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GROUND WATER NITRATE-N CONCENTRATIONS ON AN EASTERN COASTAL PLAINS WATERSHED

by

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Summary: Nonpoint source pollution from agriculture has been a major concern, particularly where intensive agricultural operations exist near environmentally sensitive waters. To address these nonpoint source pollution concerns, a Water Quality Demonstration Project (WQDP) was initiated on the Herrings Marsh Run (HMR) watershed in Duplin County, NC. In the WQDP, 84 ground water monitoring well sites were established on 21 farms selected to represent the major farming practices on the watershed. On the HMR watershed, nitrate-N contamination of ground water was not a widespread problem. Seventy-four percent of the ground water monitoring sites had nitrate-N less than the drinking water standard of 10 mg/L. Mean nitrate-N concentrations were below 10 mg/L on all but four farms.

Keywords: Water quality, Nitrate-N, Ground water

INTRODUCTION

Contamination of ground water by agricultural chemicals is a major concern in the eastern Coastal Plain as well as throughout the USA. Nitrate contamination is a particular concern for both health and environmental quality. Ground water is the major source of drinking water for more than 90% of rural households and 75% of cities in the USA (Goodrich et al., 1991). Nitrate may cause methemoglobinemia (blue baby syndrome) in infants (Federal Register, 1985) when it is above the maximum contaminate level (MCL) of 10 mg/L (U. S. EPA, 1992). Additionally, nitrate interaction with other dietary substances may cause health problems in humans (Madison and Brunett, 1985).

The Environmental Protection Agency (U. S. EPA, 1990) found that nitrate-N was the most common contaminant detected in rural wells and community water supplies (57 and 52%, respectively), with 2.4 and 1.2%, respectively, of these wells exceeding the MCL of 10 mg/L. Later, Spalding and Exner (1993) compiled a review on the occurrence of nitrate ground water in the USA. They found elevated ground water nitrate concentrations in areas where soils were well-drained and irrigation was necessary for crop growth. Most of these areas were west of the Missouri River. Spalding and Exner (1993) also found that ground water in highly agricultural areas in the southeastern USA was generally not contaminated. Vegetative uptake and denitrification in warm, wet, carbon-rich soils were the factors they found responsible for the natural remediation of nitrate in shallow ground water. This finding was similar to those of Gilliam (1991), who concluded that properly fertilized fields in the eastern Coastal Plain did not have a problem with nitrate contamination of ground water. However, he reported ground water contamination was more likely when nitrogen was applied above recommended rates.

Nitrogen may be lost to the environment when applied in excess of the crop's ability to use in a harvestable product. Many fields in the eastern Coastal Plain are multi-cropped, which require several applications of various pesticides and nutrients. Nitrate leaching to ground water is a potential problem because of high rainfall, sandy textures, and low soil organic matter levels. Adoption of improved management practices can help reduce the potential of these chemicals being lost to the environment. Nitrate leaching is also a concern because of the large amounts of swine and poultry waste being produced in the eastern Coastal Plain.

Since 1988, the swine population in North Carolina has risen from approximately two million to more than eight million (USDA-NASS, 1995). Operation size is also a concern with 86% of the swine population produced on farms with greater than two thousand head (USDA-NASS, 1995). This rapid expansion of the swine industry and use of industrial methods for production has led to environmental concerns. In addition to swine, poultry is extensively produced in the eastern Coastal Plain. Approximately 80 million turkeys and chickens are produced annually in North Carolina alone (USDA-NASS, 1995). Production of waste from these sites is often greater than nutrient demand by local crops. Barker and Zublena (1995) reported that several counties in North Carolina produced more nitrogen in plant-available nutrients from animal manure than needed by non-legume agronomic and forage crops. Together, intensive crop and animal production poses a great contamination potential if adequate nutrient management practices are not implemented. Natural landscape characteristics of eastern Coastal Plain watersheds, such as large wooded riparian zones and soils with high organic matter, typically have helped mitigate elevated nutrient levels from reaching streams and shallow ground water (Gilliam, 1991). However, with the large influx of animal production and limited land for waste application, these natural characteristics can become overloaded and their effectiveness negated.

To address these environmental concerns, a Water Quality Demonstration Project involving federal, state, and local agencies; private industry; and local landowners was initiated in 1990 on a watershed in the Cape Fear River Basin in Duplin County, NC (Stone et al., 1995). The demonstration watershed, Herrings Marsh Run (HMR), has many characteristics typical of an intensive agricultural area in the eastern Coastal Plain of the USA (Hubbard and Sheridan, 1989). Duplin County has the highest agricultural revenue from livestock of any county in North Carolina and is second in total revenue to neighboring Sampson County (North Carolina Dept. of Agriculture, 1996).

The objectives of the study were to determine the distribution and trends of nitrate-N in shallow ground water of the HMR watershed during the Water Quality Demonstration Project.

METHODS

The Herrings Marsh Run (HMR) watershed is located in the Coastal Plains physiographic region of Duplin County, North Carolina. The HMR watershed contains 2,044 ha and is centered at approximately latitude 35° 06′ North and longitude 77° 56′ West. On the HMR watershed, 105 ground water monitoring wells were established on 21 farms (figure 1) from August 1991 through March 1993. The farms were selected to cover the watershed both on a geographical basis and to represent the farming practices on the watershed. The majority of the farms with monitoring wells are in row crops. They represent farms with and without implemented nutrient management plans. Two of the row crop farms have their main source of nitrogen from poultry litter and poultry compost. The other farms have practices that include pastures for grazing cattle, for hay production, and for application of swine lagoon effluent. The predominant soil series in the watershed is Autryville (Loamy, siliceous, thermic Arenic Paleudults); secondary soil series are Norfolk (Fine-loamy, siliceous, thermic Typic Kandiudults), Marvyn-Gritney (Clayey, mixed, thermic Typic Hapludults), and Blanton (Loamy siliceous, thermic Grossarenic Paleudults).

Local topography and interaction with the landowners and farmers were used to determine ground water monitoring well placement to minimize their influence on normal farming activities. Local topography was assumed to be a guide for determining ground water flow gradients. Wells at each farm were located both up- and down-gradient to monitor ground water flow to and from the fields. Typically three to five monitoring wells were installed at each farm. Farm A had 24 monitoring wells installed in the spray fields and surrounding riparian zone. In analyzing the data, the 24 wells on Farm A were grouped into three representative field sites (old spray field, new spray field, and surrounding wells) to avoid biasing the results. This gave a total of 84 ground water monitoring well sites on the watershed.

Ground water monitoring wells were installed using a SIMCO 2800[1] trailer-mounted drill rig equipped with 108-mm i.d. hollow-stem augers. The well casings and screen were 50-mm i.d. threaded schedule 40 PVC, and well screens were 1.5 m long. Well bottoms were placed on an impermeable layer or to a depth of 7.6 m if the impermeable layer could not be located above that depth. Water table depths in the watershed were generally 1.5 to 3 m below the soil surface. Monitoring wells were constructed according to NC Dept. of Environmental Management regulations. A filter pack of coarse sand was placed around well screens. An annular seal of bentonite was placed above the filter sand. Concrete grout was then placed above the bentonite to the soil surface to prevent contamination from the surface. Locking well covers were installed to prevent unauthorized access. WaTerra foot valves (model D-25) and high density polyethylene tubing were installed in each well to provide dedicated samplers.

Collection of shallow ground water from monitoring wells began in October 1991. Before each sample was collected, the static well water depth was measured, and one to three well volumes were purged. A glass sample collection bottle was rinsed with the well water, filled with a sample, packed in ice, and transported to the laboratory. Wells were sampled monthly.

All water samples were transported to the USDA-ARS, Soil, Water, and Plant Research Center in Florence, SC, for analysis. Water samples were analyzed using a TRAACS 800 Auto-Analyzer for nitrate-N, ammonium-N, total Kjeldahl nitrogen, ortho-phosphorus, and total phosphorus using EPA Methods 353.2, 350.1, 351.2, 365.1, and 365.4, respectively (U.S. EPA, 1983). EPA-certified quality control samples were routinely analyzed to verify results.

Statistical analyses on the collected ground water samples were performed using the SAS system (SAS, 1990). An analysis of variance (ANOVA) on the shallow ground water nitrate-N concentrations was performed. The analysis compared the individual farm mean ground water nitrate-N concentrations, and compared mean farm nitrate-N concentration by subwatershed to determine any spatial distribution of nitrate-N in the HMR watershed. Duncan's multiple range test was used to determine statistical differences among means for farms, subwatersheds, and practices. Regression analyses were then conducted to determine if any changes or linear trends in nitrate-N were apparent during the study period.

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[1]Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U. S. Dept. of Agr. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

RESULTS AND DISCUSSION

Ground Water Nitrate-N Levels on HMR

Eighty-four ground water monitoring well sites were sampled on the HMR watershed. These wells were located in fields and along field borders and were not used for drinking water. Seventy-four percent of the wells (62 well sites) had mean nitrate-N less than the safe drinking water standard of 10 mg/L (Figure 2). Mean nitrate-N concentrations between 10 and 20 mg/L were observed on 19% of the wells (16 well sites), and nitrate-N concentrations above 20 mg/L were observed in 7% (6 well sites) of the wells. These results are similar to other research findings in the Coastal Plain. Gambrell et al., (1975) and Jacobs and Gilliam (1985) observed that nitrate-N in shallow ground water beneath agricultural fields in the North Carolina Coastal Plain often exceeds 10 mg/L. Hubbard et al. (1991) observed shallow ground water nitrate-N ranging from 11 to 19 mg/L in the Coastal Plain of southern Georgia. In Virginia, Bruggeman et al. (1995) reported 17% of shallow residential wells had nitrate-N exceeding 10 mg/L. However, Jennings et al. (1991) reported that 77% of shallow (<15 m) residential wells in North Carolina had elevated nitrate-N. They attributed this high level of contamination to several factors, but the most important factor was poor well construction.

Monitoring wells at each farm were located in areas with similar practices, but the farms varied in agricultural practices. Therefore, nitrate-N values from wells on a farm were pooled to obtain mean values for that farm and practice. Seventeen of the 21 investigated farms (table 1) had mean nitrate-N concentrations better than the safe drinking water standard of 10 mg/L. These findings document that nitrate-N contamination of ground water is not a widespread problem on the HMR watershed even though it is intensively farmed. The majority of other farms appear to have appropriate nutrient management budgets. These results are also in agreement with Spalding and Exner (1993) who found that ground water was generally not contaminated in agricultural areas of the southeastern USA. Also in the eastern Coastal Plain, Ritter and Chirnside (1983) found 68% of wells sampled in Delaware contained less than 10 mg/L nitrate-N.

In the four farms with nitrate-N exceeding 10 mg/L (Figure 1; farms A, B, C, D), only one (farm A) had wells that exceeded 20 mg/L of nitrate-N. Farm A was the only farm with severe ground water contamination. It had a mean farm nitrate-N of 54 mg/L in wells and was significantly different from all the other farms using Duncan's multiple range test. Farm A had been overloaded with swine wastewater prior to the Water Quality Demonstration Project (WQDP). After initiation of the WQDP, the spray field was expanded, and wastewater application rates were reduced. It is anticipated that the site will be reclaimed with lower wastewater application rates, denitrification, and coastal bermuda hay uptake of nitrogen. The second most contaminated site was at Farm B, where a swine waste spray field had been converted from row crop. In this field, nitrate-N averaged 19 mg/L possibly caused by both intensive row crop production and continued application of swine waste. Farm B was also significantly different from the other farms. The other swine waste sprayfield, Farm N, had a mean nitrate-N of 6 mg/L. This farm had a much larger area for waste application during most of the study. However, near the end of the study, the operation was greatly expanded, and some of the monitoring wells have shown increased nitrate-N. The elevated nitrate-N concentrations at other farms in the watershed are likely related to over-application of nitrogen fertilizer. Farm C was intensively multi-cropped and averaged 13.5 mg/L nitrate-N, which is not atypical of other intensively cropped fields in the eastern Coastal Plain (Jacobs and Gilliam, 1985; Hubbard, et al., 1984). Farm D also had mean nitrate-N > 10 mg/L, which was influenced by one well located near an abandoned poultry house. Improved nutrient management would be helpful on these farms.

The ground water was also evaluated based on the predominant practice of the farms. The farms that applied swine waste effluent to bermuda grass were significantly different from the row crop farms and pastures using Duncan's multiple range test. These farms had mean nitrate-N of 46 mg/L. The row crop farms had mean nitrate-N of 7 mg/L and were statistically different from the pastures (3 mg/L). The combination of soils, landscape, and nutrient management plans at Farms R, S, and U has produced row crop farms that are not significantly different from well managed pasture. Previous research had shown similar results in ground water nitrate-N from these practices. Evans et al. (1984) found elevated ground water nitrate-N (> 18 mg/L) when swine waste was applied above recommended rates. Cappelaere and Podmore (1980) reported nitrate-N > 20 mg/L in shallow ground water from land application of swine waste. Hubbard et al. (1996) found nitrate-N concentrations approximately 20 mg/L downslope from a swine wastewater spray field. In a similar study using dairy waste effluent, Hubbard et al. (1987) found monthly nitrate-N in ground water ranging from 5 to 70 mg/L. Numerous research has also reported nitrate-N in ground water under row crop systems. Jackson et al. (1973) reported nitrate-N ranging from 7 to 9 mg/L in corn in the Coastal Plain of Georgia. However, under intensive multi-cropping and irrigation, Hubbard et al. (1984) found nitrate-N levels ranging from <1 to >100 mg/L with an average of 20 mg/L. Jacobs and Gilliam (1985) reported ground water nitrate-N ranging from 7 to 15 mg/L in row crop fields in North Carolina with the higher concentrations from intensive multi-cropping at that field. Magette et al. (1989) reported elevated nitrate-N (13-55 mg/L) in ground water under row crops in Maryland. In Iowa, Weed and Kanwar (1996) reported average nitrate-N in ground water ranging from 1 to 65 mg/L in row crops with various rotations and management practices. Owens (1990) found nitrate-N concentrations generally below 5 mg/L in an alfalfa pasture in Ohio. Watts et al. (1991) found nitrate-N concentrations approximately 5 mg/L in an irrigated pasture with orchardgrass fertilized with low application rates. They also found much higher concentrations (>10 mg/L) for increased fertilizer rates and irrigation amounts. Owens et al. (1994) found elevated (>10 mg/L) nitrate-N under heavily fertilized pastures in Ohio; but with changes in fertilization and utilizing legumes, ground water nitrate-N levels were reduced to 3-4 mg/L. Chichester (1977) in Ohio and Bergstrom (1987) in Sweden also found low ground water nitrate-N concentrations from pastures.

Distribution of Ground Water Nitrate-N by Subwatershed in HMR

The distribution of mean farm ground water nitrate-N by subwatershed is shown in figure 3. Subwatershed 2 had a total of eight farms; three of these farms (A, B, and D) had elevated mean nitrate-N concentrations. Only one other farm (C, located in subwatershed 3) in the entire watershed had nitrate-N exceeding 10 mg/L. These results correspond with earlier reports that stream nitrate-N concentrations were highest in subwatershed 2 (Stone et al., 1995). Likewise, animal waste applications were the highest in subwatershed 2 (Hunt et al., 1995), and it was the most intensively farmed part of the HMR watershed. Additionally, it had the least riparian buffer area to separate the farming practices from adjacent agricultural fields and other activities (Hunt et al., 1995). By contrast, the other subwatersheds had more extensive riparian buffer zones and, generally, they had much better water quality in the ground water and streams (Stone et al., 1995).

A statistical comparison of the subwatersheds with the Duncan's multiple range test found that subwatershed 2 with a mean nitrate-N of 34 mg/L was statistically different from the other subwatersheds. The other subwatersheds were only marginally different statistically from each other. Subwatershed 3, at 7.1 mg/L, was not different from subwatershed 4, at 6.4 mg/L, which in turn was not different from subwatershed 1 at 5.0 mg/L.

Trends in Nitrate-N in HMR

Individual farms were analyzed to determine if any changes or trends in nitrate-N concentrations had occurred during the study. A summary of the linear regression analysis of the individual farms is shown in Table 2. For the majority of the 21 farms, there were no overriding changes in nitrate-N during the study period. Seven farms on the watershed had significant linear trends in nitrate-N concentrations over the study period. Three farms (B, C, and Q) had significant positive trends in nitrate-N concentrations over the study period. Farm B had a newly established swine waste spray field. It had a predicted increase in nitrate-N of 2.8 μg/L/day or 1 mg/L/year. Both Farms C and Q were in row crop production. Farm C (Figure 4) had a predicted increase in nitrate-N concentration of 5 μg/L/day or 1.8 mg/L/year. A specific reason for this upward trend in nitrate-N concentration has not been determined but may be related to intensive multi-cropping or an adjacent poultry facility. Farm Q had a much lower predicted increase in nitrate-N concentration of 2 μg/L/day or 0.6 mg/L/year. Four farms had a decreasing concentration during the study period. Two farms (D and L), both in row crops, had a decreasing trend in nitrate-N concentration of approximately 2 μg/L/day or 0.7 mg/L/year. Farm A (Figure 5) had a significant downward trend in nitrate-N concentration of 24 μg/L/day or 8.9 mg/L/year. This was caused by the expansion of the swine wastewater spray field and the reduction of application rates. Concentrations at this site remained elevated even after these improvements, and it may take several years to reduce the contaminant concentration levels in the ground water and soils in the spray field. A simulation analysis of Farm A using GLEAMS predicted similar reductions in shallow ground water nitrate-N concentrations following the reduction of application rates and expansion of the spray field (Stone et al., 1997).

CONCLUSIONS

1) Nitrate-N contamination of ground water is not a widespread problem on the HMR watershed. Seventy-four percent of the ground water monitoring sites had nitrate-N concentrations less than the drinking water standard of 10 mg/L. Only one farm had nitrate-N greater than 20 mg/L.

2) The distribution of farms with elevated nitrate-N was affected by nutrient management. Three of the four farms with elevated nitrate-N concentrations were in subwatershed 2, which had the highest concentration of animal waste application and excess N applied.

3) There were no overriding trends in nitrate-N during the study period. Only seven of the twenty one farms had a significant tread in ground water nitrate-N. Three of these farms had increasing nitrate-N concentrations; two of these farms were in row crop production and one was a swine waste spray field; two row crop farms had decreasing nitrate-N concentrations. However, there was a significant reduction in ground water nitrate-N in a swine wastewater spray field.

4) Improved management practices on the farm with elevated nitrate-N (> 20 mg/L) have reduced nitrate-N concentrations from 77 to 45 mg/L during the study.

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Table 1. Mean of farm nitrate-N concentrations in ground water monitoring wells located within the HMR watershed.

Farm	Nitrate-N (mg/L)		Practice*
	Mean	Std. Dev.	
A	54.2	53.7	SF
B	19.1	7.2	SF
C	13.5	8.0	RC
D	10.0	7.8	RC
E	9.4	8.0	CO
F	9.2	7.4	RC
G	8.7	1.7	RC
H	7.9	3.8	RC
I	7.8	3.7	RC
J	7.6	6.4	RC
K	7.4	1.3	RC
L	7.2	6.8	RC
M	6.4	1.4	RC
N	5.9	3.1	SF
O	5.6	2.2	RC
P	5.3	5.3	RC
Q	4.5	5.5	P
R	4.2	7.0	RC
S	2.3	3.4	RC
T	1.0	1.4	P
U	0.1	0.2	RC

*RC=Row Crop, SF=Spray field, P=Pasture, CO=Compost Area

Table 2. Summary of linear regression analysis of farms for nitrate-N concentration over time.

Farm	Slope (mg/L/day)	Standard Error	r^2	T Statistic	Prov>|T|	Significant[1]
A	-0.0246	0.0036	0.46	-6.83	0.00	**
B	0.0028	0.0012	0.12	2.35	0.02	**
C	0.0054	0.0010	0.42	5.65	0.00	**
D	-0.0017	0.0007	0.15	-2.31	0.03	**
E	-0.0033	0.0015	0.14	-2.18	0.04	**
F	0.0001	0.0013	0.00	0.11	0.91	
G	-0.0011	0.0007	0.08	-1.55	0.13	
H	-0.0017	0.0011	0.08	-1.54	0.13	
I	-0.0002	0.0009	0.00	-0.25	0.80	
J	-0.0010	0.0009	0.04	-1.12	0.27	
K	-0.0012	0.0007	0.09	-1.77	0.09	
L	-0.0023	0.0007	0.28	-3.28	0.00	**
M	-0.0009	0.0005	0.07	-1.70	0.10	
N	-0.0006	0.0006	0.03	-0.99	0.33	
O	-0.0005	0.0005	0.04	-1.04	0.31	
P	-0.0009	0.0007	0.04	-1.21	0.23	
Q	0.0006	0.0011	0.01	0.52	0.61	
R	-0.0011	0.0019	0.01	-0.60	0.56	
S	0.0017	0.0006	0.20	2.65	0.01	**
T	-0.0006	0.0005	0.05	-1.20	0.24	
U	-0.0002	0.0001	0.07	-1.53	0.14	

[1] **Significant at the α=0.05 level

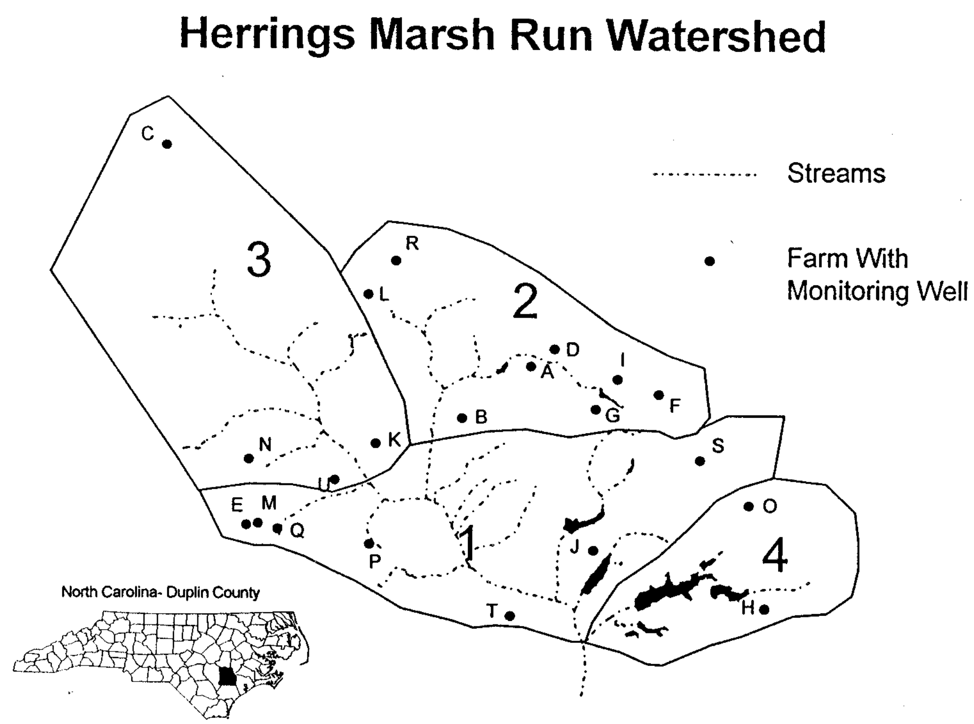

Figure 1. Herrings Marsh Run Watershed.

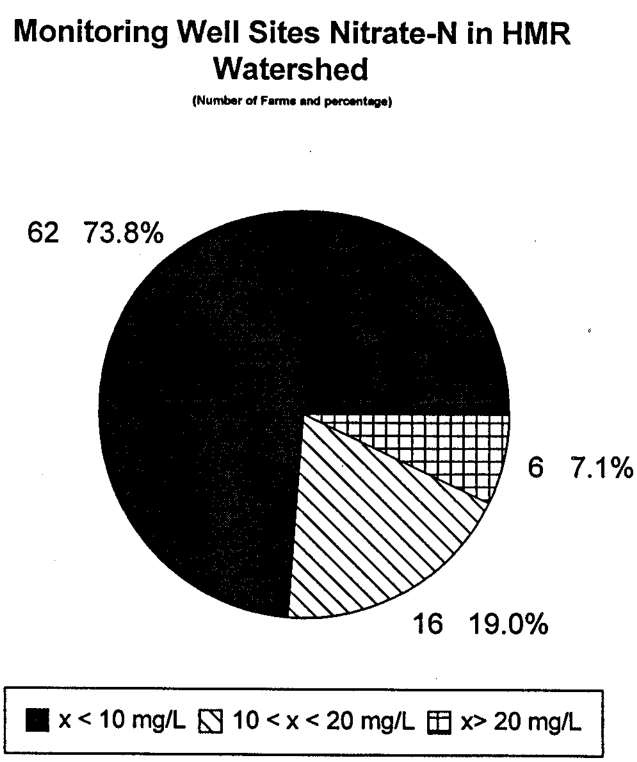

Figure 2. Ground water nitrate-N on Herrings Marsh Run Watershed.

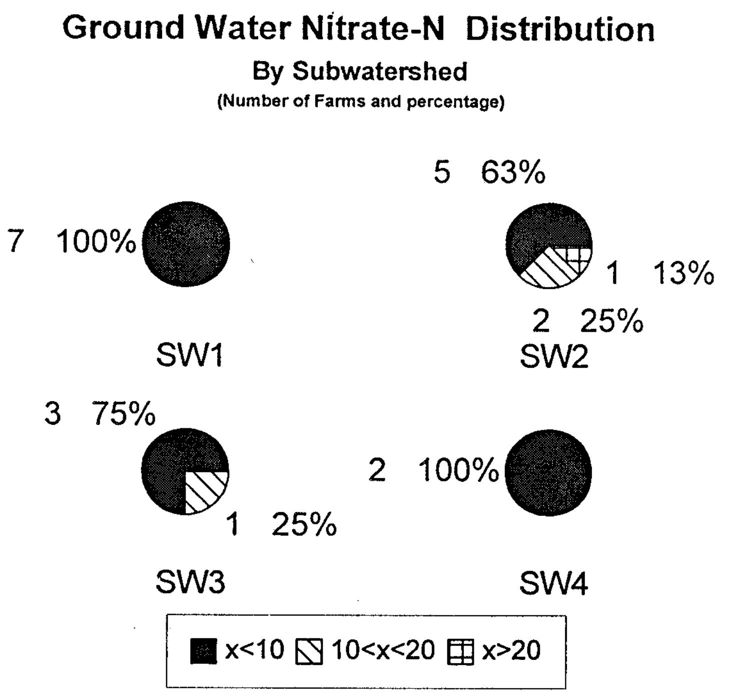

Figure 3. Ground water nitrate-N by subwatershed on Herrings Marsh Run Watershed.

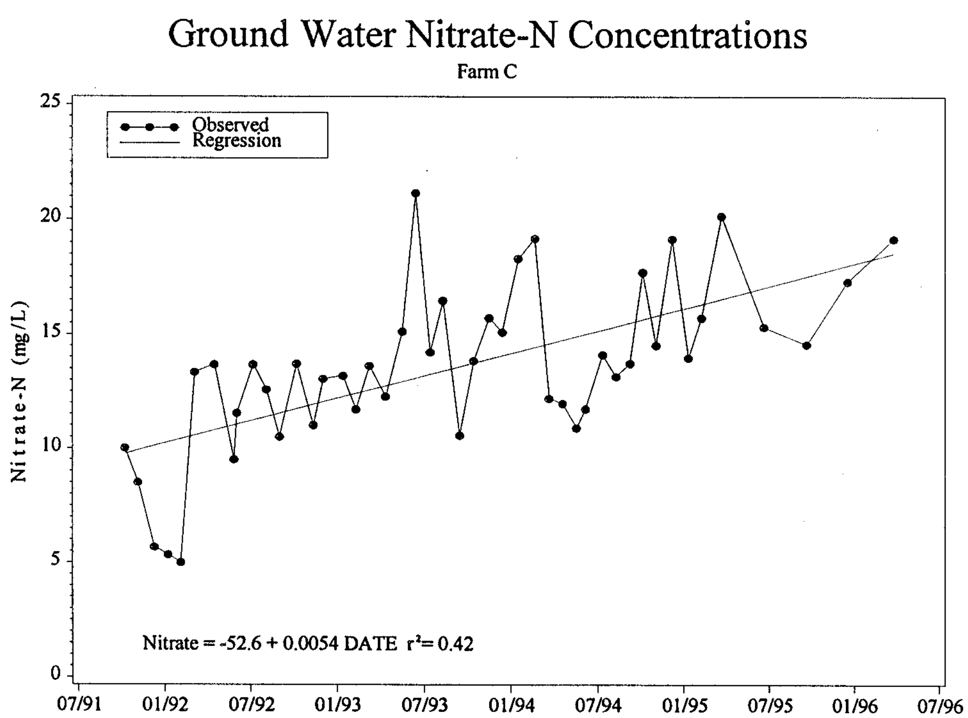

Figure 4. Ground water nitrate-N concentration for Farm C.

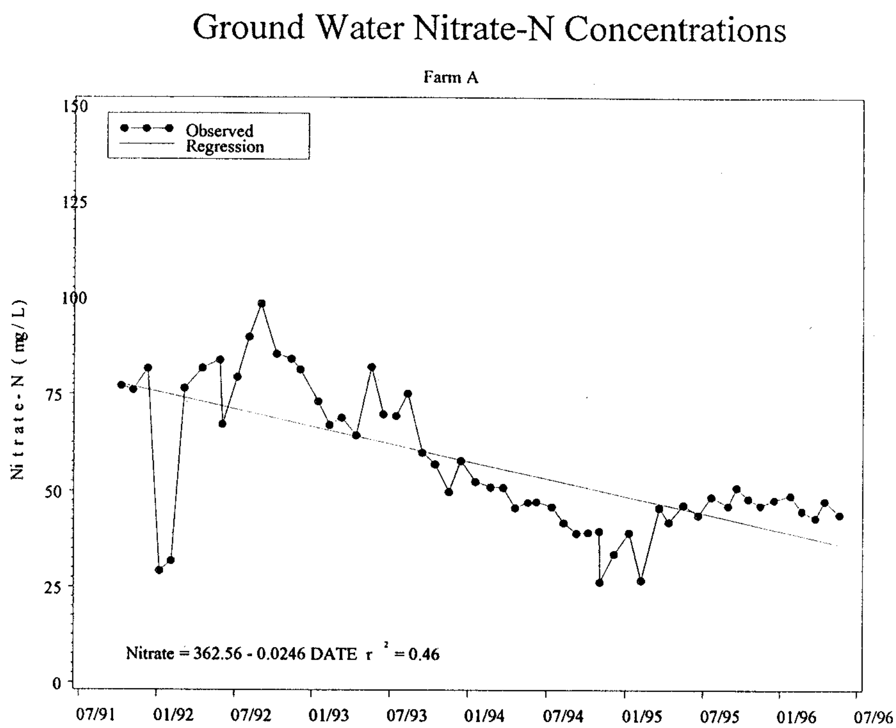

Figure 5. Ground water nitrate-N concentration in the swine waste spray field, Farm A.