WATER RESOURCES research center

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POLLUTION IN RUNOFF FROM NONPOINT SOURCES

By

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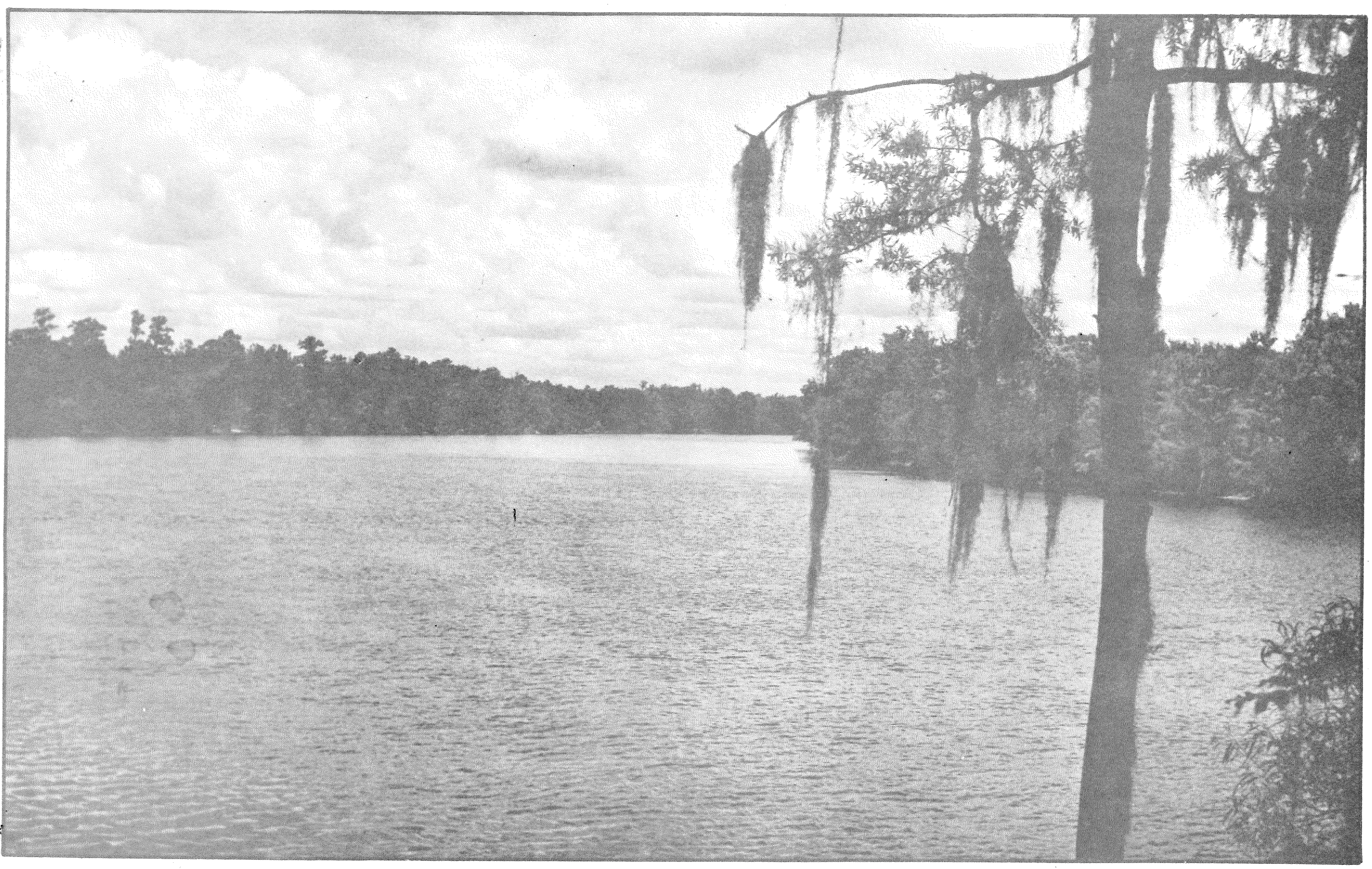

UNIVERSITY OF FLORIDA

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ABSTRACT

The increasing concern for the quality of our environment demonstrates the importance of gaining an increased understanding of the mechanisms and processes involved in nutrient movement from diffuse sources. The extent of the problem is not well defined in many areas. In this study, nitrogen and phosphorus loads were determined for two agricultural watersheds: one primarily in native forest cover and the other primarily in intensive crop production. Small plots were used to evaluate the effects of selected cultural and water management practices on nitrogen and phosphorus loads in surface runoff from sandy soils. In both of these locations, nitrogen and phosphorus losses in runoff were very small compared with amounts received by the land area in precipitation and commercial fertilizer. Techniques were developed to simulate nitrogen movement through agricultural watersheds. Simulation models are an effective tool to assist in gaining a better understanding of the complex processes and interactions that occur in a watershed system. They can help in identifying which processes are most important in controlling nitrogen movement within a watershed.

INTRODUCTION

There has been increasing concern in recent years about the quality of the water in our lakes and streams. This quality is obviously influenced by the quality of water flowing into the lakes and streams from the surrounding land areas. However, because of the widely dispersed origin of this water as runoff from the contributing watershed areas, data concerning its effects on the quality of our bodies of water have been very sparse. Good background data indicating water quality under native watershed conditions for comparative purposes are also very sparse.

The importance of minimizing nutrient losses from agricultural land is quickly recognized when one considers the high costs of commercial fertilizer. The development of management practices to reduce nutrient losses may reduce fertilizer costs and also result in improved quality of the water in lakes and streams. The extent and value of this improvement in water quality is at best very difficult to quantify. With the present concern for the environment and the quality of water in our lakes, streams and rivers, there is a need to determine the effects of our modern agricultural production technology on the nutrient loads in surface runoff. Because agricultural runoff is introduced to the streams from a non-point source, it is more difficult to determine the actual nutrient loads being introduced.

The soils and climate of Florida create a unique situation for nutrient movement through watersheds. The sandy soils along with high rainfall and warm temperatures create a condition conducive to rapid nutrient movement under some conditions. The tremendous variations in these sandy soils and their resulting effects on water movement add considerable confusion to any analysis of the potential for nutrient losses in runoff in various locations. In some locations the sandy soils are deep with corresponding water table depths of 9-12 m or more, while in nearby flatwoods areas, spodic layers and clay layers in the sandy soil may cause a shallow water table fluctuating from 2 m deep up to the ground surface. These variable soil conditions affect the volume and quality of surface runoff and the movement of nutrients into the ground water.

The problem of pollution from non-point sources is a particular concern in Florida because of its many lakes and the close intermingling of surface water and ground water. There is also the important consideration that pollution from non-point sources in Florida may quickly find its way into the estuarine zones which are of great economic and aesthetic importance. With these facts in mind, this research effort was undertaken to determine nutrient loads in runoff from native areas and watersheds in agricultural production in north central Florida (Figure 1).

The objectives of the study were (1) to determine the nitrogen and phosphorus loads in streamflow from agricultural watersheds with intensive cropping and with native vegetation, (2) to determine the effects of selected cultural and water management practices on nitrogen and phosphorus loads in agricultural runoff from sandy soils, and (3) to develop techniques to simulate nitrogen movement through agricultural watersheds.

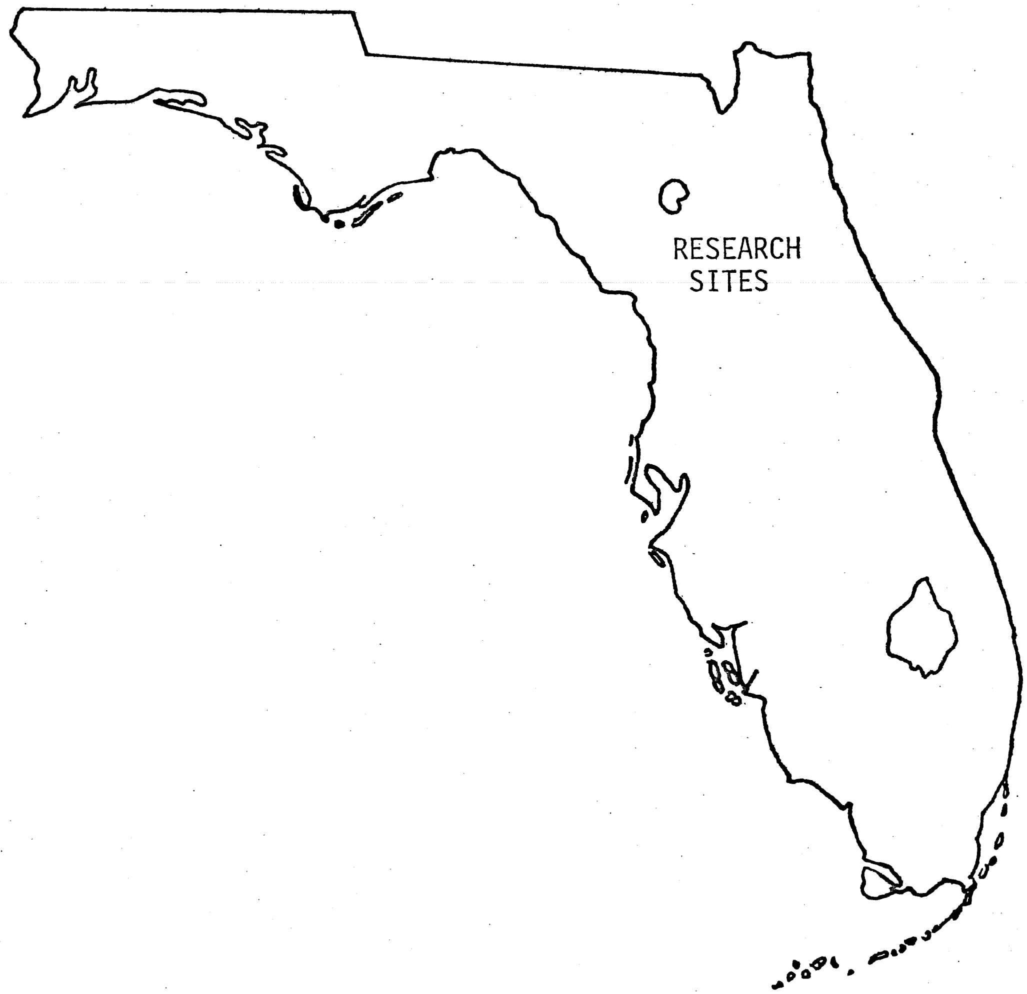

Figure 1. Map of Florida showing the location of the study area.

CHAPTER I
WATERSHED STUDIES

Methods and Procedures

One watershed of about 437 ha (upper watershed) observed in this study is primarily in native forest cover with some unimproved pasture and a very small amount of crop land. The outlet of this watershed is a small stream which flows continuously except during extremely dry periods. Another watershed of about 208 ha located immediately downstream, (lower watershed) is primarily in intensive agricultural crop production with some improved pasture near the stream. The soils in these watersheds are sandy with a clay layer at a depth of 1-2 m in most areas creating a shallow water table during wet periods. Average land slopes are 0-3 percent in the upper watershed and 3-8 percent in the lower watershed. Predominant soil associations are Arredondo-Gainesville-Fort Meade, Leon-Plummer-Rutledge, and Scranton-Ona.

Precipitation was measured by a small wedge-shaped gauge near the edge of the watersheds and a tipping bucket recording rain gauge near the center of the two watersheds. Samples were collected from the recording gauge to determine nutrient concentrations in rainfall. Stage recorders were installed on the stream at the outlet of each watershed to provide a continuous record of the stream level (Figure 2). Manning's velocity formula (Chow, 1959) was used to develop a stage-discharge relationship for use in determining flow rates and volumes and nutrient loads from the watersheds. Discharge measurements made on the stream by fluorometry techniques (Replogle et al 1966, Wilson 1968) and current meter measurements at a variety of stages verified this relationship.

At each watershed outlet an automatic water sampler collected streamflow samples every eight hours for later nitrogen and phosphorus analyses. During periods of low flow, these samples were composited into a single daily sample. Nitrogen forms measured were total Kjeldahl nitrogen (U.S. Environmental Protection Agency, 1974), ammonium nitrogen by the selective ion electrode (U.S. Environmental Protection Agency, 1974) and nitrate nitrogen by the chromotropic acid method (American Public Health Association, 1971). Phosphorus forms measured were total phosphorus and orthophosphate by the ascorbic acid method (American Public Health Association, 1971). Nutrient loads in the stream during periods of low flow

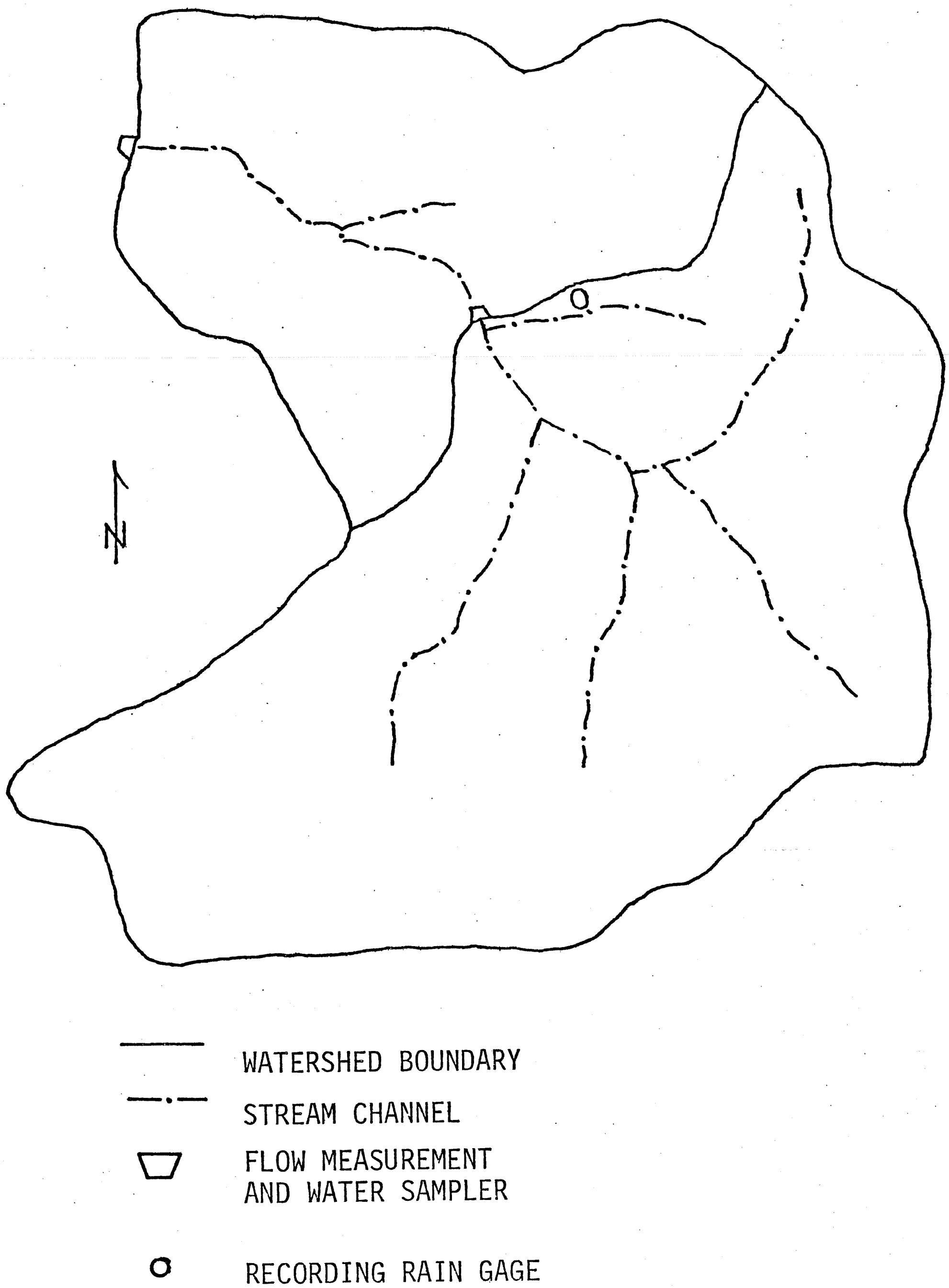

Figure 2. Map of upper and lower watersheds studied in Alachua County, Florida.

provided an indication of the movement of nutrients through the soil profile to the shallow ground water. All flow volumes and nutrient loads for the lower watershed were determined by subtracting the upper watershed measurements from those of the total watershed. Land owners in the watersheds were interviewed to determine cropping, livestock numbers, and fertilizer applied, for use as components of nutrient balances for the watersheds.

Results and Discussion

Data were collected during the period from July 1975 to June 1977. Precipitation from 7/75 - 6/76 totalled 105 cm, about 25 cm below average. From 7/76 - 6/77 precipitation totalled only 88 cm, about 42 cm below average. According to the landowners, flow levels in the stream were below normal as would be expected with this lower than average rainfall.

Tables 1 and 2 show the nitrogen and phosphorus loads in the streamflow from the upper and lower watersheds. The upper watershed is primarily in native forest cover and the lower watershed is in intensive agricultural crop production, as indicated previously. The flow-weighted average nutrient concentrations, shown in Table 3, are very similar for both the upper and lower watersheds for most nutrient forms during the same year. However, the flow volume from the lower watershed is about four times greater than that from the upper watershed during 1975-76 and somewhat greater during 1976-77. Thus, it appears that most of the increased nutrient load from the lower watershed, shown in Tables 1 and 2, can be attributed to the increased flow volume from that watershed. Flow volumes are reported as a uniform depth over the appropriate drainage area.

In Tables 4 and 5 the nutrient loads from the two watersheds are broken down to show the loads of each nutrient form occurring during storm flow and during low flow periods. Storm flow and low flow volumes also are given for both watersheds. As mentioned earlier, the nutrients in the streamflow during low flow periods are contributed by baseflow from the surrounding shallow groundwater, therefore this indicates the extent of movement of nutrients through the soil profile into the groundwater. In the upper watershed, the flow volume and nutrient loads are divided about equally between storm and low flow periods during 1975-76 while, in the lower watershed, about 80 percent of the flow volume and nutrient loads occurred during storm periods (Table 4). These

Table 1. Nitrogen load (kg/ha) in streamflow from July 1975 to June 1976 and from July 1976 to June 1977.

	Upper Watershed		Lower Watershed	
	1975-76	1976-77	1975-76	1976-77
	kg/ha			
Organic N	1.21	1.49	5.30	1.92
Ammonium N	0.11	0.07	0.68	0.09
Nitrate N	0.12	0.09	0.37	0.09
Total N	1.43	1.65	6.36	2.10

Table 2. Phosphorus load (kg/ha) in streamflow from July 1975 to June 1976 and from July 1976 to June 1977.

	Upper Watershed		Lower Watershed	
	1975-76	1976-77	1975-76	1976-77
	kg/ha			
Orthophosphate P	0.30	0.52	1.21	0.63
Total P	0.33	0.68	1.34	0.86

Table 3. Flow-weighted average nutrient concentrations (mg/l) and flow volumes (cm) for the periods July 1975 to June 1976 and July 1976 to June 1977.

	Upper Watershed		Lower Watershed	
	1975-76	1976-77	1975-76	1976-77
	mg/l			
Organic N	2.31	1.70	2.49	1.59
Ammonium N	0.21	0.07	0.32	0.07
Nitrate N	0.22	0.10	0.17	0.07
Total N	2.73	1.87	2.98	1.73
Orthophosphate P	0.58	0.59	0.57	0.52
Total P	0.63	0.77	0.63	0.71
Flow Volume, cm	5.25	8.79	21.3	12.1

Table 4. Nutrient loads (kg/ha) and flow volumes (cm) by type of flow for each watershed from July 1975 to June 1976.

	Upper Watershed		Lower Watershed	
	Storm Flow	Low Flow	Storm Flow	Low Flow
	---------------------kg/ha---------------------			
Organic N	0.61	0.60	4.30	1.00
Ammonium N	0.06	0.05	0.51	0.17
Nitrate N	0.07	0.05	0.30	0.07
Total N	0.73	0.70	5.12	1.24
Orthophosphate P	0.13	0.17	0.94	0.27
Total P	0.15	0.18	1.04	0.30
Flow Volume, cm	2.57	2.67	17.4	3.95

Table 5. Nutrient loads (kg/ha) and flow volumes (cm) by type of flow for each watershed from July 1976 to June 1977.

	Upper Watershed		Lower Watershed	
	Storm Flow	Low Flow	Storm Flow	Low Flow
	---------------------kg/ha---------------------			
Organic N	0.59	0.90	1.23	0.69
Ammonium N	0.03	0.04	0.04	0.05
Nitrate N	0.03	0.06	0.05	0.04
Total N	0.65	0.99	1.31	0.78
Orthophosphate P	0.18	0.34	0.34	0.29
Total P	0.27	0.41	0.43	0.43
Flow Volume, cm	3.50	5.29	5.73	6.34

data indicate that most of the increased flow volume and nutrient load from the lower watershed in 1975-76 occurred during storm periods. Two probable reasons for this are the more intensive land use with less ground cover and the somewhat greater land slopes in the lower watershed. This watershed is typical of this general farming area where much of the intensive agricultural production is on the more sloping land which has better drainage. Because of the very dry year of 1976-77, a much larger percentage of the total streamflow occurred as low flow, especially in the lower watershed. The nutrient loads still remained relatively proportional to flow volume between storm and low flow periods, with the exception of the organic nitrogen load in the lower watershed (Table 5).

Flow-weighted average nutrient concentrations by type of flow for each watershed showed no definite pattern for nitrogen forms (Tables 6 and 7). The concentrations were very similar between storm flow and low flow within a watershed for a given year except the one case of organic nitrogen when the concentration was doubled during storm periods. However, phosphorus concentrations reduced consistently during storm flow periods in both watersheds in 1975-76 (Table 6). This trend was consistent for individual storm flow periods as well as for the total year. This trend did not continue during 1976-77, however, except for orthophosphate in the upper watershed (Table 7).

Figures 3, 4 and 5 show the variations in monthly flow-weighted average nutrient concentrations and monthly flow volume throughout the period of record for the upper watershed. Similar relationships for the total watershed (upper and lower combined) are shown in Figures 6, 7 and 8. An examination of these data for possible correlations may be very helpful in understanding some of the processes taking place in the watersheds. This understanding is very important to the development of models for simulation of nutrient movement through watersheds. Nitrate concentrations were lowest during the fall and winter months in the upper watershed (Figure 3) as might be expected due to cooler temperatures during this period. A similar response occurred in the total watershed initially, but nitrate concentrations remained very low throughout the period of record after the first summer (Figure 6). Ammonium concentrations in the upper watershed were relatively low during most of the period of record (Figure 3). This was also true for the total watershed except for some periods in the late spring and summer when concentrations were considerably higher (Figure 6). The increased ammonium concentrations may be due to increased ammonification as the temperature increases. They also could be influenced by fertilizer applied to the

Table 6. Flow-weighted average nutrient concentrations (mg/l) by type of flow for each watershed from July 1975 to June 1976.

	Upper Watershed		Lower Watershed	
	Storm Flow	Low Flow	Storm Flow	Low Flow
	mg/l			
Organic N	2.37	2.25	2.47	2.53
Ammonium N	0.22	0.19	0.30	0.43
Nitrate N	0.26	0.18	0.17	0.18
Total N	2.85	2.62	2.95	3.13
Orthophosphate P	0.51	0.64	0.54	0.68
Total P	0.58	0.68	0.60	0.77

Table 7. Flow-weighted average nutrient concentrations (mg/l) by type of flow for each watershed from July 1976 to June 1977.

	Upper Watershed		Lower Watershed	
	Storm Flow	Low Flow	Storm Flow	Low Flow
	mg/l			
Organic N	1.69	1.71	2.15	1.08
Ammonium N	0.08	0.07	0.06	0.08
Nitrate N	0.09	0.11	0.08	0.07
Total N	1.86	1.88	2.29	1.23
Orthophosphate P	0.51	0.64	0.58	0.46
Total P	0.77	0.77	0.75	0.68

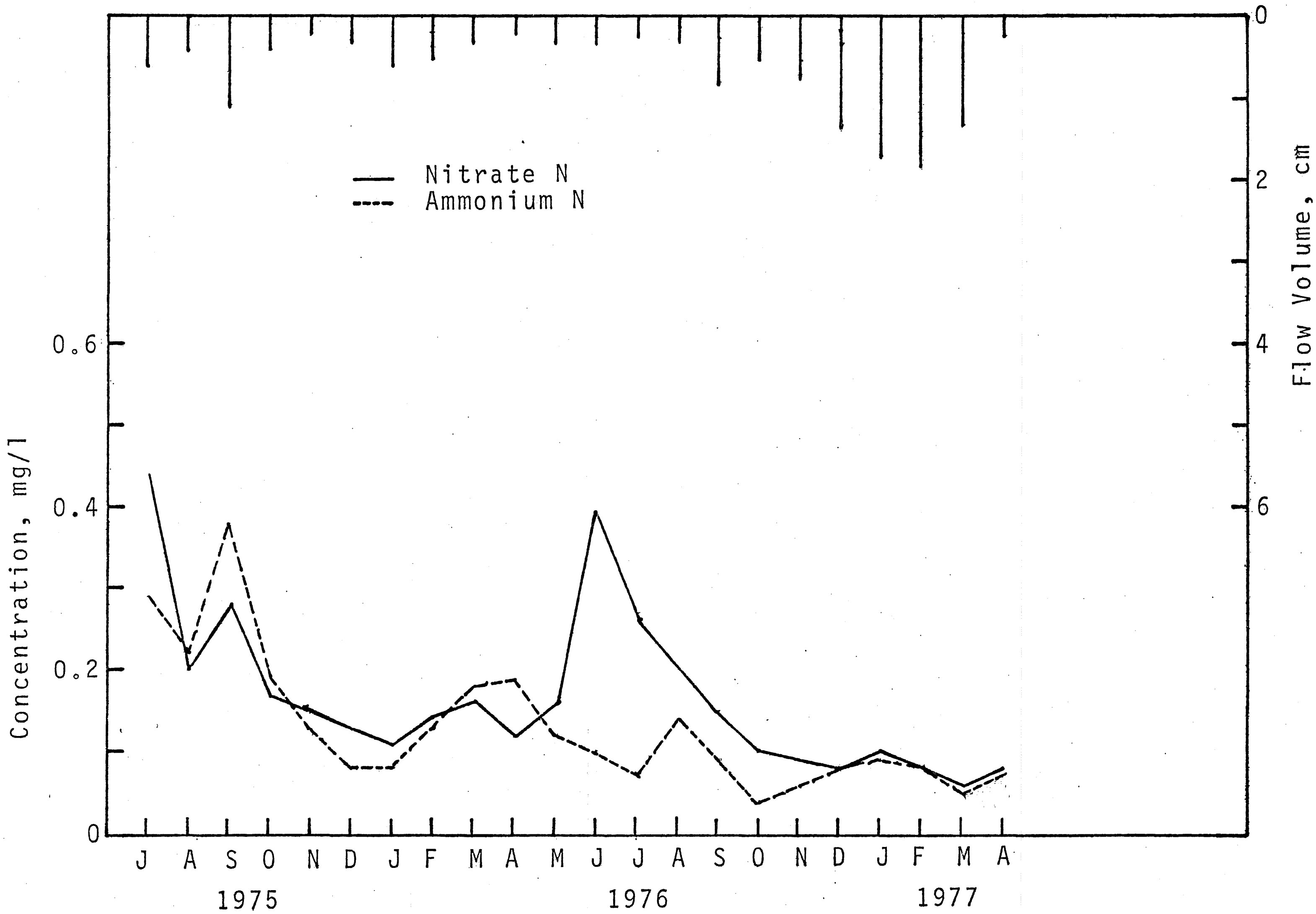

Figure 3. Monthly flow-weighted average nitrate N and ammonium N concentrations and monthly flow volume from the upper watershed.

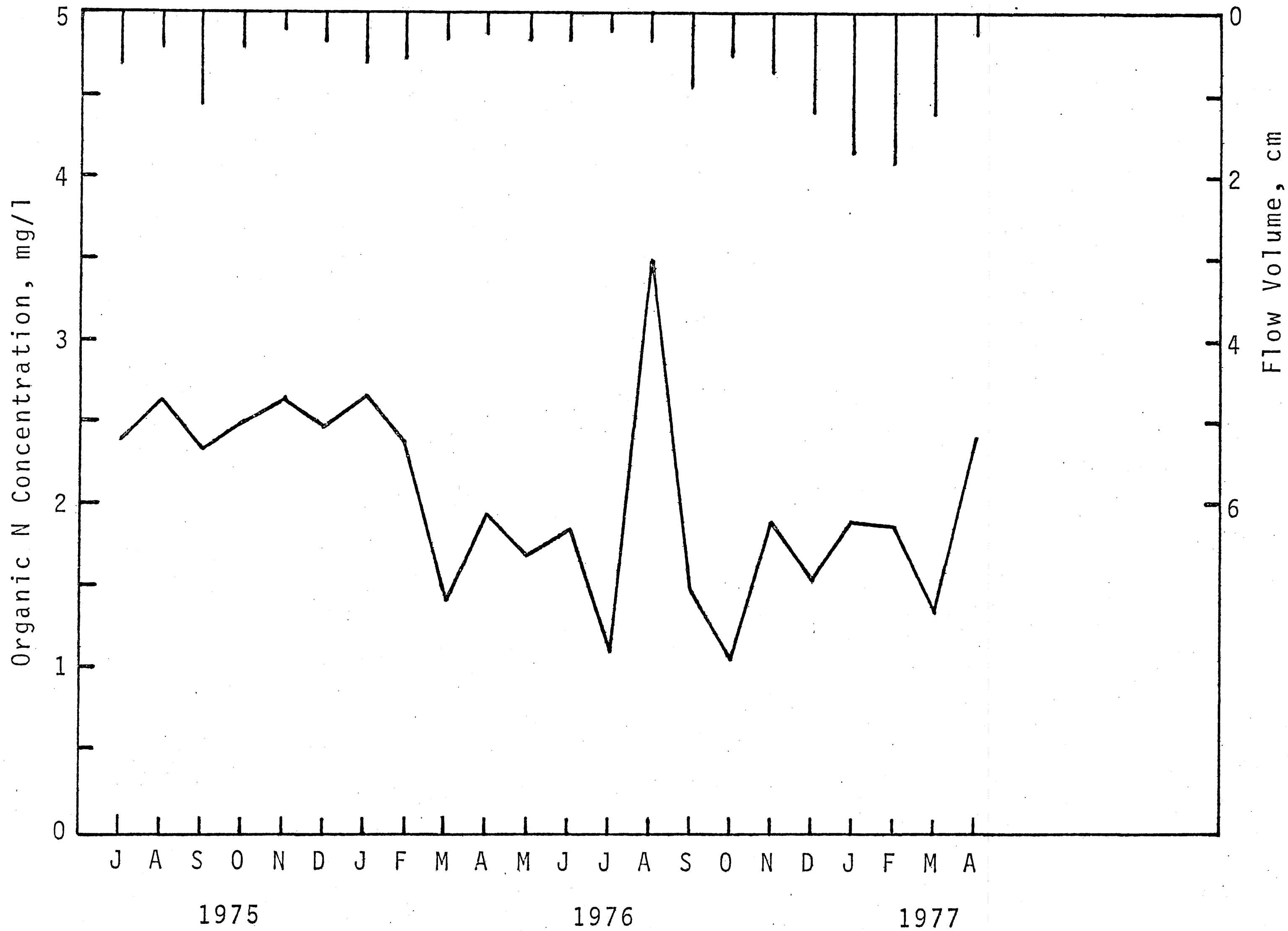

Figure 4. Monthly flow-weighted average organic N concentration and monthly flow volume from the upper watershed.

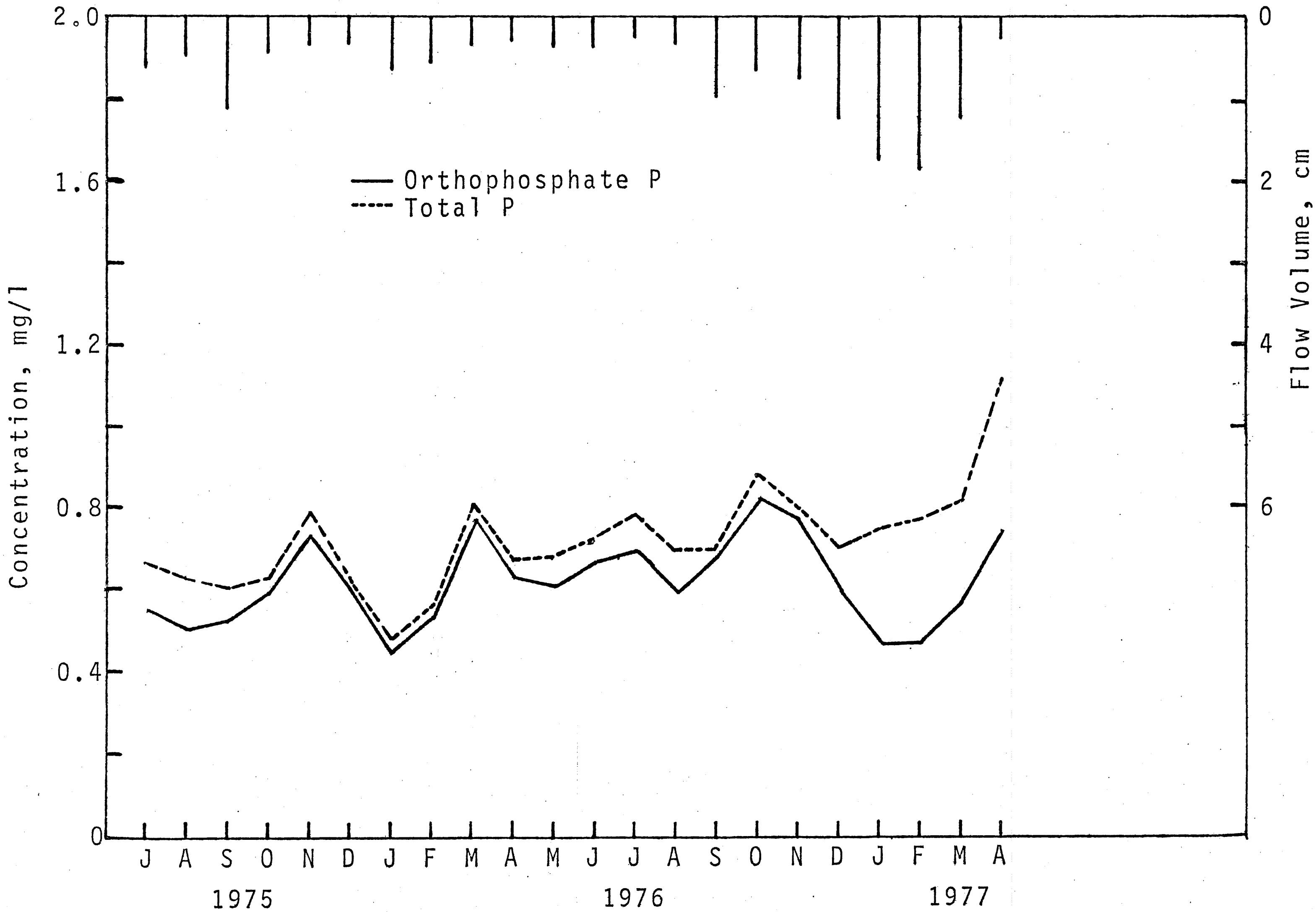

Figure 5. Monthly flow-weighted average orthophosphate P and total P concentrations and monthly flow volume from the upper watershed.

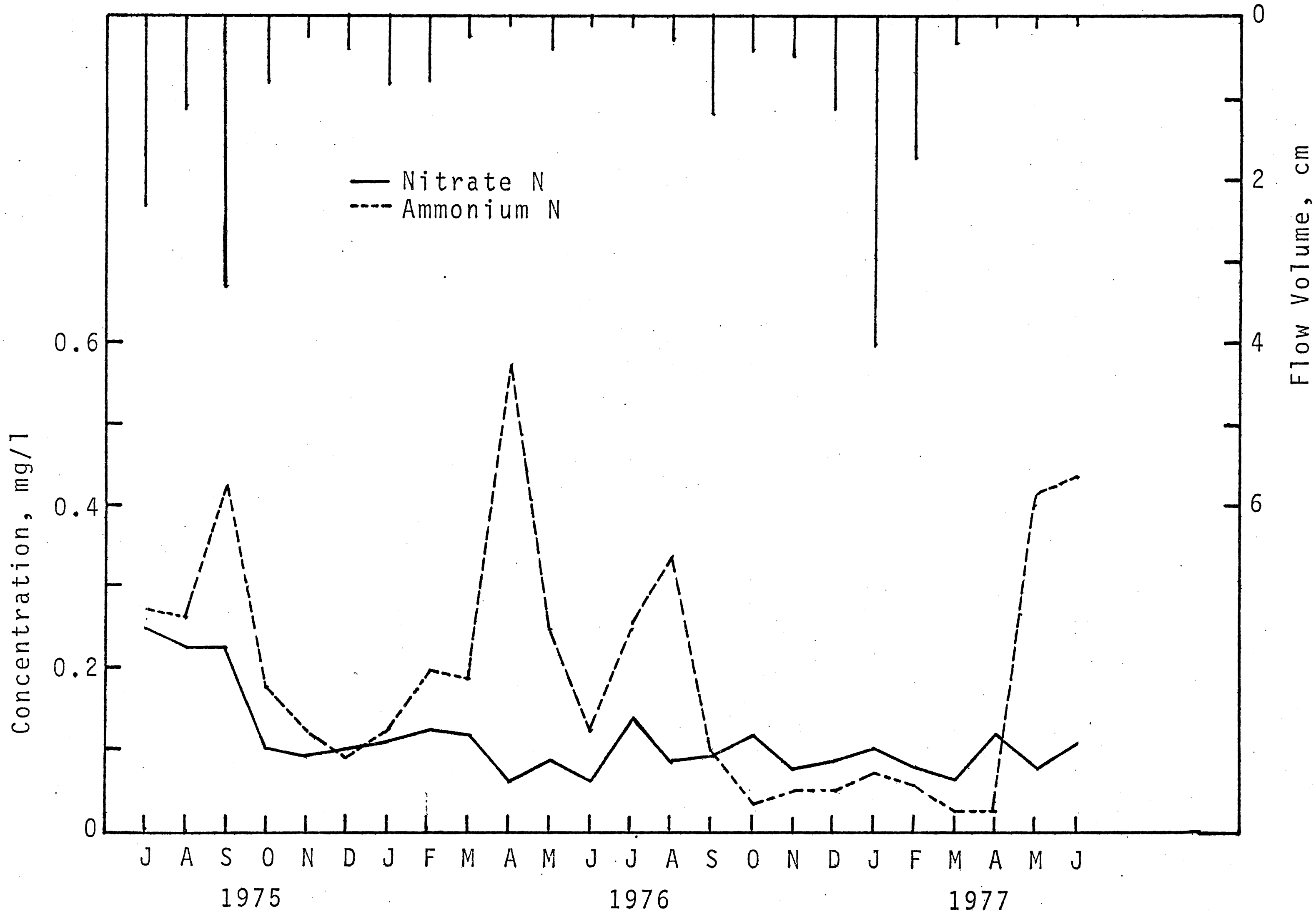

Figure 6. Monthly flow-weighted average nitrate N and ammonium N concentrations and monthly flow volume from the total watershed.

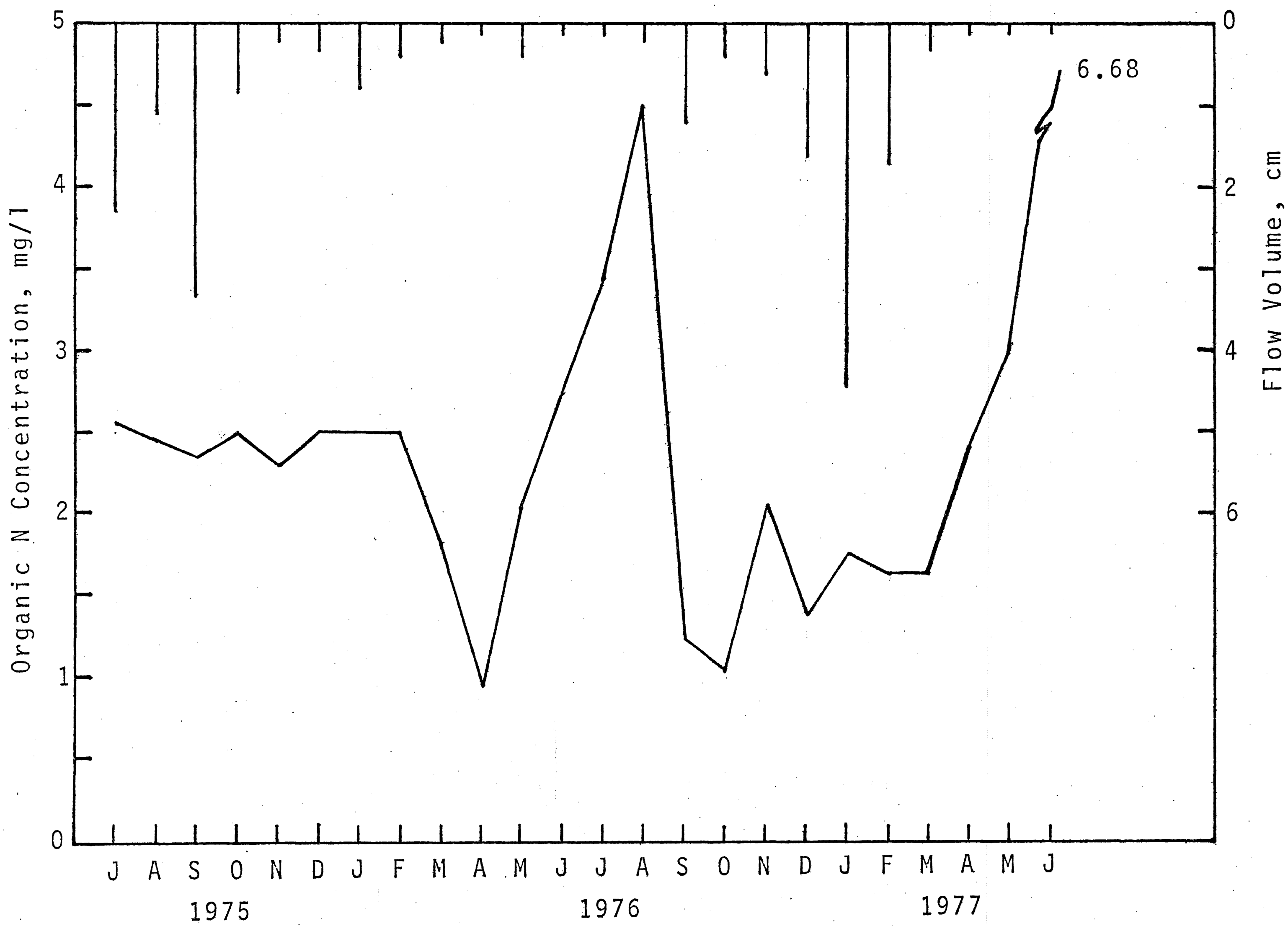

Figure 7. Monthly flow-weighted average organic N concentration and monthly flow volume from the total watershed.

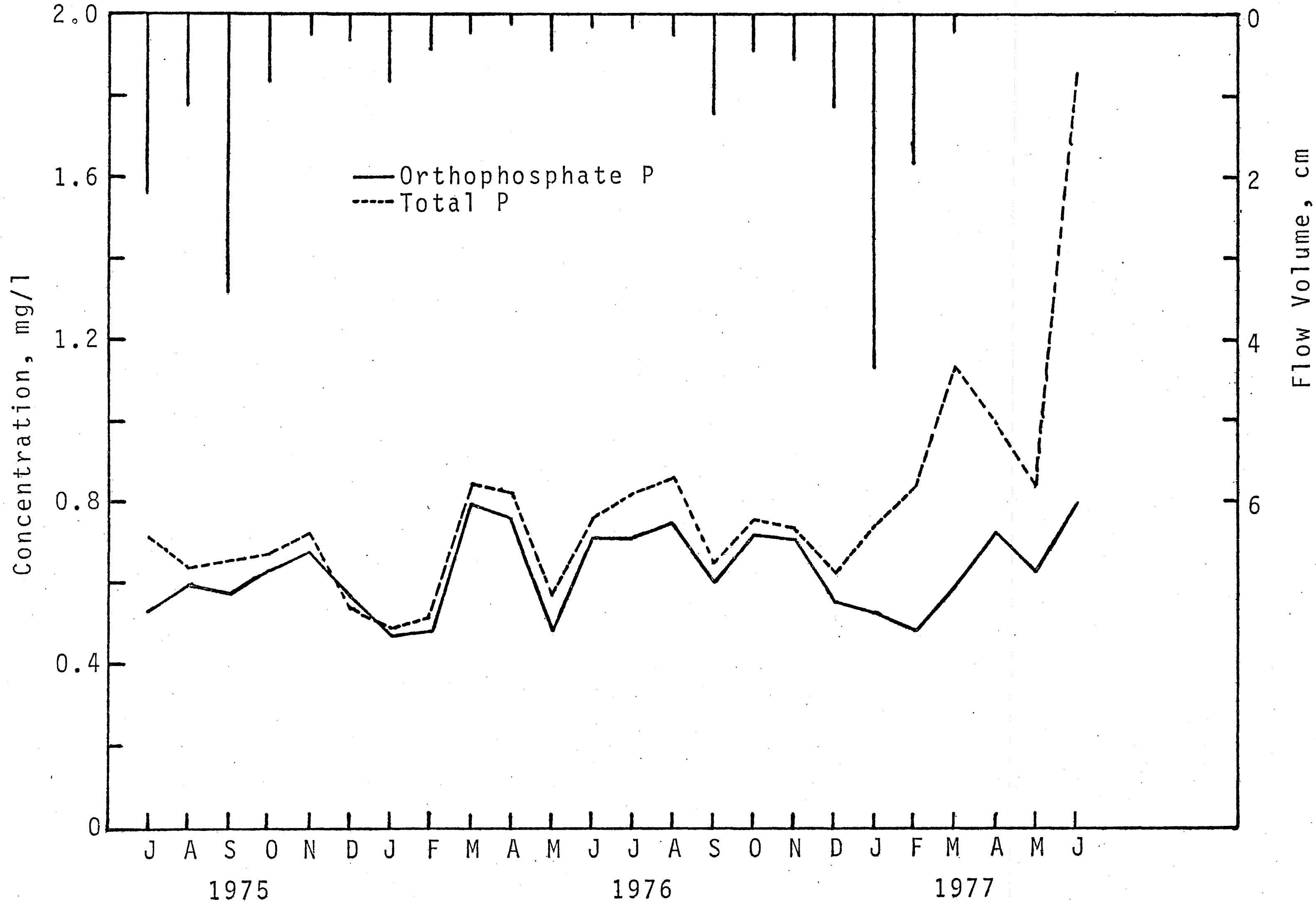

Figure 8. Monthly flow-weighted average orthophosphate P and total P concentrations and monthly flow volume from the total watershed.

watershed since most of it is applied in March and April and in the lower watershed. Figures 4 and 7 show several drops in organic nitrogen concentration that correspond to the increased ammonium concentrations as might be expected if ammonification was increasing during these months. These changes may be connected to the increase in microbial activity as warmer weather begins.

The bulk of the total phosphorus load in the stream is in the orthophosphate form as is evident in Figures 5 and 8. Phosphorus concentrations tended to decrease in months with larger flow volumes and increase in months with small flow volumes during much of the period of record (Figures 5 and 8). This is consistent with the observation made earlier about phosphorus concentrations decreasing during individual storm flow periods. This trend indicates that more than a flow-proportionate amount of the phosphorus load from the watersheds is delivered in the shallow groundwater during low flow periods and storm flow has a partial dilution effect on this phosphorus load. The soils in these watersheds are naturally rather high in phosphorus content, therefore these results were not entirely unexpected.

Components of nutrient balances were calculated for both watersheds. Average values of nitrogen and phosphorus content in the harvested crops were obtained from the literature (Carlile and Phillips 1976, Pritchett and Gooding 1975, Pritchett and Smith 1974, Thompson and Troeh 1973, USDA Soil Conservation Service 1975). In addition to the nutrient inputs listed in Tables 8 and 9, natural mineralization processes in the soil and plant residues provide some nitrogen and phosphorus. Nitrogen (N_2) fixation also provides some available nitrogen. No attempt was made to estimate the amounts provided by these processes. On the output side, leaching of nutrients to the deep groundwater should be minimal because of the relatively impermeable clay layers which underly this area. Water balance estimates for this period also support this statement. Denitrification, immobilization and phosphorus fixation are additional sinks that may account for much of the difference between inputs and outputs in Tables 8 and 9. While the nutrient balances in Tables 8 and 9 are not complete, they do serve to show the relative magnitudes of some of the individual components of the balances. For example, nutrient losses in streamflow were considerably smaller than the amount of nutrients added to the watersheds in precipitation during this period. An exception to this was phosphorus losses in 1976-77 when precipitation input was very low and shallow groundwater flow was greater than in 1975-76, resulting in phosphorus losses greater than precipitation input. Nutrient losses in streamflow

Table 8. Components of the nitrogen balance for each watershed for the periods July 1975 to June 1976 and July 1976 to June 1977.

	Upper Watershed		Lower Watershed	
	1975-76	1976-77	1975-76	1976-77
	kg/ha			
Fertilizer	21.0	33.3	96.9	142.7
Animal Waste		5.7	7.2	24.2
Precipitation	18.9	16.7	18.9	16.7
Harvested Crops	19.9	19.2	93.6	55.1
Streamflow	1.43	1.65	6.36	2.10

Table 9. Components of the phosphorus balance for each watershed for the periods July 1975 to June 1976 and July 1976 to June 1977.

	Upper Watershed		Lower Watershed	
	1975-76	1976-77	1975-76	1976-77
	kg/ha			
Fertilizer	6.4	3.1	33.2	32.7
Animal Waste		1.5	1.9	6.5
Precipitation	1.57	0.44	1.57	0.44
Harvested Crops	3.4	2.0	19.1	8.1
Streamflow	0.33	0.68	1.34	0.86

amounted to only a small percentage of the nutrients applied in commercial fertilizer. The 1976-77 crop season was extremely dry resulting in a total loss for many crops. This accounts for the decrease in nutrients removed in harvested crops from 1975-76 to 1976-77.

Summary

Two agricultural watersheds were instrumented to determine water quantity and quality measurements. The upper watershed of 437 ha was primarily in forest cover with some pasture and a small amount of row crop. The lower watershed of 208 ha was mostly in intensive agricultural crop production with some pasture. The following results are from data collected during the two-year period:

1. Nitrogen and phosphorus loads in streamflow were approximately proportional to the flow volume in the two watersheds during each year.

2. The average total nitrogen concentration was about 10 percent greater in the lower watershed the first year, and about 10 percent smaller the second year. The average total phosphorus concentrations were the same in both watersheds the first year, and about 10 percent smaller in the lower watershed the second year.

3. The larger flow volume per hectare in the lower watershed as compared to the upper watershed occurred mostly during storm periods and was probably primarily due to land use and topography differences.

4. Average concentration changes between storm and low flow periods were small in both watersheds. About 50 percent of the flow volume and nutrient load from the upper watershed occurred during storm flow periods, while about 80 percent of the flow volume and nutrient load from the lower watershed occurred during storm flow periods in 1975-76. During 1976-77 the fractions were about 40 and 50 percent, respectively.

5. Components of nutrient balances indicate that nutrient losses in streamflow are a very small part of the total nutrient flow system in these two watersheds. Total nitrogen and phosphorus losses in streamflow were

equivalent to about five percent of the commercial fertilizer applied in each watershed. Nutrient loads in streamflow also were less than those contributed to the watersheds in precipitation during the period with one exception.

CHAPTER II
SMALL PLOT EXPERIMENTS

Small plot experiments were conducted during three crop years to evaluate the effects of cultural practices, fertilizer application methods, and water management on nutrient loads in surface runoff from sandy soils. These practices were evaluated on plots producing bell peppers and tomatoes. Practices evaluated the first two seasons on bell peppers (1975 and 1976) included (1) plastic mulch over the plant bed with all fertilizer applied beneath the plastic at planting time, (2) no mulch over the plant bed with all fertilizer applied at planting time, and (3) no mulch over the plant bed with fertilizer applied in three equal applications during the growing season. All treatments received sprinkler irrigation. Practices evaluated the last season (1977) were (1) drip irrigation under plastic mulch with fertilizer applied through the irrigation system at weekly intervals on both tomatoes and bell peppers, and (2) drip irrigation under plastic mulch with all fertilizer banded along the plant row at planting time on bell peppers.

Methods and Procedures

The small plot experiments were conducted at the University of Florida Horticultural Unit near Gainesville. The experiments for 1975 and 1976 used six plots (5.5m by 15m) containing three beds of bell peppers each fertilized at a rate of 224 kg N/ha from ammonium sulfate, 84 kg P/ha from superphosphate, and 140 kg K/ha from potassium chloride. There were two replicates of each of the three treatments enumerated above.

Beds were formed by a specially designed rototiller. Fertilizer was applied to the raised beds and the beds were again rototilled to mix the fertilizer. Plastic mulch was then applied to the appropriate plots before peppers were transplanted from greenhouse beds. Sprinkler irrigation was applied as required throughout the season to provide adequate moisture.

Critical depth flumes and water stage recorders were installed at the end of each plot to measure surface runoff. Automatic samplers were placed at each flume to collect a flow proportional composite water sample from each runoff event.

Water samples were analyzed for organic N by the microkjeldahl method (U.S. Environmental Protection Agency, 1974), ammonium N by the selective ion electrode method (U.S. Environmental Protection Agency, 1974), nitrate N by the chromotropic acid method (American Public Health Association, 1971), orthophosphate P by the ascorbic acid method (American Public Health Assoication, 1971), and total P by the ascorbic acid method after persulfate digestion (American Public Health Association, 1971). Sediment concentrations in most samples were very low because of the sandy soils and small slopes ($<$ 1 percent), therefore all analyses were run on the unfiltered sample.

Nutrient loads from the plots were calculated by a specially written flow and nutrient analysis computer program. The program provided runoff volumes, nutrient loads, and average nutrient concentrations on a storm event, monthly, and seasonal basis. This analysis program also was used in the watershed studies of Chapter I.

During 1977 the experiment used six plots. All plots were drip irrigated under plastic mulch and received 40 kg N/ha, 120 kg P/ha, and 40 kg K/ha broadcast at planting time. In addition, the tomato treatment and one bell pepper treatment received weekly applications of N and K fertilizer through the irrigation system to total 135 kg N/ha and 168 kg K/ha by drip irrigation. The other bell pepper treatment received an additional 135 kg N/ha and 168 kg K/ha banded along the plant row at planting time with none applied in the irrigation. Each of the above treatments had two replicates. The methods and procedures used during this last season were the same as the first two seasons except that sprinkler irrigation was not used and all beds received plastic mulch.

These experiments were superimposed upon larger, more comprehensive studies being conducted simultaneously in cooperation with other researchers. Some of their findings (to be available soon) may contribute to an understanding of the results presented here. (D. A. Graetz, personal communication. Soil Science Department, University of Florida, Gainesville. 1978).

Results and Discussion

Treatments were randomly assigned to plot locations within the experimental area each year. All results presented are averaged over the two replicates of each treatment. During 1975, surface runoff amounts were 6.32 cm from the plastic mulch, 5.49 cm from the no mulch, and 3.84 cm from the split fertilizer treatment. Difficulties with the automatic water samplers prevented obtaining enough samples to calculate nutrient loads for the entire season. Grab samples were collected from a runoff event in May that produced about one-fourth of the total seasonal runoff from most plots. Nutrient concentrations in these samples were very similar to the average concentrations measured during 1976 (Table 11). In 1975 there was less leaching of fertilizer nitrogen in plots with plastic mulch (D. A. Graetz, personal communication). Split fertilizer application also resulted in more efficient use of nitrogen than in the unmulched single application. Near the end of the crop season there did not appear to be adequate nitrogen for good plant growth in either of the unmulched treatments, while the mulched treatment was adequate.

Surface runoff volumes and nutrient loads from the three treatments during 1976 are shown in Table 10. Somewhat greater runoff was expected from the mulched plots because the mulch prevented infiltration on the plant bed to a great extent. Differences in surface runoff volume between the treatments were not consistent during the two years. This inconsistency probably resulted from the great amount of variation between individual plots even with the same treatment. Precipitation during the period of record was 81 cm and 77 cm for 1975 and 1976, respectively. Runoff volumes were relatively low, as expected. Nutrient loads from all treatments also were relatively low, especially when compared with the amount of fertilizer applied. Nutrient loads in runoff from the plastic mulch and no mulch treatments during 1976 were similar for all nitrogen and phosphorus forms (Table 10). However, nutrient loads were considerably higher from the split fertilizer treatment for all forms. This was partially because of a greater runoff volume from this treatment. Table 11 shows, however, that concentrations also were somewhat greater from the split fertilizer treatment. This was especially true for the ammonium N and nitrate N forms. The timing of fertilizer applications relative to rainfall was a very important factor in causing this treatment difference. When runoff occurs soon after fertilizer is applied, as happened during this experiment with the split applications, the fertilizer is subject to washoff in the runoff water. Therefore, while the split applications resulted in more efficient use of nitrogen, runoff losses were increased in this particular year because of the timing problem. Runoff losses were still very minimal, however.

Fertilizer leaching losses from the unmulched treatment in 1976 were much greater than from the mulched and split fertilizer

Table 10. Nutrient loads (kg/ha) and surface runoff volume (cm) from bell peppers with plastic mulch, no mulch, and no mulch with split fertilizer applications during 1976.

	Plastic Mulch	No Mulch	Split Fertilizer
	-----------------	kg/ha	-----------------
Organic N	0.93	0.94	1.35
Ammonium N	0.10	0.06	0.19
Nitrate N	0.12	0.12	0.72
Total N	1.15	1.12	2.26
Orthophosphate P	0.13	0.21	0.37
Total P	0.18	0.28	0.46
Runoff Volume, cm	4.78	5.31	7.49

Table 11. Flow-weighted nutrient concentrations (mg/1) in surface runoff from bell peppers with plastic mulch, no mulch, and no mulch with split fertilizer applications during 1976.

	Plastic Mulch	No Mulch	Split Fertilizer
	-----------------	mg/1	-----------------
Organic N	1.93	2.06	1.78
Ammonium N	0.17	0.12	0.26
Nitrate N	0.36	0.22	0.94
Total N	2.46	2.40	2.98
Orthophosphate P	0.28	0.40	0.48
Total P	0.38	0.56	0.61

application treatments (D. A. Graetz, personal communication). This effect was more prominent than during 1975 as a result of heavy rainfall occurring early in the growing season. Fruit yields were much lower from the unmulched treatment as a result of these leaching losses. Leaching losses and fruit yields were very similar for the mulched and the split fertilizer treatments (D. A. Graetz, personal communication).

In 1977 both tomatoes and bell peppers were grown on the experimental plots. All plots with bell peppers were planted to sweet corn as soon as the peppers were finished producing fruit; while the tomato plots were left idle after the crop was finished. Therefore, the direct comparison of the two fertilizer application methods was limited to the immediate growing season from April to July, 1977. Precipitation during this period totalled 30 cm. This is normally a rather dry time of year in north central Florida, resulting in the relatively low surface runoff volumes shown in Table 12. Because of the very small amount of runoff, most of the nutrient loads are correspondingly small. More variation among treatments can be observed from the nutrient concentrations in runoff water shown in Table 13. Because of the relatively large amount of variability between plots of the same treatment, it is difficult to attribute the differences in nutrient loads and concentrations for this short period to actual treatment effects. Information on leaching losses is not yet available from these treatments (D. A. Graetz, personal communication).

On July 29, 1977 all plots with bell peppers were planted to sweet corn. These plots received 42 kg N/ha, 56 kg P/ha, and 56 kg K/ha at planting. The plots were sidedressed with 40 kg N/ha from ammonium nitrate on September 1 and again on September 13. The tomato plots were left idle after production finished as indicated previously and received no more fertilizer. Nutrient loads and runoff volumes for the complete season from April, 1977 to January, 1978 are shown in Table 14 for all treatments. Precipitation during this period was 83 cm. Nutrient loads from drip fertilized tomatoes and drip fertilized peppers followed by sweet corn were similar. Additional nutrient losses from the production of the sweet corn crop were not observed. The slightly larger nutrient loads from the pepper and sweet corn treatment were more than accounted for by the somewhat larger runoff volume from that treatment. It follows that most of the nutrient concentrations in runoff water (Table 15) were smaller for the drip fertilized peppers and sweet corn than for the tomatoes.

The primary nutrient forms, if any, expected to be affected by fertilizer applied for crop production are ammonium N and nitrate N. The band fertilized peppers followed by sweet corn had

Table 12. Nutrient loads (kg/ha) and surface runoff volume (cm) from drip fertilized tomatoes, drip fertilized bell peppers, and band fertilized bell peppers during the growing season April to July, 1977.

	Drip Fertilized Tomatoes	Drip Fertilized Peppers	Band Fertilized Peppers
	kg/ha		
Organic N	0.10	0.36	0.59
Ammonium N	0.04	0.04	0.02
Nitrate N	0.03	0.04	0.08
Total N	0.17	0.44	0.69
Orthophosphate P	*	0.02	0.01
Total P	*	0.04	0.01
Runoff Volume, cm	0.17	0.40	0.26

*less than 0.005

Table 13. Flow-weighted nutrient concentrations (mg/l) in surface runoff from drip fertilized tomatoes, drip fertilized bell peppers, and band fertilized bell peppers during the growing season April to July, 1977.

	Drip Fertilized Tomatoes	Drip Fertilized Peppers	Band Fertilized Peppers
	mg/l		
Organic N	2.28	3.86	6.68
Ammonium N	0.85	0.39	0.40
Nitrate N	0.80	0.45	1.14
Total N	3.93	4.70	8.22
Orthophosphate P	0.04	0.19	0.07
Total P	0.08	0.34	0.12

Table 14. Nutrient loads (kg/ha) and surface runoff volume (cm) from drip fertilized tomatoes, drip fertilized bell peppers, and band fertilized bell peppers during the period April, 1977 to January, 1978.

	Drip Fertilized Tomatoes	Drip Fertilized Peppers[1]	Band Fertilized Peppers[1]
	kg/ha		
Organic N	1.17	1.21	1.86
Ammonium N	0.10	0.13	1.48
Nitrate N	0.10	0.15	0.36
Total N	1.37	1.49	3.70
Orthophosphate P	0.24	0.26	0.36
Total P	0.43	0.55	0.46
Runoff Volume, cm	3.86	5.21	6.16

[1]Sweet corn followed peppers on July 29, 1977

Table 15. Flow-weighted nutrient concentrations (mg/l) in surface runoff from drip fertilized tomatoes, drip fertilized bell peppers, and band fertilized bell peppers during the period April, 1977 to January, 1978.

	Drip Fertilized Tomatoes	Drip Fertilized Peppers[1]	Band Fertilized Peppers[1]
	mg/l		
Organic N	3.22	2.12	2.40
Ammonium N	0.25	0.24	2.06
Nitrate N	0.27	0.27	0.50
Total N	3.74	2.63	4.96
Orthophosphate P	0.64	0.56	0.60
Total P	1.13	1.19	0.78

[1]Sweet corn followed peppers on July 29, 1977

increased losses of both these nitrogen forms compared with the other treatments (Table 14). The increased losses were greater than that accounted for by the slightly larger runoff volume from this treatment. This is reflected by the higher ammonium N and nitrate N concentrations in Table 15. These increased losses occurred primarily during August, which was a relatively wet month (21 cm of rain). Most of the increased ammonium N loss occurred from only one of the two plots with this treatment. As referred to earlier, the relatively large variability between plots in a given treatment makes it difficult to determine whether it is a real treatment difference or a result of the natural heterogeneity in the many factors which interact to affect the overall nutrient losses. Since it was not feasible to have enough plots for a valid statistical analysis this question cannot be answered from this experiment. The increased nitrate N loss, however, was relatively uniform in both plots. This gives more indication of a real treatment difference. The most important result of these 1977 plot studies was that the total nutrient loads in runoff from all treatments, even with a double crop on some treatments, were very small compared to the fertilizer applied and the natural contributions from rainfall (Table 16). One exception to this was that the total phosphorus loads in runoff were nearly the same as the contribution in rainfall. Table 16 indicates that these relationships also were true during 1976.

Summary

The small plot experiments evaluated the effects of management practices including use of mulch, fertilizer application methods and timing, and double cropping on nitrogen and phosphorus losses in surface runoff. In all but one case, nitrogen and phosphorus losses in surface runoff were less than one percent of the amount applied in fertilizer. In all treatments total nitrogen losses in surface runoff were less than 25 percent of the contribution of rainfall. Total phosphorus losses in surface runoff were less than or equal to the contribution in rainfall except in one case when the runoff loss was about 30 percent greater than the contribution in rainfall. Phosphorus contributions in rainfall, however, were very low.

Ammonium N and nitrate N losses in runoff were greater from the split fertilizer application than from a single application because of the timing of runoff events which happened to occur soon after the split applications were made. No changes in nutrient losses by runoff were observed from use of plastic mulch.

Table 16. Nitrogen and phosphorus contributions from fertilizer and rainfall compared with the largest surface runoff losses from any treatment during a given year.

	Fertilizer Applied	Rainfall Contribution	Surface Runoff Losses (Largest)
	kg/ha		
1976 Peppers			
Total N	224	15.8	2.26
Total P	84	0.46	0.46
1977 Tomatoes			
Total N	175	14.5	1.37
Total P	120	0.42	0.43
1977 Peppers and Corn			
Total N	297	14.5	3.70
Total P	176	0.42	0.55

No increased nutrient losses in runoff were measured from double cropping which had extra fertilizer applied, except for the treatment where all of the first crop (peppers) fertilizer was applied at planting time. In this case, ammonium N and nitrate N losses were greater with double cropping, however there was a large variation between plots with the same treatment so this may not have been a real treatment effect.

CHAPTER III
SIMULATION MODEL DEVELOPMENT

Modeling Approach

Movement of nitrogen through agricultural watersheds involves many complex processes and interactions within the watershed. These processes are illustrated in Figure 9, adapted from Stewart (1976). In order to simulate nitrogen movement through a watershed into streamflow the potential amount of nitrogen available for transport must be known. This nitrogen can come from many sources including precipitation, fertilizer, animal wastes, and soil organic nitrogen reserves. Movement of this nitrogen in water through the watershed depends upon its form. Therefore, transformation processes and rates must be simulated. These are dependent upon watershed conditions including soil temperature, moisture content, soil type, pH, aeration, agricultural practices, and organic matter content (Porter 1975, Duffy and Franklin 1972, Hagin and Amberger 1974, Mehran and Tanji 1974). There are numerous sinks for nitrogen within the watershed including uptake by crops, immobilization of nitrate, and denitrification. These sinks reduce the amount of nitrogen available for movement from the watershed in streamflow.

Transport of nitrogen through a watershed also depends very heavily upon the hydrology of the watershed. Therefore, a good hydrologic simulation of the watershed is very important for the simulation of nitrogen movement. The hydrologic model should simulate the quantity of water moving through the watershed, its rate and direction for both overland and subsurface flow. This requires a comprehensive deterministic hydrologic model. It is particularly important that the hydrologic model predict the quantity of runoff and subsurface flow that results from different land-use areas and surface covers within the watershed.

The modeling approach used in this study was (1) to select a hydrologic model, meeting the above criteria, that was already developed and had been tested in a number of areas, (2) develop a model to simulate the nitrogen sources, sinks, and transformation processes within a watershed, and (3) couple the above two models together to obtain a simulation of the water and nitrogen movement through a watershed.

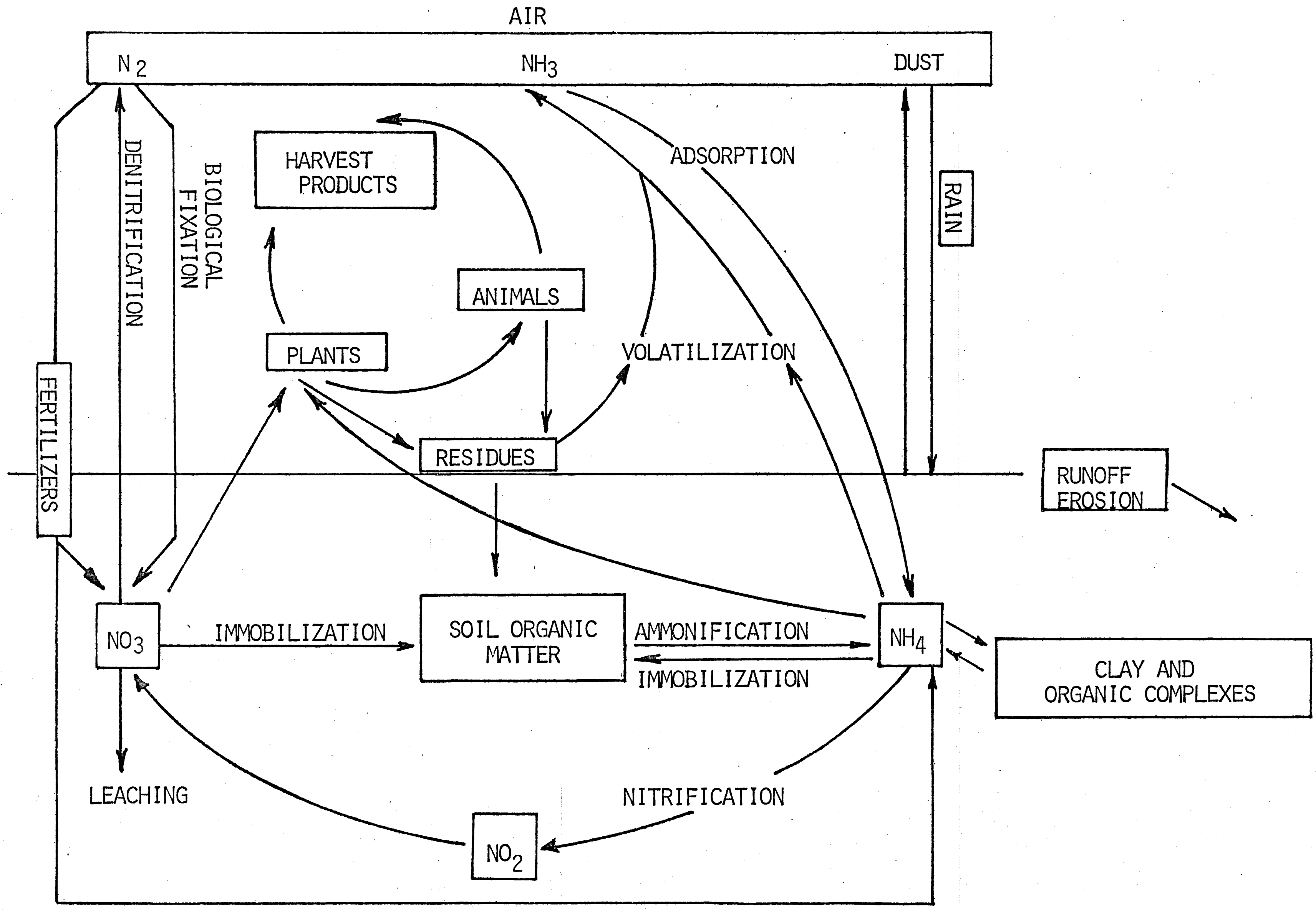

Figure 9. The nitrogen cycle in agriculture.

Hydrologic Model Calibration

The USDAHL-74 revised model of watershed hydrology (Holtan et al, 1975) was chosen as the hydrologic model for this study. This model is a deterministic, semi-empirical lumped hydrologic model. It was developed by the USDA Hydrograph Laboratory to be used as a practical tool for predicting runoff and infiltration in relatively small watersheds under natural rainfall conditions. The model utilizes some well known mathematical descriptions of the major hydrologic processes within a watershed. The model is written in Fortran IV computer language. Input requirements are relatively large. About 72 different parameters are required as input in addition to the historical climatic data. Computation time requirements are relatively low since no numerical solutions are involved in the computation processes. The model has been evaluated in a number of locations around the United States in the past few years (Nicks et al 1977, Hanson 1977, Crow 1977, Perrier et al 1977, Molnau and Yoo 1977, James et al 1977). It divides the watershed into hydrologic response zones based upon soil and watershed conditions. It also provides for response differences due to land use. Daily moisture status in the soil profile, soil water movement in both the vertical and horizontal directions, and other pertinent variables are readily available for use in a nutrient movement model. The USDAHL model is designed with each major hydrologic process in a separate subroutine. This makes understanding, modification, and improvement of the model easier. These are all advantages of this model for use with a nutrient transport model. Because of its advantages the USDAHL-74 model was chosen to serve as the hydrologic part of a larger model to simulate nitrogen movement through an agricultural watershed.

The hydrologic model was calibrated using data from the agricultural watersheds described in Chapter I. The USDAHL model requires four types of input parameters in addition to climatic data: watershed, soils, land use, and hydraulic (Holtan et al, 1975). Tables 17, 18, and 19 list the input parameter values used in the model to obtain the best simulation of streamflow for the calibration period of January to June, 1976. This combination of input parameters was selected after considerable trial and error selection of values for certain parameters as explained in the following discussion. The watershed was divided into three zones based upon hydrologic response. Zone 1 is the very flat upper part of the watershed, zone 2 is the hillside portion with more slope, and zone 3 is the alluvium portion of the watershed along the stream channel. The watershed parameters and some land use

Table 17. Watershed input parameters for USDAHL-74 model.

WATERSHED PARAMETERS

Size: 645 ha   Number of Zones: 3   Number of Crops: 45
Deep Groundwater Recharge: 1.27 mm/hr

ZONE PARAMETERS

Zone	Watershed Area, percent	Length, m	Slope, percent	Final Infiltration Capacity, mm/hr	Topsoil Depth, cm	Total Soil Depth, cm
1	75	274	0.4	1.27	38	127
2	15	305	2.0	7.62	38	127
3	10	122	0.8	1.27	64	127

Table 18. Soil input parameters for USDAHL-74 model.

TOPSOIL

Zone	Total Porosity, percent	Field Capacity, percent	Wilting Point, percent	Antecedent Soil Water, percent	Cracking, percent
1	35	20	7	20	0
2	35	20	7	20	0
3	56	40	15	40	0

SOIL PROFILE BELOW TOPSOIL

Zone	Total Porosity, percent	Field Capacity, percent	Wilting Point, percent	Antecedent Soil Water, percent	Cracking, percent
1	32	20	10	30	0
2	32	15	4	30	0
3	45	30	17	45	0

Table 19. Routing and land use input parameters for USDAHL-74 model.

ROUTING PARAMETERS

Number of Routing Coefficients: 3   Channel Routing, Δt: 0.2 hr
Channel Coefficient: 1.0 hr   Initial Channel Flow: 0.0025 mm/hr

Subsurface Routing:

Regime	Q-max, mm/hr	Coefficient, hr
1	0.13	22.0
2	0.05	90.0

Cascading:

Zone	To Next Zone, percent	Rest Goes To
1	80	Alluvium
2	90	Channel
3		Channel

LAND USE PARAMETERS

Crop	Row Crop	Small Grain	Forest	Grass
A Value	0.20	0.30	1.00	0.30
Crop Vd, mm	1.27	2.54	2.54	2.54
ET/EP	1.60	1.4	2.0	1.4
Root Depth, cm	51	51	254	76
Upper Temp., °C	30	27	27	27
Lower Temp., °C	7	4	4	4
Zone Area, 70:				
1	25	15	45	15
2	40	10	40	10
3	0	0	80	20

parameters were determined from U.S. Geological Survey quadrangle maps, judgements from direct observations of the watershed, and aerial photos of the watershed. The remaining land use parameters and the routing parameters were determined using the procedures described in Holtan et al (1975). Soil input parameters were determined from data on Florida soils in Stewart et al (1963).

The value for deep groundwater recharge was initially determined as 0.02 mm/hr by estimating average annual precipitation, ET, and streamflow yield in the area as suggested by Holtan et al (1975). This resulted in excessive streamflow and essentially no deep recharge occurring during the six month calibration period. Free water must be present in the bottom layer of the soil profile for deep recharge to occur in the model. This condition was present in the model for only a very short time. For this reason, the deep groundwater recharge value was increased to 1.27 mm/hr, equal to the final infiltration capacity of the soil. This change resulted in a better simulation of streamflow volume and 11.3 mm of deep recharge during the calibration period. This amount was still relatively low for deep recharge, however, precipitation was below normal during this calibration period.

Weekly average pan evaporation and air temperature data were obtained from the nearest observation station a few miles away from the watershed. Rainfall was measured with a recording gauge and a small wedge-shaped gauge on the watershed. Break-point rainfall data from the recording gauge for model input were poor during portions of the calibration period because of instrument malfunctions. Estimated data were used in these cases.

In this region, soil and watershed conditions are such that much of the runoff occurs by shallow lateral return flow. Overland flow also occurs during and immediately after heavy rainfall periods. Under these soil and watershed conditions, the subsurface flow components of a hydrologic model become very important to a good streamflow simulation. Considerable difficulties were encountered during calibration in obtaining a good simulation of the storm hydrograph shape and timing. A large portion of the problem was in the empirical equation used in the USDAHL model to determine the recession curve coefficients and maximum subsurface flow rates for each zone. In the model these are a function of the watershed length, watershed slope, watershed area, final infiltration capacity, and free water capacity. This approach does not appear to adequately represent the subsurface flow characteristics under the conditions encountered in this study. Holtan et al (1975) also suggest this as an area for further research.

In calibration of the USDAHL model, the output parameters of primary interest were the total flow volume, the monthly flow volume, and the daily flow volume and streamflow hydrograph for a selected period. Observed and simulated monthly flow volumes from the watershed for the calibration period are shown in Table 20 along with monthly rainfall. Simulated runoff volume for the total period compared very well with the observed runoff volume. The monthly distribution was less accurate, however. Runoff volume was underestimated in the lower rainfall months and overestimated in the one month of higher rainfall. Table 21 gives a more detailed look at a portion of the wet month of May. Most of the runoff occurred during a six-day period that was preceded by relatively dry conditions. Runoff volume for the rainy period was overestimated because the model generated sustained high flows during most of the period (Figure 10). The time of the simulated peak discharge was delayed, but was very close to the magnitude of the observed peak discharge. Subsurface flow was not adequately simulated to provide appropriate recession characteristics on the discharge hydrograph. This resulted in an overestimated flow volume for the period. Detailed study of the model output data indicated that the model generated excessive lateral flows through the top soil layer to the stream during storms before downward percolation filled the lower soil layers with moisture. This contributed to the poor simulation of the hydrograph recession curve.

In summary, calibration of the USDAHL-74 hydrologic model to the research watershed resulted in an acceptable simulation of total water yield for the period. Simulation of daily and monthly flows was not as good as desired. Components of the model needing modification to improve the hydrologic simulation of this watershed were indentified.

Nitrogen Model Development

The goal in developing the nitrogen model was to simulate the nitrogen concentrations and loads in streamflow from a watershed. The first requirement was to adequately account for the sources of nitrogen in the watershed. Precipitation is a significant source of nitrogen and needs to be accounted for as an input of nitrogen to the watershed (see Tables 8 and 16). Nitrogen concentrations in rainfall are highly variable with both time of year and location, making it difficult to use average values for input to a model (Allen and Kramer, 1972). Fertilizer and animal wastes applied to a watershed are other sources of nitrogen that need to be

Table 20. Observed and simulated monthly flow volume and observed rainfall for the research watershed during the calibration period in 1976.

Month	Rainfall, mm	Observed Runoff, mm	Simulated Runoff, mm	Error, percent
January	45.0	8.51	8.00	-6.0
February	42.9	7.84	3.89	-50.4
March	39.9	1.84	0.00	-100.0
April	24.9	0.17	0.00	-100.0
May	191.8	4.63	8.84	90.9
June	37.1	0.51	0.00	-100.0
Total	381.6	23.50	20.73	-11.8

Table 21. Observed and simulated daily flow volume and observed rainfall for the research watershed from May 23 to May 28, 1976.

Day	Rainfall, mm	Observed Runoff, mm	Simulated Runoff, mm	Error, percent
23	69.1	1.03	0.91	-11.6
24	8.4	0.80	2.97	271.2
25	15.5	0.89	2.24	151.7
26	0.0	0.52	2.13	309.6
27	7.9	0.30	0.51	70.0
28	4.1	0.18	0.05	-72.2
Total	105.0	3.72	8.81	136.8

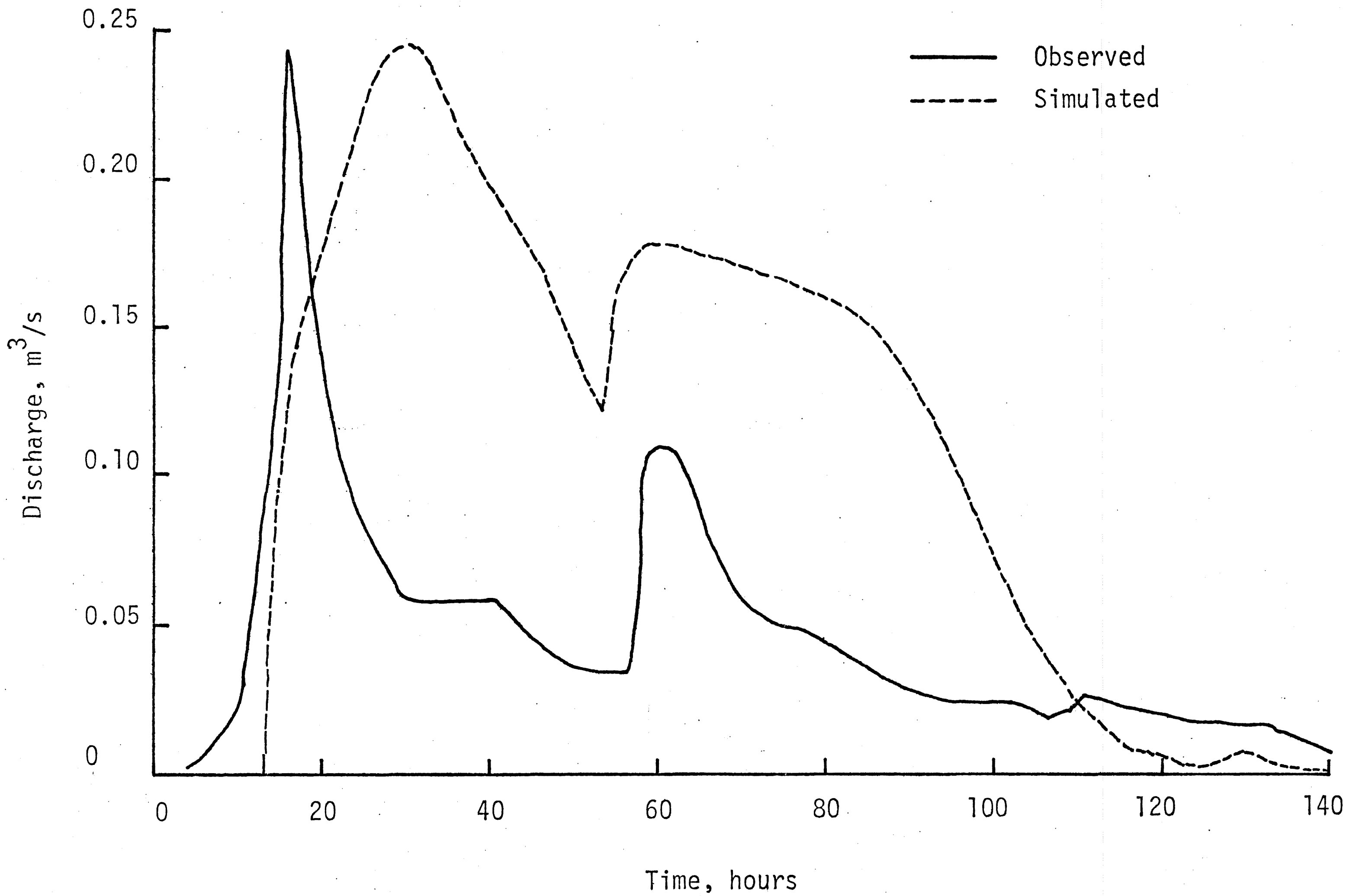

Figure 10. Observed and simulated discharge hydrographs for the period May 23-28, 1976.

accounted for by a model. Organic decomposition of crop residues, leaf litter, and organic matter accumulations on the watershed surface may contribute nitrogen. The effect of this nitrogen source is likely to be a function of season, moisture, and temperature. In particular, at the end of the growing season when temperatures are still relatively high there may be large influxes of organics and rapid decomposition with release of soluble forms of nitrogen (M. D. Smolen, personal communication. Southern Piedmont Research and Continuing Education Center, Virginia Polytechnic Institute and State University, Blackstone. 1977). Under Florida conditions this may be a significant source of the soluble organic nitrogen occurring in streamflow. While erosion is a large source of nitrogen in streamflow in many areas, it is not a significant source in much of Florida. The soil organic nitrogen pool is another source of nitrogen in a watershed. This nitrogen becomes available for movement through the watershed slowly by the natural mineralization process. Mineralization is primarily a function of temperature and moisture.

Nitrogen may also be removed from the system in a watershed through several sinks. The largest nitrogen sink is uptake by crops. It is a function of transpiration and nitrate concentration in the root zone. Mass flow is the predominate mechanism for moving nitrate through the soil to the plant roots (Barber, 1962). Therefore, nitrogen uptake should be closely connected to transpiration. The amount of transpiration also is related to the amount of adsorbing root surface and reflects the growth rate of the plant (Frere et al, 1975). Other nitrogen sinks are volatilization of ammonia, immobilization, and denitrification. Volatilization of ammonia occurs only from the soil surface or the upper soil layer and is probably not significant except from application of ammonium fertilizers or animal wastes. Immobilization is the conversion of inorganic nitrogen forms to organic forms. It depends upon the amount of nitrogen in the soil and the carbon-nitrogen (C:N) ratio. Denitrification usually occurs when poor aeration limits the amount of free oxygen in the soil. It is dependent on several factors including organic matter content, moisture, temperature, oxygen concentration, and pH. Denitrification is rapid if conditions are favorable. Appreciable losses of nitrogen as nitrogen gas can occur even when conditions favorable to denitrification exist for only a day or less. Estimates of total losses by denitrification on cropped lands average 10 to 20 percent of all nitrates formed or added as fertilizers and can be as much as 40 to 60 percent of added nitrate nitrogen (Donahue et al, 1977). Patrick et al (1976) showed that denitrification was even significant in well-drained agricultural soil in the absence of excessive organic matter.

After the nitrogen sources and sinks have been provided for in a model, the transformation processes and rates regulating changes in nitrogen forms must be considered in order to simulate the nitrogen losses in streamflow. This is important because of the different reactions that take place in the soil-water-air-plant system for different nitrogen forms. In model formulation of these processes, it appears that first-order rate equations are adequate (Frere 1975, Rao et al 1976). Mineralization rates, or decomposition of organic nitrogen to ammonium, and nitrification rates of ammonium to nitrate are dependent on several factors including soil temperature, moisture content, soil type, pH, aeration, agricultural practices, C:N ratio, and organic matter content. Models can be developed to consider one or all of these factors with varying degrees of sophistication (Frere et al 1975, Duffy and Franklin 1972, Mehran and Tanji 1974, Hagin and Amberger 1974, Donigian and Crawford 1976, Donigian et al 1977). Beek and Frissel (1973) simulated heat flow in the soil to determine the soil temperatures for use in nitrogen transformation calculations. This required inputs of air temperature, soil moisture, soil heat conductivity and soil heat capacity.

The approach chosen for this study was to select relatively simple expressions for the most important parts of the nitrogen cycle and develop a simple model to interface with the USDAHL-74 hydrologic model. Other expressions could then be added to this model to include other nitrogen forms and transformation processes to obtain a better simulation as the model is tested and further developed. Based on this approach, the nitrate option of the ACTMO model (Frere et al, 1975) was selected for use as a basic nitrogen model. It has the advantage of being designed to be interfaced with the USDAHL-74 model, however it was not available in this form. The basic framework of this nitrate model was developed as an option of the ACTMO model, but it was never operational (M. H. Frere, personal communication. Southern Great Plains Research Watershed, USDA-SEA, Chickasha, Oklahoma. 1977).

The ACTMO nitrate model considers only the soil organic nitrogen and fertilizer applied as nitrogen sources. Organic nitrogen is mineralized to nitrate according to a first order rate equation. The rate coefficient is sensitive to temperature and moisture. The watershed is separated into zones as in the USDAHL-74 model, and fertilizer can be applied by zone in one or two applications. The only nitrogen sink considered by the model is plant uptake. Nitrate uptake is a function of the amount of nitrate available in the soil, the amount of evapotranspiration from each soil layer weighted for the distribution of the nitrate within layers, and the amount of water available in the soil. Vertical and lateral water flow through each soil layer, calculated in the USDAHL-74 hydrologic model, is used in the ACTMO nitrate model to calculate the nitrate movement through the soil profile to the stream. These calculations are all made independently for each zone of the watershed to provide the total watershed output. The ACTMO model has been changed from a storm basis to operate on a daily basis with daily input parameters being supplied from the USDAHL-74 hydrologic model. The ACTMO model considers only nitrate and does not simulate the amount or movement of any other nitrogen forms, with the exception of the amount of soil organic nitrogen remaining to be mineralized. Nitrate is assumed to move only by subsurface flow, therefore none is allowed to move in surface runoff. This assumes that all surface applied fertilizer is dissolved and moves into the soil with the initial infiltration before overland flow begins.

The ACTMO nitrate model was first cleared of errors and operated as an independent model on our Amdahl 470-V6 computer. It was then converted to run on a daily basis instead of its original storm basis. The next step was to interface it with the USDAHL-74 hydrologic model. This involved locating the appropriate parameters in the USDAHL-74 model and writing them in the correct sequence on a magnetic tape during its operation. This tape was then used to provide the input parameters to the ACTMO nitrate model. The nitrate model requires some additional direct input parameters related to the initial nitrogen status of the watershed and fertilizer applied during the period of simulation.

Modeling nitrogen movement through a watershed is a very difficult and complex problem. This model is only the first step in the process of developing a model to satisfactorily simulate movement of nitrate, ammonium, and soluble organic nitrogen forms through agricultural watersheds. The model has not as yet been tested, however this will be done very soon. This research is being continued to include simulation of organic and ammonium nitrate forms. Precipitation and organic matter decomposition will be included as nitrogen sources. The concentration of soluble organic nitrogen in surface runoff will be assumed to be a function of seasonal variables, land use and cover. Denitrification will be included as a nitrogen sink based on a first order rate equation. The rate coefficient will be a function of organic nitrogen content in the soil profile, temperature, and moisture content, as a representation of aeration in the soil.

CONCLUSIONS AND RECOMMENDATIONS

Nitrogen and phosphorus loads were determined for two agricultural watersheds: one primarily in native forest cover and the other primarily in intensive crop production. Nitrogen and phosphorus concentration differences between the two watersheds were very minimal over the period of record. Nutrient concentration changes also were minimal between storm and low flow periods in both watersheds. This leads to the conclusion that nutrient loads were relatively proportional to streamflow volume. Nitrogen and phosphorus losses in streamflow were minor compared with amounts received by the watersheds in precipitation and commercial fertilizer.

Small plots were used to evaluate the effects of selected cultural and water management practices on nitrogen and phosphorus loads in surface runoff from sandy soils. Again, on these small plots nitrogen and phosphorus losses in surface runoff were small compared with the contributions to the plots in rainfall and commercial fertilizer. Since the magnitude of nutrient losses from all treatments was small, it was difficult to determine whether differences among treatments were the result of the treatments. Because of the natural heterogeneity, even on this small scale, there were relatively large differences in both runoff amounts and nutrient concentrations between plots with the same treatment. Therefore, conclusive differences among treatments could not be determined.

Techniques were developed to simulate nitrogen movement through agricultural watersheds. The USDAHL-74 model of watershed hydrology has several advantages that make it a good choice to provide the hydrologic information required to model nitrogen movement. Calibration of the model to the research watersheds was adequate, but not as good as expected. This was in part the result of the poor quality of some of the rainfall input data during the calibration period. The model should be modified in its subsurface and return flow components to better simulate the conditions of high lateral return flows with a shallow watertable, as encountered in this study. The ACTMO nitrate model provides a good framework for development of a more complete model of nitrogen transformations and movement. Simulating nitrogen transformations and movement through a watershed is a very difficult and complex problem. This nitrate model needs to be modified to include other nitrogen forms. Precipitation and organic matter decomposition are important nitrogen sources and denitrification is an important sink. These factors need to be included if the model is to simulate conditions similar to those encountered in this study. Simulation models are an effective tool to assist in gaining a better understanding of the complex processes and interactions that occur in a watershed system. They can help in identifying which processes are most important in controlling nitrogen movement within a watershed.

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