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IMPACT OF ANIMAL WASTE ON WATER QUALITY IN AN EASTERN COASTAL PLAIN WATERSHED

P.G. Hunt, K.C. Stone, F.J. Humenik, and J.M. Rice

INTRODUCTION

As part of the USDA's Presidential Water Quality Initiative, a five-year water quality demonstration project was initiated in 1990 on a watershed located on the Cape Fear River Basin in Duplin County, North Carolina (Stone et al., 1995). Streams of the basin have been officially designated environmentally sensitive and are, thus, subject to the highest applicable North Carolina water quality standards. The 2,044-ha 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). These include 1) intensive crop and animal production, 2) shallow ground waters that are used for drinking water, and 3) close connections of shallow ground waters, streams, and sensitive environmental areas.

Annual nutrient usage for crop production in the watershed is estimated at 145 metric tons of nitrogen (N), 64 metric tons of phosphorus (P), and 243 metric tons of potassium (Stone et al., 1994). Although swine and poultry operations produce sufficient quantities of waste to supply 62% of the N and 96% of the P, 90% of the nutrients applied to cropland are supplied by commercial fertilizers. Animal waste is applied as solid and liquid to both row and forage crops. The application of large quantities of commercial fertilizers coupled with the production of large quantities of animal waste provides a potential for N and P contamination of surface and ground water. The initial phase of the project evaluated the effect of existing agricultural management practices on stream and ground water quality within the watershed. The second phase of the project evaluated the impact of management changes and landscape modifications on water quality.

METHODS

WATERSHED CHARACTERISTICS

Agricultural practices in the watershed include 1,093 ha of cropland, 708 ha of woodlands, and 212 ha of farmsteads, poultry facilities, and swine facilities. The major agricultural crops on the watershed include corn (*Zea mays L.*)

415 ha, soybeans [*Glycine max* (L.) Merr.] 273 ha, tobacco (*Nicotiana tabacum* L.) 131 ha, wheat (*Triticum aestivum* L.) 121 ha, and vegetables 162 ha. The primary 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 (Claey, mixed, thermic Typic Hapludults), and Blanton (Loamy siliceous, thermic Grossarenic Paleudults).

MASS BALANCE

A simple N and P mass balance was calculated using results of farm surveys (personal communication, S.W. Coffey, North Carolina State University, Raleigh, North Carolina, 1994). Estimates of land applications of N and P were made using conversion factors typical of the swine and poultry industry of North Carolina (Barker and Zublena, 1995); N and P inputs (fertilizer, livestock waste, legume residual) and outputs (crop and residue) were recorded in the farm surveys. The differences between the inputs and outputs were calculated, and values of excess N and P were obtained. The excess N and P as estimated from the surveys were then compared with the N and ortho-phosphate-P loading rates observed at the stream sampling stations.

STREAM WATER EVALUATION

Stream water sampling stations were established within the watershed in cooperation with the US Geological Survey during 1990 (Figure 1) (Stone et

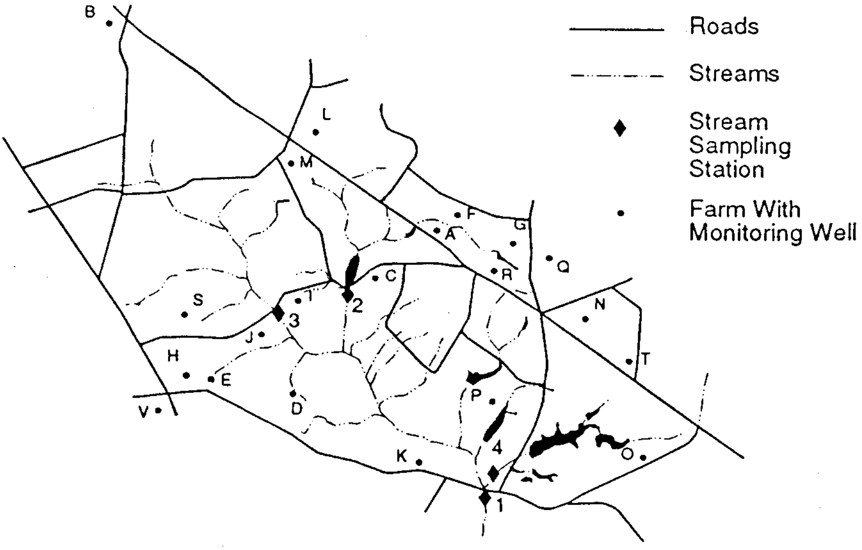

Figure 1. Location of stream sampling stations and farms with ground water monitoring wells on Herrings Marsh Run watershed.

al., 1995). Sub-watershed outlets are indicated in Figure 1 at the diamond-shaped stream sampling stations 1-4. Stations were located on tributaries as well as at the upper reach and at the watershed outlet of HMR. The upper reach of HMR (sampler 3) had extensive riparian buffer zones and relatively little poultry and swine production activities (257 ha of the total 537 ha were forested). The upper reach tributary (sampler 2) had extensive swine and crop production, but less extensive riparian buffer zones (146 ha of the total 425 ha were forested). Stream water samples were taken with auto samplers, and flow was measured at stream sampling stations as described in Stone et al. (1995). All water samples were acidified upon sampling and transported to the USDA-ARS research center in Florence, South Carolina, for analyses. Water samples were analyzed for nitrate-N, ammonium-N, total Kjeldahl-N, ortho-P, and total P using US EPA Methods 353.2, 350.1, 351.2, 365.1, and 365.4, respectively (US EPA, 1983). A TRAACS 800[1] Auto-Analyzer was used, and EPA-certified quality control samples were routinely analyzed to verify results.

GROUND WATER EVALUATION

Ground water monitoring wells were installed using a SIMCO 2800 trailer-mounted drill rig on 24 farms in the HMR watershed from 1991 through 1994 (Figure 1). Well bottoms were positioned on an impermeable layer or at a depth of 7.6 m if the impermeable soil layer could not be located above that depth (Stone et al., 1994). Water table depths in the watershed were generally 1.5 to 3 m below the soil surface. The farms exemplify the agricultural practices used in the watershed. The majority of the farms with monitoring wells were in row crops. There was a mix of farms with and without implemented nutrient management plans. Poultry litter and compost were the main sources of N on two row crop farms. Several farms applied swine lagoon effluent to pasture for hay production.

RIPARIAN ZONES

An overcut riparian zone of approximately 1.2 ha was contiguous to a 3.7-ha Coastal bermudagrass (*Cynodon dactylon* L.) field that was used for swine wastewater treatment. Approximately 2.2 and 1.0 Mg/ha/year of N and P, respectively, were applied in swine waste water. The portion of the field used for wastewater treatment was initially too small (about 1.1 ha), and overloading had occurred. During our study the treatment field was expanded, and hardwood trees were planted in the riparian zone. Starting from the field, the species planted were green ash (*Fraxinus pennsylvanica* Marsh.), red maple (*Acer rubrum* L.), sycamore (*Platanus occidentalis* L.), water oak (*Quercus nigra* L.), and cypress (*Taxodium distichum* (L.) Rich.). Ground water wells were

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

established in the treatment field and in the riparian zone. Point in time "grab" samples were collected in the stream contiguous to two of the wells in the riparian zone. Denitrification potential in the soil of the spray field and riparian zone was assessed by use of the acetylene blockage method (Smith et al., 1978).

IN-STREAM WETLAND EVALUATION

The stream from sub-watershed 2 flowed through a wetland that existed in the bottom of an old pond with a breached dam. Beavers built a dam across the old breach in April 1993. The dam initially suffered substantial sidewall erosion, and it was necessary to reinforce the sidewalls and direct the flow over the center of the dam. The expanded wetland area upstream of station 2 was about 3.3 ha when the water level at the dam was approximately 3.1 m above the bottom of the stream bed. Stream water sampling stations have been installed upstream of the wetland. All statistical analysis of the data was accomplished using SAS version 6.07 (SAS, 1990).

RESULTS AND DISCUSSION

MASS BALANCE

The estimated total N and P applied as animal waste in sub-watershed 2 (425 ha) were 22.7 and 16.7 Mg/year, respectively (Table 1). Sub-watershed 3 (537 ha) had only swine waste, with 5.8 Mg N and 2.7 Mg P applied each year. The total watershed minus sub-watersheds 2 and 3 (1082 ha) received an estimated 47.4 Mg N and 42.0 Mg P in animal waste each year. The impact of animal waste on sub-watershed 2 was greater than on sub-watershed 3 or the whole watershed; the N and P would have averaged 53 and 39 kg/ha/year, respectively, if applied evenly to sub-watershed 2. A uniform application rate of animal waste in sub-watershed 3 would have resulted in 14 kg/ha N and 5 kg/ha P. Stone et al. (1995) estimated that the excess N applied to crops as animal waste and fertilizers was 85, 55, and 38 kg/ha/year for sub-watershed 2, sub-watershed 3, and the total watershed, respectively (Table 2). Excess P applications were estimated to be 57, 15, and 30 kg/ha/year in sub-watershed 2, sub-watershed 3, and the total watershed, respectively.

STREAM QUALITY

The geometric mean (antilog of the mean of the log of the data) of nitrate-N concentrations in the tributary from sub-watershed 2, the HMR from sub-watershed 3, and the HMR watershed outlet at station-1 were 5.4, 1.2, and 2.0 mg/L, respectively, from September 1991 to June 1993 (Table 3). Ammonia-N concentrations had the same relationship, but they were much smaller than nitrate-N concentrations. The stream flow from the upstream stations was less than one third the 0.147 m^3/s of the HMR watershed outlet. The mass flux of N from sub-watershed 3 was 4 kg/day. On the other hand, the N flux from sub-

Table 1. Nitrogen and phosphorus from manure in the Herrings Marsh Run (HMR) watershed.

Waste Source	Location	N	P
		----Mg/yr----	
Swine	Sub-watershed 2	10.6	5.0
Poultry		12.1	11.7
Total		22.7	16.7
	Sub-watershed 3	5.8	2.7
		0.0	0.0
		5.8	2.7
	Main Watershed		
	Minus Sub-watershed 2 & 3	11.4	5.4
Poultry		36.0	36.6
Total		47.4	42.0

Table 2. Excess applied nitrogen (N) and phosphorus (P) and stream loadings for the Herrings Marsh Run watershed (modified from Stone et al., 1995).

	Sampling Station†		
Nutrient Loading	1	2	3
	----kg/ha/year----		
Excess N Applied	38	85	55
Stream N Loading	3	22	6
Excess N % Loss in Stream	8%	26%	11%
Excess P Applied	20	57	15
Stream Ortho-phosphate Loading	0.5	0.9	0.4
Excess P % Loss in Stream	3%	2%	3%

†Station 1 is located at the watershed outlet. Station 2 is the Herrings Marsh Run tributary. Station 3 is the Herrings Marsh Run main and is used as a background reference.

Table 3. Mean daily nutrient concentrations and mass fluxes over the sampling period for three stream monitoring stations in the Herrings Marsh Run watershed in Duplin County, North Carolina (modified from Stone et al., 1994).

	Sampling Stations		
Nutrient Discharge	1	2	3
Concentration	----mg/L----		
Nitrate	2.01	5.34	1.18
Ammonia	0.15	0.42	0.08
o-phosphate	0.14	0.15	0.06
Mass Flux	----kg/day----		
Nitrate	22.17	19.61	3.56
Ammonia	2.08	1.34	0.28
o-phosphate	2.24	0.57	0.17
	----m^3/s----		
Stream Flow	0.147	0.041	0.034

watershed 2 (21 kg/day) was nearly as large as that from the watershed outlet (24 kg/day). Ortho-phosphate-P concentrations in the streams were generally less than 0.2 mg/L, and the mass flow differences among the streams resulting from the small concentration differences were of little environmental significance.

The impact of N and P inputs upon stream water quality was very different. Most of the P was bound by the soil, and very little of the excess (less than 3%) reached the streams. Nitrogen was much more mobile, and over 25% of the estimated excesses in sub-watershed 2 were lost in stream flow, predominantly as nitrate.

GROUND WATER QUALITY

Ortho-phosphate-P concentrations were less than 0.05 mg/L in all wells, and nitrate-N was less than 10.0 mg/L in wells on 19 of the 24 farms (Stone et al., 1994). In the five farms with wells that exceeded 10 mg/L of nitrate-N (Figure 1; farms A, B, C, F, and R), only farm A had wells that exceeded 20 mg/L nitrate-N. Farm A had mean concentrations of 20 and 83 mg/L of ammonia-N and nitrate-N, respectively, in wells in a bermudagrass field that had been overloaded with swine waste water prior to the Water Quality Demonstration Project. The waste water spray field has been expanded in area, but the ground water quality has not yet improved. It is anticipated that lower wastewater application rates, denitrification, and Coastal bermuda hay uptake of N will reclaim the site in time. Three of the other four high-nitrate-N farms were also located in sub-watershed 2. Thus, stream and ground water nitrate-N levels were highest in the portion of the watershed with the highest level of animal waste production.

HARDWOOD RIPARIAN ZONE

First year growth of the planted hardwood trees has been excellent in the reestablished riparian zone contiguous to the swine waste water disposal field of farm A. The trees will soon constitute a significant sink for the N that moves to the stream. Initial denitrification enzyme analyses indicated that the riparian zone had significant denitrification potential, particularly near the creek. The creek had mean ammonia-N and nitrate-N concentrations of 4.1 and 8.7 mg/L, respectively, substantially lower than the 13 and 59 mg/L of ammonia-N and nitrate-N, respectively, in the shallow ground water that flowed through the riparian zone. Thus, significant nitrate-N and ammonia-N were removed, but significant amounts also moved from the waste water disposal site through the riparian zone to the stream. In such instances, some form of in-stream treatment is desirable, and the need for stream clean-up suggested that an in-stream wetland would be desirable.

IN-STREAM WETLAND

Prior to the establishment of the 3.2-ha, in-stream wetland, the mean nitrate concentration from sub-watershed 2 at sampler 2 was about 5.5 mg/L, and the mean ammonia-N concentration was 0.42 mg/L (Table 2). The concentration of nitrate-N in the water entering the wetland a few hundred meters upstream of sampler 2 remained about the same as the pre-wetland concentrations (Table 4). After the wetland was established, the concentration of nitrate-N in the stream leaving the wetland at station 2 was 1 mg/L or less in the warmer months. However, the wetland was less effective in N removal during the cooler months. This seasonal effect was probably due to less plant growth and slower denitrification in the cooler months. Ammonia-N and ortho-phosphate-P were not altered greatly. They were generally less than 0.4 and 0.2 mg/L, respectively, before and after flow through the wetland.

SUMMARY

Nitrate-N in stream and ground water was highest in the portion of the HMR watershed with the highest concentration of swine and poultry production. Four of the five farms with high nitrate-N were in the sub-watershed with highest swine and poultry production density. However, only five of the 24 tested farms had mean ground water nitrate-N concentrations in excess of 10 mg/L, and only one of the farms had mean nitrate-N concentrations in excess of 20 mg/L. Ortho-phosphate-P in streams and ground waters was affected very little by animal waste applications, even when in close association with a heavily overloaded waste disposal site.

A riparian zone removed substantial amounts of nitrate-N and ammonia-N from the shallow ground water of an overloaded swine waste water disposal site. An in-stream wetland was very effective in the removal of nitrate-N from a stream that had nitrate-N in excess of 5 mg/L. Development and use of adequate nutrient management plans along with the creation, enhancement, and preservation of riparian and wetland landscape features offer the opportunity to minimize the adverse effects of animal waste disposal in the eastern Coastal Plain.

Table 4. Mean nitrate-N in stream water of an in-stream wetland in sub-watershed 2.

Flow	Time Period		
	Fall 93	[illegible]	Spring 94
	mg/L		
In-flow	7.0 (1.1)	6.7 (1.1)	6.3 (1.4)
Out-flow	0.8 (1.0)	4.9 (0.9)	1.0 (1.1)

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