Effects of Waste-Disposal Practices on Ground-Water Quality at Five Poultry (Broiler) Farms in North-Central Florida, 1992-93

By Hilda H. Hatzell

U.S. Geological Survey

Water-Resources Investigations Report 95-4064

Prepared in cooperation with the
FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

Tallahassee, Florida
1995

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Multiply	By	To obtain
inch (in.)	2.54	centimeter
foot (ft)	0.304	meter
mile (mi)	1.609	kilometer
gallon (gal)	3.785	liter
pound (lb)	453.6	gram
acre	0.4047	hectare
ton per acre	2.24	megagrams per hectare

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) 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

mg/L = milligrams per liter
µS/cm = microsiemens per centimeter
in/yr = inch per year
yr = year

Acronyms

FPF = Florida Poultry Federation, Incorporated
MCL = Maximum contaminant level
PVC = Polyvinyl chloride

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Abstract

Waste-disposal areas such as chicken-house floors, litter stockpiles, fields that receive applications of litter, and dead-chicken pits are potential sources of nitrates and other chemical constituents in downward-percolating recharge water. Broiler-farms in north-central Florida are concentrated in a region where the Upper Floridan aquifer is unconfined and susceptible to contamination. Eighteen monitoring wells installed at five sites were sampled quarterly from March 1992 through January 1993. Increases in median concentrations of constituents relative to an upgradient well were used to determine the source of the nitrate at two sites. At these sites, increases in the median concentrations of nitrate as nitrogen in ground water in the vicinity of waste-disposal areas at these sites were: 5.4 mg/L for one chicken house; 9.0 mg/L for a second chicken house; 2.0 mg/L for a fallow field that received an application of litter; and, 2.0 mg/L for a dead-chicken pit. At the three remaining sites where the direction of local ground-water flow could not be ascertained, the sources of concentrations of nitrate and other constituents could not be determined. However, median nitrate concentrations in the vicinity of waste-disposal areas at these sites were: 45.5 mg/L for a set of two chicken houses; 3.0 mg/L for a stockpile area; and, 2.1 mg/L for a hayfield that received an application of litter. The nitrate concentration in ground water in the vicinity of a field that had previously received heavy applications of litter increased from 3.0 mg/L to 105 mg/L approximately 4 months after receiving an application of commercial fertilizer. Increases in concentrations of organic nitrogen in ground water in the vicinity of waste-disposal areas may be related to the decomposition of litter and subsequent movement with downward percolating recharge water.

INTRODUCTION

Waste disposal practices on poultry farms are thought to be affecting the quality of ground water in north-central Florida. Poultry farms in north-central Florida produce broilers, or chickens processed for meat. Broilers are raised in large open houses that have bedding material on the floor. Production practices on the poultry (broiler) farms create two types of wastes, litter and dead chickens. Litter, which is a mixture of bedding material and manure, is generally a dry material with a consistency similar to commercial potting media. Litter is periodically removed from the chicken-house floors and is either spread directly from the houses onto the fields by broadcasting or stockpiled on the land surface. Stockpiled litter is either sold for use off the farm or applied to the farm fields at a later time.

Broiler farms usually dispose of dead chickens on the farm. Under average production conditions in north-central Florida, approximately 2 percent of the birds in each production cycle die or are removed (Harold Barns, Field Operations Manager for Gold Kist Poultry, oral commun., 1993). Although several methods of disposal are used, a common one is to place dead chickens in a covered pit that is dug into the soil. The bottoms of these pits are usually not lined to prevent the downward movement of materials from the pits.

The decomposition of litter and dead chickens provides possible sources of nitrate and other constituents that may affect ground-water quality. The amounts of chemical constituents in litter vary with differences in bedding material and diet of the birds. Grundey (1980, p. 53) reported the following by-weight percentages for fresh, undiluted, broiler litter: 2.4 percent nitrogen, 1.0 percent phosphorus, and 1.2 percent potassium. Nitrogen in the form of nitrate as well as other constituents are released during decomposition. Dissolved nitrate does not readily combine with other substances that might remove nitrate from the water. When water containing nitrate and other constituents moves downward from the land surface to recharge an aquifer, the water quality of the aquifer may be degraded.

The United States Environmental Protection Agency has set the maximum contaminant level (MCL) for nitrate in drinking water at 10 mg/L of nitrate as nitrogen. Concentrations of nitrate greater than the MCL can become a health risk, especially to infants less than six months old. The risk is related to the chemical conversion of nitrate to nitrite in the body (Bouchard and others, 1992). Nitrite can convert hemoglobin to methemoglobin. The loss of hemoglobin reduces the ability of blood to transport oxygen. When this condition occurs at toxic levels, it is called methemoglobinemia. The MCL for nitrate is based on an epidemiological survey in 1951 that found no known cases of methemoglobinemia in infants when the nitrate concentrations in drinking water were less than 10 mg/L nitrate as nitrogen (Bouchard and others, 1992).

The major source of drinking water in the Suwannee River Water Management District is the Floridan aquifer system. In this district, which is located in north-central Florida (fig. 1), all of the freshwater withdrawals for self-supplied domestic uses and for public supply in 1990 were made from the Floridan aquifer system (Marella, 1992). Public supply includes water used for household purposes and for commercial establishments such as motels and office buildings. In addition, 95 percent of the freshwater withdrawals for agricultural uses in the district were made from the Floridan aquifer system.

The likelihood of water from the land surface moving into the Upper Floridan aquifer is indicated by the yearly rate of recharge to the aquifer. Aucott (1988) grouped the yearly rates of recharge to the Floridan aquifer system into three classes: less than 1 inch per year (in/yr), between 1 and 10 in/yr, and greater than 10 in/yr. A large part of the area of the Suwannee River Water Management District is classified in the highest class of recharge (fig. 1). This high rate of recharge makes the Upper Floridan aquifer in north-central Florida vulnerable to contamination from surface sources.

Broiler production is an important agricultural industry in north-central Florida. The State ranked twelfth in broiler-production in the Nation in 1991 (Florida Agricultural Statistics Service, 1992). The combination of the agricultural importance of broiler production and the vulnerability of the Upper Floridan aquifer created a need for more information about the effects of litter storage and disposal of litter and dead chickens on water quality. In 1992, in cooperation with the Florida Department of Environmental Protection (formerly, Florida Department of Environmental Regulation), the U.S. Geological Survey initiated a study of the effects of waste-disposal practices on ground-water quality at five broiler farms in north-central Florida.

The objectives of the study were (1) to determine if concentrations of nitrates and other chemical constituents have increased in ground water in the vicinity of five broiler farms, and (2) when increases are identified, to attempt to relate those increases to specific waste-disposal practices used on broiler farms. In addition to nitrate, chemical constituents evaluated included potassium, chloride, nitrite, ammonium, phosphorus, organic nitrogen, and organic carbon. Changes in concentrations of these constituents were used to evaluate the effect of waste-disposal practices on ground-water quality.

Purpose and Scope

This report presents and evaluates the water-quality data obtained from a total of 21 monitor wells located on four broiler farms in Suwannee County and one broiler farm in Lafayette County (fig. 1). Most monitor wells were open to the Upper Floridan aquifer and were sampled quarterly for one year beginning in March 1992. This report also summarizes the results of a questionnaire that was used to characterize the litter disposal practices of broiler farms in north-central Florida and to select the five study sites.

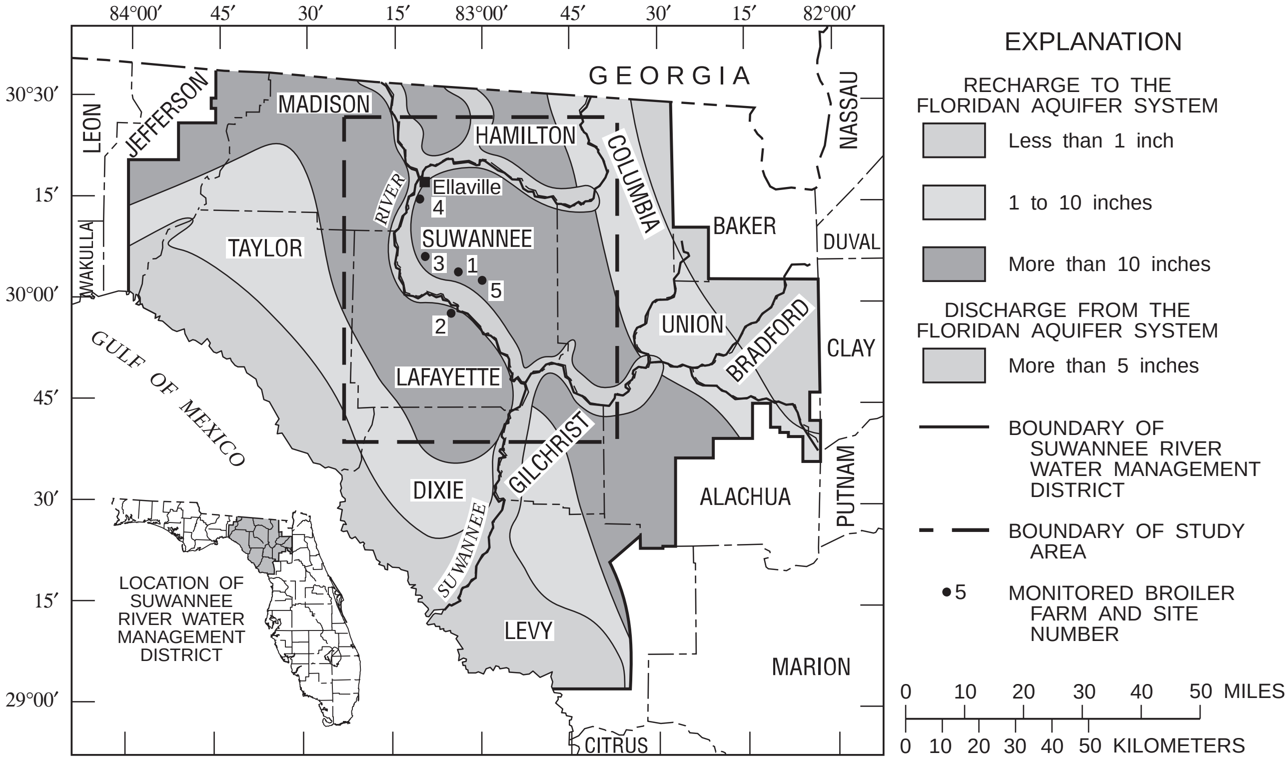

Figure 1. Locations of study area boundaries, monitored poultry farms, and yearly rates of recharge and discharge to the Floridan aquifer system.

Suwannee and Lafayette Counties were selected for the study because these counties are the major broiler-producing counties in north-central Florida. Suwannee and Lafayette Counties each produced more than 10 million broilers in 1987 (Florida Agricultural Statistics Service, 1992). Both counties are also located in an area that has a yearly recharge rate to the Floridan aquifer system of greater than 10 in/yr (fig. 1).

Physical Setting

The study area is in north-central Florida and includes Suwannee and Lafayette Counties. The climate of the study area is characterized by warm summers and mild winters (Crane, 1986). The average annual rainfall over a 30 yr period ranges from 52 to 56 in/yr in Suwannee County and from 56 to 60 in/yr for Lafayette County (Jordan, 1984).

The land surface of the study area is characterized by a karstic terrain with almost no surface-water drainage other than sinkholes. This land surface is underlain by undifferentiated surficial deposits consisting of light-gray, unconsolidated to poorly-indurated quartz sands over clayey quartz sands and sandy clays that are poorly to moderately indurated (Crane, 1986). A generalized schematic of the hydrogeology of the study area is presented in figure 2.

The Floridan aquifer system is a thick sequence of carbonate rocks that is separated into the Upper and Lower Floridan aquifers by a middle confining unit. The uppermost units of the Upper Floridan aquifer in the study area are the Suwannee and Ocala Limestones. The Suwannee Limestone of Oligocene age consists of two interbedded rock types: a cream to tan, crystalline limestone with numerous small cavities, and a white to cream, finely pelletal limestone (Miller, 1986). The Ocala Limestone of Eocene age consists of two rock types: a soft, somewhat friable, porous coquina found in the upper part of the formation and a fine-grained, micritic limestone found in the lower part (Miller, 1986). Miller (1986) described the Ocala as one of the most permeable rock units in the Floridan aquifer system.

In the northeastern part of the study area, the Upper Floridan aquifer is overlain by an upper confining unit, the Hawthorn Formation. The Hawthorn Formation

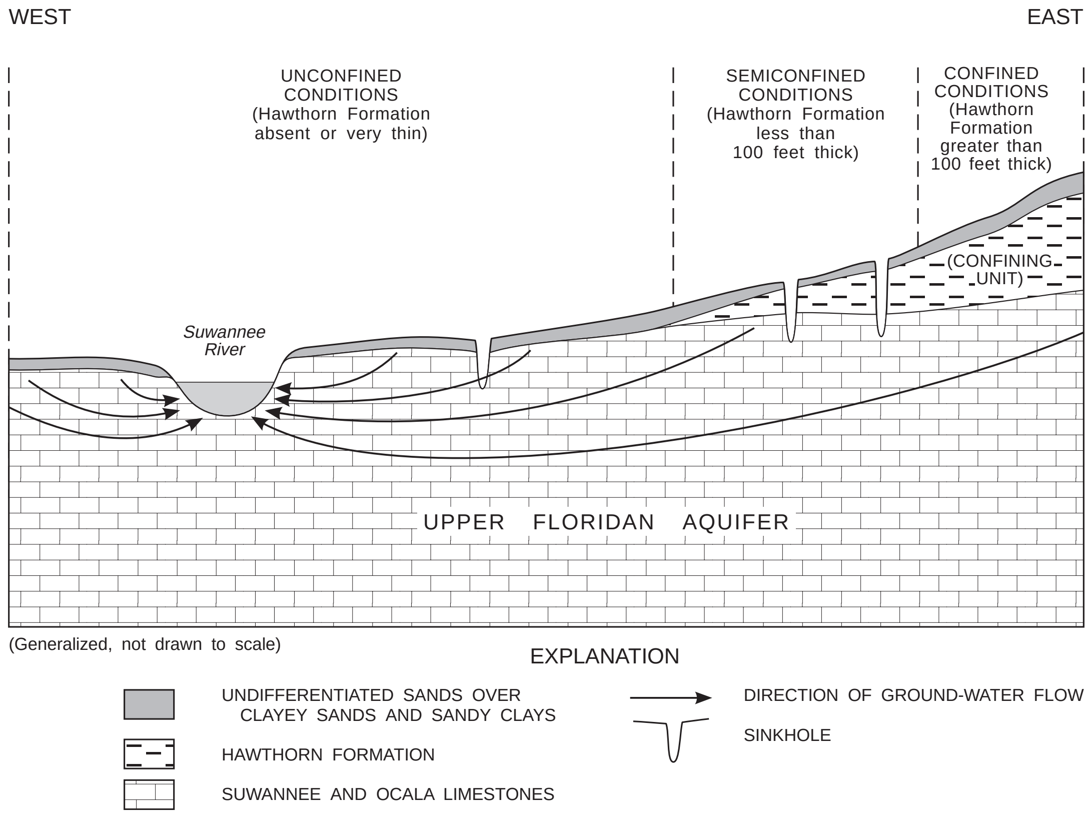

Figure 2. Generalized schematic of the hydrogeology of the study area.

consists of mostly clay, silt and sand beds that are complexly interbedded and highly variable (Miller, 1986). The Hawthorn is less permeable than the underlying limestones of the Upper Floridan aquifer.

Along with the amount of recharge to the aquifer, the degree of confinement is another indicator of the vulnerability of an aquifer to contamination from surface sources. Downward percolating water from the surface enters the aquifer more readily where the aquifer is unconfined and less readily where the aquifer is confined. The degree of confinement of the Upper Floridan aquifer has been divided into three conditions: confined, semiconfined, and unconfined (figs. 2 and 3) (Bush, 1988). In the parts of the study area where the Hawthorn Formation is more than 100 ft thick, the Upper Floridan aquifer is confined. In parts where the Hawthorn is less than 100 ft thick and breached by sinkholes, the Upper Floridan aquifer is semiconfined. In parts where the Hawthorn is missing or very thin, the Upper Floridan aquifer is unconfined. The five monitored broiler farms are located in areas where the Upper Floridan aquifer is unconfined (fig. 3).

The direction of regional flow of the ground water in the Upper Floridan aquifer is shown on the potentiometric-surface map of the study area (fig. 4). Ground water in the vicinity of the monitored poultry farms flows toward the Suwannee River. Ground water from the Upper Floridan aquifer discharges into the Suwannee River through the river banks and through springs feeding the river.

Previous Reports

Few reports have been published about water quality in north-central Florida. Andrews (1992) evaluated the effects of waste disposal practices of dairy farms on surface- and ground-water quality in north Florida. Descriptions of ground-water quality for the Upper Floridan aquifer in north-central Florida have been included in reports by Katz (1992), Maddox and others (1992), and Sprinkle (1989). Other reports have described only surface-water quality. The surface-water quality in the Suwannee River Basin was examined by Hull and others (1981) for the period of August 1968, through December 1977; by Coffin (1981) for the period of April 1978, to December 1979; and by Coffin (1982) for 1980. Earle (1975) described the quality of surface-water runoff in the Suwannee River Water Management District (fig. 1).

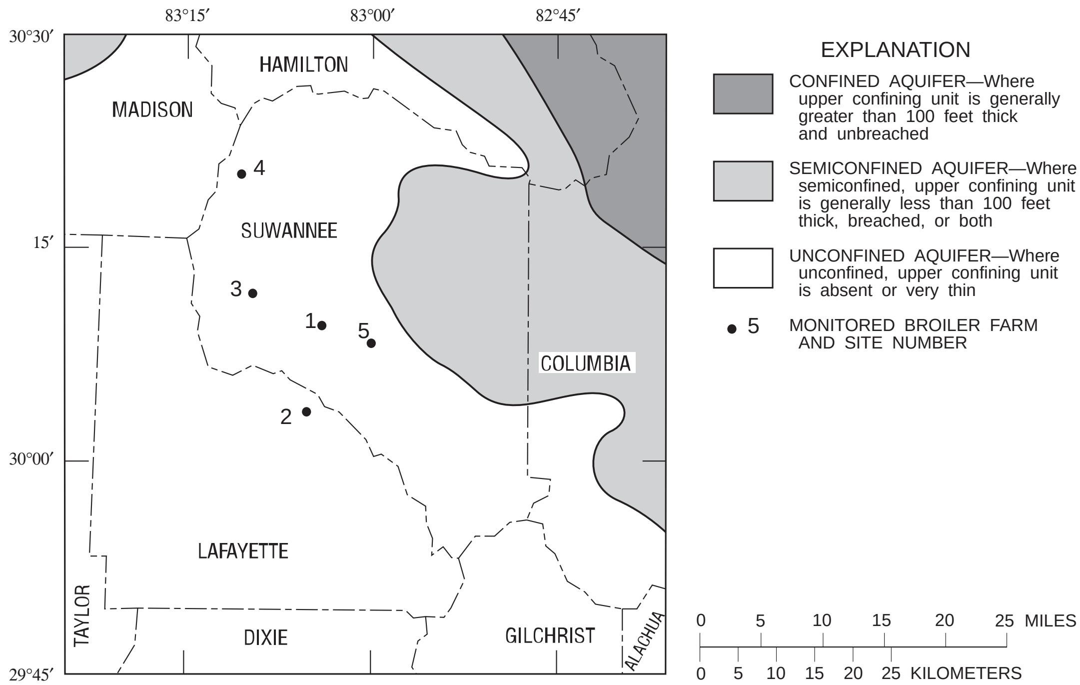

Figure 3. Distribution of confined, semiconfined, and unconfined conditions of the Upper Floridan aquifer in the study area.

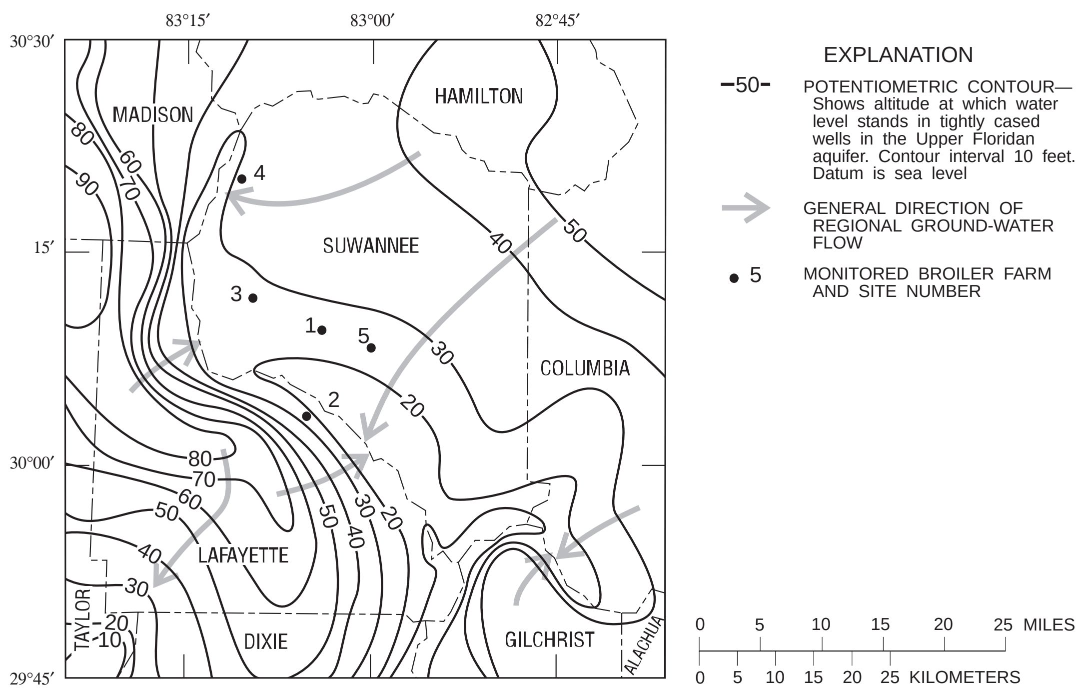

Figure 4. Potentiometric-surface contours and directions of regional ground-water flow in the Upper Floridan aquifer in the study area, May, 1990.

The hydrogeology of the Lower Suwannee River Basin is discussed by Crane (1986). Additional information about the hydrology and geology of the Floridan aquifer system in north-central Florida is found in reports by Miller (1986), and Bush and Johnston (1988).

Acknowledgments

The author wishes to thank all of the poultry farmers in the study area who answered the questionnaire, participated in interviews, and provided guided tours of their broiler farms. Special thanks are extended to Daniel and Patricia Evans, Randall Hewitt, Thomas McIntosh, Samantha Tuttle, and James Wainwright for their patience and participation in the project and to Harold Barns, Field Operations Manager for Gold Kist Poultry. The author also thanks Edward Cox and the Florida Poultry Federation, Incorporated, for their assistance in distributing the questionnaire. Appreciation is extended to the staff of the Suwannee River Water Management District for their assistance in providing water-quality data and well log descriptions for the study area.

METHODOLOGY

In the initial phase of the project, a questionnaire was prepared and mailed to broiler producers in the study area. In the second phase, 21 wells were drilled and water samples from 18 of these wells were analyzed. The methods used to prepare and distribute the questionnaire, select farms, construct wells, and collect and analyze the water samples are discussed in the following sections.

Questionnaire

At the time the project was initiated, little information was available about the practices of the broiler industry in north-central Florida. As many as three poultry companies were operating in the study area with each company contracting with individual producers to raise birds that were then processed by the company. Initial field observations indicated that the production procedures and litter-disposal practices of producers varied in relation to the contracting company. A questionnaire was developed to gain information that could be used to characterize litter-disposal practices of broiler farms in north-central Florida.

The questionnaire, a copy of which is provided in the appendix, was reviewed for content and clarity by two specialists who were knowledgeable about broiler production in north-central Florida. The questionnaires were assigned numbers to provide anonymity for the participants. In July 1991, 112 sealed packets were delivered to the offices of the Florida Poultry Federation, Incorporated (FPF). The FPF attached mailing labels and sent the packets to broiler producers in north-central Florida. The results from 32 broiler producers were compiled by the author.

Selection and Monitoring of Farms

Selection of the farms to be monitored was based on the information from the questionnaire and interviews with questionnaire respondents who indicated a willingness to participate in the monitoring program. With the assistance of the FPF, these respondents were asked to provide their names and telephone numbers. Thirteen broiler farms in the study area were visited and evaluated as possible sites. Of the 13 broiler farms, 5 were selected as monitoring sites (fig. 1). The criteria for selection were the broiler-production and waste-disposal characteristics of the farm, the hydrogeology of the area, and the willingness of the producers to cooperate.

The objective of the monitoring scheme was to locate wells near or in four areas where wastes were concentrated: chicken houses, stockpiles of litter, fields receiving litter, and dead-chicken pits. Both the chicken houses and the stockpiles represent the waste-storage portion of waste-disposal practices. The litter that accumulates in the chicken houses is not removed until the birds are taken to the processing plant. For this report, the four areas are designated as waste-disposal areas. Not all of the waste-disposal areas were monitored on each of the five farms.

Wells were placed near chicken houses that were relatively isolated from current or previous dead-chicken pits. These pits are often located in between the houses. The stockpiles selected for monitoring were in areas that had been used for stockpiling for several years. The size and presence of stockpiles vary as the litter is removed and new stockpiles are located to meet the producer needs.

Two types of fields were chosen for monitoring: fields that received either higher rates or frequent applications of litter, and fields that received lower rates of litter with occasional applications of fertilizer. The fields receiving high rates of litter are often called

Table 1. Description of monitor wells at five broiler farms in north-central Florida, 1991

[--, no data; and ft, feet]

Well number[1]	Well depth (feet below land surface)	Altitude of land surface (feet above sea level)	Altitude at top of limestone (feet above sea level)	Physical description of undifferentiated surficial deposits above limestone (thickness in feet)
1-1	87	74	--	Sand (40 ft), clayey sand (20 ft), sand (27 ft)
1-2	55	74	25	Sand (7 ft), clayey sand (4 ft), clay (8 ft), clayey sand (7 ft), clay (23 ft)
1-3	54	74	57	Sand (1 ft), clay (6 ft), clay with limestone stringers (10 ft)
1-4	50	73	52	Sand (4 ft), clayey sand (4 ft), clay (9 ft), clay with limestone stringers (4 ft)
2-1	37	62	27	Sand (35 ft)
2-2	45	62	23	Sand (39 ft)
2-3	35	63	40	Sand (21 ft), sandy clay (2 ft)
3-1	74	80	23	Sand (11 ft), clayey sand (7 ft), sandy clay (5 ft), clay (3 ft), clay with limestone fragments (31 ft)
3-2	63	79	41	Sand (8 ft), clayey sand (5 ft), sandy clay (10 ft), clay (8 ft), clay with limestone fragments (7 ft)
3-3	61	77	30	Sand (10 ft), clayey sand (14 ft), sandy clay (2 ft), clay (21 ft)
3-4	68	80	--	Sand (14 ft), clayey sand (3 ft), sand (36 ft), clay (7 ft), sandy clay (2 ft), clay (6 ft)
3-5	64	80	54	Sand (7 ft), sandy clay (3 ft), clay (7 ft), clay with limestone fragments (9 ft)
3-6	60	80	35	Sand (7 ft), clayey sand (2 ft), sandy clay (2 ft), clay (34 ft)
4-1	64	74	39	Sand (20 ft), clayey sand (5 ft), sandy clay (4 ft), clay (6 ft)
4-2	64	74	44	Sand (22 ft), clayey sand (3 ft), sand (3 ft), clay (2 ft)
4-3	65	75	35	Sand (18 ft), sandy clay (2 ft), clay with limestone stringers (6 ft), limestone (1 ft), void (8 ft), clay (5 ft)
5-1	80	94	34	Sand (1 ft), clay (13 ft), clay with limestone fragments (26 ft), limestone (2 ft), clay (18 ft)
5-2	72	92	27	Clayey sand (1 ft), clay (11 ft), clay with limestone fragments (31 ft), clay (4 ft), clay with limestone fragments (18 ft)
5-3	71	93	33	Sand (5 ft), clayey sand (29 ft), sandy clay (1 ft), clay (25 ft)
5-4	71	87	31	Sand (2 ft), clay (54 ft)
5-5	62	91	39	Sand (6 ft), clay (46 ft)

[1]The first number indicates the site; the second number indicates the well.

load-out fields and are generally located near the chicken houses. These fields are the most likely ones to receive most or all of the litter removed or 'loaded out' of the houses when producers have limited time between shipments of birds. One dead-chicken pit that was somewhat isolated from the houses was selected for monitoring. All of the farms had at least one current or previous dead-chicken pit near the houses.

Sites for monitoring wells were selected to define the ground-water quality upgradient and downgradient of the waste-disposal areas relative to the direction of regional flow of water in the Upper Floridan aquifer. Wells were placed upgradient of the waste-disposal areas to account for the effects of land uses outside the boundaries of the monitored farm because the broiler farms are often dispersed among other agricultural activities. Wells were placed downgradient of waste-disposal areas to account for any enrichment from the small areas occupied by the chicken houses, stockpiles, dead-chicken pits, and some of the load-out fields. These waste-disposal areas were frequently in close proximity to one another.

Well Construction

A total of 21 monitoring wells were constructed on 5 broiler farms in January 1992. Descriptions of these wells are provided in table 1. All of the monitored farms are located in areas where the Upper Floridan aquifer is unconfined (fig. 3). Nineteen wells were completed in limestone in the Upper Floridan aquifer. Wells tapping the Upper Floridan aquifer were drilled with hollow stem augers until the top of the limestone was reached (table 1). Air-rotary drilling was used to extend the boreholes into the limestone. Wells 1-1 and 3-4 were drilled to the top of the limestone; well 1-1 was screened in quartz sands and well 3-4 was screened in clay and sandy clay. Before setting well 3-4, drilling mud was added to the borehole in an attempt to stabilize the sidewall that had collapsed when the augers were withdrawn. Schedule 80 PVC threaded, 2-in diameter casing with a 10 ft section of PVC screen attached was placed in the borehole of each well. The annular space around the screen was packed with sand to a distance of approximately 1 ft above the top of the screen and was capped with 1 ft of hydrated bentonite pellets. The augers were then removed and the annular space between the bentonite and the land surface was filled with neat Portland Type I cement. All of the wells were developed by first surging with compressed air and then by pumping or bailing. Altitudes for the top of the well casing were surveyed to sea level (the National Geodetic Vertical Datum of 1929).

Sample Collection and Analysis

The wells were sampled during the weeks of March 30, July 13, and October 5, 1992 and the week of January 4, 1993. Before water samples were collected, a volume of water three times the volume of water standing in the casing was removed by either pumping or bailing. Water levels, and the specific conductance, pH, and temperature of water samples were measured in the field during sampling. The direction of regional flow was determined from the potentiometric-surface map of the Upper Floridan aquifer (Meadows, 1991).

Constituents in water samples collected from the monitor wells were analyzed using standard U.S. Geological Survey analytical methods (Fishman and Friedman, 1989). Samples were analyzed for the following dissolved ions: potassium, chloride, nitrite-plus-nitrate as nitrogen, nitrite as nitrogen, ammonium as nitrogen, and phosphorus. Samples were also analyzed for dissolved organic nitrogen and dissolved organic carbon. The nitrate concentration for each sample was calculated by subtracting the nitrite concentration from the nitrite-plus-nitrate concentration. When the nitrite concentration was less than the reporting limit of 0.01 mg/L, the nitrite-plus-nitrate concentration was used as the nitrate concentration.

Median concentrations were used in the discussion of the constituents on each farm. When the number of samples was even, the median was calculated as the average of the two central observations. When one of the two central observations was less than the reporting limit, that central observation was replaced with a value equal to one half the reporting limit before the median was calculated.

The effects of the waste-disposal practices on ground-water quality were ascertained by determining increases in concentrations of nitrates and other constituents along flow lines. A triangulation procedure was used to determine the direction of local ground-water flow from water-level altitudes for sites 1 and 3 (Heath, 1987, p. 11). Increases in concentrations were evaluated relative to the direction of local ground-water flow and relative to time. The increase in concentration relative to flow was calculated by subtracting the median concentrations of nitrates or other constituents in water samples for an upgradient well from median concentrations in water samples from a well downgradient of a each waste-disposal area that was monitored. Increases in concentrations with time were evaluated by comparing concentrations for successive sampling events at each well.

CHARACTERISTICS OF BROILER FARMS

The questionnaire results provided information about the characteristics of the production and waste-disposal practices of broiler producers in north-central Florida. This information was used to identify typical waste-disposal practices and to select broiler farms for monitoring that were representative of the poultry industry in the study area.

Questionnaire Results

The following information was derived from 32 respondents to the 112 questionnaires mailed to broiler producers in north-central Florida in July 1991.

Several of the questions asked general information about the respondents and their production practices (appendix). The respondents were producers who raised broilers or chickens that are removed from the farm between 6 and 7 weeks of age and processed for meat. The length of time that respondents had been producing broilers in the study area ranged from 1 to 25 years. Based on the number of years in production, the respondents divided into two distinct groups. Twenty respondents had between 1 and 10 years of experience and 12 respondents had between 19 and 25 years of experience. The length of production time indicates that many of the chicken houses in the area may have been in the same location for a long time.

Broiler production is likely to be part of a larger agricultural operation that raises other animals. Only 34 percent of the broiler producers raised chickens and no other animals. Fifty percent, or 16 respondents, maintained a cow-calf operation and 2 of those 16 respondents also raised pigs. Of the remaining five broiler producers, one had a dairy operation, two raised pigs, one raised goats, and one raised rabbits. The combination of chickens with other animals indicates that many of the farms may have more than one source of manure.

Table 2. Broiler production characteristics of five monitored broiler farms in north-central Florida, 1991

Site number	Exper-ience (years)	Number of chicken houses	Size of chicken houses (feet)	Number of birds per chicken house	Material beneath chicken house	Depth of sawdust (inches)
1	18	2	37 × 320	14,000	dirt	3
2	20	2	36 × 480	24,000	dirt	2
		2	36 × 320	19,500		
3	10	3	40 × 480	24,000	dirt	6
		2	30 × 320	15,000		
4	3	3	40 × 480	24,000	dirt	1.5
5	16	6	40 × 600	30,000	dirt	6

The number and size of chicken houses vary from farm to farm. The average number of houses for 32 broiler producers was 3.2 houses per farm with a range from 2 to 7 houses per farm. Generally, broiler producers mentioned three house sizes: 49 houses were listed as 36 ft by 320 ft with 15,000 birds per house; 29 houses were listed as 36 ft by 480 ft with 21,500 to 22,500 birds per house; and 38 houses were listed as 40 ft by 480 ft with 24,000 birds per house. The number of birds per square foot of house was 1.3 for broiler houses. Field observations in the study area indicated that the size of houses and numbers of birds per house may be increasing. New broiler houses and recently remodeled ones were observed to be 40 ft by 620 ft with 32,000 birds per house. Larger houses create larger volumes of litter for disposal.

All respondents used sawdust as the bedding material on the floors of the houses and 74 percent removed litter after every shipment of birds to the processing plant. The average depth of the sawdust applied to the floor of broiler houses by 30 respondents was 3.8 in. The median depth of sawdust was 4 in and the range was 1 to 8 in. An average depth of 2.2 in of litter was removed from the floor of broiler houses during each removal or load-out for 30 respondents. The median depth of litter removed was 2 in and the range was from 1 to 4 in. Two broiler producers indicated that they removed more litter than the depth of sawdust applied. Of the 32 broiler producers, 87 percent removed litter four or more times per year. Three broiler producers indicated that they removed litter 2 to 3 times per year and one removed litter only once every year. The material under the houses was described as dirt by 25 respondents, as dirt and clay by 6 respondents, and as clay by 1 respondent.

After removal from the houses, the litter was stockpiled or spread or both. Only one respondent listed stockpiling without spreading. Seventy-two percent, or 23 respondents, spread litter without stockpiling; of these, 18 respondents spread on their own land, 4 spread on other farms, and 1 spread on a combination of his own land and other farms. An average of 1.4 tons of litter was applied per acre and the range was from 0.03 to 6 tons per acre. The average number of times per year that litter from broiler houses was stockpiled was 3.9 times with a range from 1 to 6 times per year. The average length of time for the stockpiles was 6.5 weeks with a range from 2 to 16 weeks. In addition to spreading or stockpiling, eight broiler producers fed litter to cows.

Monitored Farms

The production and waste-disposal practices of the five broiler farms selected for monitoring sites (tables 2 and 3) were generally characteristic of the broiler industry in 1991 as described in the results of the questionnaire. Producers at sites 1 and 3 spread litter directly from the houses onto field. Producers at sites 2 and 5 use a combination of stockpiling and spreading. The producer at site 4 stockpiles the litter and sells it.

Table 3. Waste-disposal characteristics of five monitored broiler farms in north-central Florida, 1991

[--, not applicable]

Site number	Depth of litter removed (inches)	Stock-piling (number of times per year)	Stock-piling, length of time (weeks)	Spread-ing (number of times per year)	Spread-ing rate (tons per acre)
1	2	0	--	5	0.3
2	2	5	8	5	0.3
3	3	0	--	5	1
4	3	2	3	0	--
5	3	4	8	1	3

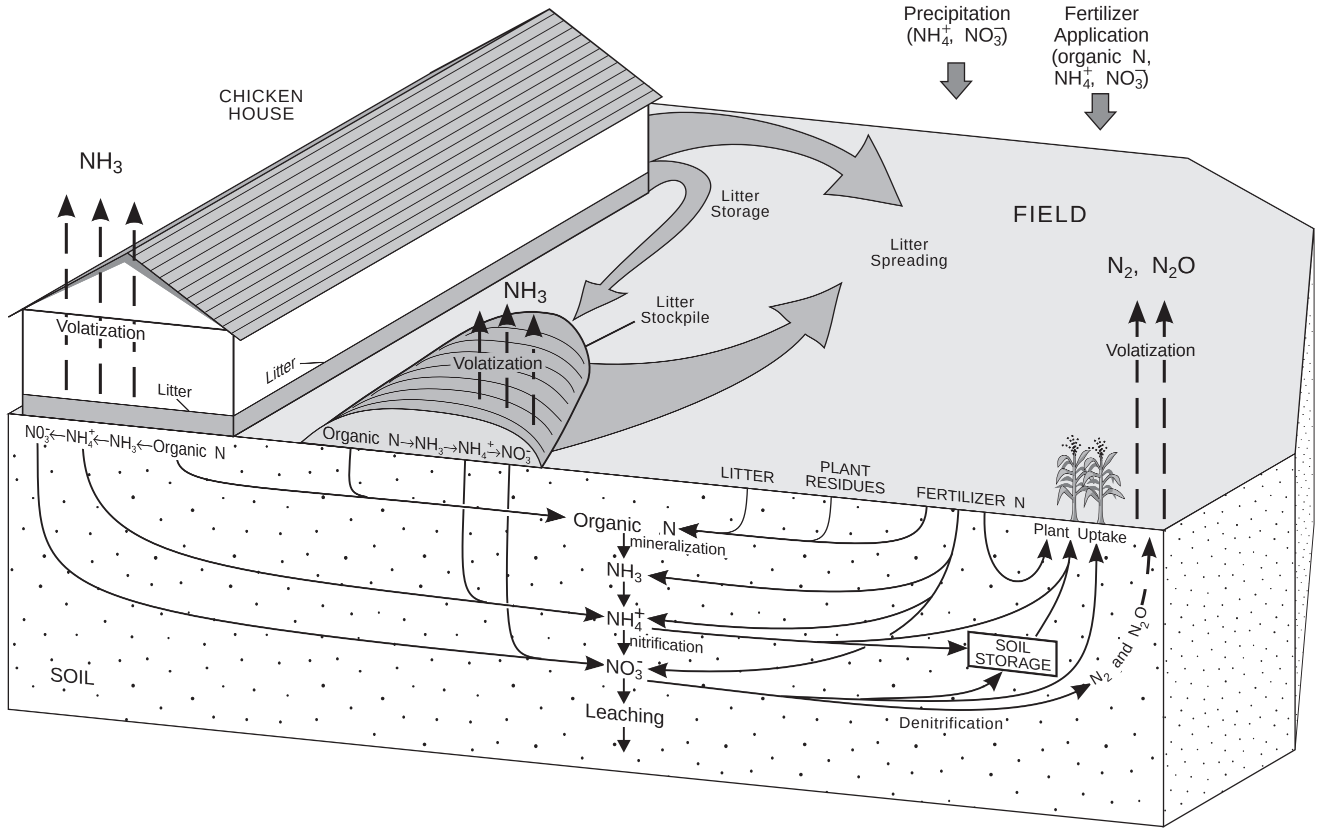

Figure 5. Schematic of nitrogen cycling associated with litter disposal on broiler farms.

In addition, the producer at site 2 feeds some of the litter to cows located on a second farm. The producer at site 5 maintains a small cow-calf operation at the same location as the chicken houses.

NITROGEN CYCLING ON BROILER FARMS

The nitrogen cycle provides a framework for understanding how waste disposal practices on broiler farms can affect the concentrations of nitrate in ground water. The nitrogen cycle describes the pathways and mechanisms of conversion from one chemical form of nitrogen to another. Because nitrogen has many forms and consequently many pathways, a detailed nitrogen cycle can be very complex. An example of a complex nitrogen cycle for livestock is provided by Hauck and Tanji (1982). For this report, the nitrogen cycle presented in figure 5 includes only the major nitrogen forms and pathways associated with litter disposal on the broiler farms. The chemical forms of nitrogen can be divided into two major groups, organic nitrogen and inorganic nitrogen. For this report, organic nitrogen is defined as all forms of nitrogen that are part of carbon-based (organic) compounds. Inorganic nitrogen consists of all other forms of nitrogen that are not organic. The chemical names and formulas of some of the organic and inorganic forms of nitrogen in figure 5 are listed in table 4.

Table 4. Forms of organic and inorganic nitrogen in the nitrogen cycle for a broiler farm

Chemical name	Chemical formula	Nitrogen group
amine	[1]$R - NH_2$	organic
urea	$CO(NH_2)_2$	organic
uric acid	$C_5H_4N_4O_3$	organic
ammonia	NH_3	inorganic
ammonium	NH_4^+	inorganic
nitrite	NO_2^-	inorganic
nitrate	NO_3^-	inorganic
molecular nitrogen	N_2	inorganic
nitrous oxide	N_2O	inorganic

[1]General formula in which R represents a carbon-hydrogen group with varying numbers of carbon atoms.

Nitrogen from Litter

Litter is the mixture of bedding material and manure that is formed on the floors of the chicken houses on broiler farms (fig. 5). Litter is generally a dry material with a consistency similar to commercial potting media. The litter is periodically removed from the houses, replaced by fresh bedding material, and either spread directly from the houses onto the fields by broadcasting or stockpiled on the land surface. Stockpiled litter is either sold for use off the farm or applied to the farm fields at a later time.

The primary source of nitrogen in the litter is the manure which has a typical nitrogen content of 4.5 percent by weight (Gilmour and others, 1987). The forms of nitrogen in poultry manure include urea, uric acid, and complex organic forms such as amines (table 4). The bedding material may also be a source of organic nitrogen derived from plants although the relative amount of nitrogen in the bedding material is low compared to the manure. Organic nitrogen in the litter is mineralized to ammonia by microorganisms. If water is not present in sufficient quantities, then the ammonia volatilizes into the atmosphere as a gas. If sufficient water is present, then the ammonia will dissolve to form ammonium.

Ammonium in soil can follow two different pathways (fig. 5). Along one pathway, ammonium is taken up by plants or stored in the soil and later released for plant uptake. The ammonium is converted to organic nitrogen inside the plants. When the plants die, the organic nitrogen in the plant residue is mineralized or converted to ammonia. Along a second pathway, ammonium is converted into nitrite by microorganisms that oxidize the ammonium to obtain energy. Nitrite is then oxidized by other microorganisms to form nitrate. This microbial conversion of ammonium to nitrite to nitrate is called nitrification. Mineralization and nitrification can also occur in the litter in the chicken houses or in stockpiles although the rate of occurrence is not known.

Nitrate in the soil can follow several pathways (fig. 5). Along one pathway, nitrate is stored in the soil or taken up by plants. This plant-uptake pathway is the same as the one described for ammonium. Along a second pathway, nitrate is denitrified. Denitrification is the microbial conversion of nitrate to gaseous forms of nitrogen such as molecular nitrogen and nitrous oxide (table 4). Under reducing conditions when molecular oxygen is limited or unavailable, certain microorganisms are able to use the oxygen in the nitrate ions. Depending on physical and chemical conditions present, all of the oxygen in the nitrate can be removed to produce molecular nitrogen or some of the oxygen can be removed to produce nitrous oxide. Both molecular nitrogen and nitrous oxide are gases that can volatilize into the atmosphere. Denitrification can occur in the litter in the chicken houses or in stockpiles but like nitrification, the rate of occurrence is not known.

A third pathway for nitrate is leaching. Leaching is a process in which materials in solution are removed from the soil by the percolation of water. Nitrate will most readily leach from soil when the nitrate concentrations are high and the volume of percolating water is large (Legg and Meisinger, 1982). If the direction of the percolating water is downward, nitrate will move with the water, out of the soil profile, and into the geologic formations beneath. Once the nitrate has passed through the soil profile, the rate of conversion of nitrate to other nitrogen forms decreases because nitrate is less likely to be taken up by plants or denitrified by microorganisms. Plant roots are concentrated in the upper layers of soil and are rarely present at depths below the soil profile. In addition, the populations of microorganisms that convert the various forms of nitrogen to other forms are much smaller in the geologic formations beneath the soil.

Waste disposal practices for litter can affect the amount of nitrate in ground water by affecting the amount of nitrogen in the cycle. The decomposition of the litter produces forms of nitrogen that enter the cycle. If plant uptake and loss to the atmosphere are nearly equal to the amount of nitrogen provided by the litter, then the amount of nitrate available for leaching is small. When large volumes of litter are present, the amount of nitrate available for leaching increases. If sufficient volumes of water are added, then nitrate is likely to leach out of the soil. As water that contains nitrate percolates through the geologic formations and recharges an aquifer, the concentrations of nitrate in the aquifer water will be increased and the water quality will be affected.

Nitrogen from Other Sources

Sources of nitrogen other than litter are present on most broiler farms (fig. 5). Nitrogen from fertilizer applied to fields can enter the nitrogen cycle. Nitrogen in the form of ammonium or nitrate in precipitation can also enter the cycle, although the amount of nitrogen added by precipitation is very small relative to the

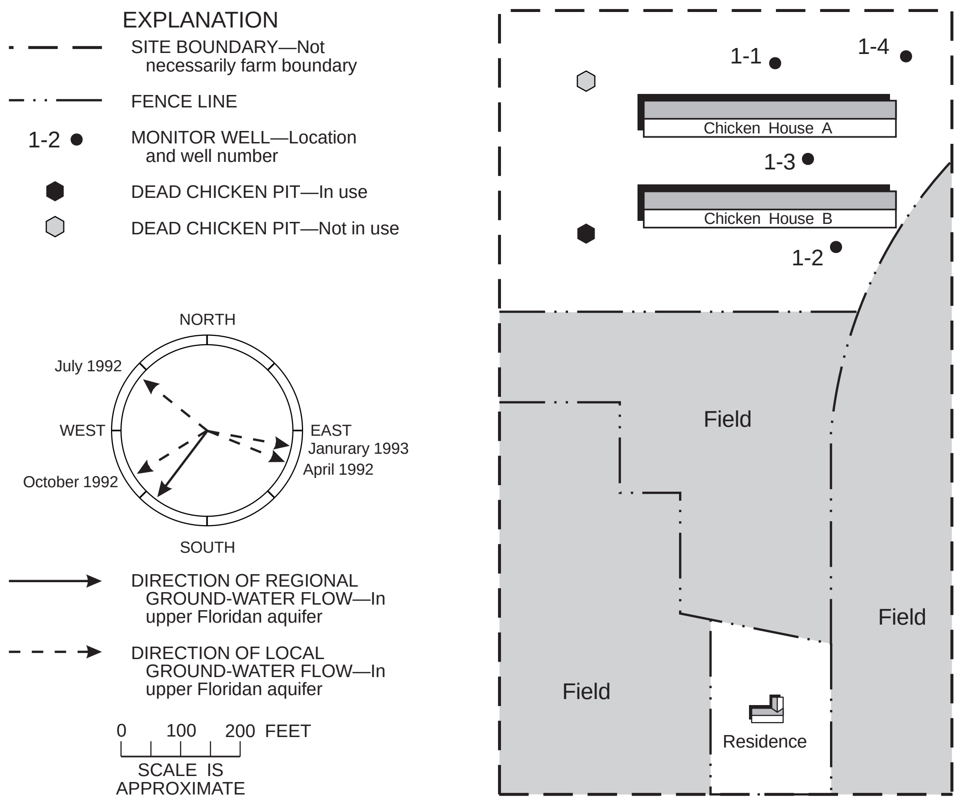

Figure 6. Locations of waste-disposal areas and monitor wells, and the direction of ground-water flow at site 1.

amounts added by fertilizer and litter. The nitrogen from these sources follows the same pathways described in previous paragraphs. If the concentration of any one of the nitrogen forms becomes too high and sufficient water is available, then that nitrogen form has the potential to be leached out of the soil.

A possible source of nitrogen not described in figure 5 is the nitrogen released during the decomposition of dead chickens. Field observations indicate that broiler farms in the study area usually dispose of dead chickens on the farm. The most common method appears to be placement of the dead chickens in a covered pit that is not lined with materials to prevent the downward leaching of nitrogen. The forms and amounts of nitrogen released during the decomposition of the dead chickens in the pits are unknown.

HYDROLOGIC AND CHEMICAL CONDITIONS

Variable hydrologic conditions at the sites complicated the evaluation of the effects of broiler waste-disposal practices on ground-water quality. These conditions included wells located in hydrochemical environments that were not characteristic of the sites and the uncertainty of the direction of ground-water flow in the Upper Floridan aquifer. Directions of flow and locations of wells for sites 1 through 5 are shown in figures 6 through 10, respectively, and water-level altitudes are provided in table 5.

Three of the 21 wells for the project were located in hydrochemical environments that were different from the environments of the other monitor wells. Water samples from well 1-1 at site 1 (fig. 6) were colored dark brown, contained suspended colloids, and had an odor of hydrogen sulfide. Well 3-4 at site 3 (fig. 8) was screened in gray-colored sediments and water samples from the well had higher concentrations of organic carbon than other wells at the site. The casing of well 5-4 at site 5 (fig. 10) was breached during installation and the well screen was partly filled with sand and other debris that contaminated the water samples. Data from these wells were not used in the evaluation of the effects of the waste-disposal practices on water quality, thus reducing the number of wells that were used to 18.

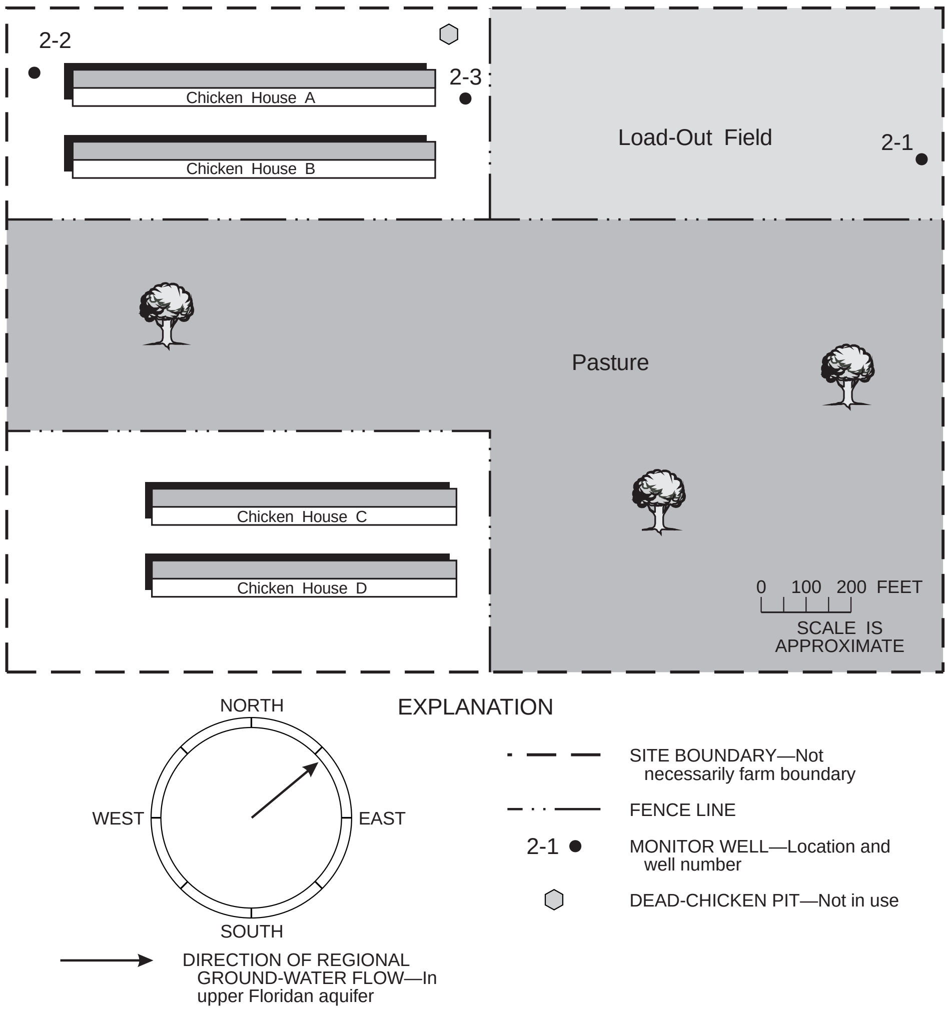

Figure 7. Locations of waste-disposal areas and monitor wells, and the direction of ground-water flow at site 2.

The uncertainty of direction of flow was related to differences between directions of regional and local flow. At site 1 (fig. 6), the direction of local flow changed with time as shown by azimuths. At site 3 (fig. 8), the direction of local flow was toward the southeast while the direction of regional flow was toward the southwest. These differences between the directions of local and regional flow may be related to the small number of wells used to determine the direction of local flow at each site as well as other factors, such as differences in the rate of local recharge to the aquifer, local topography, presence of nearby sinkholes, pumping from nearby water-supply wells, and possible exchanges of water between the Suwannee River and the Upper Floridan aquifer.

The differences between the directions of local and regional flow indicated that the direction of regional flow should not be used for sites where the direction of local flow could not be determined. At sites 2, 4, and 5, the direction of local flow was not calculated. Based on the well locations and the small differences in water-level altitudes among wells, the data were unsuitable for triangulation at site 2 (fig. 7) and site 4 (fig. 9). At site 5 (fig. 10), large changes in water-level altitudes (table 5) occurred in wells 5-3 and 5-4 that were located in the vicinity of the sinkholes in the pasture. These changes in water levels indicated that the sinkholes may be providing a hydraulic connection between the water in the part of the Upper Floridan aquifer near the land surface and the water in deeper parts of the aquifer.

At sites 2, 4, and 5, increases in median nitrate concentrations could not be estimated because the direction of local ground-water flow was unknown.

At sites 1 and 3, monitor wells placed upgradient or downgradient of waste-disposal areas relative to the *regional* flow were not aligned upgradient or downgradient of the waste-disposal areas relative to the direction of the *local* flow. Therefore, the differences between the directions of local and regional flow affected the estimates of increases in median concentrations of nitrate and other constituents by changing the emphasis of the monitoring scheme for each site. Because the increases in median concentrations were estimated by subtracting the median concentrations for upgradient wells from those for downgradient wells, the lack of alignment of wells in the direction of local flow may have resulted in a bias of the effects of the waste-disposal areas on ground-water quality.

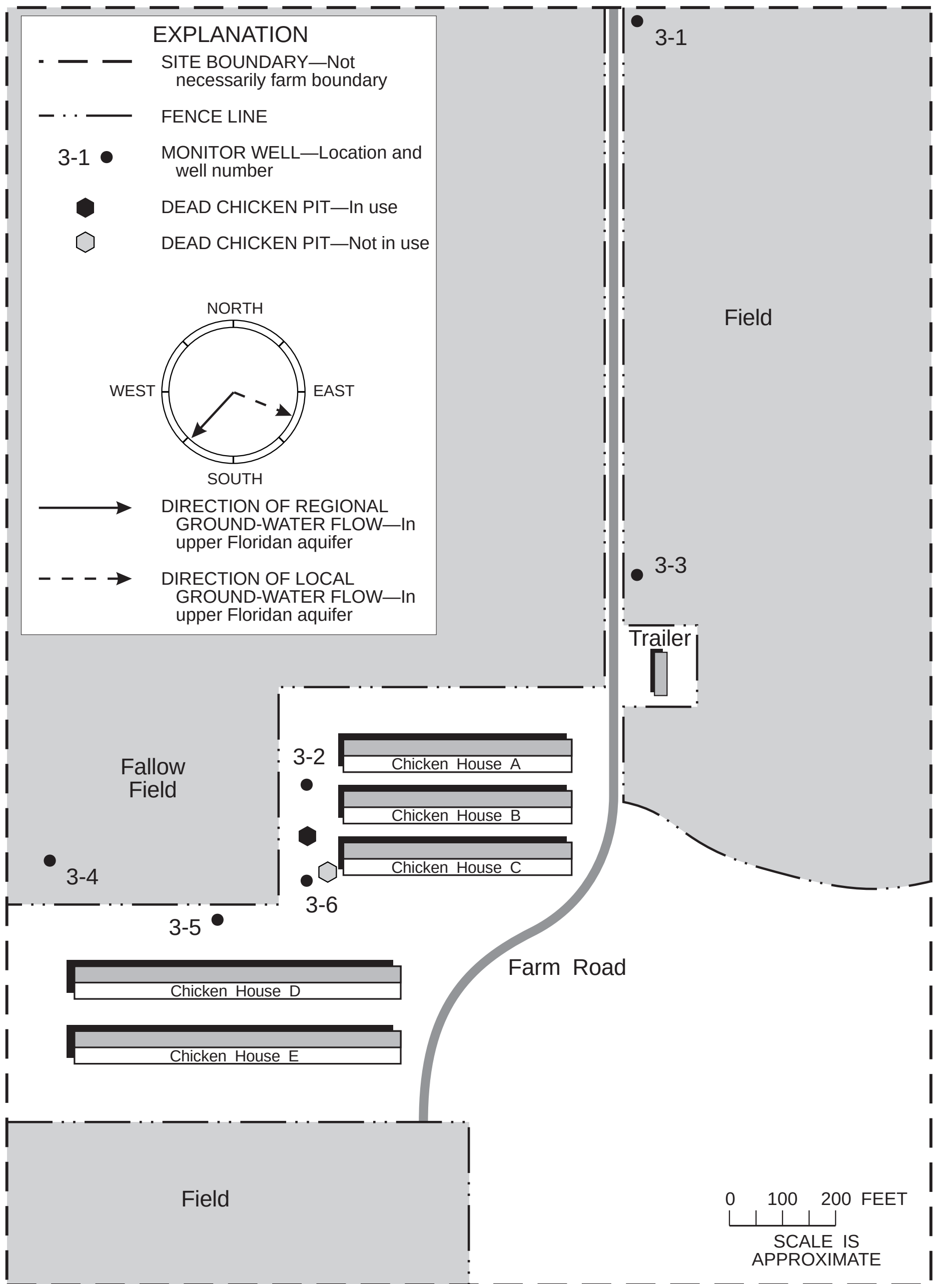

Figure 8. Locations of waste-disposal areas and monitor wells, and the direction of ground-water flow at site 3.

The differences between directions of local and regional flow also might have affected the detection of enrichment of nitrates and other constituents from off-site sources. Since increases in median nitrate concentrations could not be calculated at sites 2, 4, and 5, the median nitrate concentrations for water samples from wells in the vicinity of a specific waste-disposal area at these sites could include nitrate concentrations from sources other than the specific waste-disposal area. Possible sources of off-site nitrate concentrations in ground-water samples include crop fertilizers, animal manure, and septic tanks. Field observations and the results from the questionnaire indicated that broiler farms in the study area sometimes were involved in other agricultural activities and that they were generally located among farms with other types of agricultural production. Farms in Suwannee and Lafayette Counties in 1990 grew watermelons, sweet corn, potatoes, field corn, tobacco, wheat, soybeans, and hay (Richard Marella, U.S. Geological Survey, unpub. data, 1994). There were also 19 dairy farms in Suwannee County and 30 dairy farms in Lafayette in 1990 (Suwannee River Water Management District, unpub. data, 1989). In addition, septic tanks and small package plants were used for domestic waste disposal by 46 percent of the population of Suwannee County and 82 percent of the population of Lafayette County in 1990 (Marella, 1994).

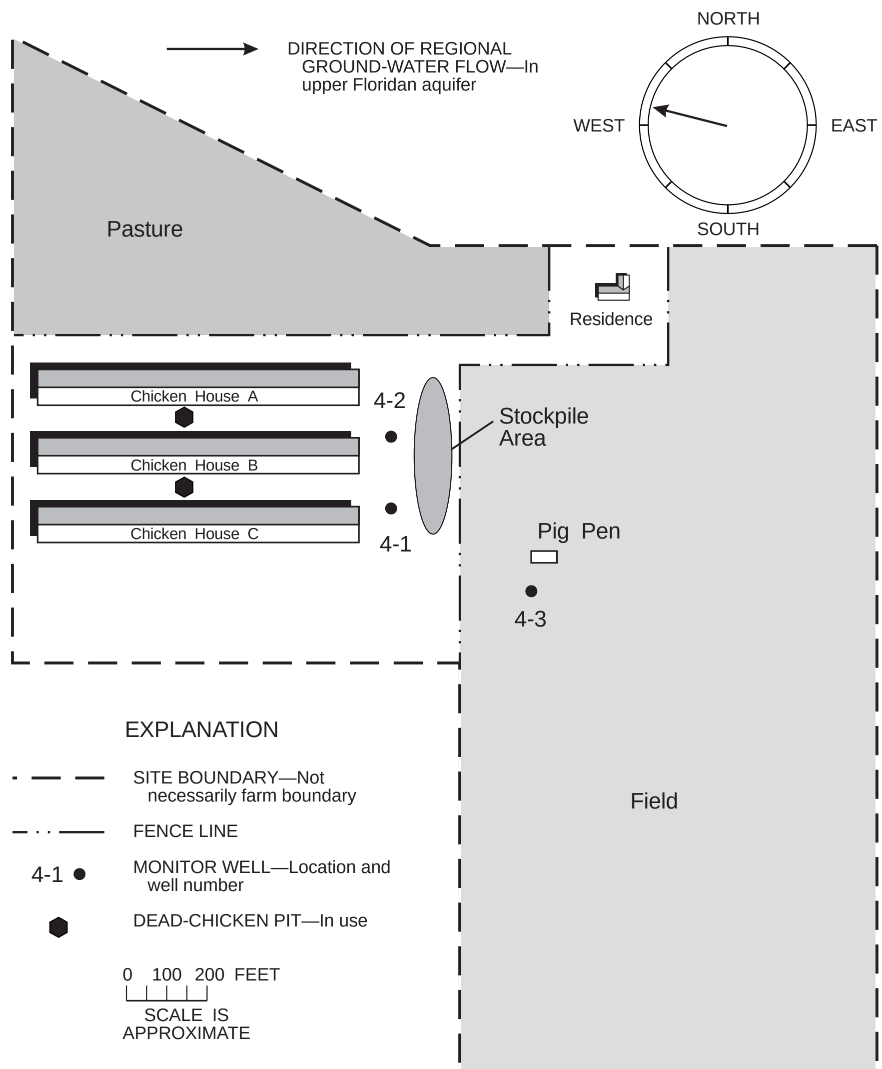

Figure 9. Locations of waste-disposal areas and monitor wells, and the direction of ground-water flow at site 4.

The uncertainty in the detection of nitrates and other constituents from off-site sources indicates that the effects of broiler waste-disposal practices can not be evaluated by subtracting the median historical concentrations of constituents in ground water from the median concentrations of constituents in ground water beneath the sites. The historical data provided by Katz (1992) (table 6) for north-central Florida were largely based on information from the Florida Ground Water Monitoring Network which was established to assess

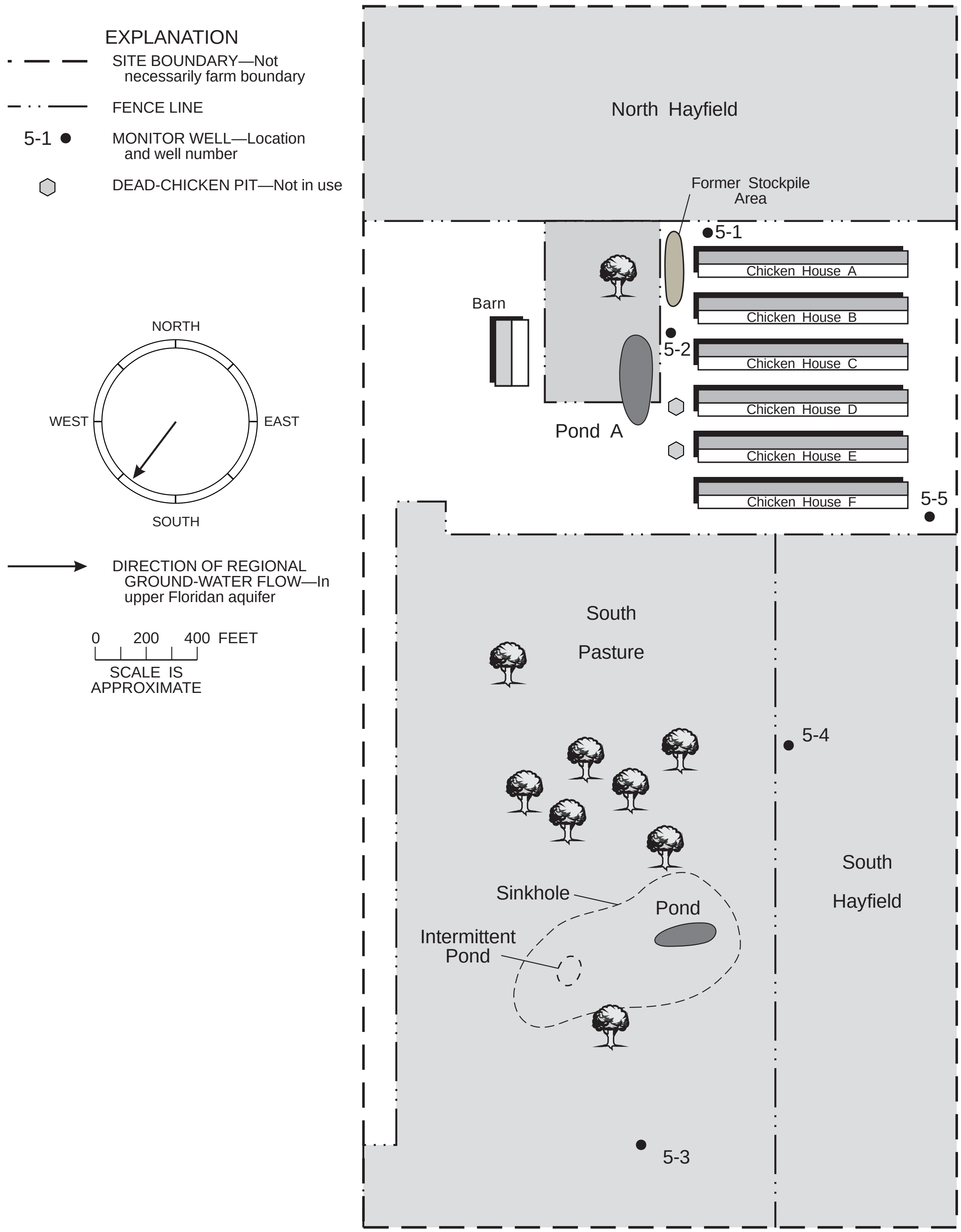

Figure 10. Locations of waste-disposal areas and monitor wells, and the direction of ground-water flow at site 5.

Table 5. Water-level altitudes at five broiler farms in north-central Florida, from March 1992 through January 1993

[Water-level altitude is in feet above sea level]

Well number[1]	Date of sampling	Water-level altitude	Well number[1]	Date of sampling	Water-level altitude	Well number[1]	Date of sampling	Water-level altitude
1-1	04-01-92	40.04	3-1	04-02-92	33.62	4-2	04-03-92	38.47
1-2	04-01-92	39.69	3-1	07-14-92	32.52	4-2	07-16-92	32.57
1-2	07-13-92	38.15	3-1	10-07-92	31.40	4-2	10-06-92	32.23
1-2	10-05-92	37.27	3-1	01-05-93	30.55	4-2	01-07-93	--
1-2	01-06-93	36.66	3-2	04-03-92	34.58	4-3	04-02-92	38.51
1-3	04-01-92	39.74	3-2	07-14-92	32.70	4-3	07-16-92	32.56
1-3	07-13-92	37.15	3-2	10-08-92	31.61	4-3	10-07-92	32.54
1-3	10-05-92	37.28	3-2	01-05-93	30.84	4-3	01-07-93	33.16
1-3	01-06-93	36.68	3-3	04-03-92	33.71	5-1	04-01-92	34.36
1-4	04-01-92	39.70	3-3	07-14-92	31.88	5-1	07-15-92	32.26
1-4	07-13-92	37.15	3-3	10-07-92	30.90	5-1	10-06-92	32.84
1-4	10-05-92	38.33	3-3	01-05-93	30.01	5-1	01-04-93	32.02
1-4	01-06-93	36.64	3-4	04-03-92	34.48	5-2	03-31-92	--
2-1	03-31-92	46.43	3-4	07-14-92	32.92	5-2	07-16-92	32.20
2-1	07-13-92	43.05	3-4	10-07-92	31.48	5-2	10-06-92	32.48
2-1	10-05-92	44.78	3-4	01-05-93	30.98	5-2	01-04-93	31.99
2-1	01-06-93	43.78	3-5	04-02-92	34.62	5-3	03-31-92	38.95
2-2	03-31-92	47.02	3-5	07-14-92	32.77	5-3	07-15-92	32.35
2-2	07-13-92	44.09	3-5	10-08-92	31.67	5-3	10-06-92	32.55
2-2	10-05-92	46.55	3-5	01-05-93	30.92	5-3	01-04-93	34.11
2-2	01-06-93	45.34	3-6	04-02-92	34.60	5-4	04-01-92	34.84
2-3	03-31-92	45.87	3-6	07-14-92	32.72	5-4	07-15-92	30.44
2-3	07-13-92	42.38	3-6	10-08-92	31.64	5-4	10-06-92	32.94
2-3	10-05-92	44.53	3-6	01-05-93	30.91	5-4	01-04-93	32.31
2-3	01-06-93	43.31	4-1	04-02-92	38.52	5-5	03-31-92	34.54
2-3	01-06-93	43.31	4-1	07-16-92	32.47	5-5	07-15-92	32.32
			4-1	10-07-92	32.38	5-5	10-06-92	32.62
			4-1	01-07-93	33.18	5-5	01-04-93	32.18

[1]The first number indicates the site; the second number indicates the well.

the regional water quality of the major aquifers in Florida. This historical data can be used as baseline data to evaluate the likelihood of enrichment of nitrates from off-site sources. However, use of this historical data for evaluation of increases in concentrations of nitrate and other constituents at specific sites is analogous to using the regional flow to represent local flow at the sites. Correctly placed upgradient wells are needed to detect possible effects from other land uses so that nitrate and other constituents added to ground water off-site are not included in the estimates of increases in concentrations of nitrates and other constituents attributed to waste-disposal areas on-site.

Table 6. Historical concentrations of chemical constituents in ground water in north-central Florida

[Modified from Katz, 1992, table 1, ground-water basin IV]

Chemical constituent	Number of observations	Median concentration (mg/L)	Minimum concentration (mg/L)	Maximum concentration (mg/L)
Nitrate, as nitrogen	174	0.01	0.0	3.4
Phosphorus	171	0.05	0.0	0.90
Potassium	182	0.5	0.06	66.0
Chloride	182	7.4	2.6	3,100

EFFECTS OF WASTE-DISPOSAL PRACTICES ON GROUND-WATER QUALITY

The effects of waste-disposal practices at broiler farms on ground-water quality were evaluated by determining whether concentrations of nitrate and other chemical constituents increased in ground water in the vicinity of waste-disposal areas at five sites.

Site 1

Site 1 is located in southwest Suwannee County, approximately 4 mi northeast of the Suwannee River (fig. 1). The waste-disposal areas of interest were two chicken houses that were approximately 15 years old (fig. 6). Each house contained 14,000 birds (table 2) for a period of 5 to 6 weeks. During the 2-to 3-

Table 7. Water-quality characteristics at site 1 and median concentrations of chemical constituents calculated by well number at site 1

[ft, feet; µS/cm, microsiemens per centimeter at 25 degree Celsius; °C, degrees Celsius; mg/L, milligrams per liter; <, less than; and --, no data. Median concentrations given in shaded areas]

Well number	Date of sampling	Specific conductance (µS/cm)	pH	Temperature (°×C)	Potassium (mg/L)	Chloride (mg/L)	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	Ammonium-nitrogen (mg/L)	Phosphorus (mg/L)	Organic nitrogen (mg/L)	Organic carbon (mg/L)
[1]1-1	04-01-92	110	6.7	23.5	1.0	3.0	0.1	0.03	0.03	0.15	0.31	1.2
1-2	04-01-92	470	7.3	23.0	1.5	5.4	18	<0.01	0.01	0.08	<0.20	0.7
1-2	07-13-92	468	7.1	23.5	1.8	4.7	19	<0.01	0.02	0.10	<0.20	1.4
1-2	10-05-92	448	7.3	23.0	1.6	4.6	20	<0.01	<0.01	0.10	<0.20	0.7
1-2	01-06-93	452	7.5	22.5	1.3	4.5	21	<0.01	0.01	0.08	<0.20	--
Median					1.6	4.7	19.5	<0.01	0.01	0.09	<0.20	0.7
1-3	04-01-92	493	7.2	23.0	0.7	4.9	9.4	<0.01	0.01	0.08	<0.20	0.6
1-3	07-13-92	535	6.9	23.0	0.7	4.3	10	<0.01	0.02	0.07	0.25	1.0
1-3	10-05-92	510	7.1	22.5	0.6	3.0	11	<0.01	<0.01	0.07	<0.20	0.9
1-3	01-06-93	500	7.4	22.5	0.6	4.0	26	<0.01	0.01	0.09	<0.20	--
Median					0.7	4.2	10.5	<0.01	0.01	0.08	<0.20	0.9
1-4	04-01-92	485	7.2	21.5	0.4	5.3	5.2	<0.01	0.02	0.10	<0.20	1.3
1-4	07-13-92	551	6.9	22.0	0.4	5.3	5.4	<0.01	0.01	0.16	0.23	1.4
1-4	10-05-92	542	7.0	22.0	0.4	5.5	5.0	<0.01	<0.01	0.11	<0.20	1.3
1-4	01-06-93	532	7.3	22.5	0.1	5.1	4.9	<0.01	0.02	0.10	0.21	--
Median					0.4	5.3	5.1	<0.01	0.02	0.10	<0.20	1.3

[1]Data for well not used in evaluation of waste-disposal practices.

week period when the houses were empty, litter was removed and spread on fields at the site without stockpiling.

The chicken houses were isolated from two dead-chicken pits located approximately 100 feet west of the houses (fig. 6). These pits were not selected for monitoring because of the conditions associated with each pit. The pit to the northwest of the chicken house A had not been used in more than five years and was empty. The pit to the southwest of chicken house B was in use but was located in a field that was occasionally fertilized with litter and planted in hay.

The changes in the direction of local flow (fig. 6) complicated the evaluation of increases in the median concentration of nitrate and other constituents at site 1 as a function of flow. Although the direction of local flow changed with time, well 1-4 was always upgradient of chicken houses A and B. The median nitrate concentration of water samples from well 1-4 (table 7) was 1.7 mg/L greater than the maximum historical concentration of nitrate (table 7) which indicates that water samples from well 1-4 may be enriched with nitrates from off-site sources. In addition, relative to the direction of local ground-water flow, chicken house A was upgradient of chicken house B in July 1992 but was downgradient in April and October 1992 and January 1993. Consequently, the nitrate concentrations in water samples taken in July 1992 were not used in the calculation of increases in the median nitrate concentrations.

Nitrate is the dominant form of nitrogen in ground water in the vicinity of the chicken houses at site 1 (table 7). Relative to well 1-4, the increase in the median nitrate concentration of ground water in well 1-3 in the vicinity of chicken house A was 5.4 mg/L (table 7 and fig. 6). Relative to well 1-3, the increase in the median nitrate concentration in ground water in the vicinity of chicken house B was 9.0 mg/L. The difference in the relative increase in nitrate concentration for the two chicken houses can be related to differences in the hydrogeology at the locations of the monitor wells (table 1), and differences in the production and waste-management practices in the houses. The difference in the relative increase may also be related to additions of nitrate concentrations from the southwest dead-chicken pit during periods when the direction of flow is toward the southeast (fig. 6).

Increases in nitrate concentrations with time were different for wells 1-2 and 1-3 (fig. 11). Nitrate concentrations in water samples from well 1-2 in the vicinity of chicken house B showed a gradual increase over the period of sampling. In contrast, nitrate concentrations

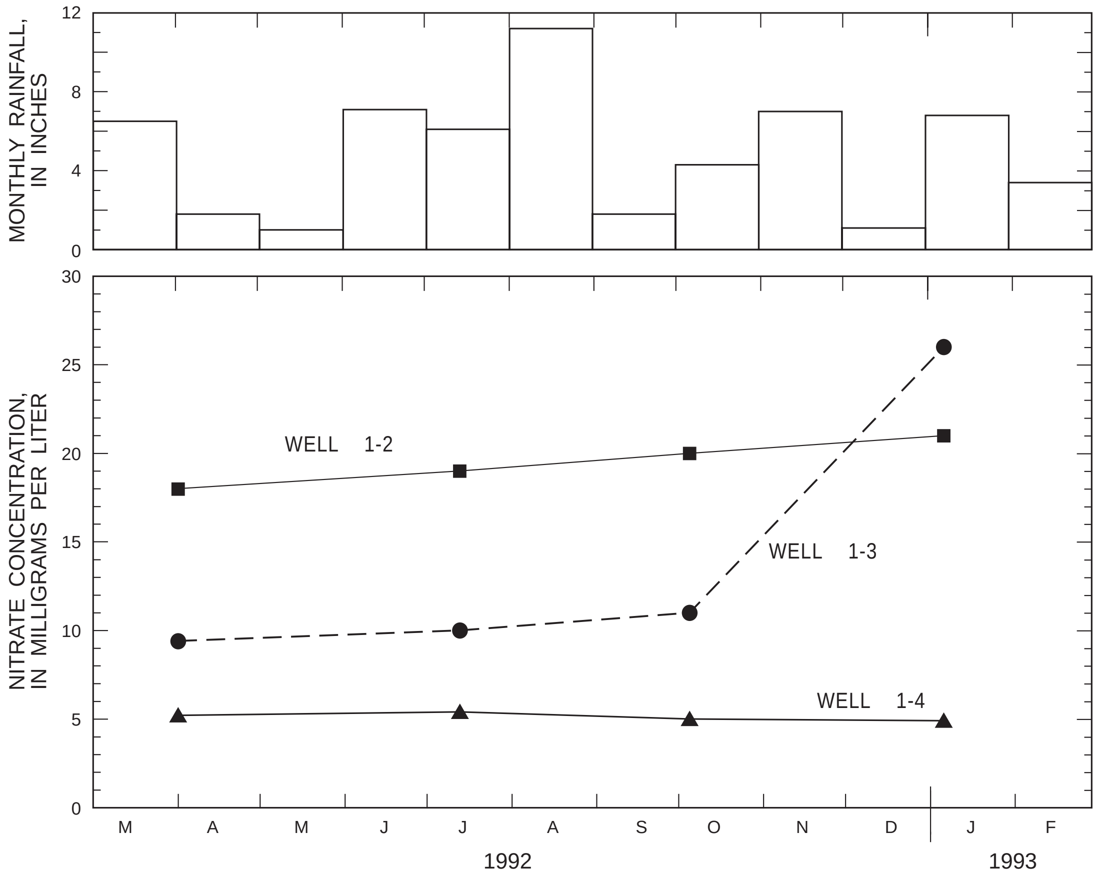

Figure 11. Changes in nitrate concentrations in water samples from wells 1-2, 1-3, and 1-4 at site 1, from March 1992 through January 1993, and monthly rainfall totals at Ellaville, Fla.

in water samples from well 1-3 in the vicinity of chicken house A increased sharply from the third to the fourth sampling event. Nitrate concentrations in water samples from well 1-4 remained uniform over the period of sampling. The pattern of gradual increase of nitrate concentrations with time for well 1-2 in the vicinity of chicken house B does not appear to be related to the pattern of monthly rainfall values (fig. 11) from Ellaville, Fla., which is approximately 17 mi to the northeast of site 1. The sharp increase in nitrate concentration for well 1-3 in the vicinity of chicken house A might be related to the potential increase in the amount of recharge water associated with the high rates of rainfall in August 1992 (fig. 11). The sharp increase might also be the result of an error in the nitrate concentration in the water sample from January 1993.

A strong positive correlation between the nitrate concentration and potassium concentrations (fig. 12) indicates that the chicken houses at site 1 could also be the source of increases in potassium in ground-water in vicinity of the houses. The water sample from well 1-3 taken in January 1993 and labeled A in figure 12 may have an error in the nitrate concentration since the nitrate concentration is about 15 mg/L higher than what might be expected from an examination of the graphs in figures 11 and 12. If point A is not included, the correlation between nitrate and potassium concentrations can be described by the regression equation shown in figure 12. The correlation coefficient, r, equals 0.95 which indicates a high degree of correlation between the nitrate and potassium concentrations. If the chicken houses are the source of the nitrate concentrations then the high correlation between nitrate and potassium concentrations implies that the chicken houses are also the source of the potassium at site 1.

The concentrations of phosphorus and chloride do not increase relative to either the nitrate concentrations or time at site 1 (table 7). The median phosphorus concentrations are slightly greater than the median historical concentration of 0.05 mg/L for phosphorus in north-central Florida and the median chloride concentrations are slightly below the historical median concentration of 7.4 mg/L (table 6).

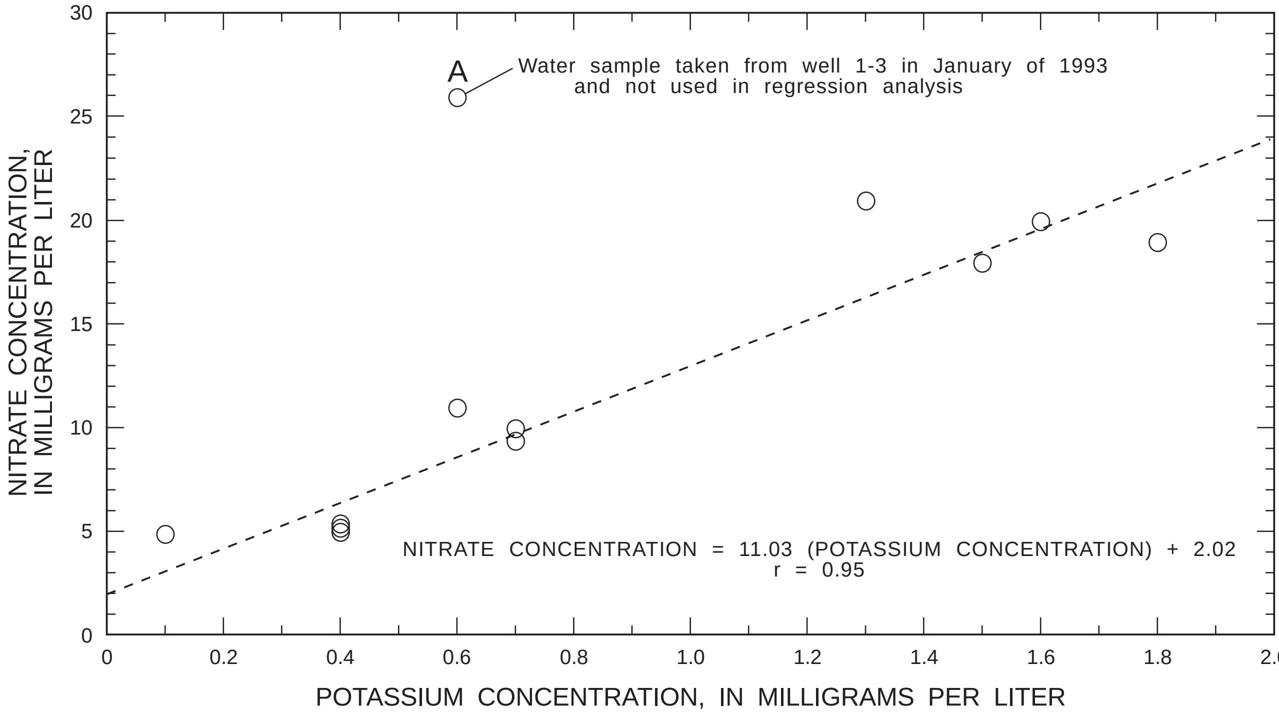

Figure 12. Potassium concentrations versus nitrate concentrations in water samples from wells 1-2, 1-3, and 1-4 at site 1.

Site 2

Site 2 is located in Lafayette County, approximately 2 1/2 mi southwest of the Suwannee River (fig. 1). The waste-disposal areas of interest at site 2 were a load-out field and four chicken houses (fig. 7). The load-out field is 4.6 acres and is generally planted with millet in the warm season and rye in the cool season. The producer did not remember applying any commercial fertilizer to the field during the 5 years before the monitoring wells were installed.

The farm has two sets of chicken houses that are approximately 500 ft apart (fig. 7). Chicken houses A and B were enlarged sometime after the original construction in 1978 and chicken houses C and D were built in 1972. Similar to chicken houses at site 1, the chicken houses at site 2 contained birds for five to six weeks and were empty between production cycles for approximately two to three weeks. When the houses were empty, litter was removed and spread on fields either at the site or on another farm. A dead-chicken pit that had not been used in five years is located northeast of chicken house A (fig. 7). No dead-chicken pits were in use at the site.

Nitrate is the dominant form of nitrogen in ground water in the vicinity of the chicken houses at site 2 (table 8). The median nitrate concentration of well 2-3 in the vicinity of the chicken houses was 45.5 mg/L (table 8). The median nitrate concentration in well 2-3 was not compared to an upgradient well for the site because the direction of local ground-water flow could not be determined. Therefore, the sources of the nitrate concentration for well 2-3 can include chicken houses and other land uses in the vicinity of the houses.

A gradual increase in nitrate concentrations with time for well 2-3 (fig. 13) did not appear to be related to rainfall or litter removal. If the increase in nitrate concentration with time were related to the downward percolation of water from rainfall, the increase would be expected to fluctuate in a way similar to the rainfall pattern in figure 13 because the downward percolation of rainwater can occur rapidly in the unconsolidated sands at site 2 (table 1). A fluctuation in nitrate might also be expected if the changes in nitrate concentration in time were related to the repeated accumulation and removal of litter in the houses. The cause of the gradual increase in nitrate concentrations for the chicken houses at site 2 cannot be determined without additional information or sampling. In contrast to the increase in nitrate concentrations, the concentrations of potassium, phosphorus, and chloride in well 2-3 (table 8) did not increase with time (table 8).

Table 8. Water-quality characteristics at site 2 and median concentrations of chemical constituents calculated by well number at site 2

[ft, feet; µS/cm, microsiemens per centimeter at 25 degree Celsius; °C, degrees Celsius; mg/L, milligrams per liter; <, less than; and --, no data. Median concentrations given in shaded areas]

Well number	Date of sampling	Specific conduct-ance (µS/cm)	pH	Tem-pera-ture (°C)	Potas-sium (mg/L)	Chloride (mg/L)	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	Ammo-nium-nitrogen (mg/L)	Phos-phorus (mg/L)	Organic nitrogen (mg/L)	Organic carbon (mg/L)
2-1	03-31-92	134	5.9	21.5	8.0	6.6	3.0	0.01	0.01	0.08	<0.20	3.1
2-1	07-13-92	343	6.2	21.5	15	17	18	<0.01	0.03	0.20	0.76	3.5
2-1	10-05-92	1,790	6.4	22.0	55	54	105	<0.01	<0.01	0.02	0.87	4.5
2-1	01-06-93	1,230	6.3	22.5	60	37	94	<0.01	0.02	0.03	0.69	---
Median					35	27	56	<0.01	0.02	0.06	0.73	3.5
2-2	03-31-92	238	7.3	23.0	1.7	3.7	<0.01	<0.01	0.04	0.05	<0.20	2.0
2-2	07-13-92	229	6.9	22.5	1.3	3.4	<0.01	<0.01	0.03	0.03	0.40	2.6
2-2	10-05-92	229	7.0	22.5	1.4	3.2	<0.01	<0.01	0.04	0.09	0.43	3.0
2-2	01-06-93	243	6.9	22.5	0.9	3.4	0.05	<0.01	0.04	0.03	<0.20	--
Median					1.4	3.4	<.01	<0.01	0.04	0.04	0.25	2.6
2-3	03-31-92	493	7.4	23.0	5.2	13	36	0.01	0.01	0.18	<0.20	0.9
2-3	07-13-92	510	7.5	23.5	5.4	15	42	<0.01	0.01	0.20	<0.20	2.0
2-3	10-05-92	551	7.6	23.0	4.8	12	49	<0.01	<0.01	0.15	<0.20	1.1
2-3	01-06-93	573	7.6	22.5	5.2	11	51	<0.01	0.01	0.14	<0.20	--
Median					5.2	12.5	45.5	<0.01	0.01	0.17	<0.20	1.1

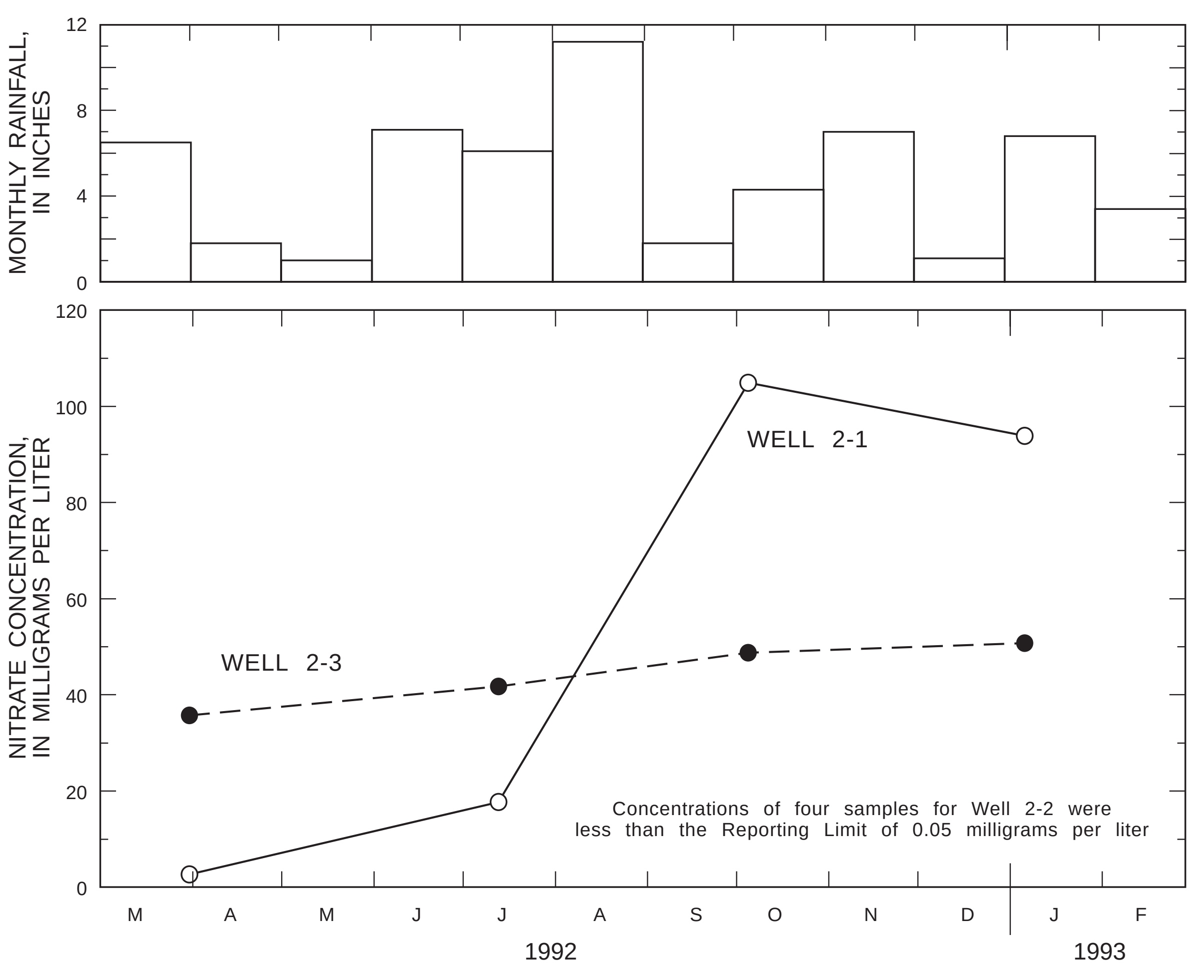

Figure 13. Changes in nitrate concentrations in water samples from wells 2-1, 2-2, and 2-3 at site 2, from March 1992 through January 1993, and monthly rainfall totals at Ellaville, Fla.

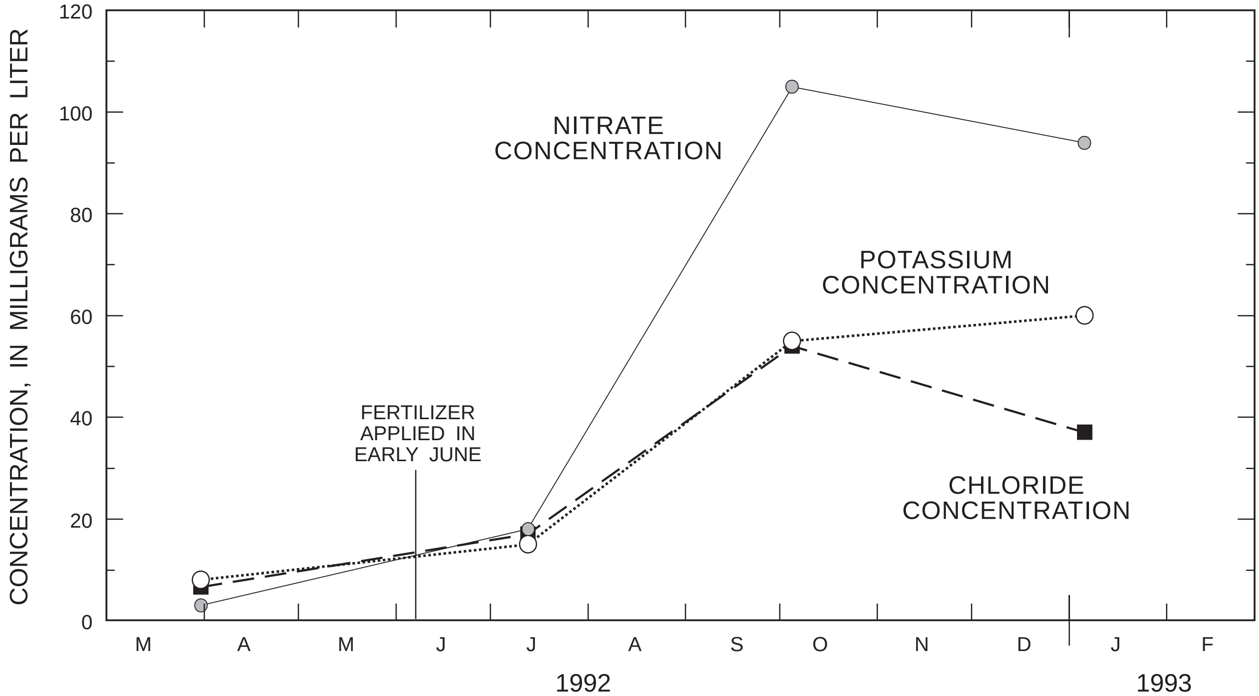

Figure 14. Changes in nitrate, potassium, and chloride concentrations for water samples from well 2-1 at site 2, from March 1992 through January 1993.

The nitrate concentrations in water samples from well 2-1 in the vicinity of the load-out field were affected by the application of commercial fertilizer to the load-out field during the monitoring period. In the first week in June 1992, the producer broadcast 1,820 lbs of fertilizer on the field at the rate of approximately 75 lbs of nitrogen, 8 lbs of phosphorus, and 63 lbs of potassium per acre. In the sample taken approximately one month after the fertilizer application, the nitrate concentration in well 2-1 had increased to from 3.0 mg/L to 18 mg/L (fig. 14). Approximately 4 months after the fertilizer application, the nitrate concentration for the well had increased to 105 mg/L and 7 months after, had decreased to 94 mg/L.

The large increase in nitrate concentration from 18 mg/L in July 1992 to 105 mg/L in October 1992 for well 2-1 in the vicinity of the load-out field may be related to downward percolation resulting from increased amounts of recharge water from rainfall. If the monthly rainfall at site 2 (fig. 13) was similar to that at Ellaville, Fla., which is about 25 miles north of site 2 (fig. 1), then the highest rainfall of the year occurred in August. Conversely, the decrease in nitrate concentration in water samples from January 1993 may be related either to lower rainfall amounts resulting in less downward percolation or the mixing of the earlier recharge water with the aquifer resulting in dilution, or both.

The sources of the nitrate concentrations in well 2-1 in the vicinity of the load-out field could have been fertilizer and partly decomposed litter. Concentrations of organic nitrogen and organic carbon were higher in the water samples taken after the field was fertilized (table 8). These increases in organic constituents indicate that the previously applied litter was decomposing. However, changes in potassium and chloride concentrations in well 2-1 followed the pattern of the nitrate concentrations with time (fig. 14). Both constituents would be expected to increase after the fertilizer application since both are common components of commercial fertilizers and, like nitrate, are not strongly retained by soil (Bohn and others, 1979). If the concentrations were high and if a sufficient volume of water were available for downward percolation, then potassium and chloride would leach from the soil profile. The effect of the unfertilized load-out field on increases in nitrate concentrations was not evaluated because an upgradient well was not available and only one water sample from well 2-1 in the vicinity of the load-out field was not affected by application of fertilizer. The nitrate concentration before the fertilizer was applied was 3.0 mg/L (table 8) for well 2-1 in March 1992.

Site 3

Site 3 is located in west-central Suwannee County, approximately 3 1/2 mi east of the Suwannee River (fig. 1). The waste-disposal areas of interest were a fallow field that received litter, and an isolated dead-chicken pit (fig. 8). The fallow field is 24 acres and was fallowed, or not planted, for two years prior to 1992. The fallow field received litter in early April 1992 and was planted with corn during the summer. Most of the land on the farm had not received commercial fertilizer in the previous 10 years.

The dead-chicken pit currently in use on site 3 is located about 100 ft west of chicken houses B and C in an area where monitor wells could be installed without interfering with normal farm operations (fig. 8). The pit is different from most of the pits observed in the study area in that the sides are constructed of concrete blocks. However, the pit is similar to others in that the floor was not lined during construction to prevent downward movement of soluble constituents. Two other dead-chicken pits that were abandoned were located close to the chicken houses (fig. 8). Chicken houses A, B, and C were 30 years old and chicken houses D and E were 4 years old in 1992.

Nitrate concentrations in water samples from well 3-1 could be enriched with off-site sources of nitrate. Relative to the direction of local ground-water flow, well 3-1 is upgradient of possible sources of nitrates from the farm. The median nitrate concentration of well 3-1 (table 9) is 9.6 mg/L greater than the maximum historical concentration (table 6).

Table 9. Water-quality characteristics at site 3 and median concentrations of chemical constituents calculated by well number at site 3

[ft, feet; µS/cm, microsiemens per centimeter at 25 degree Celsius; °C, degrees Celsius; mg/L, milligrams per liter; <, less than; and --, no data. Median concentrations given in shaded areas]

Well number	Date of sampling	Specific conductance (µS/cm)	pH	Temperature (°×C)	Potassium (mg/L)	Chloride (mg/L)	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	Ammonium-nitrogen (mg/L)	Phosphorus (mg/L)	Organic nitrogen (mg/L)	Organic carbon (mg/L)
3-1	04-02-92	281	8.2	22.5	0.6	7.6	13	<0.01	0.03	0.06	<0.20	1.1
3-1	07-14-92	302	7.4	22.5	0.7	7.5	6.7	<0.01	0.01	0.07	<0.20	1.2
3-1	10-07-92	317	7.6	22.5	1.2	8.6	12	<0.01	0.02	0.11	0.47	2.6
3-1	01-05-93	319	8.0	23.0	0.6	7.7	13	<0.01	0.02	0.08	0.33	--
Median					0.7	7.7	13	<0.01	0.02	0.08	0.22	1.2
3-2	04-03-92	257	7.7	21.5	0.5	6.6	14	<0.01	0.01	0.05	<0.20	1.1
3-2	07-14-92	303	7.5	23.5	0.5	7.3	14	<0.01	0.01	0.07	0.65	<0.1
3-2	10-08-92	286	7.9	22.5	0.7	6.7	13	<0.01	0.01	0.05	0.39	1.4
3-2	01-05-93	279	8.0	23.0	0.5	5.7	15	<0.01	0.01	0.04	<0.20	--
Median					0.5	6.7	14	<0.01	0.01	0.05	0.25	1.1
3-3	04-03-92	296	7.7	21.5	0.7	7.7	15	<0.01	0.01	0.05	<0.20	0.6
3-3	07-14-92	312	7.5	23.0	1.0	7.2	15	<0.01	0.04	0.12	1.40	6.0
3-3	10-07-92	312	7.5	22.5	1.0	7.3	15	<0.01	0.01	0.04	0.42	1.1
3-3	01-05-93	319	8.0	23.0	0.8	6.7	15	<0.01	0.01	0.05	<0.20	--
Median					0.9	7.3	15	<0.01	0.01	0.05	0.26	1.5
[1]3-4	04-03-92	200	6.1	--	2.3	3.6	<0.01	0.06	0.08	0.44	--	--
[1]3-4	07-14-92	408	6.6	21.5	5.8	6.4	0.09	0.04	0.21	0.47	<0.20	6.0
[1]3-4	10-07-92	418	6.6	22.5	7.3	5.7	0.02	0.06	0.29	--	0.41	15
[1]3-4	01-05-93	--	--	--	5.5	5.7	<0.01	--	0.09	0.26	0.33	--
Median					5.7	5.7	0.01	0.06	0.15	0.44	0.33	10.5
3-5	04-02-92	249	8.0	22.0	1.0	6.4	9.5	0.01	0.03	0.05	<0.20	2.5
3-5	07-14-92	285	7.7	22.0	0.5	6.8	15	<0.01	0.01	0.08	<0.20	0.8
3-5	10-08-92	293	7.9	22.5	1.0	6.8	13	<0.01	0.04	0.10	0.41	1.0
3-5	01-05-93	296	8.1	22.5	0.5	6.5	15	<0.01	0.01	0.03	<0.20	--
Median					0.8	6.7	14	<0.01	0.02	0.07	<0.02	1.0
3-6	04-02-92	284	7.8	22.5	0.5	6.2	15	0.01	0.01	0.07	<0.20	0.3
3-6	07-14-92	272	7.5	23.5	0.6	6.6	13	<0.01	0.02	0.09	<0.20	1.2
3-6	10-08-92	339	7.7	21.0	1.0	7.2	17	<0.01	0.02	0.11	0.51	1.6
3-6	01-05-93	333	8.0	--	0.5	6.2	20	<0.01	0.01	0.04	<0.20	--
Median					0.02	6.4	16	<0.01	0.02	0.08	<0.02	1.2

[1]Data for well not used in evaluation of waste-disposal practices.

Nitrate is the dominant form of nitrogen in ground water in the vicinity of the fallow field. Relative to well 3-1, the increase in nitrate concentration for well 3-3 downgradient to the fallow field is 2.0 mg/L (table 9). The median nitrate concentration in well 3-3 was higher than the concentrations in wells 3-2 and 3-5. This higher concentration was expected since ground water traversing the field along the direction of local flow would travel a longer distance from the western edge of the field to well 3-3 than to wells 3-2 and 3-5 (fig. 8). The longer travel distance would allow more nitrate to enter the aquifer with recharge water. However, the median concentrations of other chemical constituents such as potassium, phosphorus, and chloride showed only small differences among wells 3-1, 3-2, 3-5, and 3-3 (table 9).

The application of litter to the fallow field in early April 1992 and the subsequent planting of corn appeared to have little effect on the nitrate concentration of the ground water in the vicinity of the field (wells 3-2, 3-3, and 3-5 in fig. 15). The lack of increase in nitrate concentrations after litter application can be

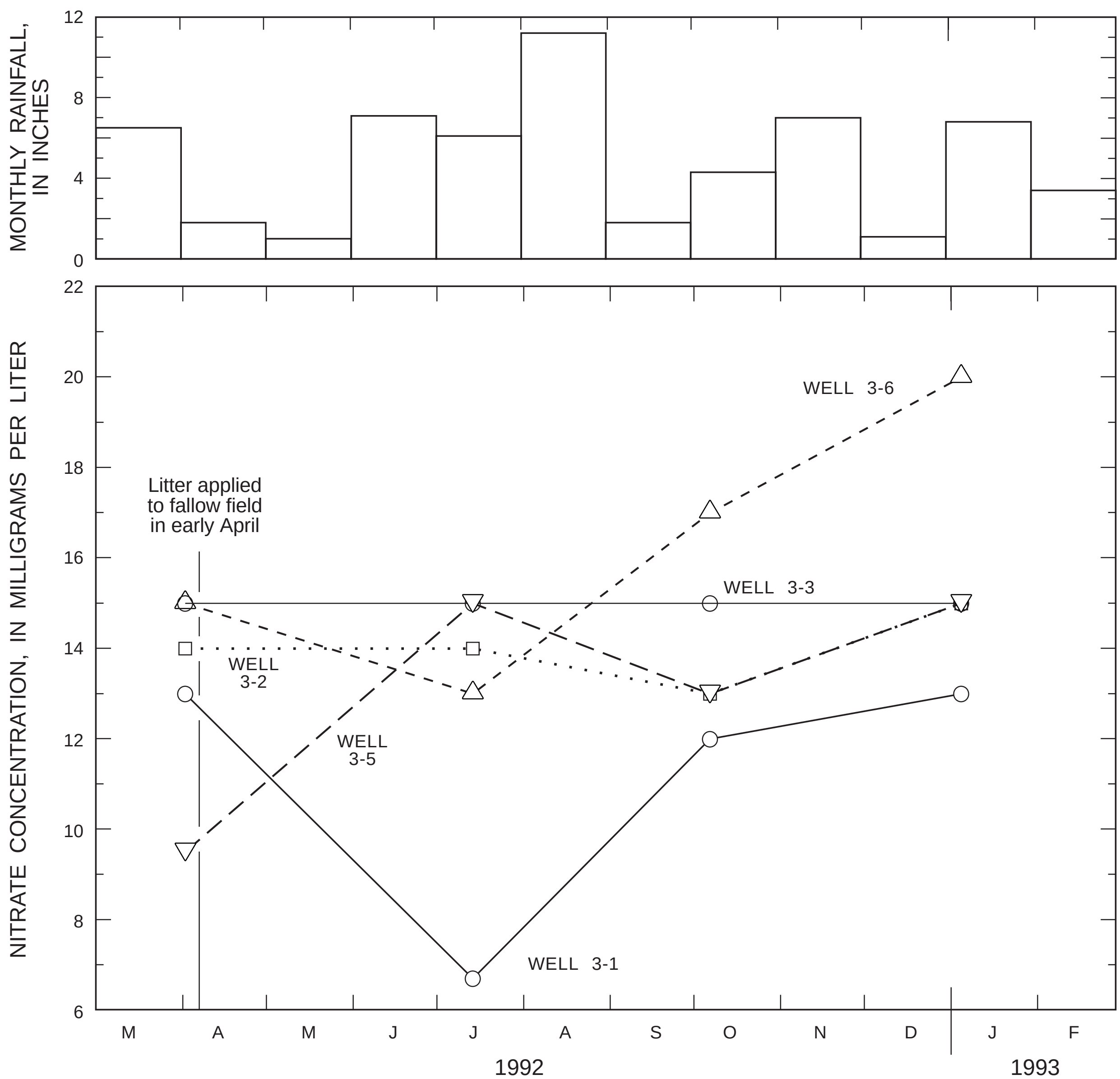

Figure 15. Changes in nitrate concentrations in water samples from wells 3-1, 3-2, 3-3, 3-5, and 3-6 at site 3, from March 1992 through January 1993, and monthly rainfall totals at Ellaville, Fla.

explained in several ways. Either nitrate from the litter was absorbed by the corn plants and did not leach from the fallow field, or the length of time for nitrate in the recharge water to reach the aquifer was longer than the sampling period of the project, or both. The length of time required for nitrate to percolate through the unconsolidated sediments to the ground water depends on several factors including the amount of rainfall (fig. 15) and the composition of the sediments.

Changes in the concentration of organic nitrogen in samples from wells 3-2, 3-3, and 3-5 after litter application may indicate that downward percolating water did recharge the aquifer in the vicinity of the fallow field during the sampling period of the project. At the time of litter application in April 1992, the median concentration of organic nitrogen in water samples from the three wells was below the reporting limit of 0.20 mg/L (table 9). Three months after the litter application, the median concentration had increased to 0.65 mg/L. After 6 months, the median concentration of samples from the 3 wells had decreased to 0.41 mg/L and after 9 months, the median concentration was once again below the reporting limit. The source of the organic nitrogen could have been the decomposition of the litter applied to the fallow field or it could have been related to the decomposition of soil organic matter that can occur during the preparation of the field for planting (Stevenson, 1982). The decrease in the organic-nitrogen concentration may have been related to the microbial decomposition of the organic nitrogen.

The organic-nitrogen concentration for well 3-1 was greater than the reporting limit of 0.20 mg/L in October 1992 and January 1993 (table 9). The source of the organic nitrogen could be the farming activities to the northeast of well 3-1 while the delayed increase in the organic-nitrogen concentration may be related to the length of time for off-site ground water to move into the vicinity of well 3-1.

Nitrate is the dominant form of nitrogen in ground water in the vicinity of the dead-chicken pit. The median nitrate concentration in well 3-6 downgradient to the pit increased by 2.0 mg/L compared to the concentrations in wells 3-2 and 3-5 which are located upgradient to the pit relative to the direction of local ground-water flow (table 9 and fig. 8). The nitrate concentration in water samples from well 3-6 increased with time for the sampling events in July and October 1992 and in January 1993 (fig. 15). This increase may have been related to the number of dead-chickens added to the pit and the amount of recharge water entering the aquifer. The concentrations of organic carbon in water samples from well 3-6 showed a small increase with time (table 9). The dead-chicken pit appeared to have little or no effect on the concentrations of the other constituents (table 9).

Site 4

Site 4 is located in west Suwannee County, approximately 1 mi east of the Suwannee River and 2 mi south of Ellaville, Fla. (fig. 1). The waste-disposal area of interest was a litter stockpile area (fig. 9). The stockpile area was approximately 2 years old in 1991 and is located east of three chicken houses that were 4 years old. The litter in the chicken houses at site 4 was loaded-out from 5 to 6 times per year and was usually stacked in the stockpile area. Since each load-out of litter was sold as soon as possible after stacking, the stockpiles of litter were intermittent. A stockpile was present from March 11 to 25, from May 15 to June 1, and from September 3 to 10 in 1992 (fig. 16). The litter from the load-outs of July 3 and November 14, 1992 was spread on a pasture located north of the chicken houses. In the previous years, the producer sold most of the litter and did not spread it on the farm.

Nitrate was the dominant form of nitrogen in wells 4-1 and 4-2 in the vicinity of the stockpile area. The median nitrate concentration in well 4-1 was 3.0 mg/L (table 10). The median nitrate concentration in well 4-2 was 1.4 mg/L and was calculated from three sampling events instead of four. Since the direction of local ground-water flow is not known for this site, the increases in the median concentration in wells 4-1 and 4-2 relative to an upgradient well were not calculated.

Nitrate concentrations increased with time for the three wells at site 4 (fig. 16). These increases with time could be related to nitrate enrichment from nearby land uses. Well 4-3 is in the vicinity of a small pig pen that may be contributing to the nitrate concentrations (fig. 9). Wells 4-1 and 4-2 are located between the stockpile area and the chicken houses (fig. 9). The increase in nitrate concentrations with time for wells 4-1 and 4-2 may be related to the presence or absence of litter stockpiles in the stockpile area and to the amount of rainfall. Of the three stockpiles present during the sampling period of the study, two occurred early in the sampling period and one occurred about midway through the sampling period (fig. 16). Monthly rainfall amounts at Ellaville, Fla.,which is about 3 mi north of site 4, were greater than 6 in. for the months of

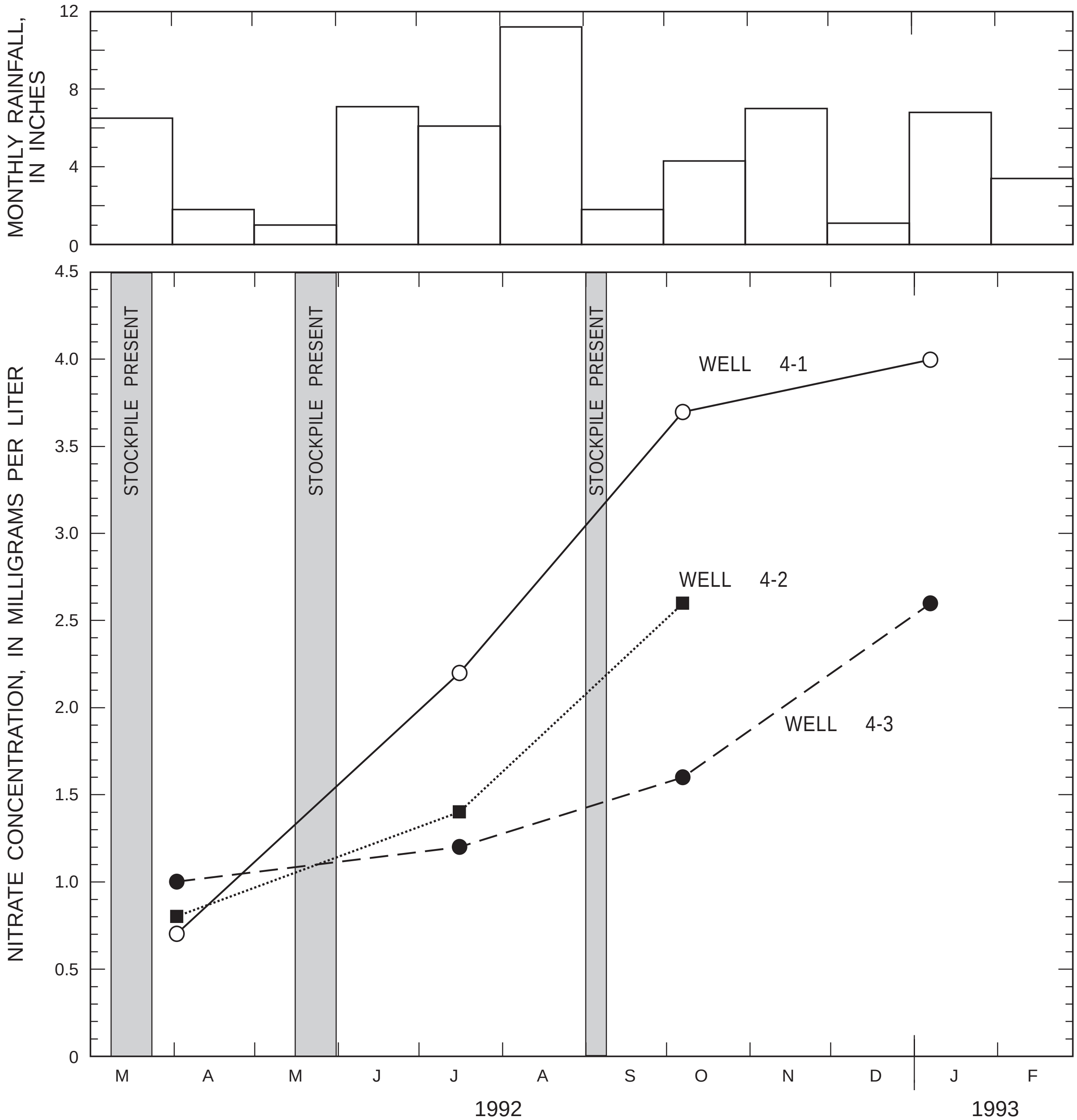

Figure 16. Changes in nitrate concentrations in water samples from wells 4-1, 4-2, and 4-3, from March 1992 through January 1993, time periods when stockpile was present at site 4, and monthly rainfall totals at Ellaville, Fla.

January, March, June, July, August, and November 1992, and January 1993 (fig. 16). Downward percolating rain water may have leached nitrate from the litter stockpiles out of the soil profile and increased the nitrate concentration in the ground water as the rainwater recharged the aquifer.

Increases in the organic-nitrogen concentration associated with increases in the nitrate concentration (table 10) appeared to be related to the presence of the stockpiles. Stockpiles were present in March, May, and September 1992 (fig. 16). Concentrations of organic nitrogen above the reporting limit of 0.02 mg/L were found in water samples taken from wells 4-1 and 4-2 in July 1992 (table 10). The concentration of organic nitrogen in the water sample taken from well 4-1 in October 1992 was above the reporting limit.

Concentrations of potassium, phosphorus, and chloride exhibited only small differences among the

Table 10. Water-quality characteristics at site 4 and median concentrations of chemical constituents calculated by well number at site 4

[ft, feet; µS/cm, microsiemens per centimeter at 25 degree Celsius; °C, degrees Celsius; mg/L, milligrams per liter; <, less than; and --, no data. Median concentration given in shaded areas]

Well number	Date of sampling	Specific conductance (µS/cm)	pH	Temperature (°×C)	Potassium (mg/L)	Chloride (mg/L)	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	Ammonium-nitrogen (mg/L)	Phosphorus (mg/L)	Organic nitrogen (mg/L)	Organic carbon (mg/L)
4-1	04-02-92	313	7.7	21.0	0.6	3.6	0.7	<0.01	0.02	0.05	<0.20	0.4
4-1	07-16-92	431	7.2	22.5	1.1	4.8	2.2	<0.01	0.06	0.05	0.75	1.6
4-1	10-07-92	462	7.2	22.5	1.3	5.0	3.7	<0.01	<0.01	0.08	0.22	1.9
4-1	01-07-93	459	7.3	22.5	0.9	5.0	4.0	<0.01	<0.01	<0.02	<0.20	--
Median					1.0	4.9	3.0	<0.01	0.01	0.05	<0.20	1.6
4-2	04-03-92	347	7.5	21.0	0.4	3.3	0.8	<0.01	0.01	0.04	<0.20	0.6
4-2	07-16-92	384	7.4	22.5	0.6	3.9	1.4	<0.01	0.01	0.04	0.20	0.6
4-2	10-06-92	426	7.3	21.5	0.7	4.2	2.6	<0.01	<0.01	0.04	<0.20	1.6
Median					0.6	3.9	1.4	<0.01	0.01	0.04	<0.20	0.6
4-3	04-02-92	418	7.7	21.5	0.5	3.9	1.0	<0.01	0.01	0.05	1.2	0.5
4-3	07-16-92	381	7.4	22.5	0.5	3.2	1.2	<0.01	0.01	0.03	<0.20	0.3
4-3	10-07-92	394	7.4	22.0	0.5	3.3	1.6	<0.01	<0.01	0.03	<0.20	1.9
4-3	01-07-93	381	7.4	22.5	0.1	2.8	2.6	<0.01	0.01	<0.02	<0.20	--
Median					0.5	3.3	1.4	<0.01	0.01	0.03	<0.20	0.5

three wells. The median concentrations of these constituents were similar to the median concentrations of these constituents for the historical data (table 10 and table 6).

Site 5

Site 5 is located in southwest Suwannee County, approximately 6 mi east of the Suwannee River (fig. 1). The broiler operation at site 5 is part of a 160-acre farm that also has pastures for a cow-calf operation and hayfields. There are six chicken houses on the farm (fig. 10). The waste-disposal areas of interest were the south hayfield and a former stockpile area for litter. The hayfield is adjacent to a pasture and is planted in permanent Bermuda grass that is over-seeded with oats in the cool season. Litter was applied to the 20-acre south hayfield at the approximate rate of 3 tons per acre in July and October 1992. Litter had been occasionally applied to the south pasture but not during the sampling period of the project. No commercial fertilizer was applied at site 5 during the period of sampling.

The former stockpile area is located west of chicken houses A and B (fig. 10). The area had contained litter stockpiles for several years prior to the installation of monitoring wells. The stockpiles on this farm are different than the stockpiles described in the questionnaire because the producer disposed of dead chickens by burying them in the piles. Prior to the start of this project, the use of the dead-chicken pits west of chicken houses C and D had been discontinued (fig. 10).

Nitrate was the dominant form of nitrogen in ground water in well 5-3 in the vicinity of the pasture and in well 5-4 in the vicinity of the south hayfield. The median nitrate concentration is 1.0 mg/L for well 5-3 and 2.1 mg/L for well 5-4 (table 11). Since the direction of local ground-water flow is not known for site 5, the increase in the median concentrations in wells 5-3 and 5-4 relative to an upgradient well could not be calculated.

The applications of litter to the south hayfield in July and October 1992 did not appear to increase the nitrate concentrations with time for well 5-4 (fig. 17). The lack of increase with time might be related to several factors. The nitrate mineralized from the litter spread on the field could have been absorbed by the plants and did not leach from the soil profile, or the amount of time required for downward percolating water to recharge the aquifer was longer than the sampling period of the project. The limestone at site 5 is overlain by a thick layer of clay (table 1) that may increase the time for downward movement of water compared to sites characterized by layers of coarser sediments such as sand.

Table 11. Water-quality characteristics at site 5 and median concentrations of chemical constituents calculated by well number at site 5

[ft, feet; µS/cm, microsiemens per centimeter at 25 degree Celsius; °C, degrees Celsius; mg/L, milligrams per liter; <, less than; and --, no data. Median concentrations given in shaded areas]

Well number	Date of sampling	Specific conductance (µS/cm)	pH	Temperature (°×C)	Potassium (mg/L)	Chloride (mg/L)	Nitrate-nitrogen (mg/L)	Nitrite-nitrogen (mg/L)	Ammonium-nitrogen (mg/L)	Phosphorus (mg/L)	Organic nitrogen (mg/L)	Organic carbon (mg/L)
5-1	04-01-92	345	7.5	22.0	0.4	4.7	1.1	<0.01	0.01	0.06	<0.20	1.7
5-1	07-15-92	382	7.4	22.0	0.3	5.2	1.1	<0.01	0.02	0.06	<0.20	0.3
5-1	10-06-92	369	7.3	22.5	0.4	5.0	1.6	<0.01	<0.01	0.04	<0.20	1.1
5-1	01-04-93	382	7.5	22.5	0.9	4.5	1.9	<0.01	0.02	0.08	0.26	--
Median					0.4	4.9	1.4	<0.01	0.02	0.06	<0.20	1.1
5-2	03-31-92	--	--	--	--	--	--	--	--	--	--	--
5-2	07-16-92	348	7.5	23.0	1.2	5.0	1.2	<0.01	0.04	0.15	0.40	2.1
5-2	10-06-92	359	7.4	21.5	2.3	5.0	1.5	0.05	0.04	0.15	0.66	11.0
5-2	01-04-93	376	7.7	22.5	3.5	4.5	1.7	0.01	0.04	0.04	<0.20	--
Median					2.3	5.0	1.5	0.01	0.04	0.15	0.40	6.7
5-3	03-31-92	363	7.2	22.0	0.5	7.1	1.0	<0.01	0.01	0.06	<0.20	1.8
5-3	07-15-92	363	7.3	22.0	0.5	4.8	1.0	<0.01	0.01	0.04	<0.20	<0.1
5-3	10-06-92	346	7.4	22.5	0.4	4.6	1.0	<0.01	<0.01	0.04	<0.20	1.0
5-3	01-04-93	358	7.6	23.0	0.4	4.1	1.1	<0.01	0.01	0.03	<0.20	--
Median					0.5	4.7	1.0	<0.01	0.01	0.04	<0.20	1.0
5-4	04-01-92	435	7.3	22.0	2.0	6.1	2.1	0.09	0.05	0.15	0.43	3.7
5-4	07-15-92	498	7.1	23.0	2.2	10.0	--	<0.01	0.02	0.09	<0.20	2.3
5-4	10-06-92	401	7.1	22.0	1.0	6.5	2.3	<0.01	<0.01	0.11	0.26	1.5
5-4	01-04-93	421	7.4	22.5	1.5	5.6	2.0	0.01	0.04	0.22	0.49	--
Median					1.8	6.3	2.1	<0.01	0.03	0.13	0.27	2.3
[1]5-5	03-31-92	299	8.4	22.0	2.3	4.7	0.8	0.01	0.03	0.23	0.27	26
[1]5-5	07-15-92	331	7.5	23.0	1.1	4.8	0.8	<0.01	0.04	0.27	0.49	19
[1]5-5	10-06-92	363	7.5	22.5	13.0	5.0	0.9	<0.01	0.05	0.40	1.2	55
[1]5-5	01-04-93	499	8.5	--	71.0	4.9	0.5	0.01	0.14	0.30	2.3	--
Median					7.7	4.9	0.8	<0.01	0.05	0.29	0.85	26
POND A	10-06-93	75	7.3	--	13.0	2.4	0.2	0.02	0.21	1.80	1.2	--

[1]Data for well not used in evaluation of waste-disposal practices.

The litter applied to the south hayfield in July and October 1992 may have increased the concentrations of the organic nitrogen and phosphorus with time in water samples from well 5-4. The organic-nitrogen concentration increased from below the reporting limit of 0.20 mg/L in July to 0.26 mg/L in October 1992 and to 0.49 mg/L in January 1993 (table 11). The phosphorus concentrations in water samples from well 5-4 followed the same pattern as that for organic nitrogen (table 11).

Nitrate is the dominant form of nitrogen in ground water in well 5-2 in the vicinity of the former stockpile. The median nitrate concentration in well 5-2 was 1.5 mg/L (table 11) and was similar to the median nitrate concentration of 1.4 mg/L in well 5-1. Well 5-1 is located between the north hayfield and the northern most chicken house. Increases in nitrate concentrations with time in well 5-2 were similar to the increases in well 5-1 (fig. 17).

Concentrations of constituents in well 5-2 may have been affected by intermittent pond A nearby the well (fig. 10). Pond A was located in a small topographic depression and the presence of water in it was noted in field observations made in October 1991. Pond A was dry during the sampling events in April and July 1992 and in January 1993 but it contained water and was sampled in October 1992. Concentrations of constituents in the pond-water sample and median concentrations of constituents in water samples from wells 5-1 and 5-2 were compared (table 11). Concentrations of ammonium, organic nitrogen, potassium, and phosphorus were highest in the pond, intermediate in well 5-2 and lowest in well 5-1. The intermediate concentrations of these constituents in well 5-2 may be the result of mixing of downward percolating water from the pond with ground water in the vicinity of well 5-2.

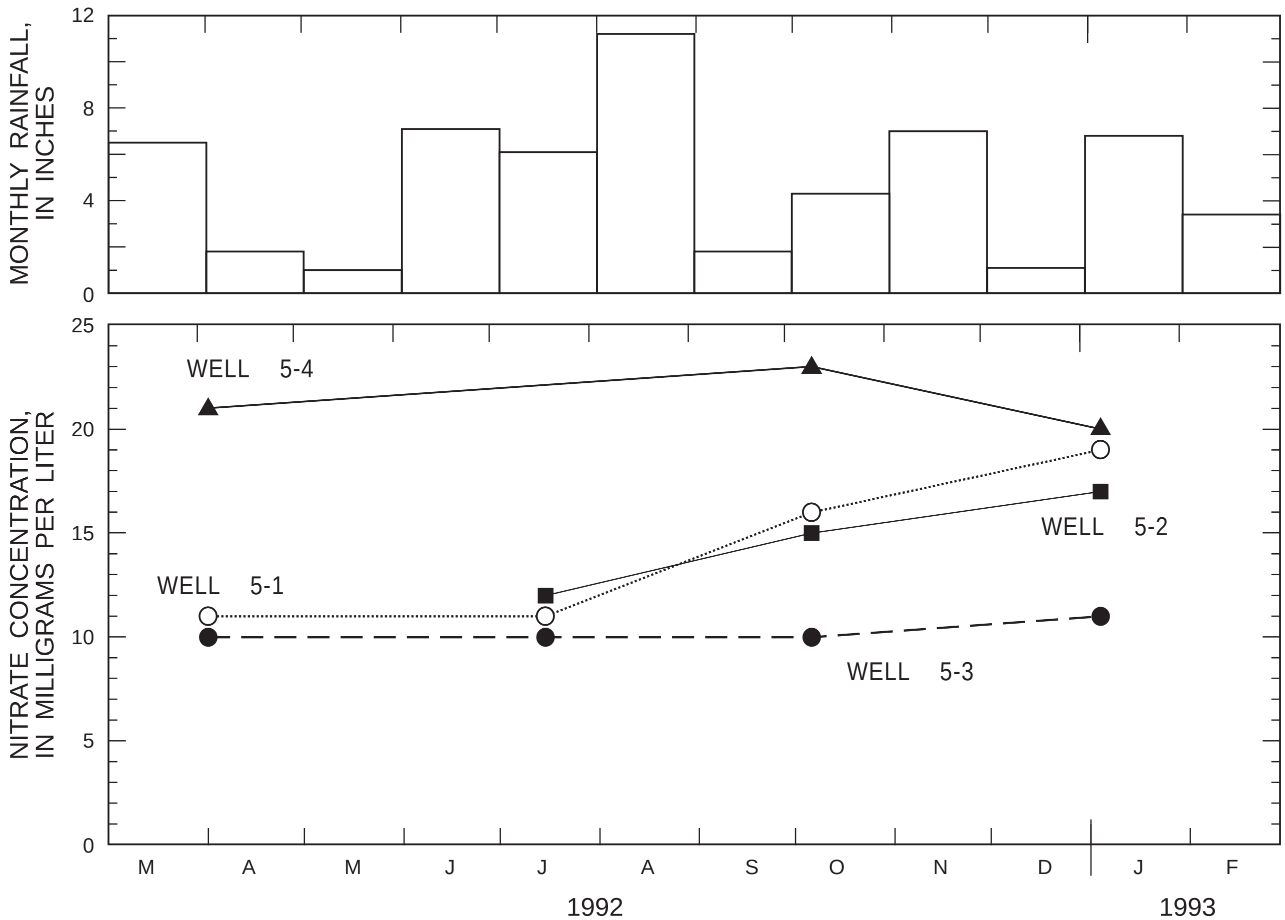

Figure 17. Changes in nitrate concentrations in water samples from wells 5-1, 5-2, 5-3, and 5-4 at site 5, from March 1992 through January 1993, and monthly rainfall totals at Ellaville, Fla.

SUMMARY AND CONCLUSIONS

A project was initiated in 1991 to determine if increases in concentrations of nitrate and other chemical constituents were occurring in ground water in the vicinity of broiler farms in north-central Florida and to relate any increases to specific waste-disposal practices used on broiler farms. The major source of broiler-farm waste is litter which is a mixture of bedding material and manure found on the floors of the chicken houses. Litter waste-disposal practices include storage of litter in chicken houses and in stockpiles, and application of litter to fields. A secondary source of waste is dead chickens that are usually placed in pits that have unlined floors. Decomposition of these wastes may release nitrate and other constituents that can move out of the soil profile with downward percolating water. If the percolating water recharges an aquifer, such as the Upper Floridan aquifer, then the quality of water in that aquifer can be affected by an increase in concentrations of nitrate and other constituents.

Four broiler farms in Suwannee County and one broiler farm in Lafayette County were selected as monitoring sites based on the results of a questionnaire mailed to broiler producers in the area. Monitoring wells drilled at the sites were sampled in March, July, and October 1992 and January 1993. Water samples from 18 wells were analyzed for the following dissolved constituents: potassium, chloride, nitrite-plus-nitrate as nitrogen, nitrite as nitrogen, ammonium as nitrogen, phosphorus, organic nitrogen, and organic carbon.

The uncertainty of the direction of ground-water flow in the Upper Floridan aquifer and the uncertainty about sources of nitrate concentrations in some of the monitoring wells complicated the evaluation of the effects of broiler waste-disposal practices on ground-water quality. The uncertainty in direction of ground-water flow was caused by differences between the direction of regional flow that was determined from potentiometric-surface maps and the direction of local flow that was determined from water-level altitudes in the monitoring wells. The uncertainty in the direction of flow contributed to the uncertainty about the sources of nitrate concentrations in some of the monitoring wells. At two sites where the direction of flow could be determined, increases in median nitrate concentrations associated with a specific waste-disposal area were calculated by subtracting the median nitrate concentration for a well upgradient of the area from a well downgradient relative to the direction of local ground-water flow. At three sites where the direction of local flow was not determined, increases in median nitrate concentrations for waste-disposal areas at these sites were not calculated. In addition, concentrations of nitrate and other constituents in ground-water in wells in the vicinity of some of the waste-disposal areas may have been enriched by land-use activities off-site. Broiler farms in the study area sometimes included other agricultural activities and were generally located among farms with other types of agricultural production.

Ground-water quality was monitored at four types of waste-disposal areas: chicken houses, litter stockpiles, fields receiving litter, and a dead-chicken pit. Nitrate was the constituent with the highest concentrations in water samples from the monitoring wells at all of the sites. Nitrate concentrations ranged from below the reporting limit of 0.05 mg/L through 105 mg/L. Nitrate was also the dominant form of nitrogen at all sites.

Older chicken houses affected the ground-water quality at one site and possibly at another. Older chicken houses represent an accumulation of production practices that may have changed over the years. Newer houses that were more likely to represent current practices were not monitored because dead-chicken pits are frequently located among the houses. At one site, two chicken houses that were approximately 15 years old in 1992 were monitored separately. Relative to the well upgradient of the waste-disposal areas, an increase of 5.4 mg/L in the median nitrate concentration was calculated for water samples taken from the well in the vicinity of one of the chicken houses. Relative to the well in the vicinity of the first chicken house, an increase of 9.0 mg/L in the nitrate concentration was calculated for water samples taken from the well in the vicinity of the second chicken house. Nitrate concentrations also increased with time in the vicinity of both chicken houses. At a second site, two chicken houses that were 14 years old in 1992 were monitored together. The median nitrate concentration for the well in the vicinity of the houses was 45.5 mg/L and the nitrate concentrations for the well increased with time. The source of the nitrate concentrations in the ground water in the vicinity of the chicken houses at this site can not be determined without additional hydrologic information.

Nitrate concentrations in water samples from wells in the vicinity of stockpile areas were generally lower than nitrate concentrations for wells in the vicinity of chicken houses. At one site, a stockpile area that was 2 years old received litter from three chicken houses 5 to 6 times per year. Because the litter was usually sold, the stockpiles were intermittent during the sampling period. The median nitrate concentration of water samples from a well in the vicinity of the stockpile area was 3.0 mg/L. Nitrate concentrations increased with time for all wells at the site, including a well that was not in the immediate vicinity of the waste-disposal areas. The cause of the increase of nitrate concentrations with time at the site was not known. Concentrations of constituents for a well at a second site with a stockpile area appeared to have been affected by an intermittent pond nearby.

Ground-water quality in the vicinity of fields receiving litter during the sampling period was affected more by the application of commercial fertilizer than the application of litter. Ground-water quality was monitored in the vicinity of three fields at separate sites: a load-out field that received an application of commercial fertilizer, a fallow field that received an application of litter, and a Bermuda grass hayfield that received two applications of litter. A load-out field is a field that often receives most or all of the litter removed, or loaded out, from the chicken houses. The nitrate concentration in the water sample from the well in the vicinity of the load-out field was 3.0 mg/L prior to application of commercial fertilizer at the rate of 75 lbs/acre of nitrogen. Approximately 4 months after the fertilizer application, the nitrate concentration for the well had increased to 105 mg/L and at 7 months after the application, the nitrate concentration had decreased to 94 mg/L. The fallow field was not planted for two years prior to the initiation of monitoring. Relative to a well located upgradient of the waste-disposal areas at the site, the largest increase in the median nitrate concentration for a well downgradient of the fallow field was 2.0 mg/L. The nitrate concentration in the downgradient wells for the fallow field did not increase with time after the application of litter and the subsequent planting of corn. The Bermuda grass hayfield was overseeded with oats during the cool season. The median nitrate concentration for water samples from the well in the vicinity of the hayfield was 2.1 mg/L. The nitrate concentration for the well did not increase with time during the sampling period. The sources of the nitrate concentrations in ground water in the vicinity hayfield can not be determined without additional hydrologic information.

The median nitrate concentration in ground water in the vicinity of a dead-chicken pit increased by 2.0 mg/L relative to two wells upgradient of the pit. The pit was constructed of concrete blocks set on an unlined floor. The nitrate concentration in water samples from the well downgradient to the dead-chicken pit increased during the latter part of the sampling period. The cause for the increase was not known.

Increases in concentrations of organic nitrogen in ground water may be related to the decomposition of litter and subsequent movement with downward percolating recharge water. Increases in organic nitrogen concentrations occurred in wells in the vicinity of the fallow field and the hayfield after litter applications. Increases in the organic-nitrogen concentrations for the wells in the vicinity of the stockpile area appeared to be related to the presence of the stockpiles.

The pattern of changes in concentrations of other constituents was similar to the pattern of changes in nitrate concentrations in a few instances. A strong positive correlation between concentrations of nitrate and potassium at one site indicated that the chicken houses may also be a source of potassium; however, no relationship between nitrate and potassium concentrations was found for the chicken houses at a second site. In addition, concentrations of potassium and chloride followed the pattern of changes for nitrate concentrations in a well in the vicinity of the load-out field that had received an application of commercial fertilizer.

The results of this study indicate that increases in the concentrations of nitrate and other constituents occurred in ground water in the vicinity of broiler farms. The disposal of litter and dead chickens is the likely source of the increases in nitrate concentrations in ground water. However, relating those increases to specific waste-disposal areas was limited by the number of wells and the sampling duration. An adequate number of correctly placed upgradient wells are needed to precisely monitor enrichment from both off-site land uses and on-site disposal areas. A longer sampling duration is needed to account for the intermittent nature of stockpiles, the application of litter to fields during growing seasons, and the potential lag time for downward percolating water to recharge the aquifer.

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APPENDIX

Broiler Production and Waste-Disposal Practices Questionnaire

POULTRY PRODUCTION SURVEY
(U.S. Geological Survey; Tallahassee, FL)

July, 1991 QUESTIONNAIRE NUMBER: _______________

Most of the questions in this survey are multiple choice or short answer. For multiple choice questions, please circle the letter(s) for all answers that best describe your farm operation. If you answer "other", please describe it briefly.

1. I have been producing poultry on this farm for ___________ years.

2. On my farm, I raise:
   a. broilers
   b. pullets
   c. hens

3. On my farm, I also keep:
   a. dairy cows
   b. cow/calf (beef)
   c. pigs
   d. other____
   e. I keep only chickens

4. I have ___________(number) chicken houses of size __________ feet by

   __________ feet each with ________________ birds per house.

5. I line the floors of my houses with:
   a. sawdust
   b. woodchips
   c. other____
   d. I don't line the floors

6. Directly below the litter (or manure) in my houses is a layer of:
   a. dirt
   b. clay
   c. concrete
   d. other____

7. The average depth of sawdust (or other floor material) in my houses

   is about ____________ inches.

more on reverse side

8. When I remove litter (or manure) from my houses, I remove a layer about _____________ inches deep.

9. I remove the litter (or manure) from the house floors:
   a. after every shipment of chickens
   b. more than 5 times per year
   c. 4-5 times per year
   d. 2-3 times per year
   e. once per year
   f. other____

10. When I remove litter (or manure) from my houses, I:
   a. spread it directly on my own fields
   b. spread it directly on someone else's fields
   c. sometimes have to stock pile it
   d. usually have to stock pile it
   e. feed it to cows
   f. other____
   g. feed it back to the chickens

<u>If you spread litter (or manure)</u>, please answer the following question:

11. I spread litter or manure about ____________ times per year. I apply about ____________ tons to ___________ acres at one time.

<u>If you stock pile litter (or manure)</u>, please answer the following question:

12. I stock pile about ___________ tons of litter (or manure) ___________ times per year for about ____________ weeks at a time.

13. Would you be interested in the establishment of a waste disposal system (that would include composting) with federal cost sharing through the ASCS?
   a. yes   b. no   c. maybe

14. Would you be interested in participating in a voluntary water-quality monitoring program in which the cost of installing and sampling wells is paid by the U.S. Geological Survey?
   a. yes   b. no   c. maybe

15. Please mark the location of your farm with an 'x' on the map of the three-county area. (The reason for this request is to obtain an accurate map of farm locations that can be compared to other maps. The purpose of comparing maps is to look for general trends and patterns.)