Stream nitrogen changes in an eastern Coastal Plain watershed

K.C. Stone, P.G. Hunt, J.M. Novak, M.H. Johnson, D.W. Watts, and F.J. Humenik

ABSTRACT: Agricultural nonpoint source pollution (NPS) is a major water quality concern throughout the United States and the world. Concerns over agricultural nonpoint source pollution are heightened where intensive agricultural operations exist near environmentally sensitive waters. 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 the Herrings Marsh Run watershed in the Cape Fear River Basin in Duplin County, North Carolina. Best management practices (BMPs) to reduce nutrient losses to the environment included nutrient and animal waste management plans, soil conservation practices, and an in-stream wetland (ISW). Stream nitrate-N and ammonia-N were measured at the watershed outlet and at three subwatershed outlets from 1990-1998 to evaluate the effectiveness of the best management practices. The project was divided into pre-in-stream wetland (September 1990-May 1993) and post-in-stream wetland (June 1993-December 1998) time periods because the majority of the best management practices were implemented at the time of the in-stream wetland establishment. Post- in-stream wetland stream nitrate-N concentrations were significantly reduced on the watershed (56%) and on each of the three subwatersheds (4% to 56%). The watershed nitrate-N concentrations were reduced from 2.01 to 0.88 mg/L (ppm). One subwatershed had stream nitrate-N concentrations reduced from 5.63 to 2.74 mg/L (ppm). Nitrate-N mass export from the watershed was significantly reduced on an annual basis from 7.14 to 3.88 kg/ha (6.37 to 3.46 lb/ac). Ammonia-N concentrations and mass export from the watershed were unchanged from the pre- to post-in-stream wetland periods. The results of this study indicate that the implemented best management practices were effective in reducing nitrogen loss from the Herrings Marsh Run watershed.

Keywords: In-stream wetland, nitrogen, nonpoint source pollution, water quality

Agricultural nonpoint source pollution (NPS) is a major water quality concern throughout the United States and the world. The 2000 National Water Quality Inventory (USEPA, 2000) reported that runoff from agricultural lands was the leading source of pollution in the impaired rivers and streams assessed. In the midwestern United States, agricultural nonpoint source pollution has been cited as a major contributor to elevated nutrient levels in streams and rivers (Jaynes et al., 1999). Additionally, nitrate-N loading in the Mississippi River has been linked to hypoxia related problems in the Gulf of Mexico (Rabalais et al., 1996). In the eastern United States, the USEPA (2000) identified nonpoint source pollution from agriculture as a major contributor to nutrient loading of Chesapeake Bay.

Agricultural nonpoint source pollution may occur when nutrients are applied at rates greater than crops can utilize or when timing of nutrient applications occurs in close proximity to heavy rainfalls. In the United States eastern Coastal Plain, nutrient leaching is a potential problem because of high annual rainfall, sandy textures soils, and soils with low organic matter and high water tables. Nutrients are transported to streams by overland flow or by lateral shallow ground water movement (Novak et al., 2002).

Concerns over agricultural nonpoint source pollution are heightened where intensive agricultural operations exist near environmentally sensitive waters. In the eastern Coastal Plain of the United States, these concerns are especially critical because shallow ground water tables and coastal estuaries can be affected by nonpoint source pollution (NCDEHNR, 1992; Hubbard and Sheridan, 1989). In the eastern Coastal Plain of North Carolina, agriculture nonpoint source pollution has been identified as a significant problem (Jacobs and Gilliam, 1985; North Carolina Division of Water Quality, 1996; Spruill et al., 1998). This problem is particularly acute in watersheds with concentrated animal production.

Nutrient leaching and runoff are particularly problematic in the North Carolina eastern Coastal Plain because of the large amounts of swine and poultry waste being produced and applied to crops (Barker and Zublena, 1995; Stone et al., 1995; Stone et al., 1998). Kellogg (2000) identified the Cape Fear river basin in eastern North Carolina as one of the most vulnerable to contamination by animal manures.

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, North Carolina (Stone et al., 1995). Duplin County, North Carolina is typical of an intensive agricultural county in the eastern Coastal Plain of the United States. It has the highest agricultural revenue of any county in North Carolina, with intense poultry and swine production (North Carolina Department of Agriculture, 1996; USDA-NASS, 1995). The demonstration watershed, Herrings Marsh Run, has many characteristics typical of an intensive agricultural area in the eastern Coastal Plain of the United States (Hubbard and Sheridan, 1983). The Water Quality Demonstration Project was implemented to determine water quality benefits from

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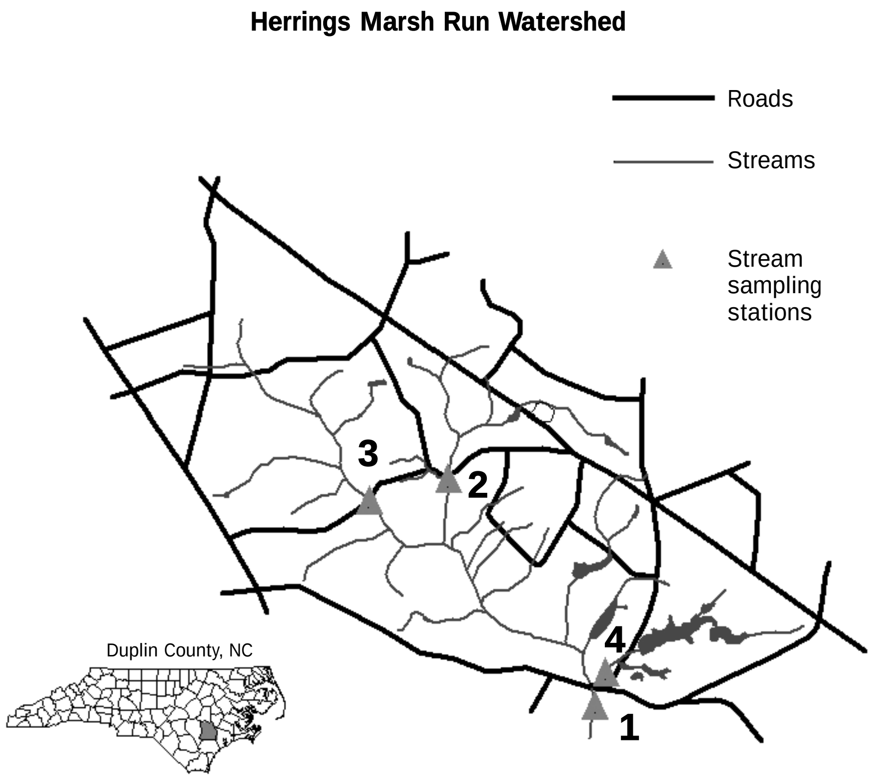
voluntary adoption of improved management practices. Previous studies documented the baseline water quality and the impact of incremental changes on water quality. The objective of this work is to analyze the overall 8-year project results to determine the stream nitrogen changes in the Herrings Marsh Run watershed from the voluntary implementation of best management practices.

Methods and Materials

Site description and operation. The Herrings Marsh Run watershed is located in the coastal plain region of eastern North Carolina (longitude, 77˚ 54' 50" west; latitude, 35˚ 04' 25" north). The Herrings Marsh Run is a 2360 ha (5832 ac) watershed located within the Cape Fear river basin. To evaluate the Herrings Marsh Run watershed, we divided the watershed along natural drainage system and established monitoring stations at the watershed outlet (subwatershed 1) and at 3 subwatersheds (subwatershed 2 to subwatershed 4). The Herrings Marsh Run watershed is 43% forested and 57% cropland or pasture (Stone et al., 1995). The 386 ha (954 ac) (34% forested and 66% non-forested) subwatershed 2 was intensively cropped and contained the most swine and poultry operations in the Herrings Marsh Run watershed at the beginning of the study. Subwatershed 2 had been overloaded with nitrogen, and the stream draining this sub-watershed contained excessive nitrogen (Stone et al., 1995). At the stream exit, there was a small wetland landscape area. Hunt et al. (1999) hypothesized and demonstrated that enhancement and repair of a breached dam at the wetland area would create an in-stream wetland that would improve stream water quality by lowering the nitrate-N concentration. Prior to replacing the breached dam, beavers began constructing their own dam at the in-stream wetland outlet. The beaver dam was reinforced to direct water over the center of the dam and to prevent the side walls from eroding. The in-stream wetland impounded approximately 3.3 ha (8.2 ac), and it ranged in depth from about 0.2 to 2 m (0.7 to 7 ft). Emergent aquatic weeds occupied approximately 40% of its surface area and the in-stream wetland perimeter was dominated by trees [swamp tupelo (*Nyssa biflora*), red maple (*Acer rubrum*), and black willow (*Salix nigra*)]. Details on the overall performance of the in-stream wetland can be seen in Hunt et al. (1999).

Subwatershed 3 contained 583 ha (1441-ac) (51% forested and 49% non-forested) and was initially chosen to provide background nutrient concentrations levels. Subwatershed 3 contained fairly extensive riparian buffers compared to subwatershed 2. During the project, subwatershed 3 received increased numbers of swine (about 3,000 to about 14,000 head), which impacted the stream nutrient concentrations (Stone et al., 1998). Subwatershed 4 contained 296 ha (731 ac) (32% forested, 61% non-forested, and 7% lakes) and the dominant stream features were the presence of several lakes that influenced the stream nutrient characteristics. Agricultural best management practices implemented throughout the watershed included nutrient and animal waste management plans, and soil conservation practices (Cook et al., 1996). Nutrient management plans were developed for 887 ha (2,192 ac). Animal waste utilization plans were developed on 168 ha (415 ac). The best management practices for reduced nutrient use included split applications of nitrogen on corn, sidedressing nitrogen according to soil type, and proper crediting of nitrogen content in animal waste. Soil conservation practices on the watershed included conservation crop rotation, cover and green manure crops, and residue management.

Figure 1
Stream water sampling stations in the Herrings Marsh Run Watershed in Duplin County, North Carolina.



Stream monitoring. Stream water quality monitoring stations were established at the Herrings Marsh Run watershed outlet and at subwatershed 2 and subwatershed 3, in September 1990 (Figure 1). A stream water quality monitoring station for subwatershed 4 was established in August 1991. Each monitoring station consisted of a U.S. Geological Survey gaging station and a non-refrigerated automated water sampler. Flow measurements were obtained in cooperation with the U.S. Geological Survey in Raleigh, North Carolina. A U.S. Geological Survey gaging station consisted of a stilling well located in the side of the stream bank and a stage recorder used to measure and record the stream stage. The stream stage was recorded at 15-min intervals. A stage-discharge relationship, developed from water velocity measurements taken at various stream stages, was used to calculate the stream flow. Velocity measurements and corresponding stage readings were taken every 6 to 8 weeks.

The automated water samplers were programmed to collect daily time-based

Table 1. Yearly, cumulative, and mean annual rainfall totals for the Herrings Marsh Run Watershed. Rainfall from National Weather Service Goldsboro, North Carolina and Herring Marsh Run watershed for the pre- and post-in-stream wetland (ISW) periods.

Period	Year	Rain (mm) n	Sum
Pre-ISW	1990	92	337*
	1991	365	1385
	1992	366	1312
	1993	151	506**
	Cumulative Total	974	3540
	Mean Annual		1327
Post-ISW	1993	214	797**
	1994	365	1071
	1995	365	1259
	1996	366	1517
	1997	365	1316
	1998	365	1304
	Cumulative Total	2040	7263
	Mean Annual		1300

* 1990 rainfall from start of sampling October 1, 1990 through December 31, 1990.

** Pre-ISW 1993 rainfall was from January-May, Post-ISW 1993 rainfall was from June-December.

composite samples. In October 1993, the automated samplers were reprogrammed to collect 2-day composite samples comprised of 24 sub-samples taken at 120-min intervals. Beginning in November 1994, the samplers were reprogrammed to collect 3.5-day composite samples. Each composite sample was comprised of 42 sub-samples collected at 120-min intervals. Later, in March 1997, the samplers were reprogrammed to collect 7-day composite samples consisting of 42 sub-samples taken at 240-min intervals. Diluted sulfuric acid was placed in the sampler bottles prior to sample collection to avoid nutrient losses. The acidified samples were collected each week for nutrient analysis. Mass export rates were obtained by multiplying the nutrient concentration with the average flow rate for the samples. Rainfall used in the evaluation and analysis were obtained from the North Carolina climatological weather station in Goldsboro, North Carolina approximately 30 km (19 mi) from the watershed and from our tipping bucket rain gages located on the Herrings Marsh Run watershed.

Sample analysis. After removal from the automated samplers, all water samples were refrigerated and transported to the U.S. Department of Agriculture-Agricultural Research Service (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-N and ammonia-N, using EPA Methods 353.2 and 350.1, respectively (USEPA, 1983). EPA-certified quality control samples were routinely analyzed to verify results.

Statistical analysis. Although no official pre- versus post- best management practices period was initially defined, we divided the project into a pre-in-stream wetland and post-in-stream wetland time period because at the time of the in-stream wetland establishment, the majority of the best management practices on the watershed were either implemented or were in the process of being implemented (Cook et al., 1996). We divided the watershed evaluation into an initial period (pre-in-stream wetland) from September 1990-May 1993, and a post-in-stream wetland period from June 1993-December 1998. Initial findings and a status of the initial observations and conditions on the Herrings Marsh Run watershed of concentrations and exports were reported by Stone et al. (1995).

Statistical analyses on the collected stream water samples were performed using the SAS system (SAS, 1990). Mean and standard deviations were calculated to evaluate both the overall water quality parameters for the entire study period and also for the pre- and post-in-stream wetland evaluation periods. Statistical difference between evaluation periods at each watershed outlet were calculated using the Proc GLM procedure using the Waller-Duncan mean comparison test along with the nonparametric Wilcoxon test.

Results and Discussion

Rainfall. Rainfall totals for the study period varied over the study period (Table 1) with individual yearly rainfall totals ranging from 1,071 to 1,517 mm (42 to 60 in). Several tropical storms contributed to the rainfall totals in 1996. The total rainfall for the pre-in-stream wetland period was 3,540 mm (139 in) over a 974-day interval resulting in a mean annual rainfall of 1,327 mm (52 in, Table 1). The post-in-stream wetland establishment total rainfall was 7,262 mm (286 in) over 2,040 days with a 1,300 mm (51 in) mean annual rainfall total. Overall, mean annual rainfalls for both the pre- and post-in-stream wetland periods were within about 27 mm (1 in).

Stream flow. The watershed stream flows varied based on the rainfalls. The stream flow at the Herrings Marsh Run watershed outlet and subwatersheds were typical of coastal plain watershed with increased flow in the spring and lower flows in the summer months except for events related to tropical storms and hurricanes. At the Herrings Marsh Run outlet and at each subwatershed, the mean daily stream flow was significantly higher in the pre-in-stream wetland period than the post-in-stream wetland period (Table 2). The total stream flow for the Herrings Marsh Run outlet (subwatershed 1) for the pre-in-stream wetland period 0.29 m^3/s (10.2 ft^3/s) (338 mm/yr or 13.3 in/yr) compared to the post-in-stream wetland stream flow of 0.24 m^3/s (8.5 ft^3/s) (321 mm/yr or 12.6 in/yr). Likewise at subwatersheds 2 and 3, mean daily stream flows were significantly higher for the pre-in-stream wetland period. Several tropical storms added to stream flows during the post-in-stream wetland period in 1995 and 1996.

Possible explanations for the reduced flows during the post-in-stream wetland period could be related to the best management practices implemented and riparian zone protection. Additionally, the reduced flows could also be attributed to the establishment of the in-stream wetland, particularly in subwatershed 2 along with the existence of beavers and their impounding small areas throughout the watershed. Little evidence of beavers was observed in the watershed prior to the establishment of the in-stream wetland.

Overall nitrogen concentrations and export. Nitrate-N concentrations. The nitrate-N concentration leaving the 2,360 ha (5,832 ac) Herrings Marsh Run watershed was 1.21 mg/L (ppm) for the entire project duration (1990-1998) (Table 2). This watershed outlet nitrate-N concentration was significantly lower ($p<0.05$) than the concentrations leaving subwatershed 2 (3.49 mg/L or ppm) and subwatershed 3 (1.30 mg/L or ppm), using the Waller and Wilcoxon sign test. Nitrate-N concentrations leaving subwatershed 4 (1.24 mg/L or ppm) were not significantly different

Table 2. Pre- and post-in-stream wetland (ISW) mean stream flow, nitrate-N and ammonia-N concentrations, and annual nitrate-N and ammonia-N export from the Herrings Marsh Run Watershed.

		Flow (m^3/s)			Nitrate-N (mg/L)			Ammonia-N (mg/L)			Mass Nitrate-N (kg/ha)			Mass Ammonia-N (kg/ha)		
		n	Mean	Std	n	Mean	Std	n	Mean	Std	n	Mean	Std	n	Mean	Std
Site	Period															
SW-1	Pre-ISW	666	0.29	0.35	666	2.01b	0.62	653	0.26a	0.36	666	7.14b	8.25	653	0.82a	1.59
	Post-ISW	1741	0.24	0.36	1658	0.88a	0.61	1625	0.26a	0.44	1658	3.88a	7.94	1626	0.75a	1.59
	Total	2407	0.25	0.36	2324	1.21	0.80	2278	0.26	0.42	2324	4.82	8.16	2279	0.77	1.59
SW-2	Pre-ISW	630	0.06	0.06	630	5.63b	1.43	613	0.64b	0.73	630	24.34b	21.14	613	2.91b	5.37
	Post-ISW	1779	0.05	0.08	1779	2.74a	2.30	1761	0.56a	0.81	1779	14.09a	26.83	1761	1.81a	4.23
	Total	2409	0.05	0.07	2409	3.49	2.46	2374	0.58	0.79	2409	16.77	25.85	2374	2.09	4.57
SW-3	Pre-ISW	703	0.08	0.13	703	1.41b	0.75	660	0.19b	0.23	703	7.65b	14.29	660	0.80a	2.89
	Post-ISW	1594	0.05	0.09	1594	1.25a	0.90	1569	0.36a	0.56	1594	5.06a	12.53	1570	0.77a	3.42
	Total	2297	0.06	0.10	2297	1.30	0.86	2229	0.31	0.50	2297	5.85	13.14	2230	0.78	3.27
SW-4	Pre-ISW	593	0.04	0.07	593	1.28a	0.60	575	0.30b	0.30	593	5.52b	7.54	575	0.98a	2.28
	Post-ISW	1399	0.04	0.05	1399	1.22a	0.70	1383	0.35a	0.39	1399	3.92a	4.43	1383	0.89a	1.20
	Total	1992	0.04	0.05	1992	1.24	0.67	1958	0.34	0.37	1992	4.40	5.59	1958	0.91	1.60

Period means followed by the same letter are not significantly different at the 0.05 level using a Duncan-Waller test.

from the Herrings Marsh Run concentrations using the Waller test, but were significantly different when the Wilcoxon sign test was used. These results are consistent with the cultural practices throughout the watershed; subwatershed 2 was more intensively farmed, and it had higher populations of livestock during the majority of the study period.

Ammonia-N concentrations. The ammonia-N concentration leaving the Herrings Marsh Run watershed was 0.26 mg/L (ppm). The ammonia-N concentrations leaving the subwatersheds were significantly higher than the Herrings Marsh Run outlet concentration (Table 2). Subwatershed 3 and subwatershed 4 had similar outlet ammonia-N concentrations, 0.31 and 0.34 mg/L (ppm) respectively. Subwatershed 2 had the highest ammonia-N concentration, 0.58 mg/L (ppm).

Nitrate-N export. The mean annual mass nitrate-N export from the entire Herrings Marsh Run watershed was 4.82 kg/ha (4.3 lb/ac) for the entire project duration. Annual subwatershed 4 nitrate-N export of 4.40 kg/ha (3.93 lb/ac) was not significantly different from the Herrings Marsh Run outlet. Nitrate-N export from subwatershed 3 was significantly higher than the Herrings Marsh Run outlet and subwatershed 4 with a mean annual export of 5.85 kg/ha (5.22 lb/ac). These annual exports were similar to other studies in the eastern Coastal Plain (Inamdar et al., 2001). However, the annual nitrate-N export from subwatershed 2 was 16.8 kg/ha (14.99 lb/ac). This was approximately 3 times higher than the other Herrings Marsh Run subwatersheds and the watershed outlet.

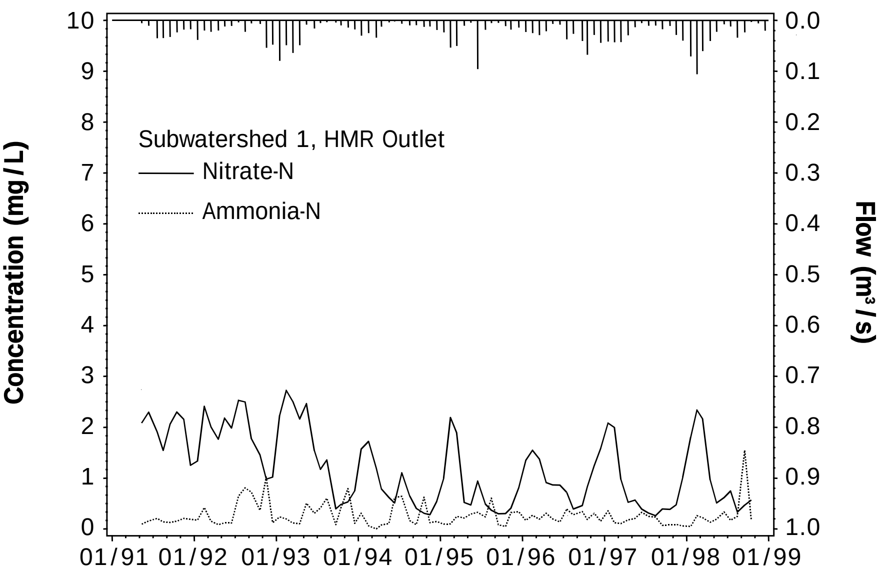
Ammonia-N export. The mean annual ammonia-N export from the Herrings Marsh Run watershed was 0.77 kg/ha (0.69 lb/ac). Mean annual ammonia-N export from subwatersheds 3 and 4 were 0.78 and 0.91 kg/ha (0.7 and 0.81 lb/ac) respectively, and they were not significantly different from the Herrings Marsh Run outlet export. Subwatershed 2 had a mean annual ammonia-N export of 2.09 kg/ha (1.86 lb/ac), which was approximately 3 times the rate leaving the Herrings Marsh Run watershed.

Pre- and post-in-stream wetland analyses. Nitrate-N concentrations. The pre-in-stream wetland nitrate-N concentrations from the watershed (Table 2, Figures 4 and 5) show that two of the subwatersheds (subwatersheds 3 and 4) had relatively low concentrations (<1.5 mg/L or ppm). Subwatershed 3 was initially identified as a "background" site. This subwatershed had extensive riparian buffers along the stream, and contained few animal production facilities. Subwatershed 4 had similar nitrate-N concentration during the pre-in-stream wetland period. Subwatershed 4 was dominated by pastureland and had a large reservoir 0.5 km (0.3 mi) upstream from the sampling station that tended to buffer nutrient transport from the upper reaches of the subwatershed.

The pre-in-stream wetland nitrate-N concentrations from subwatershed 2 were highly elevated (5.63 mg/L or ppm) (Table 2, Figure 3). Suspected causes for these elevated concentrations were the intensive cropping and animal production in the subwatershed. This subwatershed was targeted for implementation of several best management practices including the reconstruction of a lagoon that was undersized and suspected of leaking, and expansion of a swine lagoon effluent spray field that had been undersized and overloaded. The elevated nitrate-N concentrations from subwatershed 2 contributed to the overall Herrings Marsh Run watershed (subwatershed 1) outlet concentration of 2.01 mg/L (ppm). The watershed outlet concentrations were elevated and were higher than concentrations in similar watersheds in the eastern Coastal Plain. For example, Inamdar et al. (2001) reported nitrate-N concentration ranging from 0.8-1.76 mg/L (ppm) for a Virginia Coastal Plain watershed. We concluded that subwatershed 2 had been highly impacted by intensive cropping and animal production and that it was impacting the entire Herrings Marsh Run outlet concentrations.

The post-in-stream wetland period produced consistently lower nitrate-N concentrations from all subwatersheds and from the watershed outlet. Subwatershed 3, initially identified as our "background characteristic" site, had an 11% reduction in nitrate-N concentration from 1.41 to 1.25 mg/L (ppm). Subwatershed 4 had a smaller 5% nitrate-N reduction from 1.28 to 1.22 mg/L (ppm). The major reductions in nitrate-N concentration came from subwatershed 2 and the Herrings Marsh Run watershed outlet. The implementation of best management practices and the establishment of the in-

Figure 2
Mean monthly flow, nitrate-N and ammonia-N concentrations for the Herrings Marsh Run watershed.



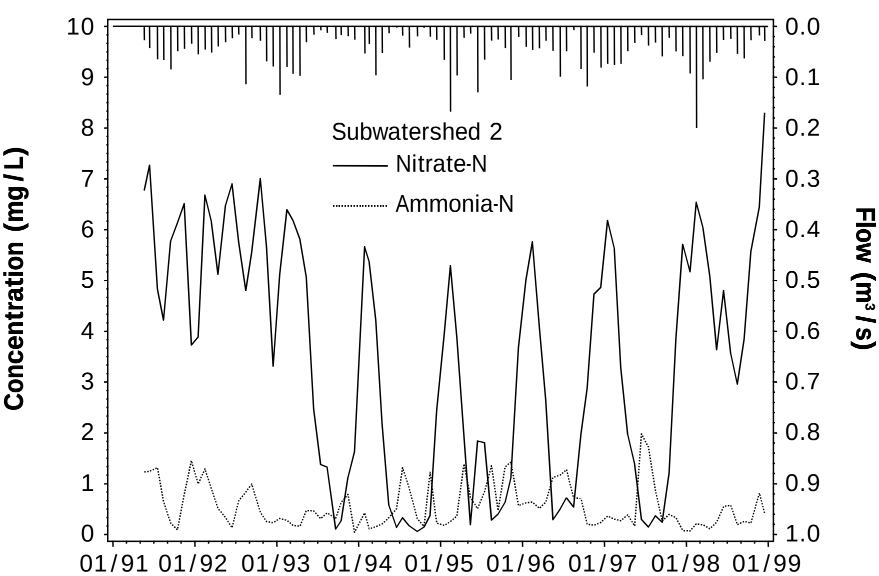
stream wetland in subwatershed 2 reduced nitrate-N concentration by 51% from (5.63 to 2.74 mg/L or ppm). Hunt et al. (1999) reported that the in-stream wetland alone reduced inlet nitrate-N concentrations by 70% during from 1994-1996 and was highly effective during warmer months (April-November) but less effective during the colder months (December-March).

The effectiveness of the in-stream wetland as well as the cumulative effects of the other implemented best management practices throughout the entire watershed helped reduce the outlet nitrate-N concentrations by 56% (from 2.01 to 0.88 mg/L or ppm, Table 2 and Figure 2). The post-in-stream wetland nitrate-N concentrations from the Herrings Marsh Run outlet were consistent with other findings on eastern Coastal Plain watersheds (Inamdar et al., 2001: Spruill et al., 1998).

Ammonia-N concentrations. The ammonia-N concentrations from pre- and post-in-stream wetland periods were not as straightforward as the nitrate-N concentrations. The ammonia-N concentrations from subwatershed 2 were significantly reduced by approximately 12%. This reduction was observed mainly during the colder months (Hunt et al., 1999) and was attributed to more oxidated conditions (Figure 3). Average ammonia-N concentrations increases in subwatershed 3 and subwatershed 4 were higher during the post-in-stream wetland period by 47% and 14% respectively (Figures 4 and 5, Table 2). The subwatershed 3 concentration increase almost doubled from the pre-in-stream wetland level of 0.19 to 0.36 mg/L (ppm) for the post-in-stream wetland period. Much of this increase was suspected to be a result of the increase in animal production in subwatershed 3 (Stone et al., 1998). During the post-in-stream wetland period, swine production increased from about 3,300 to about 14,000 head. The subwatershed 4 concentration increase was small (about 0.05 mg/L or ppm) and could potentially be affected by the release of water from the ponds that dominate the stream system in that subwatershed. Although the individual subwatersheds had both increases and decreases in ammonia-N concentrations, the entire Herrings Marsh Run watershed (subwatershed 1) ammonia-N concentrations were unchanged for the pre- and post-in-stream wetland periods.

Nitrate-N export. The nitrate-N exports were significantly reduced from the Herrings Marsh Run watershed and each subwatershed during the post-in-stream wetland period (Table 2). The reductions ranged from 29% for subwatershed 4 to 46% for the entire Herrings Marsh Run watershed. During the pre-in-stream wetland period, subwatershed 2 had an annual export of approximately 24 kg/ha (21.4 lb/ac) compared to 14 kg/ha (12.5 lb/ac) for the post-in-stream wetland period. The lower nitrate-N export from subwatershed 2 was mainly attributed to the implementation of the best management practices and establishment of the in-stream wetland. Most of the reduction occurred from April to November each year and was attributed to more biological

Figure 3
Mean monthly flow, nitrate-N and ammonia-N concentrations for subwatershed 2 of the Herrings Marsh Run watershed.



activity (Hunt et al., 1999). During the cooler months, the export rates were more similar to the pre-in-stream wetland export rates.

Annual nitrate-N export reductions for subwatershed 3 and subwatershed 4 were not as dramatic. Reductions from each subwatershed were 2.5 kg/ha (2.23 lb/ac) for subwatershed 3 and 1.5 kg/ha (1.33 lb/ac) for subwatershed 4. Subwatershed 3 had reduced nitrate-N export despite having a dramatic increase in animal production during the mid part of the study period.

The Herrings Marsh Run watershed annual export was reduced 46% from approximately 7 kg/ha to 4 kg/ha (6.2 to 3.6 lb/ac). These reductions in the nitrate-N exports at the outlet and subwatershed 3 and subwatershed 4 were similar to other studies in the eastern Coastal Plain. We speculate that in addition to the reduction caused by the in-stream wetland, other observed smaller impoundments by beavers downstream from subwatershed 2 were instrumental in further reducing the nitrate-N export in that section of the watershed, which further assisted in reducing nitrate-N export in the entire watershed.

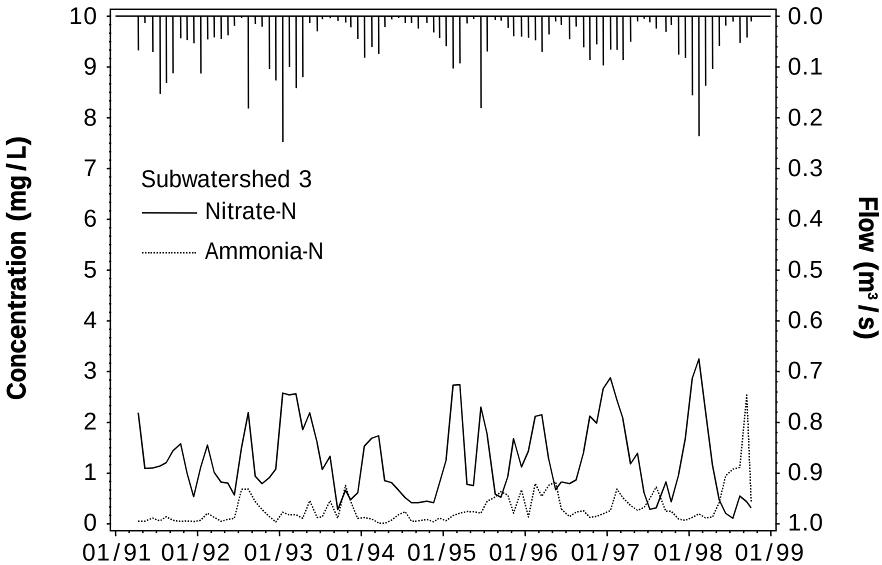
Ammonia-N export. The annual ammonia-N export from subwatershed 2 was significantly lower during the post-in-stream wetland period than during the pre-in-stream wetland period. The subwatershed 2 annual ammonia-N export was 38% lower (similar to nitrate-N export reductions). Again, these reductions were mainly attributed to the effectiveness of the in-stream wetland. The annual ammonia-N export from subwatershed 3, subwatershed 4, and the entire Herrings Marsh Run watershed were not significantly different compared to the pre-in-stream wetland period. However, they all had small reductions ranging from 4 to 9%. The pre- and post-in-stream wetland ammonia-N export from subwatershed 3 and subwatershed 4 were not significantly different, although they had significant concentration increases. This may be attributed to the lower and highly variable flow rates during the post-in-stream wetland period. However, the mean Herrings Marsh Run ammonia-N export from the pre- and post-in-stream wetland periods were approximately the same.

Summary and Conclusion

The original objective of the demonstration project was to determine if the implementation of voluntary best management practices could improve overall watershed water quality.

Figure 4

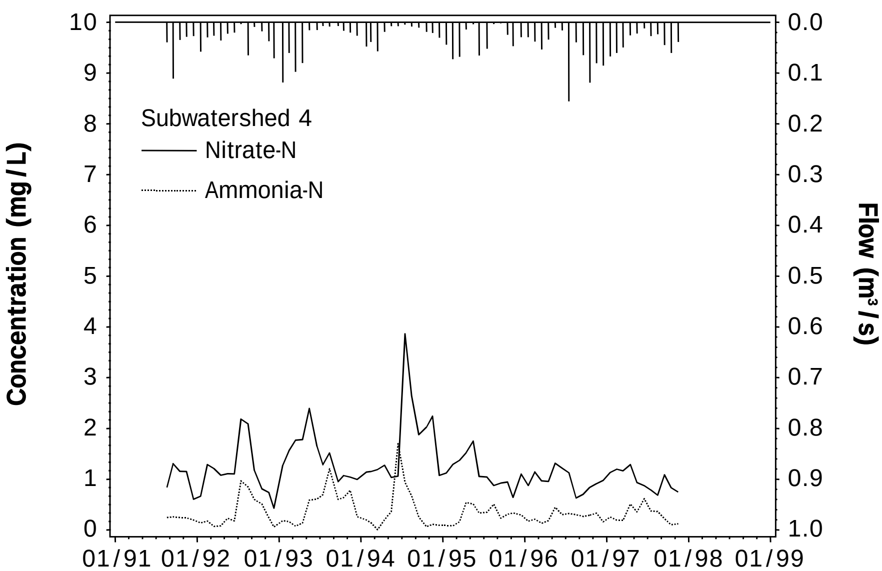
Mean monthly flow, nitrate-N and ammonia-N concentrations for subwatershed 3 of the Herrings Marsh Run watershed.



The nitrate-N concentrations and mass exports were significantly reduced at the watershed outlet and at the three individual subwatersheds. The nitrate concentration reductions were from about 4% to 50% on the subwatersheds and approximately 56% on the entire Herrings Marsh Run watershed. The ammonia-N concentrations were reduced in one subwatershed (about 12%), but increased in two of the other watersheds that had low pre-in-stream wetland concentrations. The overall Herrings Marsh Run watershed ammonia-N concentration was unchanged. The ammonia-N export from subwatershed 2 was significantly reduced (38%). Ammonia-N exports from the other

Figure 5

Mean monthly flow, nitrate-N and ammonia-N concentrations for subwatershed 4 of the Herrings Marsh Run watershed.



subwatersheds and the entire Herrings Marsh Run watershed were not significantly reduced during the study period. The results of this study indicate that voluntary adoption and implementation of improved management practices can have measurable improvements in watershed water quality.

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