NITRATE-N DISTRIBUTION AND TRENDS IN SHALLOW GROUNDWATER ON AN EASTERN COASTAL PLAINS WATERSHED

K. C. Stone, P. G. Hunt, M. H. Johnson, T. A. Matheny

ABSTRACT. *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, North Carolina. The WQDP was implemented to determine water quality benefits from voluntary adoption of improved management practices. In the WQDP, 84 groundwater 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 groundwater was not a wide spread problem. Seventy-four percent of the groundwater 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 16 of the 21 farms. Of the four farms with nitrate-N exceeding 10 mg/L, one farm had mean nitrate-N that exceeded 20 mg/L. This farm had an undersized and overloaded swine wastewater spray field. After the spray field was expanded and application rates were reduced, groundwater nitrate-N concentrations declined; but they continued to exceed 20 mg/L. Other farms with swine waste spray fields had mean groundwater nitrate-N concentrations <20 mg/L throughout the study period. Groundwater nitrate-N concentrations under row crops were <10 mg/L on all but two farms. Three of the four farms with nitrate-N concentrations exceeding 10 mg/L were in a subwatershed of the HMR that had the highest concentration of animal waste application and excess nitrogen applied. Of the 21 farms, three farms had a significant increasing trend in groundwater nitrate-N while four farms had a significant decreasing trend. The overloaded swine wastewater spray field had a significant decreasing nitrate-N trend. Most farms with concentrations less than 10 mg/L had no detectable trend in nitrate-N concentration during the study. These findings indicate that nitrate-N contamination of groundwater is not a widespread problem on the HMR watershed even though it is intensively farmed.*

Keywords. *Groundwater, Contamination, Nitrate-N.*

Contamination of groundwater 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. Groundwater 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% of these wells exceeding the MCL of 10 mg/L. Later, Spalding and Exner (1993) compiled a review on the occurrence of nitrate in groundwater in the USA. They found groundwater nitrate concentrations exceeding 10 mg/L 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 groundwater in highly agricultural areas in the southeastern USA generally did not exceed 10 mg/L. Vegetative uptake and denitrification in warm, wet, carbon-rich soils were the factors they found responsible for the natural remediation of nitrate in shallow groundwater. 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 groundwater nitrate exceeding 10 mg/L. However, he reported groundwater 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 requires several applications of various pesticides and nutrients. Nitrate leaching to groundwater is a potential problem because of high rainfall, sandy textures, and low soil organic matter levels. Hubbard et al. (1984) found nitrate-N averaging 20 mg/L under intensive multi-cropping and irrigation in the Coastal Plain of Georgia. Adoption of improved management practices can

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help reduce the potential of these chemicals being lost to the environment.

Nitrate leaching is also a concern because large amounts of swine and poultry waste are 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 2,000 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 could be used by non-legume agronomic and forage crops. Together, intensive crop and animal production pose a great contamination potential if adequate nutrient management practices are not implemented. Groundwater nitrate-N exceeding 10 mg/L was observed by Evans et al. (1984) when swine waste was applied above recommended rates. 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 groundwater (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 local landowners, private industry, and federal, state, and local agencies was initiated in 1990 on a watershed in the Cape Fear River Basin in Duplin County, North Carolina (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 agricultural 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 groundwater 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 2044 ha and is centered approximately at latitude 35°06′North and longitude 77°56′West. On the HMR watershed, 84 groundwater monitoring well sites were established on 21 farms (fig. 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

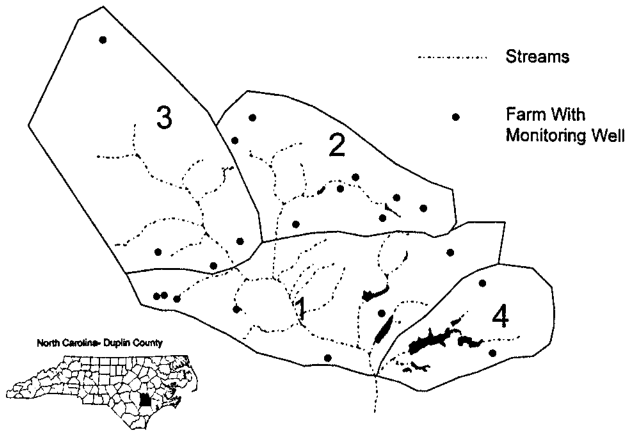

Figure 1–Location of farms with monitoring wells and subwatersheds in the Herrings Marsh Run watershed.

on the watershed. Fifteen of the farms were in row crops. They represented farms with and without implemented nutrient management plans. Two of the row crop farms had their main source of nitrogen from poultry litter and poultry compost. The other seven farms had practices that included pastures for grazing cattle, for hay production, and for application of swine lagoon effluent. The predominant soil series in the watershed was Autryville (Loamy, siliceous, thermic *Arenic Paleudults*); secondary soil series were 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 groundwater monitoring well placement to minimize their influence on normal farming activities. Local topography was used as a guide for determining groundwater flow gradients. Wells at each farm were located both up- and down-gradient to monitor groundwater flow to and from the fields. Typically three to five monitoring wells were installed at each farm.

Groundwater monitoring wells were installed using a SIMCO 2800 trailer-mounted drill rig equipped with 108-mm i.d. hollow-stem augers. The well casings and screens 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 North Carolina 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.

Shallow groundwater monitoring wells were sampled from October 1991 to May 1996. 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, South Carolina, for analyses. Water samples were analyzed using a TRAACS 800 Auto-Analyzer for nitrate-nitrogen, ammonium-nitrogen, 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 groundwater samples were performed using the SAS system (SAS, 1990). The Duncan's multiple range test was used to determine statistical differences among means for farms, subwatersheds, and practices. A linear regression analysis was then conducted to determine if any changes or linear trends in nitrate-N were apparent during the study period. The time interval used in regression analysis was calculated as the number of days from 1 October 1991 (the month groundwater sampling began).

Results and Discussion

Groundwater Nitrate-N Levels on HMR

Eighty-four groundwater 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 (fig. 2). Mean nitrate-N concentrations between 10 and 20 mg/L were observed in 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 groundwater beneath agricultural fields in the North Carolina Coastal Plain often exceeds 10 mg/L. Hubbard et al. (1991) observed shallow groundwater 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 nitrate-N exceeding 10 mg/L. They attributed this high level of contamination to several factors, but the most important factor was poor well construction.

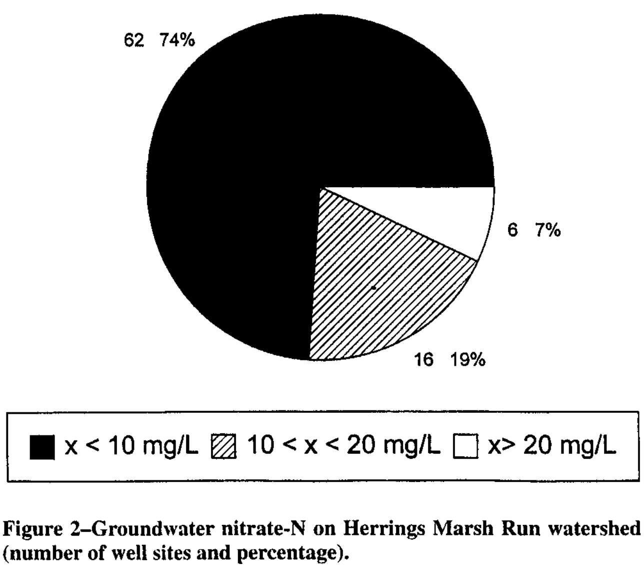

Figure 2–Groundwater nitrate-N on Herrings Marsh Run watershed (number of well sites and percentage).

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 below the EPA drinking water standard of 10 mg/L. These results are in agreement with Spalding and Exner (1993), who found that nitrate-N concentrations in groundwater generally did not exceed 10 mg/L 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 (table 1; Farms A, B, C, and D), one farm (Farm A) had wells that exceeded 20 mg/L of nitrate-N. 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 groundwater nitrate-N will be improved with the lower wastewater application rates, denitrification, and Coastal bermuda grass uptake of nitrogen.

The second highest groundwater nitrate-N concentrations were on 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 spray field, Farm N, had a mean nitrate-N of 6 mg/L. This farm had a much larger area for waste

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

Farm	Number of Observations	Nitrate-N (mg/L) Mean	Nitrate-N (mg/L) Std. Dev.	Practice*
A	972	54.2	53.7	SF
B	80	19.1	7.2	SF
C	129	13.5	8.0	RC
D	98	10.0	7.8	RC
E	91	9.4	8.0	CO
F	142	9.2	7.4	RC
G	112	8.7	1.7	RC
H	88	7.9	3.8	RC
I	96	7.8	3.7	RC
J	197	7.6	6.4	RC
K	62	7.4	1.3	RC
L	131	7.2	6.8	RC
M	76	6.4	1.4	RC
N	196	5.9	3.1	SF
O	166	5.6	2.2	RC
P	147	5.3	5.3	RC
Q	106	4.5	5.5	P
R	117	4.2	7.0	RC
S	191	2.3	3.4	RC
T	116	1.0	1.4	P
U	87	0.1	0.2	RC

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

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. Nitrate-N concentrations exceeding 10 mg/L at two 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 should be helpful on these farms.

The groundwater 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 groundwater nitrate-N of 46 mg/L. The row crop farms had mean groundwater 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 have produced row crop farms with groundwater nitrate-N concentrations that are not significantly different from well managed pasture. Previous research on groundwater in swine waste spray fields has found nitrate-N concentrations often exceeding 20 mg/L (Evans et al., 1984; Cappelaere and Podmore, 1980; Hubbard et al., 1996). Previous groundwater research under row cropping systems found nitrate-N concentrations ranging from <1 to >100 mg/L with most studies finding nitrate-N concentrations <20 mg/L (Jackson et al., 1973; Hubbard et al., 1984; Jacobs and Gilliam, 1985; Magette et al., 1989; Weed and Kanwar, 1996). Research on pastures found groundwater nitrate-N concentrations generally below 5 mg/L (Owens, 1990; Watts et al., 1991; Owens et al., 1994; Chichester, 1977; Bergstrom, 1987).

Distribution of Groundwater Nitrate-N by Subwatershed in HMR

The distribution of mean farm groundwater 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 mean nitrate-N concentrations exceeding 10 mg/L. One other farm (Farm C, located in subwatershed 3) in the entire Herring Marsh Run 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 groundwater and streams (Stone et al., 1995).

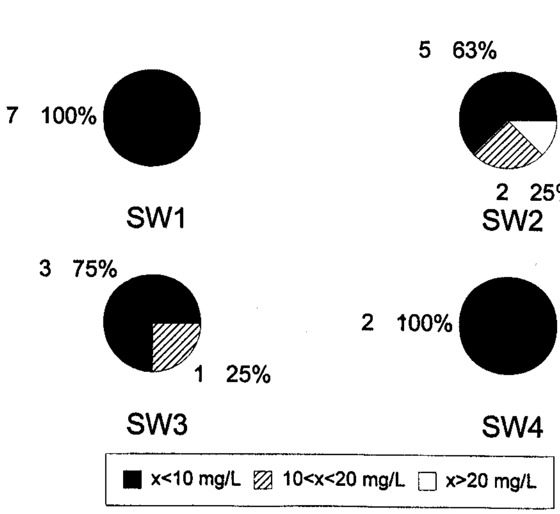

Figure 3–Groundwater nitrate-N distribution by subwatershed on Herrings Marsh Run watershed (number of farms and percentage).

A statistical comparison of the subwatersheds with the Duncan's multiple range test found that subwatershed 2 with a mean groundwater nitrate-N of 34 mg/L was statistically different from the other subwatersheds. The other subwatersheds were only marginally different from each other statistically. Subwatershed 3, at 7.1 mg/L, was not statistically different from subwatershed 4, at 6.4 mg/L, which in turn was not statistically 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 groundwater nitrate-N concentrations had occurred during the study. A summary of the linear regression analysis of the individual farms is shown in table 2. Fourteen of the 21 farms showed no significant change ($\alpha = 0.05$) in groundwater nitrate-N during the study period. Seven farms on the watershed had significant linear trends in groundwater nitrate-N concentrations over the study period. Three farms (B, C, and S) had significant increasing trends in nitrate-N concentrations over the study period. Farm B had a newly established swine waste spray

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

Farm	Intercept (mg/L)	Slope* (mg/L/day)	Slope Standard Error	r^2	T Statistic	Prov > |T|	Significant
A	77.740	–0.0246	0.0036	0.46	–6.83	0.00	**
B	16.830	0.0028	0.0012	0.12	2.35	0.02	**
C	9.720	0.0054	0.0010	0.42	5.65	0.00	**
D	11.550	–0.0017	0.0007	0.15	–2.31	0.03	**
E	12.430	–0.0033	0.0015	0.14	–2.18	0.04	**
F	9.280	0.0001	0.0013	0.00	0.11	0.91	
G	9.800	–0.0011	0.0007	0.08	–1.55	0.13	
H	9.450	–0.0017	0.0011	0.08	–1.54	0.13	
I	7.970	–0.0002	0.0009	0.00	–0.25	0.80	
J	8.690	–0.0010	0.0009	0.04	–1.12	0.27	
K	8.450	–0.0012	0.0007	0.09	–1.77	0.09	
L	9.360	–0.0023	0.0007	0.28	–3.28	0.00	**
M	7.050	–0.0009	0.0005	0.07	–1.70	0.10	
N	6.700	–0.0006	0.0006	0.03	–0.99	0.33	
O	6.110	–0.0005	0.0005	0.04	–1.04	0.31	
P	5.990	–0.0009	0.0007	0.04	–1.21	0.23	
Q	4.010	0.0006	0.0011	0.01	0.52	0.61	
R	5.770	–0.0011	0.0019	0.01	–0.60	0.56	
S	0.690	0.0017	0.0006	0.20	2.65	0.01	**
T	1.600	–0.0006	0.0005	0.05	–1.20	0.24	
U	0.290	–0.0002	0.0001	0.07	–1.53	0.14	

* The time interval used in regression analysis was calculated as the number of days from 1 October 1991 (the month groundwater sampling began).

** Significant at the $\alpha = 0.05$ level.

field. It had a predicted increase in groundwater nitrate-N of 2.8 μg/L/day or 1 mg/L/year. Both Farms C and S were in row crop production. Farm C (fig. 4) had a predicted increase in groundwater nitrate-N concentration of 5 μg/L/day or 1.8 mg/L/year. A specific reason for this upward trend in groundwater nitrate-N concentration has not been determined but may be related to intensive multi-cropping or an adjacent poultry facility. Farm S had a much lower predicted increase in groundwater 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 groundwater nitrate-N concentration of approximately 2 μg/L/day or 0.7 mg/L/year. Farm A (fig. 5) had a significant downward trend in groundwater 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 still exceed 20 mg/L even after these improvements, and it may take several years to reduce the contaminant concentration levels in the groundwater and soils in the spray field. A simulation analysis of Farm A using GLEAMS predicted similar reductions in shallow groundwater nitrate-N concentrations following the reduction of application rates and expansion of the spray field (Stone et al., 1998).

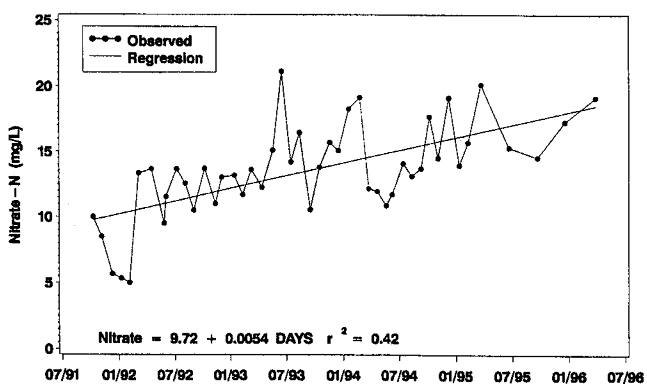

Figure 4–Observed groundwater nitrate-N concentrations and regression for Farm C.

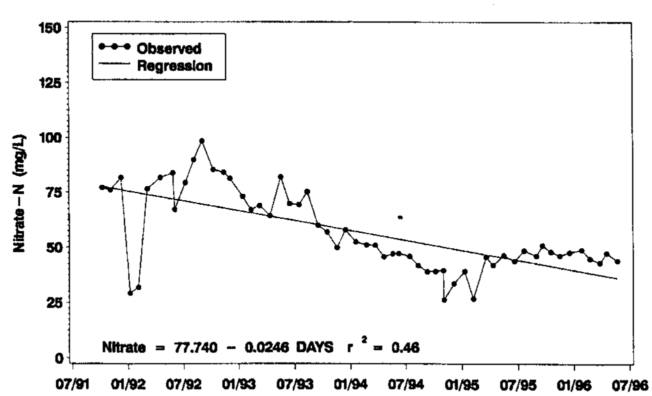

Figure 5–Observed groundwater nitrate-N concentrations and regression for Farm A.

CONCLUSIONS

1. Nitrate-N contamination of groundwater is not a widespread problem on the HMR watershed. Seventy-four percent of the 84 groundwater monitoring sites had nitrate-N concentrations less than the drinking water standard of 10 mg/L. Three farms had nitrate-N between 10 and 20 mg/L. One farm had nitrate-N exceeding 20 mg/L.
2. The distribution of farms with nitrate-N exceeding 10 mg/L was affected by nutrient management. Three of four farms with nitrate-N concentrations exceeding 10 mg/L 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. Seven of the 21 farms had a significant trend in groundwater nitrate-N. Three 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. A significant reduction in groundwater nitrate-N was observed for an overloaded swine wastewater spray field after improved management practices were implemented.
4. Improved management practices have reduced nitrate-N concentrations from 77 to 45 mg/L on a farm (Farm A) with a historically overloaded swine wastewater spray field.

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