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Water quality and hydrology in farm-scale coastal plain watersheds: Effects of agriculture, impoundments, and riparian zones

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Abstract: Dense dendritic stream networks in the Tifton Upland (southeastern U.S. coastal plain) provide an opportunity to determine the effects of land management practices on individual farms on downstream hydrology and water quality. A typical farm will be drained by two or three small streams. The streams may be bordered by riparian forests or impounded into farm ponds. Two adjacent farm-scale basins, both of which were 50 to 60 ha (124 to 148 ac) in size were compared for seven years to determine the effects of upstream agricultural land uses, downstream riparian zones, and small impoundments on stream water quality and hydrology. Stream water quality was sampled at four points on the two basins and at a downstream outlet where the two streams came together in a farm pond. The north basin had more cropland than the south basin and had much more area in plastic-covered beds for vegetable production. The south basin had less land in crop production and much more of the total basin area in farm ponds used to supply irrigation water. The north basin had more surface runoff and higher loads of all nutrients and sediment. The south basin had only 55% of the total runoff of the north basin, probably due to the presence of about 6% of the total watershed area in farm ponds. Up to 26% of the north basin (38% of total cropland) was occupied by wide plastic-covered beds in the last two years of the study. Large quantities of sediment transported in surface runoff from these fields on the north basin led to increases in sediment concentrations and loads of over 100 times compared to both the south basin and to earlier years of the study. Based on reductions in differences in loads and concentrations between upstream and downstream sites, there is less potential to reduce nutrients and sediment once these materials are in stream flow than when water is moving to streams through a riparian buffer. A downstream pond that received inputs from both the north and south basins had significantly lower concentrations of most nutrients and sediments than either of the upstream sampling sites.

Key words: erosion—farm ponds—nutrients—sediment—suspended solids

Agricultural watersheds in the southeastern coastal plain are generally characterized by intensive crop production on moderately to well-drained upland soils and riparian forests and wetlands on poorly and very poorly drained soils along streams (Lowrance and Leonard 1988). Previous studies of nutrient and sediment transport from coastal plain watersheds have generally focused on larger watersheds, which are made up of numerous farms (Inamdar et al. 2001; Jordan et al. 1997; Lowrance and Leonard 1988; Lowrance et al. 1985). Very few studies have examined the scale of watershed that is similar to the size of a single farm. Additionally, a number of studies have examined the nonpoint source pollution control functions of riparian forest buffers in agriculture on a field scale (Daniels and Gilliam 1996; Jacobs and Gilliam 1985; Lowrance et al. 2000; Sheridan et al. 1999). Most of these studies used a hill slope approach, tracking subsurface and/or surface inputs of nutrients and sediments from the edge of a field through the buffer system. No studies in the coastal plain have taken a stream segment approach and examined the changes in transport of agriculturally derived pollutants entering and exiting a stream reach. Knowledge of stream flow water quality and hydrology are necessary to understand the influence of extreme events and poor management practices. The stream reach approach is difficult because of the problems of achieving replication of stream reaches and because of the difficulty involved in making reliable input/output measurements on stream reaches without impacting the physical, chemical, and/or biological attributes of stream flow.

This study compares two adjacent farm-sized basins in the southeastern coastal plain, each with significant agricultural land use. The study area was chosen because data were available from earlier studies on the edge of field effects of riparian zones (Lowrance et al. 2000); edge of field sediment transport (Sheridan et al. 1999); and subsurface hydrology (Bosch et al. 1994). Hydrologic measurements were made to minimize disturbance by using existing road culverts, where possible, and the watershed was selected because of similar land use but different area in ponds to make comparisons simpler. The study allows comparison of the hydrology and water quality of the two basins as well as the changes occurring within downstream reaches. The basins were instrumented to measure water, sediment, and nutrient outputs at two points (upstream and downstream) within both of the basins. In addition, the study was designed to determine the changes in agriculturally derived inputs (water, sediment, nutrients) in a short stream segment by measuring upstream inputs and downstream outputs in stream flow. The upslope watersheds of both stream segments are agricultural but have very different characteristics. Nutrient concentrations of the two upstream basins are compared to a downstream outlet exiting a farm pond after the confluence of the streams in the upper portion of the pond.

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Figure 1
Aerial view of watersheds in March 1993.

Notes: Field numbers shown were used to gather crop and land cover data. Note that the pond system on the south basin between fields 017 and 018 was not complete. By 1996 when the study began, the other three ponds shown in figures 2 to 4 had been constructed.

Methods and Materials

Study Area. The study was conducted on small basins (Gibbs farm) in the drainage of the Little River Watershed near Tifton, Georgia, for over seven years, from October 1996 through November 2004. The Little River is an eight-digit hydrologic unit of the Suwannee River Basin. The Little River Experimental Watershed (LREW) is the upper 334 km^2 (129 mi^2) of the Little River and is the subject of long-term hydrologic and water quality research by USDA-ARS and cooperators (Lowrance et al. 1985; Lowrance and Leonard 1988; Sheridan 1997). Although the Gibbs Farm basins are not in the part of the gauged drainage of the LREW, they are only about 12 km (7.4 miles) away. The Gibbs farm basins are similar in land use, soils, and hydrogeology to the gauged portion of the watershed. Long-term average data for the LREW showed that average precipitation of 122 cm (48 in) produced average stream flow of 37 cm (14.6 in), with stream flow accounting for 30% of rainfall (Sheridan 1997).

The LREW and the Gibbs farm basins are located in the Tifton Upland physiographic region, which is characterized by intensive agriculture in relatively small fields in upland areas and riparian forests along stream channels. The Gibbs farm basins are typical of the region with 23 fields identified within the 123 ha (304 ac) basin with an average field size of 3 ha (7.4 ac) (figure 1 and table 1).

The total basin was defined by site 8925, the outlet of a farm pond (figures 2 to 4). The two paired basins were each defined by an upstream gauging site and a downstream gauging site (figures 2 to 4). On the south basin, the upstream site was designated 8921, and the downstream site was 8922. On the north basin, the upstream site was 8923, and the downstream site was 8924. On both basins the distance from the upstream to downstream sites was about 200 m (620 ft). Each site can be used to define a surface watershed based on topography and field drainageways. The total basin defined at the farm pond outlet (8925) is 123 ha (304 ac, table 1). The two basins defined by the downstream gages are 60.8 ha (150 ac) and 50.4 ha (125 ac), respectively for the south and north basins. Both the south and north basins are nested in the larger basin defined by 8925. The watersheds defined by 8921 and 8923 are nested in the full south (8922) and north (8924) basins, respectively.

The area and generalized land cover of each watershed are in table 1. Both the south and north basins include stream reaches bordered by mature riparian forest. There were large differences in percent forest and percent fields, but the largest difference was in percent ponds (table 1). The south basin had about four times more pond area than the north basin. In addition, the ponds on the south basin were newer, with most of the pond area constructed between 1993 and 1996. Ponds on the south basin were used to irrigate the south basin cropland. The one small pond on the north basin was constructed prior to 1993 (figure 1) and has undergone at least 11 years of sedimentation. Field observations indicated that storage volumes in the small pond on the north basin

Table 1
Average land use for 1996 to 2004 in the five watersheds.

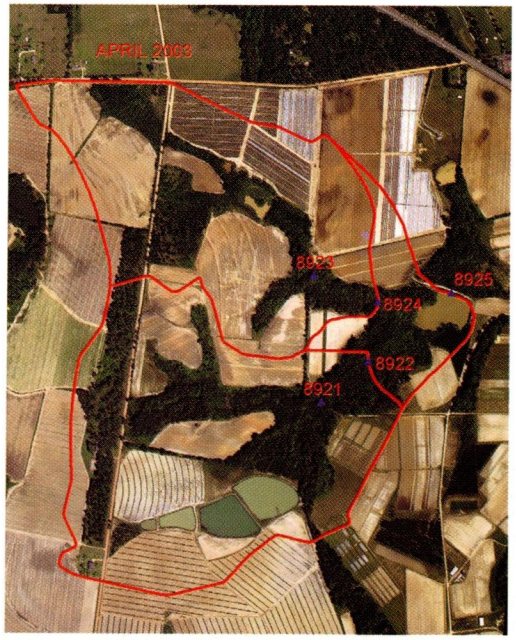
Basin	Watershed	Roads (ha)	Roads (%)	Fields (ha)	Fields (%)	Forest (ha)	Forest (%)	Ponds (ha)	Ponds (%)	Total (ha)
South	8921	0.84	1.48	29.56	51.8	23.10	40.4	3.60	6.30	57.11
South	8922	0.84	1.39	30.24	49.7	26.17	43.0	3.60	5.92	60.85
North	8923	0.46	0.98	31.80	68.0	13.77	29.5	0.71	1.52	46.74
North	8924	0.46	0.91	33.22	65.9	16.06	31.8	0.71	1.41	50.44
Total	8925	1.30	1.06	68.24	55.4	48.10	39.0	5.62	4.56	123.27

Notes: Watershed 8921 is nested in 8922. Watershed 8923 is nested in 8924. All four sites (8921 to 8924) are nested within watershed 8925.

Figure 2
Aerial view of watersheds in February 2002.

Notes: Watershed boundaries are shown in red with corresponding station number. Note the lack of plastic-covered beds for vegetables.

Figure 3
Aerial view of watersheds in April 2003.



Notes: Note fields on the north basin, above stations 8923 and 8924, where plastic-covered beds for vegetable production have been installed. Plastic-covered beds were being installed on field 006 when this photograph was taken.

have been significantly reduced by sedimentation. The north basin pond was not used for irrigation.

In addition to differences in the generalized land cover for the north and south basins, there were some differences in crop distribution. We conducted summer crop cover surveys for 1996 through 1998 and quarterly crop surveys for 1999 to 2004 based on a field map (figure 1). Proportions were calculated by using crop cover for each sampling date and computing a total area of crop cover for the entire record period. The sum of areas for each crop was computed and calculated as a percent of the total crop area through time. The two watersheds had similar proportions of winter fallow land (40% and 41%, respectively) and winter small grains (15% for both watersheds). There were differences in row crops (corn, cotton, peanuts—24% and 28%, respectively) and truck crops (vegetables, melons—11% and 16%, respectively); and pasture (8% and 0%, respectively). Overall, row crops and truck crops were 35% of the cropland in the south basin and 44% of the cropland in the north basin. In addition, a higher proportion of the truck crop land was in plastic-covered beds in the north basin. In the later years of the study (2003 to 2004), all of the truck crop land was in plastic-covered beds in the north basin while only about one-third of the truck crops in the south basin were on plastic-covered beds (figures 3 and 4). In addition, the plastic-covered beds on the south basin were much narrower plastic, and runoff from the rows emptied into the farm ponds rather than going to the stream through the riparian zone (figures 3 and 4).

Hydrology and Water Quality Sampling. Water quality sampling began in October, 1996, and hydrologic measurements began in December 1997. Beginning in December 1997, stream flow stages were measured at the four stream gauging sites using Druck pressure transducers. Stage measurements were made every ten minutes and recorded with a Campbell CR-10 data logger. Stage measurements at sites 8921 and 8923 were taken at the existing culvert pipes. Site 8921 had a 61 cm (24 in) culvert, and site 8923 had a 76 cm (30 in) culvert. At sites 8922 and 8924, broad-crested v-notch weirs were installed to constrict stream flow for accurate stage and discharge measurements. At all four gauged sites, a combination of hydraulic flow theory and standard discharge measurements were

Figure 4
Aerial view of watersheds in March 2004.

Note: Plastic-covered beds have been installed in fields on north watershed.

used to develop rating equations for discharge versus stage. Rainfall was measured at a recording tipping bucket rain gage (Texas Instruments Inc.) located on the watershed.

Stream samples for water quality analysis were collected at sites 8921 to 8924 from October 1996 through November 2004. Samples from site 8925 (pond outflow site) were collected from January 2001 through November 2004. Samples were taken in one of two ways. From October 1996 through October 1997, all samples were collected as weekly grab samples in the main flow of the channel. Beginning in November 1997, flow proportional samples were collected at sites 8921 to 8924 using ISCO Model 2910 automated composite samplers. The samplers were controlled by the data logger with the frequency of pumping proportional to the flow rate (Jordan et al. 1997). Stream stage versus discharge relationships were used in the data logger to calculate discharge. The accumulated discharge was stored by the data logger, and when a programmed quantity of flow had occurred, the data logger pulsed the sampler. The sampler can be programmed to sample on each pulse or to wait up to 9999 pulses before taking a sample. The ISCO 2910 samplers were used to pump samples into chemically clean glass jars lined with chemically clean polyethylene sampling bags. The composite samples were collected every week, usually on Mondays, so each sample represents the flow for the previous seven days. Samples were not preserved using acid or any other preservative.

Water Quality Analysis. All water samples were placed on ice in coolers and transported to the laboratory in Tifton, Georgia, about 15 minutes from the field site. In the lab, samples were filtered through pre-weighed Whatman 934 AH filters, and the filters were dried and weighed for determination of suspended sediment (Sheridan et al. 1999). An aliquot of the filtrate was stored for nutrient analysis. In addition, an aliquot of the unfiltered sample was frozen for analysis of total Kjeldahl N (TKN) and total P in a digestate. The filtered sample was analyzed for nitrate-N, ammonium-N, dissolved molybdate reactive P (ortho P), and chloride using EPA approved colorimetric techniques (Clesceri et al. 1998) on a Lachat Flow Injection Analyzer within seven days of collection. The unfiltered sample was analyzed for TKN and total P using digestion and colorimetric techniques adapted from EPA approved methods (Clesceri et al. 1998). Beginning in 1998, filtered samples were analyzed for dissolved organic carbon using a Shimadzu model 5050 TOC analyzer. Beginning in 2001, filtered samples were analyzed for potassium using standard methods on a Perkin-Elmer atomic absorption spectrophotometer.

Data Analysis and Statistics. Water quality parameters were calculated from the measured values. Total N was the sum of NO_3-N and TKN. Organic N was TKN minus NH_4-N. Inorganic N was the sum of NO_3-N plus NH_4-N.

For some analyses, hydrologic data were grouped by season. Because of rainfall patterns and the timing of instrumentation coming online, we grouped December through November into water years. Stream flow is generally very low or zero until rains start in early winter, typically in early December. For purposes of this study, season 1 (winter) was defined as December through February, season 2 (spring) was March through May, season 3 (summer) was June through August, and season 4 (fall) was September through November. This seasonal alignment also corresponds well to seasonal changes in agricultural practices and has proven useful for previous hydrologic studies in the coastal plain (Sheridan et al. 1999).

Flow-weighted mean concentrations were calculated for watersheds 8921 to 8924 for the time period December 1, 1997, through November 30, 2004. Flow-weighted concentrations were calculated as follows:

$$\text{Flow-weighted mean} = \sum((\text{weekly flow (L)} * \text{weekly concentration (mg L}^{-1}))/\text{total flow (L)}) \quad (1)$$

The concentration data were tested for normal distribution using the Univariate Procedure of the Statistical Analysis System (SAS 1999). The concentration data were not normally distributed so typical analysis of variance was not used. Instead, the NPAR1WAY Procedure of SAS (SAS Institute 1989) with the Kruskal-Wallis test of the Wilcoxon Scores was used. NPAR1WAY is a nonparametric procedure that tests whether the distribution of a variable has the same location parameter across different groups. The Kruskal-Wallis tests the null hypothesis that the groups are not different from each other by testing whether the rank sums are different based on a Chi-square distribution (Sokal and Rohlf 1981). Data were analyzed to determine if there were concentration differences among watersheds

Figure 5
Sediment deposition in the stream channel at station 8923, due to erosion from field 006.

Note: About 55 cm (1.8 ft) of sediment deposition occurred in less than two years.

Figure 6
Erosion from field road at base of field 006, showing depth below original ground surface.

Note: Over 60 cm (2 ft) of erosion occurred in less than two years.

for the entire record period, to determine if there were differences in the flow-weighted concentrations, and to determine if there were differences among watersheds 8921 to 8925 for the period February 2001 through November 2004. Significant differences of at least the 0.05 level were reported.

Loads were calculated based on concentrations in the flow proportional samples. The concentration for a weekly composite sample was multiplied times the total flow for the week represented by the sample. There were a total of 556 weeks during the record period December 1, 1997, through November 30, 2004, on watersheds 8921 to 8924 when flow was measured and samples were taken. On 25 of these weeks (4% of total samples), a grab sample was used instead of the flow proportional composite sample.

Estimates of Gross Erosion. In March 2003, plastic-covered beds for vegetable production were installed up and down the slope in field 006 on the north side of the north basin (figures 1 and 4). This field became a significant source of sediment input directly to the stream for the north basin (figure 5). Sediment was derived from the wheel tracks between plastic-covered beds and from the field road at the bottom of the hill slope. Because of the large amounts of erosion observed to be coming from this field, we estimated the mass of erosion by field measurements so the gross erosion could be compared to the stream sediment transport. Gross erosion from the fields was estimated from the apparent loss of soil in eroded wheel tracks (EWTs) and the field road bordering the field. Low-altitude, high-resolution aerial photographs taken in March 2003 and April 2004 were used to estimate the number and length of each wheel track subject to excessive erosion. The depth and width of the wheel tracks and the depth and width of down-cutting on the road were measured in the field with a tape measure in August 2004. The eroded depth of the road was compared to the original ground surface elevation on the other side of a field fence. This technique made for a very simple estimate of the road depth because the other side of the field fence was in grass and was at the original elevation (figure 6). The depth of the EWTs was measured at five locations on the hill slope for 10 wheel tracks. The depth of the EWTs was compared to the depth of uneroded wheel tracks (UWTs) on similar beds on flat surfaces at the top of the field.

The UWTs were adjacent to beds established at the same time as field 006 beds but were on flat surfaces at the top of the watershed. Visual inspection of the UWTs indicated there was negligible erosion but that the beds had settled over time after installation. The gross erosion was estimated as the amount of soil lost from EWTs and the eroded field road. For the EWTs, the gross erosion A_{wt} was estimated by the following:

$$A_{wt} = \sum \text{length of EWT (m)} * \text{width of EWT (m)} * (\text{depth EWT} - \text{depth UWT (m)}) * \text{bulk density (Mg/m}^3) \quad (2)$$

The gross erosion from the field road (A_{fr}) was estimated for different eroded segments of the road (ESR) in a similar manner:

$$A_{fr} = \sum \text{length of ESR (m)} * \text{width of ESR} * \text{depth ESR(m)} * \text{bulk density (Mg m}^{-3}) \quad (3)$$

Bulk density (1.4 Mg m^{-3}) was estimated from soil survey samples taken at the Gibbs research farm on a Tifton Series soil (Perkins et al. 1986).

Total gross erosion (A) from field number 006 was the sum of A_{wt} and A_{fr}. Using this technique, the total gross erosion from the field was only that erosion that occurred from March 2003 through November 2004. Because of the pattern of rainfall, this included two periods of high erosion rates (spring and summer 2003, and spring and early summer 2004). Thus, the gross erosion estimates were considered to be most of the erosion that would occur in two years of erosion. A sediment delivery ratio (percent) was calculated for 2003 and 2004 for the north basin as follows:

$$(\sum \text{stream sediment transport}/\sum \text{gross erosion}) * 100 \quad (4)$$

Results and Discussion

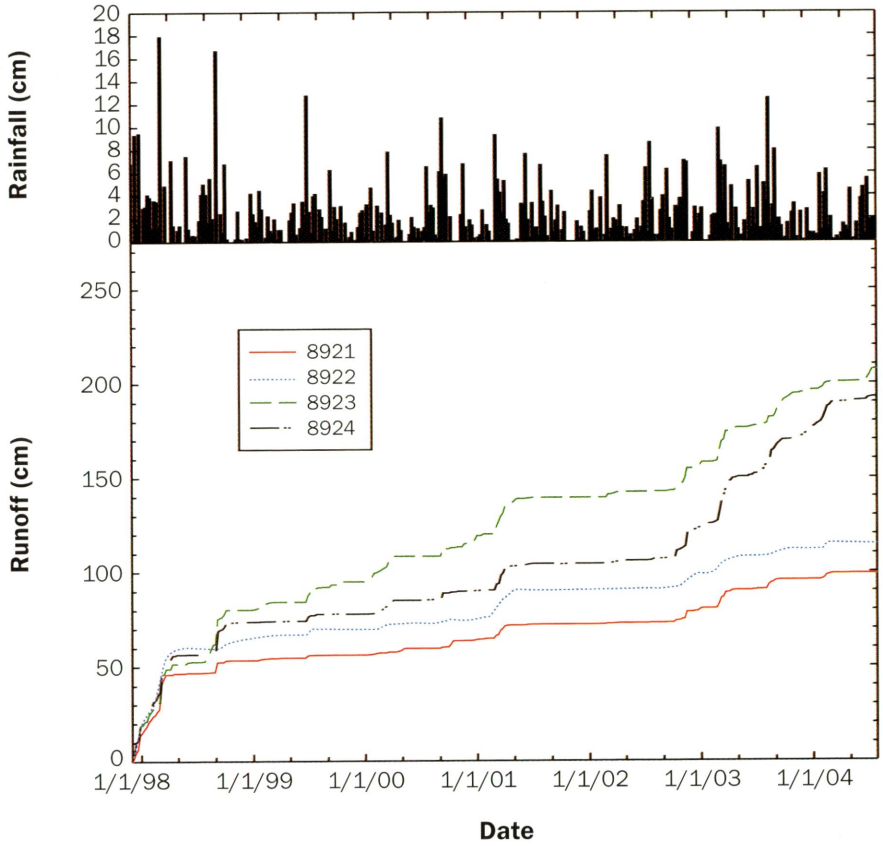
Hydrology. The two watersheds had significantly different amounts of runoff. Beginning in the first year of stream flow measurements, at the time of a very large rainfall event from Tropical Storm Earl in September 1998, the north basin (8923 and 8924) produced more runoff than the south basin (8921 and 8922) at both the upstream and downstream sites (figure 7). This trend continued throughout the study period with the exception of the end of the drought period (2001 through late 2002) when very little runoff occurred from any of the watersheds (figure 7). For the entire study period, the north basin (8923 and 8924) had 1.84 times the cumulative runoff as south basin (8921 and 8922) (figure 7 and table 2). For the entire study, the average of the upstream and downstream sites showed that north basin had about 209 cm (82 in) of runoff and the south basin had about 113 cm (45 in) of runoff (table 2). Runoff was about 27% and 15% of measured rainfall on the north and south basins, respectively (table 2). The basins also had large seasonal differences which are related to land use differences (table 2). During winter (December through February) and spring (March through May), runoff on the north basin was about 1.4 times that from the south basin. During summer (June through August) and fall (September through November), the north basin had 3.8 and 2.9 times the runoff of south basin (table 2).

Land use differences between the two watersheds, particularly the large amount of pond area on the south basin, were probably responsible for the differences in stream flow until early 2003 when plastic-covered beds were installed in the north basin. For the hydrologic record period, the north basin had a similar amount of stream flow for the record period as nearby watersheds that are part of the long-term LREW (SEWRL 2007). Land use and farming practices in LREW are similar to the Gibbs farm basins. Stream flow for the watershed nearest to the Gibbs farm basins (watershed O) was 205 cm (81 in) for the record period December 1, 1997, through November 30, 2004, very similar to the north basin. The largest differences between north and south basins occurred during the summer and fall (table 2) when upslope runoff was collected in the pond system on the south basin and subsequently used for irrigation. Runoff volumes from the two basins began to diverge markedly in early 2003 when wide plastic-covered beds were installed on the north basin (figure 7). Runoff from the north basin was probably enhanced by the amount of area under plastic-covered beds, especially from 2003 to 2004. During this time period, all of the truck crops on the north basin were in wide plastic-covered beds with narrow wheel-tracks. Beds were being installed when the aerial photograph was taken on March 19, 2003 (figure 3). When bed preparation was completed on the north basin in late April 2003, at least 26% of the entire basin, 38% of the total cropland, was in wide plastic-covered beds. These beds were often installed up and down the slope to minimize turning during bed installation. This condition persisted through all of 2004 and is shown in figure 4 for March 2004. Therefore for April 2003 through the end of the study, 26% of the north basin was in wide plastic-covered beds that drained directly into the riparian forest. In contrast, only 12% of the south basin was in plastic-covered beds in March 2004. These plastic-covered beds were narrower and drained into the ponds on the south basin (figure 4). In addition, in certain periods stream flow occurred on the north basin due to over-irrigation of the plastic-covered beds with drip irrigation. The combination of significant portions of the north basin under plastic and periods of over-irrigation from the drip lines led to slightly enhanced runoff from the north basin. The differences in the watersheds that led to large differences in overall stream flow, especially the ponds in the south basin, are reflected in nutrient and sediment load differences shown below.

There were very large interannual differences in precipitation and stream flow amounts for the 1997 to 2004 record period (figure 7). The first year of the study (December 1997 through November 1998) was a wet year, with 142 cm (60 in) of precipitation (long-term mean 122 cm) (Sheridan et al. 1997). The next four years were drought years with 12 month totals of 89 cm (35 in) , 102 cm (40 in), 96 cm (38 in), and 107 cm (42 in) (figure 7). December 2002 to November 2003 had 126 cm (50 in) of rainfall, close to the long-term mean of 122 cm (48 in). These differences in precipitation are reflected in differences in stream flow (figure 7). It is especially striking that after the four-year drought, there was a much greater stream flow response in the north basin than the south basin when rainfall returned to near-average conditions.

Sediment and Nutrient Concentrations. Sediment and nutrient concentrations were significantly different among the four nested watersheds (8921 to 8924, tables 3 and 4) and the outlet of the pond (8925) (table 5). For the entire record period, 1996 to 2004, arithmetic mean concentrations of sediment, NH4-N, NO3-N, Total N, inorganic N, ortho-P, DOC, and K were higher on the north basin (8923 and 8924) than on the south basin (8921 and 8922) (table 3). This reflected the greater intensity of agricul-

Figure 7
Weekly precipitation and weekly cumulative flow for the four watersheds, December 1, 1997 through November 30, 2004.



Notes: Watershed 8921 is nested in 8922 and watershed 8923 is nested in 8924. Note large increases in flow from the north basin (8923 and 8924) beginning in early 2003 when installation of plastic beds was increasing.

ture, particularly vegetable production, on the north basin. Although most trends were similar for flow-weighted concentrations (December 1997 to November 2004), flow-weighted sediment and nitrate concentrations were higher than arithmetic mean concentrations and flow-weighted TKN and DOC were lower than arithmetic mean concentrations on all four watersheds (tables 3 and 4). Potassium showed the largest and most consistent difference between the south basin and the north basin. It appears that K levels may be a good indicator of the effects of agricultural activity within these watersheds. Although there were no significant regressions of concentration versus discharge for any of the watersheds (data not shown), flow-weighted concentrations that were higher than arithmetic mean concentrations indicated increased concentrations during high flows and lower flow-weighted concentrations indicated lower concentrations during high flows.

Although there were not large differences among the nested watersheds within a basin, the upstream watersheds (8921 and 8923) had higher sediment and inorganic N and P concentrations, and the downstream watersheds (8922 and 8924) tended to have higher DOC concentrations (tables 3 and 4). This trend was more evident for flow-weighted concentrations, especially for sediment. The largest differences between upstream and downstream concentrations for both arithmetic means and flow-weighted concentrations were for sediment and ortho-P between 8923 and 8924 (tables 3 and 4).

The downstream outlet of the entire watershed (8925) showed the influence of the lower farm pond on water quality for the record period February 2001 through November 2004 (table 5). The pond outlet had significantly lower concentrations of sediment, NH_4-N, NO_3-N, and inorganic N. Concentrations of DOC and K at 8925 were intermediate between the values for the north basin and the south basin (table 5).

Flow-weighted sediment concentrations showed very large changes over time (figure

Table 2
Stream flow for south and north basin and the subwatersheds, stream flow as a percent of rainfall, and north basin stream flow over south basin stream flow for each season and the total record period.

Season	South basin stream flow (cm)		North basin stream flow (cm)		Rainfall (cm)	Stream flow/rainfall		North stream flow/ south stream flow
	8921	8922	8923	8924		South	North	
1 (D, J, F)	36.8	46.0	55.0	58.2	163.2	25.4%	34.7%	137%
2 (M, A, M)	38.4	49.2	65.0	64.4	173.7	25.2%	37.2%	148%
3 (J, J, A)	7.6	6.9	32.1	23.1	236.0	3.1%	11.7%	381%
4 (S, O, N)	23.2	18.4	60.0	60.1	199.8	10.4%	30.1%	289%
Total	105.7	120.5	212.1	205.8	772.7	14.7%	27.0%	184%

Notes: Season 1 was December, January, and February. Season 2 was March, April, and May. Season 3 was June, July, and August. Season 4 was September, October, and November.

Table 3
Arithmetic mean concentrations for each watershed for the entire record period, October 1996 to November 2004.

Watershed (number of samples)	Sediment[b] (mg L-1)	NH4-N[b] (mg L-1)	NO3-N[b] (mg L-1)	Total N[a] (mg L-1)	Inorganic N[b] (mg L-1)	Organic N[c] (mg L-1)	TKN[c] (mg L-1)	Ortho-P[b] (mg L-1)	Total P[c] (mg L-1)	Cl[c] (mg L-1)	DOC[a] (mg L-1)	K[b] (mg L-1)
8921 (252)	30.0	0.14	0.30	2.42	0.44	1.73	2.05	0.017	0.29	10.7	7.61	2.14
8922 (223)	29.8	0.15	0.27	2.64	0.42	1.97	2.32	0.013	0.34	10.8	8.65	2.50
8923 (227)	297	0.28	0.57	3.07	0.85	1.98	2.46	0.041	0.33	11.3	6.79	8.24
8924 (239)	204	0.20	0.45	2.81	0.65	1.92	2.30	0.023	0.33	11.1	8.72	8.87

[a] Significantly different at least the 0.0001 level based on Kruskal Wallis test.
[b] Significantly different at least the 0.05 level based on Kruskal Wallis test.
[c] No significant difference based on the Kruskal Wallis test.

Table 4
Flow weighted mean concentrations for each watershed for the hydrologic record period, December 1997 to November 2004.

Watershed	Sediment (mg L-1)	NH4-N (mg L-1)	NO3-N (mg L-1)	Total N (mg L-1)	Inorganic N (mg L-1)	Organic N (mg L-1)	TKN (mg L-1)	Ortho-P (mg L-1)	Total P (mg L-1)	Cl (mg L-1)	DOC (mg L-1)	K (mg L-1)
8921	43.6	0.13	0.71	2.14	0.84	1.31	1.44	0.022	0.30	9.77	6.44	2.42
8922	31.2	0.14	0.59	1.81	0.72	1.08	1.22	0.004	0.22	9.40	6.70	2.57
8923	300	0.20	0.64	2.19	0.84	1.34	1.55	0.065	0.28	8.42	6.55	8.39
8924	263	0.22	0.59	2.39	0.80	1.59	1.81	0.027	0.33	8.64	6.81	8.08

Table 5
Mean concentrations for five watersheds for the period February 2001 to November 2004.

Watershed (number of samples)	Sediment[b] (mg L-1)	NH4-N[a] (mg L-1)	NO3-N[b] (mg L-1)	Total N[c] (mg L-1)	Inorganic N[a] (mg L-1)	Organic N[c] (mg L-1)	TKN[c] (mg L-1)	Ortho-P[c] (mg L-1)	Total P[c] (mg L-1)	Cl[c] (mg L-1)	DOC[a] (mg L-1)	K[b] (mg L-1)
8921 (86)	34.8	0.06	0.34	2.27	0.39	1.87	1.93	0.016	0.32	9.59	8.21	2.19
8922 (65)	56.9	0.06	0.27	2.30	0.33	1.97	2.03	0.011	0.38	9.80	9.00	2.47
8923 (68)	583	0.14	0.47	2.38	0.62	1.76	1.90	0.026	0.43	9.58	7.10	8.48
8924 (74)	446	0.10	0.47	2.39	0.57	1.82	1.93	0.021	0.40	8.98	8.25	8.98
8925 (50)	24.0	0.07	0.24	2.08	0.31	1.77	1.84	0.019	0.26	8.43	8.17	4.64

[a] Significantly different at at least the 0.0001 level based on Kruskal-Wallis test.
[b] Significantly different at at least the 0.05 level based on Kruskal-Wallis test.
[c] Not significantly different based on the Kruskal-Wallis test.

8). For the first five years of the study, including the drought years, all flow-weighted sediment concentrations were similar on the north and south basins. For the final two years of the study, the flow-weighted sediment concentrations were much higher on the north basin (figure 8). These sediment concentration increases coincided with the increased use of wide plastic-covered beds for vegetable production observed on the north basin (figures 3 and 4). Plastic-covered beds substantially accelerated runoff and erosion from the non-covered surfaces due to the large area of impervious surface. This effect has also been observed in Oxisols under plastic-covered beds for pineapple production in Hawaii (Wan and El Swaify 1999) and in Ultisols under plastic-covered beds for tomato production in Maryland (Rice et al. 2004).

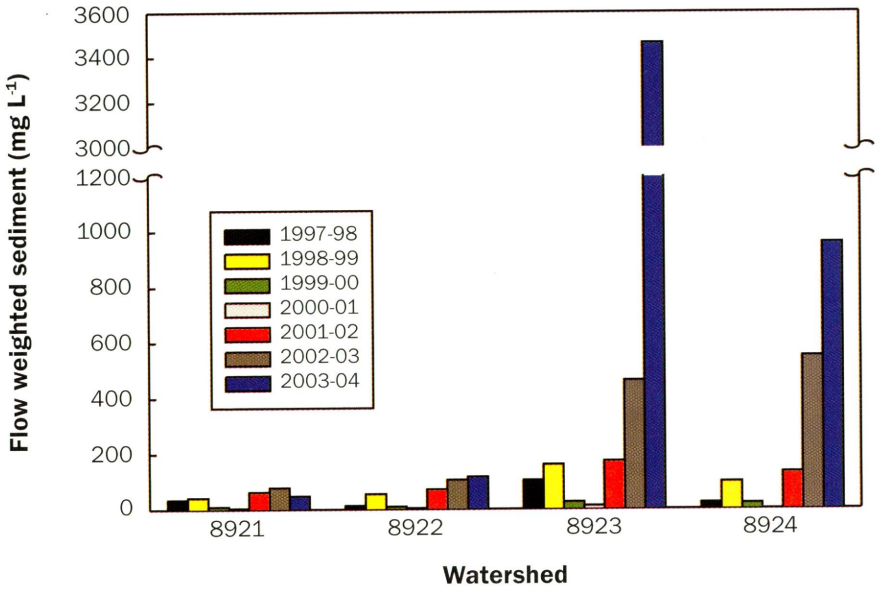
Sediment and Nutrient Loads. The large differences in both stream flow volumes and nutrient concentrations between the north and south basins led to large differences in sediment and nutrient loads for the two basins (table 6). Nutrient loads were typically at least twice as high on the north basin (8923 and 8924) as the south basin (8921 and 8922). Ortho-P and K loads were 7 to 10 times higher and sediment loads were over 10 times higher from the north basin than the south basin (table 6).

Annual loads from the four subwatersheds reflected both the great variability in flow from a wet year (1997 to 1998) to drought years (1998 to 1999, 1999 to 2000, 2000 to 2001), and to an average year (2002 to 2003). Loadings of all nutrients and sediment ranged over at least one order of magnitude between years (table 7). Although there were very large differences in loads between watersheds within a year, with the exception of sediment, the differences were larger among years for the watersheds. For instance, the wet year (1997 to 1998) had over four times the load of total N than the three drought years combined. The average year (2002 to 2003) had about 1.5 times the total N load as the three drought years.

Sediment loads on the north basin increased by 8 to 10 times in the final two

Figure 8

Flow weighted sediment concentrations for the seven water years of the study on the four watersheds.



Notes: Watershed 8921 is nested in 8922, and watershed 8923 is nested in 8924. Increased sediment concentrations on the north basin (8923 and 8924) in 2003 and 2004 coincided with increased area of plastic covered beds on the north basin.

years of the study (table 7). These increases were due to increased flow (table 7 and figure 7) and to increased flow-weighted sediment concentrations (figure 8) during this time period. Similar increases were not seen on the south basin. The sediment load increases were apparently due to the large area of plastic beds that was installed immediately upslope of the gauging station at 8923 (figure 4). Estimates of the gross erosion from just field 006 immediately above the gauging station (shown in red on figure 4) were 2,290 Mg (2,525 ton) from a 4.52 ha (11.16 ac) field. Although this was only part of the gross erosion from the fields on the north basin, from aerial photographs and field observations field 006 appeared to be the most erosive portion of the watershed. Total average stream flow sediment load was 217 Mg (239 ton) from the north basin (204 Mg at 8923 and 230 Mg at 8924) during 2003 and 2004. The sediment delivery ratio (stream sediment transport/gross erosion) from the north basin was about 9% based only on the estimated gross erosion from field 006. Clearly, field 006 provided only part of the total gross erosion from the north basin. The actual sediment delivery ratio would have been less than 9% if the entire gross erosion from the north basin was considered.

Comparisons of North and South Basins. The stream flow of the north and south basins was apparently influenced in opposite directions by changes in land use over the course of the study. This response was due to the increase in area of plastic-covered beds on the north basin and the large amount of pond area on the south basin. Although further studies are needed, these data indicated that on a watershed basis a high percent of plastic-covered beds will increase runoff, and a high percentage of ponds will decrease runoff. Based on hydrologic differences alone, the ponds on the south basin appeared to have greater effect.

Both concentrations and loads of nutrients were increased on the north basin when compared to the south basin. As with hydrology, there were effects on nutrient transport resulting from both the increase in plastic-covered beds on the north basin and the greater area of ponds on the south basin. The downstream effects of the farm pond (8925) were to decrease sediment and most nutrient concentrations. Although not directly measured at the pond outflow, it is likely that the overall effect of the upstream ponds on the south basin was to decrease sediment and nutrient concentrations also. The decrease in stream flow and the decrease in nutrient concentrations combined to make nutrient loads on the south basin much lower than on the north basin.

The effects of the total land use in the north and south basins was most apparent in the differences in sediment transport. Erosion from the plastic-covered beds on the north basin led to large amounts of coarse material deposition in the riparian forest, both immediately above and below the gauging station at 8923. The stream flow sediment loads at 8923 were probably underestimated because of the inability of the ISCO automated sampler intake line to sample these coarse materials. The downstream sediment load at 8924, consisting of more fine material, was probably quantified more completely and is a good estimate of the amount of suspended

Table 6

Average annual precipitation, runoff, and sediment and nutrient loads for the four watersheds for the record period, December 1997 to November 2004.

Watershed	Precipitation (cm)	Runoff (cm)	Sediment (kg ha^{-1}yr^{-1})	NH4-N (kg ha^{-1}yr^{-1})	NO3-N (kg ha^{-1}yr^{-1})	Total N (kg ha^{-1}yr^{-1})	Inorganic N (kg ha^{-1}yr^{-1})	Organic N (kg ha^{-1}yr^{-1})	TKN (kg ha^{-1}yr^{-1})	Ortho-P (kg ha^{-1}yr^{-1})	Total P (kg ha^{-1}yr^{-1})	Cl (kg ha^{-1}yr^{-1})	DOC (kg ha^{-1}yr^{-1})	K (kg ha^{-1}yr^{-1})
8921	110	15.1	58.4	0.20	0.96	3.19	1.14	2.05	2.23	0.03	0.42	14.90	8.53	1.43
8922	110	17.3	51.7	0.23	0.97	3.04	1.20	1.84	2.07	0.01	0.39	17.51	9.61	1.60
8923	110	30.3	822.9	0.58	1.90	6.06	2.47	3.72	4.30	0.20	0.75	26.16	17.14	9.99
8924	110	29.4	716.7	0.57	1.54	7.09	2.11	5.00	5.57	0.08	1.09	26.26	17.77	13.07

Note: Watershed 8921 is nested in 8922, and watershed 8923 is nested in 8924.

Table 7
Annual (water year) precipitation, runoff, and sediment and nutrient loads for the four watersheds.

Water Year (Dec. to Nov.)	Watershed	Flow (cm)	Sediment (kg ha^{-1}yr^{-1})	NH4-N (kg ha^{-1}yr^{-1})	NO3-N (kg ha^{-1}yr^{-1})	Total N (kg ha^{-1}yr^{-1})	Inorganic N (kg ha^{-1}yr^{-1})	Organic N (kg ha^{-1}yr^{-1})	TKN (kg ha^{-1}yr^{-1})	Ortho-P (kg ha^{-1}yr^{-1})	Total P (kg ha^{-1}yr^{-1})	Cl (kg ha^{-1}yr^{-1})	DOC (kg ha^{-1}yr^{-1})	K (kg ha^{-1}yr^{-1})
1997-1998														
(RF = 142 cm)	8921	53.9	191.5	1.00	5.20	10.63	6.20	4.44	5.43	0.134	1.163	57.7	19.4	–
	8922	66.1	90.6	1.21	4.55	11.91	5.76	6.16	7.38	0.016	1.006	75.4	19.4	–
	8923	76.8	817.1	2.47	8.00	17.13	10.47	6.66	9.13	0.838	1.451	80.4	26.9	–
	8924	70.4	165.8	2.73	5.10	17.05	7.83	9.22	11.95	0.201	1.175	85.7	25.8	–
1998-1999														
(RF = 89 cm)	8921	2.8	11.8	0.01	0.09	0.13	0.09	0.05	0.06	0.015	0.001	3.1	2.9	–
	8922	5.0	27.0	0.01	0.71	0.84	0.72	0.12	0.13	0.009	0.030	5.2	4.8	–
	8923	14.7	225.0	0.21	1.15	1.38	1.29	0.12	0.32	0.182	0.009	12.7	11.5	–
	8924	4.2	39.4	0.03	0.44	0.55	0.46	0.10	0.13	0.036	0.001	3.6	3.7	–
1999-2000														
(RF = 102 cm)	8921	7.4	6.5	0.04	0.05	0.34	0.08	0.26	0.30	0.019	0.043	7.1	6.2	–
	8922	5.1	4.4	0.06	0.05	0.35	0.11	0.24	0.30	0.004	0.048	3.6	5.7	–
	8923	20.2	52.2	0.19	0.83	2.81	1.02	1.79	1.99	0.108	0.193	17.2	17.0	–
	8924	11.9	24.0	0.12	0.28	0.87	0.41	0.46	0.58	0.031	0.128	8.6	10.6	–
2000-2001														
(RF = 96 cm)	8921	8.6	4.0	0.04	0.28	0.73	0.32	0.41	0.45	0.003	0.021	9.3	6.2	2.16
	8922	15.7	6.1	0.19	0.41	1.23	0.59	0.63	0.82	0.003	0.100	15.6	12.4	4.03
	8923	24.2	28.1	0.20	0.59	2.42	0.79	1.63	1.83	0.002	0.165	23.1	15.6	9.91
	8924	14.5	0.7	0.17	0.52	1.80	0.69	1.12	1.28	0.004	0.054	11.9	10.2	8.71
2001-2002														
(RF = 107 cm)	8921	6.5	40.9	0.04	0.18	4.92	0.22	4.70	4.74	0.026	0.106	5.5	5.7	1.78
	8922	6.8	47.9	0.01	0.55	4.12	0.56	3.56	3.57	0.010	0.196	4.8	7.6	1.98
	8923	15.4	259.3	0.16	0.98	9.51	1.14	8.37	8.53	0.089	0.331	13.5	10.4	13.09
	8924	17.4	222.9	0.12	0.71	10.56	0.82	9.73	9.85	0.148	0.467	9.8	15.9	16.80
2002-2003														
(RF = 126 cm)	8921	16.9	132.6	0.08	0.74	2.95	0.82	2.13	2.21	0.008	1.416	14.8	12.8	3.58
	8922	14.0	147.8	0.09	0.40	1.95	0.49	1.46	1.55	0.004	1.159	10.4	11.4	3.15
	8923	40.2	1783.2	0.60	1.04	5.63	1.60	4.93	5.53	0.082	2.660	21.5	26.2	28.47
	8924	51.2	2737.3	0.58	2.80	9.08	3.35	5.81	6.39	0.055	3.953	30.6	33.9	38.08
2003-2004														
(RF = 111 cm)	8921	9.9	21.3	0.16	0.20	2.66	0.26	2.39	2.45	0.010	0.170	6.8	6.5	2.46
	8922	7.8	37.9	0.03	0.13	0.90	0.16	0.74	0.77	0.012	0.170	7.6	6.0	2.02
	8923	23.4	2595.3	0.24	0.74	3.54	0.98	2.56	2.80	0.082	0.423	14.7	12.4	18.46
	8924	36.8	1826.8	0.25	0.94	9.72	1.19	8.53	8.78	0.066	1.83	33.6	24.3	27.89

Notes: Watershed 8921 is nested in 8922 and makes up the south watershed. Watershed 8923 is nested in 8924 and makes up the north watershed.

sediment leaving the overall north basin. Field observations indicated that obvious deposition of coarse sand sediments reached about 60% of the distance from 8923 to 8924 but that few coarse sediments reached 8924. Mapping and quantifying the depth and mass of the sedimentation above and below station 8923 has not been done but is a future research need for this project.

Comparisons of Upstream and Downstream Sites. Although both basins had riparian buffers above the upstream sampling sites (8921 and 8923), the areas between the upstream and downstream sites (8922 and 8924) had a larger percent of the total area in riparian forest (figures 2 to 4). In addition, the areas above 8921 and 8923 contained most of the intensive agriculture in both of the basins. Concentrations of sediment, NO_3-N, inorganic N and ortho-P were consistently lower at the downstream sites (8922 and 8924).

Table 8

Average annual precipitation, runoff, and sediment and nutrient loads for the south and north watersheds in this study and for the average watersheds.

Basin	Precipitation (cm)	Runoff (cm)	Sediment (kg ha^{-1}yr^{-1})	NH4-N (kg ha^{-1}yr^{-1})	NO3-N (kg ha^{-1}yr^{-1})	Total N (kg ha^{-1}yr^{-1})	Inorganic N (kg ha^{-1}yr^{-1})	Organic N (kg ha^{-1}yr^{-1})	TKN (kg ha^{-1}yr^{-1})	Ortho-P (kg ha^{-1}yr^{-1})	Total P (kg ha^{-1}yr^{-1})	Cl (kg ha^{-1}yr^{-1})	DOC (kg ha^{-1}yr^{-1})	K (kg ha^{-1}yr^{-1})
South	110	16.2	55.1	0.21	0.96	3.12	1.17	1.94	2.15	0.02	0.40	16.2	9.07	1.51
North	110	29.8	770	0.57	1.72	6.57	2.29	4.36	4.93	0.14	0.92	26.2	17.5	11.5
J, K, N, O	118	28.8	NA	0.09	0.50	2.61	0.59	2.28	2.38	0.10	0.76	NA	NA	NA
B, F, K	120	34	64.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes: J, K, N, and O in 1979 to 1981 (from Lowrance et al. 1985). B, F, and K in 1984 to 1986 (from Hubbard et al. 1990). Values shown as NA were not measured in earlier study.

Loads of only sediment and ortho-P were consistently lower at the downstream sites (tables 4 to 7). Both the load and concentration differences (downstream-upstream) are larger on the north basin where concentrations and loads entering from upstream were higher (tables 4 to 7). Although these load and concentration differences are consistent and significant, they are a much smaller percentage difference than reported along transects from fields to streams at the same sites (Lowrance et al. 2000; Lowrance and Sheridan 2005; Sheridan et al. 1999). In the transect studies through riparian zones, decreases in sediment and inorganic N concentrations from fields to the stream of 90% for both concentration and load were observed. Although ortho-P loads were reduced by 60% to 67% in comparison of upstream and downstream, sediment load reductions were only 10% to 13% (calculated from table 6). Apparently, with the exception of ortho-P, there was less potential for nutrient and sediment load reduction for water flowing in the channel through a well-buffered stream reach than for water moving through a buffer toward the channel. Although this would appear to be a general conclusion from this study, it is also important to point out that on the more heavily loaded north basin, it is very likely that coarse sediment passing through station 8923 was underestimated. In addition, the north basin had a substantial reduction in NO_3-N load and thus inorganic N load, with reductions of 18% and 12%, respectively. This may indicate that more heavily loaded stream reaches would achieve more load reduction due to both buffers and generally less intensive land use compared to the upstream sites.

Effects of Ponds on the Basins. Farm ponds are a common feature of agricultural watersheds in the southeastern coastal plain, particularly in the Tifton Upland. In this region, ponds are typically constructed into the Miocene age Hawthorne Formation material that is an effective aquiclude. Where constructed on stream channels, ponds store stream flow but they are also used as irrigation sources. Ponds provide still water to promote sedimentation and bioavailable nutrients are taken up by algae. In many cases the surface water and shallow ground water captured by ponds are supplemented by deep wells which pump from the Floridan Aquifer at depths of 60 to 200 m (197 to 656 ft) below the ground surface. Data gathered in this study provided both direct and indirect evidence of the effects of ponds within these basins. Although hydrologic measurements of outflow were not available from any of the ponds within the watersheds, it appeared that stream flow volumes were reduced on the south basin due to the upstream ponds. The large percentage of the watershed in ponds (6.3% of watershed 8921) is the most logical explanation for the low stream flow in this basin. Stream-flow reductions by the upstream ponds caused load reductions but there were also large concentration differences between 8921 and 8923. It is less clear that these concentration differences are due to the ponds above 8921 because of the more intensive agriculture on the north basin, especially above 8923.

The downstream pond, sampled at site 8925, clearly had reduced outflow concentrations compared to the water flowing into the pond as measured at 8922 and 8924. The most pronounced difference was between 8924 and 8925 with the higher concentrations from the north basin being reduced by over an order of magnitude for sediment and a factor of two for nitrate. Clearly the downstream pond had generally lower concentrations in outflow but the effects on loads were not measured. Future research will allow quantification of loads from both the upstream and downstream ponds.

Comparison to Other Coastal Plain Watersheds. Comparisons of stream flow on the south and north basins to other watersheds in the LREW for the same record period showed that stream flow from the north basin was similar to watershed O, a 1,650 ha (4,077 ac) watershed located about 12 km (7.4 miles) from the Gibbs farm basins. For the period December 1997 through November 2004, watershed O had average annual flow of 27.9 cm (11 in) (Sheridan unpublished data), compared to 16.3 cm (6.4 in) and 29.8 cm (11.7 in), respectively, for the south and north basins. It is likely that the lower stream flow on the south watershed is due to the large amount of pond storage compared to both the north watershed and watershed O and that the slightly higher stream flow on the north watershed is due to the influence of the plastic-covered beds for the last two years of the study.

Stream flow and nutrient loadings from the Gibbs farm are comparable to earlier studies in the Little River watershed (Lowrance et al. 1985) and other coastal plain watersheds. Lowrance et al. (1985) reported loads from four subwatersheds of Little River for a three-year period (1979 to 1981) that included about 1.5 years of near average rainfall and 1.5 years of lower than average rainfall. Hubbard et al. (1990) reported sediment loads from Little River (watershed B) and two subwatersheds for 1984 to 1986. Results from these studies, along with the south and north basins of the current study are summarized in table 8. Once again, the north basin has a higher runoff/rainfall ratio than the south watershed (0.273 and 0.149, respectively) and the north watershed is more similar to the average of watersheds B, F, J, K, N, and O, which have a runoff/rainfall ratio of 0.244. Although nutrient loads were generally higher on both the north and south basins than on watersheds J, K, N, and O, the biggest difference was in inorganic N. This is likely due to a difference in proportion of cropland because the Gibbs farm watersheds had about 55%

cropland while watersheds J, K, N, and O averaged 35% cropland during the earlier record period. Sediment loads from watersheds B, F, and K were similar to the south basin of the Gibbs farm and much less than the north basin (table 8).

Other studies have shown that both stream flow and nutrient loads from larger Coastal plain watersheds were generally comparable to those measured at the Gibbs farm. Jordan et al. (1997) found that annual discharge ranged from 35 to 45 cm yr^{-1} (13.8 to 17.7 in yr^{-1}) for 17 watersheds in the Chesapeake Bay drainage. These watersheds ranged from 14 to 293 km^2 (5.4 to 113 mi^2) in size, considerably larger than the Gibbs farm watersheds. Total N and Total P discharge from these watersheds ranged from 0.9 to 16 kg N ha^{-1} yr^{-1} (0.8 to 14 lb ac^{-1} yr^{-1}) and 0.07 to 3.2 kg P ha^{-1} yr^{-1} (0.06 to 2.8 lb ac^{-1} yr^{-1}). Loads from the Gibbs farm watersheds are generally in the middle of these ranges of loads. The Jordan et al. (1997) study showed that N loads increased as percent agriculture increased but that P loads did not. In contrast, both total N and total P loads were higher on the north watershed of this study, although much of the difference is due to lower stream flow on the south watershed.

Inamdar et al. 2001 also measured total N and total P loads in two nested watersheds of Nomini Creek, a Coastal plain tributary of the Chesapeake Bay in Virginia. They found that a 214 ha (528 ac) subwatershed had about twice the total stream flow (both before and after BMP implementation) as the entire 1,463 ha (3,615 ac) watershed. The pre-BMP and post-BMP values for stream flow from the nested watersheds ranged from 18 to 47 cm yr^{-1} (7.1 to 18.5 in yr^{-1}). All loads on the Nomini Creek watersheds were higher than those measured in the Gibbs farm watersheds although the sediment loads were only slightly higher than the sediment loads from the north basin of the Gibbs farm (1,050 kg ha^{-1} yr^{-1} vs. 818 kg ha^{-1} yr^{-1}). Although agronomic and structural BMPs led to significant decreases in total N on the Nomini Creek watersheds, there was no effect on total P. In contrast, the ponds on the south basin of the Gibbs farm contributed to decreases in both total N and total P loads compared to the north basin, primarily due to lower flows. Understanding the effects of the south basin ponds was complicated by the effects of farming practices in the north basin in the final two years of the study.

Summary and Conclusions

There were very large differences between the two adjacent basins due to the prevalence of farm ponds on the south basin (decreased runoff, nutrient, and sediment transport) and plastic-covered beds on the north basin (increased runoff, nutrient, and sediment transport). Although these results are not unexpected, it was not known that farm ponds occupying as little as 6.3% of the basin could have such a large influence on stream flow. Additionally, a relatively small portion of the north basin had a large impact on sediment transport. Future studies will provide more detailed hydrologic and water quality data within these watersheds to complete our understanding of these effects.

Although it is not known how these effects would compare to similar practices on larger watersheds, it is very clear that these land use effects are substantial on these small watersheds. Typically, watersheds in the Withlacoochee, Little, and Alapaha watersheds that make up the Western Upper Suwannee River basin have 1% to 2% of the watershed in farm ponds. This study indicated that an increase to 6% of a watershed in farm ponds could have large effects on total stream flow. These effects may be more pronounced in drought and average years than in wet years. Counterbalancing the negative effects on downstream water delivery would be beneficial for water quality by decreasing nutrient and sediment concentrations.

Large differences were also observed in sediment and nutrient transport due to installation of plastic-covered beds for vegetable production. Large quantities of sediment transported in surface runoff increased sediment deposition in riparian forest buffers but also led to hundredfold increases in stream flow sediment transport. Less potential existed for nutrient and sediment load reduction once the materials entered streams surrounded by riparian forest buffers than when water moves to streams through riparian forest buffers down slope from fields. The use of plastic-covered beds in erodible landscapes presents challenges for conservation, especially when beds are installed up and down the slope. Installing beds on the contour, along with careful management of drip irrigation, is necessary to avoid excessive erosion and nutrient transport.

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