Reconnaissance of Water Quality at Four Swine Farms in Jackson County, Florida, 1993

By Jerilyn J. Collins

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CONVERSION FACTORS, SEA-LEVEL DATUM, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
inch (in.)	2.54	centimeter
inche per year (in/yr)	2.54	centimeters per year
foot (ft)	0.304	meter
acre	0.4047	hectare
gallon per minute (gal/min)	0.06309	liter per second
foot squared per day (ft^2/d)	0.09290	meter squared per day

Temperature degrees Fahrenheit (°F) and degrees Celsius (°C) may be converted as follows:

$$°C = 5/9 \times (°F - 32)$$

$$°F = (1.8\ °C) + 32$$

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

Abbreviations and Acronyms

mg/L = milligrams per liter
ppt = parts per thousand
pH = parts hydrogen
µS/cm = micrograms per centimeter
USEPA = U.S. Environmental Protection Agency
MCL = Maximum contaminant level
PVC = Polyvinalchloride

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Abstract

The quality of ground water on four typical swine farms in Jackson County, Florida, was studied by analyzing water samples from wastewater lagoons, monitoring wells, and supply wells. Water samples were collected quarterly for 1 year and analyzed for the following dissolved species: nitrate, nitrite, ammonium nitrogen, phosphorus, potassium, sulfate, chloride, calcium, magnesium, fluoride, total ammonium plus organic nitrogen, total phosphorus, alkalinity, carbonate, and bicarbonate. Additionally, the following field constituents were determined in the water samples: temperature, specific conductance, pH, dissolved oxygen, and fecal streptococcus and fecal coliform bacteria.

Chemical changes in swine waste as it leaches and migrates through the saturated zone were examined by comparing median values and ranges of water-quality data from farm wastewater in lagoons, shallow pond, shallow monitoring wells, and deeper farm supply wells. The effects of hydrogeologic settings and swine farm land uses on shallow ground-water quality were examined by comparing the shallow ground-water-quality data set with the results of the chemical analyses of water from the Upper Floridan aquifer, and to land uses adjacent to the monitoring wells. Substantial differences occur between the quality of diluted swine waste in the wastewater lagoons, and that of the water quality found in the shallow pond, and the ground water from all but two of the monitoring wells of the four swine farms. The liquid from the wastewater lagoons and ground water from two wells adjacent to and down the regional gradient from a lagoon on one site, have relatively high values for the following properties and constituents: specific conductance, dissolved ammonia nitrogen, dissolved potassium, and dissolved chloride. Ground water from all other monitoring wells and farm supply wells and the surface water pond, have relatively much lower values for the same properties and constituents.

To determine the relation between land uses and ground-water quality on the four swine farms, ground-water-quality data were divided according to the following land uses: confined operations in which swine are kept in houses and not allowed to roam freely, and unconfined operations in which swine are allowed to roam freely in determined areas. Confined operations had lagoons to receive the diluted swine wastes washed from the houses.

INTRODUCTION

Growing concern about the effects of farm animal waste upon the quality of ground and surface water in north Florida have prompted several studies in recent years. These studies were conducted to determine the effects that livestock farm management practices have on the input of large quantities of nitrate, ammonia, and soluble organic nitrogen species that are susceptible to nitrification to nitrate (Andrews, 1992; 1994; Hatzell, 1995). A principle reason for this concern is that N-species nitrogen enrichment in waters used by humans can cause numerous health problems and birth defects (Fan and others, 1987; Mirvish, 1990; and Bouchard and others, 1992).

Soluble forms of nitrogen and phosphorus are the main constituents of livestock waste affecting ground water that are a potential threat to the health of both livestock and humans; these n-species and p-species serve as plant nutrients (Goldberg, 1986; Krider, 1987). Enrichment of ground water with nutrients such as nitrate and phosphorus, common constituents in leachate from livestock wastes, can also cause the eutrophication of surface water bodies receiving inflows of ground water from springs or from diffuse seepage or ground water containing these leachates. Overuse of fertilizer and the disposal of sewage and livestock wastes have been cited as major reasons for elevated nitrate concentrations in ground water in agricultural areas. In Coastal Plain regions where farming practices are conducted over aquifers composed of unconsolidated sediments, nitrate contamination may occur primarily as a result of high annual rainfall (55 or more in/yr) and a subtropical temperature (65 –70 ×°F) that promote rapid weathering of overburden sediments, even when nutrients are used according to recommended practices. Research indicates that current best management practices do not assure that producers in Coastal Plain regions will always comply with the standard for maximum contaminant level of 10 mg/L for nitrate. (Magette and others, 1989).

Water-quality degradation in agricultural areas may be caused by erosion and sedimentation, animal wastes, fertilizer, and pesticides. Best management practices that control surface water runoff, and soil erosion will reduce particulate nitrogen and phosphorus loads to surface water, but may increase the amount of nitrate leaching to ground water. Applying only enough nutrients to meet crop needs will reduce nitrogen and phosphorus losses to the soil. Phosphorus is usually adsorbed in the soil profile; therefore, nitrogen species can be considered the primary constituents of concern in ground water in agricultural areas. Waste-loading from confined areas is greater than from sites where manure is applied to croplands or from livestock grazing areas (Ritter, 1988).

Case studies conducted in Delaware, Iowa, and California indicate that commercial fertilizers contribute more nitrogen to ground water than does animal waste; however, this does not reduce the importance of proper management of manure nitrogen. Certain segments of animal waste management systems are responsible for most of the contaminants to ground water. These segments are areas of high animal concentrations such as barnyards, manure storage ponds, treatment lagoons, and sites of manure applications on agricultural land. (Krider, 1987). Since the estimated annual wet manure product in pounds per animal is: 3,407 for breeding swine, and 2,227 for feeding swine (Brodie, and others, 1981), the potential for contamination of ground and surface waters from these sources can be substantial.

The Upper Floridan aquifer of the Floridan aquifer system is the principal source of potable water in north Florida. Generally unconfined and lying close to or at the land surface in the study area, this aquifer is vulnerable to contamination from wastes deposited on the land surface as the result of high recharge rates (Aucott, 1988). The U.S. Geological Survey, in cooperation with the Florida Department of Environmental Protection, began this reconnaissance of water quality at four swine farms in Jackson County in 1992 to determine the effects of swine farms on ground-water quality in north Florida.

Purpose and Scope

The purpose of this report is to describe the quality of water in wastewater lagoons, ground water, and surface water at four swine farms in Jackson County, Fla. (fig. 1), and to discuss factors affecting the quality of ground water at those swine farms. This report presents water-quality data obtained from January through October 1993 of quarterly sampling of 19 monitoring wells constructed during the study, 3 water-supply wells, 1 pond, and 2 wastewater lagoons located on the four swine farms. A brief discussion of the physical setting and hydrology of Jackson County is presented to characterize the subsurface geology that controls the movement of water on and below the land surface.

Physical Setting

The project study area is comprised of four swine farms in Jackson County in the central Florida Panhandle within the Dougherty Karst District. This physiographic district is characterized by a low, rolling terrain that includes a substantial part of southwest Georgia and northwest Florida. Land surface altitudes in the region range from 70 to 260 ft above sea level. Dissolution of near-surface carbonate rocks has resulted in a topography dominated by karstic landforms in the study area (Brooks, 1981).

The climate of this area is moderate throughout the year with an average normal temperature of approximately 66.5 °F. and an average annual rainfall of 56 in. (Owenby and Ezell, 1992).

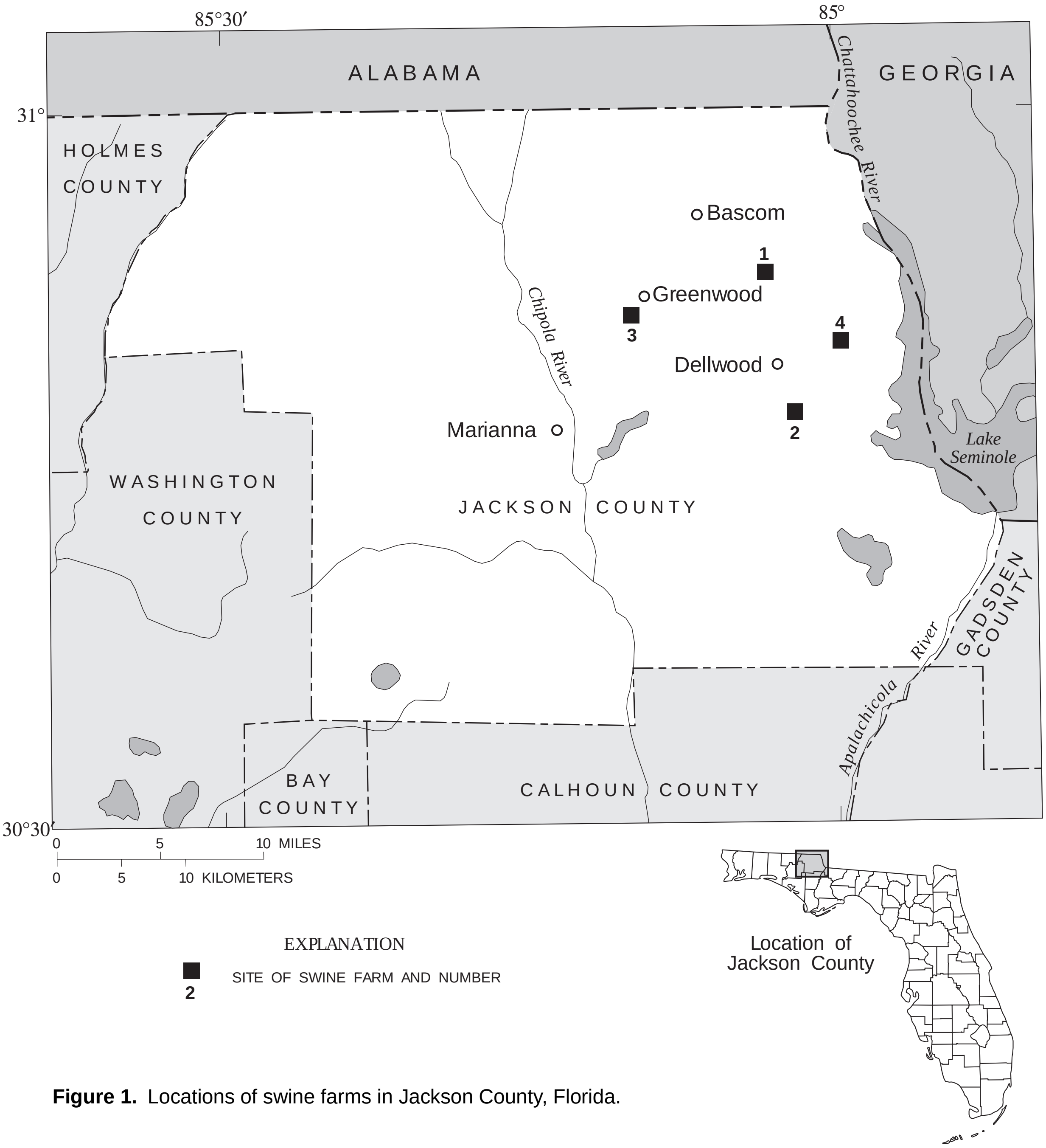


Figure 1. Locations of swine farms in Jackson County, Florida.

Acknowledgments

The author thanks Thomas Tyus, Ted Bruner, Glenell Conner, and the staff of the Swine Unit of the Institute for Food and Agricultural Sciences of the University of Florida for allowing access to their properties and for their interest in this study. The author also thanks the personnel of the Jackson County Extension Service and the National Resources Conservation Service for assistance.

NITROGEN IN THE ENVIRONMENT

N-species nitrogen are the primary constituents of concern in ground water in the vicinity of livestock operations. Nitrate concentrations of ground water in agricultural areas commonly exceed the maximum concentration level of 10 mg/L nitrate-nitrogen at some time during the year (Madison and Brunett, 1984). Nitrate concentrations have exceeded natural background concentrations in ground water in most states

(Bouchard and others, 1992). Because one of the principal environmental effects of livestock operations is the elevation of nitrate-nitrogen concentrations in ground water, and because there is a high potential for leaching of nitrate to the Upper Floridan aquifer, it is useful to examine both the nitrogen cycle and typical livestock waste management practices of swine farms in Jackson County.

Consumption of water having nitrate concentrations exceeding the primary drinking water standard of 10 mg/L, has been associated with methemoglobinemia, a condition that diminishes the ability of blood to absorb oxygen because of the replacement of hemoglobin with methemoglobin (Virgil and others, 1965; National Research Council, 1985). Methoglobinemia, commonly known as "blue-baby syndrome," primarily affects infants younger than 6 months, causing cyanosis and rare fatalities (Bouchard and others, 1992). Nitrate is also a precursor for carcinogenic nitrosamines. Nitrosamines in human digestive tracts and elevated concentrations of nitrate in drinking water have been correlated with increased incidence of stomach cancer in humans (Forman and others, 1985; Mirvish, 1990). Additionally, elevated nitrate concentrations in drinking water have been tentatively associated with increased incidence of birth defects (Dorsch and others, 1984; Fan and others, 1987).

The Nitrogen Cycle

Nitrate (NO_3) in ground water is produced through a series of processes comprising the nitrogen cycle, shown schematically in figure 2. Nitrate in ground water may be derived from many sources, including natural deposits, nitrogen in soils, plant debris, human and animal wastes, synthetic fertilizers, and atmospheric deposition. As rainwater reaches the land surface, it dissolves animal wastes and other organic detritus and transports ammonium nitrogen and organic nitrogen into soils. In soils, these forms of nitrogen are often adsorbed to clay or organic particles, where they are available for absorption by plant roots. When soils receive more nitrogen than they can adsorb and than plants on the surface can utilize, ammonium nitrogen and organic nitrogen remain in solution in soil water and can be oxidized to nitrate nitrogen through the process of nitrification that is performed by selected soil bacteria that are active in oxidized environments (Andrews, 1992). Because it is negatively charged, the nitrate molecule is not electrostatically adsorbed to negatively charged rims of soil and clay particles, as is ammonium nitrogen; therefore, nitrate can travel downward with percolating water through the unsaturated zone to the saturated zone.

Two processes that reduce the amount of nitrate nitrogen reaching and residing in the saturated zone are plant uptake, which generally does not occur below the soil zone, and denitrification. Denitrification reduces nitrate to gaseous nitrous oxide or nitrogen gas which outgas to the unsaturated zone. Denitrification can occur either inorganically or organically in anoxic environments. Inorganic denitrification involves the transfer of oxygen atoms from nitrate to reduced metals such as iron or manganese. Organic denitrification requires an organic substrate and the presence of denitrifying bacteria which remove oxygen atoms from nitrate to respire in anoxic environments. Denitrification is especially prevalent in waterlogged, organic-rich soils, but may also occur in anoxic conditions in the saturated zone (Andrews, 1992).

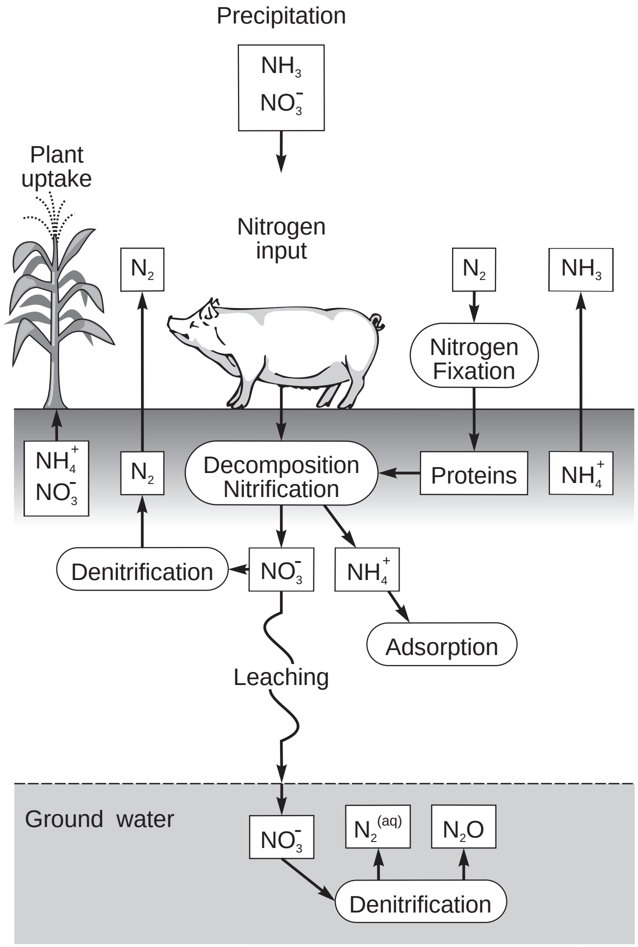


Figure 2. The nitrogen cycle in the subsurface environment. (Modified from Andrews, 1992, p. 5.)

Nitrogen fixation, which converts nitrogen gas to proteins that can be broken down by soil bacteria to ammonium nitrogen and nitrite plus nitrate nitrogen, is caused by bacteria, such as rhizobium, which symbiotically occupy the roots of legumes and a few other types of plants. Generally, nitrogen fixation only creates ammonium nitrogen and nitrite plus nitrate nitrogen in amounts that host plants can utilize and when these nutrients are present in amounts sufficient for plant nutrition, nitrogen fixation does not occur (Andrews, 1990).

In humid temperate environments such as north Florida, nitrate-containing minerals are not found in notable amounts because of their high solubilities in water. The following sections discuss the use of nitrogen isotopes to determine the sources of nitrate.

Nitrogen Isotope Ratios in Nitrate

The ratio of nitrogen isotopes in nitrate can qualitatively indicate the source of nitrate in ground water (Delwiche and Steyn, 1970). Nitrogen isotope analysis compares the ratio of the two stable isotopes of nitrogen, ^{14}N and ^{15}N, in a standard (atmospheric nitrogen gas), to the ratio of these nitrogen isotopes in nitrate in a water sample. Atmospheric nitrogen gas consists principally of ^{14}N (99.62+ or –0.0002 percent) (Nier, 1955). The ratio of nitrogen isotopes in nitrate in a water sample is expressed as $\delta^{15}N$ in parts per thousand (ppt) using the following equation:

$$\delta^{15}N = \frac{(^{15}N/^{14}N)\text{sample} - (^{15}N/^{14}N)\text{standard}}{(^{15}N/^{14}N)\text{standard}} \times 1{,}000.$$

Samples depleted in ^{15}N relative to the atmosphere have negative values of $\delta^{15}N$, whereas samples enriched in ^{15}N have positive $\delta^{15}N$ values.

Nitrate leached from inorganic fertilizers has $\delta^{15}N$ values ranging from –3 to +2 ppt (Krietler, 1975). Nitrate leached from inorganic fertilizers has nitrogen isotope ratios similar to atmospheric nitrogen gas because these fertilizers are derived from atmospheric nitrogen through the Haber-Bosch process which combines nitrogen and hydrogen gases under high pressures and temperatures in the presence of a platinum catalyst to create anhydrous ammonia. Nitrate leached from soils typically has a $\delta^{15}N$ ranging from +2 to +8 ppt (Kreitler, 1975). Enrichment of ^{15}N in nitrate leached from soils can be caused by preferential uptake of the lighter ^{14}N by plant roots (Delwiche and Steyn, 1970). Nitrate leached from animal wastes has $\delta^{15}N$ values ranging from +10 to +20 ppt (Krietler, 1975). Nitrate leached from animal wastes is enriched in ^{15}N compared to nitrate derived from the atmosphere and from soils, because lighter ammonia molecules (NH_3 containing the ^{14}N isotope) preferentially evaporate from wastes after deposition on the land surface (Watkins and others, 1972).

In July 1993, samples were collected for nitrogen isotope analysis from four wells on the swine farms. The wells selected for this sampling were those being sampled quarterly and having the highest nitrate concentrations. The results are discussed in the water-quality section of this report.

HYDROGEOLOGY

In addition to being affected by fertilizer application, cropping, and waste management practices, shallow ground-water quality beneath swine farms in the Florida Panhandle is also affected by the hydrologic characteristics of the Upper Floridan aquifer and by the nature of ground-water flow through it. This section briefly describes hydrogeologic characteristics of the aquifer in the study area. The surficial geology in Jackson County is depicted in figure 3.

The geomorphology and hydrogeology of the study area are typical of a karstic terrain. As the carbonate rocks beneath the residuum chemically weather and collapse, subsidence features known as sinkholes commonly develop. As noted in Roaza and others (1989), sinkhole development in this region of Jackson County is dense with greater than 2,800 mapable surface karstic features.

Sinkholes that collapse into the underlying limestone may breach low permeability clays and are usually filled in with the overlying residuum material. Sinkholes that penetrate into the limestone serve as major conduits by which surface contaminants may directly enter the Upper Floridan aquifer. Substances on the land surface may also enter the aquifer by seepage through the sandy clay residuum overlying the Upper Floridan aquifer. Surface runoff of rainfall directly to rivers in the study area is virtually nonexistent. Most of the runoff seeps into the Upper Floridan aquifer that is drained via the subsurface into the Chipola River, Lake Seminole, and the Chattahoochee River. The recharge potential to the Upper Floridan aquifer in the study area ranges from high in the area of site 3 to moderate to low in the area of sites 1, 2, and 4 (Aucott, 1988; Roaza, and others, 1989, fig. 17).

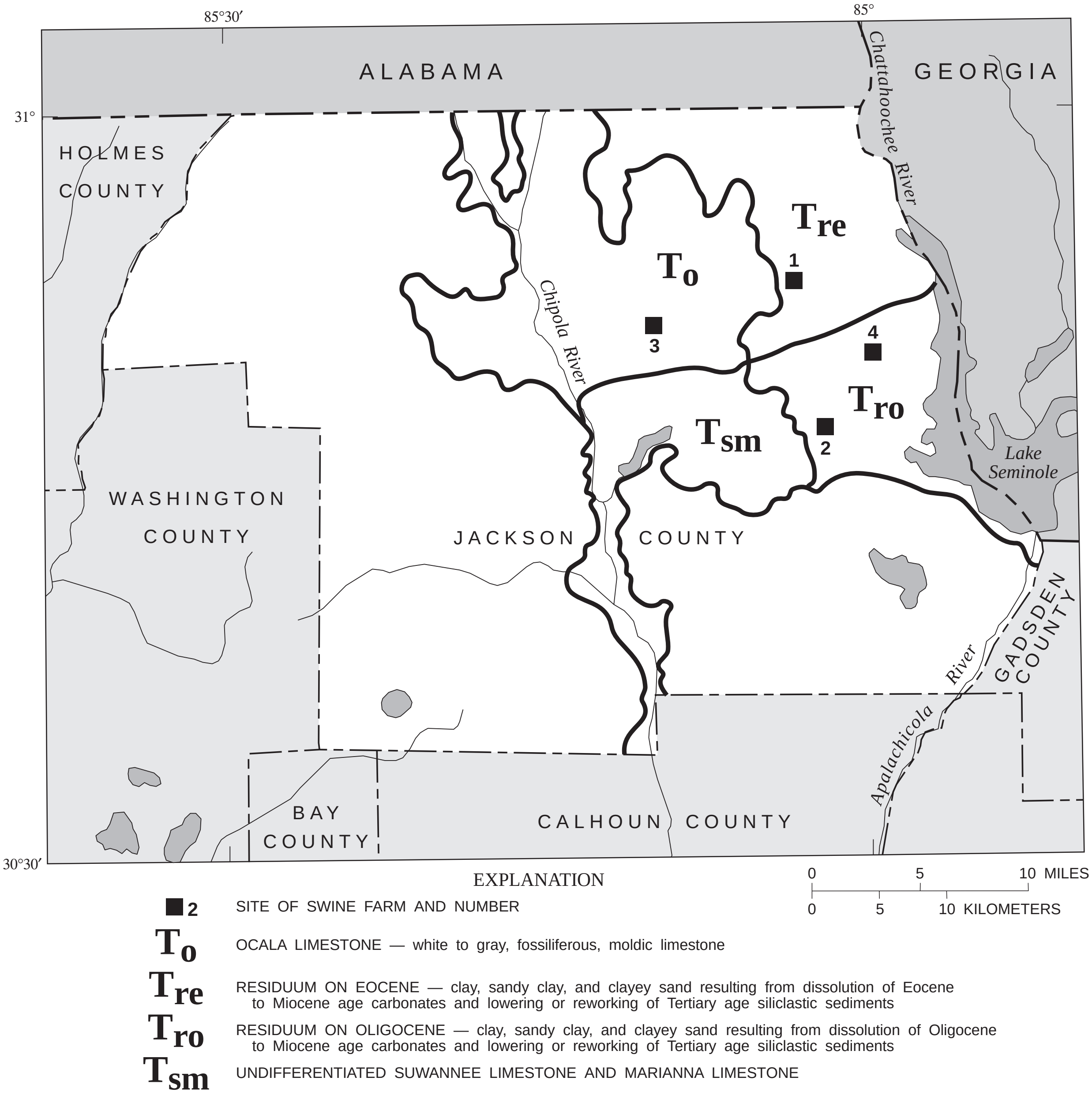


Figure 3. The surficial geology in the area of the swine farms in Jackson County, Florida. (Modified from Scott, 1993.)

The soils in the study area are the sand ridges and the uplands. The sand ridge soil unit is generally well to moderately well drained, is sandy to depths of more than 40 in., and is loamy below. The uplands soils are well to poorly drained and may be loamy from depths of 20 to 80 in. All soils in this area have a medium to high potential for nitrate loss due to leaching and a medium to high potential for phosphate loss due to runoff (United States Department of Agriculture and others, revised work plan for karst cropland in Jackson County, Fla., written commun., 1991). Macropore flow (pore size of greater than 4 millimeters thickness) appears to contribute significantly to the recharge of the aquifer. Rapid increase of nitrate values in the ground water resulting from fertilization demonstrates the ability of macropore flow to transport fertilizer derived nitrate which has been flushed from the tilled soil layer. Other agriculture chemicals may also be transported to the aquifer in this manner (Wells and Krothe, 1989). Both of the unconfined swine operations discussed in this report are situated on these two soil types.

Below the soil horizons, the unsaturated zone consists of a relatively thin layer of unconsolidated clastic sediments composed of sandy clays and clayey sands. These materials directly overlie the carbonate rocks of the Upper Floridan aquifer throughout the study area. The overburden material has been described as post-Miocene age terrace deposits and river flood plain residuum deposited by streams (Moore, 1955). The lithology of the overburden material is highly variable and includes sand, sandy clay, clayey-silty sand, and clay. Weathered carbonate detritus is commonly present near the bottom of the overburden (fig. 3).

Previous studies (Clemons and others, 1987; Roaza and others, 1989) indicate that the county background concentrations for dissolved nitrate nitrogen in the ground water of Jackson County range from 1.5 to 2.5 mg/L.

The regional ground-water flow in the Upper Floridan aquifer in Jackson County is controlled by the Chattahoochee River and Lake Seminole in the eastern part of the county and the Chipola River in the central part of the county (fig. 4). Sites 1 and 2 lie in a plateau area where the regional flow generally is to the east. Flow at site 4 also is generally to the east. Regional flow at site 3 is to the southwest. All four sites lie between the two rivers. Although water levels in all monitoring wells on all farms were measured for an 11-month period from December 1992 through October 1993, with the exception of February and March 1993, flow directions in the Upper Floridan aquifer cannot be determined because of inadequate spacing between wells and because just five of the monitoring wells were screened in the limestone of the Upper Floridan aquifer. The remaining monitoring

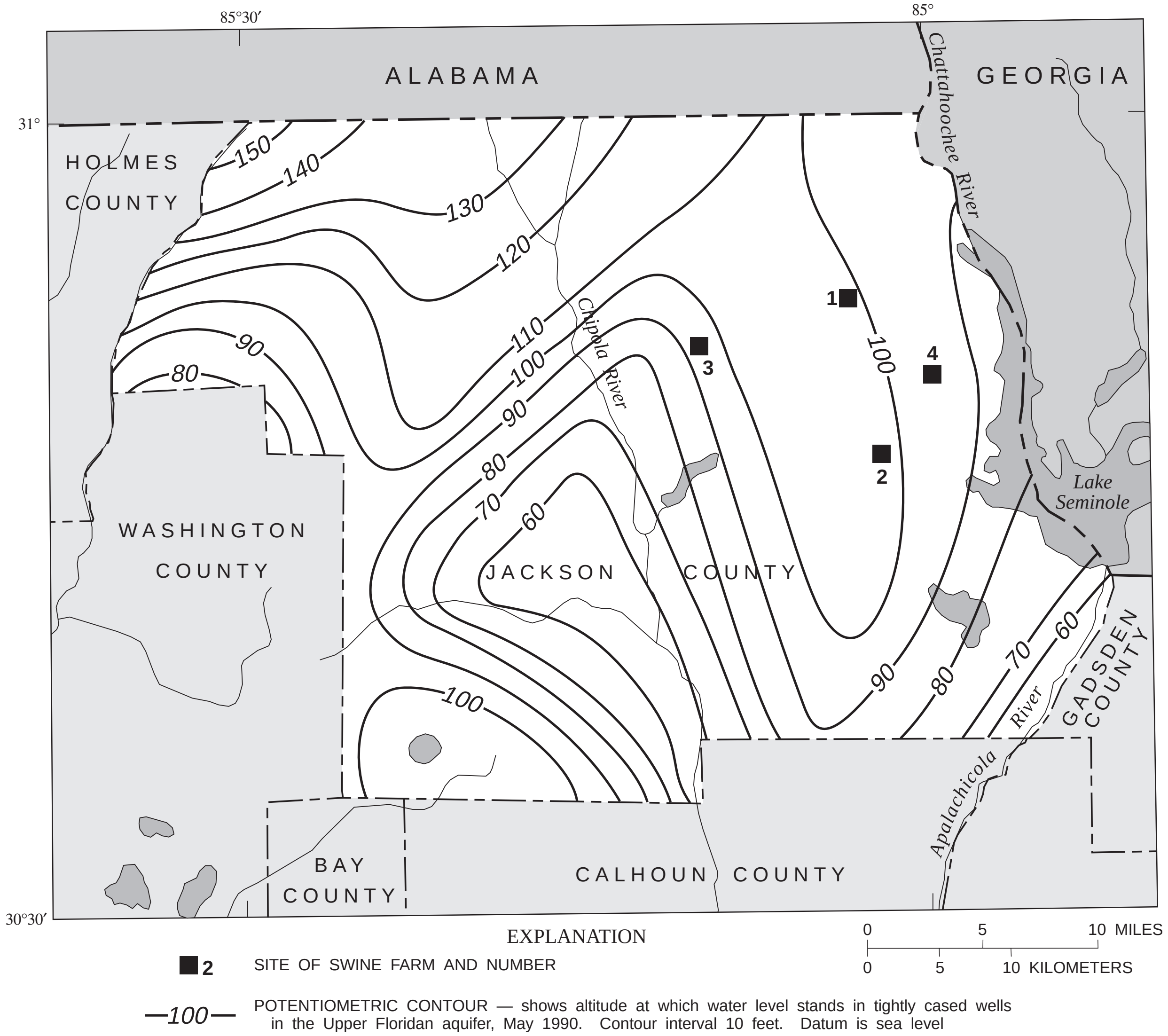


Figure 4. Potentiometric surface contours of the Upper Floridan aquifer in Jackson County, Florida, May 1990. (Modified from Meadows, 1991.)

wells were screened in the unconsolidated materials overlying the limestone. Local flow in the study area is defined as the flow in the unconsolidated material overlying the Upper Floridan aquifer. The variability of this unconsolidated material combined with the placement of the remaining monitoring wells made the determination of ground-water flow within this material overlying the limestone, difficult to determine. Water-level data collected during the study are presented in appendix I.

The top of the Upper Floridan aquifer coincides with the first occurrence of vertically continuous carbonate rock. Regionally, the structural top of the carbonate sequence dips to the south. Because of chemical weathering, the altitude of the top of the aquifer is highly irregular and ranges from about 60 to 120 ft above mean sea level in the study area. Thickness of the aquifer in the study area ranges from about 150 to 225 ft (Miller, 1986). The transmissivity of the Upper Floridan aquifer in this area ranges from 100,000 to 1,000,000 in ft^2/day with potential well yields of 10,000 gal/min (Andrews, 1990).

DESCRIPTION OF THE STUDY AREA

Swine herds in the study area can be classified as unconfined or confined. Unconfined herds are kept in fields or pastures with the animal waste being deposited directly on the ground; however, confined herds are kept in special swine houses with the waste from these houses channelled into treatment lagoons. In this report, unconfined operations are represented by sites 1 and 4 (figs. 5 and 6), and confined operations are represented by sites 2 and 3 (figs. 7 and 8).

Selection of the farms to be monitored was based on typical management practices, length of operation, and hydrogeologic setting. The objective of the monitoring program was to evaluate the effect on the ground water beneath these areas as a result of the wastes produced by animal herds. Wells for monitoring were located near or in areas where wastes were concentrated, such as wastewater lagoons, natural surface-water bodies that receive runoff, swine holding areas, and other livestock pastures or cultivated croplands. Characteristics (years of operation, total acreage devoted to swine herd operations, average number of swine, and waste-management features) of the four monitored swine farms are given in table 1.

Time, budgetary constraints, and subsurface geology determined the number and location of the monitoring wells. Sites 1 and 4 had one well each finished in the limestones of the Upper Floridan aquifer. Both of these sites were of the unconfined swine herd type with long-term operations. The Upper Floridan wells were installed to determine what, if any, effect the swine waste had upon water quality of the ground water beneath these sites. None of the wells at site 2 were in the limestone of the Upper Floridan aquifer because the top of the limestone was greater than 50 ft below the land surface, and the residuum at this site was a tight clay. All of wells at site 3 were finished in the limestone of the Upper Floridan aquifer because the top of the limestone was within 20 ft of the land surface at this site.

Site 1 has been occupied and farmed continually for over 50 years (fig. 5). Swine herds have been kept in two areas about 0.5 mi apart: one area is located near wells 1-1, 1-2, 1–3 (adjacent to a barnyard area), and 1-4 (in a pasture in which a small cattle and horse herd is periodically kept); the second area is about 0.5 mi west of the first area, surrounded by planted cropland, and is located near wells 1-5, 1-6, and 1-7. The herds are rotated from field to field periodically and allowed to forage on harvested fields near wells 1-4, 1-5, 1-6, and 1-7. In 1993, the swine herd at this farm ranged in size from less than 20 to around 100. The herd population was at a maximum during January 1993 and decreased throughout the study period. One supply well, B-1 is located approximately 350 ft southwest of well 1-3, and the second supply well, 1-1 is located approximately 325 ft south of well 1-5.

The seven monitoring wells at site 1 were placed in two separate locations 0.5 mi apart. Wells 1-1, 1-2, and 1-3 were placed to the north and east of an area where the swine were kept. Well 1-4 was placed south and up the regional gradient to these wells approximately 0.1 mi. Well 1-3 was finished in the limestones of the Upper Floridan aquifer to help determine if swine waste waere affecting the quality of water in that aquifer. Wells 1-5, 1-6, and 1-7 were drilled to obtain water-quality data in an area where this farm’s owner planned to locate a confined swine herd operation. Wells 1-5 and 1-6 were placed adjacent to the future wastewater lagoon, and well 1-7 was located down the regional gradient from there.

Site 1 is located in an area where the top of the Upper Floridan aquifer is overlain by 55-70 ft of sandy clays and clayey sands. Wells 1-1 and 1-3 are paired wells with well 1-3 being screened in the Upper Floridan aquifer. These wells are on the eastern edge of what seems to be a small sinkhole.

Figure 5. Aerial photography of site 1, Jackson County, Florida.

Site 4 has been occupied and farmed for more than 70 years (fig. 8). The swine herd at site 4 is located most of the year in an area near a shallow pond fed by surface-water runoff and precipitation. Currently, the only livestock at this farm are the swine herd and a few goats that are moved periodically and allowed to forage in the cultivated fields after the harvesting of the crops. The swine herd population varied between about 20 to more than 200 during the study period. The herd population was at a maximum in January 1993 and decreased throughout the study.

The five monitoring wells at site 4 were located, with the exception of well 4-1, in the area where the swine herd is usually kept. Well 4-1 was located northwest up the regional gradient and adjacent to this area.

Site 4 is located in an area where the top of the limestones of the Upper Floridan Aquifer lies 60 or more ft below the land surface. These limestones are overlain by unconsolidated sands and clays (fig. 3). All five of the monitoring wells are located in the area near the pond. Well 4-1, is at the northwestern edge of the area where the herd is located most of the year, and is surrounded on three sides by cultivated cropland. Wells 4-2 and 4-3 are paired wells, with well 4-2 screened in the limestone of the Upper Floridan aquifer, and are within the area where the swine herd is located most of the year; wells 4-4 and 4-5 are likewise within this area; well 4-5 is next to the shallow pond.

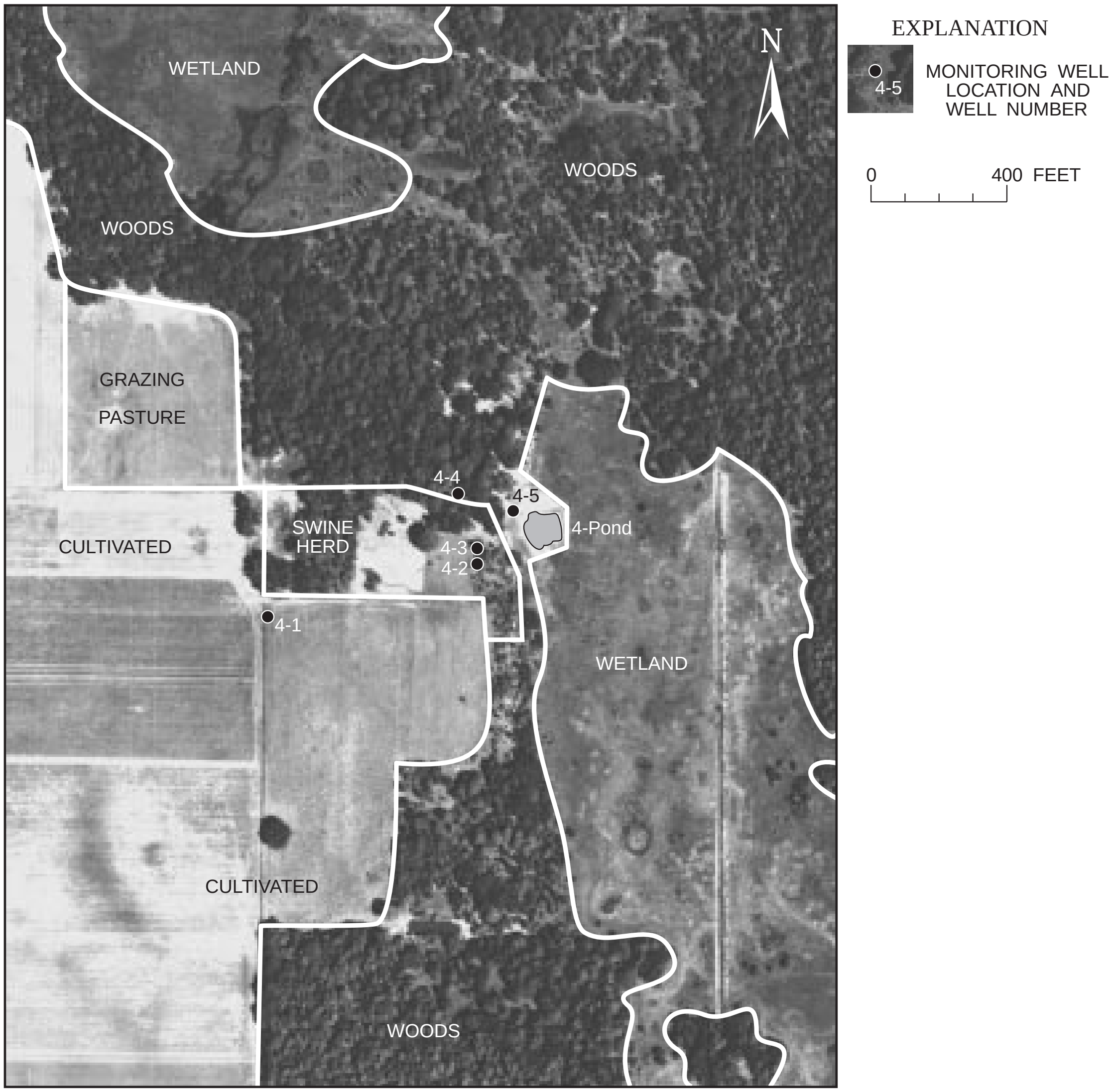


Figure 6. Aerial photography of site 4, Jackson County, Florida.

Two swine farms in the study area (sites 2 and 3) have houses that accumulate waste that is washed into lined lagoons. The lagoon at site 2 is finished in stiff red clay and is an anaerobic settling pond. The lagoon system at site 3 is finished in limestone and is a two-stage process type; the first and larger lagoon is an anaerobic settling pond, and the second, smaller lagoon contains overflow from the first lagoon (fig. 7). Wastewater from the lagoon at site 3 is occasionally sprayed on crops to prevent lagoon overflow and as fertilizer for cultivated fields adjacent to the lagoons. Wastewater from the lagoon at site 2 is occasionally sprayed on crops in times of drought. Both lagoons normally lose their contents through a combination of evaporation and seepage. Figure 9 is a schematic representation of the lagoon systems used on these two farms.

Site 2 has been farmed with both crops and livestock for more than 30 years. This farm has had a confined swine herd operation for this entire period. The swine herd population during 1993 varied from approximately 20 to nearly 100. The population was greatest at the beginning of the study (January 1993) and decreased thereafter. The swine herd is kept in three adjacent houses and is separated according to the age of the animals. Waste from one of three swine houses at this farm is channeled into a one-stage lagoon, whereas wastewater from the other two houses is channeled to a ditch that bifurcates around the lagoon, with one drainage passing by well 2-1 and the other passing by well 2-2. The lagoon is located in a pasture in which forage is planted for the cattle and horse herds. The lagoon is excavated into a low-permeability clay and is lined with plastic. The four monitoring wells are located one on each side of the lagoon. Water from the lagoon is sprayed on nearby crops in times of drought.

The four monitoring wells at site 2 were placed adjacent to the four sides of the wastewater lagoon. All were finished in the residuum above the limestones of the Upper Floridan aquifer. The residuum at this site is a tight red clay.

Site 2 is located where the top of the Upper Floridan aquifer is between 50 to 60 ft below the land surface, with the overburden at the location of the lagoon and monitoring wells composed entirely of the stiff red clay.

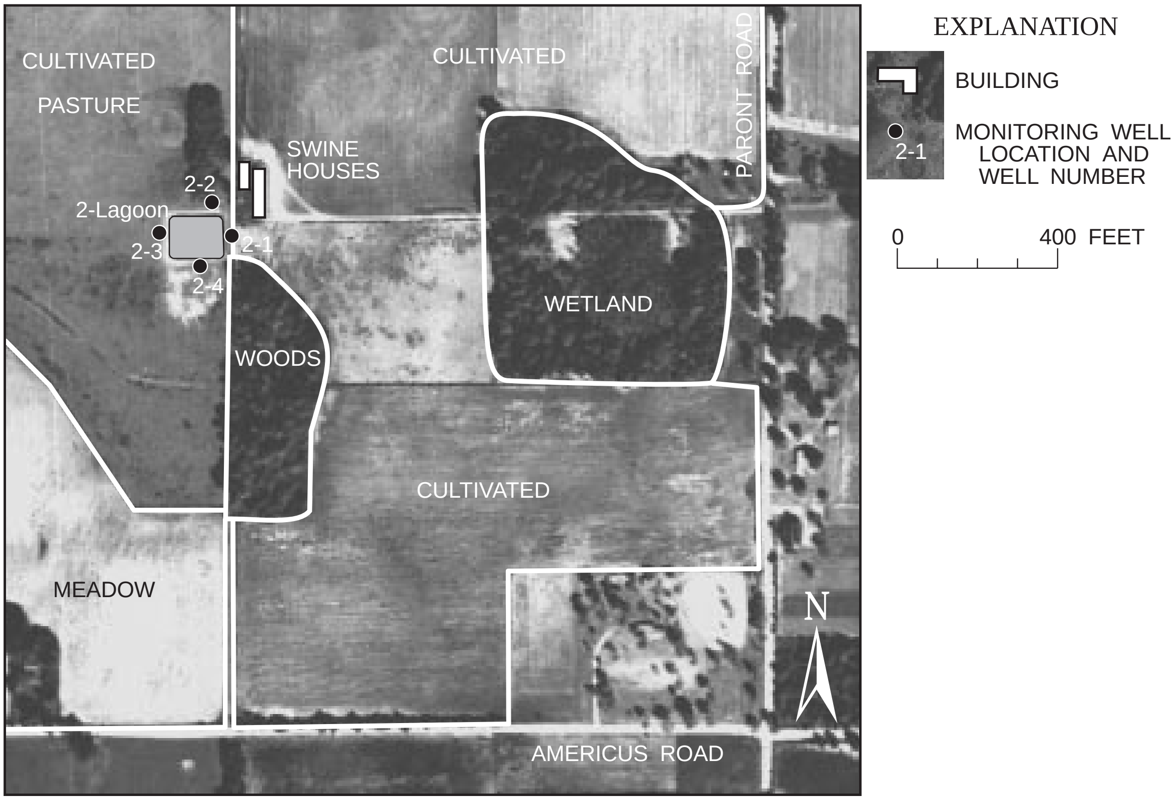


Figure 7. Aerial photography of site 2, Jackson County, Florida.

Site 3 has been in operation for 19 years. The swine herd at this farm is confined most of the time, but parts of the herd are released in fenced areas adjacent to the swine houses for foraging, for experiments, and to hold excess population. Herd population at this farm ranged from approximately 30 to more than 100 during the study period. The herd population was at a maximum in January 1993 and decreased throughout the study. The wastewater lagoon system on this site consists of two stages. Wastewater from the lagoons is pumped onto nearby crops as needed as a source of fertilizer, and to prevent overflow from the lagoons. The lagoons are excavated into the limestone of the Upper Floridan aquifer and lined with plastic.

The three monitoring wells at site 3 were finished in the limestones of the Upper Floridan aquifer since these limestones lie 10 to 15 ft below the land surface at this site. Wells 3-2 and 3-3 were placed adjacent to the wastewater lagoon, and well 3-1 to the east and up the regional gradient from wells 3-2 and 3-3.

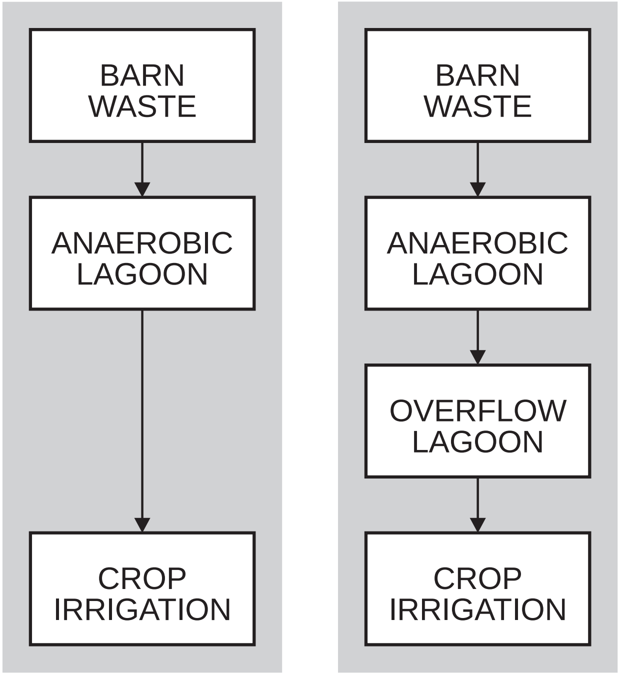
Site 3 is located where the top of the Upper Floridan aquifer is at or near the land surface. At the location of the lagoon and monitoring wells, the overburden consists of 10 to 15 ft of sandy clay and clay (fig. 3). Well 3-1 is located on the edge of a cultivated field northeast of the lagoon, whereas wells 3-2 and 3-3 are adjacent to the first-stage lagoon. Supply well B-3 is located approximately 500 ft southwest of the lagoon and wells 3-2 and 3-3.

Figure 8. Aerial photography of site 3, Jackson County, Florida.

Table 1. Characteristics of four monitored swine farms.

Farm site	Years of operation	Total acreage[1]	Number of swine[2]	Waste-management features
1	>50	5 – 10	75 – 100	Unconfined
2	>30	<1	50 – 75	Confined, one-stage lagoon
3	19	<1	50 – 200	Confined, two-stage lagoon
4	>75	10 – 20	50 – 200	Unconfined

[1] Average acreage devoted to swine herd.
[2] Average maximum herd size.



Wastewater Lagoon System at site 2

Wastewater Lagoon System at site 3

Figure 9. Wastewater lagoon operations on sites 2 and 3, Jackson County, Florida.

METHODS

From July to October 1992, 19 monitoring wells were installed at four swine farms in the study area. Wastewater lagoons, monitoring wells, supply wells, and a pond on these farms were sampled four times between January and October 1993. Three supply wells on two farms were sampled once for the same constituents as the monitoring wells, and five monitoring wells on two farms were sampled once for N-nitrogen isotope ratios (table 2). Methods used for site selection for well installation, sample collection and analyses, and data analysis are discussed in the following sections. Five of the monitoring wells were screened in the limestone of Upper Floridan aquifer system, and fourteen screened in the unconsolidated material overlying the limestone.

Installation of Wells

All of the sites are located in areas where the Upper Floridan aquifer is unconfined or near the land surface. All of the wells were drilled with hollow stem augers. Air-rotary drilling was used to extend boreholes of selected wells into the limestone of the Upper Floridan aquifer. Wells completed in the residuum above the limestone were drilled until saturated sediments were returned to the land surface by hollow stem augers. The wells were completed using threaded, 2-in. diameter schedule 80 PVC pipe as casing with a 10-ft section of PVC slotted screen attached at the bottom. The annular space around the screen was packed with sand to a distance of approximately 1 ft above the top of the screen, which was capped with 12 in. of hydrated bentonite pellets. The augers were then removed and neat Portland Type I cement was tremied into the remaining annular space between the casing and the borehole. All of the wells were developed by first surging with compressed air and then by pumping or bailing until the water was clear. Altitude of the land surface at the wells at each farm were estimated from U.S. Geological Survey 7.5 minute quadrangle topographic maps (Bascom, Fla.–Ga., 1982, Dellwood, Fla., 1982, Fairchild Fla.–Ga., 1955, and Marianna, Fla., 1982).

Table 2. Site identification, physical properties, water quality sample type, and number of samples
[N/A, not applicable; SS, standard suite of analyses]

Well, lagoon, or pond	Site ID	Well depth	Screened depth	Aquifer sampled	Water quality sampled	Number of samples
1-1	305326085032401	43	33-43	Residuum	SS[1]	4
1-2	305328085032601	50	40-50	Residuum	SS	4
1-3	305326085032402	103	93-103	Upper Floridan	SS; Nitrogen isotopes, Iodide, Bromide	[2]4;1
1-4	305315085032701	47	37-47	Residuum	SS	4
1-5	305335085040001	57	47-57	Residuum	SS	4
1-6	305335085040101	61	51-61	Residuum	SS	4
1-7	305338085035301	61	51-61	Residuum	SS; Iodide, Bromide	[2]4,1
B-1	None[3]	[4]85	Unknown	Upper Floridan	SS	1
I-1	None[3]	[4]102	Unknown	Upper Floridan	SS	1
2-1	304709085021001	26	16-26	Residuum	SS	4
2-2	304710085021002	39	29-39	Residuum	SS	4
2-3	304709085021303	49	39-49	Residuum	SS	4
2-4	304708085021204	48	38-48	Residuum	SS	4
3-1	305110085103401	44	34-44	Upper Floridan	SS	4
3-2	305109085103801	54	44-54	Upper Floridan	SS	4
3-3	305108085103701	50	40-50	Upper Floridan	SS	4
B-3	None[3]	[4]118	Unknown	Upper Floridan	SS	1
4-1	305004085000301	40	30-40	Residuum	SS; Nitrogen isotopes, Iodide, Bromide	[2]4,1
4-2	305007084595901	78	68-78	Upper Floridan	SS	4
4-3	305007084595902	36	26-36	Residuum	SS	4
4-4	305012084595801	37	27-37	Residuum	SS Nitrogen isotopes, Iodide, Bromide	[2]4,1
4-5	305009084595801	38	28-38	Residuum	SS; Nitrogen isotopes, Iodide, Bromide	4
Lagoon 2	304709085021200	N/A	N/A	N/A	SS	4
Lagoon 3	305109085103700	N/A	N/A	N/A	SS	4
Pond	305008084595600	N/A	N/A	N/A	SS	4

[1] Standard suite of analyses consists of water temperature, pH, specific conductance, nitrite plus nitrate nitrogen, ammonia nitrogen, phosphorus, potassium, chloride, and sulfate.
[2] One-time sampling for isotopes, iodide, or bromide.
[3] Well not in U.S. Geological Survey WATSTORE data base.
[4] Depth given based on oral communication with farm owner.

Water-Quality Sampling Procedures

Water samples were collected from wastewater lagoons, monitoring wells, and swine farm supply wells. All sampling sites except the supply wells were sampled quarterly from January through October 1993. Samples from the lagoons were collected by immersing sample bottles in the fluid parts on the lagoons until the bottles were filled. Before collection of samples from monitoring wells, the wells were purged by either bailing with a sterilized PVC bailer or by pumping with a Grundflos Redi-Flo2 pump. Purging with the bailer continued until at least three standing casing volumes of water had been removed from the well and the specific conductance of the bailed water had stabilized. Purging with the pump continued for at least 15 minutes and until the temperature and specific conductance of the pumped water had stabilized. Samples were then collected in polyethylene bottles. Supply wells were allowed to flow through wellhead spigots for at least 15 minutes before samples were collected. The farm supply wells were sampled one time only. A one-time sampling of four monitoring wells for nitrogen isotope ratios at sites 1 and 4 was done to help distinguish the inorganic versus organic sources of the nitrate in the ground water.

Quality assurance and control were done in the field during each sampling period. Blank water was furnished by the U.S. Geological Water Quality Service Unit in Ocala, Fla., and were analyzed concurrently with and using the same analytical methods used to analyze the field samples. Duplicate samples also were collected and analyzed from two farms during each trip. Blank water was also used to plate for fecal-streptococcal and fecal-coliform bacteria.

Field measurements made at the time of sampling included water level (in monitoring wells only), pH, temperature, specific conductance, and (in the pumped wells), dissolved oxygen. Counts of fecal-coliform and fecal-streptococcal bacteria were made in the field using the membrane-filter method (Britton and Greeson, 1987). However, the bacterial counts were variable; generally, wastewater in the lagoons had higher counts than the ground-water samples. The results are not discussed in the text, but are presented in appendix IV. Likewise, the dissolved oxygen values are not discussed in the text, but are given in appendix IV. Constituents measured at the Quality of Water Service Unit in Ocala, Fla., using standard USGS analytical methods (Fishman and Friedman, 1989) included dissolved concentrations of nitrate, nitrite, ammonium nitrogen, phosphorus, potassium, sulfate, chloride, calcium, magnesium, fluoride, total ammonium plus organic nitrogen, total phosphorus, alkalinity, carbonate, and bicarbonate.

WATER QUALITY

Chemical analyses were performed on ground water from 19 monitor wells and from surface water taken from the 2 waste lagoons and a pond sampled during January, April, July, and October 1993. The results of the analyses are given in appendix III. Mean, median, minimum, and maximum values of specific conductance and selected parameters, consisting of nitrite plus nitrate, ammonium, and phosphorus for each well, lagoon, and pond, were computed from the values for the four sampling period. Results of statistical analysis for concentrations of the aforementioned parameters, in addition to specific conductance, are presented as boxplots of the median values in figures 10 through 13. The mean, median, minimum, and maximum for all analysis are tabulated in table 3.

In July 1994, for the purpose of nitrogen isotope analysis, an additional sample was collected from five of the monitor wells on two farms. Four of the samples (from wells 1-3, 4-1, 4-4, and 4-5) were analyzed, and the results are given in appendix III. Nitrate nitrogen isotope analysis yielded δ^{15} values of 2.1 and greater. As discussed in an earlier section of this report, a δ^{15} of less than 2 is typical of nitrate leached from inorganic fertilizers. Therefore, the δ^{15} values determined from the samples obtained from these sites are indicative of either soils or animal waste sources. With the exception of well 4-1, all wells are located near where swine herds are kept, and so these values probably reflect leaching from soil enriched in swine waste (Delwich and Stern, 1970). The value of 4.1 was obtained from water taken from well 4-1, located just outside the area where the herd is kept, adjacent to the cultivated fields, and regionally upgradient from the other wells.

It was during this sampling period that the quarterly samples from the above-mentioned five wells were analyzed for the presence of dissolved bromide and iodide to determine if they would be feasible tracers of swine waste, because these chemical species are typically included in commercial swine feed. Most samples had concentrations that were below the detection limit of less than 0.01 mg/L for bromide and less than 0.001 mg/L for iodide; therefore, no further sampling and analyzing for bromide and iodide was performed.

Samples were also collected in July from three farm supply wells on two of the farms. These samples were analyzed for the same inorganic constituents that were analyzed for in the waters from the monitoring wells. The purpose of these analyses was to determine enrichment of any of the chemical species in the ground water of the Upper Floridan aquifer at greater depths than those of the monitoring wells. The ground-water chemistry from the farm supply wells, all screened in the limestone of the Upper Floridan aquifer, was similar to the chemistry of the monitoring wells screened shallower in the limestone of the aquifer. Temperature, pH, and specific conductance measured at all four swine farms are typical of values measured in the ground water elsewhere in this region (20 –28 °C, 6.6 –8.2 pH units, and 153 μS/cm) (Sprinkle, 1989; Katz, 1992).

Sites with Unconfined Operations

Water-quality characteristics for ground water beneath site 1 are statistically summarized in table 4. The median values for pH and specific conductance in the relatively shallower wells 1-2 and 1-4, (5.1 pH units and 24 μS/cm, respectively) are less than the median values from the other wells on this farm (7.6 pH units and 172 μS/cm, respectively) (table 3). The lower values found in the water sampled from wells 1-2 and 1-4 are most likely reflecting differences in residuum composition rather than no influence from animal wastes. Water from wells 1-3, 1-5, and 1-6 have the highest median values for dissolved nitrite plus nitrate (2.5 mg/L), though the median for all seven monitoring

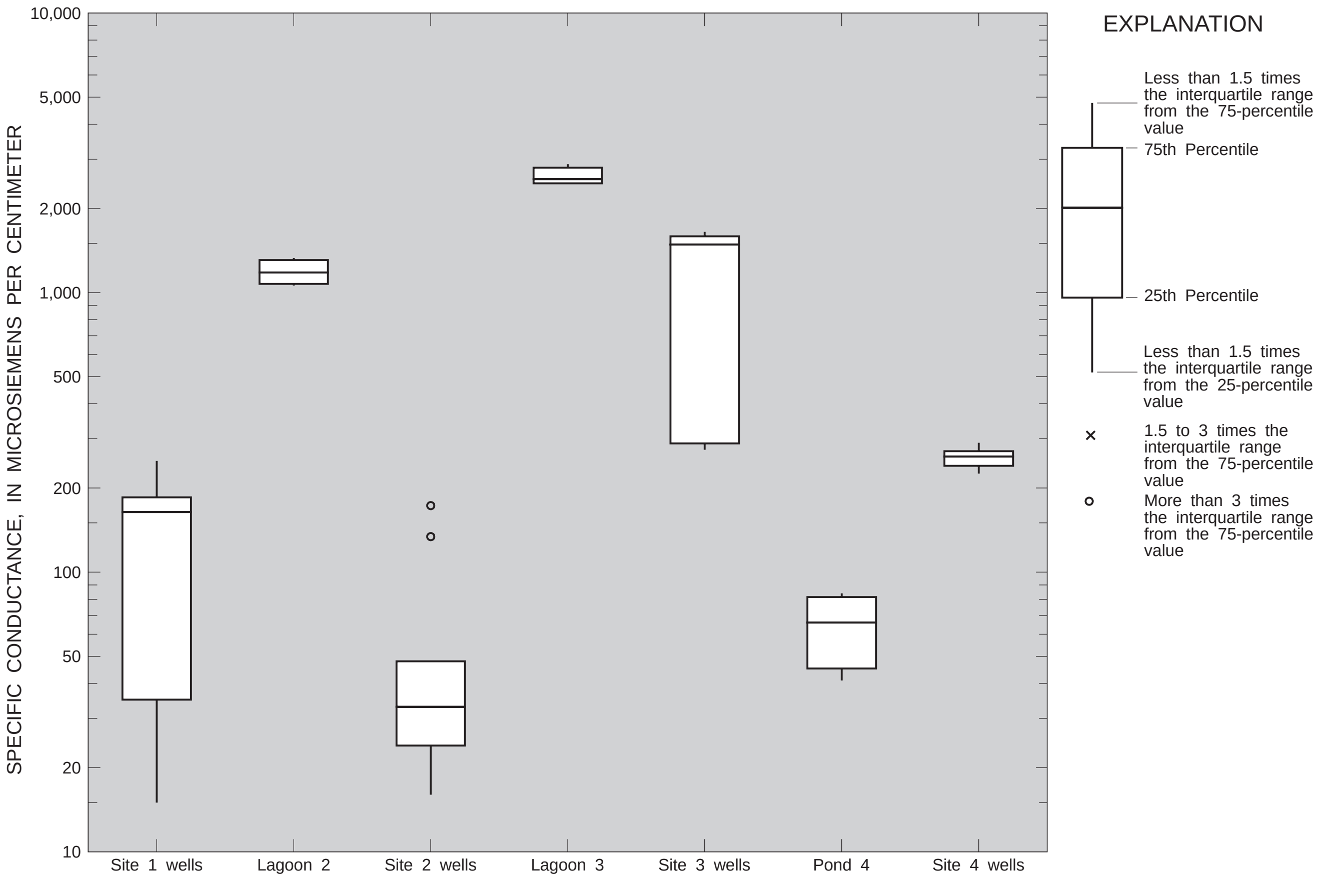


Figure 10. Specific conductance of water from wells, lagoons, and pond.

wells is 1.4 mg/L. The low median ammonia values from all seven monitoring wells (0.02 mg/L) in conjunction with the relatively higher values for the nitrite plus nitrate suggests that nitrification is occurring in the ground waters at this site.

Site 4 has been in operation for the greatest number of years and has the highest density of animals of the farms studied reported herein. Ground water from the farm on this site had the highest concentration of dissolved nitrite plus nitrate nitrogen (13 mg/L in well 4-5) of any of the four farms. Ground water from monitored wells on this farm had a median concentration value of 8.0 mg/L of dissolved nitrite plus nitrate nitrogen (table 5). This is the highest observed median value for any of the four farms in this study.

A comparison of the median value of dissolved nitrite plus nitrate nitrogen with the median value for ammonia indicates that nitrification is occurring in the shallow ground water beneath this farm. Water from well 4-2, finished in the limestones of the Upper Floridan aquifer, had the second lowest median value for dissolved nitrite plus nitrate, 7.0mg/L, at this site; the lowest median value of 5.4 came from water from well 4-4. The highest median value of 9.3 mg/L for this constituent was from water from well 4-1, and the highest maximum concentration of 13.0 mg/L came from water from well 4-5. Both wells 4-4 and 4-5 are within the area occupied by the swine herd during most of the year. Well 4-1 is located at the western edge of the area where the swine are kept and adjacent to cultivated and fertilized farmland. The chemical fertilizer applied to the cultivated crops is possibly a source of the high maximum value for dissolved nitrite plus nitrate nitrogen from water from this well.

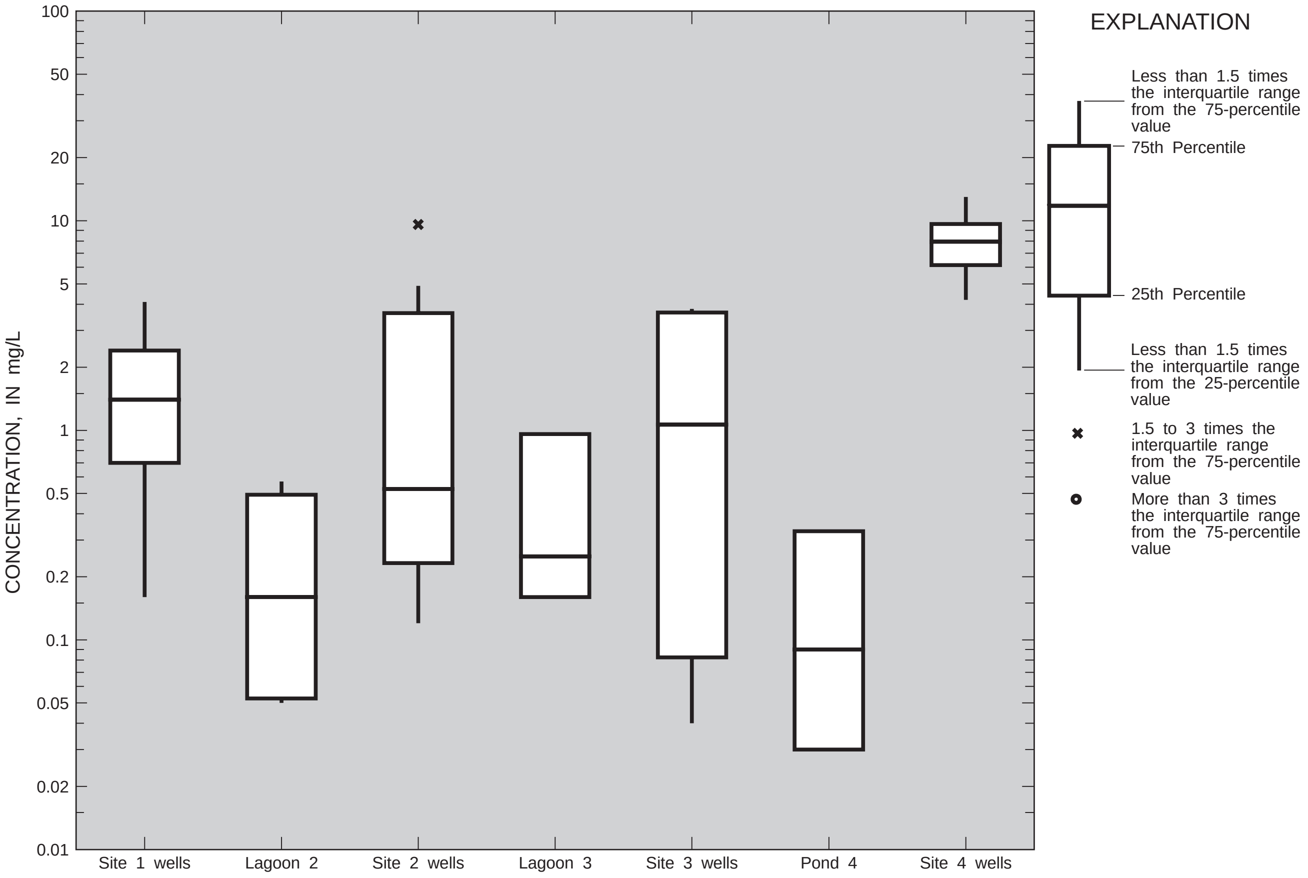


Figure 11. Concentrations of dissolved nitrate plus nitrite nitrogen in water from wells, lagoons, and pond.

Summary statistics are presented in tables 4 and 5 and figures 13 and 14 for the unconfined swine herd operations at sites 1 and 4. Sites 1 and 4 each had one monitoring well finished in the limestones of the Upper Floridan aquifer. Mean and median values of dissolved nitrate plus nitrate nitrogen, ammonia nitrogen, and phosphorus in the ground water from monitoring wells 1-3 and 4-2, fall within the minimum and maximum extremes of these values. It is for this reason that the analyses for Upper Floridan wells 1-3 and 4-2 are combined with analyses for wells completed in the residuum.

Water from the shallow pond at site 4 had median values for the selected dissolved constituents (in milligrams per liter): nitrite plus nitrate 0.09, ammonia 0.03, phosphorus 0.06. The median value for specific conductance was 66 µS/cm. Comparing the median value for the dissolved nitrite plus nitrate nitrogen with that of ammonia suggests that some denitrification is occurring in the shallow pond.

Sites with Confined Operations

Ground water from beneath site 2, with the exception of well 2-1, had median values for selected dissolved chemical constituents that were comparable to or lower than the medians from the other sites. Water from the lagoon had constituent concentrations that were considerably higher than in the wells (table 6). This indicates that water from the lagoon does not influence to a great degree the ground water in the residuum. The relatively high median nitrite plus nitrate and ammonium concentrations in well 2-1 (table 3) are probably the result of seepage of animal waste from the ditch adjacent to the lagoon into the shallow aquifer. A comparison of the dissolved nitrite plus nitrate values with those of dissolved ammonium suggest that denitrification is occurring in the wastewater of the lagoon, but not in the shallow ground water near wells 2-1, 2-2, 2-3, and 2-4.

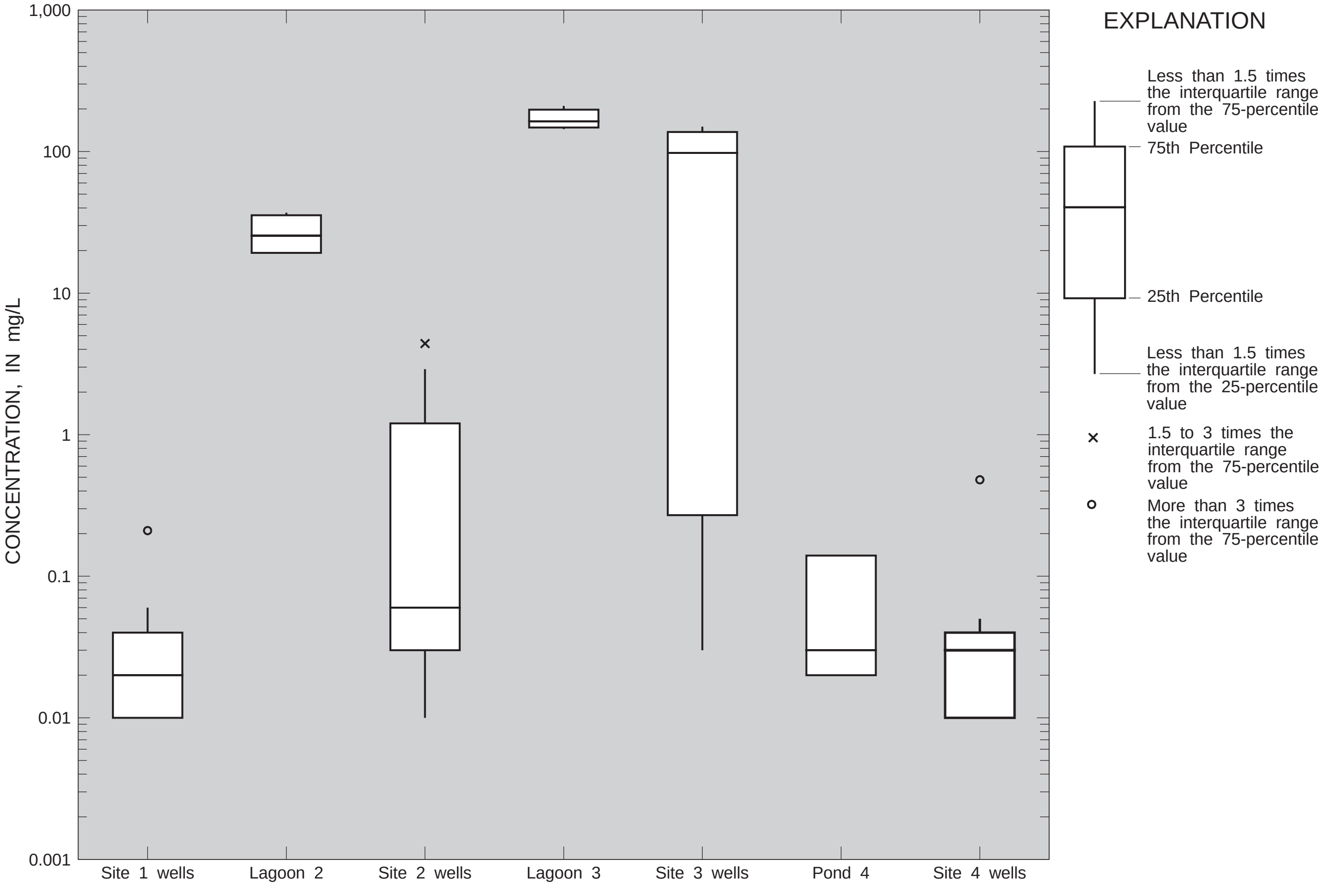


Figure 12. Concentrations of dissolved ammonium in water from wells, lagoons, and pond.

Ground water beneath site 3 had median values for selected dissolved constituents (table 7) that are considerably higher than the values for the water beneath site 2. The wastewater from the anaerobic lagoon had relatively high median values of dissolved constituents. Water in wells 3-2 and 3-3 down gradient from the lagoon had much higher concentrations of ammonia, nitrogen, and of phosphorus than waters from well 3-1, indicating that water from the lagoon influences ground-water quality at the site. The decidedly different chemical composition of water in well 3-1 likely is because the well is located to the east and regionally upgradient of the lagoon. Dissolved nitrite plus nitrate nitrogen is higher in water from well 3-1, whereas dissolved ammonia and phosphorus were much higher in water from wells 3-2 and 3-3. A comparison of the concentrations of dissolved nitrite plus nitrate and with the concentrations of dissolved ammonium in water from well 3-1 indicates that denitrification is occurring in the wastewater lagoon and in the ground water from wells 3-2 and 3-3.

A one-time sampling of water from a farm supply well located nearby and down the regional gradient from the lagoons and from the wells 3-2 and 3-3 had a chemical composition similar to that of water from well 3-1. This indicates that the poorer quality lagoon water is not influencing the water being pumped from deeper in the Upper Floridan aquifer.

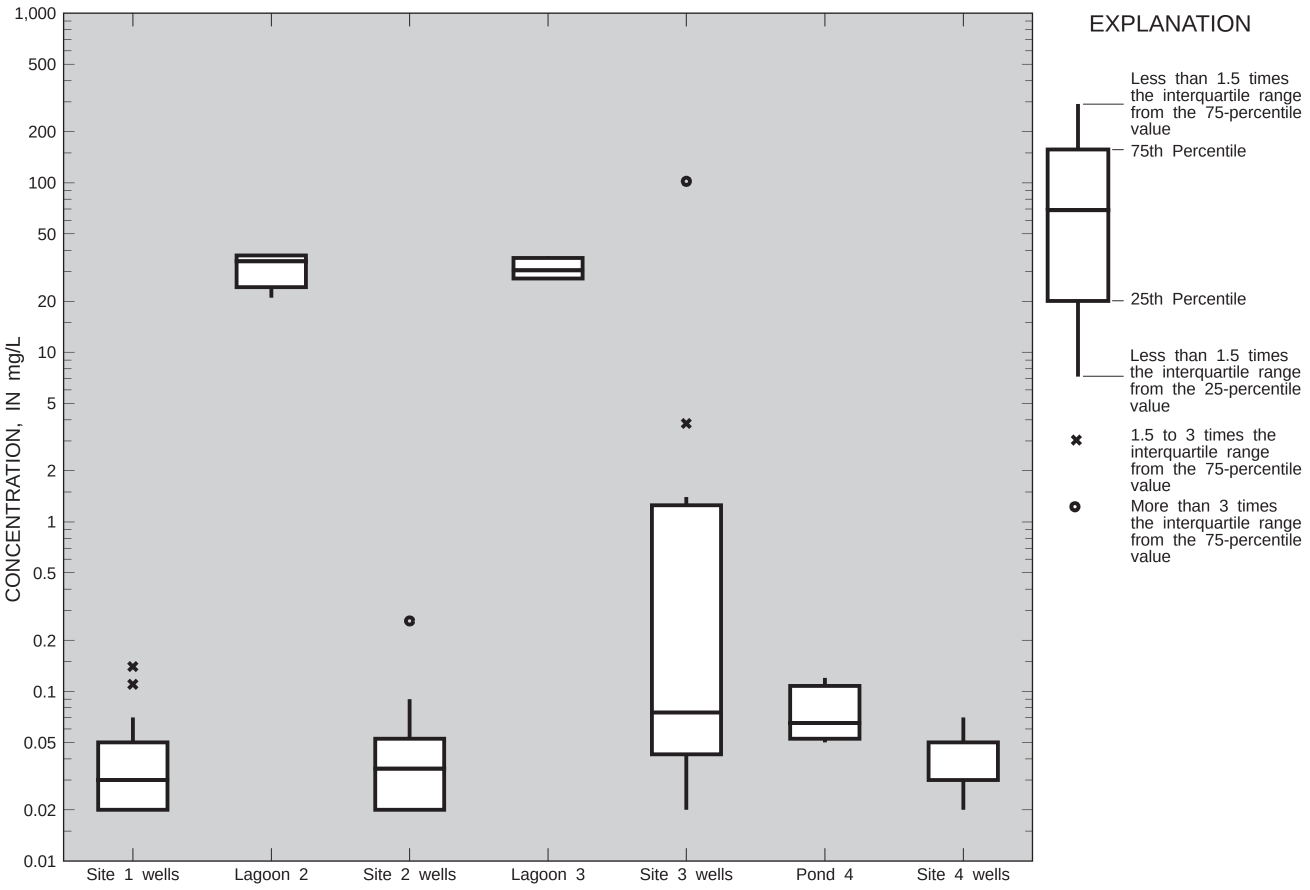


Figure 13. Concentrations of dissolved phosphorus in water from wells, lagoons, and pond.

Comparison of Water Quality Between Unconfined and Confined Operations

Water quality characteristics were compared, when possible, between unconfined and confined operations. Difficulties in making comparisons arose because of conditions at site 3. As stated earlier, the lagoon at site 3 (confined operations) is possibly affecting the ground-water quality, whereas the lagoon at site 2 (confined operations) seems to be having no effect on its underlying ground water. Furthermore, the wells at site 3 are completed in the Upper Floridan aquifer, whereas all the wells at site 2 and all but one of the wells at sites 1 and 4 (unconfined operations) are completed in the residuum. Therefore, comparisons between unconfined and confined operations are restricted to sites 1 and 4 with site 2.

Specific conductance is a good indicator of the presence of dissolved inorganic compounds in ground water. A comparison of the specific conductance statistics from sites 1, 2, and 4 showed an increase in the specific conductance values from ground water from sites 1 and 4 when compared with those from site 2, possibly indicating that waste from the unconfined swine herds is influencing the ground water underneath sites 1 and 4. Other possible influences on the chemistry of the ground water are the sandier residuum that underlies sites 1 and 4, and the tight red clay residuum that underlies site 2.

Table 3. Statistics of selected water-quality constituents in water from wells, lagoons, and pond
[All values are in milligrams per liter]

Sample location	Statistic	Temperature	Ph	Specific conductance	Nitrite plus nitrate nitrogen	Ammonia nitrogen	Phos- phorus
Wells							
1-1	Minimum	20.5	6.5	90	0.16	0.01	0.02
	Maximum	22.0	7.5	213	0.38	0.03	0.11
	Mean	21.2	6.9	143	0.31	0.02	0.05
	Median	21.0	6.7	135	0.34	0.02	0.07
1-2	Minimum	21.0	4.9	15	0.70	0.01	0.02
	Maximum	22.0	5.3	22	0.84	0.04	0.02
	Mean	21.5	5.1	17	0.76	0.02	0.02
	Median	21.5	5.0	16	0.76	0.02	0.02
1-3	Minimum	21.5	7.8	188	4.1	0.01	<0.02
	Maximum	22.0	8.0	212	2.4	0.04	0.05
	Mean	21.7	7.8	199	3.0	0.02	0.03
	Median	21.5	7.8	198	2.6	0.02	0.04
1-4	Minimum	22.0	5.0	29	0.49	<0.01	0.03
	Maximum	22.0	5.9	44	0.75	0.04	0.05
	Mean	22.0	5.3	34	0.63	0.02	0.04
	Median	22.0	5.2	31	0.64	0.02	0.04
1-5	Minimum	21.0	7.9	163	2.2	0.01	0.02
	Maximum	22.0	8.0	177	2.8	0.21	0.07
	Mean	21.5	8.0	167	2.5	0.07	0.04
	Median	21.5	8.0	164	2.5	0.04	0.04
1-6	Minimum	21.0	7.8	160	1.5	0.01	0.03
	Maximum	22.0	8.1	176	3.1	0.06	0.14
	Mean	21.5	7.9	170	2.4	0.03	0.06
	Median	21.5	7.9	172	2.4	0.02	0.04
1-7	Minimum	21.0	7.7	172	1.3	0.01	0.02
	Maximum	22.5	8.2	250	2.0	0.05	0.05
	Mean	21.8	7.9	202	1.5	0.03	0.04
	Median	21.8	7.8	192	1.4	0.02	0.04
2-1	Minimum	20.0	4.9	134	4.6	1.2	<0.02
	Maximum	21.5	5.4	269	9.6	4.4	0.06
	Mean	20.8	5.1	188	5.9	2.4	0.04
	Median	20.8	5.1	173	4.8	2.0	0.04
2-2	Minimum	21.5	5.6	24	0.33	0.04	0.03
	Maximum	21.5	5.9	34	0.70	0.23	0.26
	Mean	21.5	5.8	29	0.51	0.10	0.10
	Median	21.5	5.9	29	0.50	0.06	0.05
2-3	Minimum	21.5	5.3	21	0.45	<0.01	0.02
	Maximum	21.5	5.5	38	0.63	0.03	0.05
	Mean	21.5	5.4	28	0.53	0.02	0.03
	Median	21.5	5.4	27	0.52	0.02	0.02
2-4	Minimum	21.5	6.0	15	0.12	0.01	<0.02
	Maximum	21.5	6.9	48	0.20	0.10	0.05
	Mean	21.5	6.5	33	0.18	0.04	0.03
	Median	21.5	6.5	34	0.20	0.03	0.03
3-1	Minimum	21.5	7.6	274	2.6	0.03	0.02
	Maximum	21.5	7.7	300	3.8	0.73	0.06
	Mean	21.5	7.6	284	3.4	0.29	0.04
	Median	21.5	7.6	280	3.7	0.20	0.04
3-2	Minimum	21.0	6.9	1,560	<0.02	130	0.82
	Maximum	21.5	7.0	1,650	0.12	150	3.8
	Mean	21.2	6.9	1,610	0.06	142	1.8
	Median	22.2	6.9	1,620	0.05	144	1.3

Table 3. Statistics of selected water-quality constituents in water from wells, lagoons, and pond--Continued

Sample location	Statistic	Temperature	Ph	Specific conductance	Nitrite plus nitrate nitrogen	Ammonia nitrogen	Phos-phorus
3-3	Minimum	21.0	6.9	1,040	0.04	93	0.05
	Maximum	22.0	7.0	1,520	1.3	103	0.09
	Mean	21.3	6.9	1,380	0.66	99	0.07
	Median	21.0	6.9	1,485	0.64	100	0.08
4-1	Minimum	22.0	7.0	238	8.8	0.01	0.03
	Maximum	22.0	7.4	269	11	0.48	0.06
	Mean	22.0	7.2	256	9.2	0.13	0.04
	Median	22.0	7.1	259	9.3	0.02	0.03
4-2	Minimum	22.0	7.6	225	5.9	0.01	0.02
	Maximum	22.5	7.9	240	7.5	0.04	0.04
	Mean	22.2	7.8	233	6.8	0.02	0.03
	Median	22.0	7.8	235	7.0	0.02	0.02
4-3	Minimum	22.0	7.9	243	6.6	<0.01	0.03
	Maximum	22.0	8.1	260	11	0.82	0.04
	Mean	22.0	8.0	252	9.0	0.22	0.04
	Median	22.0	8.0	252	9.1	0.02	0.04
4-4	Minimum	21.5	7.1	240	4.2	0.01	0.02
	Maximum	21.5	7.3	280	6.0	0.04	0.07
	Mean	21.5	7.2	263	5.2	0.03	0.05
	Median	21.5	7.3	266	5.4	0.03	0.06
4-5	Minimum	21.0	7.7	247	8.9	<0.01	<0.02
	Maximum	22.0	8.9	288	13	0.05	0.05
	Mean	21.5	8.1	270	10	0.02	0.03
	Median	21.5	7.8	272	9.2	0.02	0.03
Lagoon 2	Minimum	ND	7.6	1,060	0.05	19	21
	Maximum	ND	8.7	1,330	0.57	37	38
	Mean	ND	8.3	1,190	0.24	27	32
	Median	ND	8.5	1,180	0.16	26	34
Lagoon 3	Minimum	22.0	7.2	2,470	<0.02	148	27
	Maximum	22.0	7.5	2,880	0.96	160	37
	Mean	22.0	7.3	2,600	0.35	156	31
	Median	22.0	7.3	2,520	0.20	160	30
Pond 4	Minimum	23.5	6.4	41	<0.02	<0.01	0.06
	Maximum	23.5	6.6	84	0.33	0.14	0.12
	Mean	23.5	6.5	64	0.12	0.05	0.08
	Median	23.5	6.6	66	0.06	0.02	0.06

Table 4. Summary statistics of field measurements and selected dissolved constituents in water from the seven monitoring wells at site 1

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NA, not applicable]

Characteristic or constituent and unit of measurement	Mean	Median	Minimum	Maximum
Number of samples (unless otherwise footnoted)	28	28	NA	NA
Temperature, in degrees Celsius	[1]21.6	21.5	20.5	22.5
pH	7.0	6.9	4.9	8.1
Specific conductance, in µS/cm	140	130	15	250
Nitrite plus nitrate nitrogen, in mg/L	1.6	1.4	0.16	3.1
Ammonia, in mg/L	0.03	0.02	0.01	0.21
Phosphorus, in mg/L	1.1	0.03	0.02	0.14

[1] Mean calculated from 20 samples.

Table 5. Summary statistics of field measurements and selected dissolved constituents in water from the five monitoring wells and pond at site 4

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NA, not applicable]

Water-quality property or constituent and unit of measurement	Mean	Median	Minimum	Maximum
Wells				
Number of samples (unless otherwise footnoted)	16	16	NA	NA
Temperature, in degrees Celsius	[1]22.0	21.8	21.0	22.0
pH	7.6	7.6	7.0	8.9
Specific conductance, in µS/cm	265	257	225	288
Nitrite plus nitrate nitrogen, in mg/L	8.0	7.95	<0.01	13
Ammonia, in mg/L	0.65	0.03	<0.01	1.6
Phosphorus, in mg/L	0.04	0.03	<0.02	0.07
Pond				
Number of samples (unless otherwise footnoted)	4	4	NA	NA
pH	6.5	6.6	6.4	6.6
Specific conductance, in µS/cm	63	66	41	84
Nitrite plus nitrate nitrogen, in mg/L	0.12	0.09	<0.01	0.33
Ammonia, in mg/L	0.05	0.03	<0.01	0.14
Phosphorus, in mg/L	0.08	0.065	0.05	0.12

[1] Mean calculated from 12 samples.

Table 6. Summary statistics of field measurements and selected dissolved constituents in water from the four monitoring wells and lagoon at site 2

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NA, not applicable]

Water-quality property or constituent and unit of measurement	Mean	Median	Minimum	Maximum
Wells				
Number of samples (unless otherwise footnoted)	20	20	NA	NA
Temperature, in degrees Celsius	[1]21.2	21.3	20.0	21.5
pH	[2]5.2	5.7	4.9	6.8
Specific conductance, in µS/cm	62	66	16	173
Nitrite plus nitrate nitrogen, in mg/L	1.8	0.525	0.12	9.6
Ammonia, in mg/L	0.65	0.06	0.01	4.4
Phosphorus, in mg/L	0.05	0.035	0.02	0.26
Lagoon				
Number of samples (unless otherwise footnoted)	4	4	NA	NA
pH	[3]8.3	8.5	7.6	8.7
Specific conductance, in µS/cm	1,190[3]	1,180	1,060	1,330
Nitrite plus nitrate nitrogen, in mg/L	[4]0.15	0.16	0.05	0.57
Ammonia, in mg/L	26.8	25.5	19	37
Phosphorus, in mg/L	27	34.5	21	38

[1] Mean calculated from 5 samples.
[2] Mean calculated from 12 samples.
[3] Mean calculated from 3 samples.
[4] Mean calculated from 8 samples.

Table 7. Summary statistics of field measurements and selected dissolved constituents in water from the three wells and lagoon at site 3

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NA, not applicable]

Water-quality property or constituent and unit of measurement	Mean	Median	Minimum	Maximum
Wells				
Number of samples (unless otherwise footnoted)	12	12	NA	NA
Temperature, in degrees Celsius	[1]21.8	21.7	21.0	22.0
pH	7.2	7.1	6.9	7.7
Specific conductance, in µS/cm	1,260	1,130	274	1,650
Nitrite plus nitrate nitrogen, in mg/L	1.3	1.065	0.02	3.8
Ammonia, in mg/L	81.1	98.0	0.03	150.
Phosphorus in mg/L	0.64	0.075	0.02	3.80
Lagoon				
Number of samples (unless otherwise footnoted)	4	4	NA	NA
pH	7.3	7.3	7.2	7.5
Specific conductance, in µS/cm	2,600	2,520	2,470	2,880
Nitrite plus nitrate nitrogen, in mg/L	0.34	0.25	0.02	0.96
Ammonia, in mg/L	156.0	160.0	148.0	160.0
Phosphorus, in mg/L	31.0	30.5	27.0	37.0

[1] Mean calculated from 8 samples.

Comparison of median concentrations of nitrite plus nitrate nitrogen shows that the median values are higher at sites 1 and 4, the highest at site 4, compared to site 2. The high values at site 4 possibly are attributed to the heavily (inorganic) fertilized cultivated fields that surround this site. Three wells at site 1 with the highest median concentrations of nitrite plus nitrate nitrogen are likewise surrounded by fertilized cultivated fields.

Comparison of dissolved ammonium nitrogen between the sites generally shows lower median concentrations associated with unconfined operations (fig. 12). The higher median value from site 2 is attributed to the high maximum ammonium concentration in water from well 2-1. Water in this well appears to be influenced by the wastewater resulting from channeling of wastewater down a natural drainage feature near the well. With the exception of the dissolved ammonium concentrations in well 2-1, the ammonium concentration in water beneath site 2 is very similar to the concentrations in the waters below sites 1 and 4.

Comparison of median values for dissolved phosphorus between sites 1, 2, and 4 show no differences. Even though the lagoon at site 2 has a higher median concentration of phosphorus, there appears to be little affect on the ground water at this confined operation.

SUMMARY AND CONCLUSIONS

Growing concern about the effects of farm animal waste upon the quality of both ground and surface water in north Florida have prompted several studies in recent yearsthat are aimed at examining the effects that various livestock farm management practices have on the input of N-species nitrogen to ground water. The study area for this report was in Jackson County, in the central Florida Panhandle within the Dougherty Karst District in the humid Coastal Plain of the southeastern United States. This physiographic region includes a large part of southwest Georgia and northwest Florida and has a topography dominated by karst landforms. The Upper Floridan aquifer lies close to or at the land surface in the project study area and is the principal aquifer of the region. Susceptibility to contamination—directly, from or through runoff into sinkholes, and indirectly, through the vadose zone—is the major impetus for this study. To examine the effect of swine farms on the quality of ground water on four swine farms in Jackson County, water samples from wastewater lagoons, a pond, and monitoring wells taken at quarterly intervals for 1 year. These samples were analyzed for the dissolved species of nitrate, nitrite, ammonium nitrogen, phosphorus, potassium, sulfate, chloride, calcium, magnesium, fluoride, total ammonium plus organic nitrogen, total phosphorus, alkalinity, carbonate, and bicarbonate.

The four farms studied in this report followed two different management practices: two had unconfined operations where the herd was allowed to roam freely within a specified area, and then allowed to forage in fields after they had been harvested; whereas the other two farms had confined operations where the herd was kept in houses and the waste from those houses was washed into lagoons for treatment—one farm had a one-stage lagoon whereas the other had two-stage lagoon. The length of operations for the four farms in this report varied from 19 to over 75 years.

All four farms have monitor wells near cultivated fields that receive applications of inorganic fertilizers throughout the year, and with the exception of site 3, they are surrounded by other farms that are cultivated and fertilized. The median values of nitrite plus nitrate nitrogen detected in ground water beneath the farms are all below the U.S. Environmental Protection Agency (USEPA) drinking standard and, except at one site, are at the lower end of the range for this parameter in comparison to countywide background concentrations (Clemons and others, 1987; Roaza and others, 1989). The nitrate nitrogen isotope ratios indicate livestock waste as a major source of the dissolved nitrite plus nitrate nitrogen found in the ground water monitoring wells. But a mixed source is more likely, given the application of inorganic fertilizers on and around the farms. The underlying soils and overburden composition have much to do with how much the nitrogen from livestock waste influences the chemical makeup of the ground water in this area.

The dissolved concentrations of nitrite plus nitrate nitrogen in the ground water from the 19 monitoring wells show slight fluctuations, ranging from a low of <0.02 mg/L to a high of 13 mg/L, with most concentration values falling between 1.3 and 8.0 mg/L . The dissolved concentrations of phosphorus in water from the monitoring wells fluctuated from a minimum of <0.02 mg/L to a maximum of 3.8 mg/L. The number of analyses, both per site and per monitoring wells, were insufficient to establish significant differences between the concentrations of the chemical constituents of the analyzed species from ground water from the Upper Floridan aquifer and water from the overlying residuum.

As the study by Magette and others (1989) reported, in the humid Coastal Plain of the southeastern United States, especially in karstic terrain, the dissolved concentrations of nitrite plus nitrate nitrogen will occasionally exceed the 10 mg/L USEPA standard for drinking water (U.S. Environmental Protection Agency, 1986) in agricultural areas due to the combination of climate, soil, and hydrogeology.

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APPENDIX I

Water Levels During 1993 in 19 Monitored Wells, Jackson County, Florida

Appendix I. Water levels during 1993 in 19 monitored wells, Jackson County, Florida

Well Number	Date	Altitude, in feet above sea level
1-1	12-22-92	86.52
1-1	01-14-93	89.43
1-1	04-13-93	94.89
1-1	05-12-93	93.11
1-1	06-15-93	90.51
1-1	07-21-93	90.60
1-1	08-18-93	87.34
1-1	09-16-93	86.14
1-1	10-07-93	85.48
1-2	12-22-92	86.63
1-2	01-14-93	89.67
1-2	04-14-93	94.97
1-2	05-12-93	93.26
1-2	06-15-93	90.66
1-2	07-21-93	88.75
1-2	08-18-93	87.49
1-2	09-16-93	86.26
1-2	10-07-93	85.51
1-3	12-22-93	86.45
1-3	01-14-93	89.59
1-3	04-13-93	94.63
1-3	05-12-93	92.87
1-3	06-15-93	90.28
1-3	07-20-93	88.52
1-3	08-18-93	87.16
1-3	09-16-93	85.99
1-3	10-07-93	85.24
1-4	12-22-92	86.14
1-4	01-14-93	89.89
1-4	04-13-93	93.59
1-4	05-12-93	92.80
1-4	06-15-93	89.43
1-4	07-21-93	87.60
1-4	07-21-93	87.60
1-4	08-18-93	86.37
1-4	09-16-93	85.25
1-4	10-06-93	84.56
1-5	12-22-92	84.64
1-5	01-15-93	87.68
1-5	04-13-93	92.46
1-5	05-12-93	91.22
1-5	06-15-93	88.96
1-5	07-21-93	87.17
1-5	08-18-93	85.88
1-5	09-16-93	84.81
1-5	10-06-93	84.14
1-6	12-22-92	84.46
1-6	01-15-93	87.45
1-6	04-13-93	92.18
1-6	05-12-93	90.99
1-6	06-15-93	88.78
1-6	07-21-93	88.04
1-6	08-18-93	85.67
1-6	09-16-93	84.66
1-6	10-06-93	84.01
1-7	12-22-93	83.33
1-7	01-15-93	86.24
1-7	01-15-93	86.24
1-7	04-13-93	91.25
1-7	05-12-93	90.01
1-7	06-15-93	87.71
1-7	07-20-93	86.00
1-7	08-18-93	84.66
1-7	09-16-93	83.55
1-7	10-06-93	82.86
2-1	12-23-93	93.59
2-1	01-12-93	95.09
2-1	04-15-93	93.87
2-1	05-12-93	91.65
2-1	06-15-93	88.77
2-1	07-19-93	85.49
2-1	08-18-93	83.59
2-1	09-16-93	82.75
2-1	10-04-93	81.75
2-2	12-23-92	92.05
2-2	01-12-93	93.95
2-2	04-15-93	92.97
2-2	05-12-93	90.16
2-2	06-15-93	86.41
2-2	07-19-93	83.42
2-2	08-18-93	81.81
2-2	09-16-93	80.54
2-2	10-04-93	79.77
2-3	12-23-92	87.43
2-3	01-12-93	88.69
2-3	04-15-93	88.66
2-3	05-12-93	83.50
2-3	06-15-93	81.87
2-3	07-19-93	79.09
2-3	08-18-93	77.51
2-3	09-16-93	76.14
2-3	10-04-93	75.53

Appendix I. Water levels during 1993 in 19 monitored wells, Jackson County, Florida--Continued

Well Number	Date	Altitude, in feet above sea level
2-4	12-23-92	89.18
2-4	01-12-93	90.77
2-4	04-15-93	90.24
2-4	04-15-93	90.24
2-4	05-12-93	87.86
2-4	06-15-93	83.94
2-4	07-19-93	80.93
2-4	08-18-93	79.20
2-4	09-16-93	77.92
2-4	10-04-93	77.30
3-1	12-22-92	75.27
3-1	01-13-93	78.12
3-1	04-12-93	77.94
3-1	05-12-93	76.71
3-1	06-15-93	75.18
3-1	07-22-93	74.26
3-1	07-22-93	74.26
3-1	08-18-93	73.56
3-1	09-16-93	73.11
3-1	10-05-93	72.81
3-2	12-22-92	75.26
3-2	01-13-93	78.41
3-2	04-12-93	77.89
3-2	05-13-93	76.52
3-2	06-15-93	74.95
3-2	07-22-93	74.00
3-2	08-18-93	73.31
3-2	09-16-93	72.83
3-2	10-05-93	72.49
3-3	12-22-92	75.27
3-3	01-13-93	78.43
3-3	01-13-93	78.43
3-3	04-12-93	77.90
3-3	05-12-93	75.54
3-3	06-15-93	74.96
3-3	07-22-93	74.04
3-3	08-18-93	73.36
3-3	09-16-93	72.88
3-3	10-05-93	72.58
4-1	12-23-92	85.72
4-1	01-13-93	87.34
4-1	04-15-93	88.06
4-1	04-15-93	88.06
4-1	05-12-93	87.16
4-1	06-15-93	85.93
4-1	07-20-93	85.64
4-1	08-18-93	84.14
4-1	09-16-93	82.73
4-1	10-06-93	81.54
4-2	12-23-92	85.57
4-2	01-13-93	87.08
4-2	04-14-93	87.86
4-2	05-12-93	87.00
4-2	06-15-93	85.81
4-2	07-21-93	85.53
4-2	08-18-93	84.05
4-2	09-16-93	82.62
4-2	10-05-93	81.52
4-3	12-23-92	85.58
4-3	01-13-93	87.07
4-3	04-14-93	87.85
4-3	05-12-93	86.99
4-3	06-15-93	85.81
4-3	07-21-93	85.52
4-3	08-18-93	84.05
4-3	09-16-93	82.63
4-3	10-05-93	81.53
4-4	12-23-92	85.49
4-4	01-14-93	87.10
4-4	04-15-93	87.93
4-4	05-12-93	87.04
4-4	06-15-93	85.82
4-4	07-20-93	85.54
4-4	08-18-93	84.02
4-4	09-16-93	82.62
4-4	10-04-93	81.58
4-5	12-23-92	85.54
4-5	01-14-93	87.02
4-5	04-14-93	87.80
4-5	05-12-93	86.96
4-5	06-15-93	85.78
4-5	07-20-93	85.53
4-5	08-18-93	84.52
4-5	09-16-93	82.61
4-5	10-04-93	81.60

APPENDIX II

Generalized Lithologic Descriptions of the 19 Monitored Wells, Jackson County, Florida

APPENDIX II. Generalized lithologic descriptions of the 19 monitored wells [S.B. -- screened bottom; LS -- limestone rock]

Well	Depth below land surface	Lithology
SITE 1		
1-1	0 ft-S.B.	Mixture of clayey sand, clay & sand and sandy clay with possible limestone rock (LS) stringers & pebbles at 18 ft to 21 ft.
	43	Total depth
1-2	0 ft-11 ft	Sand, clayey sand to sandy clay
	11 ft-34 ft	Clays
	34 ft-S.B.	Clays with pebbles & sandy clay
	50	Total depth
1-3	0 ft- 3 ft	Sand
	3 ft-78 ft	Clayey sands & sandy clays
	78 ft-S.B.	Rock (LS)
	103	Total depth
1-4	0 ft- 2 ft	Sand
	2 ft-10 ft	Clayey sand & sandy clays
	10 ft-28 ft	Clays
	28 ft-S.B.	Sandy clays
	47	Total depth
1-5	0 ft- 8 ft	Clayey sand
	8 ft-35 ft	Clays
	35 ft-S.B.	Clays with possible LS (clay at bottom)
	57	Total depth
1-6	0 ft- 7 ft	Clayey sand
	7 ft-24 ft	Clays
	24 ft-S.B.	Sandy clays with possible LS from 33 ft to bottom
	61	Total depth
1-7	0 ft- 4 ft	Sand & clayey sand
	4 ft-22 ft	Clays (some quartz fragments at 33 ft to 37 ft)
	22 ft-S.B.	Sandy clays & clayey sands
	61	Total depth
SITE 2		
2-1	0 ft-.5 ft	Soil
	.5 ft-S.B.	Clays
	26	Total depth
2-2	0 ft-S.B.	Clays
	39	Total depth
2-3	0 ft-S.B.	Clays
	49	Total depth

2-4	0 ft-30 ft	Clays
	30 ft-36 ft	Clays with rock fragments
	36 ft-40 ft	Clays with quartz pebbles
	40 ft-S.B.	Clays
	48	Total depth
SITE 3		
3-1	0 ft-17 ft	Clays
	17 ft-21 ft	Rock (LS) seams
	21 ft-33 ft	Clays & rock chips
	33 ft-S.B.	Rock (LS)
	44	Total depth
3-2	0 ft-12 ft	Clays
	12 ft-14 ft	Rock (LS) & clays
	14 ft-S.B.	Rock (LS)
	54	Total depth
3-3	0 ft-17 ft	Clays
	17 ft-38 ft	Clays & rock (LS) with rock (LS)-chip mix
	38 ft-S.B.	Rock (LS) & interfingering clays
	50	Total depth
SITE 4		
4-1	0 ft- 2 ft	Soil & sand
	2 ft-S.B.	Clays with small rock fragments throughout
	40	Total depth
4-2	0 ft- 1 ft	Sand
	1 ft-13 ft	Sandy clays with small rock fragments from 8 ft to 13 ft
	13 ft-35 ft	Clays (void at 35 ft)
	35 ft-60 ft	No return
	60 ft-S.B.	Rock (LS) with void & no return from 63 ft to bottom
	78	Total depth
4-3	0 ft- 1 ft	Sand
	1 ft-16 ft	Sandy clay with small quartz fragments from 8 ft to 11 ft
	16 ft-S.B.	Clays
	36	Total depth
4-4	0 ft- 6 ft	Sand & clayey sand
	6 ft- 8 ft	Sandy clay
	8 ft-S.B.	Clays
	37	Total depth
4-5	0 ft- 2 ft	Clayey sand
	2 ft-14 ft	Sandy clays
	14 ft-S.B.	Clays
	38	Total depth

APPENDIX III

Selected Field Data and Dissolved Nutrient Data from Ground Water from Three Supply Wells at Two Swine Farms, Jackson County, Florida, and from the Blank Water Samples

Well	Temperature	Specific conductance	pH	NH_3	NO_2	NO_3	Org	PO_4
1-B	--	187	7.9	0.03	<0.01	3.29	--	0.03
1-I1	21.0	165	7.9	0.02	<0.01	2.39	0.02	--
3-B1	--	365	7.4	1.5	0.05	5.25	--	0.03