. The Florida Turfgrass Association provided assistance for a questionnaire on pesticide and fertilizer use. Thanks also are given to Kato MacDonald of Winter Park Estates Treatment Plant, Ken Stanczykowski of Valrico Wastewater Treatment Plant, Mike Miller and John Czahoroski of Meadowoods Utilities in Sarasota, and all the golf course maintenance people who provided assistance throughout the study.

Approach

Three pairs of golf courses were selected to determine the effect of irrigation with reclaimed water on pesticide leaching. Each pair consisted of one golf course using ground water for irrigation and one using reclaimed water. Pairs were located in the same area and had similar pesticide use. A questionnaire on pesticide use was designed and sent out to 265 golf courses in central Florida. Response to the questionnaire was poor, and individual contacts with golf course superintendents were necessary to locate golf courses willing to participate in the study.

Selected golf course pairs were Buckhorn Springs Golf and Country Club and Pebble Creek Golf and Country Club in Hillsborough County, the Groves and Highlands golf courses in Sarasota County, and Winter Pines Golf Course and Ventura Country Club in Orange County (fig. 1). Of these six golf courses, Buckhorn Springs, Groves, and Winter Pines use treated effluent for irrigation. Paired golf courses were selected to have similar hydrologic settings, but because of difficulty finding golf courses willing to cooperate, some compromises were necessary. For example, golf courses in Hillsborough County have different hydrologic settings; Pebble Creek is part of a broad flood plain with cypress swamps, while Buckhorn Springs is part of a higher sand ridge and karst terraine. Because the alternative would have been to select golf courses with similar settings but different pesticide use, the decision was made that pesticide use was the primary consideration. The two paired golf courses in Sarasota County (Groves and Highlands) provide the best comparison based on differences in irrigation type because they are adjacent and managed by the same superintendent. Other than type of irrigation water, these two courses are nearly identical. The golf courses in Orange County are in similar hydrologic settings, but Winter Pines is older.

The first step in the analysis is to determine whether significant differences exist between shallow ground waters on golf courses with different irrigation sources. Secondly, can these differences be attributable to irrigation water type, or other factors? If differences in ground-water quality are similar to differences in irrigation water quality, a cause and effect relation can be established. To determine whether these differences affect pesticide occurrences, differences in frequency of pesticide occurrences at golf courses with different types of irrigation must be established. Once these are established, a mechanism for the interaction must also be determined if the irrigation factor is to account for the differences in pesticide occurrence. In this study, statistical methods were used to quantify relations between water quality constituents and irrigation types.

Three additional golf courses were added to the study in the second year to obtain data on pesticides in ground water in other parts of the State. The three additional golf courses, referred to as the statewide courses, were Bonaventure Country Club in Broward County, Pensacola Naval Air Station Golf Course in Escambia County, and Skiing Paradise golf course in Lake County. The statewide golf courses all use ground water for irrigation.

Four wells or drive points were installed at each of the paired golf courses, with two wells or drive points located near greens and two near tees. Drive points are very small wells, consisting of stainless steel slotted well points (4-in. long by 3/16-in. diameter) threaded to teflon tubing. A fifth well was added at each of the three statewide courses in the maintenance area where pesticides are mixed and loaded before application. Existing golf course monitor wells were used if they were in suitable locations. Although information on existing well construction was not always available, these wells were finished at the surface using appropriate methods for monitor well installation (ie., locked caps, well protectors and concrete pads).

Drive points rather than wells were installed with difficulty at Pebble Creek and Buckhorn Springs

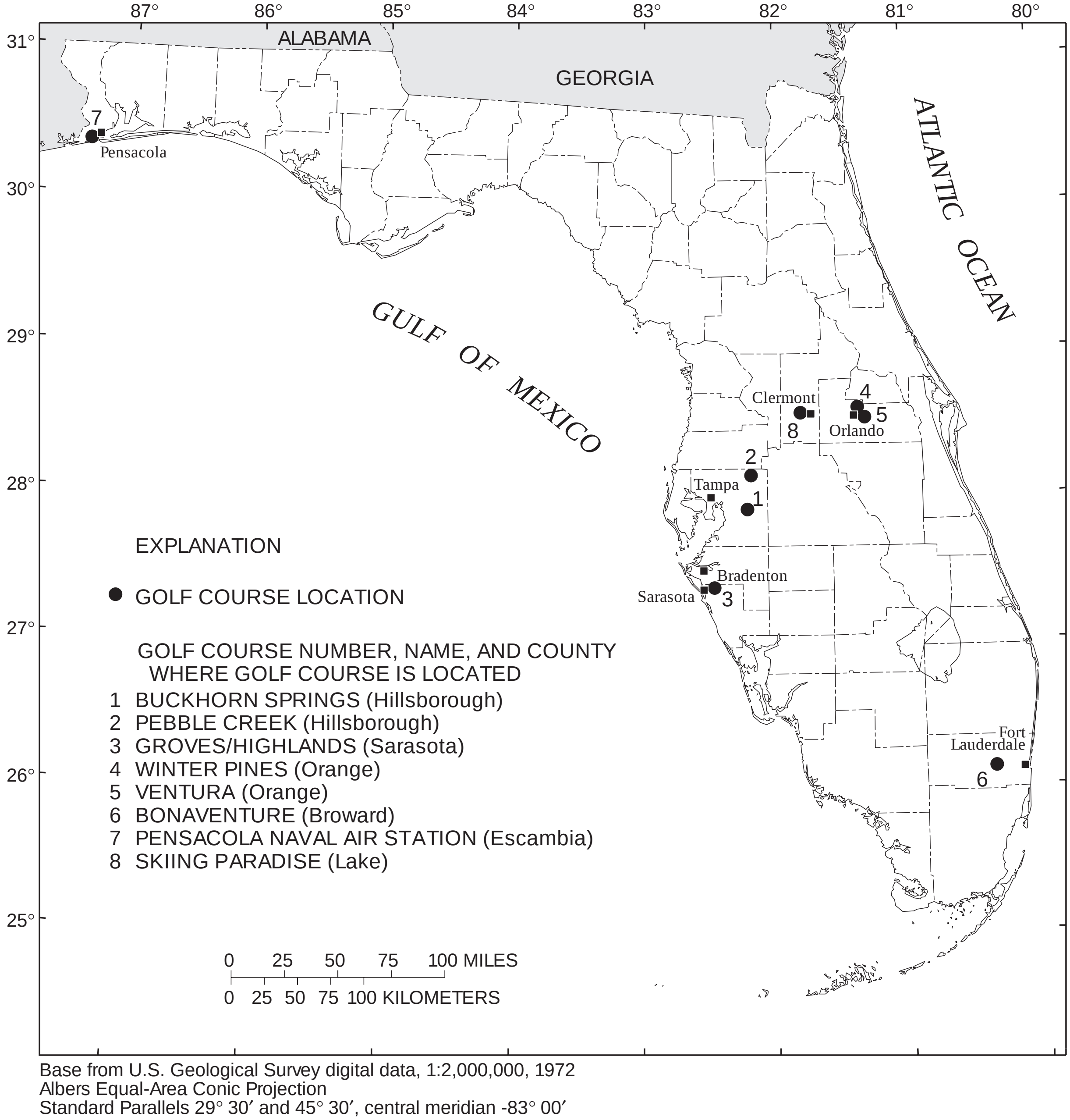

Figure 1. Location of golf courses participating in the study.

golf courses, but it was determined that installation of drive points would not be possible in the fine-grained sediments encountered at other courses. The drive points were placed below the water table in a pre-driven hole using a hollow steel rod and a power hammer. Drive points were initially thought to be preferable to wells because installation was expected to be easier, and they are less disruptive to the subsurface because of the smaller hole diameter. Although drive points cover a smaller zone of contribution compared with wells, water from the two types of sampling points are considered equally representative of the surficial aquifer.

A list of sampling sites including well names and depths is given in table 1. Site codes listed in table 1 reflect the location of the well on the golf course relative to the nearest tee, green, or fairway. For example, the site code PC13G is the well near the 13th green at Pebble Creek golf course. Location maps of individual golf courses are provided in the section on site descriptions.

Table 1. Sampling site information

[na, not applicable; PVC, polyvinyl chloride; --, unknown]

Name	Site Code	Latitude-longitude	Type	Material	Depth (feet)	Screen (feet)
PAIRED GOLF COURSES						
Buckhorn Springs Golf Course						
Buckhorn Springs 3 Green	BH3G	2754200821457	drive point	teflon/SS [1]	12	0.12
Buckhorn Springs 3 Tee	BH3T	2754270821507	drive point	do.	11	.12
Buckhorn Springs 7 Green	BH7G	2754330821459	drive point	do.	10	.12
Buckhorn Springs 7 Tee	BH7T	2754320821443	drive point	do.	12	.12
Buckhorn Springs Effluent Storage Pond	BHEFF	2754050821419	effluent pond	na	na	na
Valrico Wastewater Plant	VWP	2757470821349	plant effluent	na	na	na
Buckhorn Springs Pond	BHPD	2754220821456	pond	na	na	na
Pebble Creek Golf Course						
Pebble Creek 7 Tee	PC7T	2809070822031	well	2 in. PVC	10	3
Pebble Creek 8 Green	PC8G	2809140822050	drive point	teflon/SS[1]	7	.12
Pebble Creek 13 Green	PC13G	2808500822029	drive point	teflon/SS[1]	7	.12
Pebble Creek 16 Tee	PC16T	2808540822027	well	2 in. PVC	8	3
Pebble Creek Irrigation	PCFL	2809150822047	irrigation system	mixed	na	na
Pebble Creek Pond	PCPD	2808530822027	pond	na	na	na
Groves Golf Course						
Groves 2 Green	G2G	2721520822856	well	2 in. PVC	8	2.5
Groves 4 Tee	G4T	2721530822907	well	do.	8.5	2.5
Groves 5 Green	G5G	2721570822909	well	do.	8.5	2.5
Groves 18 Tee	G18T	2721480822905	well	do.	7	2.5
Groves Effluent Storage Pond	GEFF	2721230822849	effluent pond	na	na	na
Meadowoods Wastewater Plant	MWP	2720580822814	plant effluent	na	na	na
Groves Pond	GPD	2721530822906	pond	na	na	na
Highlands Golf Course						
Highlands 5 Tee	H5T	2722130822904	well	2 in. PVC	19	2.5
Highlands 6 Tee	H6T	2722240822903	well	do.	11	2.5
Highlands 7 Green	H7G	2722140822844	well	do.	10	2.5
Highlands 9 Green	H9G	2721580822846	well	do.	8	2.5
Highlands Irrigation	HFL	2721570822832	irrigation well	12 in. PVC	650	295
Highlands Pond	HPD	2722130822903	pond	na	na	na
Winter Pines						
Winter Pines 1 Green	W1G	2834590811839	well	2 in. PVC	9	2.5
Winter Pines 7 Tee	W7T	2834310811844	well	do.	13[2]	--
Winter Pines 12 Green	W12G	2834510811848	well	do.	14[2]	--
Winter Pines 18 Tee	W18T	2835050811855	well	do.	16[2]	--
Winter Park Estates Wastewater Plant	WEFF	2836220811845	treatment plant	na	na	na
Winter Pines Pond	WPD	2834310811852	pond	na	na	na
Ventura Golf Course						
Ventura 7 Tee	V7T	2830330811738	well	2 in. PVC	8	2.5
Ventura 9 Green	V9G	2830350811753	well	do.	11	2.5
Ventura 11 Green	V11G	2830450811739	well	do.	8	2.5
Ventura 18 Tee	V18T	2830360811802	well	do.	9	2.5
Ventura Irrigation	VFL	2830400811748	irrigation well	iron	370	186
Ventura Pond	VPD	2830450811740	pond	na	na	na

Table 1. Sampling site information—Continued

[na, not applicable; PVC, polyvinyl chloride; --, unknown]

Name	Site Code	Latitude-longitude	Type	Material	Depth (feet)	Screen (feet)
STATEWIDE GOLF COURSES						
Bonaventure Golf Course						
Bonaventure 2 Green	B2G	2607090802223	well	2 in. PVC	10	2.5
Bonaventure 7 Green	B7G	2607080802235	well	do.	11	2.5
Bonaventure 15 Green	B15G	2607240802246	well	do.	12	2.5
Bonaventure 17 Green	B17G	2607280802221	well	do.	9	2.5
Bonaventure Mix-load	BML	2607380802216	well	do.	29[2]	--
Pensacola Naval Air Station Golf Course						
Pensacola NAS 10 Green	N10G	3021400871643	well	4 in. PVC	30[2]	--
Pensacola NAS 14 Green	N14G	3021400871700	well	1.25 in.PVC	35	2.5
Pensacola NAS 14 Tee	N14T	3021490871652	well	do.	17	2.5
Pensacola NAS 16 Green	N16G	3021340871707	well	do.	25	2.5
Pensacola NAS Mix-load	NML	3021560871701	well	2 in. PVC	15	2.5
Skiing Paradise Golf Course						
Skiing Paradise 3 Tee	S3T	2832230814949	well	2 in. PVC	14	2.5
Skiing Paradise 4 Green	S4G	2832340814953	well	do.	9.5	2.5
Skiing Paradise 4 Tee	S4T	2832340814947	well	do.	7.5	2.5
Skiing Paradise 5 Frwy	S5F	2832310814951	well	do.	8	2.5
Skiing Paradise Mix-load	SML	2832180814920	well	do.	8	2.5

[1]3/16 in. teflon tubing and stainless steel drive point.

[2]Existing wells, depth measured with steel tape.

Well construction specifications were designed to prevent contamination from the land surface. Wells were installed to about 3 ft below the water table using the hollow-stem auger method. Because turf grass was considered to be a potential source of contamination, additional precautions were taken during drilling. A 1-foot deep by 2-foot diameter grass and soil plug was removed from each well site before placing the auger in the hole, and drill cuttings were collected on a sheet of plywood with a hole cut for the auger. Auger flights and all drilling equipment were pressure washed with hot water from a potable water supply before drilling and between holes. Flush-threaded schedule 40 polyvinyl chloride (PVC) was used for well casings and screens. A schematic diagram of well construction is shown in figure 2. Silica sand was placed next to the screen by slowly pouring sand down the annular space between the casing and the hollow stem as the auger was slowly withdrawn, up to a level approximately one foot above the top of the screen. The sand filter pack was followed by a fine sand annular seal, pre-hydrated high density bentonite grout, and a concrete pad and lockable well protector. Drive points were finished in the same manner as wells. Wells and drive points were developed by pumping with a peristaltic pump at the maximum pump rate or attainable yield for approximately one hour.

Water samples were collected quarterly for one year at most sampling sites and analyzed for the constituents listed in table 2. Major constituent groups are pesticides, major ions, trace elements, and nutrients. Samples at the paired golf courses were collected between May 1992 and March 1993, and samples at the statewide golf courses were collected between February 1993 and March 1994. A broad range of 41 pesticides that might be found in water samples from golf courses was analyzed. Water samples were analyzed at the Florida Department of Environmental Protection (FDEP) laboratory in Tallahassee, Fla., except for methylene blue active substance (MBAS), which was analyzed at the U.S. Geological Survey (USGS) laboratory in Ocala, Fla. Approximately 25 percent of the total number of samples were blanks or duplicates used for quality assurance.

Samples collected for pesticide analyses require a great deal of care and the use of special materials to prevent contamination. Ground-water samples for pesticide analyses were collected from wells or drive points through a teflon tube that remained in

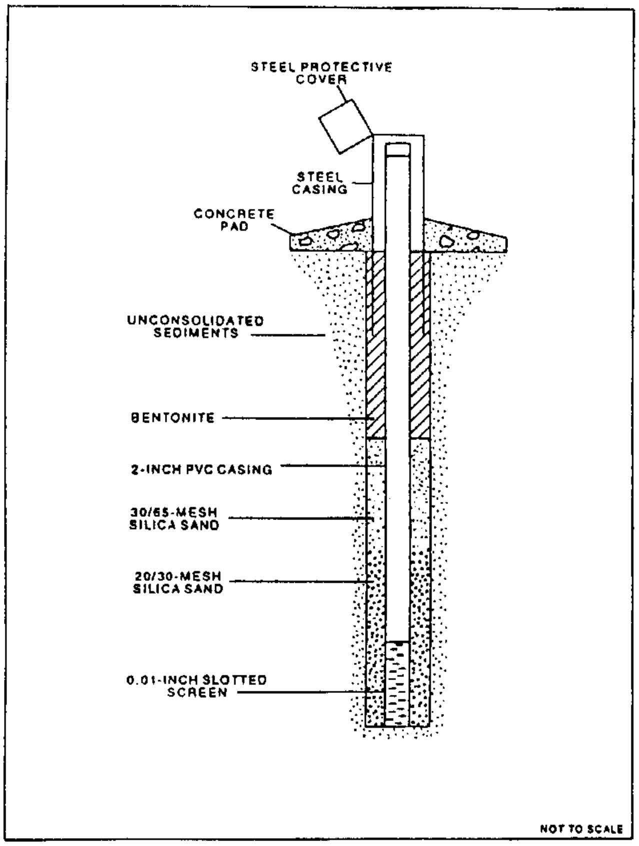

Figure 2. Schematic of typical well construction.

the well throughout the study. Samples were pulled into a 4-liter glass bottle with a vacuum applied by a peristaltic pump. Surface-water samples were collected a few inches below the surface in glass sample bottles held in a stainless steel basket sampler. Effluent samples were collected using either of the above methods, depending on accessibility. Cleaning procedures for sampling equipment and sample preservation were according to standard procedures documented in project quality assurance plans. Dissolved constituents were filtered through a high-capacity disposable in-line 0.45 micron nylon filter. Wells were pumped until pH, specific conductance, and temperature of water were stabilized between 5-min intervals. Field measurements were made for pH, specific conductance, dissolved oxygen, temperature, and alkalinity. Samples were shipped to the FDEP lab overnight.

Ancillary water-quality and water level data from monitor wells associated with golf courses using reclaimed water were gathered from local utilities. Utilities that provide reclaimed water for irrigation at golf courses are required to monitor the shallow ground water on or near the golf course as part of a ground-water monitoring plan associated with the reuse permit (Florida Department of State, 1990). For golf courses in this study that use reclaimed water, the appropriate utility collects and analyzes samples quarterly and provides the analytical data to FDEP, who checks it for compliance with regulatory standards. Data from the monitor wells associated with the courses using reclaimed water for irrigation for the study period are included as an appendix.

DESCRIPTION OF STUDY AREAS

Florida has a generally humid subtropical climate, but weather varies considerably in different parts of the state. The six paired sites and Skiing Paradise site are located in central Florida (fig. 1). The average annual temperature in central Florida is about 72 ^{o}F, and average annual rainfall in this area for the period 1961-90 varied from 43.92 inches (in.) in Tampa to 52.27 in. in Bradenton (National Oceanic and Atmospheric Administration, 1994). Rainfall across central Florida averaged 62.76 in., or 17 percent above normal, during the study period (April 1992-March 1993) for the paired sites. While the majority of stations had above average rainfall for the period, most of this excess was due to the very heavy rains that occurred in south-central Florida during late June 1992. This heavy rain affected the Sarasota County paired golf course sites more than the other central Florida sites, with rainfall at the nearby Bradenton station about 17 in. for the final week in June of 1992.

The two remaining sites are at the farthest reaches of the state, in Pensacola in the northwest, and in Fort Lauderdale near the southeast coast. Pensacola has a much cooler and wetter climate than peninsular Florida, with an annual average temperature of 68 ^{o}F and average annual rainfall for the period 1961-90 of 62.25 in. (National Oceanic and Atmospheric Administration, 1994). Rainfall during the sampling period (February 1993-February 1994) was 63.47 in., 6 percent below normal. Fort Lauderdale has an annual average temperature of 75 ^{o}F, and average annual rainfall for the period 1961-90 of 59.34 in.(National Oceanic and Atmospheric Administration, 1994). Rainfall during the sampling period (February 1993-March 1994) was 68.64 in., 10 percent above normal. Monthly rainfall data for all sites are listed in table 3.

Table 2. Chemical constituents analyzed for the study

[MDL, minimum detection limit; mg/L, milligrams per liter; µg/L, micrograms per liter; Note: accuracy is calculated as percent recovery according to methods described in FDEP (1993)]

Constituent	MDL		Accuracy (percent)
DISSOLVED CONSTITUENTS			
Nutrients and organic carbon			
Organic carbon	1	mg/L	80-120
Ammonia-N	0.01	mg/L	do.
Nitrate plus nitrite-N	.02	mg/L	do.
Organic Nitrogen	.05	mg/L	do.
Phosphorus	.02	mg/L	do.
Ortho-Phosphate as P	.02	mg/L	do.
Trace elements			
Aluminum	50	µg/L	do.
Antimony	3	µg/L	do.
Arsenic	1	µg/L	do.
Beryllium	0.5	µg/L	do.
Cadmium	3	µg/L	do.
Chromium	10	µg/L	do.
Copper	5	µg/L	do.
Iron	3	µg/L	do.
Lead	1	µg/L	do.
Manganese	1	µg/L	do.
Mercury	.1	µg/L	do.
Molybdenum	2	µg/L	do.
Selenium	1	µg/L	do.
Strontium	3	µg/L	do.
Thallium	50	µg/L	do.
Vanadium	3	µg/L	do.
Zinc	5	µg/L	do.
Anions			
Alkalinity	1	mg/L	do.
Chloride	2	mg/L	do.
Fluoride	.1	mg/L	do.
Silica	.2	mg/L	do.
Sulfate	2		do.
Cations			
Calcium	.02	mg/L	do.
Magnesium	.02	mg/L	do.
Potassium	.1	mg/L	do.
Sodium	.1	mg/L	do.

Constituent	MDL		Accuracy (percent)
WHOLE WATER CONSTITUENTS			
Chlorinated pesticides			
Aldrin	.01	µg/L	14-90
Gamma-BHC	.01	µg/L	72-108
Chlordane	.02	µg/L	45-119
Chlorothalonil	.02	µg/L	36-128
Heptachlor	.01	µg/L	38-102
Heptachlor epoxide	.01	µg/L	78-124
Nitrogen and phosphorus containing pesticides			
Ametryn	.05	µg/L	30-130
Atrazine	.05	µg/L	60-130
Bromacil	.3	µg/L	45-130
Chlorpyrifos ethyl	.1	µg/L	30-130
Diazinon	.05	µg/L	51-125
Ethoprop	.10	µg/L	30-130
Fenamiphos	.03	µg/L	50-140
Fenamiphos sulfoxide	.2	µg/L	50-225
Fenamiphos sulfone	.1	µg/L	20-165
Fenarimol	.2	µg/L	40-145
Hexazinone	.2	µg/L	80-155
Iprodione	.5	µg/L	10-200
Isofenphos	.05	µg/L	80-130
Malathion	.1	µg/L	85-130
Metalaxyl	.6	µg/L	70-130
Methamidophos	1.0	µg/L	0-90
Metribuzin	.2	µg/L	40-150
Naled	.3	µg/L	50-145
Pronamide	.3	µg/L	50-150
Simazine	.05	µg/L	40-140
Triademefon	.4	µg/L	80-135
Acid extractable herbicides			
2,4-D	2	µg/L	53-155
2,4,5-T	2	µg/L	54-168
Bentazon	2	µg/L	72-150
Dicamba	2	µg/L	38-118
MCPP	2	µg/L	63-135
Picloram	2	µg/L	9-137
Carbamate pesticides			
Carbaryl	4	µg/L	78-132
Carbofuran	4	µg/L	69-141
Bendiocarb	2	µg/L	87-125
Urea herbicides			
Oryzalin	.4	µg/L	68-132
Diuron	.4	µg/L	70-115
Linuron	.4	µg/L	70-125
Others			
Glyphosate	20	µg/L	48-162
Acephate	1.5	µg/L	5-160
MBAS	.1	µg/L	89-115[1]

[1]U.S. Geological Survey, written commun., 1995.

Table 3. Rainfall and irrigation at the nine golf courses, 1992-93

[Rainfall for Buckhorn Springs from Hillsborough River State Park National Weather Service (NWS) site; rainfall for Groves/Highlands from Bradenton NWS site; rainfall for Ventura from Orlando International Airport NWS site; rainfall for Skiing Paradise from Clermont NWS site; irrigation and rainfall for others from golf course records; NAS, Naval Air Station; gal, gallons; gpd, gallons per day; E, estimate; --, not available]

Month	Buckhorn Springs		Pebble Creek		Groves/ Highlands	Groves	Highlands
	Rainfall (inches)	Irrigation (gpd)	Rainfall (inches)	Irrigation (gpd)	Rainfall (inches)	Irrigation (gpd)	Irrigation (gpd)
1992							
April	4.80	--	4.3	81,000	2.93	169,000	143,000
May	0.37	--	0.4	48,000	0.15	305,000	256,000
June	12.96	--	14.1	37,000	22.34	133,000	179,000
July	1.52	--	2.8	45,000	7.07	137,000	111,000
August	7.81	--	11.1	35,000	10.22	94,000	64,000
September	7.52	--	6.9	30,000	3.91	73,000	92,000
October	3.17	--	4.1	66,000	3.19	140,000	101,000
November	3.85	--	4.3	43,000	1.81	185,000	151,000
December	0.62	--	0.8	43,000	1.59	97,000	107,000
1993							
January	5.06	--	5.7	25,000	9.03	30,000	15,000
February	2.90	--	3.7	16,000	2.03	108,000	65,000
March	3.25	--	6.4	45,000	2.16	151,000	102,000
April	3.17	--	1.9	33,000	3.73	165,000	136,000
Total Average	57.00	--	66.5	16,685,000 gal 42,000 gpd	70.16	54,348,000 gal 137,000 gpd	46,286,000 gal 117,000 gpd

Month	Winter Pines		Ventura		Bonaventure	Pensacola NAS	Skiing Paradise
	Rainfall (inches)	Irrigation (gpd)	Rainfall (inches)	Irrigation (gpd)		Rainfall (inches)	
1992							
April	6.3	98,000	9.10	--			
May	2.4	53,000	1.19	--			
June	5.8	100,000	8.68	--			
July	2.0	170,000	2.60	--			
August	13.2	11,000	8.03	--			
September	9.3	18,000	7.13	--			
October	5.3	78,000	5.17	--			
November	6.3	81,000	2.74	--			
December	0.3	70,000	0.88	--			
1993							
January	5.1	55,000	4.89	--	8.5	3.87	6.04
February	2.5	104,000	1.48	--	1.9	5.12	1.92
March	5.1	62,000	6.26	--	7.3	8.00	5.25
April	1.1	168,000	1.78	--	3.8	4.19	2.58
May					7.5	1.95	4.47
June					3.0	4.36	2.36
July					8.0	2.31	2.93
August					7.3	3.06	5.39
September					4.7	5.98	1.75
October					13.1	6.94	2.58
November					1.7	.63	.10
December					.6E	3.67	1.08
Total Average	64.7	32,331,000 gal 82,000 gpd	59.93		67.4	50.08	36.45

Buckhorn Springs Golf Course

Buckhorn Springs Golf and Country Club is located in south-central Hillsborough County on Miller Road and has been operating since the late 1960's (fig. 3). Before the golf course was built, the western part of the course was a citrus grove for about 10 years, and the eastern part of the course was pasture or open land. The area around the golf course is currently low density residential development. On the west side of the course the houses have septic tanks, which, in addition to the previous land use for citrus cultivation, can be a complicating factor in the analysis of water-quality data.

Buckhorn Springs golf course is topographically situated in one of the highest areas of Hillsborough County in a karst terrain (Upchurch and Littlefield, 1988; Jones and Upchurch, 1993). The karst in this area is characterized by internal drainage and cover collapse sinkholes (Sinclair and others, 1985; Trommer, 1987). The course trends northwest to southeast (fig. 3), with land-surface altitudes ranging from about 135 ft above sea level on the northwest end to less than 60 ft above sea level on the southeast end. Dominant soil types on the west side of the golf course where the sampling sites are located are Candler and Lake fine sands (Soil Conservation Service, 1989a), which are characterized as excessively drained soils occurring on slopes and uplands. They have low to very low water-holding capacity and less than 2-percent organic content. These soil types are commonly used for citrus production.

The hydrogeology of Buckhorn Springs golf course is unusual, as the topographically lower southeast side of the course does not contain a persistent water table (surficial) aquifer. Shallow wells monitored by the County on the east side of the course were dry from September 1988 to January 1993. Wells could not be placed on the east side of the course for this study because shallow ground water was not found during drilling. Trommer (1987) also notes the absence of a surficial aquifer in this area. A water table does exist, however, on the higher northwest side of the course. In some areas, water seeps at the land surface where the water table intersects the hillslope at an approximate altitude of 100 ft. This has caused problems with roadbed failure and saturated lawns in nearby neighborhoods (Westinghouse Environmental and Geotechnical Services, Inc., 1989). Ground-water levels on the western side of the golf course vary from less than 1 to 22 ft below land surface (Hillsborough County Public Utilities Department, written commun., 1993). Depths to water in the drive points installed during this study are estimated to be between 5 and 11 ft below land surface.

Geophysical data indicate a subsurface collapse feature under Miller Road, shown in the cross section in figure 4 (T. Griffin, Hillsborough County Public Utilities, written commun., 1992). Shallow ground water appears to flow from the west side of the course into this feature, which has a more direct connection to the underlying Floridan aquifer than the surrounding area. On the east side of the golf course, the direction that irrigation water and water from the storage pond migrate in the subsurface is not apparent.

Buckhorn Springs golf course uses treated effluent from Valrico Wastewater Treatment Plant, 4 mi north of the golf course, to irrigate. Valrico plant is an advanced wastewater treatment plant permitted to treat 4 Mgd (million gallons per day) of sewage. Over 1 Mgd of treated effluent is pumped from the Valrico plant to Buckhorn Springs and another golf course, but how much of this water goes to each of the golf courses is not known. Treated effluent is pumped from the plant to two storage ponds at Buckhorn Springs golf course. The storage ponds are located on the southeastern part of the course, and also are used to hold runoff from surrounding neighborhoods.

Irrigation records were not kept at this golf course during the study, but more recent records indicate that irrigation averages about 1.0 per week (Bill Moore, Buckhorn Springs golf course superintendent, oral commun., 1996).

Hillsborough County maintains six wells on the golf course which are sampled quarterly for nutrients and other constituents (appendix). Two of these wells are located on the eastern side of the course and have always been dry. The locations of sampling sites at Buckhorn Springs golf course are shown in figure 3. Sites used for this study are described in table 1.

Pebble Creek Golf Course

Pebble Creek Country Club is in northeast Hillsborough County on State Road 581 and has been operating since the mid-1960's (fig. 5). The land was previously undeveloped, and the area surrounding the subdivision is undeveloped cypress swamp and lowlands.

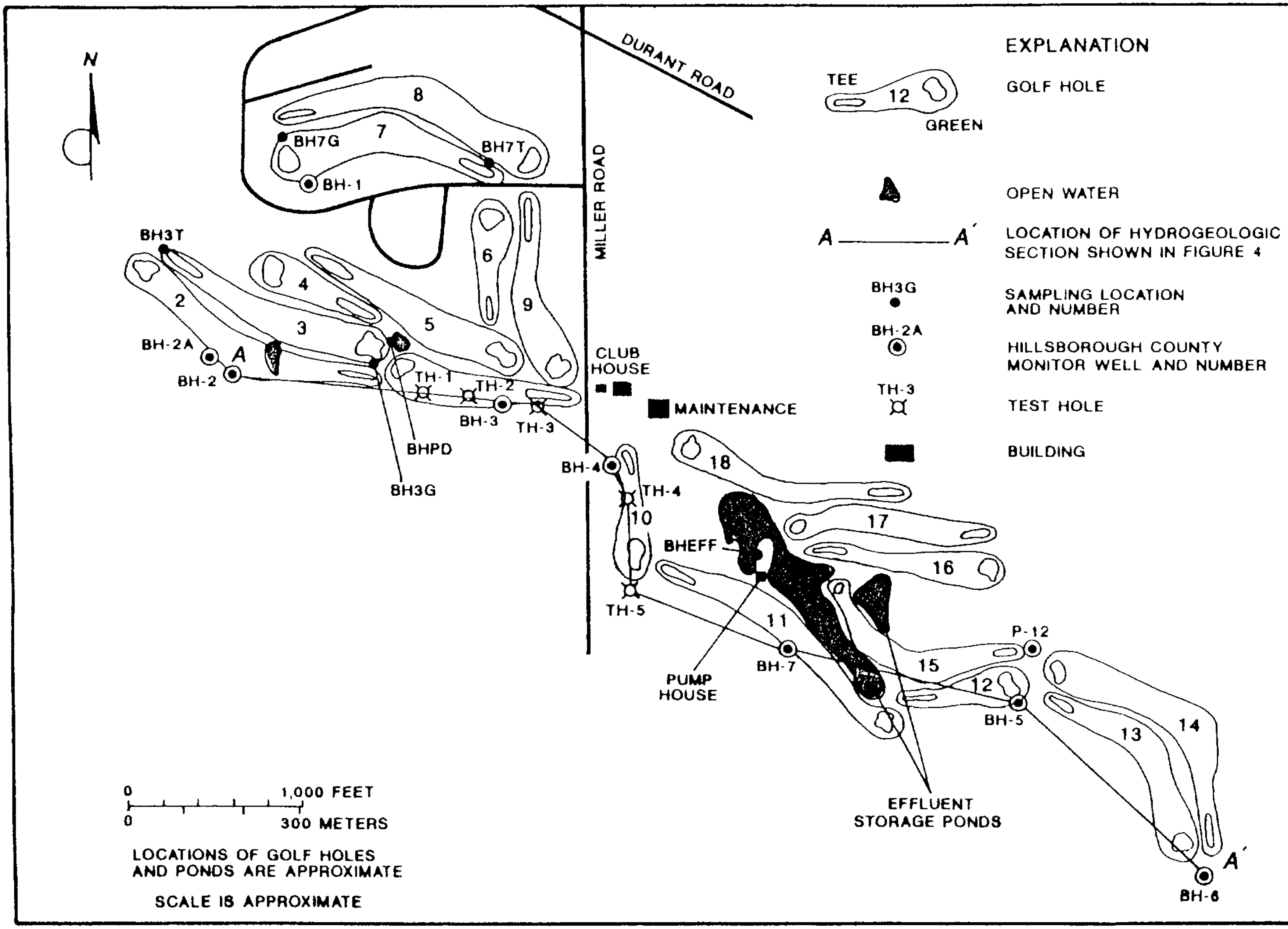

Figure 3. Sampling sites at Buckhorn Springs golf course near Tampa, Florida.

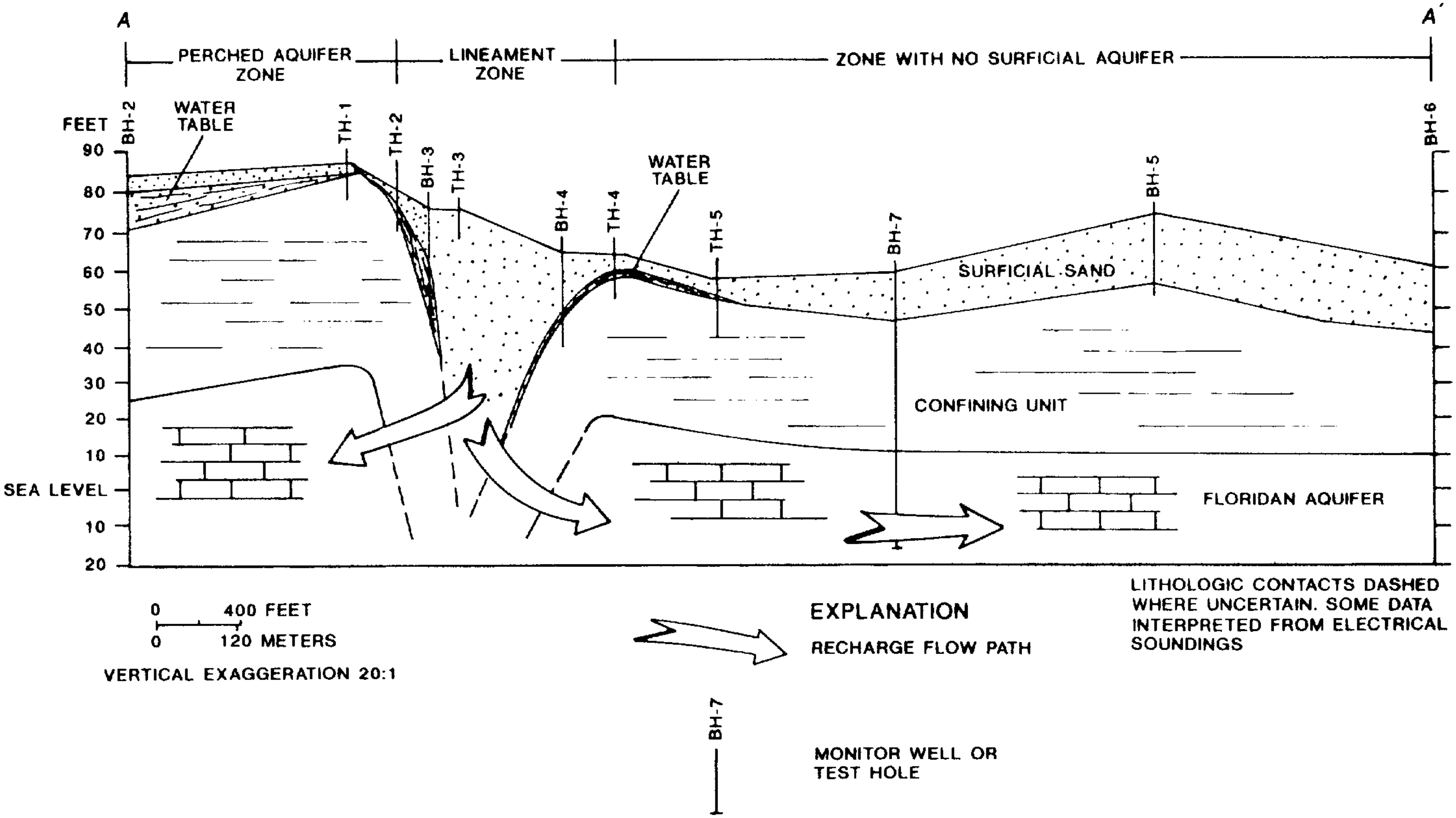

Figure 4. Hydrogeologic section *A-A′* through Buckhorn Springs golf course (modified from T. Griffin, Hillsborough County, Florida, 1992).

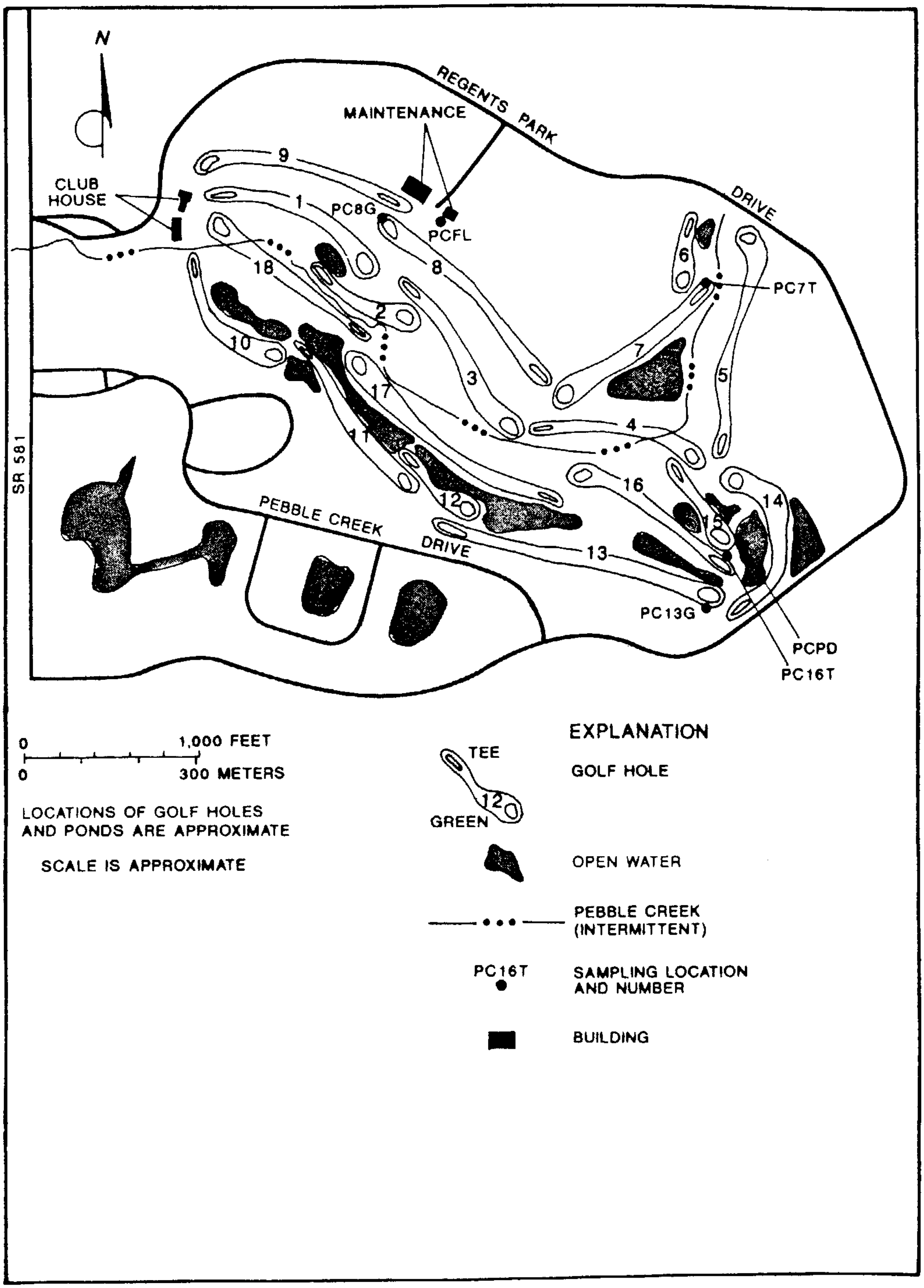

Figure 5. Sampling sites at Pebble Creek golf course, near Tampa, Florida.

The area of the golf course is part of a flood plain, and land-surface altitudes range from about 45 to 50 ft above sea level. Pebble Creek, which runs westward through the golf course, is a small, intermittent, tributary stream. Shallow ground-water levels measured during the study ranged from about 3 to 7 ft below land surface. The dominant soil type in the area is Myakka fine sand, which occurs on level, poorly drained, broad flatwoods plains (Soil Conservation Service, 1989a). This soil type typically has low water-holding capacity and a soil organic content less than 2 percent. The Pebble Creek area also includes low-lying swamps and sloughs, which are commonly flooded during wet periods.

The golf course used ground water from two wells open to the Upper Floridan aquifer to irrigate during this study. Wells were either pumped directly to the irrigation system or into a holding pond. Irrigation amounts are listed in table 3. Distribution lines now link the irrigation system to the sewage treatment plant located next to the golf course. During the study period, the sewage treatment plant discharged to Pebble Creek. Locations of sampling sites at Pebble Creek golf course are shown in figure 5 and described in table 1.

Groves and Highlands Golf Courses

The Groves and Highlands golf courses are part of the Meadows Country Club, which includes three 18-hole golf courses and is located on the eastern edge of the city of Sarasota in northwest Sarasota County (fig. 6). Highlands golf course opened in 1986 and Groves golf course opened in 1987. As the name implies, the area that is now Groves golf course was once a citrus grove 10 years prior to the development of the golf course (Smalley, Wellford, and Nalven, Inc., 1987). The remainder of the area was open land or pasture.

The area that is now Groves and Highlands golf courses was low, flat, and poorly drained in its natural state. Ditches were constructed over 40 years ago to improve drainage. These ditches flow south and westward and eventually into the Gulf of Mexico. Land-surface altitudes range from about 25 to 30 ft above sea level. Ground-water levels measured for this study ranged from about 3 to 6 ft below land surface at Groves and from about 2 to 16 ft below land surface at Highlands. Soils in the area where samples were collected include Cassia, Myakka, Holopaw, Ona, and Pomello fine sands (Soil Conservation Service, 1991). Differences in soil types are due to differences in topographic setting, from depressional areas to flatwoods ridges; differences in drainage capacity, from very poor to moderately well drained; and differences in fertility, from very low to medium. All soil types occur on nearly level areas and have low water-holding capacity.

Highlands golf course used irrigation water from a well open to the intermediate and Upper Floridan aquifers during the study. The golf course owners were in the process of obtaining permits to use effluent for irrigation on this course and the third golf course. Groves golf course has been using treated effluent for irrigation since it opened. The effluent water comes from Meadowood Wastewater Treatment Plant just to the south of the golf courses, and is temporarily stored in a lake near the golf course. Meadowood plant is an extended aeration plant and is permitted to treat 750,000 gpd. Irrigation amounts for Groves and Highlands golf courses are listed in table 3. Meadowood Utility maintains and samples four wells around the perimeter of Groves golf course, and one well near the lake. Locations of sampling sites are shown in figure 6 and described in table 1.

Winter Pines Golf Course

Winter Pines golf course has been open since 1968 and is located in central Orange County, northeast of Orlando on the west side of Semoran Blvd (SR 436) and south of Banchory Road (fig. 7). Before the course was built, part of the land was a farm and the rest was swamp. The surrounding area is high density residential development.

The topography at Winter Pines is flat, low, and poorly drained, with land-surface altitudes ranging from 90 to 95 ft above sea level. Water levels range from 4 to 8 ft below land surface. Soils in this area are classified in the Smyrna-Urban land complex, consisting of fine sand on nearly level, poorly drained, urban land or flatwoods (Soil Conservation Service, 1989b). These soils typically require drainage systems to allow development. Normal water tables in these soils are very close to the surface, but drainage canals through the golf course have reduced water levels. Depressional mucky soils also occur at Winter Pines and water-holding capacity of the soils is generally low, except in mucks where it is high.

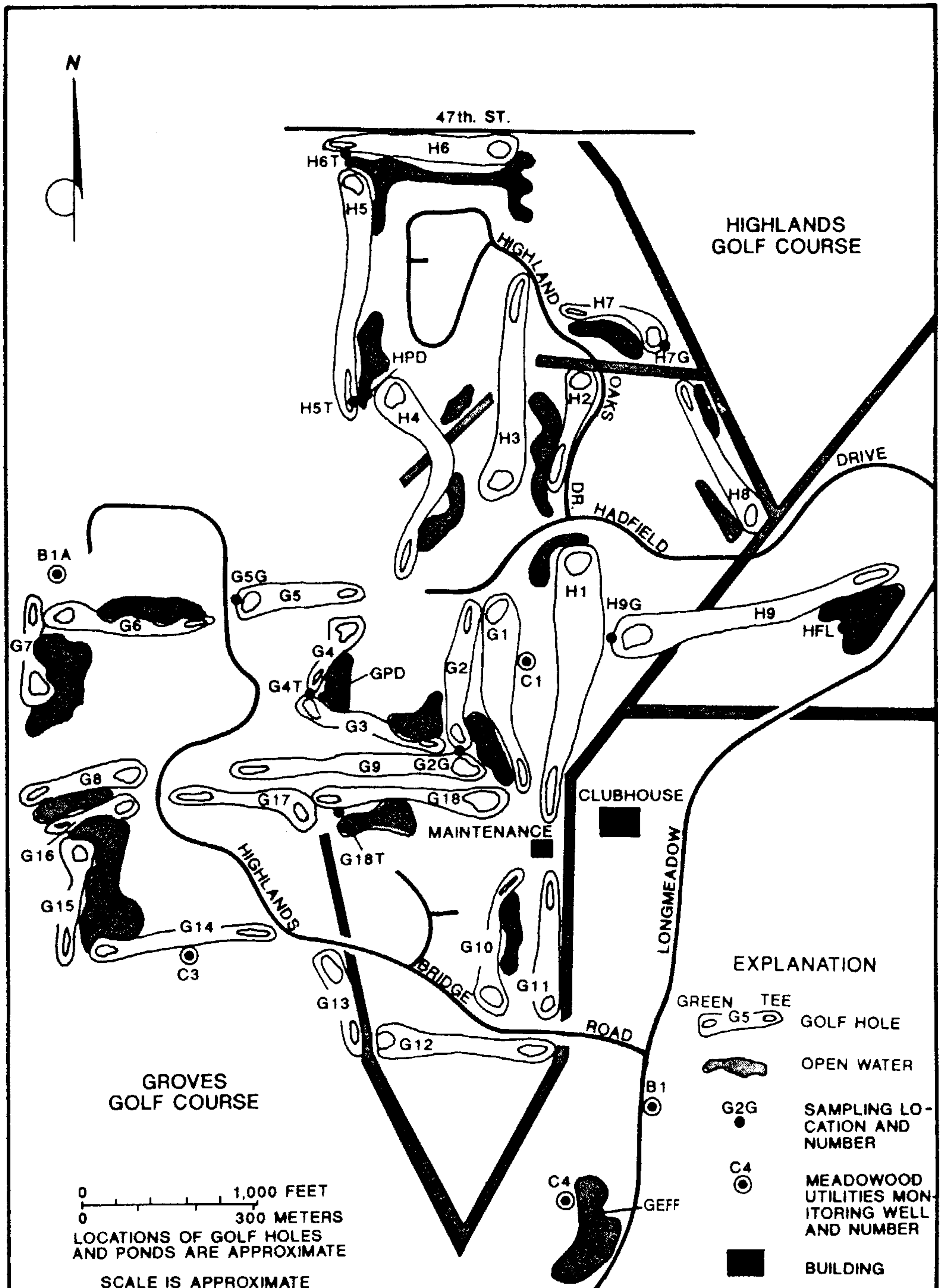

Figure 6. Sampling sites at the Groves and Highlands golf courses, near Sarasota, Florida.

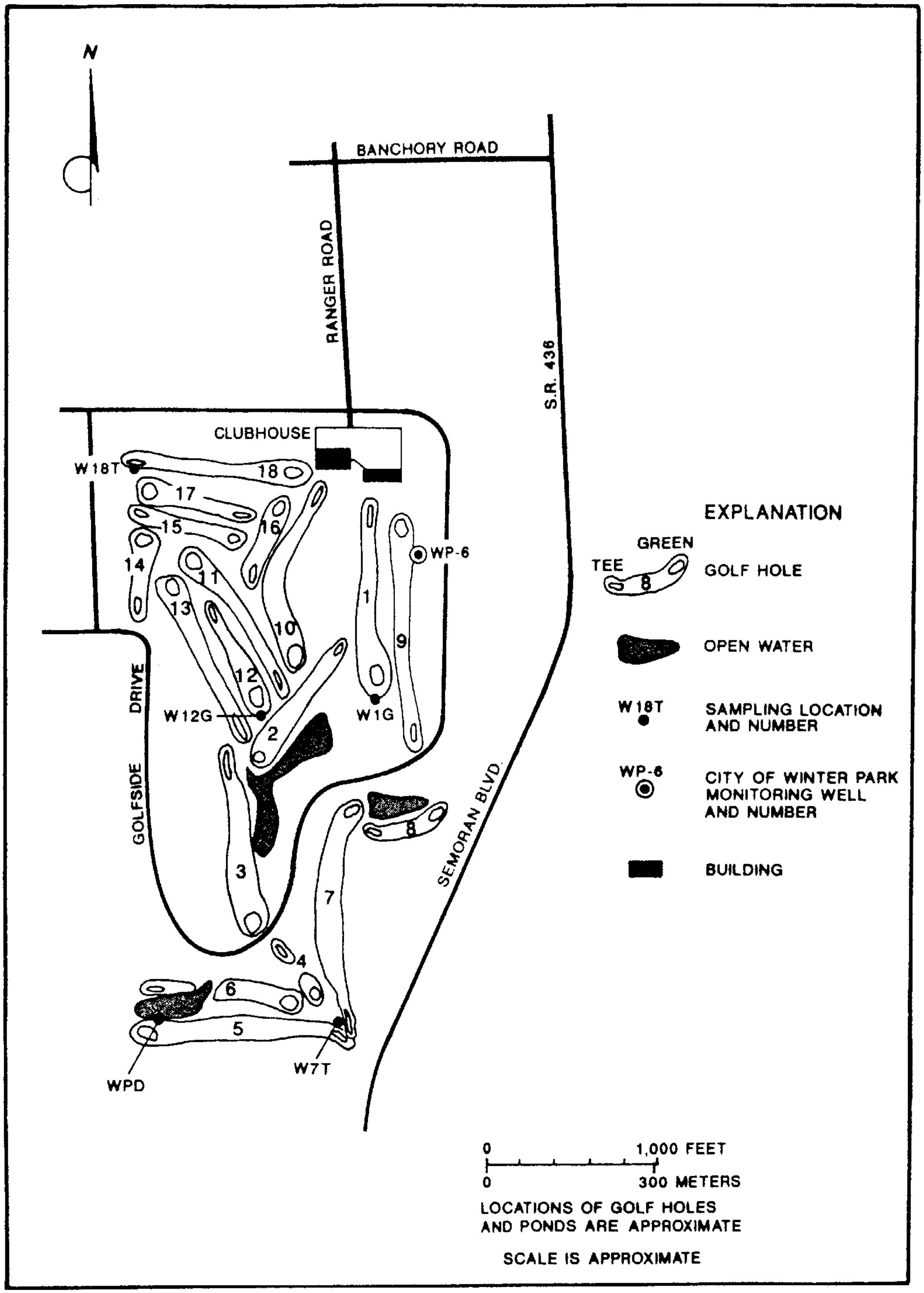

Figure 7. Sampling sites at Winter Pines golf course, near Orlando, Florida.

Winter Pines uses effluent from the Winter Park Estates Treatment Plant one-half mi north of the golf course for irrigation. Winter Park Estates plant is an extended aeration plant, with a treatment capacity of 750,000 gpd, all of which is reused. The treated wastewater is applied directly as irrigation and is not stored in ponds on the golf course. Irrigation amounts are shown in table 3. Four monitor wells on the course are maintained by the city of Winter Park as part of the wastewater reuse permit (fig. 7). Three of these were in suitable locations to be used for this study (W7T, W12G, and W18T), and one additional well was drilled (W1G). Locations of sampling sites are shown in figure 7 and are described in table 1.

Ventura Golf Course

Ventura Country Club was built in 1980 in southeastern Orlando in central Orange County, southeast of the intersection of Curry Ford Road and Raper Dairy Road (fig. 8). A dairy farm existed on part of the land before the subdivision and golf course were built. The surrounding area, with the exception of a cypress swamp located on the eastern boundary of the golf course, is currently being developed into residential housing to the extent that the poorly drained soils will allow.

The topography at Ventura is flat, low, and poorly drained. Land-surface altitudes range from 90 to 100 ft above sea level. Surface water in this part of Florida is drained internally through numerous swamps and lakes. Runoff from the golf course is drained by a series of interconnected narrow lakes and canals.

Soils on the golf course are similar to those at Winter Pines golf course and are also classified as a Smyrna-Urban land complex. Water levels measured in wells for this study ranged from about 6 to 8 ft below land surface. Soils are representative of depressional sloughs or swamps towards the eastern edge of the golf course where sampling sites V7T and V11G are located. Organic content of soils at Ventura is low to moderate, and can be high where mucks occur at the surface in the depressional areas. Three Upper Floridan aquifer wells provide irrigation for the golf course, but records of irrigation amounts were not kept during the study. Locations of sampling sites are shown in figure 8 and described in table 1.

Bonaventura Golf Course

Bonaventure Country Club consists of two 18-hole golf courses located in east-central Broward County near the intersection of State Road 84 (Alligator Alley) and Bonaventure Boulevard (fig. 9). Only the western golf course was monitored during this study. The area was part of the Everglades before the golf course was built in 1968. The surrounding land south of State Road 84 is being developed into a residential area.

The topography of this area is extremely flat at a land-surface altitude of about 6 ft above sea level. Water would naturally pond here for most of the year, but drainage systems have reduced water levels in the shallow aquifer. Water levels measured in wells for this study ranged from 2 to 5 ft below land surface. The soil type at the golf course is Plantation muck, a nearly level very poorly drained muck overlying sand and limestone (Soil Conservation Service, 1984). This muck has very high organic content (greater than 50 percent), and high water content.

The limestone underlying the soil at shallow depths is part of the Biscayne aquifer, a surficial aquifer that supplies most of the water for Broward County and the rest of southeastern Florida (Howie, 1987). The surface and shallow subsurface have been modified at the golf course by dredging lakes and using the fill to create greens and other playing areas. The sequence of layers noted during drilling was a thin layer of soil followed by 2 to 4 ft of sandy limestone fill, followed by undisturbed limestone.

Irrigation water for the golf course comes directly from lakes on the golf course which are an open connection to the aquifer. Locations of sampling sites are shown in figure 9 and described in table 1.

Pensacola Naval Air Station Golf Course

During the study period, the Pensacola Naval Air Station in southwestern Pensacola had two 18-hole golf courses near the entrance road south of Bayou Grande (fig. 10). The golf courses were built in the early 1950's. Before the golf courses were built the land was unused and wooded.

The Naval Air Station is located in southern Escambia County on a peninsula. A string of barrier islands separates the peninsula from the Gulf of Mexico. Topography indicates that the area was probably formed as a broad beach ridge during a recent high

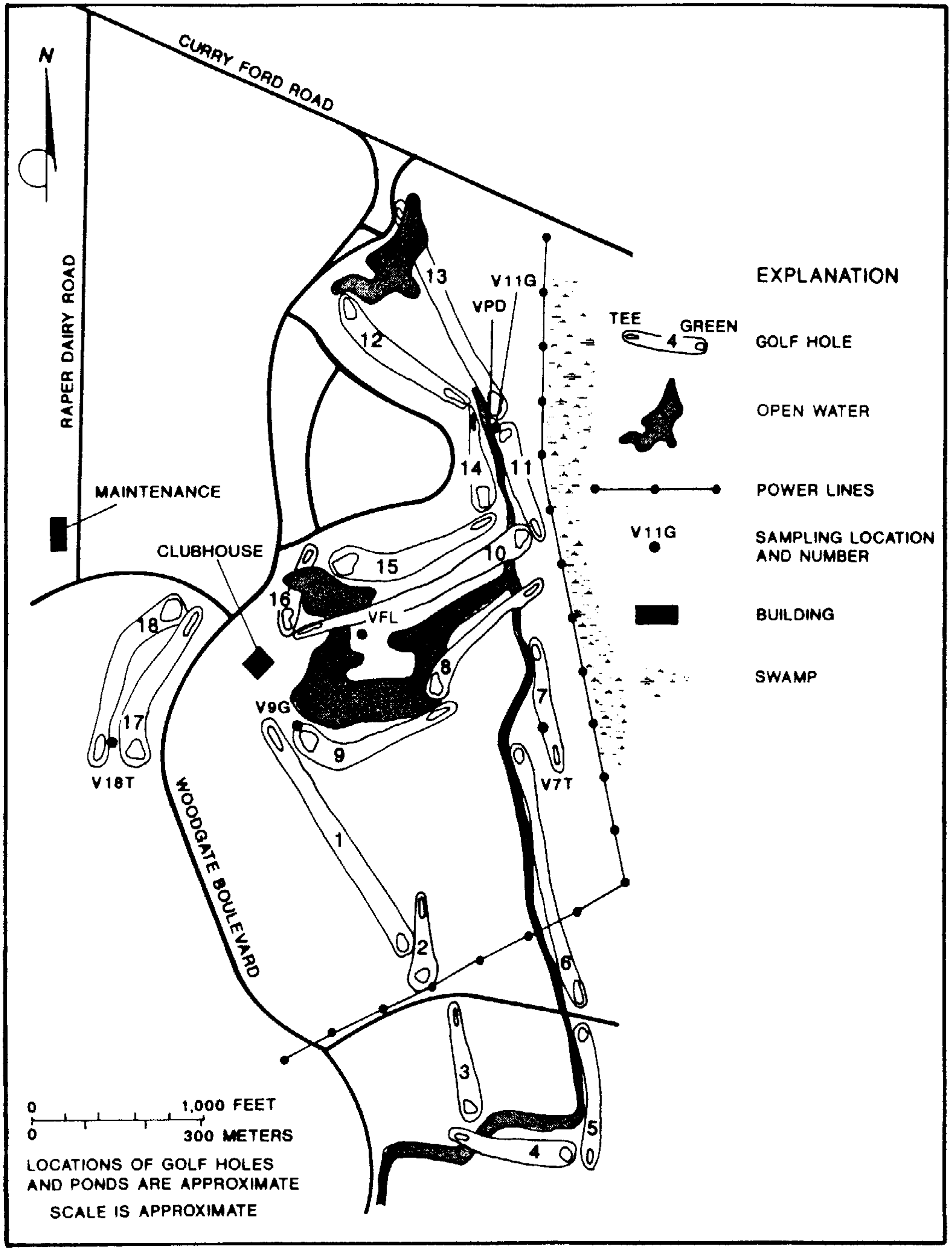

Figure 8. Sampling sites at Ventura golf course, near Orlando, Florida.

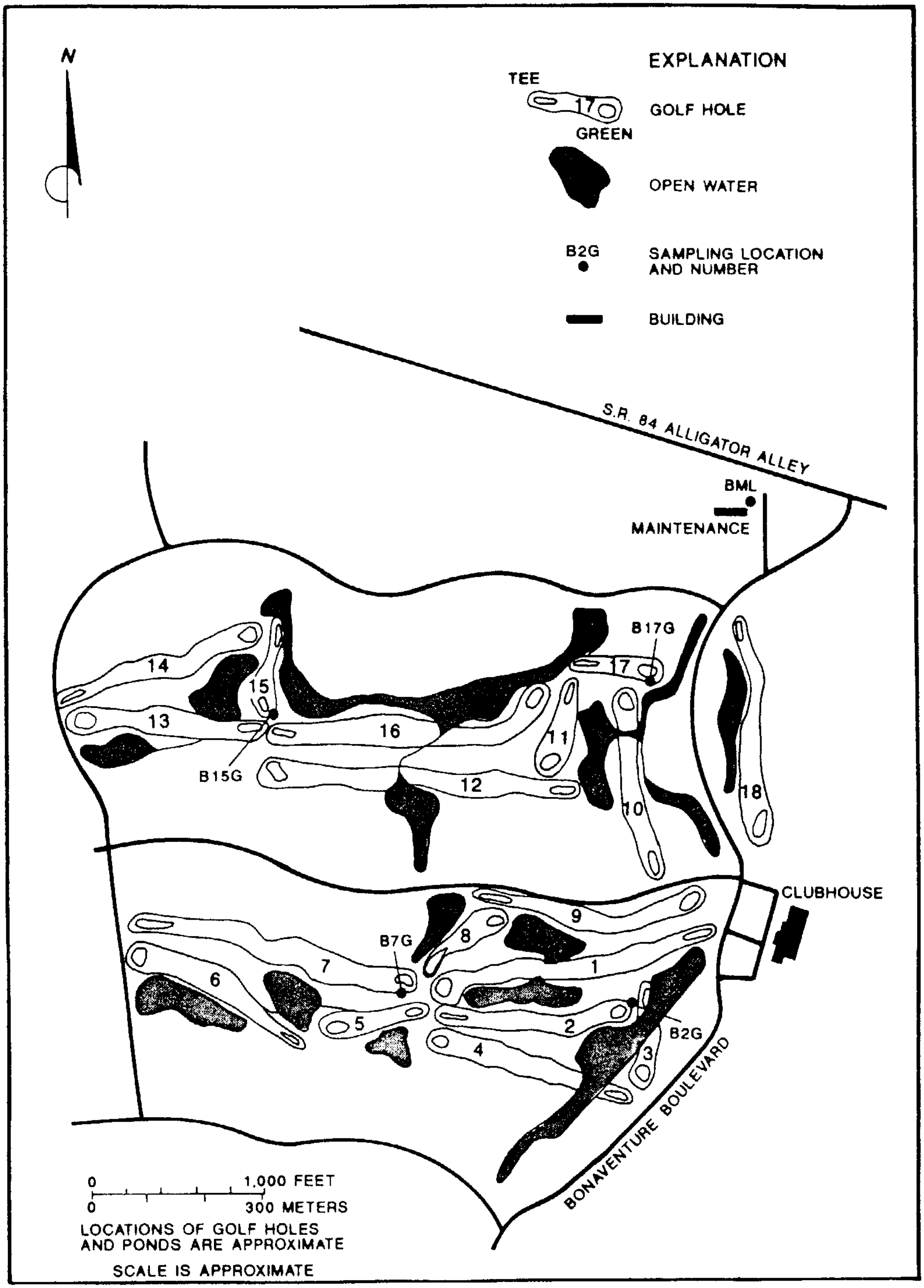

Figure 9. Sampling sites at Bonaventure golf course, near Ft. Lauderdale, Florida.

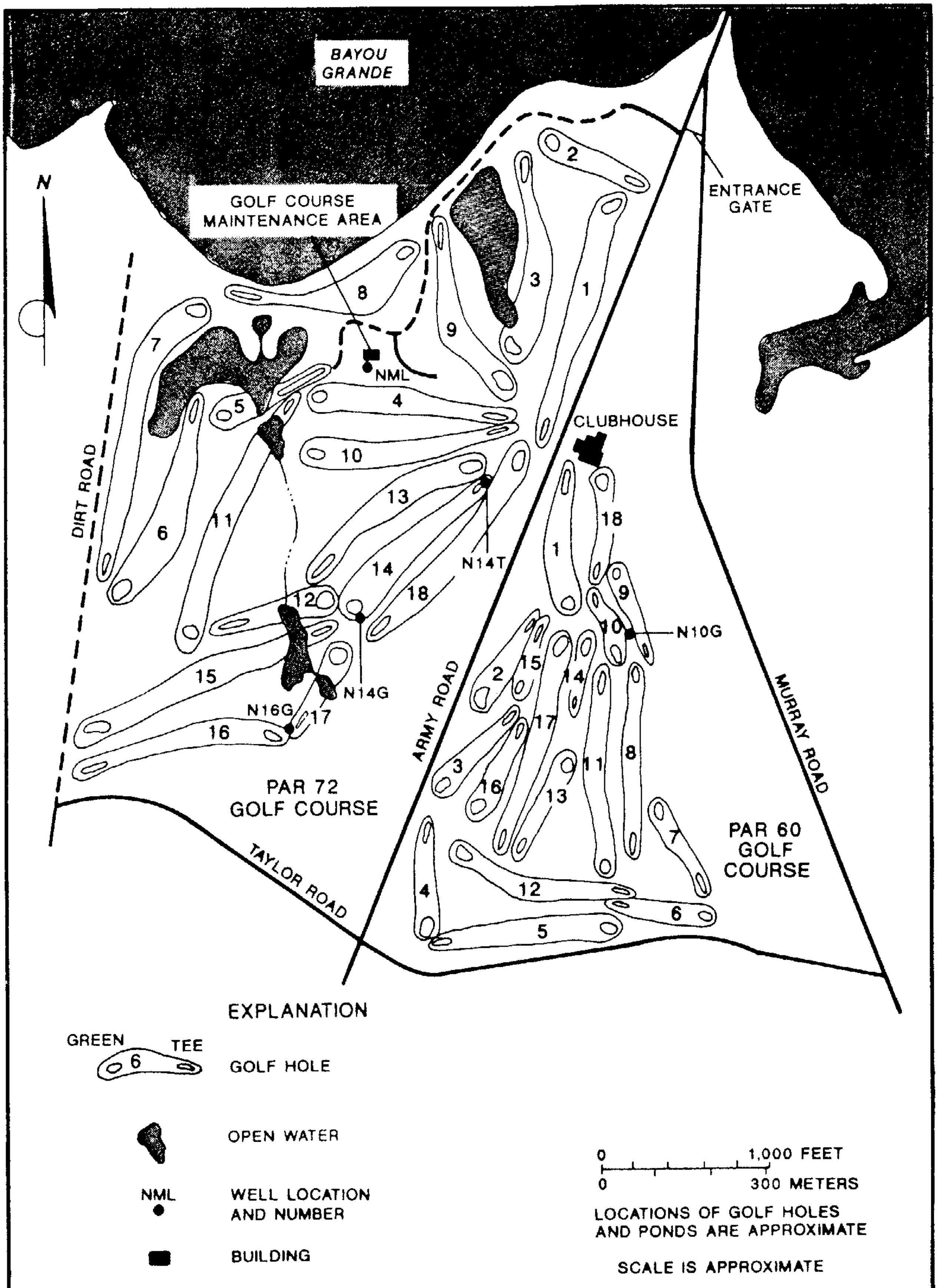

Figure 10. Sampling sites at Pensacola Naval Air Station golf course, near Pensacola, Florida.

sea level stand (Marsh, 1966). Land-surface altitudes on the golf course range from just above sea level to about 35 ft above sea level. Detailed soil surveys of the Naval Air Station are not published, but a general classification of the soils lists two types, Klej-Leon fine sands and Lakewood-Lakeland fine sands (Soil Conservation Service, 1960). The Klej-Leon sands are typical of lowland, somewhat poorly drained areas with a moderately high water table. These soils occur in the lower areas of the golf course near Bayou Grande. The Lakewood-Lakeland sands are characteristic of the upland areas of the golf course that are excessively to somewhat excessively drained (Soil Conservation Service, 1960). Both soil types have low organic content. Water levels measured for this study ranged from 10 to 25 ft below land surface, and ground water generally flows to the north toward Bayou Grande (Ecology and Environment, Inc., 1991).

The golf courses irrigate using a combination of water supplied by the public utility and ground water from an on-site well. Both sources ultimately come from the regional sand and gravel aquifer (Schmidt, 1978). Irrigation water is temporarily stored in a pond on the western golf course. Irrigation records were not kept during the study period. Locations of sampling sites are shown in figure 10 and described in table 1.

Skiing Paradise Golf Course

Skiing Paradise Golf Course (also called Swiss Fairways) is located about 50 miles west of Orlando on County Road 565A (Montevista Road) in Lake County (fig. 11). This 9-hole golf course was constructed in 1991. Before construction of the golf course, the land was used for citrus cultivation.

The Skiing Paradise golf course is on the west bank of Sumner Lake. Land-surface altitude ranges from 100 ft above sea level near the lake to 135 ft above sea level on a hill to the south. This area consists of numerous lakes separated by sandy hills, and is a recharge area to the Floridan Aquifer system. Potential for downward leakage to the Floridan Aquifer in this area is considered to be relatively high (Grubb, 1977).

Soils are dominated by Albany or Apopka sands, which are described as nearly level to sloping, somewhat poorly drained to well-drained sandy soils with a sandy clay loam subsoil. These soils are typical of upland ridges, and are well suited to citrus production (Soil Conservation Service, 1975). They have low organic contents and low water-holding capacities. Depth to water measured in wells used for this study was between 3 and 10 ft below land surface.

A persistent clay layer at an approximate altitude of 100 ft above sea level was noted during monitor well drilling, and many parts of the golf course were unsuitable for shallow monitor wells because there was no water overlying the clay. The clay layer is assumed to be areally extensive because it has been encountered throughout the golf course property during well installation and while several lakes were dredged. This clay layer is probably responsible for ponding of irrigation and rainwater on lower parts of the course.

Irrigation water at Skiing Paradise golf course is supplied by a Floridan aquifer well located on the golf course. Irrigation records were not kept during the sampling period. Locations of sampling sites are shown in figure 11 and described in table 1.

WATER QUALITY

This section describes water quality of shallow ground water, irrigation water, and ponds associated with golf courses in Florida. Golf course operations that may affect water quality include the use of fertilizers and pesticides, and irrigation with ground water from deep aquifers or reclaimed water. This study focused on the effects of golf course operations on ground water. Surface-water sampling was done at paired golf courses for comparison with ground water, and irrigation water was sampled to determine differences between irrigation waters that might affect pesticide mobility. Most water-quality constituents are discussed by golf course so that comparisons can be made between ground-water and irrigation-water quality. A discussion of pesticide occurrences in water, which was a primary objective of the study, is in a subsequent section.

Shallow ground-water quality at golf courses is assumed to reflect turf management practices because of the relatively short traveltime of water from the land surface to the water table. Depths to the water table ranged from 2 to 25 ft below land surface in wells on golf courses included in this study. Filtration and biological activity that take place as water moves through the unsaturated zone also have an effect on water quality. Surficial aquifers beneath rapidly drained soils are expected to show a more direct effect from turf-management practices than aquifers beneath poorly draining soils.

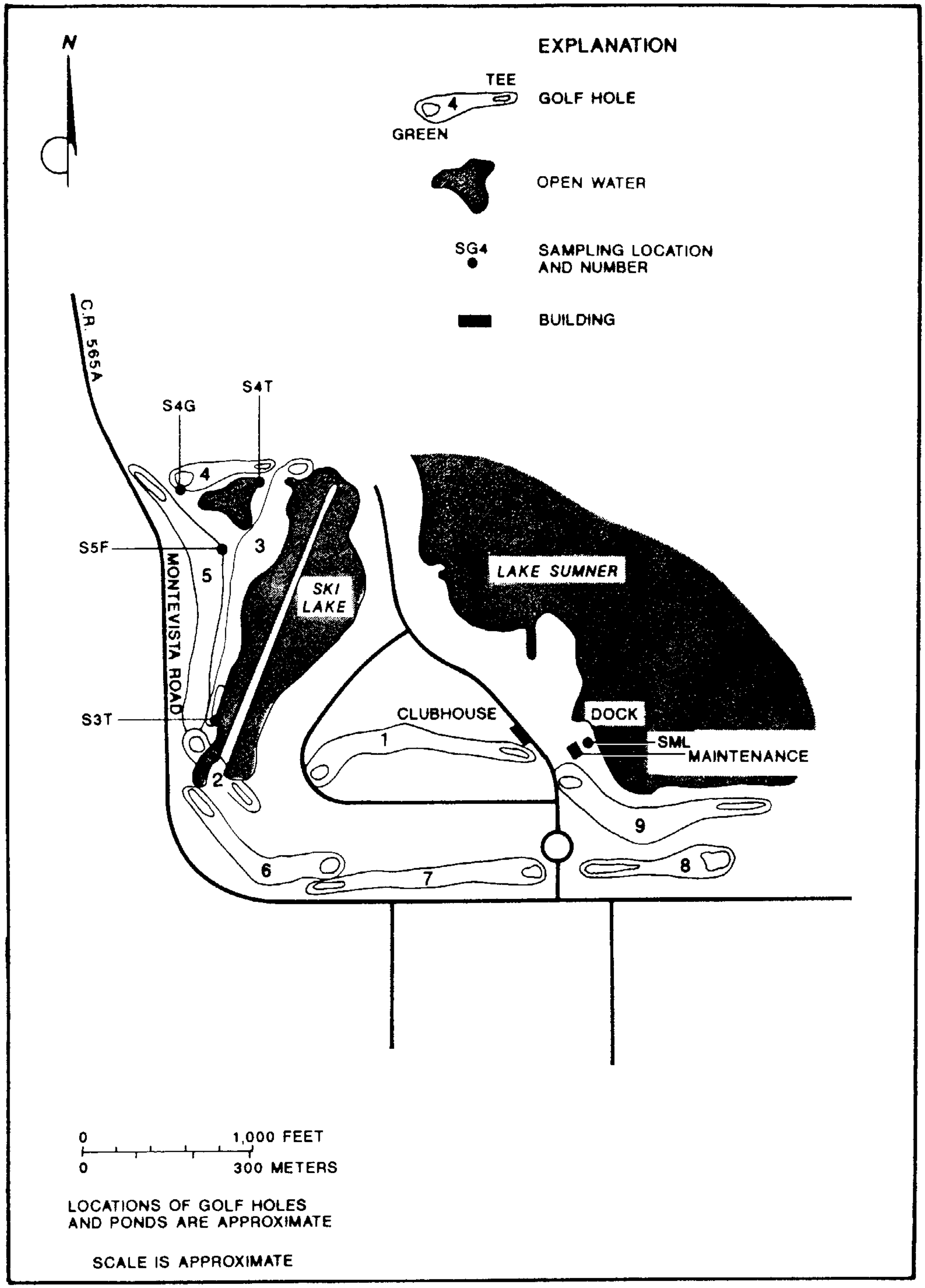

Figure 11. Sampling sites at Skiing Paradise golf course, near Clermont, Florida.

Water quality in the shallow ground water, or surficial aquifer, is naturally variable and background composition is difficult to characterize on more than a local level. The surficial aquifer in rapidly drained, undeveloped sandy areas typically contains water with low dissolved solids, slightly acidic pH, measurable dissolved oxygen, low concentrations of bicarbonate, dissolved organic carbon (DOC) and nutrients, and a sodium-chloride water type (Pollman and others, 1991). Ambient water quality in a poorly drained wetland area can be expected to have similar chemistry except for higher dissolved solids and higher DOC (Dierburg and Brezonik, 1985). Proximity to the coast also will affect water quality in the surficial aquifer if the area has been covered by the sea, leaving residual salts in surficial formations.

Samples of effluent water to be used as irrigation water were collected to determine the chemical characteristics of reclaimed water. Samples from deep irrigation wells or irrigation systems also were collected at the golf courses that were not using reclaimed water. Irrigation and effluent samples were only collected at the six paired golf courses.

Surface-water samples were collected at one pond on each of the six paired golf courses. Ponds are an integral part of the golf course, adding to the complexity of the course as water hazards, providing needed runoff storage, and sometimes an irrigation water source. Nutrient runoff from turf areas creates highly productive systems, and algal growth in ponds is a common problem.

Field Measurements

Water-quality data are presented in both graphical and tabular format. Statistics for some field constituents are plotted by golf course for visual comparison. Analytical data for major ions, nutrients, trace elements, and field constituents are listed in table 4, which, because of its length, appears at the end of the report on page 61. Field measurements that were made at each site (depth to water, pH, temperature, specific conductance, dissolved oxygen, and alkalinity) also are presented in table 4.

Ground Water

Values of pH in the surficial aquifer are typically less than 7.0, reflecting the low pH of rainfall and production of carbonic acid in the soil zone. For samples collected for this study, pH of ground water from individual samples ranged from 3.62 at a Winter Pines well (W1G) to 7.18 at a Bonaventure well (BML)
(fig. 12). Ground water at Bonaventure golf course has higher pH because the surficial aquifer at this site consists of carbonate rock. At other sites, the surficial aquifer consists of silica sand. For the six paired golf courses, median pH is lower at effluent-irrigated courses than at ground-water irrigated courses.

Because of the close proximity of surficial aquifers to land surface in the study area (usually less than 25 ft), temperature of water from shallow wells follows a seasonal trend analogous to air temperature. Temperature also is correlated with latitude, and golf courses farther north have lower ground-water temperatures. Shallow ground-water temperatures ranged from 19.1 ^{o}C at a Pensacola NAS well (NML) on March 31, 1993, to 28.2 ^{o}C at a Groves well (G18T) on August 27, 1992.

Specific conductance in shallow ground water at the golf courses is greater than background specific conductance because fertilizer application in the form of salts adds to the ionic strength. Irrigation-water type also affects the specific conductance because some irrigation wells pump water from highly mineralized aquifers. Specific conductance of water from individual ground-water samples ranged from 84 microsiemens per centimeter (μS/cm) at Pensacola NAS (N14G) to 2,810 μS/cm at Bonaventure (B7G) (table 4, fig. 12). Overall, ground water at Highlands golf course had the highest specific conductance, with a median of 1,217 μS/cm, while Bonaventure had a slightly lower median of 1,155 μS/cm. Variability of specific conductance among wells also was largest at Highlands and Bonaventure golf courses. The remaining golf courses had median specific conductances of less than 600 μS/cm.

High concentrations of dissolved oxygen (DO) in ground water indicate relatively rapid recharge to the water table. Rainwater is saturated with DO, but the concentration normally is reduced by microbial respiration as water infiltrates through an active soil zone. Shallow ground water in all wells at Groves, Highlands, Winter Pines, Ventura, Bonaventure, and Skiing Paradise golf courses had median DO concentrations less than 1.0 mg/L (fig. 13). Ground water in wells at Buckhorn Springs, Pebble Creek, and Pensacola NAS golf courses had higher DO concentrations. Of the golf courses with higher DO in ground water, all but Pebble Creek have well-drained soils.

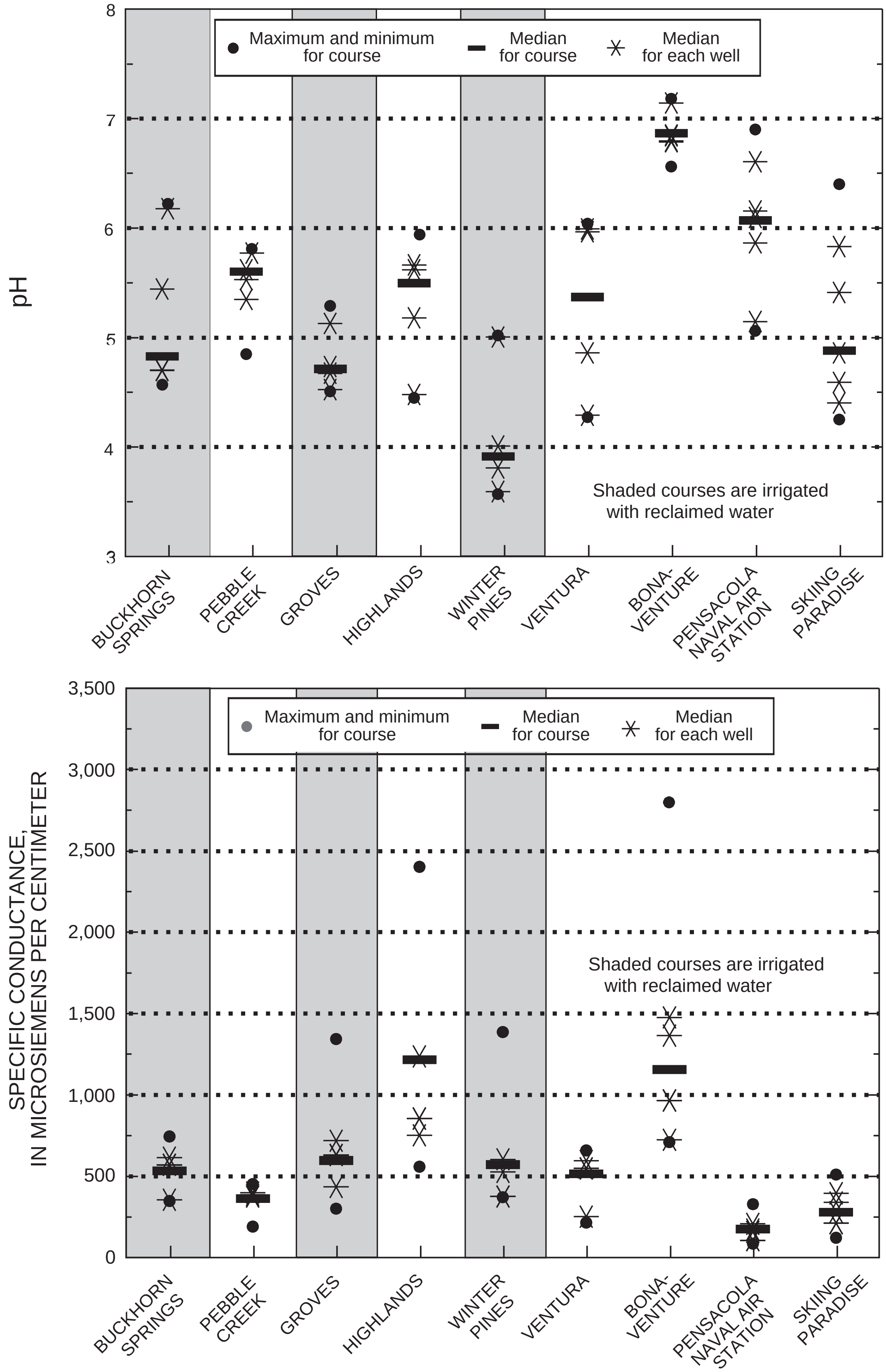

Figure 12. Summary of pH and specific conductance values of ground water at golf courses.

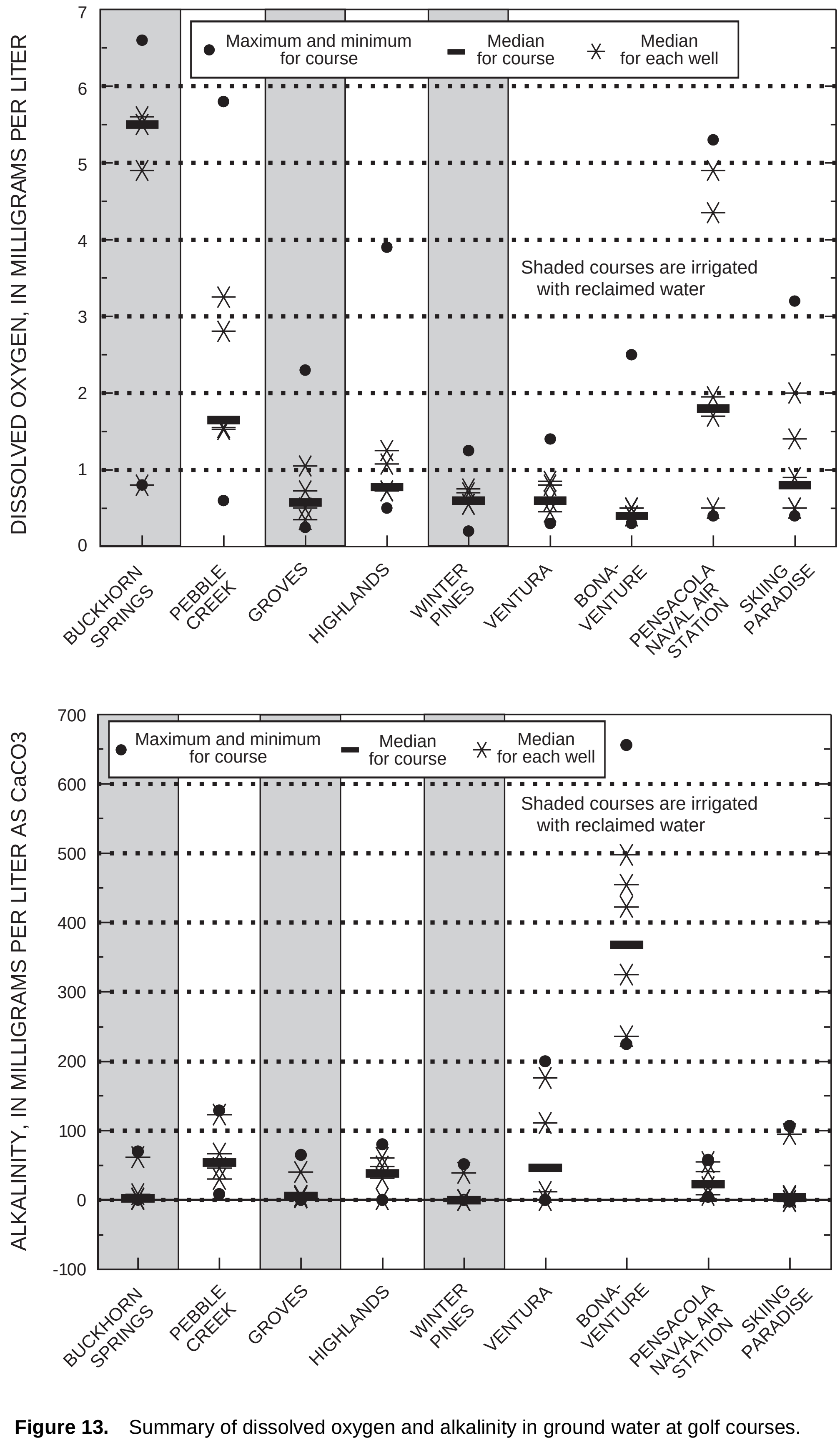

Figure 13. Summary of dissolved oxygen and alkalinity in ground water at golf courses.

Alkalinities as calcium carbonate of individual samples ranged from -2.3 mg/L at a Skiing Paradise well (S4T) to 656 mg/L at a Bonaventure well (B7G) (fig. 13). Negative alkalinities were calculated from Gran titrations. Low alkalinities of many shallow ground-water samples reflect the low ground-water pH and lack of contact with carbonate materials during recharge. Higher alkalinities are associated with golf courses irrigated with ground water from deeper aquifers (Pebble Creek, Highlands, and Ventura), and golf courses in areas where the surficial aquifer is a carbonate rock (Bonaventure).

Treated Effluent and Irrigation Water

The pH of individual treated effluent samples ranged from 5.3 at the Winter Park Estates WTP (WEFF) to 8.7 at the Groves effluent storage pond (GEFF) (table 4). The regulatory requirement for pH of water discharged from treatment plants is 6.0 to 8.5 (Florida Department of State, 1993). Reclaimed water that is stored in ponds before it is used for irrigation acquires a higher pH than plant discharge because of photosynthetic consumption of carbon dioxide by aquatic plants (Goldman and Horne, 1983). The pH of water from Winter Park Estates WTP was lower because samples were collected immediately after chlorination, which reduces pH (Sawyer and McCarty, 1978).

Specific conductance of treated effluent samples ranged from 505 µS/cm at Winter Park Estates WTP (WEFF) to 845 µS/cm at Valrico WTP (VWP). Specific conductance of effluent stored in ponds was lower than effluent sampled directly from treatment plants because of dilution by rainwater. At Buckhorn Springs and Groves golf courses, specific conductance of ground water was lower than that of reclaimed irrigation water at all wells except one (G5G). At Winter Pines, specific conductance of ground water was higher than treated effluent except at well W18T.

Dissolved oxygen (DO) in samples from treated effluent ranged from 1.0 mg/L at Meadowoods WTP (MWP) to 10.9 mg/L at Groves effluent storage pond (GEFF). The relatively low value at Meadowoods plant reflects the point in the system where the sample was taken, which was immediately before the flume that aerates the outflow stream at the end of the contact chamber. At Groves effluent storage pond, DO was at supersaturated concentrations from the production of oxygen during photosynthesis. DO concentration in ground water was always less than the concentration in effluent at any individual golf course, indicating that oxygen is removed as water infiltrates downward to the water table.

Values of pH for irrigation well samples ranged from 7.4 to 7.6, typical of the carbonate aquifers that supply water to these wells. Specific conductance of irrigation water from wells was within the ranges of shallow ground water at each site. Water from the intermediate aquifer, used for irrigation at Highlands golf course (well HFL in table 4), is more mineralized than water from the Floridan aquifer system, which is used at Pebble Creek (PCFL) and Ventura (VFL). At Pebble Creek golf course, irrigation water has higher DO concentration and lower temperature than expected because surface water also contributes to the irrigation system. At Ventura golf course, sampling after a pressure tank may have increased the DO concentration of irrigation water, and may also affect some trace element concentrations.

Pond Water

Values of pH measured near the surface of golf course ponds ranged from 4.7 at Winter Pines (WPD) to 9.5 at Buckhorn Springs (BHPD). Pond pH is typically higher than ground water pH because of photosynthesis. Consumption of carbon dioxide in ponds by photosynthesis was often at peak levels during midday when samples were generally collected (Goldman and Horne, 1983).

Pond temperatures are even more closely related to air temperatures than are shallow ground water temperatures. Pond temperatures ranged from 17.3 ^{o}C at Winter Pines (WPD) on December 15, 1992 to 34.4 ^{o}C at Highlands (HPD) on June 22, 1992.

Specific conductance of ponds ranged from 113 µS/cm at Ventura (VPD) to 888 µS/cm at Highlands (HPD). Pond specific conductance was always considerably lower than ground water, except for one well at Buckhorn Springs (BH3G), which is located downgradient from the pond at that site. Dilution by rainwater probably accounts for the lower specific conductance in ponds.

High DO concentration is another product of photosynthesis in golf course ponds. DO ranged from 2.5 mg/L at Highlands (HPD) to 15.4 mg/L at Winter Pines (WPD). Dissolved oxygen concentrations above saturated conditions were common in golf course ponds.

Major Ions, Nutrients and Trace Elements

Major ion compositions of water samples are represented by trilinear diagrams, which show the percentages of major cations and anions in the water. Compositions of ground water at paired golf courses are plotted together to show differences in major ion chemistry between paired sites and the relation between irrigation- and ground-water quality.

Nutrients were analyzed in water samples to determine the effect of fertilizer application on water quality at golf courses. The presence of nitrogen and phosphorus in water samples was quantified by analyses for dissolved nitrate plus nitrite, dissolved ammonia, dissolved ammonia plus organic nitrogen, and dissolved orthophosphate. Because nitrite concentrations usually are very low, the sum of nitrate and nitrite is assumed to be equivalent to nitrate concentration and will be referred to as "nitrate" in the rest of the report.

Seventeen trace elements were analyzed in water for this study (table 2). Of these, arsenic will be discussed in the section on pesticides, because it is a component of monosodium methanearsonate (MSMA), a herbicide commonly used on golf courses in Florida. Of the trace elements analyzed, antimony, mercury, selenium, and thallium were not detected in any water samples. Detection limits for trace elements varied depending on the laboratory accuracy on the day that the sample was analyzed. When discussing concentrations of trace elements, only those concentrations above the highest detection limit used in the analysis of the element were considered meaningful. When concentrations were qualified as high, moderate, or low, it refers to the concentration relative to all samples collected for this study. Classifications were based on the frequency distributions of the data. Ranges of concentrations for commonly occurring trace elements are as follows:

Element	Range (µg/L)	Low	Moderate	High
Iron	<3-30,000	<3-152	153-1,750	>1750
Aluminum	<50-8,900	<50-248	249-1,130	>1,130
Manganese	<1-830	<1-9	10-36	>36
Strontium	3-15,000	>3-103	104-471	>471

Buckhorn Springs Golf Course

At Buckhorn Springs golf course, which uses reclaimed water for irrigation, sodium is the dominant cation in most ground water (fig. 14), and chloride or chloride and sulfate are the dominant anions. Water from one well, BH3G, has chloride and bicarbonate as the dominant anions. Water from well BH3G most closely resembles the reclaimed irrigation water. The chemistry of this well is different from other wells on this course because it is in a low area where drainage from the course is focused. The pond that is just upgradient to this well is also a focus of drainage on the golf course, and it also has similar major ion composition to the irrigation source. With the exception of well BH3G, ground water at Buckhorn Springs has very low alkalinity.

Treated effluent samples from Buckhorn Springs, as well as the other effluent-irrigated golf courses, have calcium and sodium as the dominant cations (fig. 15). Water from Valrico WTP (VWP), which irrigates Buckhorn Springs golf course, generally has no dominant anions. Samples from Valrico WTP have similar major ion composition to samples from the effluent storage pond on the golf course, but concentrations in the pond are more dilute (table 4). Compared to the shallow ground water, reclaimed water used for irrigation at Buckhorn Springs has higher bicarbonate concentration. Buckhorn Springs pond has calcium and sodium as dominant cations, and no dominant anions (fig. 16). Its composition falls within the range of shallow ground-water samples.

Nutrients in ground water at Buckhorn Springs are mainly in the form of nitrate, reflecting the use of nitrate fertilizers, rapid infiltration, and aerobic conditions in the ground water at this course. Water from wells BH3T, BH7G, and BH7T had nitrate concentrations ranging from 0.51 to 8.7 mg/L (table 4). Only well BH3G had ammonia as the dominant nutrient in water, with concentrations ranging from 1.2 to 1.9 mg/L. Water from well BH3G also had high orthophosphate concentrations ranging from 3.0 to 4.6 mg/L.

Valrico WTP, which delivers water to Buckhorn Springs golf course, uses an advanced nitrification/denitrification treatment process to remove most of the nitrogen in the waste stream. Phosphorus is removed by chemical precipitation with alum. Consequently, nutrient concentrations in plant effluent and in the effluent-storage pond on the golf course were low.

Buckhorn Springs pond had the highest nitrate concentrations of all ponds, ranging from 0.04 to 2.3 mg/L. Orthophosphate concentrations in all of the golf course ponds were below 0.2 mg/L and were commonly much lower.

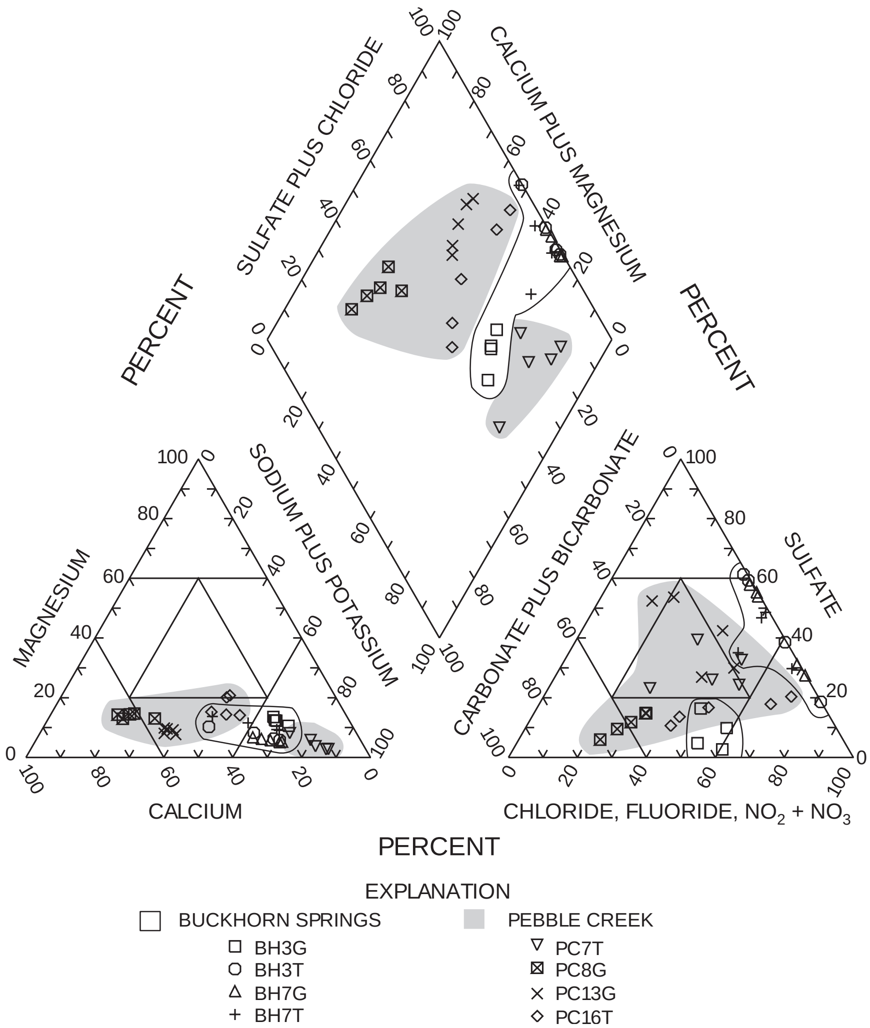

Figure 14. Trilinear diagram showing major ion composition of ground water from Buckhorn Springs and Pebble Creek golf courses.

Trace element concentrations in ground water, effluent-irrigation water, and pond water at Buckhorn Springs were generally low. Water from well BH3G had high iron, with a range of concentrations from 8,600 to 11,000 µg/L. Zinc concentrations in samples from Valrico WTP (VWP) ranged from 15 to 18 µg/L, and strontium concentration was 1,300 µg/L (table 4).

At Buckhorn Springs golf course, Hillsborough County has collected data from their own compliance wells since 1988 on water-level, pH, temperature, specific conductance, turbidity, chloride, total dissolved solids (TDS), nitrate, fecal coliform bacteria, total organic carbon, and sodium (see appendix). One shallow compliance well is designated by the County as a background water-quality monitor well, but its location downgradient of the golf course playing areas makes it more representative of ground water that has been affected by golf course operations. Two Floridan wells also were monitored by Hillsborough County, one background well located northeast of the course and one compliance well on the golf course.

Hillsborough County sampled all wells quarterly until May 1992, when sampling frequency was reduced. Data collected for this study were comparable to data from the compliance wells for pH, specific conductance, chloride, and sodium with the following exception; water from compliance well BH-4 has considerably lower values for these constituents than any other shallow ground-water sites. The low values of these constituents indicate that this well may be getting recharge water from Miller Road or other unmanaged areas during the rainy season.

Nitrate concentrations in water from the shallow Hillsborough County compliance wells have frequently exceeded the MCL of 10 mg/L (Florida

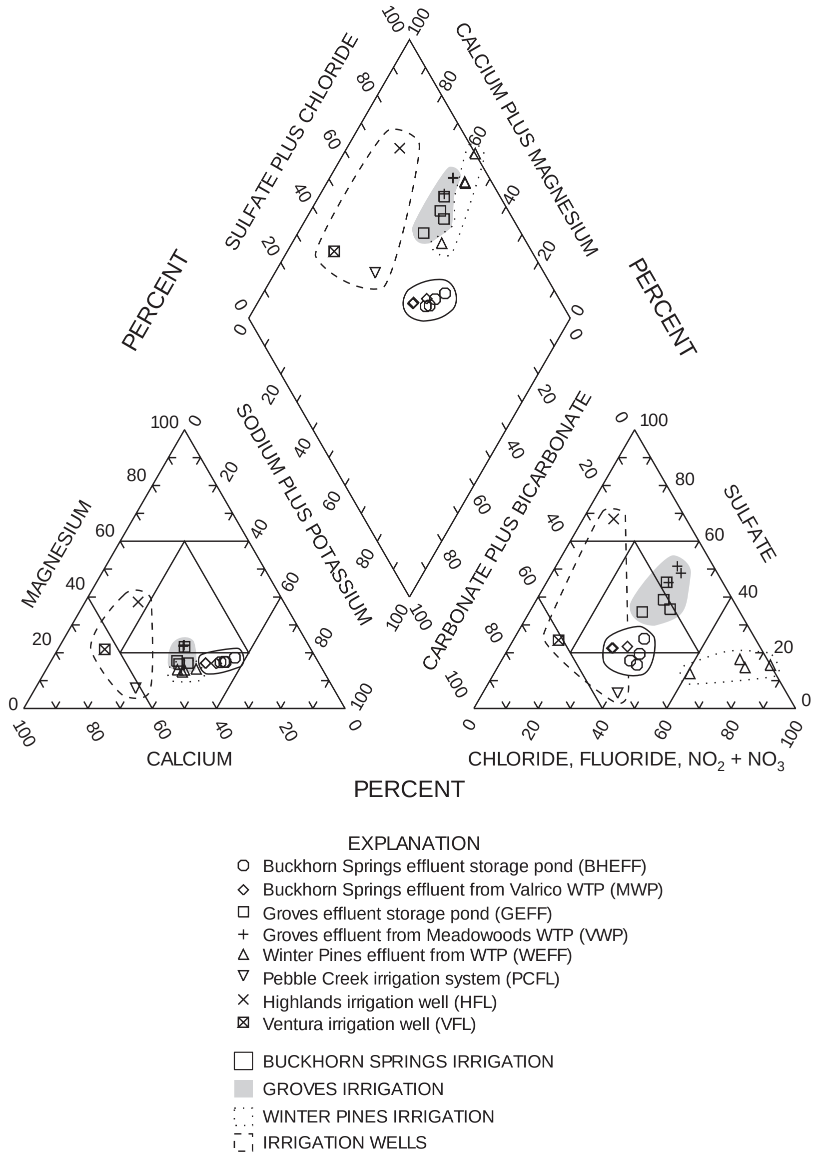

Figure 15. Trilinear diagram showing major ion composition of treated effluent and irrigation water.

exceeded the MCL of 10 mg/L (Florida Department of State, 1993a), and are higher than concentrations measured in water from wells installed for this study for the same time period. The effluent source for Buckhorn Springs golf course irrigation water was converted from secondary (Bloomingdale Interim Wastewater Treatment Plant) to advanced (Valrico Wastewater Treatment Plant) in January 1990. Even though effluent nitrate concentrations at Valrico WTP are much lower than they were at the old plant (0.04 mg/L compared to 8.0 mg/L for 24-hour composite samples from 1990 and 1987, respectively (Hillsborough County, written commun., 1994)), nitrate concentrations in ground water from the compliance wells did not decrease after the new plant opened. This indicates that effluent is not the primary source of nitrate to groundwater at Buckhorn Springs golf course.

Two monitor wells open to the upper Floridan aquifer were sampled by Hillsborough County as part of the reuse permit. Water from the well located on the golf course had higher specific conductance and concentrations of sodium, chloride, nitrate, and TDS than water from the background well. Concentrations of these constituents in water from the Floridan well on the golf course also were higher than other Floridan wells in the area (Jones and Upchurch, 1993). Concentrations of sodium, chloride, and TDS, and specific conductance values, increased from September 1988 to January 1993 in water from the Floridan aquifer compliance well at Buckhorn Springs golf course,

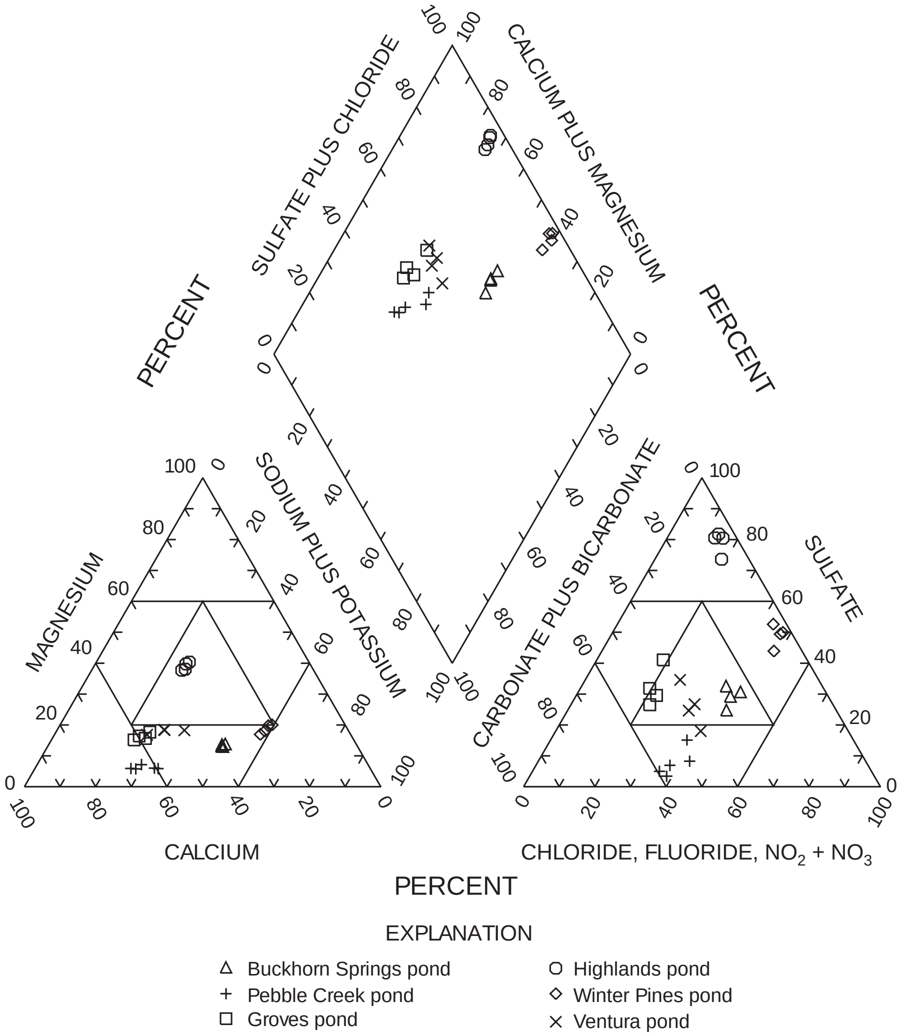

Figure 16. Trilinear diagram showing major ion composition of golf course ponds.

suggesting that irrigation with reclaimed water is affecting the quality of water in this aquifer. During this period, chloride concentration in water from the Floridan aquifer well on the golf course increased from 42 to 76 mg/L (Hillsborough County written commun., 1994). This well is also downgradient from the collapse feature under Miller Road (fig. 4), which may provide a more direct connection between the surficial and Floridan aquifers.

Pebble Creek Golf Course

Pebble Creek golf course, the ground water irrigated golf course paired with Buckhorn Springs, has more variable ground-water chemistry than Buckhorn Springs (fig. 14). Dominant cations in ground-water samples from this course are calcium and sodium, and generally there are no dominant anions (bicarbonate, sulfate and chloride all greater than 20 percent of total anions).

The Pebble Creek irrigation sample (PCFL) is a calcium bicarbonate water type associated with the Upper Floridan aquifer in recharge areas (Swancar and Hutchinson, 1995). Major ions in water from Pebble Creek irrigation system are similar to those at well PC8G, but the irrigation water has a greater percentage of calcium and bicarbonate than water from the other shallow wells (fig. 15).

Pebble Creek pond has calcium as the dominant cation, and bicarbonate and chloride as the dominant anions (fig. 16). The major-ion chemistry of the pond water falls within the ranges of shallow ground-water.

Well PC13G was the only one of the four wells at this golf course with measurable nitrate in all samples, with nitrate concentration ranging from 0.3 to 10 mg/L.

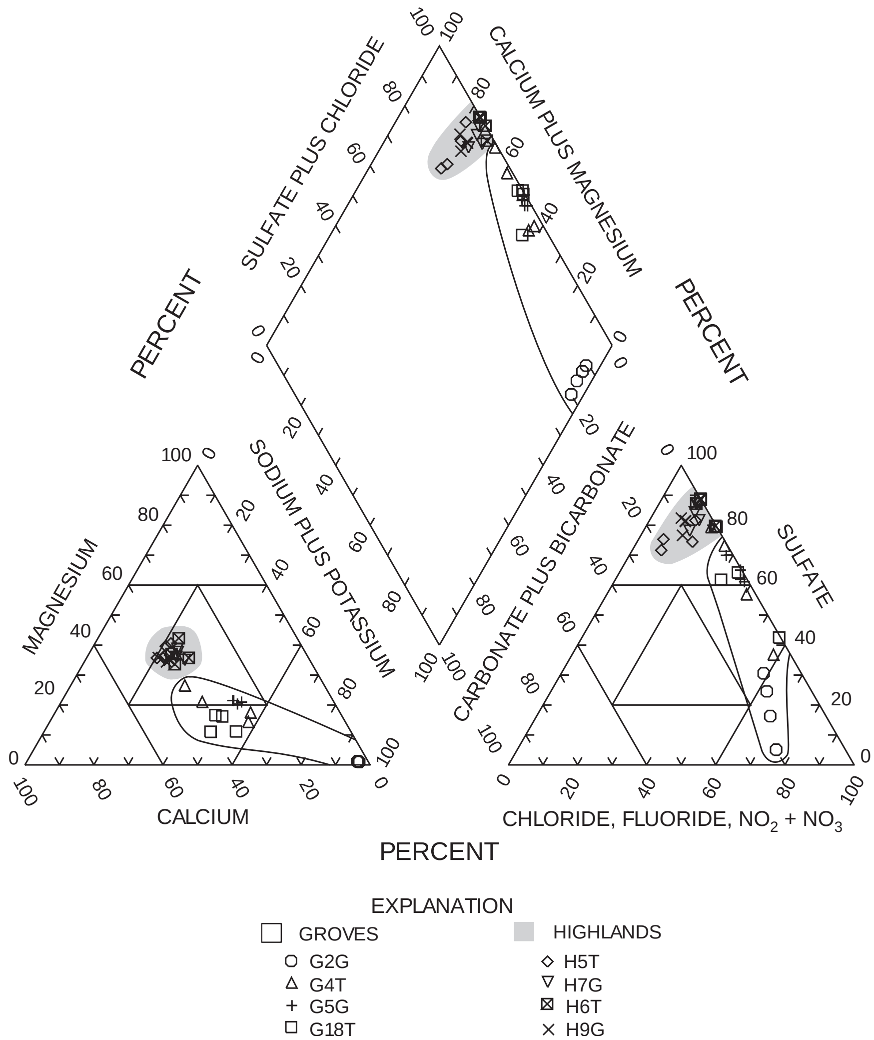

Figure 17. Trilinear diagram showing major ion composition of ground water from the Groves and Highlands golf courses.

Water from the other three wells had measurable ammonia and organic nitrogen, ranging from 0.21 to 3.5 mg/L of ammonia at wells PC7T and PC8G, respectively. Organic nitrogen ranged from 1.2 to 4.4 mg/L at wells PC7T and PC16T, respectively. Water from the irrigation system and pond at Pebble Creek had low nutrient concentrations.

At Pebble Creek golf course, water from the PC16T well had an anomalous, high concentration of beryllium in one sample (57 µg/L). This is the only analysis for beryllium above the highest detection limit during this study. Water from the PC8G well had very high iron (18,000 to 20,000 µg/L), which may be from particulates in the consistently turbid water at this site. Water from the PC13G and PC7T wells had relatively high concentrations of aluminum (990 to 1,300 µg/L, and 690 to 2,300 µg/L, respectively), compared to other shallow ground water.

Water from the irrigation system at Pebble Creek had low levels of trace elements. The sample from Pebble Creek irrigation system (PCFL) had measurable zinc (14 µg/L). The higher pH of irrigation samples may partially account for the lower trace element concentrations compared to ground water samples. Metal cations are more likely to exist as free ions in solution at lower pH (Stumm and Morgan, 1981). The Pebble Creek pond contained low levels of the trace elements measured for this study.

Groves Golf Course

Groves and Highlands golf courses, which are adjacent and constitute a pair with different types of irrigation, have chemically distinct ground-water types (fig. 17, shown above). Groves has either calcium and sodium or sodium as the dominant cations, and sulfate or chloride as the dominant anion. Water from wells

G4T, G5G, and G18T had field alkalinities less than 7 mg/L for all samples.

Samples from Meadowoods WTP (MWP) and Groves effluent storage pond (GEFF) have calcium and sodium as the dominant cations and no dominant anions (fig. 15). Samples from Meadowoods WTP (MWP), which provides the water that irrigates Groves golf course, has similar major ion composition to samples from the effluent storage pond used to store irrigation water, but concentrations in the effluent pond are more dilute (table 4). The irrigation water at Groves has higher bicarbonate concentration than the shallow ground water. Groves pond (GPD) also has consistently higher calcium and bicarbonate concentrations than ground water at that course (fig. 16).

Nitrate concentrations ranged from 1.2 to 26 mg/L in water from well G4T, with two samples exceeding the MCL (table 4). Nitrate concentrations in individual samples from wells G18T and G5G ranged from below the detection limits to 17 mg/L. Nitrate concentration in water from well G2G was always below 0.05 mg/L, but ammonia concentration ranged from 11 to 14 mg/L and organic nitrogen ranged from 3 to 4 mg/L. Ammonia and organic nitrogen concentrations were low in water from other wells on this golf course.

Nutrients are not removed during processing at the Meadowoods WTP, and consequently samples from this plant (MWP) have high concentrations of nitrate (8.7 to 15 mg/L) and orthophosphate (3.6 to 4.1 mg/L) (table 4). Nutrient concentrations in Groves effluent-storage pond (GEFF) indicate that some of the nutrients are removed from the water as it resides in the storage pond, before it is used to irrigate the golf course.

Concentrations of all nutrients in golf course ponds were generally low, with trace levels and values below detection limits making up approximately half of the data. Orthophosphate concentrations in ponds were all below 0.2 mg/L and were commonly much lower.

Water from well G2G had high vanadium (41 to 53 μg/L), low iron (1,200 to 1,600 μg/L), and moderate aluminum (2,300 to 3,600 μg/L) concentrations. Vanadium may be associated with the high dissolved organic carbon in water from well G2G (Hem, 1985). Water from wells G4T and G5G had very high zinc (190 to 860 and 320 to 350 μg/L, respectively), high aluminum (1,300 to 2,100 and 1,200 to 1,500 μg/L, respectively), and high manganese concentrations (110 to 830 and 94 to 130 μg/L, respectively). One sample from well G4T also had a cadmium concentration of 11 μg/L, which exceeds the MCL of 5 μg/L and was the only occurrence of cadmium above the highest detection limit. High zinc concentration in shallow ground water is associated with citrus land use in Florida (Rutledge, 1987), and may be a relict of the previous land use at this golf course. Water from well G18T had zinc ranging from less than detection limits to 32 μg/L, variable iron (100 to 3,400 μg/L), and moderate to high aluminum concentrations (870 to 1,700 μg/L).

Effluent samples both directly from treatment plants and from storage ponds generally contained low levels of trace elements. Water from Groves effluent storage pond (GEFF) and Meadowoods WTP (MWP) had high strontium concentrations (1,900 to 4,100 μg/L and 4,500 to 4,600 μg/L, respectively). Water from Meadowoods WTP had zinc concentrations ranging from 38 to 59 μg/L. At Groves pond (GPD), copper concentrations were above the detection limit in 3 of 4 samples. Elevated copper is probably due to the use of copper sulfate to control algal growth.

Five compliance monitor wells are installed at Groves golf course. These wells are sampled quarterly as part of the reclaimed-water reuse permit by Meadowood Utilities, which operates the sewage treatment plant for the subdivision. Two of these wells reflect background conditions in the surficial aquifer, and three are downgradient compliance wells (appendix). Compliance well C-4 is located west of the effluent storage pond, which is separate from the golf-course operation (fig. 6). The same constituents are measured in these compliance wells as at Buckhorn Springs.

Water from background wells at Groves golf course had higher pH, lower specific conductance, and lower sodium, chloride, and nitrate concentrations compared to water from compliance wells and wells installed for this study (appendix and table 4). Water from compliance wells sampled by Meadowood Utilities had similar concentrations of sodium, chloride, and nitrate, and specific conductance values to water from wells installed for this study with the following exceptions; well C-1 had negligible nitrate, well C-3 had lower sodium and chloride concentrations, and well C-4 had higher specific conductance. The C-4 compliance well had one occurrence of nitrate exceeding the MCL of 10 mg/L. Water from monitor wells sampled by Meadowood Utility had higher pH than water from wells installed for this study. No trends were evident in any water-quality constituents from these wells.

Highlands Golf Course

Ground water from wells at Highlands golf course did not have a dominant cation (calcium, magnesium and sodium plus potassium all greater than 20 percent of the total cations), and sulfate was the dominant anion (fig. 17). Highlands ground water was the least variable in major ion composition of any ground water at the golf courses studied, and analyses plot very close together on the trilinear diagram.

Water from the irrigation well at the Highlands golf course (HFL) is a calcium-magnesium-sulfate water representative of the intermediate aquifer in Sarasota County (Hutchinson, 1984) (fig. 15). Water from the pond at Highlands golf course has the same dominant major ions as water from shallow wells (fig. 16).

Nitrate concentrations in ground water at Highlands golf course were variable, ranging from less than detection limits in some samples from all wells to 9.8 mg/L in one sample at well H6T (table 4). Ammonia concentrations were low, ranging from less than detection limits at well H5T to 2 mg/L at well H6T. Orthophosphate concentrations ranged from 0.57 to 1.8 mg/L in samples from well H9G. Organic nitrogen was generally low, with the highest concentrations in water from H9G well, ranging from 1.1 to 2.8 mg/L. Water from the irrigation well and the pond at Highlands golf course had low nutrient concentrations.

Water from the well H7G had elevated vanadium (5 to 30 μg/L) and iron (170 to 8,500 μg/L) and high manganese (110 to 210 μg/L) concentrations. Water from well H6T had high aluminum concentrations (1,200 to 2,000 μg/L). Water from all of the Highlands sampling sites had high strontium concentrations, corresponding to the high strontium in water from the irrigation well.

Winter Pines Golf Course

The third pair of golf courses, Ventura and Winter Pines, have overlapping ground-water major ion composition (fig. 18). Winter Pines ground waters have either sodium or sodium and magnesium as dominant cations, or they have no dominant cations. Sulfate and/or chloride are the dominant anions. All samples from wells W1G, W12G, and W18T had acidic pH and alkalinity concentrations less than zero.

Treated effluent samples associated with the three golf courses using reclaimed water have calcium and sodium as the dominant cations. Water from Winter Park Estates WTP (WEFF), which goes to Winter Pines golf course, has chloride and nitrate as dominant anions. At Winter Pines, the irrigation water has more calcium than the shallow ground water, and nitrate is a dominant anion in the irrigation water in contrast with sulfate in the ground water (fig. 15). The dominant cations in the golf course pond are calcium and sodium, and dominant anions are chloride and sulfate (fig. 16).

Nitrate concentrations in ground water at Winter Pines were generally low, ranging from less than detection limits to 1.4 mg/L (table 4). Ammonia, organic nitrogen, and orthophosphate were high in water from well W7T, ranging from 15 to 20 mg/L, 1 to 9 mg/L, and 1.7 to 2.0 mg/L, respectively.

Nutrients are not removed from water at Winter Park Estates WTP, and concentrations in effluent (WEFF) were high, with nitrate and orthophosphate concentrations ranging from 15 to 19 mg/L and 0.95 to 1.9 mg/L, respectively. Water from this plant goes directly to the golf course irrigation system rather than to a storage pond. Winter Pines pond (WPD) had ammonia concentrations ranging from 0.078 to 1.3 mg/L.

Trace element concentrations in ground water were generally low at Winter Pines golf course. Wells W1G, W7T, and W12G had moderate to high iron concentrations, ranging from 1,900 to 3,300 μg/L, 1,100 to 1,200 μg/L, and 1,900 to 2,100 μg/L, respectively. Water from well W12G also had high aluminum concentrations (7,800 to 8,900 μg/L). Water from Winter Park Estates WTP (WEFF) had elevated copper (16 to 35 μg/L) and measurable zinc (9 to 21 μg/L) concentrations. Golf course ponds generally contained low levels of the trace elements measured for this study. At Winter Pines pond (WPD), copper concentrations were above the detection limit in some samples.

Three of the four wells monitored by the City of Winter Park (W7T, W12G, and W18T) were used for this study because they were located on the golf course near tees and greens, which are controlled chemical-use areas. The fourth well, WP-6, is located near a fairway, where chemical use is more random (fig. 8). Samples required as part of the reuse permit for wells other than WP-6 were collected by the USGS between September 1992 and April 1993 and were analyzed by the utility.

Data from the compliance wells at Winter Pines are collected by the City of Winter Park on depth to water, turbidity, chloride concentration, total dissolved

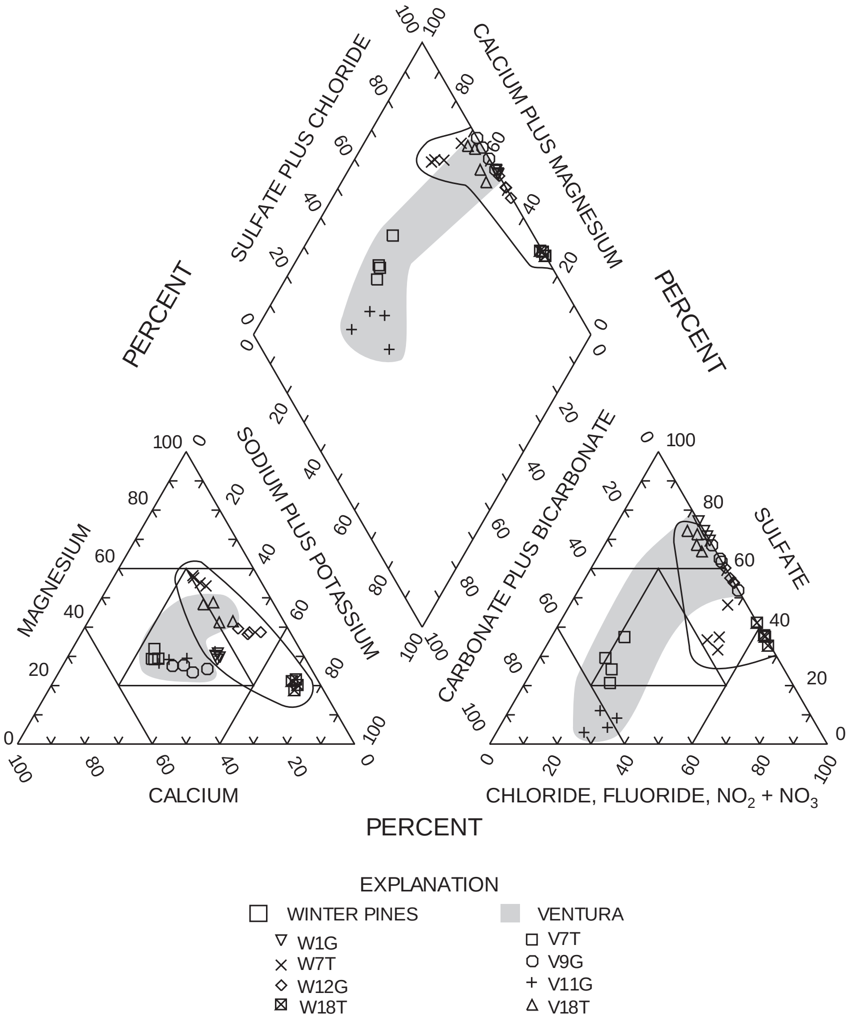

Figure 18. Trilinear diagram showing major ion composition of ground water from Winter Pines and Ventura golf courses.

solids (TDS), nitrate, and fecal coliform bacteria concentration. Nitrate concentrations in ground water at Winter Pines were low in samples collected by the utility, and often were below 1 mg/L (appendix). Specific conductance and concentrations of most major ions were considerably lower in water from pre-existing monitor wells than well W1G, which was installed for this study. Some of this difference may be attributable to incomplete development of the recently installed well W1G. Specific conductance and concentrations of major ions in water from well W1G decreased with time, but values remained higher than the pre-existing wells throughout the study.

Ventura Golf Course

Ground water at Ventura has no dominant cations (fig. 18). Dominant anions are either bicarbonate, sulfate, or there are no dominant anions. All samples from well V9G had alkalinity concentrations less than zero because of the acidity of the water (pH less than 4.5). The Ventura irrigation sample (VFL) is a calcium bicarbonate water type associated with the Upper Floridan aquifer in recharge areas (Swancar and Hutchinson, 1995) (fig. 15). Irrigation water at Ventura golf course has more calcium than the shallow ground water, and more bicarbonate than wells V18T and V9G. Chloride concentration of water from shallow wells at Ventura is higher than in the irrigation well. The dominant cations in Ventura pond (VPD) are calcium and sodium, and there are no dominant anions (fig. 16).

Nitrate concentrations in ground water at Ventura golf course were low, with half of the concentrations below detection limits. Ammonia and organic nitrogen concentrations were high in water from well

V11G, ranging from 2 to 15 mg/L and 3 to 17 mg/L, respectively (table 4). Water from wells V7T and V18T had ammonia concentrations ranging from 2.1 to 5.2 mg/L and 1.6 to 3.0 mg/L, respectively. Water from well V11G had orthophosphate concentrations ranging from 0.57 to 1.4 mg/L. Water from Ventura irrigation well (VFL) and pond (VPD) had low nutrient concentrations.

Water from Ventura golf course wells had high iron concentrations ranging from 870 to 30,000 µg/L. The two wells with the highest iron concentrations, V7T and V11G, were located on the east side of the course, in an area where iron-rich nodules were encountered during well drilling. One sample from well V7T also contained a lead concentration (16 µg/L) that exceeds the 15 µg/L MCL for drinking water. Water from this well also had moderate vanadium concentrations (ranging from 13 to 17 µg/L) relative to samples collected from other wells during this study. Water from well V9G had moderate to high aluminum concentrations ranging from 1,000 to 1,400 µg/L. Water from well V11G had high vanadium (28 to 33 µg/L) and moderate to high manganese (25 to 280 µg/L) concentrations. Similar to well G2G, vanadium may be associated with the high dissolved organic carbon concentration in water from this well (DOC ranging from 75 to 110 mg/L). Ventura irrigation well (VFL) had the only occurrence of molybdenum above detection limits (31 µg/L). Ventura pond (VPD) had copper concentrations above the detection limit. Elevated copper is probably due to the use of copper sulfate to control algal growth.

Bonaventure Golf Course

The major ion chemistry of shallow ground water at Bonaventure golf course is very consistent, reflecting the near-surface limestones of the Biscayne aquifer. The ground-water type is calcium bicarbonate. Smaller percentages of sodium and chloride indicate the incomplete flushing of salt water from the formation (Howie, 1987).

Nutrients in ground water at Bonaventure were mainly in the form of ammonia and organic nitrogen, with concentrations ranging from 1.5 to 15 mg/L of ammonia and 0.2 to 2.1 mg/L organic nitrogen (table 4). Nitrate concentrations were typically below detection limits.

At Bonaventure golf course, one sample from well B17G had a lead concentration of 17 µg/L, which is above the MCL for this element. Water from wells B2G, B7G, and B15G had high iron concentrations ranging from 1,200 to 1,900 µg/L, 4,000 to 5,100 µg/L, and 2,300 to 3,100 µg/L, respectively. Water from well B7G also had high manganese concentrations ranging from 120 to 230 µg/L. All shallow ground water at this golf course had elevated concentrations of strontium, derived from the substitution of strontium for calcium in the limestone.

Pensacola Naval Air Station Golf Course

Dominant cations at Pensacola NAS vary from calcium to mixed calcium, sodium, and magnesium. Dominant anions vary from bicarbonate, to mixed bicarbonate, sulfate, and chloride, to sulfate and chloride. The wells farthest inland have calcium carbonate water, while those closer to Bayou Grande have higher concentrations of sodium, chloride, and sulfate. Nitrate plus nitrite accounted for between 11 and 25 percent of the anions in water from wells NML, N10G, and N14T, making it a significant contributor to the ionic balances of water at those sites. Ground water at Pensacola NAS is generally more dilute than at other sites because of the higher rainfall in this part of the State. The low concentrations of other ions partially account for the significance of nitrate in the ionic balance.

Nitrate concentrations in ground water at Pensacola NAS golf course ranged from 0.61 to 9.9 mg/L (table 4). Nitrate was highest in water from well N14T. Ammonia, organic nitrogen, and orthophosphate concentrations were either below detection or were at trace levels in nearly all samples from this golf course.

Ground water at Pensacola NAS golf course had very low concentrations of most trace elements. Wells N14T and N16G had moderate to high manganese concentrations ranging from 32 to 41 µg/L and 26 to 72 µg/L, respectively. Water from well N10G had zinc concentrations ranging from 9 to 11 µg/L.

Skiing Paradise Golf Course

Calcium is the dominant cation in ground water at Skiing Paradise golf course, and sulfate and chloride are the dominant anions. Exceptions are well S3T, which has a mixed anion water type, and the mix and load well (SML), which has nitrate plus nitrite as the dominant anion in water. Nitrate concentration was high enough to be a major anion (greater than 20 percent of the total anions) in some samples from wells S3T, S4T, and S4G.

During the 6 months over which samples were collected at Skiing Paradise, nitrate increased in water from wells S3T, S4G, and SML to concentrations in the last sample (March 1994) of 16, 8.7, and 35 mg/L, respectively (table 4). All samples from well SML, which is downgradient from the maintenance area, had nitrate concentrations exceeding the 10 mg/L MCL. Ammonia, organic nitrogen, and orthophosphate concentrations in shallow ground water at this course were generally low.

Skiing Paradise golf course had low concentrations of trace elements in ground water. Water from well S4T had moderate zinc (38 to 60 µg/L), low aluminum (1,300 to 1,800 µg/L), and moderate manganese (30 to 46 µg/L) concentrations. Water from well S4G also had moderate zinc concentrations (29 to 40 µg/L).

Dissolved Organic Carbon and Surfactants

Dissolved organic carbon, MBAS (an indicator of detergent-surfactant concentration), and surface tension were measured in water samples for this study. Surfactants reduce the surface tension of liquids, and a tensiometer was used as a screening method for soap, detergent, or other surface active agents in water. High concentrations of either dissolved organic carbon or surfactants can increase the solubility of non-polar organic compounds (Chiou and others, 1986, Kile and Chiou, 1989).

Dissolved organic carbon (DOC) in ground water ranged from below detection limits at NAS well N16G to 110 mg/L at Winter Pines well W7T (table 4). In addition to well W7T, water from two other wells had high DOC concentrations (greater than 90 mg/L); Groves well G2G and Ventura well V11G. Ground water at both Pebble Creek and Bonaventure golf courses also had DOC concentrations greater than 30 mg/L. DOC concentration in ground water was directly related to organic nitrogen concentration, with both constituents indicating an active biological system. Golf courses located in areas with poorly drained soils had higher DOC in ground water. For the 13 sites where soil samples were collected and analyzed for soil organic carbon, no relation was found between DOC in ground water and soil organic carbon content.

Dissolved organic carbon was slightly higher in effluent samples than in ground-water samples at Buckhorn Springs and Groves golf courses, with the exception of the Groves 2G well, which had very high DOC. DOC in samples from Winter Park Estates WTP was equal to or less than DOC in ground water at Winter Pines golf course. DOC was lower in water from irrigation wells than in shallow ground water at Pebble Creek, Highlands, and Ventura golf courses.

Dissolved organic carbon concentrations in ponds were less than or equal to concentrations in ground water and effluent. At Groves, Highlands, and Pebble Creek golf courses, DOC in ponds was lower than in ground water. At Buckhorn Springs and Winter Pines, it was approximately equal to the ground-water concentration, and at Ventura, DOC concentration in the pond was intermediate to water from wells having relatively low DOC (wells V9G and V18T) and those with high DOC (V7T and V11G).

Concentrations of methylene blue active substances (MBAS), an indicator of detergent surfactant concentration, were generally below detection limits. Concentrations of MBAS in shallow ground water ranged from below the detection limit of 0.1 mg/L in all samples from 18 wells to 1.6 mg/L at well V11G. No MBAS was detected in ground-water samples from the Skiing Paradise golf course.

MBAS concentrations in samples from Valrico and Meadowoods wastewater treatment plants (VWP and MWP) were all below the detection limit of 0.1 mg/L, as were concentrations in water from irrigation wells (PCFL, HFL, and VFL). Groves effluent storage pond (GEFF) had two MBAS detections of 0.24 and 0.13 mg/L, and samples from Winter Park Estates WTP (WEFF) had one occurrence of MBAS at 0.15 mg/L.

Winter Pines pond was the only site of all types with measurable MBAS in all samples. Because MBAS concentrations in ground water and irrigation water are generally low for this site, the source of surfactants to the pond may be runoff from nearby streets and residential areas.

Surface-tension measurements also were made using a du Nouy ring tensiometer on 42 samples collected between May and October 1992 (American Society of Testing and Materials, 1989). No samples had surface tensions below 70 dynes per centimeter, a value expected for distilled water. Surface tension must be lower than 55 dynes per centimeter to be an indicator of surfactants in the sample (C. Chiou, USGS, oral commun., 1992).

Quality-Assurance Samples

One of four samples collected during this study was a quality-assurance sample, giving a total of 66 quality-assurance samples. There were roughly equal numbers of three types of quality-assurance samples collected; equipment blanks, field blanks, and duplicates. Equipment blanks were analyte-free blank water processed through the sampling equipment in the same manner as an environmental water sample. Field blanks were analyte-free blank water transferred directly to sample bottles. Duplicates were samples collected sequentially at the same site. Analyte-free water for pesticides, MBAS, and organic carbon was purchased from a laboratory supply company. Analyte-free water for major ions and nutrients was taken from the deionized water system at the USGS office in Tampa, Fla., where the quality-assurance data for this project are available for inspection.

Calcium and silica were detected at low levels (maximum concentrations of 0.3 and 1.1 mg/L, respectively) in 67 and 47 percent of the blank samples. These results indicate that the blank water used for quality assurance samples was not free from these constituents at the level of the analysis. Other constituents that were detected at low levels in greater than 10 percent of the blanks were; dissolved organic carbon (13 percent), ammonia (18 percent), iron (18 percent), and sodium (11 percent). Concentrations of these and other constituents detected in blanks are either lower than or approximately equal to the lowest values found in actual samples, and are therefore not considered an indication of significant contamination during sampling. Water-quality constituents above detection limits occurred more often in equipment blanks than field blanks, indicating a slight increase in sample contamination as samples were processed.

Three blank samples were contaminated by organic constituents, especially a herbicide, picloram. Environmental water samples collected at the same time also had significant concentrations of the same and/or unknown organic constituents. Data on all pesticides for these samples, which were collected at Groves and Highlands golf courses during June and July 1992, were subsequently discarded. The source of contamination to these samples was never identified, but fortunately no further organic contamination of blanks occurred during the study.

Duplicate analyses of sequential samples generally showed good agreement. Constituents with more than three pairs of duplicate samples having a difference greater than or equal to 10 percent were; dissolved organic carbon, sulfate, nitrate plus nitrite, and iron. Two different methods were used to collect DOC samples, and these may have contributed to the error in DOC duplicates. Discrepancies in nitrate plus nitrite analyses were mainly for samples with concentrations between 4 and 8 mg/L. Discrepancies in iron concentrations were mainly for concentrations less than 300 μg/L. Major ion and nutrient analyses of eight additional duplicates sent to the USGS laboratory in Ocala, Fla., agreed with the FDEP laboratory results.

PESTICIDE OCCURRENCES AT FLORIDA GOLF COURSES

Pesticide use on golf courses and in other areas is a concern because of the toxicity of these compounds to diverse life forms. While the shift to more rapidly degrading products over the years has reduced the potential for long-term contamination by persistent chemicals, manufacturers and users are not able to determine ahead of time all of the possible ways that pesticides will interact with the environment. Monitoring of pesticides and their degradation products in the environment is an ongoing task for regulatory agencies as more data are published on pesticide behavior in natural systems, and as new products are continually added to the market.

Summary of Pesticide Occurrences at Nine Florida Golf Courses

This study was the first to collect samples for a broad range of pesticides in surface, ground and irrigation water on Florida golf courses. For this reason, the water-quality data presented here are significant, independent of the results related to the use of reclaimed water for irrigation. Water samples were analyzed for the pesticides listed earlier in this report in table 2. The pesticides in the following list were not detected in any water samples. Pesticides with trade names alongside their chemical names are ones that were reported to be used on at least one of the participating golf courses.

Pesticides analyzed for but not detected in water samples from golf courses (trade names for compounds reported to be used are in parentheses)

Chlorothalonil (Daconil)	Heptaclor
Fenarimol (Rubigan)	Heptachlor epoxide
Iprodione (Chipco 26019)	Hexazinone
Metribuzin (Sencor)	Naled
Triademefon (Bayleton)	Linuron
Dicamba (Trimec)	2,4,5-T
MCPP (Mecoprop)	Picloram
Carbaryl (Sevin)	Carbofuran
Bendiocarb (Turcam)	
Glyphosate (Roundup)	

When pesticides were detected in shallow ground water at golf courses, concentrations were generally low, and 45 percent of all occurrences were at trace levels (table 5). Two golf courses had no pesticides detected in ground water (Groves and Winter Pines), and one had only two occurrences, both at trace levels (Pensacola NAS). There were six occurrences of pesticide concentrations above the drinking water maximum contaminant level (MCL) or ground water guidance concentration (GC) in shallow ground water. Arsenic concentration was above the MCL of 50 µg/L four times in water from three wells. Bentazon and acephate were detected in shallow ground water at concentrations above the GC once each. Table 5 presents analytical results on pesticide concentrations in water samples. Table 6 presents a summary of pesticide occurrences at Florida golf courses.

In addition to arsenic, bentazon, and acephate, the following pesticides were present in ground water from at least one site; atrazine, bromacil, diazinon, diuron, fenamiphos, metalaxyl, oxydiazon, and simazine. Fenamiphos degradation products, fenamiphos sulfoxide and fenamiphos sulfone, were also detected in ground water, typically along with the parent compound. Of these pesticides, bromacil, diazinon, fenamiphos sulfone, metalaxyl, and oxydiazon were detected only at trace levels in ground water.

Fenamiphos and its degradation products were detected in ground water at more sites than any other pesticide, occurring in water from nine wells. Bentazon was detected in samples from six wells, and arsenic was detected in samples from five wells. Of the pesticides that were detected in ground water, bromacil, diazinon, and diuron were not reported to be used by the golf course superintendents. The occurrence of pesticides in water from the mix and load wells in the maintenance areas of the statewide golf courses was not more common than the occurrence in ground water on other parts of those golf courses.

Samples taken directly from irrigation wells on Highlands (HFL) and Ventura (VFL) golf courses contained no detectable pesticides. Samples from WTP's (VWP, MWP, and WEFF) contained trace levels of atrazine, bromacil, and gamma-BHC (Lindane)(table 5). One sample from Valrico WTP (VWP) contained atrazine above trace level. Gamma-BHC was at least tentatively identified in treated effluent from all wastewater treatment plants.

At least one pesticide was present in all but one of the pond samples collected during the study (table 6). More individual pesticides were detected in ponds compared to ground water, but the additional pesticides that were detected were at trace levels. Concentrations of pesticides in golf course ponds were generally low, with 60 percent of all occurrences at trace levels (table 5).

Pesticides detected in ground-water samples from Buckhorn Springs golf course were diuron, bentazon, fenamiphos and fenamiphos sulfoxide, atrazine, bromacil, diazinon, and oxadiazon (table 6). Diuron was present in all samples from well BH3G at concentrations ranging from 0.58 to 1.2 µg/L. Bentazon was present in water from wells BH3G, BH3T, and BH7G at concentrations ranging from a trace level of 3.3 to 120 µg/L. A sample from well BH3T contained 120 µg/L bentazon, which exceeds the ground water guidance concentration (GC) of 20 µg/L for the pesticide established by the State of Florida (Florida Department of Environmental Protection, 1994). Fenamiphos was detected in one sample from each of the wells BH3T and BH3G at trace levels. Fenamiphos sulfoxide, atrazine, bromacil, diazinon, and oxadiazon also were detected in the October 1992 sample from well BH3T at concentrations of 0.54 µg/L, 0.18 µg/L, 0.20 µg/L (trace level), 0.054 µg/L (trace level), and 0.048 µg/L (trace level), respectively. No pesticides were detected in samples from well BH7T. Although detected in some samples, diuron, atrazine, bromacil, and diazinon were not used on the golf course. Bromacil may have been used in this area when it was a citrus grove prior to development of the golf course.

Table 5. Pesticides detected in water samples

[µg/L, micrograms per liter; N, presumptive evidence of presence of material; T, value is less than practical quantitation limit; K, actual value is known to be less than value given; *, exceeds MCL or guidance concentration; NU, not used; ANS, area not specific (i.e., used on roughs and fairways rather than greens); F. sulfoxide, fenamiphos sulfoxide; F. sulfone, fenamiphos sulfone; dup., duplicate sample]

Site code	Date sampled	Pesticide detected	Concentration (µg/L)	Remarks	Date of last reported use of pesticide
		Part A. Ground-water samples			
		Buckhorn Springs			
BH3G	5-27-92	Diuron	0.58		NU
	10-7-92	do.	.76	T	NU
	dup.	do.	.84		NU
	1-5-93	do.	1.1		NU
		Fenamiphos	.030	K	8-31-92
	3-10-93	Diuron	1.2		NU
		Bentazon	3.3	T	7-1-92
BH3T	5-26-92	Bentazon	8.9	N	Not used in 1992 prior to sample
	dup.	Bentazon	8.2	N	do.
	10-8-92	Fenamiphos	.068	T	8-31-92
		F. sulfoxide	.54		do.
		*Bentazon	120		7-1-92
		Atrazine	.18		NU
		Bromacil	.20	K	NU
		Diazinon	.054	T	NU
		Oxadiazon	.048	T	7-6-92 ANS
BH7G	5-26-92	Bentazon	9.6	N	Not used in 1992 prior to sample
		Pebble Creek			
PC8G	5-18-92	Fenamiphos	.18	T	4-13-92
	6-10-92	do.	.11	T	4-13-92
	10-5-92	do.	.16		7-13-92
	12-22-92	do.	.17		7-13-92
	3-18-93	do.	.16		7-13-92
PC16T	5-20-92	Diuron	2.6		NU
		Highlands (Samples collected between 6-17-92 and 6-22-92 at this course were contaminated during collection or transportation)			
H5T	8-18-92	Fenamiphos	.072	T	7-30-92 ANS
	11-20-92	do.	.073	T	10-22-92 ANS
		F. sulfoxide	.20	K	do.
	2-18-93	Fenamiphos	.062	T	10-22-92 ANS
H6T	12-1-92	Bentazon	6.5		8-25-92 ANS
H7G	8-25-92	Fenamiphos	.26		7-30-92
		F. sulfoxide	.27	T	do.
		Metalaxyl	.5	K	Not used 6-1-92 to 8-25-92
	12-2-92	Fenamiphos	.10	T	10-22-92
		Bentazon	8.4		8-25-92
	dup.	Fenamiphos	.15		10-22-92
		Bentazon	7.0		8-25-92
	2-17-93	Fenamiphos	.13	T	10-22-92
		F. sulfoxide	.40	T	do.
		Bentazon	11		1-15-93 ANS
H9G	8-19-92	Fenamiphos	.05	K	7-30-92
		Arsenic	45		8-19-92 ANS
	12-1-92	*do.	126		10-29-92
	2-18-93	*do.	92.1		1-21-93
		Ventura			
V7T	7-15-92	Fenamiphos	.71		June 1991
		Diuron	5.8		NU
	9-21-92	Fenamiphos	.37		June 1991
		Diuron	4.6		NU
	12-9-92	Fenamiphos	.33		June 1991
		Diuron	2.8		NU
	3-1-93	Fenamiphos	.28		June 1991
		Diuron	2.6		NU

Table 5. Pesticides detected in water samples—Continued

[µg/L, micrograms per liter; N, presumptive evidence of presence of material; T, value is less than practical quantitation limit; K, actual value is known to be less than value given; *, exceeds MCL or guidance concentration; NU, not used; ANS, area not specific (i.e., used on roughs and fairways rather than greens); F. sulfoxide, fenamiphos sulfoxide; F. sulfone, fenamiphos sulfone; dup., duplicate sample]

Site code	Date sampled	Pesticide detected	Concentration (µg/L)	Remarks	Date of last reported use of pesticide
		Ventura—Continued			
V9G	9-17-92	Fenamiphos	.034	T	June 1991
		F. sulfoxide	.75		do.
		F. sulfone	.10	K	do.
	dup.	Fenamiphos	.040	T	do.
		F. sulfoxide	.83		do.
		F. sulfone	.10	K	do.
	12-9-92	Fenamiphos	.045	T	do.
		F. sulfoxide	.41	T	do.
	3-1-93	Fenamiphos	.046	T	do.
V11G	9-21-92	Arsenic	47.7		9-11-92
	12-16-92	do.	31		1-12-92
	3-2-93	do.	21.7		1-12-92
		Bonaventure			
BML	3-24-93	Arsenic	22.2		Not used in 1993 prior to sample
	6-8-93	do.	39.8		do.
		Simazine	.16	T	NU
	9-13-9	*Arsenic	51		6-22-93 ANS
		Simazine	.57		NU
	12-28-93	Arsenic	13		6-22-93 ANS
		Simazine	.13	T	NU
	dup.	Arsenic	13		6-22-93 ANS
		Simazine	.13	T	NU
B2G	6-7-93	Arsenic	49.6		Not used in 1993 prior to sample
	9-13-93	Simazine	3.3		NU
	12-27-93	Arsenic	20		6-22-93 ANS
		Simazine	.13	T	NU
		Bonaventure			
B7G	6-8-93	Arsenic	40.3		Not used in 1993 prior to sample
	9-15-93	Simazine	.092	T	NU
	12-27-93	*Arsenic	59		6-22-93 ANS
		Pensacola NAS			
N10G	3-31-93	F. sulfoxide	.56	T	9-12-91
	6-23-93	do.	.20	K	9-12-91
		Skiing Paradise			
S3T	10-14-9	Bromacil	.75	K	NU
	1-4-94	do.	.85	T	NU
	3-8-94	do.	.75	K	NU
S4G	1-3-94	Bentazon	5		
S4T	1-4-94	Acephate	2.0	T	
	3-8-94	*Acephate	8.8		
S5F	1-3-94	Bromacil	.75	K	NU
		<u>Part B. Irrigation-water samples</u>			
		Buckhorn Springs			
BHEFF	5-28-92	Atrazine	.18		NU
		Fonophos	.24		5-19-92
	10-8-92	Bentazon	2.4	T	7-1-92
	1-6-93	Atrazine	.36		NU
	3-15-93	Atrazine	.98		NU
		Chlorpyrifos	.10	K	7-11-92
		Diazinon	.50		NU
		Simazine	3.6		3-10-92
		Fenamiphos	.063	T	2-18-93
		F. sulfoxide	1.0		do.
		F. sulfone	.13	T	do.
VWP	1-5-94	Gamma-BHC	.023	N	
	dup.	do	.024	N	
	3-14-94	Atrazine	.58		

Table 5. Pesticides detected in water samples—Continued

[µg/L, micrograms per liter; N, presumptive evidence of presence of material; T, value is less than practical quantitation limit; K, actual value is known to be less than value given; *, exceeds MCL or guidance concentration; NU, not used; ANS, area not specific (i.e., used on roughs and fairways rather than greens); F. sulfoxide, fenamiphos sulfoxide; F. sulfone, fenamiphos sulfone; dup., duplicate sample]

Site code	Date sampled	Pesticide detected	Concentration (µg/L)	Remarks	Date of last reported use of pesticide
		Pebble Creek			
PCFL	3-14-94	*Atrazine	7.9		
		2,4-D	24		
		Groves (Samples collected between 6-17-92 and 6-22-92 at this course were contaminated during collection or transportation)			
GEFF	12-8-92	Gamma-BHC	0.017	N	
		Atrazine	.038	T	
		Bromacil	.20	K	
	2-25-93	Atrazine	.050	K	
MWP	1-6-94	Gamma-BHC	.018	N	
		Bromacil	.75	K	
	3-9-94	Atrazine	.13	K	
		Winter Pines			
WEFF	3-9-93	Gamma-BHC	.024	T	
		Part C. Surface-water samples			
		Buckhorn Springs			
BHPD	5-27-92	Atrazine	.17		NU
		Isofenphos	.046	T	1990
		Fonophos	.32		5-19-92
	1-5-93	Atrazine	.92		NU
		Chlordane	.10	K	NU
		Simazine	.083	T	1-5-93
	dup.	Atrazine	.94		NU
		Chlordane	.10	K	NU
		Simazine	.085	T	1-5-93
	3-10-93	Atrazine	.32		NU
		Simazine	.17	T	1-6-93
		Fenamiphos	.13	T	2-18-93
		F. sulfoxide	3.2		do.
		F. sulfone	.36	T	do.
		Pebble Creek			
PCPD	5-20-92	Atrazine	1.3		NU
		Diuron	.31		NU
		Ametryn	.055	T	NU
	6-11-92	Atrazine	.34	A	NU
		Ametryn	.035	T	NU
	9-23-92	Acephate	2.8	T	9-10-92
		Methamidophos	1.0	K	do.
		Atrazine	.42		NU
	12-21-92	do.	.65		NU
	3-18-93	do.	2.5		NU
	dup.	do.	2.4		NU
		Groves (Samples collected between 6-17-92 and 6-22-92 at this course were contaminated during collection or transportation)			
GPD	8-26-92	Atrazine	.099	T	NU
		Fenamiphos	.05	K	7-24-92 ANS
		F. sulfoxide	.20	K	do.
	12-7-92	Atrazine	.030	K	NU
		Bromacil	.20	K	NU
	2-23-93	Atrazine	.17	T	NU
		Pronamide	.97	T	2-23-93
		Highlands (Samples collected between 6-17-92 and 6-22-92 at this course were contaminated during collection or transportation)			
HPD	8-20-92	Fenamiphos	.09	T	7-30-92
		F. sulfoxide	.17	T	do.
	11-20-92	Fenamiphos	.059	T	10-22-92
		F. sulfoxide	.34	T	do.

Table 5. Pesticides detected in water samples—Continued

[µg/L, micrograms per liter; N, presumptive evidence of presence of material; T, value is less than practical quantitation limit; K, actual value is known to be less than value given; *, exceeds MCL or guidance concentration; NU, not used; ANS, area not specific (i.e., used on roughs and fairways rather than greens); F. sulfoxide, fenamiphos sulfoxide; F. sulfone, fenamiphos sulfone; dup., duplicate sample]

Site code	Date sampled	Pesticide detected	Concentration (µg/L)	Remarks	Date of last reported use of pesticide
		Highlands—Continued			
	2-18-93	Atrazine	.10	T	NU
		Fenamiphos.	.059	T	10-22-92
		F. sulfoxide	.39	T	do.
		Winter Pines			
WPD	7-23-92	Atrazine	.29		NU
		Ethoprop	7.7		Not used 4-1-92 to 7-23-92
		Fenamiphos	.06	T	do.
		Pronamide	1.0		4-21-92
		Simazine	.48		Not used 4-1-92 to 7-23-92
		Diuron	1.4		NU
	9-16-92	Fenamiphos	.030	K	8-19-92 ANS
		F. sulfoxide	.20	K	do.
		F. sulfone	.10	K	do.
		*Acephate	19		9-3-92
		Methamidophos	1.1	T	do.
		Oxadiazon	.13		Not used 4-1-92 to 9-16-92
		Ethoprop	.54	T	9-10-92
		Simazine	.25		Not used 4-1-92 to 9-16-92
		Malathion	.082		NU
	12-15-92	Fenamiphos	.081	T	10-1-92
		F. sulfoxide	.77	T	do.
		Acephate	1.5	K	12-1-92
		Atrazine	.10	T	NU
		Diuron	.57	T	NU
		*Simazine	5.7		Not used 4-1-92 to 12-15-92
	3-3-93	F. sulfoxide	.3	T	10-1-92
		Oryzalin	2.2		NU
		Atrazine	.65		NU
		Diuron	.49		NU
		*Simazine	38		2-17-93 ANS
		Ventura			
VPD	7-16-92	Atrazine	.09	T	NU
		Diuron	1.2		NU
	dup.	Atrazine	0.095	T	NU
		Diuron	1.1		NU
	9-22-92	Oxadiazon	.027	T	NU
		Diazinon	.062	T	NU
		Malathion	.21	T	NU
	12-17-92	Atrazine	.39		NU
		Diuron	.41	T	NU
	3-2-93	Atrazine	.29		NU
		Diuron	.51	T	NU

Table 6. Summary of pesticide occurrences at nine golf courses in Florida

[Pesticides are ranked by total number of detections from greatest to least; duplicate samples are not included in counts; NAS, Naval Air Station; occurrences of fenamiphos degradation products fenamiphos sulfoxide or fenamiphos sulfone are only counted as fenamiphos if samples do not also contain fenamiphos; --, not detected]

Part A. Ground water
Golf course (number of detections/number of wells)

Pesticide	Buckhorn Springs	Pebble Creek	Groves	Highlands	Winter Pines	Ventura‘	Bona-venture	Pensacola NAS	Skiing Paradise	Total detections/ number of wells/number of courses
Fenamiphos	2/2	5/1	--	7/3	--	7/2	--	2/1	--	23/9/5
Arsenic	--	--	--	3/1	--	3/1	8/3	--	--	14/5/3
Diuron	4/1	1/1	--	--	--	4/1	--	--	--	9/3/3
Bentazon	4/3	--	--	3/2	--	--	--	--	1/1	8/6/3
Simazine	--	--	--	--	--	--	6/3	--	--	6/3/1
Bromacil	1/1	--	--	--	--	--	--	--	4/2	5/3/2
Acephate	--	--	--	--	--	--	--	--	2/1	2/1/1
Atrazine	1/1	--	--	--	--	--	--	--	--	1/1/1
Diazinon	1/1	--	--	--	--	--	--	--	--	1/1/1
Metalaxyl	--	--	--	1/1	--	--	--	--	--	1/1/1
Oxadiazon	1/1	--	--	--	--	--	--	--	--	1/1/1
Total	14/3	6/2	0/0	14/4	0/0	14/3	14/3	2/1	7/4	71/20/7

Part B. Irrigation water (includes samples from wastewater treatment plants, effluent storage ponds, and irrigation wells)
Golf course (number of detections/number of sites)

Pesticide	Buckhorn Sprints	Pebble Creek	Groves	Highlands	Winter Pines	Ventura	Total detections/ number of sites/ number of courses
Atrazine	4/2	1/1	3/2	--	--	--	8/5/3
Gamma-BHC	1/1	--	2/2	--	1/1	--	4/4/3
Bromacil	--	--	2/2	--	--	--	2/2/1
Bentazon	1/1	--	--	--	--	--	1/1/1
Chorpyrifos	1/1	--	--	--	--	--	1/1/1
Diazinon	1/1	--	--	--	--	--	1/1/1
Fenamiphos	1/1	--	--	--	--	--	1/1/1
Fonophos	1/1	--	--	--	--	--	1/1/1
Simazine	1/1	--	--	--	--	--	1/1/1
2,4-D	--	1/1	--	--	--	--	1/1/1
Total	11/2	2/1	7/2	0/0	1/1	0/0	21/6/4

Part C. Surface water (ponds)
Golf course (number of detections)

Pesticide	Buckhorn Springs	Pebble Creek	Groves	Highlands	Winter Pines	Ventura	Total detections/ number of courses
Atrazine	3	5	3	1	3	3	18/6
Fenamiphos	1	--	1	3	4	--	9/4
Diuron	--	1	--	--	3	3	7/3
Simazine	2	--	--	--	4	--	6/2
Acephate	--	1	--	--	2	--	3/2
Malathion	--	--	--	--	1	1	2/2
Methamidophos	--	1	--	--	1	--	2/2
Oxadiazon	--	--	--	--	1	1	2/2
Pronamide	--	--	1	--	1	1	2/2
Ametryn	--	2	--	--	--	--	2/1
Ethoprop	--	--	--	--	2	--	2/1
Bromacil	--	--	1	--	--	--	1/1
Chlordane	1	--	--	--	--	--	1/1
Diazinon	--	--	--	--	--	1	1/1
Fonophos	1	--	--	--	--	--	1/1
Isofenphos	1	--	--	--	--	--	1/1
Oryzalin	--	--	--	--	1	--	1/1
Total	9	10	6	4	23	9	61/6

The reclaimed-water storage pond at Buckhorn Springs golf course (BHEFF) contained higher concentrations and greater numbers of pesticides than water from Valrico WTP (VWP), which provides irrigation water to the golf course (table 5). At Buckhorn Springs, atrazine, fenamiphos sulfoxide, fonophos, diazinon, and simazine were above trace levels in the effluent storage pond. Atrazine was in three of the four samples collected from Buckhorn Springs effluent storage pond at concentrations ranging from 0.18 to 0.98 μg/L. Fenamiphos sulfoxide, fonophos, diazinon, and simazine were detected once each in the storage pond at concentrations of 1.0, 0.24, 0.50, and 3.6 μg/L, respectively. Bentazon, chlorpyrifos ethyl, fenamiphos, and fenamiphos sulfone were detected once each at trace levels in water from the effluent storage pond. The storage pond also receives storm-water runoff from surrounding neighborhoods, which may be a source of pesticides to the pond.

At Buckhorn Springs, atrazine, isofenphos, fonophos, chlordane, simazine, fenamiphos, fenamiphos sulfoxide, and fenamphos sulfone were detected in the pond near the third green. Concentrations of atrazine ranged from 0.17 to 0.92 μg/L. Concentrations of isofenphos, chlordane, simazine, fenamiphos and fenamiphos sulfone were at trace levels. Concentrations of fonophos and fenamiphos sulfoxide in single samples were 0.32 and 3.2 μg/L, respectively.

Pesticides detected in ground-water samples at Pebble Creek were fenamiphos (all samples from well PC8G) and diuron (one sample from well PC16T) (table 5). No pesticides were detected in samples from wells PC13G and PC7T. Fenamiphos concentrations in water from PC8G ranged from a trace level of 0.11 μg/L to 0.18 μg/L. Dates when fenamiphos was last used at Pebble Creek before each sample was collected are also listed in table 5. Diuron was not used at any of the participating golf courses.

The irrigation system at Pebble Creek (PCFL) was only sampled once, and had significant concentrations of atrazine (7.9 μg/L, which is above the MCL), and 2,4-D (24 μg/L). The irrigation system consists of two wells and a storage pond. The storage pond also receives storm-water runoff from the surrounding neighborhood. Because this site was only sampled once and the contribution of water from different surface and ground water sources is unknown, the source of these pesticides is unclear. Atrazine was not used on the golf course; however, 2,4-D was used to control weeds.

At Pebble Creek pond (PCPD), atrazine, diuron, ametryn, acephate, and methamidophos were detected in water samples (table 5, part C). Atrazine was in all Pebble Creek pond samples at concentrations ranging from 0.34 to 2.5 μg/L. Diuron was in one sample at a concentration of 0.31 μg/L, while ametryn (two samples), acephate, and methamidophos were at trace levels.

No pesticides were detected in ground-water samples collected from Groves golf course. Results of pesticide analyses for both Groves and Highlands golf courses from the first quarter sampling in June and July 1992 were discarded because of possible sample contamination during collection or transportation. Field blank samples during this period indicated an unknown source of contamination.

Groves reclaimed-water storage pond (GEFF) contained trace levels of the same pesticides detected in water from Meadowoods WTP (MWP), which discharges water to the pond. This storage pond also receives storm-water runoff, but the surrounding area is undeveloped and is used as a park with an exercise trail. Atrazine, fenamiphos, fenamiphos sulfoxide, bromacil and pronamide were at trace levels in samples from the Groves pond on the golf course near the fourth tee (GPD).

Pesticides detected in ground water at Highlands golf course were fenamiphos, fenamiphos sulfoxide, metalaxyl, arsenic, and bentazon (table 6). Fenamiphos was detected in samples from wells H5T (three samples), H7G (three samples), and H9G (one sample) at concentrations ranging from a trace level of 0.05 to 0.26 μg/L. Fenamiphos sulfoxide was detected in samples from wells H5T and H7G at trace concentrations ranging from 0.20 to 0.40 μg/L. Metalaxyl was detected in one sample from well H7G at a trace concentration. Arsenic was present in all three samples from well H9G, with two samples at concentrations above the MCL of 50 μg/L (92 and 126 μg/L). Arsenic in these samples is assumed to be derived from the herbicide MSMA, which is used monthly at this golf course. Bentazon was detected in water from wells H6T (one sample) and H7G (two samples) at concentrations ranging from 6.5 to 11 μg/L. Atrazine, fenamiphos, and fenamiphos sulfoxide were at trace levels in samples from Highlands pond (HPD).

Pesticides were not present in any ground water samples at Winter Pines golf course. Atrazine, ethoprop, fenamiphos, fenamiphos sulfoxide, fenamiphos sulfone, pronamide, simazine, diuron, acephate, methamidophos, oxadiazon, malathion, and oryzalin were detected in at least one sample out of the four collected from the pond at Winter Pines golf course (WPD) (table 6). Atrazine, ethoprop, simazine, diuron and acephate were at trace and quantifiable concentrations in at least two samples from the pond. Pronamide, oxadiazon, malathion and oryzalin were in single pond samples at concentrations of 1.0, 0.13, 0.082, and 2.2 µg/L, respectively. Fenamiphos, fenamiphos sulfoxide, fenamiphos sulfone, and methamidophos were detected at trace levels in the pond. There were three occurrences of pesticide concentrations above the MCL or the GC in the pond at Winter Pines golf course. Simazine was detected twice at concentrations above the MCL of 4 µg/L and acephate was detected once above the GC of 7.5 µg/L.

Pesticides detected in ground water at Ventura golf course were fenamiphos, fenamiphos sulfoxide, fenamiphos sulfone, diuron, and arsenic (table 6). Fenamiphos was present in samples from wells V7T (all four samples) and V9G (three samples), at concentrations ranging from a trace level of 0.034 µg/L to 0.71 µg/L (table 5). Fenamiphos sulfoxide and fenamiphos sulfone, both degradation products of fenamiphos, were detected in water from well V9G. Diuron was present in all samples from well V7T at concentrations ranging from 2.6 to 5.8 µg/L. Arsenic was detected in three samples from well V11G at concentrations ranging from 21.7 to 47.7 µg/L. No pesticides were detected in water from well V18T.

The pond at Ventura golf course (VPD) contained detectable concentrations of atrazine, diuron, oxadiazon, diazinon, and malathion. Concentrations of atrazine ranged from a trace level of 0.09 µg/L to 0.39 µg/L. Diuron also was detected in three samples at concentrations ranging from a trace level of 0.41 µg/L to 1.2 µg/L. Oxadiazon, diazinon, and malathion were at trace levels in one sample.

Pesticides in ground water at Bonaventure golf course were arsenic and simazine. Arsenic was present in water from wells BML, B2G, and B7G at concentrations ranging from 13 to 59 µg/L (table 5). Arsenic concentrations exceeded the MCL of 50 µg/L at the mix and load site (BML) (51 µg/L) and well B7G (59 µg/L). Simazine was detected in samples from the same wells as arsenic, at concentrations ranging from a trace level of 0.092 µg/L to 3.3 µg/L. No pesticides were detected in water from wells B15G and B17G.

Trace levels of fenamiphos sulfoxide in two samples from well N10G were the only pesticides detected in ground water samples from Pensacola NAS golf course.

Pesticides detected in ground water at Skiing Paradise golf course were bromacil, bentazon, and acephate (table 6). Bromacil was present at trace concentrations in water from wells S3T (three samples) and S5F (one sample), and may be due to the previous land use for citrus cultivation. Bentazon was present in one sample from well S4G at a concentration of 5 µg/L. Acephate was present in two samples from well S4T at concentrations of 2.0 and 8.8 µg/L. The second occurrence of acephate exceeds the guidance concentration of 7.5 µg/L.

Discussion of Pesticides Found in Water Samples

The following paragraphs discuss the frequency and distribution of individual pesticides in water on Florida golf courses. Information is also presented about pesticide mobility, and the relation of pesticide use to detections. Pesticides are discussed alphabetically by chemical name. Chemical characteristics of pesticides detected in water samples are shown in table 7.

Acephate (Orthene) is an insecticide used on all golf courses participating in the study. It was detected in water samples from one well and two ponds, with two of the four occurrences over the guidance concentration (GC) established by the State (Florida Department of Environmental Protection, 1994) (table 5). Occurrences in the Winter Pines pond (WPD) and Pebble Creek pond (PCPD) were either 13 or 14 days from the last application. Methamidophos, a degradation product of acephate, was present in some of the samples where acephate was detected. Acephate and methamidophos are reported to degrade to immobile compounds after 20 days (Meister, 1994).

Ametryn is a herbicide that was detected twice at trace levels in Pebble Creek pond (PCPD), but is not used at that golf course. In Florida, ametryn may be used in combination with another triazine herbicide, simazine (Meister, 1994). Ametryn is persistent in the environment, with a half-life in aqueous solution greater than one week (United States Environmental Protection Agency, 1989).

Arsenic is a component of the highly soluble herbicide MSMA, which was used at all golf courses participating in the study. Arsenic was detected on three golf courses, but only in ground-water samples. Arsenic concentrations in water from Highlands well H9G ranged from 45 to 126 µg/L. MSMA was applied

Table 7. Characteristics of pesticides found in water samples

[mg/L, milligrams per liter; mPa, milliPascal; Kow, octanol-water partition coefficient; Koc, organic carbon partition coefficient; Toxicity based on EPA classification from oral LD50 for rats, class I=high, class II=moderate, class III=slight, class IV=low; MCL, maximum contaminant level; GC, guidance concentration (FDEP, Florida Department of Environmental Protection, 1994), values are guidance concentrations unless otherwise noted; µg/L, microgram per liter; I, insecticide; H, herbicide; N, nematicide; F, fungicide; OP, organophosphate; >, greater than; -, not available. Data from M. Sandstrom, USGS, written commun.(1992), Gustafson (1993), and Meister (1994)]

Name	Common Name	Use	Class	Solubility in water (mg/L)	Vapor pressure (mPa)	log Kow	log Koc	Toxicity	MCL/GC (µg/L)	Half-life (days in field soil)
Acephate	Orthene	I	OP	650,000	0.23	-	2.0	slight	7.5	3.0
Methamidophos (metabolite)			OP	2,000,000	40	-	2.9	high	5	6.0
Ametryn	-	H	triazine	185	0.11	-	2.6	slight	63	48.5
Atrazine	-	H	triazine	30	0.04	-	2.7	slight	3 (MCL)	81.4
Bentazon	Basagran	H	none	500	0.01	2.3	1.5	slight	17.5	22.4
Bromacil	-	H	uracil	815	0.03	2.0	1.9	low	90	265.0
Chlordane	-	I	chlorinated cyclodiene	0.05	1.33	3.0	-	moderate	2(MCL)	1772.8
Chlorpyrifos	Dursban	I	OP	0.3	1.2	5.0	4.1	moderate	21	32.2
2,4-D	-	H	chlorinated phenoxy	620	1000	1.6	1.3	slight	70 (MCL)	11.7
Diazinon	-	N	OP	40	3	3.3	3.0	moderate	6.3	32.2
Diuron	-	I	urea	42	0.41	2.0	2.7	low	14	206.8
Ethoprop	Mocap	N	OP	750	46.5	-	1.8	moderate	-	48.0
Fenamiphos	Nemacur	N	OP	400	0.13	2.2	2.2	high	1.75	15.5
Fenamiphos sulfoxide (metabolite)				3.7	-	1.3	-	-	-	-
Fenamiphos sulfone (metabolite)				85	-	1.4	-	-	-	-
Fonophos	Crusade	I	OP	13	28	-	2.9	high	14	42.3
Gamma-BHC	Lindane	I	organo-chlorine	6.5	3.5	3.8	3.0	moderate	0.2 (MCL)	449.8
Isofenphos	Oftanol	I	OP	23.8	0.53	-	-	high	-	14.2
Malathion	-	I	OP	145	1	2.9	3.3	low	140	1.0
Metalaxyl	Subdue	F	no class	7100	0.29	-	1.2	slight	420	21.0
MSMA	-	H	organic arsenical	>1,000,000	-	-	4.0	slight	50 (MCL for arsenic)	-
Oryzalin	Surflan	H	no class	24	-	-	3.4	low	350	41.5
Oxydiazon	Ronstar	H	no class	(low)	-	-	-	low	35	72.0
Pronamide	Kerb	H	amide	15	11.3	-	3.0	low	525	60.0
Simazine	Princep	H	triazine	3.5	0.001	2.2	2.1	low	4 (MCL)	72.0

on this golf course at least monthly. At Ventura well V11G, arsenic concentrations in water decreased from 47.7 µg/L to 21.7 µg/L in three samples collected between September 1992 and March 1993. MSMA was applied 10 days before the sample with the highest concentration in water from V11G was collected. Arsenic is present naturally in ground water, and background concentrations of arsenic in ground water in the United States average less than 20 µg/L (National Research Council of Canada, 1978). In table 5, arsenic concentrations near this level have sometimes been reported as pesticide occurrences to show how arsenic concentrations have changed with time. Arsenic concentrations near 20 µg/L may or may not be related to pesticide use. German (in press) reported arsenic concentrations less than detection limits for 16 out of 17 shallow ground-water samples from a pristine area in central Florida. The remaining well had a concentration of 2 µg/L. Miller and Sutcliffe (1984) reported an arsenic concentration of 9 µg/L in water from a shallow background well in a phosphate mining area.

Atrazine is a herbicide that is not used on Florida golf course playing areas because it is harmful to bermuda grass, however, it was reportedly used occasionally near clubhouses and other landscaped areas. Atrazine is the second most widely used pesticide in the country (Gianessi and others, 1986), and the most heavily used herbicide in the U.S. over the past 30 years (United States Environmental Protection Agency, 1989). Atrazine was present in all surface-water bodies; either golf course ponds or irrigation-water storage ponds, and was detected in only one well. Atrazine is the most widely detected pesticide in surface waters in Florida (Pfeuffer, 1991; Shahane, 1994). Sources of atrazine present in surface water may be runoff from residential or other landscaped areas, or rainfall (Richards and others, 1987; Goolsby and others, 1991).

Bentazon (Basagran) is a herbicide that was used on seven of the nine participating golf courses, and was detected primarily in ground water samples, with one occurrence at a trace level in a sample from a reclaimed-water storage pond. Of the seven sampling sites where bentazon was present, four were at Buckhorn Springs golf course, and only one of these occurrences was above trace levels. The high bentazon concentration in one sample from the Buckhorn Springs well BH3T (120 μg/L) may be correlated with its last use on the tees at that golf course 3 months earlier. Bentazon in ground water at Highlands golf course may be correlated with its use from 1 to 3 months before samples were collected from wells H6T and H7G. Laboratory data show that bentazon can be stable in soil for this length of time and that it is very mobile in a range of soils (Drescher and Otto, 1972; Abernathy and Wax, 1973).

Bromacil, a herbicide that has been widely used in citrus groves in Florida, was present at trace levels in water from wells on two of the golf courses where the land was previously used for citrus cultivation (Buckhorn Springs and Skiing Paradise). Bromacil was not used by the golf courses, and its occurrence is probably due to the previous land use. Bromacil was present at trace levels in the pond (GPD) and effluent-storage pond (GEFF) on Groves golf course, an area that also was once used for citrus cultivation. A trace detection at Meadowoods WTP (MWP) indicates that irrigation water also might be a source of bromacil at Groves golf course. Bromacil was the third most frequently detected pesticide in Florida surface waters (Shahane, 1994). Two field studies found bromacil residues to be persistent in a range of soils for longer than 2 years (U.S. Environmental Protection Agency, 1989).

Chlordane is an insecticide that has been used in the past against termites, but it is no longer registered for use in the U.S. Chlordane is an organochlorine pesticide and is inert to many chemical reactions and therefore persistent. A study by Cohen and others (1990) detected chlordane in ground water at concentrations above the existing health guidance level at golf courses in Cape Cod. Chlordane had been used as an insecticide and herbicide on these golf courses between the 1950's and 70's. The single occurrence of chlordane during this study at a trace level in the Buckhorn Springs pond (BHPD) does not indicate that chlordane is a commonly occurring pesticide in ground water on Florida golf courses. Chlordane was reported in six surface water samples in Florida at concentrations below 0.12 parts per billion (Shahane, 1994).

Chlorpyrifos (Dursban) is an insecticide used on all of the golf courses included in this study. It is one of the most widely used insecticides in the country (Gianessi and others, 1986). Clorpyrifos was found in one sample at a trace level in the Buckhorn Springs effluent-storage pond (BHEFF).

2,4-D is a herbicide that was most commonly used on the golf courses participating in this study in the product Trimec, a combination of 2,4-D, mecoprop, and dicamba. 2,4-D is one of the top five herbicides used in the country (Gianessi and others, 1986) and is the second most frequently detected pesticide in Florida surface waters (Shahane, 1994). However, the compound is degraded rapidly in soils by biological processes (M. Sandstrom, written commun., 1992), with a soil half-life less than 12 days (Gustafson, 1993). In an experimental setting, Watschke and Mumma (1989) found the concentration of 2,4-D in runoff to be up to twice the concentration in leachate. This herbicide was present in the sample from Pebble Creek irrigation system (PCFL), which includes a storage pond. This compound probably came into the irrigation system from the storage pond rather than the deep irrigation wells.

Diazinon is a relatively short-lived organophosphate insecticide that was present at trace levels in water from one well (BH3T) and one pond (VPD), and at a quantifiable level at one effluent storage pond (BHEFF). Although diazinon is one of the 20 highest use insecticides by weight in the country (Gianessi and others, 1986), it was not used on the golf courses. The surface-water sites may have received the compound in runoff from surrounding residential areas.

Diuron is a herbicide that was present at quantifiable levels in water from three wells (PC16T, BH3G, and V7T) and three ponds (PCPD, VPD, and WPD) during this study. Two of these three wells were adjacent to the ponds in which diuron also was present. Concentrations in ground water were higher than in ponds. Diuron is not used on the golf courses. It was present at low concentrations in other Florida surface waters (Shahane, 1994), and also present in surface waters in other areas (U.S. Environmental Protection Agency, 1989). Diuron was detectable in runoff-water sediment and soil samples for up to 3 years after application to pineapple-sugarcane fields in Hawaii (Green and others, 1977).

Ethoprop (Mocap) is a nematicide/insecticide that was detected in two samples from the pond at Winter Pines golf course (WPD). Ethoprop was used by four of the nine golf courses in this study. Although this product was used at Winter Pines, there was no reported use during the 3 months before the sample with the highest concentration of ethoprop (7.7 μg/L) was collected. Ethoprop is estimated to have a half-life of 48 days in field soils (Gustafson, 1993).

Fenamiphos (Nemacur) is an organophosphate nematicide used at all of the golf courses participating in this study. It was present at more sites sampled during this study than any other pesticide; in eight wells, four ponds, and one effluent-storage pond. A total of 27 samples contained measurable concentrations of fenamiphos, with eight concentrations above trace levels. Two degradation products of fenamiphos, fenamiphos sulfoxide and fenamiphos sulfone, were also detected in water from the same sites where the parent compound was present. The degradation products are oxidation products of fenamiphos, and have equal pesticide activity (Waggoner and Khasawina, 1974), and potentially greater toxicity as anticholinesterases (Fukuto, 1987).

Fenamiphos sulfoxide and sulfone were detected in 14 and 3 samples, respectively, but the higher detection limits (0.2 and 0.1 μg/L compared to 0.03 μg/L for most fenamiphos analyses), and the fact that these compounds were not analyzed initially, underestimate the potential occurrence of the degradation products in water at Florida golf courses. Concentrations of fenamiphos sulfoxide were from 2 to 20 times greater than fenamiphos concentrations in samples that had both compounds present. Previous and ongoing studies, including the work by Snyder and Cisar (1993), also have shown that the degradation products, especially fenamiphos sulfoxide, are commonly at higher concentrations than the parent compound in soils and leachate (Green and others, 1982; Crepeau and others, 1991; Simon and others, 1992).

The highest concentration of fenamiphos in water was 0.71 μg/L (Ventura well V7T), which is less than half the GC of 1.75 μg/L. The highest concentration of fenamiphos sulfoxide was 3.2 μg/L (Buckhorn Springs pond BHPD), which may be toxicologically significant, but standards for fenamiphos degradation products have not been established (Florida Department of Environmental Protection, 1994). At Ventura golf course, where the highest concentrations of fenamiphos occurred, the compound had not been used for over a year. At Buckhorn Springs, Pebble Creek, Groves, Highlands, and Winter Pines golf courses concentrations of fenamiphos and degradation products showed no relation to the number of days since the last reported use.

Fenamiphos is a relatively new pesticide that degrades quickly compared to many older products. The occurrence of fenamiphos in golf course ponds is unusual, as research shows it degrading rapidly in artificial light (Dime and others, 1983). Soil microorganisms also can acclimate to using fenamiphos as a food source, so that the repeated use of fenamiphos causes increased rates of degradation (Dunn, 1990; Ou, 1991). It could not be determined whether increased degradation with time was occurring at any of the golf courses studied. One of the oldest golf courses, Buckhorn Springs, still had fenamiphos detections in ground water, while one of the youngest, Groves, had no detections in ground water.

The aerobic degradation pathway of fenamiphos is by oxidation to the sulfoxide and sulfone compounds and then by hydrolysis to substituted phenols (Simon and others, 1992). Hydrolysis takes place with no microbial action at higher pH's, but also may be enzymatic (Fukuto, 1987). Deaminated fenamiphos was the primary degradation product after 7 to 14 days at a pH of 3.0 in a dark, buffered system (McNamara and Wilson, 1981). In the same study, fenamiphos was stable in a dark, buffered system at a pH of 7. The differences in fenamiphos stability related to pH may be a possible explanation for the lack of detections in ground water at Groves and Winter Pines golf courses. Both pH and alkalinity of ground water samples at these golf courses were significantly lower than their ground-water irrigated counterparts.

The insecticide fonophos (Dyphonate or Crusade) was not on the original analyte list but was identified in samples from two surface-water sites at Buckhorn Springs golf course (BHEFF and BHPD). It was used on over 60 acres of the golf course 8 days before samples were collected. Fonophos is mobile in sandy soils (Lichtenstein and others, 1972).

Gamma-BHC (Lindane) is a persistent organochlorine insecticide that was present at trace levels in samples collected during this study from WTPs and effluent-storage ponds. One potential source of gamma-BHC in wastewater is its use in products to treat head lice. The distribution of this compound in effluent and shallow ground water at two other wastewater land-application systems is reported in Hutchins and others (1985). Gamma-BHC has also been found in urine (Kutz and others, 1978).

Isofenphos (Oftanol) is an insecticide present at a trace level in one sample from Buckhorn Springs pond (BHPD). Isofenphos had not been used on the golf course for over a year.

The insecticide malathion was detected in samples from ponds at Ventura and Winter Pines golf courses (VPD and WPD) during the same week in September 1992. This compound was last used at Ventura golf course in January 1991, and was not listed as used by any of the other golf courses. Malathion was also found in surface waters in Orange County by German (1986), and was attributed to its use for either mosquito control or citrus grove spraying in the area. Three other detections in Florida surface waters are reported in Shahane (1994).

Metalaxyl (Subdue) is a fungicide present at a trace level in one sample from Highlands well H7G. This product has been previously used on this golf course.

Oryzalin (Surflan) is a herbicide used by all golf courses participating in the study. It was detected in a sample from the pond at Winter Pines golf course (WPD).

Oxadiazon (Ronstar) is a herbicide that was reported to be used on four of the nine golf courses in this study. Although not on the original analyte list, it was detected at trace levels in water from one well (BH3T) and one pond (VPD), and at a quantifiable level in another pond (WPD). The occurrences at Buckhorn Springs and Ventura may be correlated with use on the golf courses from 3 to 9 months before the samples were collected.

Pronamide (Kerb) is a herbicide used at eight of the nine golf courses. It was present in golf course ponds at Groves (GPD) and Winter Pines (WPD). The occurrence in Groves pond is probably due to airborne drift from the application of the herbicide the day samples were collected. Pronamide was used at Winter Pines 3 months before the occurrence in the pond. Degradation rates for pronamide are variable (U.S. Environmental Protection Agency, 1989).

Simazine (Princep) is a herbicide that was used on four of the participating golf courses (Buckhorn Springs, Winter Pines, Ventura and Bonaventure). It was detected in water from three wells (BML, B2G, and B7G), two ponds (BHPD and WPD), and one effluent-storage pond (BHEFF). All samples from wells that contained simazine were on Bonaventure golf course. Simazine also was used at Buckhorn Springs, and was detected twice at trace levels in the pond (BHPD), and at a concentration of 3.6 µg/L in the effluent-storage pond (BHEFF). The detection in the storage pond may be correlated with use of simazine nearby 5 days before sample collection. Simazine was detected in all samples from the pond at Winter Pines golf course (WPD), with two detections above the MCL of 4 µg/L. Simazine has been reported in eight samples from Florida surface waters, with concentrations up to 145 µg/L (Shahane, 1994).

EFFECTS OF IRRIGATION WITH RECLAIMED WATER

Statistical methods were used to quantify the effects of irrigation with reclaimed water on ground-water quality and pesticide occurrence at the six paired golf courses. The differences in ground-water quality between golf courses using reclaimed water and those using ground water for irrigation were quantified using three methods depending on the percentage of the data with values below detection limits (censored data) (Helsel and Hirsch, 1992; Inman and Conover, 1983). All methods use a level of significance (alpha) of 0.05, which means that there is a 5 percent chance of deciding a difference exists when there really isn't any difference in ground-water quality between samples grouped by irrigation type. Table 8 shows the grouping of water-quality constituents for statistical treatment.

For constituents with less than 5 percent of the data below detection limits, a t-test on ranked data (also called the Wilcoxon-Mann-Whitley rank sum

Table 8. Groupings of water-quality constituents for statistical treatment

Percentage of data with values less than detection limits		
less than 5 percent	**10 to 20 percent**	**greater than 20 percent [1]**
Alkalinity	Ammonia	Nitrate+nitrite
DOC	Manganese	Dissolved phosphorus
Calcium	Aluminum	Orthophosphate
Magnesium		Fluoride
Sodium		Copper
Potassium		Vanadium
Chloride		Zinc
Sulfate		MBAS
Silica		Pesticides
Iron		
Strontium		
Kjeldahl nitrogen		
pH		
Temperature		
Specific conductance		
Dissolved oxygen		

[1]All other metals had greater than 85 percent of data below detection limits and were not analyzed statistically.

test) was used. Nonparametric procedures such as ranking were appropriate for this analysis because distributions were typically non-normal. For these tests, mean values of constituents from the four or five samples for each well were used. When means were calculated, values less than detection limits were given the value of the detection limit. This method was felt to be acceptable for the small number of individual values in this class (nine analyses out of over 1,500), even though it introduces positive bias. Mean values must be used rather than individual sample values for this test because the four samples taken at each well are not independent of each other. Sample independence is a requirement for all of the statistical tests used. Constituents that had less than 5 percent of the data below detection limits included all major ions and field constituents.

For constituents with 10 to 20 percent of the data at less than detection limits, t-tests on ranks were calculated for each set of quarterly samples. Unlike the full data set, which includes four non-independent samples from each well, each quarterly set of samples from all wells consists of independent samples. Values less than detection limits were assigned the value of the highest detection limit used for the analysis during the study, then the data were ranked from smallest to largest. Ranking these data was an acceptable procedure because it reflects the true order of values (Helsel and Hirsch, 1992). T-tests on quarterly data also allowed for some interpretation of seasonal trends in water quality.

For constituents with greater than 20 percent of the values less than detection limits, contingency tables were used to determine if water quality differences existed based on irrigation type. All pesticides along with some inorganic constituents fell into this category. Contingency tables test whether frequency counts of occurrences in different classes are independent of their classification. In this analysis, data were grouped in two classes representing the two irrigation types. Counts are the frequency of a detected concentration in ground water of a particular constituent or group of constituents for each irrigation type. Examples will be demonstrated in the following sections, where the results also are summarized. Significant statistical relations are presented in table 9.

The pH data can be used to demonstrate the method when a constituent has less than 5 percent of the data below detection limits. Mean pH is calculated as the negative log of the mean hydrogen-ion concentration. The mean pH's of water from the 24 wells are ranked from lowest to highest, then the ranked pH's are grouped by irrigation type, reclaimed water or ground water, and a mean rank for each irrigation type is calculated. Mean rank pH at effluent-irrigated courses is 9.33 (median pH is 4.8), and mean rank pH at ground-water irrigated courses is 15.66 (median pH is 5.6). A test statistic based on the mean ranks, standard deviation, and number of samples is calculated and compared with a table based on random variables with the specified level of significance and degrees of freedom. If the test statistic is greater than the critical value in the table, then there is a significant difference between the two groups. For the pH data, the test statistic (T) is 2.41 and the critical value for an alpha of 0.05 and 22 degrees of freedom from a student's t distribution is 1.71. Because 2.41 is larger than 1.71, the difference between the means is significant under the stated assumptions.

Significant differences in mean pH (fig. 12), alkalinity (fig. 13), and chloride concentrations in ground water were found between the two irrigation types based on the t-tests on mean ranks for these constituents. Ground water at golf courses irrigated with reclaimed water had lower pH and alkalinity, and higher chloride.

Alkalinity and pH are related through carbonate equilibria, so in most natural waters increased alkalinity will accompany an increase in pH. As mentioned in the section on major ion water quality, the shallow

Table 9. Statistical summary of significant differences between ground-water quality grouped by irrigation type for paired golf courses

[Results are for 12 wells of each irrigation type; level of significance (alpha) for all comparisons is 0.05; M.GW, median of samples from ground water irrigated golf courses; M.EFF, median of samples from treated effluent irrigated golf courses; p, attained level of significance; Q1, May-July 1992; Q2, August-October 1992; Q3, November-January 1992; Q4, February-March 1993]

Part 1. T-tests on mean ranks of mean values for all quarters (constituents with less than 5 percent censored data)

Constituent	M.GW	M.EFF	p
pH	5.6	4.8	0.025
Alkalinity	44.9	1.4	.015
Chloride	38.5	69.0	.005

Part 2. Quarterly T-tests on mean ranks (constituents with between 10 and 20 percent censored data)

Constituent		M.GW	M.EFF	p
Sodium	(Q1)	27.7	50.5	.047
	(Q4)	23.2	42.7	.05
Calcium	(Q2)	41.6	24.3	.04
	(Q3)	40.3	16.4	.005
	(Q4)	34.9	17.1	.03
DOC	(Q4)	30.0	9.5	.02
Temperature	(Q4)	20.9	22.1	.04

Part 3. Contingency tables (constituents with greater than 20 percent censored data)

Constituent		Number of wells with constituent out of 12 wells for each irrigation type: Ground water irrigation	Treated effluent irrigation	p
Wells with any pesticide detection	(Q3)	8	1	.009
Wells with any pesticide detection	(Q4)	7	1	.027
Wells with pesticide detections in any quarter		9	3	.039
Wells with fenamiphos detections	(Q4)	5	0	.037

ground water at effluent-irrigated golf courses is low in bicarbonate compared to the ground-water irrigated courses. At Groves and Winter Pines golf courses, this can be explained by the lower alkalinity of the irrigation water, which averages 47 percent and 23 percent, respectively, of the alkalinity of water from the irrigation wells at Highlands and Ventura golf courses. Bicarbonate is removed from wastewater during secondary biological treatment when ammonia oxidizing (nitrifying) bacteria use it for a carbon source while they convert ammonia to nitrate for energy (Gaudy and Gaudy, 1988). Alkalinity of the treated effluent used to irrigate Buckhorn Springs golf course was high relative to the other treated effluent samples, and was greater than the alkalinity measured in Pebble Creek irrigation system. But in the ground water, the pattern is the same as at the other paired courses; shallow ground water at Pebble Creek, the ground water irrigated course, has higher mean alkalinity than Buckhorn Springs, the effluent irrigated course. It is possible that the single sample taken from the irrigation system at Pebble Creek is not representative of the irrigation water used near the sampling sites.

Chloride is a conservative ion that is not removed during wastewater treatment and is typically higher in treated effluent than in the original water supply (Feigin and others, 1991). Mean chloride concentrations in reclaimed irrigation-water supplies are at least double the concentrations in irrigation water from wells.

Quarterly t-tests on ranked data also showed significant differences between pH, alkalinity, and chloride in shallow ground water for the two irrigation types for all quarters. Other constituents that were significant in some quarters, but not in others, were sodium, calcium, DOC, and temperature (table 9). Concentrations of sodium were higher in ground water at effluent-irrigated golf courses, while calcium was higher at ground-water irrigated courses. Sodium concentration was significantly different between the two irrigation types during two sampling quarters, and calcium concentration was significantly different in three of the four quarters. DOC and temperature were only significant in the fourth quarter (February to March 1993).

Contingency tables were used to compare constituents with more than 20 percent of the data below detection limits. In this method, counts of the data above and below the detection limits for each irrigation type were made, creating a two-by-two table of independent counts. The probabilities of the counts in each category being random were tested. To maintain independence, contingency tables were constructed for each sampling quarter. Constituents in this group are listed in table 8 and include nitrate, phosphate, MBAS, and all pesticides.

For example, water from 10 wells on golf courses using effluent for irrigation, and seven wells from golf courses using ground water for irrigation, had nitrate concentrations above the detection limit in the first quarter of sampling (May through July 1992).

In the remaining two and five wells, respectively, out of 12 total wells, nitrate was not detected. The test statistic reflected the probability that the number of detections was independent of the irrigation type. Again, if the test statistic exceeded a critical value, the detections were related to the irrigation type. The example given for nitrate in ground-water samples generated a test statistic of 1.82, which was lower than the critical value, so the difference was not significant. Because of low sample size in many classes, Fisher's exact test was used to determine the test statistics and probabilities (SAS Institute, 1990).

Based on the analysis of quarterly contingency tables, the following relations were significant. The number of wells where pesticides were detected in water was significantly greater at golf courses using ground water for irrigation than at golf courses using reclaimed water for irrigation in two-quarters (November to January 1992 and February to March 1993). A total of 9 out of 12 wells from ground-water irrigated golf courses had at least one occurrence of a pesticide in water. Only 3 of the 12 wells on effluent-irrigated golf courses had any pesticide occurrences in water. Pesticide occurrences were not significantly different in water from wells associated with tees compared to greens.

Sufficient data were not available to make relevant statements about relations between most individual pesticides and irrigation type. Although there were greater numbers of pesticides detected in ground water on golf courses irrigating with ground water compared to those irrigating with reclaimed water, the limited occurrences of individual pesticides in ground water do not make it possible to determine if differences in irrigation-water quality are affecting the way most pesticides migrate to the water table. Fenamiphos was the only pesticide detected in water from enough wells to construct valid contingency tables, and this was possible only in three sampling quarters (August to October and November to January 1992, and February to March 1993). Only in the fourth quarter of sampling was there a significant difference in numbers of ground-water samples containing fenamiphos, with water from more wells on ground-water irrigated golf courses containing the compound.

The persistence of fenamiphos and its degradation products may be affected by the increased pH and buffering alkalinity of the ground water on the golf courses using irrigation water from carbonate aquifers. While the pH of shallow ground water on the golf courses irrigated with ground water was not as high as 7.0 (a value where fenamiphos has been shown to be more stable (McNamara and Wilson, 1981)), statistics show that the pH was significantly higher than ground water at courses irrigated with reclaimed water. It is also noteworthy that shallow ground water at Buckhorn Springs golf course had the highest mean pH of the golf courses irrigated with reclaimed water, and it is the only one of these courses with fenamiphos detections in ground water.

Dissolved organic carbon and MBAS concentrations are not high enough in treated effluent to affect shallow ground-water quality or pesticide mobility at the golf courses studied. Concentrations of MBAS in ground water were typically less than detection limits, and surface tensions of ground water and treated effluent were equivalent to those of distilled water. MBAS detections in ground water were not related to pesticide detections.

ENVIRONMENTAL FACTORS THAT AFFECT PESTICIDE OCCURRENCE

Factors other than irrigation-water quality that affect pesticide migration include amount of irrigation, soil drainage, and depth to the water table. These other environmental factors give an indication of the susceptibility of shallow ground water to contamination from the surface at each of the golf courses (table 10). Paired golf courses were selected to have similar hydrologic settings, but because of the difficulty finding suitable golf courses, effects of other environmental factors may be equal to or greater than the effect of irrigation water quality on shallow ground-water quality and pesticide occurrence.

Irrigation Rates

Irrigation rates at each of the paired golf courses should be important in predicting the mobility of pesticides because irrigation or rain water percolating downward through the unsaturated zone provides the driving force for movement of pesticides to the water table. Unfortunately, accurate irrigation amounts were not available at two of the paired golf courses, Buckhorn Springs and Ventura. Recorded irrigation volumes were divided by the irrigated acreage to calculate an average amount per week. Golf-course irrigation at the paired golf courses is ranked from lowest to highest in the following order, with average

Table 10. Summary of golf course information including frequency of pesticide occurrences in ground water

[DTW, depth to water in feet below land surface; EFF, irrigation with treated effluent; GW, irrigation with ground water; --, not available; e, estimated. Pesticide detections do not include fenamiphos degradation products separately]

Golf Course	Construction date	Irrigation type	Irrigation rate (inches per week)	Drainage	DTW (feet)	Pesticide detections in ground water (number of samples)
Pebble Creek	1964e	GW	0.22	poor	3-7	6 (20)
Groves	1987	EFF	0.63	very poor to moderately well	3-6	0 (12)
Highlands	1986	GW	0.58	" "	2-16	14 (12)
Winter Pines	1968	EFF	0.35	poor	4-8	0 (16)
Ventura	1980	GW	--	poor	6-8	14 (16)
Bonaventure	1968	GW	--	very poor	2-5	13 (20)
Pensacola NAS	1954e	GW	--	somewhat poor to excessive	10-25	2 (20)
Skiing Paradise	1991	GW	--	somewhat poor to well	3-10	7 (15)

irrigation amounts in inches per week in parentheses; Pebble Creek (0.22), Winter Pines (0.35), Highlands (0.58), and Groves (0.63). Irrigation at Buckhorn Springs is estimated to be 1.0 inch per week and irrigation at Ventura is probably similar to that at Winter Pines. Irrigation amounts are difficult to estimate, however, and can vary considerably from year to year depending on rainfall patterns.

Because rainfall is roughly equivalent over each pair of courses, higher irrigation rates may facilitate pesticide movement to the water table. The estimated amount of irrigation at Buckhorn Springs is much greater than at Pebble Creek. Of the golf courses irrigated with ground water, Pebble Creek has the least number of pesticide occurrences in ground water and the lowest irrigation rate. Of the courses irrigated with reclaimed water, Buckhorn Springs has the highest number of pesticide occurrences in ground water and is estimated to have the highest irrigation rate. Low irrigation rates at Pebble Creek and Winter Pines golf courses reflect the poorly-drained soils at those courses. Downward flow of water to the water table is expected to be slow under these conditions and may be an important factor limiting pesticide migration.

Soil Properties

Soil-drainage properties directly affect the amount of water a golf course uses. Golf courses with excessively drained fine sand soils, such as Buckhorn Springs, are able to use large amounts of reclaimed irrigation water without flooding. Groves and Highlands golf courses have soils with variable drainage characteristics, although none of the soils at these two-courses are as well-drained as those at Buckhorn Springs. Water may pond at the surface of the poorly drained fine sand and depressional mucks at Pebble Creek, Ventura, and Winter Pines if irrigation or rainfall is heavy.

The potential for adsorption and degradation of pesticides is increased in poorly drained soils. But, with the exception of Buckhorn Springs, all of the paired golf courses contain areas of poorly drained soils. Because soil types on most of the paired golf courses are similar, it is difficult to attribute differences in pesticide occurrences to differences in soil type. The excessively drained soil type at Buckhorn Springs is probably a significant factor in the increased pesticide occurrence at that course compared to Pebble Creek.

Depth to Water

Many pesticides will have degraded to daughter products and inert compounds before they reach the water table if vertical travel times exceed one year. Half-lives of many pesticides used at golf courses are very short, often numbered in days (Jury and others, 1987; Gustafson, 1993). Depth to water in most of the wells sampled for this study ranged from 2 to 8 ft below land surface.

Golf courses in upland areas generally have greater depths to the water table, but exceptions exist in areas where shallow perched aquifers occur. Normally, a relatively high topographic area such as Buckhorn Springs golf course would have greater depth to water, but because the surficial aquifer is perched on a relatively shallow clay layer beneath the western part of the course, the depth to water at this site is less than expected. Buckhorn Springs golf course has estimated high irrigation rates, excessively drained soils, and a shallow water table; all indications that pesticides may move vertically to the water table relatively quickly. Skiing Paradise golf course has a similar setting to Buckhorn Springs, with areas of perched water tables and areas with no surficial aquifer.

Differences in soil drainage characteristics, which are also reflected in irrigation rates, may account for the greater number of pesticide occurrences in ground water at Buckhorn Springs golf course relative to its paired golf course, Pebble Creek. Differences in irrigation-water quality may be a significant factor affecting pesticide migration at Groves and Highlands golf courses because other environmental factors are nearly identical at these two paired courses.

Environmental factors such as the ones just discussed are probably at least as important as irrigation water quality in determining pesticide migration at Florida golf courses. Differences in patterns, frequency, and method of pesticide application, which were not controlled during this study, are also extremely important for predicting pesticide occurrence in shallow ground water.

SUMMARY AND CONCLUSIONS

Shallow ground water, surface water, and irrigation water were sampled periodically from May 1992 to March 1994 at nine golf courses in Florida to describe water quality, to evaluate the occurrence of pesticides, and to investigate the effect of irrigation with reclaimed water on pesticide migration. Three pairs of golf courses were selected in central Florida to investigate the effect of using reclaimed water for irrigation on shallow ground-water quality. Pairs consisted of one course using reclaimed water and one using ground water for irrigation. Three additional golf courses were added to the study to provide information on ground-water quality at golf courses in other parts of the state.

Shallow ground-water quality at golf courses in Florida is highly variable. The use of fertilizers and irrigation with reclaimed water or water from carbonate aquifers add dissolved constituents to ground water. Specific conductance is higher in ground water under golf courses compared to undeveloped land. Dissolved oxygen concentration in shallow ground water at golf courses is generally low, and measurable DO is associated with areas of higher recharge to the surficial aquifer at Buckhorn Springs, Pensacola NAS, and Skiing Paradise golf courses. Dominant major ions in ground water were variable, but ground water at golf courses irrigated with reclaimed water was deplete in bicarbonate relative to courses irrigated with ground water from carbonate aquifers.

Shallow ground-water quality at golf courses in Florida is affected by irrigation water type. Irrigation water from wastewater treatment plants has a higher percentage of sodium, chloride, and nitrate, and lower calcium and bicarbonate relative to other ions than irrigation water from carbonate aquifers. Significant differences in mean pH, alkalinity, and chloride concentrations in ground water were found when water-quality data were grouped by irrigation type. Ground water at golf courses irrigated with reclaimed water had lower pH and alkalinity, and higher chloride concentration. Mean chloride concentrations in the reclaimed-irrigation water supplies were at least double the concentrations in the irrigation water from wells.

Even though secondarily treated effluent used for irrigation at both Groves and Winter Pines golf courses had high nitrate concentrations, statistically significant differences in nutrient concentrations in ground water were not found between golf course pairs at a 95 percent confidence level. Nitrate concentrations in water from shallow golf course wells ranged from less than 0.02 to 35 mg/L. Five wells had at least one occurrence of nitrate concentrations in water meeting or exceeding the drinking water standard of 10 mg/L. Ammonia concentrations in ground water ranged from less than 0.02 to 20 mg/L. Nitrogen species were related to ground water redox conditions. Nitrates were generally found in ground water at sites with rapidly-drained soils that also had measurable dissolved oxygen. Use of fertilizers on golf courses probably overshadows any differences in ground water nutrient concentrations that might otherwise have been attributable to irrigation-water quality.

Dissolved organic carbon, methylene blue active substances (an indicator of detergents found in effluent), and surface tension were analyzed in water samples. Dissolved organic carbon in ground water at Florida golf courses was highly variable; water from three wells on different golf courses had average DOC’s exceeding 90 mg/L. Golf courses located in areas with poorly drained soils had higher DOC in ground water. MBAS concentrations in ground water were generally below detection limits, and surface-tension measurements did not indicate the presence of any surface-active agents. Dissolved organic carbon and MBAS concentrations in treated effluent were not high enough to affect shallow ground-water quality or pesticide mobility at the golf courses studied.

Pesticides were found in 52 percent of samples from shallow ground water at golf courses, but concentrations were generally low. 45 percent of all pesticide occurrences in ground water were at trace levels and 92 percent were below drinking water maximum contaminant levels or ground water guidance concentrations. Two golf courses had no pesticides detected in ground water (Groves and Winter Pines), and one had only two occurrences, both at trace levels (Pensacola NAS). There were six occurrences of pesticide concentrations in ground water above the maximum contaminant level or guidance concentration. Arsenic was above the MCL of 50 µg/L four times in water from three wells. Bentazon and acephate were detected in ground water at concentrations above the GC once each.

Additionally, the following pesticides were present in ground water from at least one site; atrazine, bromacil, diazinon, diuron, fenamiphos, metalaxyl, oxydiazon, and simazine. Fenamiphos degradation products, fenamiphos sulfoxide and fenamiphos sulfone, were also detected in ground water. Of these pesticides, bromacil, diazinon, fenamiphos sulfone, metalaxyl, and oxydiazon were detected only at trace levels in ground water. Fenamiphos and its degradation products were detected in ground water at more sites than any other pesticide, occurring in water from nine wells. Bentazon was detected in samples from six wells, and arsenic was detected in samples from five wells. Of the pesticides that were detected in ground water, bromacil, diazinon, and diuron were not reported as used by the golf course superintendents. The occurrence of pesticides in water from the mix and load wells in the maintenance areas of the three statewide golf courses was not higher than in ground water on other parts of the golf courses. Pesticide occurrences were not significantly different in water from wells near greens compared to tees.

Samples taken directly from deeper irrigation wells on two golf courses contained no pesticides above detection limits. Samples from wastewater treatment plants contained low levels of atrazine, bromacil, and gamma-BHC (Lindane). Treated-effluent storage ponds contained equal or greater numbers of pesticides than did samples directly from treatment plants.

Nearly all of the samples from golf course ponds (96 percent) contained at least one pesticide. Concentrations of pesticides in golf course ponds were generally low, with 60 percent of all occurrences at trace levels. More individual pesticides were detected in ponds compared to ground water, but those additional pesticides found only in ponds were all at trace levels. There were three occurrences in one pond of simazine or acephate in concentrations above the MCL or GC.

The following pesticides were detected in at least one pond; acephate, ametryn, atrazine, bromacil, chlordane, diazinon, diuron, ethoprop, fenamiphos and degradation products, fonophos, isofenphos, malathion, methamidophos, oryzalin, oxadiazon, pronamide, and simazine. Of these, ametryn, bromacil, chlordane, diazinon, fenamiphos, fenamiphos sulfone, isofenphos, and metamidophos were detected at trace levels. The most commonly occurring pesticides in golf course ponds were; atrazine, which was in all six ponds and in 18 out of 23 total samples; fenamiphos and fenamiphos sulfoxide (four ponds), and diuron (three ponds). Of the pesticides that were detected in surface water, bromacil, chlordane, diazinon, diuron, fonophos, malathion, and methamidophos were not reported as used by the golf course superintendents.

Fenamiphos (Nemacur) was detected at more sites than any other pesticide, in samples from eight wells, four ponds, and one effluent storage pond. Two degradation products of fenamiphos, fenamiphos sulfoxide and fenamiphos sulfone, also were present regularly in water from the same sites as the parent compound. Other studies have reported that fenamiphos degraded after 7 to 14 days at a pH of 3 in a dark, buffered system, but that it was stable at pH 7. The differences in stability related to pH may be a possible explanation for the lack of fenamiphos detections in ground water at the Groves and Winter Pines golf courses. Both pH and alkalinity of ground water samples at these golf courses were significantly lower than their ground water irrigated counterparts.

The number of wells with detectable concentrations of at least one pesticide was significantly greater at golf courses using ground water for irrigation than at golf courses using reclaimed water. However, numbers of detections of individual pesticides were too low to interpret mechanisms of interaction between pesticides and the use of reclaimed water for irrigation. Other factors that were not controlled during this study may have been equally important in determining pesticide mobility. Differences in pesticide-use rates, soil drainage characteristics, and irrigation rates may have affected pesticide occurrences at the nine golf courses studied.

Some pesticides used for turf maintenance at golf courses in Florida have migrated downward to the shallow water table. When pesticides were detected in ground water, concentrations were usually below regulatory levels based on toxicity studies. Although differences in irrigation water quality do affect overall shallow ground-water quality, the limited occurrences of individual pesticides in ground water during this study did not make it possible to determine if differences in irrigation water quality are affecting whether or not pesticides migrate to the water table.

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Table 4. Water-quality data

[TOC, top of casing; ^{o}C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Station Number Site Code	Date	Depth to water (feet below TOC)	Water temperature (^{o}C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	pH, field (standard units)	Alkalinity ($mg/L\ CaCO_3$) field FET	Alkalinity field Gran	Alkalinity lab FET	Dissolved nitrogen, ammonia (mg/L as N)	Dissolved nitrogen, ammonia plus organic (mg/L as N)
					BUCKHORN SPRINGS GOLF COURSE						
275420082145701 (BH3G)	05-27-92	--	24.0	361	--	6.2	60	--	72	1.6	1.9
	10-07-92	--	26.2	347	0.8	6.1	58	--	43	1.2	1.5
	10-07-92	--	26.2	347	.8	6.1	58	--	43	1.2	1.5
	01-05-93	--	24.0	348	3.0	6.2	70	--	56	1.8	10
	03-10-93	--	22.7	407	.8	6.2	--	64.1	51	1.9	2.1
275427082150701 (BH3T)	05-26-92	--	24.5	612	--	4.6	--	--	ND	ND	.31
	05-26-92	--	24.5	612	--	4.6	--	--	ND	ND	.27
	10-08-92	--	26.7	734	5.5	4.7	2	--	ND	T.013	.34
	01-04-93	--	24.2	526	5.2	4.8	3	--	ND	ND	.40
	03-15-93	--	21.6	444	6.6	4.9	--	2.70	1	ND	.34
275433082145901 (BH7G)	05-26-92	--	23.5	743	--	5.4	4	--	6	.030	.77
	10-06-92	--	26.4	516	5.5	5.5	7	--	6	T.014	.51
	01-04-93	--	22.8	426	5.6	5.6	31	--	20	ND	.57
	03-11-93	--	21.3	573	6.0	5.5	--	9.50	7	ND	.48
275432082144301 (BH7T)	05-21-92	--	24.3	622	--	4.8	2	--	ND	ND	.48
	06-16-92	--	24.2	642	5.6	4.6	1	--	ND	ND	.26
	10-06-92	--	25.4	533	3.8	4.7	2	--	ND	T.016	.29
	01-06-93	--	23.3	559	5.7	4.8	3	--	ND	ND	.25
	03-11-93	--	22.1	614	4.2	4.8	--	1.10	ND	ND	.34
	03-11-93	--	22.1	612	4.1	4.9	--	16.7	ND	ND	.32
275405082141900 (BHEFF)	05-28-92	--	30.0	802	--	8.3	158	--	153	T.016	.62
	10-08-92	--	24.9	636	3.5	7.3	103	--	97	.43	.95
	01-06-93	--	22.9	816	7.7	7.7	169	--	64	.10	.68
	03-15-93	--	16.8	700	8.1	7.9	--	138	121	.11	.66
275747082134900 (VWP)	01-05-94	--	20.3	845	7.0	7.5	--	198	192	ND	0.70
	01-05-94	--	20.3	845	7.0	7.5	--	198	194	ND	.73
	03-14-94	--	22.8	845	7.8	7.5	--	175	166	T.028	.77
275422082145600 (BHPD)	05-27-92	--	28.5	494	--	9.5	71	--	64	.027	1.8
	10-07-92	--	23.8	461	8.9	7.1	57	--	51	.040	.60
	01-05-93	--	22.5	505	7.5	7.1	54	--	55	ND	.60
	01-05-93	--	22.5	505	7.5	7.1	54	--	51	ND	.58
	03-10-93	--	22.3	457	12.3	7.9	--	55.0	54	ND	.58
					PEBBLE CREEK GOLF COURSE						
280907082203101 (PC7T)	05-19-92	8.45	24.0	190	--	5.4	18	--	11	0.24	2.7
	06-16-92	8.32	24.0	207	1.5	5.3	14	--	14	.21	1.7
	10-05-92	5.26	26.5	257	0.6	5.6	60	--	45	.26	2.7
	12-22-92	7.14	23.5	222	1.7	5.4	30	--	30	.40	2.6
	03-16-93	6.14	21.0	320	1.6	5.7	--	39.5	38	.31	1.5
280914082205001 (PC8G)	05-18-92	--	25.0	363	--	5.8	123	--	121	2.80	5.1
	06-10-92	--	24.0	352	1.5	5.8	105	--	86	.98	3.5
	10-05-92	--	26.5	399	1.6	5.7	96	--	86	2.70	3.9
	12-22-92	--	23.0	435	2.1	5.8	129	--	104	3.50	7.4
	03-18-93	--	20.5	451	0.6	5.8	--	124	100	2.70	4.3
280850082202901 (PC13G)	05-18-92	--	24.5	360	--	5.8	46	--	44	T.016	4.1
	06-10-92	--	25.5	444	1.5	5.5	36	--	33	T.012	2.7
	09-24-92	--	27.0	433	4.1	5.5	32	--	31	T.032	2.9
	12-22-92	--	20.5	363	4.6	5.7	49	--	48	.034	2.6
	03-16-93	--	20.0	385	1.0	5.7	--	65.0	56	ND	2.3
280854082202701 (PC16T)	05-20-92	8.36	25.0	252	--	5.1	18	--	23	2.4	6.8
	06-11-92	8.11	25.5	265	5.8	4.9	9	--	15	2.1	3.7
	09-23-92	5.64	28.0	384	2.6	5.7	67	--	56	2.5	4.3
	12-21-92	5.63	21.5	405	3.5	5.6	97	--	101	1.8	6.0
	03-18-93	4.60	19.5	375	3.0	5.6	--	95.6	89	1.7	3.4
280915082204701 (PCFL)	03-14-94	--	20.0	326	4.5	7.6	--	80.5	78	ND	0.69
280853082202700 (PCPD)	05-20-92	--	28.5	295	--	7.3	78	--	85	ND	.87
	06-11-92	--	33.0	333	11.2	8.6	81	--	68	T.013	1.1
	09-23-92	--	30.0	274	3.8	7.0	75	--	76	T.031	.91
	12-21-92	--	23.5	289	7.0	7.8	83	--	89	.440	.81
	03-18-93	--	18.0	300	9.0	8.0	--	76.0	68	ND	.68
	03-18-93	--	18.0	300	9.0	8.0	--	76.0	72	ND	.66

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved nitrogen, $NO_2 + NO_3$ (mg/L as N)	Dissolved nitrogen, organic (calculated, mg/L as N)	Dissolved phosphorus (mg/L as P)	Dissolved phosphorus ortho (mg/L as P)	Dissolved organic carbon (mg/L as C)	Dissolved calcium (mg/L as Ca)	Dissolved magnesium (mg/L as Mg)	Dissolved sodium (mg/L as Na)	Dissolved potassium (mg/L as K)	Dissolved chloride (mg/L as Cl)
				BUCKHORN SPRINGS GOLF COURSE							
BH3G	05-27-92	T.033	0.30	3.10	3.50	8.0	13	4.5	43	4.3	55
	10-07-92	ND	.30	4.40	4.60	10	12	4.1	40	3.5	67
	10-07-92	ND	.30	4.30	4.60	10	12	4.0	39	3.5	66
	01-05-93	T.046	8.20	3.40	3.70	10	10	3.6	43	3.9	60
	03-10-93	T.022	.20	2.90	3.00	3.2	13	5.1	44	4.4	65
BH3T	05-26-92	1.90	.310	ND	T.013	T1.1	38	5.6	40	16	150
	05-26-92	1.90	.270	ND	T.010	T1.2	37	5.5	39	16	150
	10-08-92	0.510	.327	ND	ND	3.8	36	6.0	74	19	150
	01-04-93	3.00	.400	ND	ND	3.4	23	3.5	65	13	51
	03-15-93	2.80	.340	ND	ND	2.7	16	2.4	51	8.6	37
BH7G	05-26-92	8.70	.740	ND	ND	4.4	47	10	56	17	100
	10-06-92	2.70	.496	ND	ND	13	28	6.6	55	13	72
	01-04-93	5.90	.570	ND	ND	4.6	16	3.9	51	9.1	53
	03-11-93	6.00	.480	ND	ND	3.9	21	5.2	66	9.7	100
BH7T	05-21-92	6.10	.480	.077	T.028	T1.1	27	3.6	73	13	120
	06-16-92	6.20	.260	ND	T.025	1.9	28	3.6	66	11	120
	10-06-92	4.40	.274	ND	T.024	2.2	27	3.6	56	12	57
	01-06-93	1.60	.250	ND	T.024	2.7	21	2.7	66	8.2	69
	03-11-93	4.60	.340	ND	ND	9.5	23	3.2	77	8.3	71
	03-11-93	7.10	.320	ND	ND	7.0	25	3.4	76	7.9	71
BHEFF	05-28-92	ND	.604	.170	.150	5.9	45	16	92	11	120
	10-08-92	.160	.520	.120	.130	7.4	29	12	69	8.4	85
	01-06-93	.460	.580	.200	.220	7.7	46	15	86	11	110
	03-15-93	.450	.550	.410	.340	8.2	40	14	79	11	87
VWP	01-05-94	0.600	.700	0.270	0.270	9.8	62	17	91	11	94
	01-05-94	.590	.730	.280	.260	9.1	61	17	89	11	93
	03-14-94	2.30	.742	.270	.260	6.1	52	16	90	12	98
BHPD	05-27-92	.100	1.773	.210	T.037	15.0	34	7.8	48	8.2	72
	10-07-92	T.040	.560	.058	T.049	6.6	31	6.4	41	6.5	63
	01-05-93	2.30	.600	.058	.054	6.2	35	7.3	48	6.4	67
	01-05-93	2.30	.580	.066	.060	6.7	35	7.3	48	6.4	69
	03-10-93	1.40	.580	T.025	ND	3.2	30	6.6	41	5.9	53
				PEBBLE CREEK GOLF COURSE							
PC7T	05-19-92	ND	2.460	0.140	ND	44	4.2	0.60	35	1.9	33
	06-16-92	ND	1.490	ND	ND	52	3.9	.60	35	1.6	31
	10-05-92	ND	2.440	.052	ND	75	6.8	1.1	43	3.5	26
	12-22-92	ND	2.200	ND	ND	44	6.2	1.5	37	3.4	35
	03-16-93	0.540	1.190	ND	ND	84	11	2.8	44	5.4	36
PC8G	05-18-92	ND	2.30	ND	T.020	39	40	5.2	11	3.5	29
	06-10-92	ND	2.52	T.044	T.018	45	40	4.8	13	2.9	31
	10-05-92	T.051	1.20	ND	T.023	40	40	5.6	15	3.5	42
	12-22-92	ND	3.90	ND	ND	45	43	6.2	17	4.3	46
	03-18-93	T.047	1.60	T.026	ND	40	40	5.6	23	4.2	43
PC13G	05-18-92	3.30	4.084	ND	ND	58	37	3.9	21	16	37
	06-10-92	3.40	2.688	ND	ND	48	45	4.9	22	18	57
	09-24-92	10.0	2.868	ND	ND	47	43	4.6	20	22	30
	12-22-92	1.50	2.566	ND	ND	58	45	3.9	21	21	25
	03-16-93	.300	2.300	ND	ND	87	41	3.6	22	22	18
PC16T	05-20-92	.061	4.400	.930	T.012	23	15	5.6	24	2.6	58
	06-11-92	.071	1.600	ND	ND	27	13	5.4	23	2.6	57
	09-23-92	ND	1.800	ND	ND	41	31	7.4	39	5.0	70
	12-21-92	ND	4.200	ND	ND	35	30	7.5	48	4.7	67
	03-18-93	ND	1.700	ND	ND	35	25	6.9	48	4.2	55
PCFL	03-14-94	0.370	.690	.051	T.036	9.1	38	2.7	20	2.6	43
PCPD	05-20-92	ND	.870	T.021	ND	15	37	2.5	14	8.7	37
	06-11-92	ND	1.087	T.046	T.012	32	35	2.1	17	10	49
	09-23-92	ND	.879	0.047	T.033	14	36	1.9	13	7.2	35
	12-21-92	ND	.370	ND	T.020	13	37	2.0	13	6.8	35
	03-18-93	ND	.680	T.041	ND	12	33	2.0	16	7.8	39
	03-18-93	ND	.660	T.037	ND	12	33	2.0	17	7.9	39

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved sulfate (mg/L as SO_4)	Dissolved fluoride (mg/L as F)	Dissolved silica (mg/L as SiO_2)	Dissolved arsenic (µg/L as As)	Dissolved beryllium (µg/L as Be)	Dissolved cadmium (µg/L as Cd)	Dissolved chromium (µg/L as Cr)	Dissolved copper (µg/L as Cu)	Dissolved iron (µg/L as Fe)
				BUCKHORN SPRINGS GOLF COURSE						
BH3G	05-27-92	26	.32	3.9	ND	ND	ND	ND	ND	8,600
	10-07-92	T4.0	.28	4.8	ND	ND	ND	ND	ND	11,000
	10-07-92	ND	.30	4.9	ND	ND	ND	ND	ND	11,000
	01-05-93	ND	.28	5.0	ND	ND	ND	ND	ND	8,900
	03-10-93	15	.35	5.1	ND	ND	ND	ND	ND	9,200
BH3T	05-26-92	48	ND	2.2	ND	ND	T.3	ND	ND	ND
	05-26-92	48	ND	2.2	ND	ND	T.3	ND	ND	T6
	10-08-92	130	ND	3.0	ND	ND	ND	ND	ND	T8
	01-04-93	130	ND	2.8	ND	ND	ND	ND	ND	24
	03-15-93	89	ND	2.3	ND	ND	ND	ND	ND	T6
BH7G	05-26-92	160	ND	.99	ND	ND	ND	ND	ND	T4
	10-06-92	100	ND	1.3	ND	ND	ND	ND	ND	T6
	01-04-93	66	ND	.90	ND	ND	ND	ND	ND	11
	03-11-93	69	ND	1.0	ND	ND	T8.0	ND	ND	T7
BH7T	05-21-92	84	ND	3.0	ND	ND	T.3	ND	18	T9
	06-16-92	70	ND	3.3	ND	ND	T.4	ND	ND	T6
	10-06-92	110	ND	3.6	ND	ND	ND	ND	ND	15
	01-06-93	140	ND	3.4	ND	ND	ND	ND	ND	T5
	03-11-93	140	ND	3.3	ND	ND	ND	ND	ND	12
	03-11-93	130	ND	3.2	ND	ND	ND	ND	ND	11
BHEFF	05-28-92	77	.42	19	ND	ND	ND	ND	ND	T5
	10-08-92	72	.30	20	ND	ND	ND	ND	ND	T10
	01-06-93	65	.39	26	ND	ND	ND	ND	ND	T9
	03-15-93	44	.32	20	ND	ND	ND	ND	ND	T9
VWP	01-05-94	87	0.33	21	ND	ND	ND	ND	ND	22
	01-05-94	87	.38	21	ND	ND	ND	ND	ND	19
	03-14-94	86	.48	23	ND	ND	ND	ND	ND	30
BHPD	05-27-92	55	.28	4.6	11	ND	ND	ND	13	12
	10-07-92	58	.20	4.3	8	ND	ND	ND	ND	17
	01-05-93	67	.21	2.7	6	ND	ND	ND	T6	10
	01-05-93	68	.20	2.7	5	ND	ND	ND	ND	12
	03-10-93	62	.22	2.5	5	ND	ND	ND	ND	12
				PEBBLE CREEK GOLF COURSE						
PC7T	05-19-92	20	ND	4.6	12	ND	ND	ND	ND	500
	06-16-92	27	ND	5.2	8	ND	ND	ND	ND	220
	10-05-92	28	ND	4.2	22	ND	ND	ND	ND	270
	12-22-92	27	ND	4.5	19	ND	ND	ND	ND	290
	03-16-93	57	ND	4.0	14	ND	ND	ND	ND	76
PC8G	05-18-92	10	ND	6.9	7	ND	ND	ND	ND	20,000
	06-10-92	15	ND	6.8	T5	ND	T.060	ND	ND	18,000
	10-05-92	26	ND	6.2	6	ND	ND	ND	ND	18,000
	12-22-92	25	ND	6.0	6	ND	ND	ND	ND	20,000
	03-18-93	27	ND	6.1	6	ND	ND	ND	ND	18,000
PC13G	05-18-92	39	ND	2.8	ND	ND	ND	ND	ND	41
	06-10-92	53	ND	2.8	ND	ND	ND	ND	ND	30
	09-24-92	78	ND	T.35	ND	ND	ND	ND	ND	20
	12-22-92	100	ND	2.9	ND	ND	ND	ND	ND	25
	03-16-93	87	ND	3.3	ND	ND	ND	ND	ND	30
PC16T	05-20-92	21	ND	4.0	ND	ND	ND	ND	ND	1,800
	06-11-92	22	ND	4.5	ND	ND	ND	ND	ND	660
	09-23-92	32	ND	2.8	ND	57	ND	ND	T6	1,000
	12-21-92	29	ND	3.7	ND	ND	ND	ND	ND	670
	03-18-93	19	ND	3.9	ND	ND	ND	ND	ND	550
PCFL	03-14-94	7.9	0.15	.50	T5	ND	ND	ND	ND	61
PCPD	05-20-92	9.3	.16	T.29	10	ND	ND	ND	T9	31
	06-11-92	13	.16	.83	18	ND	ND	ND	ND	10
	09-23-92	T4.2	.11	2.9	16	ND	ND	ND	ND	58
	12-21-92	6.7	ND	T.25	15	ND	ND	ND	ND	36
	03-18-93	21	.11	.51	11	ND	ND	ND	T7	40
	03-18-93	5.9	ND	T.33	11	ND	ND	ND	T8	31

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; μS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved lead (μg/L as Pb)	Dissolved manganese (μg/L as Mn)	Dissolved molybdenum (μg/L as Mo)	Dissolved strontium (μg/L as Sr)	Dissolved vanadium (μg/L as V)	Dissolved zinc (μg/L as Zn)	Dissolved aluminum (μg/L as Al)	Methylene blue active substance (mg/L)
				BUCKHORN SPRINGS GOLF COURSE					
BH3G	05-27-92	ND	17	ND	ND	ND	ND	ND	--
	10-07-92	ND	19	ND	ND	ND	ND	60	<0.10
	10-07-92	ND	19	ND	ND	ND	ND	60	<0.10
	01-05-93	ND	17	ND	ND	ND	ND	ND	0.53
	03-10-93	ND	18	ND	ND	ND	ND	ND	<0.10
BH3T	05-26-92	ND	T4	ND	220	ND	ND	420	<0.10
	05-26-92	ND	T4	ND	220	ND	ND	410	<0.10
	10-08-92	ND	T5	ND	200	ND	ND	360	<0.10
	01-04-93	ND	T8	ND	130	ND	ND	260	<0.10
	03-15-93	ND	T1	ND	96	ND	ND	220	<0.10
BH7G	05-26-92	ND	T1	ND	440	ND	ND	110	<0.10
	10-06-92	ND	ND	ND	260	ND	ND	140	<0.10
	01-04-93	ND	ND	ND	150	ND	ND	60	0.84
	03-11-93	ND	ND	ND	200	ND	ND	ND	<0.10
BH7T	05-21-92	ND	T4	ND	89	ND	ND	250	<0.10
	06-16-92	ND	T5	ND	94	ND	ND	250	--
	10-06-92	ND	T5	ND	90	ND	ND	200	<0.10
	01-06-93	ND	T4	ND	68	ND	ND	160	0.53
	03-11-93	ND	T4	ND	86	ND	ND	220	0.12
	03-11-93	ND	T5	ND	99	ND	ND	210	<0.10
BHEFF	05-28-92	ND	ND	T4	1,100	ND	T8	ND	--
	10-08-92	ND	T5	T4	770	ND	ND	100	<0.10
	01-06-93	ND	T1	ND	1,000	ND	12	ND	0.84
	03-15-93	ND	T2	T5	930	ND	10	ND	<0.10
VWP	01-05-94	ND	ND	T3	1,300	ND	18	ND	<0.10
	01-05-94	ND	ND	T3	1,300	ND	17	ND	<.10
	03-14-94	ND	T2	7	1,300	ND	15	ND	<.10
BHPD	05-27-92	ND	T3	T2	140	T4	ND	670	--
	10-07-92	ND	T10	ND	110	ND	ND	80	<.10
	01-05-93	ND	T5	ND	110	ND	T5	60	<.10
	01-05-93	ND	T6	ND	110	ND	T5	60	<.10
	03-10-93	ND	T2	ND	100	ND	ND	T130	<.10
				PEBBLE CREEK GOLF COURSE					
PC7T	05-19-92	T1	T7	ND	11	T6	T9	2,300	--
	06-16-92	ND	T4	ND	11	T7	ND	2,000	--
	10-05-92	ND	T3	ND	14	T5	ND	2,100	<0.10
	12-22-92	ND	T4	ND	15	T5	T5	1,300	<0.10
	03-16-93	ND	T4	ND	28	T3	ND	690	<0.10
PC8G	05-18-92	ND	12	ND	50	T4	ND	370	--
	06-10-92	ND	12	ND	50	T5	ND	430	--
	10-05-92	ND	12	ND	48	T4	ND	320	<0.10
	12-22-92	ND	14	ND	48	T7	T5	330	<0.10
	03-18-93	ND	12	ND	47	T6	ND	360	0.21
PC13G	05-18-92	ND	T5	ND	41	T9	ND	1,300	--
	06-10-92	ND	T3	ND	50	T7	ND	1,100	--
	09-24-92	ND	T5	ND	51	T8	ND	990	<0.10
	12-22-92	ND	T3	ND	49	T7	ND	1,100	<0.10
	03-16-93	ND	T2	ND	47	T6	ND	1,100	<0.10
PC16T	05-20-92	ND	12	ND	55	ND	21	300	--
	06-11-92	ND	T7	ND	56	ND	T10	360	--
	09-23-92	ND	38	ND	67	ND	T5	440	<0.10
	12-21-92	ND	41	ND	76	ND	T7	440	<0.10
	03-18-93	ND	20	ND	63	ND	ND	430	<0.10
PCFL	03-14-94	ND	ND	ND	74	ND	14	T120	<0.10
PCPD	05-20-92	T1	T1	T1	72	T4	T7	210	--
	06-11-92	ND	ND	ND	71	ND	ND	70	--
	09-23-92	ND	T9	ND	54	ND	ND	ND	<0.10
	12-21-92	ND	T2	ND	62	ND	ND	ND	<0.10
	03-18-93	ND	ND	ND	59	ND	ND	ND	<0.10
	03-18-93	ND	ND	ND	59	ND	ND	ND	0.19

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Station Number Site Code	Date	Depth to water (feet below TOC)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	pH, field (standard units)	Alkalinity (mg/L $CaCO_3$) field FET	Alkalinity (mg/L $CaCO_3$) field Gran	Alkalinity (mg/L $CaCO_3$) lab FET	Dissolved nitrogen ammonia (mg/L as N)	Dissolved nitrogen, ammonia plus organic (mg/L as N)
					GROVES GOLF COURSE						
272152082285601	07-14-92	4.42	26.2	704	0.3	5.1	32	--	39	14.0	18
(G2G)	08-25-92	4.98	27.2	662	.4	5.1	35	--	26	14.0	18
	12-01-92	5.16	24.5	597	.3	5.3	--	--	45	12.0	15
	02-24-93	5.76	22.1	570	.7	5.3	--	65.0	37	11.0	15
272153082290701	07-13-92	6.02	26.3	1,340	2.3	4.8	6	--	3	T.020	1.6
(G4T)	08-26-92	7.12	27.4	595	1.1	4.7	5	--	2	T.024	.84
	12-08-92	7.30	24.5	300	.6	4.7	3	--	4	T.067	.85
	02-23-93	8.76	22.5	422	1.0	4.7	--	3.30	10	ND	.70
272157082290901	07-14-92	5.28	26.6	805	.4	4.8	4	--	1	T.037	.79
(G5G)	08-26-92	6.19	27.3	832	.5	4.8	6	--	1	T.030	.86
	12-07-92	7.01	25.1	630	1.3	4.8	6	--	4	.069	.80
	02-24-93	6.68	22.5	595	.5	4.8	--	6.70	ND	.075	.82
	02-24-93	6.68	22.5	595	.5	4.8	--	6.70	ND	.068	.76
272148082290501	06-23-92	6.25	25.6	686	.6	4.7	4	--	9	.30	1.6
(G18T)	08-27-92	5.29	28.2	332	.3	4.6	<0	--	2	.28	.74
	12-02-92	5.83	24.7	328	.9	4.6	--	--	12	.34	.77
	02-25-93	5.59	21.7	536	1.0	4.6	--	3.70	ND	ND	.60
272123082284900	06-23-92	--	32.1	843	10.6	8.7	68	--	86	.054	1.1
(GEFF)	06-23-92	--	32.1	843	10.6	8.7	68	--	76	.048	1.3
	08-27-92	--	29.8	549	7.9	7.9	74	--	81	.13	1.2
	08-27-92	--	29.8	549	7.9	7.9	74	--	81	.14	1.1
	12-08-92	--	21.4	733	10.9	8.1	68	--	69	.64	1.8
	02-25-93	--	18.6	710	8.5	8.5	--	65.0	69	.15	1.3
272058082281400	01-06-94	--	22.1	855	2.8	6.5	--	84.2	70	6.4	7.1
(MWP)	03-09-94	--	25.5	802	1.0	6.3	--	41.0	44	.068	.95
	03-09-94	--	25.5	802	1.0	6.3	--	41.0	41	.071	.86
272153082290600	07-13-92	--	29.0	253	5.4	6.7	52	--	50	.12	.56
(GPD)	08-26-92	--	31.2	289	11.0	7.5	67	--	56	T.029	.49
	12-07-92	--	19.6	386	11.4	8.6	86	--	81	ND	.62
	02-23-93	--	19.5	432	8.7	7.9	--	84.4	87	T.036	.61
					HIGHLANDS GOLF COURSE						
272213082290401	06-22-92	17.19	24.8	1,330	2.0	5.6	36	--	33	T.068	1.7
(H5T)	08-18-92	11.14	26.3	887	1.7	5.7	41	--	39	ND	.66
	11-30-92	14.82	25.6	558	.6	5.6	58	--	56	T.05	.53
	02-18-93	14.97	24.5	615	.8	5.7	--	55.5	56	T.036	.36
272224082290301	06-18-92	10.90	24.7	983	2.6	4.5	<0	--	2	.051	.99
(H6T)	08-19-92	7.99	27.6	838	.5	4.6	<0	--	4	.420	1.3
	12-01-92	9.39	25.1	870	.7	4.5	--	--	10	2.0	2.6
	02-17-93	9.22	23.0	837	.8	4.6	--	2.70	1	.069	1.1
272214082284401	06-17-92	6.57	23.5	1,670	.5	5.5	72	--	81	.67	1.6
(H7G)	08-25-92	6.25	25.3	2,400	.7	5.1	32	--	25	.40	1.4
	12-02-92	6.92	23.3	1,530	.8	5.1	--	--	31	1.1	2.0
	12-02-92	6.92	23.3	1,530	.8	5.1	--	--	33	1.1	2.0
	02-17-93	6.60	21.3	1,560	.8	5.3	--	30.2	32	.41	1.1
272158082284601	06-18-92	5.53	25.5	1,220	1.4	5.9	80	--	76	0.021	2.8
(H9G)	06-18-92	5.53	25.5	1,220	1.4	5.9	80	--	87	T.018	1.8
	08-19-92	3.50	27.2	1,400	0.8	5.8	70	--	65	T.043	1.1
	12-01-92	5.38	25.0	1,220	3.9	5.6	--	--	51	T.19	1.5
	02-18-93	4.44	22.4	1,260	.7	5.6	--	48.8	53	T.29	1.4
272157082283201	03-09-94	--	25.9	1,130	.5	7.4	--	145	145	.20	0.39
(HFL)											
272213082290300	06-22-92	--	34.4	888	9.4	8.9	17	--	23	.44	1.4
(HPD)	08-20-92	--	30.1	448	2.5	6.1	15	--	13	ND	.80
	11-30-92	--	20.5	659	11.5	9.4	15	--	13	ND	.81
	02-18-93	--	20.4	725	9.6	7.9	--	19.4	22	T.072	.39

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; μS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved nitrogen, $NO_2 + NO_3$ (mg/L as N)	Dissolved nitrogen, organic (calculated, mg/L as N)	Dissolved phosphorus (mg/L as P)	Dissolved phosphorus ortho (mg/L as P)	Dissolved organic carbon (mg/L as C)	Dissolved calcium (mg/L as Ca)	Dissolved magnesium (mg/L as Mg)	Dissolved sodium (mg/L as Na)	Dissolved potassium (mg/L as K)	Dissolved chloride (mg/L as Cl)
					GROVES GOLF COURSE						
G2G	07-14-92	T.032	4.0	.180	.190	90	2.8	0.70	88	27	120
	08-25-92	ND	4.0	.180	.180	99	2.8	0.60	81	28	120
	12-01-92	ND	3.0	.210	.150	110	2.2	0.50	76	26	120
	02-24-93	T.022	4.0	.170	.160	110	2.6	0.60	77	26	110
G4T	07-13-92	26.0	1.580	T.046	.050	14	100	42	70	49	45
	08-26-92	5.20	0.816	T.044	ND	11	40	13	22	46	23
	12-08-92	1.20	.783	ND	ND	9.4	12	3.8	14	25	32
	02-23-93	17.0	.700	ND	ND	9.4	17	6.9	24	32	39
G5G	07-14-92	5.20	.753	ND	ND	--	36	17	60	35	86
	08-26-92	3.50	.830	ND	ND	11	41	19	58	40	76
	12-07-92	ND	.731	ND	ND	9.9	31	13	47	29	53
	02-24-93	7.90	.745	ND	ND	8.4	30	13	42	27	46
	02-24-93	6.70	.692	ND	ND	8.4	29	13	43	28	46
G18T	06-23-92	.690	1.300	.220	ND	14	41	11	45	26	69
	08-27-92	ND	.460	ND	ND	11	21	3.5	21	14	18
	12-02-92	ND	.430	ND	ND	8.8	18	3.6	26	14	33
	02-25-93	17.0	.600	ND	ND	7.3	31	8.7	34	27	47
GEFF	06-23-92	6.70	1.046	1.50	1.50	22	60	21	60	15	86
	06-23-92	6.80	1.252	1.50	1.50	10	60	21	60	15	88
	08-27-92	.100	1.070	1.30	1.50	11	42	10	38	9.7	60
	08-27-92	.089	.960	1.30	1.40	11	44	10	40	10	58
	12-08-92	7.60	1.160	2.20	2.70	12	58	13	54	13	79
	02-25-93	6.50	1.150	2.00	2.10	17	55	13	57	16	73
MWP	01-06-94	8.70	.700	3.90	4.10	15	65	22	63	16	89
	03-09-94	15.0	.882	3.70	3.60	11	60	21	59	15	65
	03-09-94	15.0	.789	3.70	3.60	11	61	22	60	15	65
GPD	07-13-92	.063	.440	.200	.170	7.1	25	4.8	9.1	7.6	17
	08-26-92	ND	.461	.085	.086	8.5	34	5.7	10	10	20
	12-07-92	ND	.620	ND	ND	7.6	47	7.0	12	14	24
	02-23-93	.063	.574	.057	T.041	9.8	46	7.5	14	16	28
					HIGHLANDS GOLF COURSE						
H5T	06-22-92	4.00	1.632	.240	T.019	8.9	120	59	53	19	56
	08-18-92	6.70	.660	ND	T.021	10	76	40	38	15	32
	11-30-92	ND	.480	ND	T.026	9.8	43	26	19	13	17
	02-18-93	ND	.324	T.022	T.022	13	46	30	23	13	16
H6T	06-18-92	2.50	.939	T.035	ND	15	71	41	41	14	36
	08-19-92	ND	.880	.110	.073	21	63	33	41	13	35
	12-01-92	ND	.600	.110	.061	24	54	34	44	16	36
	02-17-93	9.80	1.031	.073	.080	21	56	42	35	14	34
H7G	06-17-92	T.049	.930	.490	.420	--	120	76	72	43	80
	08-25-92	T.025	1.000	.140	.150	18	210	140	130	61	120
	12-02-92	ND	.900	.310	.280	21	110	64	74	44	80
	12-02-92	ND	.900	.320	.310	19	110	64	74	43	80
	02-17-93	.300	.690	.170	.180	17	130	72	73	41	67
H9G	06-18-92	5.70	2.779	0.810	0.570	22	120	58	59	29	45
	06-18-92	4.70	1.782	1.00	.650	22	110	57	60	28	43
	08-19-92	0.260	1.057	.780	.870	23	130	68	56	31	48
	12-01-92	ND	1.310	1.50	1.80	29	99	52	51	29	46
	02-18-93	T.030	1.110	1.20	1.40	29	100	54	53	28	47
HFL	03-09-94	ND	.190	ND	ND	2.4	110	58	44	6.1	37
HPD	06-22-92	.110	.960	ND	ND	8.8	64	40	39	19	47
	08-20-92	ND	.800	.170	.140	12	32	20	20	11	26
	11-30-92	ND	.810	ND	ND	9.2	42	29	26	15	32
	02-18-93	.400	.318	ND	ND	6.9	47	34	32	16	33

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved sulfate (mg/L as SO_4)	Dissolved fluoride (mg/L as F)	Dissolved silica (mg/L as SiO_2)	Dissolved arsenic (µg/L as As)	Dissolved beryllium (µg/L as Be)	Dissolved cadmium (µg/L as Cd)	Dissolved chromium (µg/L as Cr)	Dissolved copper (µg/L as Cu)	Dissolved iron (µg/L as Fe)
				GROVES GOLF COURSE						
G2G	07-14-92	85	ND	18	T2	ND	ND	T20	ND	1,600
	08-25-92	64	ND	19	ND	ND	ND	T20	ND	1,400
	12-01-92	11	ND	17	T2	ND	ND	T20	ND	1,200
	02-24-93	36	ND	17	T3	ND	ND	T20	ND	1,400
G4T	07-13-92	430	.89	12	ND	ND	11	ND	T9	26
	08-26-92	210	.48	9.9	ND	ND	4.6	ND	T6	25
	12-08-92	70	.87	9.3	ND	ND	ND	ND	T7	60
	02-23-93	72	1.2	10	ND	ND	T4.0	ND	T5	21
G5G	07-14-92	220	.55	10	ND	ND	2.3	ND	ND	37
	08-26-92	200	.70	11	ND	ND	2.4	ND	ND	33
	12-07-92	190	.37	10	ND	ND	ND	ND	ND	76
	02-24-93	170	.44	9.8	ND	ND	ND	ND	ND	52
	02-24-93	170	.48	9.8	ND	ND	ND	ND	ND	56
G18T	06-23-92	180	ND	8.2	ND	ND	0.6	ND	ND	120
	08-27-92	96	ND	11	ND	ND	ND	ND	ND	3,400
	12-02-92	91	ND	9.4	ND	ND	ND	ND	ND	2,000
	02-25-93	91	.10	10	ND	ND	ND	ND	ND	100
GEFF	06-23-92	170	.22	3.5	ND	ND	T.070	ND	T10	T4
	06-23-92	160	.23	3.4	ND	ND	T.090	ND	T10	ND
	08-27-92	81	.12	3.8	ND	ND	ND	ND	10	T8
	08-27-92	81	.12	3.8	ND	ND	ND	ND	T10	T8
	12-08-92	110	.16	11	ND	ND	ND	ND	10	ND
	02-25-93	120	.17	5.6	ND	ND	ND	ND	T9	16
MWP	01-06-94	180	.42	14	ND	ND	ND	ND	T9	88
	03-09-94	190	.41	ND	ND	ND	ND	ND	ND	20
	03-09-94	170	.40	ND	ND	ND	ND	ND	ND	29
GPD	07-13-92	31	.14	2.0	T3	ND	ND	ND	T7	23
	08-26-92	33	.12	1.0	ND	ND	ND	ND	ND	T6
	12-07-92	54	.10	.48	ND	ND	ND	ND	23	13
	02-23-93	85	.17	.52	T3	ND	ND	ND	15	21
				HIGHLANDS GOLF COURSE						
H5T	06-22-92	550	ND	14	ND	ND	T.4	ND	10	850
	08-18-92	310	ND	15	ND	ND	T.1	ND	T7	13
	11-30-92	200	ND	15	ND	ND	ND	ND	ND	260
	02-18-93	230	ND	15	ND	ND	ND	ND	ND	250
H6T	06-18-92	460	ND	19	ND	ND	T.2	ND	T7	19
	08-19-92	370	ND	23	ND	ND	ND	ND	T7	230
	12-01-92	400	ND	22	T2	ND	ND	ND	ND	280
	02-17-93	320	ND	20	ND	ND	ND	ND	ND	20
H7G	06-17-92	640	.36	24	T4	ND	T.2	ND	T6	650
	08-25-92	1,300	.33	29	ND	ND	ND	ND	T7	5,200
	12-02-92	620	.22	25	T3	ND	ND	ND	T6	8,500
	12-02-92	580	.21	26	T4	ND	ND	ND	T5	8,500
	02-17-93	660	.26	24	ND	ND	ND	ND	ND	170
H9G	06-18-92	520	0.57	23	T22	ND	T.2	ND	13	17
	06-18-92	470	.62	24	T22	ND	T.2	ND	12	17
	08-19-92	630	.56	28	45	ND	ND	ND	T9	45
	12-01-92	500	.63	33	120	ND	ND	ND	T6	670
	02-18-93	500	.48	34	92	ND	ND	ND	ND	350
HFL	03-09-94	420	3.3	ND	ND	ND	ND	ND	ND	ND
HPD	06-22-92	330	ND	3.5	ND	ND	T.1	ND	ND	T4
	08-20-92	140	ND	2.5	ND	ND	ND	ND	ND	88
	11-30-92	260	ND	3.0	ND	ND	ND	ND	ND	T5
	02-18-93	280	ND	2.1	ND	ND	ND	ND	ND	5

Table 4. Water-quality data--Continued

[TOC, top of casing; ^{o}C, degrees Celsius; μS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved lead (μg/L as Pb)	Dissolved manganese (μg/L as Mn)	Dissolved molybdenum (μg/L as Mo)	Dissolved strontium (μg/L as Sr)	Dissolved vanadium (μg/L as V)	Dissolved zinc (μg/L as Zn)	Dissolved aluminum (μg/L as Al)	Methylene blue active substance (mg/L)
			GROVES GOLF COURSE						
G2G	07-14-92	ND	T8	ND	33	41	10	2,300	.19
	08-25-92	ND	T6	ND	28	43	T5	2,800	<.10
	12-01-92	ND	T4	ND	21	51	ND	3,600	<.10
	02-24-93	ND	10	ND	22	53	ND	3,600	.13
G4T	07-13-92	ND	830	ND	1,400	T3	860	1,600	.24
	08-26-92	ND	290	ND	630	ND	400	1,300	<.10
	12-08-92	ND	110	ND	200	ND	190	1,800	<.10
	02-23-93	ND	140	ND	280	ND	230	2,100	<.10
G5G	07-14-92	ND	100	ND	470	T5	340	1,300	.18
	08-26-92	ND	130	ND	660	T5	350	1,400	<.10
	12-07-92	ND	94	ND	410	T4	320	1,200	<.10
	02-24-93	ND	96	ND	380	ND	320	1,500	<.10
	02-24-93	ND	98	ND	380	ND	320	1,500	.10
G18T	06-23-92	ND	95	ND	470	T4	ND	870	.16
	08-27-92	ND	54	ND	230	ND	30	880	<.10
	12-02-92	ND	49	ND	200	ND	23	880	<.10
	02-25-93	ND	59	ND	350	ND	32	1,700	.08
GEFF	06-23-92	ND	ND	ND	4,000	T4	T5	ND	.24
	06-23-92	ND	ND	ND	4,100	T4	T6	ND	--
	08-27-92	ND	ND	ND	1,900	ND	T5	50	<.10
	08-27-92	ND	ND	ND	2,000	ND	ND	ND	<.10
	12-08-92	ND	ND	ND	2,400	T3	16	ND	<.10
	02-25-93	ND	ND	ND	2,300	ND	T9	80	.13
MWP	01-06-94	ND	21	ND	4,600	ND	38	ND	<.10
	03-09-94	ND	18	ND	4,600	ND	59	ND	<.10
	03-09-94	ND	19	ND	4,500	ND	57	ND	<.10
GPD	07-13-92	ND	18	ND	400	ND	ND	ND	.12
	08-26-92	ND	T3	ND	420	ND	ND	ND	<.10
	12-07-92	ND	T1	ND	660	T8	ND	80	<.10
	02-23-93	ND	T6	T2	770	T8	ND	T150	.18
			HIGHLANDS GOLF COURSE						
H5T	06-22-92	ND	120	T4	14,000	ND	ND	T60	.18
	08-18-92	ND	110	T5	6,600	T5	T6	50	<.10
	11-30-92	ND	72	6	5,300	T3	ND	ND	<.10
	02-18-93	ND	81	T5	5,200	T5	ND	ND	.08
H6T	06-18-92	ND	14	ND	4,600	T9	T8	2,000	--
	08-19-92	ND	18	ND	3,500	T4	T5	1,500	<.10
	12-01-92	ND	31	ND	3,800	ND	T5	1,200	<.10
	02-17-93	ND	73	ND	3,400	T4	T6	1,300	<.10
H7G	06-17-92	ND	110	11	2,700	18	T6	210	--
	08-25-92	ND	210	ND	6,200	T5	13	540	<.10
	12-02-92	ND	120	ND	3,300	T6	T8	400	<.10
	12-02-92	ND	120	ND	3,300	T6	T7	370	<.10
	02-17-93	ND	130	T2	3,300	30	ND	250	0.08
H9G	06-18-92	ND	40	ND	2,200	ND	T10	90	--
	06-18-92	ND	38	ND	2,400	ND	10	100	--
	08-19-92	ND	42	ND	3,300	ND	T6	180	<.10
	12-01-92	ND	37	ND	3,300	ND	T5	230	<.10
	02-18-93	ND	36	ND	2,400	ND	T5	220	.12
HFL	03-09-94	ND	ND	ND	15,000	ND	ND	ND	<.10
HPD	06-22-92	ND	ND	ND	2,100	ND	ND	90	.14
	08-20-92	ND	95	ND	940	ND	ND	ND	<.10
	11-30-92	ND	T2	ND	1,800	ND	ND	100	<.10
	02-18-93	ND	T9	ND	2,100	ND	ND	T120	<.10

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Station Number Site Code	Date	Depth to water (feet below TOC)	Water temper-ature (°C)	Spe-cific con-duct-ance (µS/cm)	Dis-solved oxygen (mg/L)	pH, field (stand-ard units)	Alkalinity ($mg/L\ CaCO_3$) field FET	Alkalinity ($mg/L\ CaCO_3$) field Gran	Alkalinity ($mg/L\ CaCO_3$) lab FET	Dis-solved nitrogen, ammonia (mg/L as N)	Dis-solved nitrogen, ammonia plus organic (mg/L as N)
					WINTER PINES GOLF COURSE						
283459081183901	07-21-92	4.42	26.2	1,390	.2	3.7	<0	--	ND	3.1	5.9
(W1G)	09-15-92	3.94	26.9	1,330	.5	3.6	<0	--	ND	2.7	4.4
	12-15-92	3.79	22.5	1,030	.6	3.7	<0	--	ND	1.7	4.5
	03-03-93	3.82	20.4	1,120	.6	3.6	<0	--	ND	2.1	3.4
283431081184401	07-22-92	6.58	25.2	554	.5	5.1	39	--	35	15.0	19
(W7T)	09-14-92	6.75	25.9	588	.8	5.1	39	--	33	16.0	20
	12-14-92	6.59	24.9	618	.7	5.1	39	--	32	16.0	25
	03-08-93	6.72	23.7	671	.7	5.1	--	51.8	16	20.0	21
283451081184801	07-23-92	8.34	24.1	527	.7	4.1	<0	--	ND	4.2	7.3
(W12G)	09-15-92	8.03	25.3	506	.5	4.1	<0	--	ND	4.3	4.8
	12-14-92	8.03	23.9	525	1.2	4.1	<0	--	ND	3.6	6.7
	12-14-92	8.03	23.9	522	1.2	4.1	<0	--	ND	3.7	7.4
	03-08-93	7.99	22.2	620	.8	4.1	--	<0.10	ND	4.4	4.5
283505081185501	07-22-92	8.06	25.4	374	.5	3.9	<0	--	ND	.86	1.2
(W18T)	09-15-92	7.14	26.2	377	.5	3.8	<0	--	ND	.47	1.2
	12-15-92	6.38	24.4	370	1.2	3.9	<0	--	ND	.89	1.5
	03-09-93	6.96	22.4	388	.6	3.9	--	<0.10	ND	.86	1.5
283622081184500	07-21-92	--	29.5	505	10.7	7.0	66	--	66	0.17	0.92
(WEFF)	09-16-92	--	28.0	551	10.8	5.3	<0	--	ND	ND	.59
	12-16-92	--	17.6	533	9.0	6.3	20	--	17	ND	.51
	12-16-92	--	17.6	533	9.0	5.9	20	--	17	.065	.49
	03-09-93	--	19.1	544	9.6	6.4	--	14.8	21	ND	.66
283431081185200	07-23-92	--	30.5	219	12.6	5.1	3	--	4	.078	.99
(WPD)	09-16-92	--	29.8	180	10.2	5.5	6	--	5	.85	1.6
	12-15-92	--	17.3	183	15.4	5.1	3	--	ND	1.30	2.0
	03-03-93	--	18.6	192	14.0	4.7	--	2.80	2	.65	1.3
					VENTURA GOLF COURSE						
283033081173801	07-15-92	8.23	26.0	396	.6	5.8	80	--	70	2.1	2.9
(V7T)	09-21-92	6.97	27.0	442	.6	6.0	100	--	68	3.0	4.0
	12-09-92	7.72	23.2	532	.6	6.0	130	--	80	5.2	9.3
	03-01-93	7.59	20.8	423	.6	6.0	--	122	89	3.1	4.1
283035081175301	07-16-92	7.19	25.5	275	.3	4.3	<0	--	ND	.069	1.4
(V9G)	09-17-92	6.57	26.4	238	.5	4.3	<0	--	ND	T.026	.52
	09-17-92	6.57	26.4	238	.5	4.3	--	--	ND	.058	.50
	12-09-92	7.07	23.6	214	.4	4.4	<0	--	ND	.072	.45
	03-01-93	6.95	21.3	263	.9	4.3	<0	--	ND	.074	.62
283045081173901	07-15-92	6.55	26.9	579	.5	5.8	160	--	109	15.0	18
(V11G)	09-21-92	6.12	27.2	609	.9	6.0	200	--	163	14.0	18
	12-16-92	6.16	22.3	658	1.3	6.0	191	--	148	14.0	23
	03-02-93	5.95	20.6	518	.8	6.0	--	161	129	2.0	19
283036081180201	07-20-92	7.12	26.0	556	.5	4.9	13	--	9	3.0	5.1
(V18T)	09-17-92	6.51	26.5	607	.8	4.9	13	--	11	2.0	2.4
	12-17-92	7.02	22.5	538	1.4	4.8	10	--	16	1.6	2.3
	03-02-93	7.30	20.3	512	.8	4.8	--	10.6	6	1.9	2.4
	03-02-93	7.30	20.3	512	.8	4.8	--	10.6	6	1.8	2.2
283040081174801 (VFL)	03-10-94	--	23.5	350	2.8	7.5	--	110	107	.25	.40
283045081174000	07-16-92	--	30.2	150	4.5	6.5	28	--	32	.04	.47
(VPD)	07-16-92	--	30.2	150	4.5	6.5	28	--	29	T.038	.58
	09-22-92	--	27.5	113	2.8	6.2	23	--	24	T.029	.54
	12-17-92	--	18.5	141	9.2	6.5	24	--	29	.045	.43
	03-02-93	--	18.7	148	8.5	6.5	--	25.5	26	.068	.45

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved nitrogen, $NO_2 + NO_3$ (mg/L as N)	Dissolved nitrogen, organic (calculated, mg/L as N)	Dissolved phosphorus (mg/L as P)	Dissolved phosphorus ortho (mg/L as P)	Dissolved organic carbon (mg/L as C)	Dissolved calcium (mg/L as Ca)	Dissolved magnesium (mg/L as Mg)	Dissolved sodium (mg/L as Na)	Dissolved potassium (mg/L as K)	Dissolved chloride (mg/L as Cl)
					WINTER PINES GOLF COURSE						
W1G	07-21-92	.250	2.80	ND	.069	22	59	44	81	63	110
	09-15-92	1.40	1.70	.059	.062	22	57	40	74	59	120
	12-15-92	0.930	2.80	.930	.051	21	40	29	57	45	91
	03-03-93	1.20	1.30	T.034	T.036	22	45	30	60	46	93
W7T	07-22-92	ND	4.0	ND	2.00	110	16	30	15	13	73
	09-14-92	ND	4.0	1.90	1.90	110	17	31	17	14	86
	12-14-92	ND	9.0	1.70	1.80	110	17	32	20	16	100
	03-08-93	T.027	1.0	1.70	1.70	100	17	33	23	18	94
W12G	07-23-92	ND	3.10	ND	T.021	12	8.5	14	21	15	63
	09-15-92	ND	0.50	ND	ND	11	6.7	13	23	15	72
	12-14-92	ND	3.10	ND	ND	12	7.9	14	25	17	77
	12-14-92	ND	3.70	ND	ND	11	7.6	14	24	16	77
	03-08-93	T.029	.10	ND	ND	12	6.5	17	35	18	89
W18T	07-22-92	.230	.340	ND	T.039	12	4.1	5.3	30	16	59
	09-15-92	.980	.730	T.044	T.025	12	2.7	5.7	28	12	62
	12-15-92	.440	.610	ND	T.022	12	3.0	5.4	29	14	59
	03-09-93	1.00	.640	ND	ND	12	3.6	6.0	30	13	65
WEFF	07-21-92	15.0	.750	2.00	1.90	21	35	7.7	43	7.9	69
	09-16-92	18.0	.590	1.30	1.40	6.7	40	7.5	37	7.5	90
	12-16-92	15.0	.510	1.30	1.40	7.4	41	7.3	41	7.6	89
	12-16-92	16.0	.425	1.30	1.40	5.4	40	7.3	39	7.5	88
	03-09-93	19.0	.660	0.950	0.950	14	38	7.4	39	7.4	78
WPD	07-23-92	ND	.912	ND	ND	15	8.4	3.4	15	11	30
	09-16-92	T.047	.750	ND	ND	15	6.7	3.1	13	11	24
	12-15-92	ND	.700	ND	ND	12	5.4	3.2	12	10	23
	03-03-93	.340	.650	ND	ND	13	6.0	3.3	12	11	25
					VENTURA GOLF COURSE						
V7T	07-15-92	ND	.80	T.040	T.036	33	26	12	12	8.5	29
	09-21-92	ND	1.00	.073	.070	31	32	13	15	10	32
	12-09-92	ND	4.10	ND	.056	33	34	13	14	13	35
	03-01-93	.061	1.00	T.044	.051	30	28	11	12	12	29
V9G	07-16-92	.630	1.331	.220	ND	7.4	14	5.7	11	12	27
	09-17-92	1.40	.494	ND	ND	6.6	13	5.1	4.9	12	17
	09-17-92	.940	.442	ND	ND	6.7	13	5.1	5.1	11	18
	12-09-92	.470	.378	ND	ND	6.8	11	4.7	5.2	11	19
	03-01-93	.910	.546	ND	ND	11	12	5.8	11	13	32
V11G	07-15-92	ND	3.0	.690	.570	110	18	13	26	13	58
	09-21-92	ND	4.0	1.30	1.40	93	46	17	23	18	52
	12-16-92	ND	9.0	.780	.950	85	38	17	22	19	59
	03-02-93	T.049	17.0	.720	.750	75	30	15	23	20	52
V18T	07-20-92	ND	2.10	ND	ND	8.1	13	22	29	23	40
	09-17-92	ND	.40	ND	ND	9.0	20	26	24	37	56
	12-17-92	ND	.70	ND	ND	8.2	19	26	14	30	50
	03-02-93	T.028	.50	ND	ND	--	16	26	15	32	42
	03-02-93	T.037	.40	ND	ND	27	15	26	16	33	42
VFL	03-10-94	ND	.150	.120	.098	3.2	45	9.1	8.8	5.2	17
VPD	07-16-92	ND	.430	ND	T.021	9.7	13	2.9	7.1	3.1	16
	07-16-92	ND	.542	ND	ND	10	13	2.8	6.9	3.0	15
	09-22-92	T.034	.511	.061	.065	13	13	2.3	4.9	3.1	11
	12-17-92	ND	.385	ND	T.028	13	13	2.9	7.0	3.4	15
	03-02-93	T.026	.382	T.028	ND	--	13	3.2	9.5	4.0	18

Table 4. Water-quality data--Continued

[TOC, top of casing; ^{o}C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved sulfate (mg/L as SO_4)	Dissolved fluoride (mg/L as F)	Dissolved silica (mg/L as SiO_2)	Dissolved arsenic (µg/L as As)	Dissolved beryllium (µg/L as Be)	Dissolved cadmium (µg/L as Cd)	Dissolved chromium (µg/L as Cr)	Dissolved copper (µg/L as Cu)	Dissolved iron (µg/L as Fe)
				WINTER PINES GOLF COURSE						
W1G	07-21-92	480	ND	26	ND	ND	ND	ND	ND	3,300
	09-15-92	450	.10	14	ND	ND	ND	ND	ND	3,000
	12-15-92	290	ND	25	ND	ND	ND	ND	ND	2,000
	03-03-93	320	.12	25	ND	ND	ND	ND	ND	1,900
W7T	07-22-92	76	ND	44	ND	ND	ND	ND	T5	1,100
	09-14-92	73	ND	47	ND	ND	ND	ND	ND	1,200
	12-14-92	100	ND	47	ND	ND	ND	ND	T6	1,100
	03-08-93	130	ND	47	ND	ND	ND	ND	ND	1,200
W12G	07-23-92	130	ND	17	ND	ND	ND	ND	ND	2,100
	09-15-92	120	ND	16	ND	ND	ND	ND	ND	1,900
	12-14-92	130	ND	17	ND	T1	ND	ND	ND	1,900
	12-14-92	120	ND	17	ND	T1	ND	ND	ND	1,900
	03-08-93	160	ND	17	ND	ND	ND	ND	ND	1,900
W18T	07-22-92	47	ND	15	T4	ND	ND	ND	T5	680
	09-15-92	52	ND	15	T2	ND	ND	ND	ND	980
	12-15-92	58	ND	14	T4	ND	ND	ND	ND	700
	03-09-93	47	ND	14	5	ND	T3.0	ND	ND	880
WEFF	07-21-92	30	ND	14	ND	ND	ND	ND	16	T7
	09-16-92	34	0.44	ND	ND	ND	ND	ND	35	12
	12-16-92	33	.40	14	ND	ND	ND	ND	24	T10
	12-16-92	27	.43	14	ND	ND	ND	ND	23	15
	03-09-93	41	.57	11	ND	ND	ND	ND	19	T6
WPD	07-23-92	43	.12	0.84	24	ND	T.080	ND	54	ND
	09-16-92	30	ND	7.0	11	ND	ND	ND	ND	15
	12-15-92	38	ND	3.8	T5	ND	ND	ND	T8	35
	03-03-93	37	.13	3.8	15	ND	ND	ND	16	35
				VENTURA GOLF COURSE						
V7T	07-15-92	67	.12	4.6	T5	T1	ND	ND	ND	19,000
	09-21-92	48	.18	8.3	5	ND	ND	ND	ND	18,000
	12-09-92	72	.12	5.9	10	ND	ND	ND	ND	27,000
	03-01-93	33	.16	5.7	7	ND	ND	ND	ND	21,000
V9G	07-16-92	65	.18	3.3	ND	T.5	ND	ND	ND	1,200
	09-17-92	60	.14	3.2	ND	T1	ND	ND	ND	1,000
	09-17-92	63	.15	5.4	ND	T1	ND	ND	ND	1,100
	12-09-92	48	.10	3.0	ND	ND	ND	ND	ND	870
	03-01-93	52	.16	3.3	ND	ND	ND	ND	ND	1,700
V11G	07-15-92	14	.15	6.4	11	ND	ND	ND	ND	30,000
	09-21-92	11	.22	3.7	48	ND	ND	ND	ND	24,000
	12-16-92	34	.16	6.3	31	ND	ND	ND	ND	29,000
	03-02-93	19	.22	5.5	22	ND	ND	ND	ND	24,000
V18T	07-20-92	180	ND	7.0	ND	ND	ND	ND	ND	3,200
	09-17-92	190	ND	3.0	ND	ND	ND	ND	ND	2,700
	12-17-92	150	ND	6.6	ND	ND	ND	ND	ND	2,800
	03-02-93	160	ND	6.7	ND	ND	ND	ND	ND	2,300
	03-02-93	160	ND	6.7	ND	ND	ND	ND	ND	2,200
VFL	03-10-94	41	.19	5.9	ND	ND	ND	ND	ND	240
VPD	07-16-92	16	.12	4.5	T2	ND	ND	ND	34	71
	07-16-92	17	.13	4.7	T2	ND	ND	ND	33	73
	09-22-92	T20	.14	4.0	10	ND	ND	ND	T8	130
	12-17-92	16	ND	2.0	T3	ND	ND	ND	65	190
	03-02-93	11	.14	1.5	T3	ND	ND	ND	19	300

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved lead (µg/L as Pb)	Dissolved manganese (µg/L as Mn)	Dissolved molybdenum (µg/L as Mo)	Dissolved strontium (µg/L as Sr)	Dissolved vanadium (µg/L as V)	Dissolved zinc (µg/L as Zn)	Dissolved aluminum (µg/L as Al)	Methylene blue active substance (mg/L)
				WINTER PINES GOLF COURSE					
W1G	07-21-92	ND	21	ND	170	T5	T6	960	.14
	09-15-92	ND	17	ND	150	T7	ND	820	<.10
	12-15-92	ND	11	ND	110	T5	ND	610	<.10
	03-03-93	ND	13	ND	120	T5	ND	660	<.10
W7T	07-22-92	T1	39	ND	170	ND	T9	250	.18
	09-14-92	ND	43	ND	190	ND	ND	250	<.10
	12-14-92	ND	42	ND	190	T4	ND	220	<.10
	03-08-93	ND	44	ND	200	T4	ND	230	.19
W12G	07-23-92	ND	T8	ND	82	T5	ND	8,800	.15
	09-15-92	ND	T8	ND	63	T5	ND	7,800	<.10
	12-14-92	ND	T8	ND	69	T4	ND	8,500	<.10
	12-14-92	ND	T8	ND	68	T4	T6	8,400	<.10
	03-08-93	ND	T7	ND	79	T5	ND	8,900	<.10
W18T	07-22-92	T3	T3	ND	22	ND	T7	1,700	.11
	09-15-92	ND	ND	ND	21	ND	ND	1,900	<.10
	12-15-92	ND	ND	ND	24	ND	ND	2,000	--
	03-09-93	ND	T1	ND	27	ND	ND	2,200	<.10
WEFF	07-21-92	ND	T3	ND	150	ND	12	ND	0.15
	09-16-92	ND	T1	ND	150	T3	9	80	<.10
	12-16-92	ND	ND	ND	160	ND	21	ND	<.10
	12-16-92	ND	ND	ND	160	ND	19	ND	--
	03-09-93	ND	T1	ND	150	ND	11	ND	<.10
WPD	07-23-92	ND	T9	ND	34	ND	ND	140	.13
	09-16-92	ND	10	ND	26	ND	ND	130	.12
	12-15-92	ND	T7	ND	26	ND	ND	270	.72
	03-03-93	ND	T8	ND	31	ND	ND	310	.25
				VENTURA GOLF COURSE					
V7T	07-15-92	T2	11	T3	81	15	ND	100	.19
	09-21-92	ND	11	T4	82	14	ND	80	<.10
	12-09-92	ND	13	ND	85	17	ND	70	<.10
	03-01-93	T16	11	T2	70	13	ND	ND	<.10
V9G	07-16-92	ND	T3	ND	43	T6	ND	1,400	.13
	09-17-92	ND	T3	ND	37	T7	ND	1,200	<.10
	09-17-92	ND	T3	ND	37	T7	ND	1,200	--
	12-09-92	ND	T2	ND	34	T5	ND	1,000	<.10
	03-01-93	T15	T3	ND	41	T6	ND	1,300	<.10
V11G	07-15-92	ND	25	ND	65	29	ND	150	.21
	09-21-92	ND	280	ND	130	33	ND	150	.10
	12-16-92	ND	250	ND	120	31	T7	130	1.6
	03-02-93	ND	130	ND	100	28	ND	T160	.12
V18T	07-20-92	ND	16	ND	41	ND	T5	250	.15
	09-17-92	ND	16	ND	50	ND	ND	230	<.10
	12-17-92	ND	18	ND	50	ND	ND	310	<.10
	03-02-93	ND	15	ND	45	ND	ND	380	<.10
	03-02-93	ND	15	ND	45	ND	ND	390	<.10
VFL	03-10-94	ND	19	31	99	ND	ND	ND	<.10
VPD	07-16-92	ND	T10	ND	48	ND	T6	50	.13
	07-16-92	T1	T10	ND	47	ND	T5	50	.14
	09-22-92	ND	15	ND	35	ND	ND	130	<.10
	12-17-92	ND	T9	ND	41	ND	14	90	<.10
	03-02-93	ND	T7	ND	43	ND	T9	T150	<.10

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Station Number Site Code	Date	Depth to water (feet below TOC)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	pH, field (standard units)	Alkalinity ($mg/L\ CaCO_3$)			Dissolved nitrogen, ammonia (mg/L as N)	Dissolved nitrogen, ammonia plus organic (mg/L as N)
							field FET	field Gran	lab FET		
				BONAVENTURE GOLF COURSE							
260709080222301	04-14-93	5.73	25.1	1,450	--	7.1	--	480	405	6.8	7.9
(B2G)	06-07-93	5.60	24.7	990	0.9	7.1	340	--	354	4.3	6.0
	09-13-93	5.89	26.3	1,370	.5	6.6	--	418	436	6.9	9.0
	12-27-93	5.71	24.7	1,400	.5	6.6	--	427	424	7.3	8.4
260708080223501	03-24-93	6.58	23.4	2,810	--	6.9	--	--	656	15.0	16
(B7G)	06-08-93	5.83	24.4	1,500	.5	6.8	520	--	537	8.5	9.2
	09-15-93	5.97	26.4	1,290	.4	6.8	--	433	459	5.6	7.2
	12-27-93	5.94	24.6	1,450	.5	6.7	--	475	488	5.6	7.6
260724080224601	03-24-93	6.66	23.0	1,390	--	7.0	--	396	414	7.1	7.3
(B15G)	06-08-93	5.61	24.7	1,390	2.5	6.9	502	--	406	6.4	6.6
	09-14-93	5.90	26.2	1,340	.5	6.7	--	516	400	6.5	7.5
	12-28-93	5.91	25.0	1,310	.5	6.6	--	--	407	6.1	7.4
260728080222101	03-23-93	3.36	23.1	1,020	.4	6.8	--	325	325	2.3	3.5
(B17G)	06-09-93	3.52	24.3	965	.4	6.9	328	--	321	1.9	3.2
	06-09-93	3.52	24.3	965	.4	6.9	328	--	318	2.6	3.5
	09-15-93	3.59	26.2	930	.4	6.9	--	394	320	2.4	3.5
	12-29-93	3.57	24.2	935	.4	6.9	--	317	311	2.1	3.6
260738080221601	03-24-93	3.54	25.4	728	.4	7.2	--	246	232	1.5	2.4
(BML)	06-08-93	3.70	25.4	723	.5	7.2	236	--	235	1.8	2.9
	09-13-93	3.98	26.0	740	.3	7.1	--	244	232	2.3	3.8
	12-28-93	3.77	25.5	709	.4	7.1	--	225	231	1.5	2.8
				PENSACOLA NAS GOLF COURSE							
302140087164301	03-31-93	18.06	20.9	170	5.0	6.1	--	19.0	20	ND	.32
(N10G)	06-23-93	19.09	21.0	137	4.3	6.2	19	--	23	T.02	.33
	09-22-93	19.16	22.2	173	4.8	5.9	--	14.0	22	ND	.30
	01-26-94	20.50	21.3	176	5.3	6.3	--	30.0	29	T.034	.57
302140087170001	03-31-93	26.04	22.1	165	5.3	6.5	--	54.0	48	ND	.17
(N14G)	06-22-93	26.97	22.3	106	1.8	6.6	43	--	39	ND	.10
	09-21-93	26.84	23.6	104	3.9	6.9	--	39.0	39	.04	.13
	01-25-94	27.07	21.3	84	4.8	6.6	--	27.0	24	ND	T.059
302149087165201	03-30-93	10.33	19.8	327	2.1	5.2	--	9.0	5	ND	.19
(N14T)	06-23-93	10.99	20.9	320	2.4	5.2	10	--	3	ND	.19
	09-22-93	11.30	22.9	312	1.4	5.1	--	4.40	4	ND	.22
	01-25-94	11.65	20.8	279	1.8	5.1	--	6.00	7	T.020	.29
302134087170701	03-30-93	14.03	21.4	194	.7	6.1	--	58.0	52	.07	.32
(N16G)	03-30-93	14.03	21.4	194	.7	6.1	--	58.0	52	.068	.27
	06-23-93	14.84	21.4	184	.5	6.1	52	--	55	.076	.31
	09-21-93	15.21	23.3	220	.5	6.1	--	49.0	52	.14	.37
	01-26-94	15.56	22.2	235	.4	6.1	--	58.0	56	ND	.13
302156087170101	03-31-93	12.86	19.1	148	2.4	5.9	--	19.0	16	ND	.50
(NML)	06-23-93	14.81	21.5	151	1.8	5.9	19	--	17	ND	.44
	09-21-93	13.51	24.2	162	1.6	5.7	--	16.0	16	T.024	.46
	01-25-94	14.13	20.1	170	1.0	5.9	--	18.0	20	T.020	.56

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved nitrogen, $NO_2 + NO_3$ (mg/L as N)	Dissolved nitrogen, organic (calculated, mg/L as N)	Dissolved phosphorus (mg/L as P)	Dissolved phosphorus ortho (mg/L as P)	Dissolved organic carbon (mg/L as C)	Dissolved calcium (mg/L as Ca)	Dissolved magnesium (mg/L as Mg)	Dissolved sodium (mg/L as Na)	Dissolved potassium (mg/L as K)	Dissolved chloride (mg/L as Cl)
					BONAVENTURE GOLF COURSE						
B2G	04-14-93	ND	1.10	ND	ND	61	190	11	87	2.3	210
	06-07-93	ND	1.70	.042	T.023	34	130	8.5	67	4.4	130
	09-13-93	ND	2.10	T.024	T.017	39	180	10	90	3.6	180
	12-27-93	T.041	1.10	T.024	T.020	33	180	10	90	3.3	190
B7G	03-24-93	ND	1.00	ND	ND	77	270	21	270	3.8	420
	06-08-93	ND	0.70	.170	.140	43	190	13	140	3.8	200
	09-15-93	ND	1.60	.190	.200	32	140	12	87	5.5	120
	12-27-93	.095	2.00	.250	.180	34	150	14	100	6.3	160
B15G	03-24-93	ND	.20	ND	ND	24	170	14	100	2.4	200
	06-08-93	ND	.20	T.018	ND	34	180	11	110	1.7	200
	09-14-93	ND	1.00	T.025	ND	31	160	11	99	1.7	180
	12-28-93	ND	1.30	ND	ND	29	150	11	94	1.7	180
B17G	03-23-93	T.042	1.20	T.032	T.030	33	120	12	74	1.6	130
	06-09-93	ND	1.30	T.027	T.020	29	130	9.8	66	1.3	130
	06-09-93	ND	.90	T.033	T.019	30	130	10	65	1.4	130
	09-15-93	ND	1.10	.051	T.024	28	110	11	66	1.6	110
	12-29-93	ND	1.50	T.020	T.023	26	110	11	67	1.6	120
BML	03-24-93	ND	.90	ND	ND	24	71	12	59	4.2	90
	06-08-93	ND	1.10	T.016	ND	25	69	12	49	4.0	95
	09-13-93	ND	1.50	T.026	ND	24	77	11	53	4.4	84
	12-28-93	ND	1.30	ND	ND	19	73	12	55	3.4	82
					PENSACOLA NAS GOLF COURSE						
N10G	03-31-93	4.70	.320	T.023	ND	2.9	11	3.1	15	4.9	15
	06-23-93	2.40	.310	T.024	ND	2.9	9.6	2.1	13	3.6	12
	09-22-93	3.40	.300	T.030	ND	2.9	9.7	2.9	15	3.9	15
	01-26-94	3.40	.536	T.023	ND	6.2	14	3.7	13	5.1	12
N14G	03-31-93	3.40	.170	ND	ND	2.2	25	1.8	4.0	0.80	5.8
	06-22-93	.930	.100	ND	ND	2.0	17	1.1	1.7	0.60	T2.0
	09-21-93	.610	.090	ND	ND	19	18	1.1	1.6	0.70	3.1
	01-25-94	.660	.059	ND	ND	2.0	12	0.90	2.5	0.70	4.2
N14T	03-30-93	9.90	.190	ND	ND	2.8	18	9.9	18	7.6	28
	06-23-93	8.90	.190	ND	ND	1.8	17	9.3	19	7.6	28
	09-22-93	8.30	.220	ND	ND	1.9	17	9.2	17	8.1	24
	01-25-94	7.00	.270	ND	ND	3.4	15	7.9	16	7.5	22
N16G	03-30-93	1.70	.250	ND	ND	3.1	28	1.8	6.1	1.5	7.6
	03-30-93	2.10	.202	ND	ND	3.2	28	1.8	5.9	1.4	7.5
	06-23-93	1.60	.234	ND	ND	3.3	27	1.7	5.2	1.4	7.5
	09-21-93	2.70	.230	T.021	ND	ND	34	2.0	5.3	1.3	8.8
	01-26-94	2.30	.130	ND	ND	6.0	37	2.3	5.8	1.4	9.5
NML	03-31-93	2.70	.500	T.028	T.027	7.3	10	3.8	8.2	5.8	13
	06-23-93	2.20	.440	T.033	T.034	5.1	11	3.9	7.8	4.9	16
	09-21-93	3.20	.436	T.037	T.021	5.4	12	4.4	8.2	5.3	13
	01-25-94	2.70	.540	T.025	T.024	5.7	13	4.6	8.0	5.0	20

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; μS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved sulfate (mg/L as SO_4)	Dissolved fluoride (mg/L as F)	Dissolved silica (mg/L as SiO_2)	Dissolved arsenic (μg/L as As)	Dissolved beryllium (μg/L as Be)	Dissolved cadmium (μg/L as Cd)	Dissolved chromium (μg/L as Cr)	Dissolved copper (μg/L as Cu)	Dissolved iron (μg/L as Fe)
				BONAVENTURE GOLF COURSE						
B2G	04-14-93	17	.14	9.6	T2	ND	ND	ND	ND	1,900
	06-07-93	11	.19	9.2	50	ND	ND	ND	ND	1,200
	09-13-93	15	.11	9.7	15	ND	ND	ND	ND	1,800
	12-27-93	13	.12	8.2	20	ND	ND	ND	ND	1,700
B7G	03-24-93	83	.18	14	T3	ND	ND	ND	ND	4,000
	06-08-93	17	.29	15	40	ND	ND	ND	ND	5,100
	09-15-93	8.6	.33	16	23	ND	ND	ND	ND	4,900
	12-27-93	10	.24	14	59	ND	ND	ND	ND	4,800
B15G	03-24-93	ND	.16	10	ND	ND	ND	ND	ND	2,300
	06-08-93	ND	.16	9.0	ND	ND	ND	ND	ND	3,100
	09-14-93	1.2	.22	8.8	ND	ND	ND	ND	ND	3,000
	12-28-93	0.80	.15	7.3	ND	ND	ND	ND	ND	2,500
B17G	03-23-93	ND	.18	10	ND	ND	ND	ND	ND	670
	06-09-93	ND	.20	11	ND	ND	ND	ND	ND	690
	06-09-93	ND	.19	11	ND	ND	ND	ND	ND	710
	09-15-93	ND	.24	10	ND	ND	ND	ND	ND	800
	12-29-93	T.27	.17	9.0	ND	ND	ND	ND	ND	600
BML	03-24-93	ND	.19	13	22	ND	ND	ND	ND	390
	06-08-93	ND	.25	13	40	ND	ND	ND	ND	410
	09-13-93	.83	.24	13	51	ND	ND	ND	ND	480
	12-28-93	ND	.27	11	13	ND	ND	ND	ND	470
				PENSACOLA NAS GOLF COURSE						
N10G	03-31-93	17	ND	5.7	ND	ND	ND	ND	ND	T3
	06-23-93	16	ND	6.0	ND	ND	ND	ND	ND	ND
	09-22-93	21	ND	5.3	ND	ND	ND	ND	--	ND
	01-26-94	21	ND	3.7	ND	ND	ND	ND	ND	ND
N14G	03-31-93	6.3	ND	2.3	ND	ND	ND	ND	ND	ND
	06-22-93	5.5	ND	2.0	ND	ND	ND	ND	ND	T17
	09-21-93	3.9	ND	2.5	ND	ND	ND	ND	ND	T4
	01-25-94	4.2	.10	2.4	ND	ND	ND	ND	ND	ND
N14T	03-30-93	57	ND	4.4	ND	ND	ND	ND	ND	ND
	06-23-93	59	ND	4.7	ND	ND	ND	ND	ND	ND
	09-22-93	55	ND	4.4	ND	ND	ND	ND	--	ND
	01-25-94	53	ND	3.7	ND	ND	ND	ND	ND	ND
N16G	03-30-93	16	ND	5.1	ND	ND	ND	ND	ND	210
	03-30-93	15	ND	5.1	ND	ND	ND	ND	ND	250
	06-23-93	15	ND	5.5	ND	ND	ND	ND	ND	160
	09-21-93	22	ND	5.4	ND	ND	ND	ND	ND	ND
	01-26-94	33	ND	4.6	ND	ND	ND	ND	ND	ND
NML	03-31-93	20	ND	4.0	ND	ND	ND	ND	ND	T8
	06-23-93	18	ND	3.9	ND	ND	ND	ND	ND	T12
	09-21-93	21	ND	3.9	ND	ND	ND	ND	ND	ND
	01-25-94	15	ND	3.3	ND	ND	ND	ND	ND	ND

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; μS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved lead (μg/L as Pb)	Dissolved manganese (μg/L as Mn)	Dissolved molybdenum (μg/L as Mo)	Dissolved strontium (μg/L as Sr)	Dissolved vanadium (μg/L as V)	Dissolved zinc (μg/L as Zn)	Dissolved aluminum (μg/L as Al)	Methylene blue active substance (mg/L)
				BONAVENTURE GOLF COURSE					
B2G	04-14-93	ND	52	ND	1,900	ND	ND	ND	.20
	06-07-93	ND	47	ND	1,100	T4	ND	ND	<.10
	09-13-93	ND	58	ND	1,500	ND	ND	ND	<.10
	12-27-93	ND	57	ND	1,500	ND	ND	ND	<.10
B7G	03-24-93	ND	230	ND	2,700	ND	ND	ND	--
	06-08-93	ND	160	ND	1,900	ND	ND	ND	<.10
	09-15-93	ND	120	ND	1,400	ND	ND	ND	<.10
	12-27-93	ND	120	ND	1,500	ND	ND	ND	<.10
B15G	03-24-93	ND	53	ND	1,700	ND	ND	ND	<.10
	06-08-93	ND	54	ND	1,600	ND	ND	ND	<.10
	09-14-93	ND	60	ND	1,500	ND	ND	ND	<.10
	12-28-93	ND	58	ND	1,400	ND	ND	ND	<.10
B17G	03-23-93	ND	92	ND	1,100	ND	ND	ND	.21
	06-09-93	ND	78	ND	1,100	ND	ND	ND	<.10
	06-09-93	ND	83	ND	1,100	ND	ND	ND	<.10
	09-15-93	ND	92	ND	940	ND	ND	ND	<.10
	12-29-93	T17	95	ND	1,000	ND	ND	ND	<.10
BML	03-24-93	ND	24	ND	880	ND	ND	ND	<.10
	06-08-93	ND	24	ND	910	ND	ND	ND	<.10
	09-13-93	ND	25	ND	830	ND	ND	ND	<.10
	12-28-93	ND	24	ND	870	ND	ND	ND	<.10
				PENSACOLA NAS GOLF COURSE					
N10G	03-31-93	ND	T3	ND	17	ND	11	ND	<.10
	06-23-93	ND	T3	ND	15	ND	10	ND	<.10
	09-22-93	ND	T6	ND	15	ND	T9	ND	<.10
	01-26-94	ND	T2	ND	22	ND	T9	ND	<.10
N14G	03-31-93	ND	T1	ND	43	ND	ND	ND	<.10
	06-22-93	ND	ND	ND	29	ND	ND	ND	<.10
	09-21-93	ND	ND	ND	31	ND	ND	ND	<.10
	01-25-94	ND	ND	ND	22	ND	ND	ND	<.10
N14T	03-30-93	ND	41	ND	39	ND	ND	ND	.20
	06-23-93	ND	39	ND	40	ND	ND	ND	<.10
	09-22-93	ND	38	ND	39	ND	T7	ND	<.10
	01-25-94	ND	32	ND	33	ND	ND	ND	<.10
N16G	03-30-93	ND	26	ND	78	ND	ND	ND	.19
	03-30-93	ND	26	ND	76	ND	ND	ND	<.10
	06-23-93	ND	40	ND	79	ND	ND	ND	<.10
	09-21-93	ND	62	ND	94	ND	ND	ND	<.10
	01-26-94	ND	72	ND	99	ND	ND	ND	<.10
NML	03-31-93	ND	T3	ND	19	ND	ND	ND	.21
	06-23-93	ND	T3	ND	21	ND	ND	ND	<.10
	09-21-93	ND	T2	ND	18	ND	ND	ND	<.10
	01-25-94	ND	T1	ND	18	ND	ND	ND	<.10

Table 4. Water-quality data--Continued

[TOC, top of casing; ^{o}C, degrees Celsius; μS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Station Number Site Code	Date	Depth to water (feet below TOC)	Water temperature (^{o}C)	Specific conductance (μS/cm)	Dissolved oxygen (mg/L)	pH, field (standard units)	Alkalinity ($mg/L\ CaCO_3$) field FET	Alkalinity ($mg/L\ CaCO_3$) field Gran	Alkalinity ($mg/L\ CaCO_3$) lab FET	Dissolved nitrogen, ammonia (mg/L as N)	Dissolved nitrogen, ammonia plus organic (mg/L as N)
SKIING PARADISE GOLF COURSE											
283223081494901 (S3T)	10-14-93	10.90	26.1	378	0.5	5.8	--	107	97	2.50	3.7
	01-04-94	11.07	22.9	394	.8	5.8	--	95.0	87	0.99	2.3
	03-08-94	10.75	21.7	509	.5	5.8	--	78.0	74	.95	1.8
283234081495301 (S4G)	10-13-93	7.80	26.1	172	.8	4.6	--	-0.50	ND	.250	0.69
	01-03-94	8.82	21.1	211	1.4	4.6	--	-1.30	ND	T.021	.49
	03-08-94	7.80	20.7	315	3.2	4.6	--	-0.98	ND	T.026	.69
283234081494701 (S4T)	10-13-93	3.98	26.5	167	1.6	4.3	--	-2.30	ND	ND	.25
	01-04-94	5.04	21.1	122	2.0	4.4	--	-1.40	ND	ND	.21
	03-08-94	3.87	21.1	135	2.1	6.4	--	-1.87	ND	ND	.22
283231081495101 (S5F)	10-13-93	5.80	26.3	150	.4	5.1	--	6.20	7	.160	1.3
	01-03-94	5.84	20.0	454	.9	5.4	--	17.0	18	.057	1.3
	03-07-94	5.72	20.1	338	1.4	5.5	--	5.20	6	T.027	.96
283218081492001 (SML)	10-18-93	5.35	26.8	240	.7	4.8	--	3.50	ND	.065	.72
	01-04-94	5.80	21.6	280	.5	4.9	--	4.00	ND	ND	.49
	03-07-94	5.53	21.0	445	.4	4.9	--	5.10	5	ND	.94

Site Code	Date	Dissolved nitrogen, $NO_2 + NO_3$ (mg/L as N)	Dissolved nitrogen, organic (calculated, mg/L as N)	Dissolved phosphorus (mg/L as P)	Dissolved phosphorus ortho (mg/L as P)	Dissolved organic carbon (mg/L as C)	Dissolved calcium (mg/L as Ca)	Dissolved magnesium (mg/L as Mg)	Dissolved sodium (mg/L as Na)	Dissolved potassium (mg/L as K)	Dissolved chloride (mg/L as Cl)
SKIING PARADISE GOLF COURSE											
S3T	10-14-93	1.90	1.200	T.033	T.032	21	48	8.2	5.1	10	21
	01-04-94	6.30	1.310	.046	T.035	18	54	8.8	6.0	11	22
	03-08-94	16.0	0.850	T.031	T.020	14	66	10	7.0	12	30
S4G	10-13-93	2.90	.440	ND	ND	5.1	15	2.7	2.5	7.9	14
	01-03-94	6.20	.469	T.021	T.016	5.1	18	4.6	4.0	8.1	17
	03-08-94	8.70	.664	ND	ND	4.3	27	6.3	8.8	14	35
S4T	10-13-93	4.10	.250	ND	ND	2.5	9.7	1.4	5.3	6.7	15
	01-04-94	.490	.210	ND	ND	2.2	6.7	1.1	6.2	5.5	14
	03-08-94	.680	.220	ND	ND	2.0	6.5	1.1	6.2	5.2	14
S5F	10-13-93	ND	1.140	ND	.00	25	13	3.0	4.2	5.4	21
	01-03-94	3.30	1.243	ND	ND	19	49	9.8	13	9.1	44
	03-07-94	2.20	.933	ND	ND	13	42	6.0	7.1	8.3	31
SML	10-18-93	14.0	.655	ND	ND	6.4	22	5.7	6.4	9.1	16
	01-04-94	21.0	.490	ND	ND	5.5	26	6.9	5.9	7.8	14
	03-07-94	35.0	.940	ND	ND	9.1	40	9.2	13	13	9.9

Table 4. Water-quality data--Continued

[TOC, top of casing; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; FET, fixed endpoint titration; Gran, Gran titration; organic nitrogen calculated as difference between dissolved ammonia plus organic and dissolved ammonia; ND, not detected; T, less than practical quantitation limit; --, no data; <, less than]

Site Code	Date	Dissolved sulfate (mg/L as SO_4)	Dissolved fluoride (mg/L as F)	Dissolved silica (mg/L as SiO_2)	Dissolved arsenic (µg/L as As)	Dissolved beryllium (µg/L as Be)	Dissolved cadmium (µg/L as Cd)	Dissolved chromium (µg/L as Cr)	Dissolved copper (µg/L as Cu)	Dissolved iron (µg/L as Fe)
				SKIING PARADISE GOLF COURSE						
S3T	10-14-93	35	ND	3.4	6	ND	ND	ND	ND	33
	01-04-94	38	ND	3.2	6	ND	ND	ND	ND	12
	03-08-94	45	ND	3.4	T4	ND	ND	ND	ND	12
S4G	10-13-93	35	ND	4.4	ND	ND	ND	ND	ND	59
	01-03-94	28	ND	3.0	ND	ND	ND	ND	ND	ND
	03-08-94	45	ND	3.1	ND	ND	ND	ND	ND	ND
S4T	10-13-93	27	0.18	6.2	ND	ND	ND	ND	ND	18
	01-04-94	26	ND	4.2	ND	ND	ND	ND	ND	21
	03-08-94	23	ND	3.9	ND	ND	ND	ND	ND	45
S5F	10-13-93	17	ND	4.0	T2	ND	T3.0	ND	T7	1,700
	01-03-94	90	ND	2.1	ND	ND	ND	ND	ND	660
	03-07-94	100	ND	1.9	ND	ND	ND	ND	ND	56
SML	10-18-93	22	0.28	8.6	ND	ND	ND	ND	ND	T16
	01-04-94	16	0.24	5.8	ND	ND	ND	ND	ND	ND
	03-07-94	35	0.46	7.6	ND	ND	ND	ND	ND	140

Site Code	Date	Dissolved lead (µg/L as Pb)	Dissolved manganese (µg/L as Mn)	Dissolved molybdenum (µg/L as Mo)	Dissolved strontium (µg/L as Sr)	Dissolved vanadium (µg/L as V)	Dissolved zinc (µg/L as Zn)	Dissolved aluminum (µg/L as Al)	Methylene blue active substance (mg/L)
				SKIING PARADISE GOLF COURSE					
S3T	10-14-93	ND	160	T2	47	T6	ND	T180	<.10
	01-04-94	ND	220	ND	58	ND	ND	T130	<.10
	03-08-94	ND	230	ND	66	ND	ND	T100	<.10
S4G	10-13-93	ND	35	ND	24	ND	29	610	<.10
	01-03-94	ND	T9	ND	23	ND	31	560	<.10
	03-08-94	ND	23	ND	32	ND	40	770	<.10
S4T	10-13-93	ND	46	ND	18	ND	60	1,800	<.10
	01-04-94	ND	30	ND	11	ND	41	1,400	<.10
	03-08-94	ND	32	ND	T10	ND	38	1,300	<.10
S5F	10-13-93	ND	24	ND	15	12	23	660	<.10
	01-03-94	ND	17	ND	37	ND	T9	660	<.10
	03-07-94	ND	T5	ND	32	ND	ND	300	<.10
SML	10-18-93	ND	22	ND	40	T5	T6	620	<.10
	01-04-94	ND	27	ND	48	ND	T6	580	<.10
	03-07-94	ND	39	ND	76	ND	T5	950	<.10

APPENDIX

Appendix. Water-quality data from monitor wells associated with reclaimed-water irrigation on golf courses

[Data provided by Hillsborough County Public Utilities Department, Meadowood Utilities of Sarasota, and Winter Park Water and Wastewater Treatment Division. ^{o}C, degrees Celsius; µS/cm, microsiemens per centimeter; ft, feet; NTU, nephelometric turbidity units; mg/L, milligrams per liter; TDS, total dissolved solids]

Buckhorn Springs Golf Course

Well Name	Date sampled	Water level (ft below top of casing)	pH	Temperature (^{o}C)	Specific Conductance (µS/cm)	Turbidity (NTU)	Chloride (mg/L)	TDS (mg/L)
				Shallow Wells				
BH-1	6-5-91	21.45	4.61	24.5	440	2.2	81.2	349
	9-16-91	19.27	4.90	26.9	336	2.5	62.5	230
	12-4-91	22.01	4.74	24.1	540	3.4	75.0	328
	3-9-92	21.18	4.72	23.3	474	2.4	55.0	332
	5-19-92	22.83	4.64	23.2	445	2.0	35.0	313
	8-3-92	22.21	4.67	25.0	549	3.0	90.0	419
	11-4-92	21.83	4.65	25.4	461	1.6	75.0	319
	1-26-93	21.69	4.66	23.1	613	1.9	65.0	415
	4-20-93	21.67	4.98	22.3	503	5.0	57.5	334
BH-2A	6-5-91	11.62	4.67	25.0	479	4.0	91.0	347
	9-16-91	9.37	4.98	26.0	431	3.0	55.0	321
	12-11 91	13.62	4.94	26.0	524	5.0	65.0	315
	3-8-92	12.57	5.00	24.0	493	5.0	54.0	283
	5-19-92	13.52	4.93	24.0	490	1.0	53.0	334
	8-4-92	12.54	5.32	25.0	571	18.0	82.0	430
	4-20-93	12.12	5.32	24.0	582	2.0	85.0	338
BH-3	6-5-91	15.96	5.12	25.0	473	1.0	84.0	341
	9-16-91	14.70	5.07	27.0	433	1.0	55.0	324
	12-11-91	DRY						
	3-9-92	15.42	5.13	24.0	430	3.0	55.0	273
	8-3-92	DRY						
	11-4-92	16.57	5.20	26.0	467	1.0	75.0	307
BH-4	6-5-91	26.62	5.26	35.7	138	1.0	10.0	112
	9-16-91	27.01	6.26	27.7	120	26.0	6.0	76
	12-11-91	DRY						
	3-9-92	27.21	6.43	22.9	170	13.0	15.4	110
	8-4-92	DRY						
	1-28-93	DRY						
				Floridan Aquifer Wells				
BH-7	6-5-91	15.81	7.01	25.0	489	1.0	68.0	412
(compliance)	9-16-91	12.48	6.80	25.0	522	.0	71.0	408
	12-4-91	16.07	6.99	24.0	619	.0	75.0	405
	3-9-92	15.91	7.01	25.0	562	1.0	72.0	386
	1-26-93	16.19	7.11	24.0	481	.0	76.0	451
P-12	6-5-91	41.47	6.91	26.0	115	1.0	7.0	99
(background)	9-16-91	31.10	6.84	26.0	128	2.0	9.0	98
	12-11-91	38.80	6.90	26.0	141	.0	10.0	90
	3-9-92	41.11	7.06	27.0	165	.0	13.0	104

Appendix. Water-quality data from monitor wells associated with reclaimed-water irrigation on golf courses—Continued

[Data provided by Hillsborough County Public Utilities Department, Meadowood Utilities of Sarasota, and Winter Park Water and Wastewater Treatment Division. mg/L, milligrams per liter; C/100 mL, colonies per 100 milliliters; <, less than]

Buckhorn Springs Golf Course

Well Name	Date sampled	Nitrate (as N, mg/L)	Fecal coliform (C/100 mL)	TOC (mg/L)	Sodium (mg/L)
			Shallow Wells		
BH-1	6-5-91	9.30	<2	2.1	65.8
	9-16-91	6.45	<2	2.3	40.1
	12-4-91	8.43	<2	2.3	69.1
	3-9-92	12.10	<2	2.7	66.0
	5-19-92	13.50	<2	1.5	61.8
	8-3-92	21.80	<2	1.2	52.4
	11-4-92	12.30	<2	9.6	54.0
	1-26-93	16.30	<2	2.6	61.4
	4-20-93	14.60	<1	1.9	55.0
BH-2A	6-5-91	4.15	<2	2.0	65.0
	9-16-91	7.27	<2	2.0	60.0
	12-11-91	5.67	<2	4.0	63.0
	3-8-92	6.76	<2	2.0	62.0
	5-19-92	13.10	<2	1.0	46.0
	8-4-92	21.20	<2	1.0	55.0
	4-20-93	10.10	<2	2.0	59.0
BH-3	6-5-91	7.86	<2	2.0	59.0
	9-16-91	7.12	<2	2.0	50.0
	12-11-91	DRY			
	3-9-92	6.02	<2	2.0	49.0
	8-3-92	DRY			
	11-4-92	6.94	<2	3.0	54.0
BH-4	6-5-91	6.32	<2	2.1	12.4
	9-16-91	2.64	<2	3.0	2.7
	12-11-91	DRY			
	3-9-92	2.45	<2	2.4	9.1
			Floridan Aquifer Wells		
BH-7	6-5-91	2.63	<2	2.0	24.0
(compliance)	9-16-91	2.64	<2	1.0	22.0
	12-11-91	3.14	<2	1.0	24.0
	3-9-92	2.75	<2	3.0	27.0
	1-26-93	0.53	<2	1.0	28.0
P-12	6-5-91	1.29	<2	3.0	4.0
(background)	9-16-91	1.49	<2	1.0	3.0
	12-11-91	1.63	<2	1.0	4.0
	3-9-92	1.96	<2	2.0	4.0

Appendix. Water-quality data from monitor wells associated with reclaimed-water irrigation on golf courses--Continued

[Data provided by Hillsborough County Public Utilities Department, Meadowood Utilities of Sarasota, and Winter Park Water and Wastewater Treatment Division. ^{o}C, degrees Celsius; µS/cm, microsiemens per centimeter; NTU, nephelometric turbidity units; mg/L, milligrams per liter; TDS, total dissolved solids]

Groves Golf Course

Well Name	Date sampled	Water level (ft below top of casing)	pH	Temperature (^{o}C)	Specific Conductance (µS/cm)	Turbidity (NTU)	Chloride (mg/L)	TDS (mg/L)
				Background Wells				
B-1	4-9-91	6.92	6.4	25.0	355	19	26.7	239
	8-28-91	7.08	6.4	29.0	330	197	23.0	236
	10-30-91	8.00	6.5	27.0	330	9	21.1	247
	2-12-92	8.00	6.6	23.0	340	141	15.5	295
	6-9-92	8.67	6.7	27.0	300	108	30.0	264
	9-1-92	7.16	6.4	28.0	320	24	16.0	319
	11-11-92	8.08	6.2	26.5	300	13	21.1	369
	2-10-93	7.58	6.1	23.0	300	117	11.1	247
B-1A	4-9-91	5.25	6.0	24.5	137	6	14.2	130
	8-28-91	4.67	5.5	28.5	160	13	3.1	85
	10-30-91	5.67	5.7	26.5	145	3	17.8	38
	2-12-92	6.00	5.9	22.5	100	19	7.8	80
	6-9-92	6.75	6.0	26.5	150	7	36.0	77
	9-1-92	4.75	5.9	27.0	152	11	17.2	123
	11-11-92	5.42	5.1	25.5	175	13	18.3	125
	2-10-93	5.33	5.4	21.5	180	16	13.0	145
				Compliance Wells				
C-1	4-9-91	4.75	6.0	24.5	520	3	42.3	387
	8-28-91	4.75	5.7	27.5	550	11	51.4	314
	10-30-91	5.92	6.3	24.5	580	3	35.0	296
	2-12-92	6.58	6.1	22.0	485	32	36.4	321
	6-9-92	6.50	6.3	25.5	550	19	56.0	384
	9-1-92	4.92	6.0	27.0	580	3	44.8	395
	11-11-92	6.00	5.6	24.5	540	10	46.1	261
	2-10-93	5.42	5.7	21.5	480	7	41.4	375
C-3	4-9-91	6.00	6.4	24.5	510	3	35.8	381
	8-28-91	6.00	6.1	28.5	480	131	29.1	224
	10-30-91	7.33	6.2	25.5	480	5	22.8	269
	2-12-92	7.75	6.3	23.0	420	28	24.8	281
	6-9-92	8.00	5.2	26.0	450	199	48.0	352
	9-1-92	6.08	6.6	27.0	500	10	33.9	360
	11-11-92	7.25	6.0	25.0	450	4	39.4	335
	2-10-93	6.58	6.6	22.0	440	41	26.7	335
C-4	4-9-91	10.58	7.1	24.0	1,500	3	56.3	1,177
	8-28-91	10.00	7.1	27.0	1,100	113	43.2	743
	10-30-91	11.58	7.4	25.0	1,250	6	64.3	731
	2-12-92	12.00	7.4	24.0	1,600	67	61.9	1,163
	6-9-92	12.50	7.1	25.5	1,500	91	78.0	1,128
	9-1-92	13.16	7.2	27.0	800	17	17.4	599
	11-11-92	11.75	6.8	25.0	695	6	26.8	515
	2-10-93	11.00	6.8	22.0	850	57	23.2	648

Appendix. Water-quality data from monitor wells associated with reclaimed-water irrigation on golf courses--Continued

[Data provided by Hillsborough County Public Utilities Department, Meadowood Utilities of Sarasota, and Winter Park Water and Wastewater Treatment Division. mg/L, milligrams per liter; C/100 mL, colonies per 100 milliliters; <, less than]

Groves Golf Course

Well Name	Date sampled	Nitrate (as N, mg/L)	Fecal coliform (C/100 mL)	TOC (mg/L)	Sodium (mg/L)
		Background Wells			
B-1	4-9-91	0.03	0	22	13.2
	8-28-91	< .03	<1	23	3.8
	10-30-91	< .17	<1	22	17.5
	2-12-92	< .03	<1	26	17.7
	6-9-92	.03	<1	28	21.5
	9-1-92	< .03	<1	23	10.4
	11-11-92	< .03	<1	20	10.4
	2-10-93	< .03	<1	21	5.5
B-1A	4-9-91	< .03	0	12	10.7
	8-28-91	< .03	<1	10	5.1
	10-30-91	.20	<1	9	14.2
	2-12-92	< .03	<1	13	21.6
	6-9-92	< .03	<1	19	18.0
	9-1-92	< .03	<1	7	15.5
	11-11-92	< .03	<1	9	14.9
	2-10-93	< .03	<1	9	12.4
		Compliance Wells			
C-1	4-9-91	< .03	0	<1	22.2
	8-28-91	.03	<1	2	13.8
	10-30-91	.07	<1	1	40.8
	2-12-92	< .03	<1	3	38.2
	6-9-92	< .03	<1	3	44.4
	9-1-92	< .03	<1	2	22.6
	11-11-92	.03	<1	3	25.2
	2-10-93	< .03	<1	2	24.1
C-3	4-9-91	.05	0	9	19.9
	8-28-91	3.23	<1	4	5.2
	10-30-91	2.57	<1	3	22.6
	2-12-92	1.62	<1	5	19.4
	6-9-92	2.31	<1	10	25.4
	9-1-92	7.23	<1	7	12.0
	11-11-92	9.06	4	4	13.0
	2-10-93	3.56	<1	3	10.9
C-4	4-9-91	13.90	0	34	18.2
	8-28-91	1.46	<1	13	7.9
	10-30-91	.86	<1	32	33.9
	2-12-92	7.92	<1	36	36.5
	6-9-92	4.29	<1	31	45.7
	9-1-92	< .03	<1	30	14.7
	11-11-92	.09	6	23	21.0
	2-10-93	4.36	<1	23	20.4

Appendix. Water-quality data from monitor wells associated with reclaimed- water irrigation on golf courses--Continued

[Data provided by Hillsborough County Public Utilities Department, Meadowood Utilities of Sarasota, and Winter Park Water and Wastewater Treatment Division. NTU, nephelometric turbidity units; mg/L, milligrams per liter; TDS, total dissolved solids; C/100 mL, colonies per 100 milliliters; <, less than]

Winter Pines Golf Course

Well Name	Date sampled	Turbidity (NTU)	Chloride (mg/L)	TDS (mg/L)	Nitrate (as N, mg/L)	Fecal coliform (C/100 mL)
W18T	6-17-91	1	84.1	268	0.4	<1
	9-9-91	3	78.8	237	.8	<1
	12-23-91	4	71.0	247	.3	<1
	3-16-92	3	77.9	285	.5	<1
	6-2-92	1	70.2	242	1.4	<1
	9-14-92	1	33.0	188	< .2	1
	12-15-92	1	30.2	185	.4	<1
	3-10-93	1	57.8	178	1.5	<1
WP-6	6-17-91	2	34.7	110	.5	<1
	9-9-91	<1	43.6	87	.5	<1
	12-23-91	22	49.3	139	< .2	<1
	3-16-92	5	57.7	122	.3	<1
	6-2-92	2	31.2	131	.3	<1
	9-14-92	4	37.0	91	< .2	<1
	12-15-92	2	45.9	122	< .2	<1
	3-10-93	10	20.5	55	.4	<1
W12G	6-17-91	5	47.0	273	.5	<1
	9-9-91	2	54.8	138	.4	<1
	12-23-91	2	58.8	236	< .2	<1
	3-16-92	2	67.6	262	< .2	<1
	6-2-92	1	70.6	322	.3	<1
	9-14-92	1	67.0	263	< .2	<1
	12-15-92	1	68.1	284	.3	<1
	3-10-93	9	80.7	320	.3	<1
W7T	6-17-91	14	46.8	378	1.8	4
	9-9-91	1	46.1	333	1.5	<1
	12-23-91	2	46.4	407	.7	<1
	3-16-92	10	59.7	508	1.1	<1
	6-2-92	16	71.5	461	.5	<1
	9-14-92	3	79.0	492	.5	<1
	12-15-92	2	82.9	611	.5	<1
	3-10-93	4	85.9	545	.6	<1