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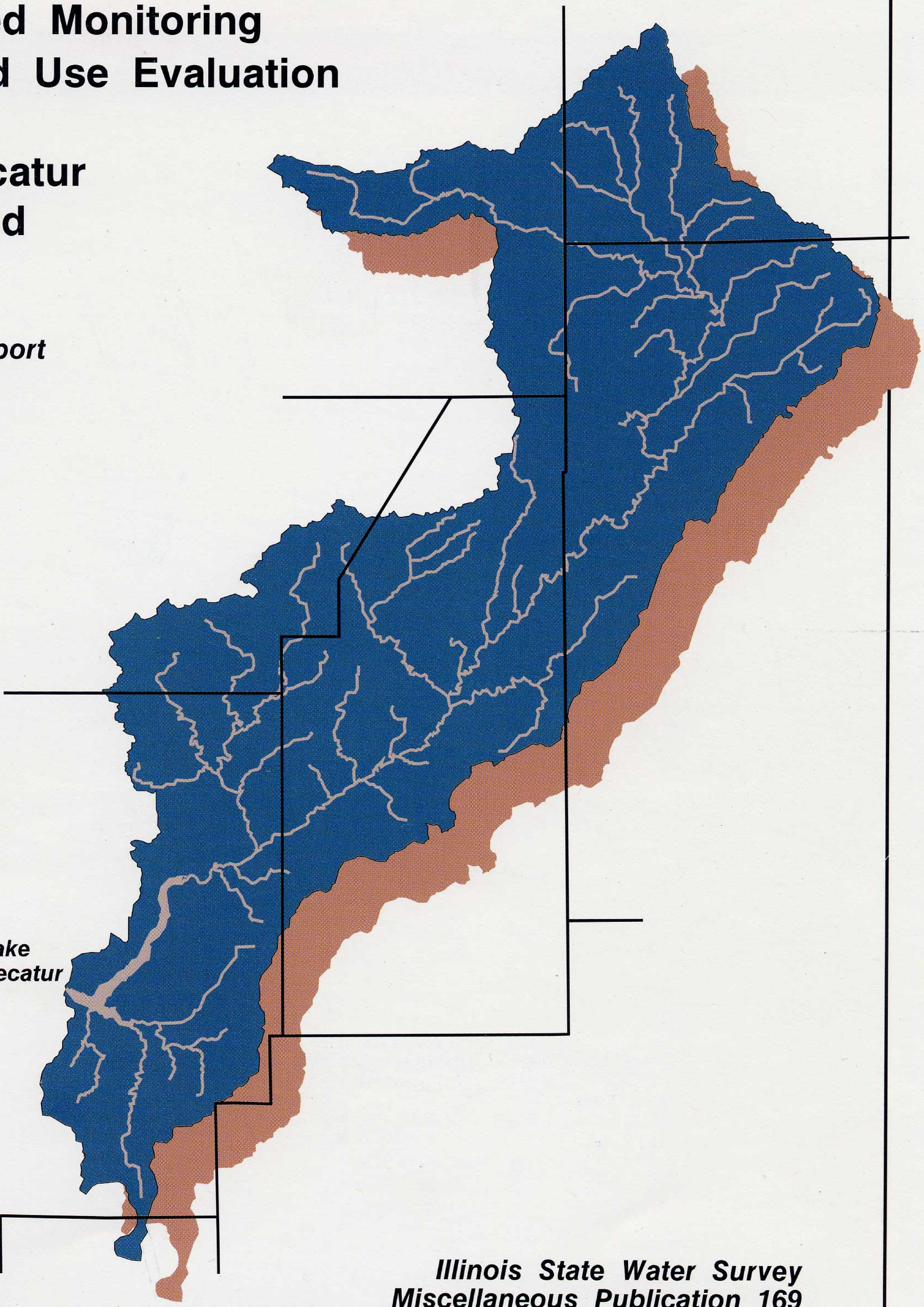
Watershed Monitoring and Land Use Evaluation for the Lake Decatur Watershed

Technical Report



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Office of Sediment & Wetland Studies

Watershed Monitoring and Land Use Evaluation for the Lake Decatur Watershed

Technical Report

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Report Prepared for the:
City of Decatur
Keith Alexander, Project Manager

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Executive Summary

Lake Decatur is the water supply reservoir for the City of Decatur. The reservoir was created in 1922 by construction of a dam to impound the flow of the Sangamon River. The dam created a lake with a volume of 20,000 acre-feet, but was later modified in 1956 to increase the maximum capacity of the lake to 28,000 acre-feet. The drainage area of the Sangamon River upstream of Lake Decatur is 925 square miles.

Lake Decatur has been experiencing water quality problems for some time. The Illinois Environmental Protection Agency (IEPA) issued eight nitrate warnings to the city from 1979 to 1992 for noncompliance of drinking water standards for nitrate. These warnings are issued when nitrate concentrations exceed the 10 milligram per liter (mg/1) maximum concentration level (MCL). Nitrate concentrations in the lake started to exceed the MCL starting in 1980, and previously the MCL was exceeded only in 1967. Since 1980, the nitrate concentration in Lake Decatur has exceeded the MCL every year except for 1993 to present. The nitrate concentrations are generally the highest during April, May, and June. However, the MCL can be exceeded almost any time of the year except during August, September, October, and November.

In 1992, the city signed a Letter of Commitment (LOC) to reduce nitrate concentration in Lake Decatur below the MCL within the next nine years. As part of the commitment, the city agreed to conduct a two-year watershed monitoring study to better understand the sources of nitrates in the watershed. The city selected the Illinois State Water Survey (ISWS) to conduct the two-year monitoring study and to develop land use management alternatives that would eventually bring the city into compliance with IEPA drinking water standards.

Review of the existing literature strongly suggests that nitrate concentrations in surface waters are strongly correlated to land use practices, especially fertilizer applications. Agriculture is the dominant land use in the Lake Decatur watershed, with row crops comprising about 87 percent of the total watershed area. The total acreage for row crops has been increasing over the years as acreage for grassy crops has drastically decreased. The increase in total acreage for row crops, combined with an even larger increase in total and per-acre fertilizer application in the watershed, is a major factor in the increased nitrate concentration in Lake Decatur.

A more detailed investigation of land uses in the watershed was done using the Illinois Department of Agriculture (IDOA) *T by 2000 Transect Survey* conducted by the Illinois Soil and Water Conservation Districts (SWCD) in 1994. Agricultural (crops) and nonagricultural (urban, rural, infrastructure, woods/open areas, and water) land uses were assessed from the survey. The dominant crops in the watershed are corn and soybeans, and the crop area in each tributary watershed varied from 99 to 77 percent. Analysis of the data detected crop rotation tendencies between the 1993 and 1994 growing seasons in each tributary watershed. Nonagricultural land use gradually increases with respect to watershed area. Urban land use occupies approximately 4.5 percent of the watershed, rural and woods/open area with 3.8 and 3.1 percent area, respectively. Percent residue cover was also collected for the survey and analyzed. The average percent watershed area for each range of percent residue cover is as follows: 50.6 percent area with 0-15 percent residue, 22 percent area with 16-30 percent residue, 8.1 percent area with 31-

50 percent residue, 6.1 percent area with 51-75 percent residue, and 2 percent area with 76-100 percent residue. The high percent of watershed area with a 0-15 percent residue cover is most likely the result of mid-planting floods in several tributary watersheds upstream of Monticello. Many farmers lost seeds to flooding and had to re-till, consequently reducing the residue cover.

To establish a proper perspective of the data collection period with respect to historical data and to properly characterize the hydrologic dynamics of the Lake Decatur watershed, a detailed analysis of the hydrology of the watershed was performed. The analysis includes a water budget of the watershed, analysis of historical streamflow data, and development of flow frequencies for tributary streams and main river stations. Based on the hydrologic analysis, it will be possible to characterize whether the data collection period was normal, above normal, or below normal in terms of precipitation and streamflow. Hydrologic characteristics of the tributary streams in the watershed can also be compared and contrasted. The results of this analysis are also important for evaluating the potential impact of land use changes in selected watersheds on the overall nitrate budget for Lake Decatur.

A major accomplishment of this project is the establishment of monitoring stations at selected locations on the main river and tributary streams to generate reliable and current hydrologic and water quality data to identify the sources and quantify the amounts of nitrate generated in the watershed. Eight major stations equipped with continuous stage recorders and three supplementary stations with staff gages near the lake were established. Three of the major stations are located on the main stem of the Sangamon River at Fisher, Mahomet, and Monticello. The tributary stations are located on Long/Big Creek, Friends Creek, Goose Creek, Camp Creek, and Big Ditch. In addition to the eight major stations, samples were collected at three urban areas in Decatur that drain directly into the lake and 15 supplementary monitoring stations in the Friends Creek and Big Ditch watersheds.

The three urban sites were established to monitor concentrations of nitrate in runoff from a residential area, a golf course, and an industrial area. Additional monitoring stations were established in Friends Creek and Big Ditch watersheds to monitor smaller sub-watersheds and drainage from areas with near uniform land use practices. Five of the sites in the Friends Creek sub-watersheds were at tile outlets.

Water quality samples are collected at each of the eight major stations and the three urban stations for nitrogen compound analysis on regular weekly visits and during storm events. Parameters analyzed include nitrate-nitrogen, ammonium-nitrogen, and total Kjeldahl nitrogen. Analysis is done for nitrate-nitrogen on a weekly basis and all three nitrogen compounds on a biweekly basis. Laboratory analysis is performed at the IEPA-certified ISWS chemistry laboratories in Champaign.

Precipitation records in the watershed show that the first-year data collection period was wetter than normal, with more than 10 inches of rainfall above normal for most of the upper portions of the watershed. Precipitation for the first year was near normal in the lower part of the watershed. On the other hand, precipitation for the second year was below normal by more than 10 inches for most of the watershed.

The great difference in precipitation amounts in the two years produced two drastically different monitoring periods in terms of hydrology and water quality. Total runoff for the first year was more than three times that of the second year. Low flows during the first year were much above normal with some record highs, whereas most of the tributary streams-were almost dry during the summer in the second year.

For the first year of data collection, the nitrate concentrations were generally above 4 mg/1. The highest concentrations were in May and June of 1993 when concentrations above 14 mg/1 were measured. The highest nitrate concentration for the first year was 15.3 mg/1 measured in Big Ditch on May 7, 1993. For a period of almost nine months from August to April, nitrate concentrations at all the stations were generally between 4 to 10 mg/1. The concentrations stayed elevated even during the summer months when they were expected to have dropped significantly. During the two months of high nitrate concentrations in May and June, the highest concentrations were measured at the Big Ditch station, while the lowest were measured at the Friends Creek station. For the rest of the year there was no consistent pattern except that Camp Creek tended to stay on the high side, while Long/Big Creek and Friends Creek tended to stay on the lower side.

During the second year, for three-and-a-half months from mid-July to the end of October, nitrate concentrations were near zero at all of the monitoring stations. Nitrate concentrations were generally lower in the second year than the first year except during March and April when, second-year concentrations were higher than the first year. The maximum concentration measured in the second year was 13.04 mg/1 at the Big Ditch station on April 12, 1995. This is significantly lower than the 15.3 mg/1 measured during the first year at the same station. The highest concentrations in the second year were measured in March and April as opposed to May and June for the first year. The highest concentrations were again measured at the Big Ditch station. Except for the months of May and June, the Big Ditch station tends to show higher concentrations and Long/Big Creek tends to show lower concentrations.

The Sangamon River stations also show the significant difference between the first- and second-year data similar to conditions observed in the tributary streams. During the first-year data collection, nitrate concentrations never fell below 2 mg/1 except once at Fisher in April 1994. During the second year, nitrate concentrations were zero or near zero for a period of three-and-a-half months from mid-July to the end of October. During the first year, nitrate concentrations were high at all three stations during May and June, started to drop in July, and essentially stayed between 2 and 8 mg/1 for the rest of the year. The highest concentration, 13.9 mg/1, was measured at Fisher on June 3, 1993. In general, the nitrate concentrations at Fisher, the upstream station, were higher than at Mahomet or Monticello and lower at Monticello than at Mahomet or Fisher. This is not, however, always the case.

Data for the second year differed from the first year in several respects. The low concentrations in the summer during the second year have already been mentioned. Another major difference was the higher nitrate concentrations during the second year as compared to the first year for the period from December 1994 to April 1995. Nitrate concentrations were consistently higher in the Sangamon River during the second year from December 1994 through

April 1995. During this period, concentrations were between 5 to 12 mg/1 in the second year as compared to 2 to 8 mg/1 for the first year. The highest concentration for the second year was 11.1 mg/1 at Fisher on April 11, 1995 as compared to 13.9 mg/1 in the first year. The highest concentrations were measured in April 1995 for the second year as opposed to June 1993 for the first year. High concentrations were higher during the first year, while low concentrations were lower in the second year.

Even though the main water quality concern and the one that is regulated at Lake Decatur is nitrate concentrations, the critical issue for watershed management is nitrate loads. It is impossible to reduce the nitrate concentration in the lake without reducing the nitrate load into the lake. Nitrate load calculations combine the effects of variability in nitrate concentrations and streamflows and allow us to determine how much nitrate is being generated from different parts of the watershed and also during different time periods. Management alternatives are more easily understood in terms of load reduction than reduction in concentration. The calculation of nitrate loads, or yields, is necessary to determine the contribution of different areas to the total nitrate input into the lake. For example, a tributary may have some of the highest nitrate concentrations, but if it is also one of the smallest sub-watersheds, its total delivery of nitrates to the lake could be quite small as compared to other sub-watersheds and thus not a significant contributor.

For the tributary streams, the annual nitrate load for the first year ranges from a low of 28 pounds per acre (lb/acre) for Long/Big Creek to a high of 49 lb/acre for Big Ditch. Next to Big Ditch, Friends Creek generates the highest nitrate load at 44 lb/acre. The other two tributaries, Goose Creek and Camp Creek, generate nitrate at almost a uniform rate of 36 to 39 lb/acre. The average annual load for all the tributaries for the first year was 39.2 lb/acre. Annual nitrate loads for the tributary streams were much smaller the second year than the first year. Loads for the second year ranged from a low of 9 lb/acre for Long/Big Creek to a high of 19 lb/acre for Friends Creek. The overall average annual load for the tributary streams was 14 lb/acre as compared to 39.2 lb/acre for the first year. The first-year loads were almost three times greater than the second-year loads.

Similar to the tributary streams, the loads for the three Sangamon River stations during the first year were significantly greater than those for the second year. The overall average annual load for the main river stations for the first year was 37 lb/acre as compared to 15 lb/acre for the second year, more than double the second-year loads. Annual loads for the main river stations were very similar for both years. During the first year, annual loads ranged from a low of 34 lb/acre at the Monticello station to a high of 40 lb/acre at the Fisher station. In the second year the loads fell within a narrow range from a low of 14 lb/acre at the Monticello station to a high of 16 lb/acre at the Mahomet station. The variability in annual load for the second year was not significant.

Based on the nitrate load data, we can conclude that the source of nitrate in the Lake Decatur watershed is truly dispersed throughout the watershed. There are no "hot spots" that are generating most of the nitrate that flows into Lake Decatur. Even though the Big Ditch and Friends Creek watersheds were observed to generate relatively higher nitrate loads per unit area during the first year, their rates were not significantly higher than the rest of the watershed.

Furthermore, the combined drainage areas of the two watersheds are approximately 16 percent of the whole watershed. More than 80 percent of the drainage area yields nitrate at almost a uniform rate.

One of the main objectives of this project was to evaluate the potential effects of alternative agricultural best management practices (BMPs) at different locations of the Lake Decatur watershed on nitrate level reduction at Lake Decatur. The AGNPS (Agricultural Nonpoint Source Pollution) model for agricultural watersheds was used for quantitative evaluation of the effects of alternative management practices on nonpoint source pollution from the Lake Decatur watershed. This model has been developed and distributed by the North Central Soil Conservation Research Laboratory of U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS).

Four broad categories of BMPs were evaluated: (1) nutrient management, (2) mitigation projects, (3) conservation practices, and (4) a combination of nutrient management and conservation practices. For evaluating nutrient management, the fertilizer application rate was varied in each of the selected sub-watersheds and combinations of sub-watersheds, one at a time, and changes of nitrate concentrations throughout the watershed and at the lake were analyzed. Mitigation projects, such as wetlands, buffer strips, and detention ponds, could be implemented in the watershed to reduce the nitrate level in Lake Decatur. Because such projects could remove nitrate, the impact of these projects was evaluated by varying the nitrogen decay parameter in the model. Since conservation practices such as conservation tillage, which increases land cover (and thus reduces runoff), they were simulated by varying the SCS curve number in the model. Finally, the fertilizer application rate and the SCS curve number were simultaneously varied to study the combined effects of nutrient management and conservation practices.

The modeling results show that nutrient management was the most effective and reliable BMP in reducing nitrate loading into the lake. Nitrate loading into the lake was directly proportional to the amount and area of nutrient application. Similarly, mitigation projects that remove nitrate were also effective in reducing nitrate loading into the lake. However, it is difficult to quantify the extent to which mitigation projects are needed. Conservation practices reduced runoff but could either reduce or increase nitrate concentrations in the lake depending upon the locations of applications with respect to the lake. Conservation practices applied over the entire watershed and over areas closer to the lake reduce nitrate concentrations in the lake. Conservation practices applied over areas further away from the lake tend to increase nitrate concentrations in the lake if nutrient applications remain the same. However, when conservation practices are combined with nutrient management they are found to be very effective.

Watershed Monitoring and Land Use Evaluation for the Lake Decatur Watershed

by
Illinois State Water Survey
Champaign, EL

Introduction

Lake Decatur is the water supply reservoir for the City of Decatur. The reservoir was created in 1922 by constructing a dam to impound the flow of the Sangamon River. The original dam had a crest elevation of 28 feet above the river bottom and a length of one-third of a mile. The dam created a lake with a volume of 20,000 acre-feet and an area of 4.4 square miles. The dam was later modified in 1956 to increase the maximum capacity of the lake to 28,000 acre-feet. Water withdrawal from the lake has been increasing over the years, reaching 36 million gallons per day in 1994. It is projected that the increasing demand will continue in the near future.

The drainage area of the Sangamon River upstream of Decatur is 925 square miles. The watershed includes portions of seven counties in east-central Illinois as shown in figure 1. The predominant land use in the watershed is row crop agriculture comprising nearly 90 percent of the land area. The major urban areas within the watershed are Decatur, Monticello, and Gibson City.

Lake Decatur has been experiencing water quality problems for some time. The lake has high concentrations of total dissolved solids and nitrates, where nitrate concentrations have been relatively high in recent years. This has created a serious situation for the drinking water supply of the City of Decatur. The Illinois Environmental Protection Agency (IEPA) has issued eight nitrate warnings to the city from 1979 to 1992 for noncompliance of IEPA drinking water standards for nitrate when concentrations exceeded 10 milligrams per liter (mg/1).

On June 10 1992, a Letter of Commitment (LOC) was signed between the IEPA and the City of Decatur. The LOC requires the city to take several steps to reduce nitrate levels in Lake Decatur to acceptable concentrations within the next nine years. One of the steps requires the city to conduct a two-year monitoring study of the Lake Decatur watershed in order to better understand the sources of nitrates in the watershed. The Illinois State Water Survey (ISWS) has received a grant from the City of Decatur to conduct the two-year monitoring study and to develop land use management strategies that would eventually bring the city under compliance for the IEPA drinking water standards.

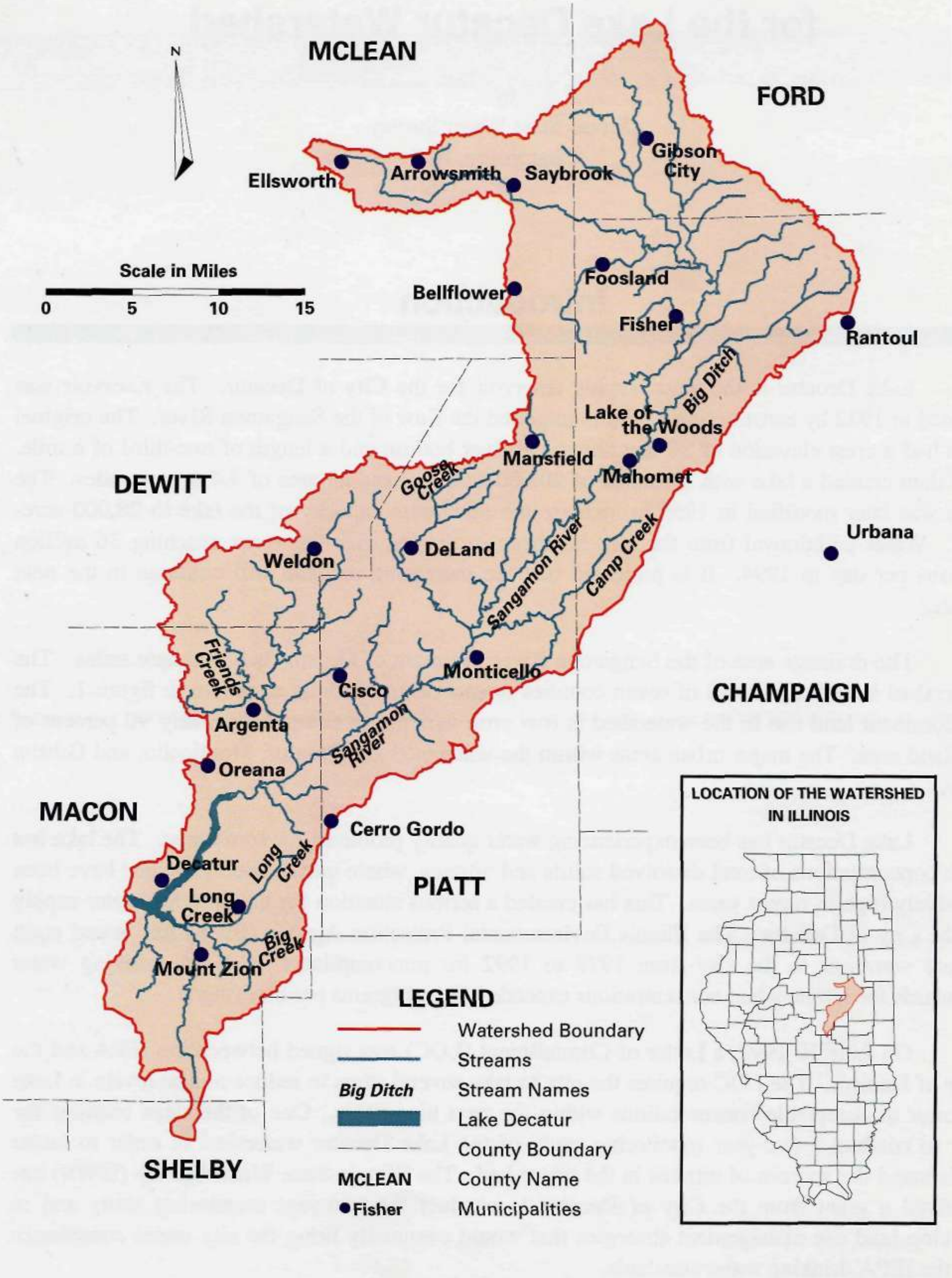

Figure 1. Location of the Lake Decatur watershed

This technical report is a product of the two years of data collection and analysis. The report is organized into five sections: Introduction, Background, Hydrology of the Lake Decatur Watershed, Hydrologic and Water Quality Monitoring, and Mathematical Modeling. The introduction discusses the need for the study; the section on water quality issues discusses the major water quality problems for Lake Decatur; the section on hydrology provides the hydrologic characteristics of the streams in the watershed; the section on hydrologic and water quality monitoring discusses the monitoring program and the results after two years of data collection; and the section on mathematical modeling presents the development of a model to evaluate the effects of best management practices (BMPs) on nitrate loading into Lake Decatur.

Acknowledgments

This work was supported by the City of Decatur. Keith Alexander, Lake Manager, served as project manager and his cooperation and assistance are greatly appreciated.

Several other city officials and staff have also been very cooperative and supportive: Terry M. Howley, Mayor; James C. Bacon, Jr., City Manager; Bruce A. McNabb, Public Works Director; Stephen F. John, Ex-Council Member; James R. Mayhugh, Sr., Water Production Manager (retired); John A. Smith, Water Production Manager (present); and Erik C. Brechnitz, Ex-Mayor.

We would also like to acknowledge the cooperation and support we have received from the following county Soil and Water Conservation Districts: Champaign: Leon Wendte, Diane McNaught, Rene Claus, and Jane Kietzman; Dewitt: Shelly Finfrock; Ford: Dale Hoogstraat; McLean: Jackie Kraft; and Macon/Piatt: Marilyn Parker, Nancy Price, Alice Love, and Greg Jackson (Natural Resources Conservation Service).

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Background

Water Quality Problems in Lake Decatur

Lake Decatur has experienced water quality problems over the years. Past studies by the U.S. Environmental Protection Agency (USEPA) and the Illinois Environmental Protection Agency (IEPA) have documented water quality problems in the lake (USEPA, 1975; IEPA, 1978). Most of the problems are associated with nonpoint source pollution generated in the watershed of the Upper Sangamon River. The lake generally has high levels of total dissolved solids and nitrates. Currently, the most pressing water quality problem in Lake Decatur is high concentrations of nitrates. Because of repeated warnings from the IEPA for noncompliance of IEPA drinking water standards for nitrates, the City of Decatur signed an agreement with IEPA to reduce the nitrate concentration in the lake to acceptable levels within a period of nine years. After evaluating several alternatives to deal with the nitrate problem, including the installation of expensive water treatment technologies at the water treatment plants, the city decided to deal with the problem at the source and implement long-lasting, cost-effective solutions.

The source of the nitrate that eventually reaches Lake Decatur is, of course, found in the watershed of the Upper Sangamon River that feeds Lake Decatur. To characterize and quantify the spatial and temporal distribution of nitrate yield in the Upper Sangamon, the City of Decatur initiated a two-year watershed monitoring project through a grant to the Illinois State Water Survey (ISWS). The purpose of the monitoring project was to collect reliable hydrologic and water quality data throughout the watershed to gain an understanding of the sources of nitrate in the watershed and then to solicit full cooperation of those residing and farming in the watershed in resolving the problem by presenting this information in an unbiased manner. Without such cooperation, it will be almost impossible to develop effective programs to deal with the problem.

To put the nitrate problem in Lake Decatur into an historical perspective, nitrate concentration data were retrieved from the City of Decatur, ISWS, and IEPA archives. Figure 2a shows data regularly collected by the city from 1967-1995. The available data from 1923-1967 was scarce and sporadic. It was included and presented in figure 2b to provide a general reference to nitrate concentrations prior to 1967. Figure 2a shows the general cyclic fluctuation of nitrate concentration from the high in the spring to the low in the summer every year. It also shows that the maximum concentrations started to exceed 10 mg/1 starting in 1980. Prior to 1980, the 10 mg/1 concentration was exceeded only in 1967. Since 1980, the maximum nitrate concentration has equaled or exceeded the 10 mg/1 maximum contamination level (MCL), except from 1993 to 1995. This fact is clearly illustrated in figure 3, which shows the annual maximum, minimum, and average nitrate concentrations in Lake Decatur for the last 28 years (City of Decatur, 1995). As seen in the figure, the maximum nitrate levels have become an increasing and consistent problem since 1980. These high concentrations of nitrates have resulted in eight nitrate warnings from the IEPA in the last 16 years. The most recent warning, issued on January 6,1992, was rescinded on July 14, 1992 (City of Decatur, 1995).

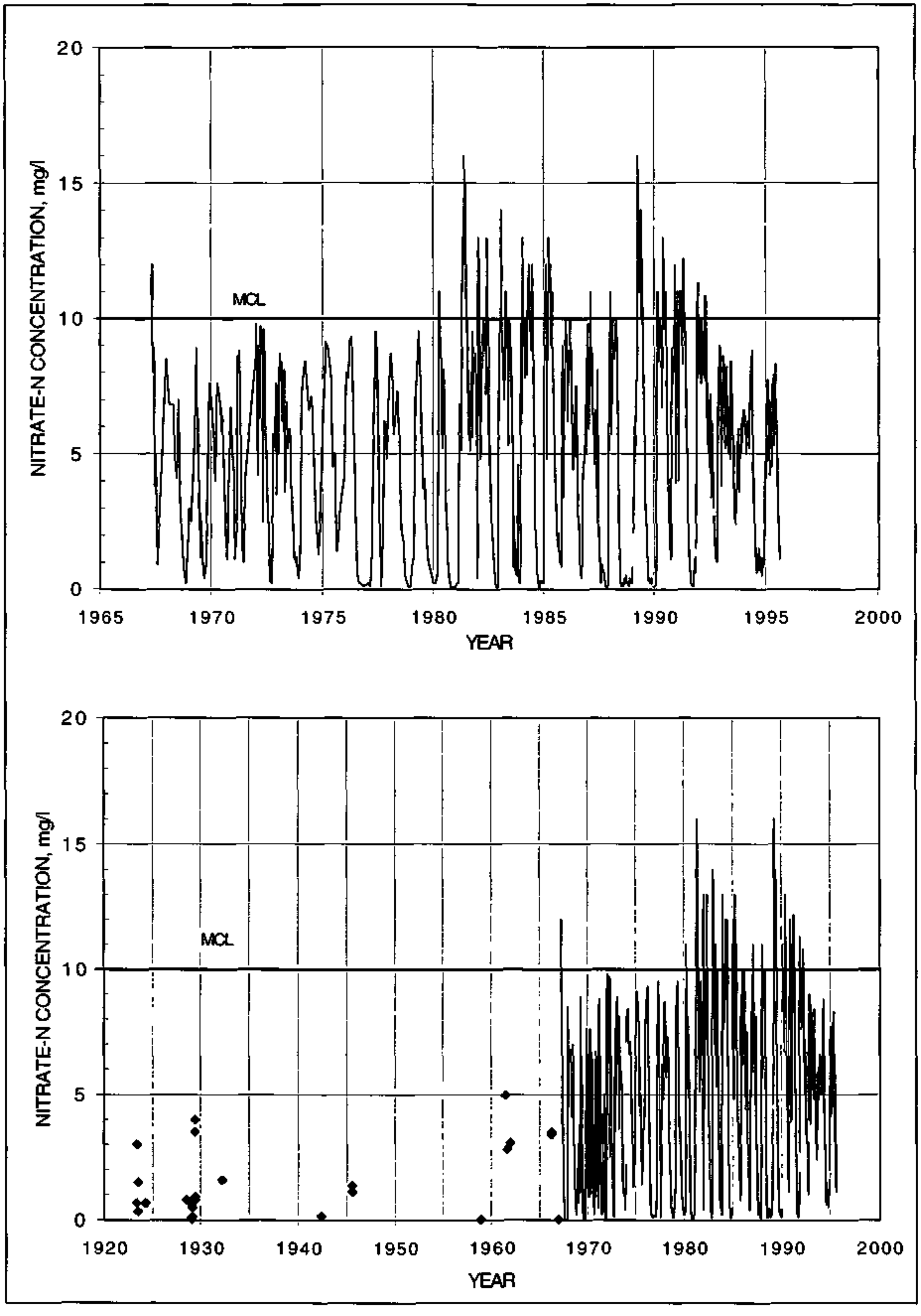


Figure 2. Nitrate concentrations in Lake Decatur from a) 1967-1995 and b) 1923-1995

It should also be noted that not only have the maximum concentrations increased but also the average nitrate concentration as shown in figure 3. An increase in the average concentration implies that the nitrate load into the lake has also increased.

Figure 4 shows the monthly maximum, average, and minimum nitrate concentrations in Lake Decatur for the period from 1967 to 1995. With respect to maximum concentrations, the most important parameter in terms of drinking water regulations, it can be concluded that concentrations of nitrate in excess of the 10 mg/1 regulatory limit can occur almost any time of the year except during August, September, October, and November when concentrations are relatively low as shown in the figure. The concentrations are generally the highest during April, May, and June.

Numerous studies and publications throughout the country document and illustrate the link between nitrate concentrations and farming practices, especially fertilizer applications (Bouchard, Williams, and Surampalli, 1992; Klepper, 1978; Klepper et al., 1974). There is a general consensus that the primary cause of high nitrate concentrations in surface water is nitrogen fertilizer application in the watershed. Some people also argue that agricultural practices other than fertilizer applications are also contributing factors in increased nitrate concentrations in surface water (Keeney and DeLuca, 1993). In any case, land use practices in the watershed are the major factor in generating as well as eventually controlling the nitrate problem in Lake Decatur. One of the major tasks of this project was to collect relevant land use data that will provide better understanding of the correlation between land use and nitrate concentrations and loads. Data and a discussion of land use in the Lake Decatur watershed are presented in the following section.

Physical Characteristics of the Lake Decatur Watershed

The Lake Decatur watershed lies in a climate region classified as humid continental, which is typical for central Illinois. The 30-year average annual precipitation (1961 to 1990) is 40.1 inches. The annual precipitation for 1993 and 1994 varies from 47.4 to 35.8 inches, respectively. In the last 30 years, the highest annual precipitation was 54.8 inches in 1973, and the lowest was 27.2 inches in 1980. The highest one-day maximum precipitation was 5.1 inches on July 26, 1992.

The Lake Decatur watershed lies in the Till Plains section of the Central Lowland physiographic province. The Till Plains section is generally characterized by broad till plains, which are mostly in a youthful erosion stage. The Upper Sangamon watershed is located on the Bloomington Ridged Plain, a subdivision of the Till Plains section, and is characterized by low broad morainic ridges with intervening wide stretches of relatively flat or gently undulating ground moraine.

There are five major types of soil areas in the watershed. Figure 5 shows the distribution of the different soil types. Area 1 is covered with the dominant soil types in the Lake Decatur watershed that consists of poorly drained Drummer and Sable silty clay loams and somewhat

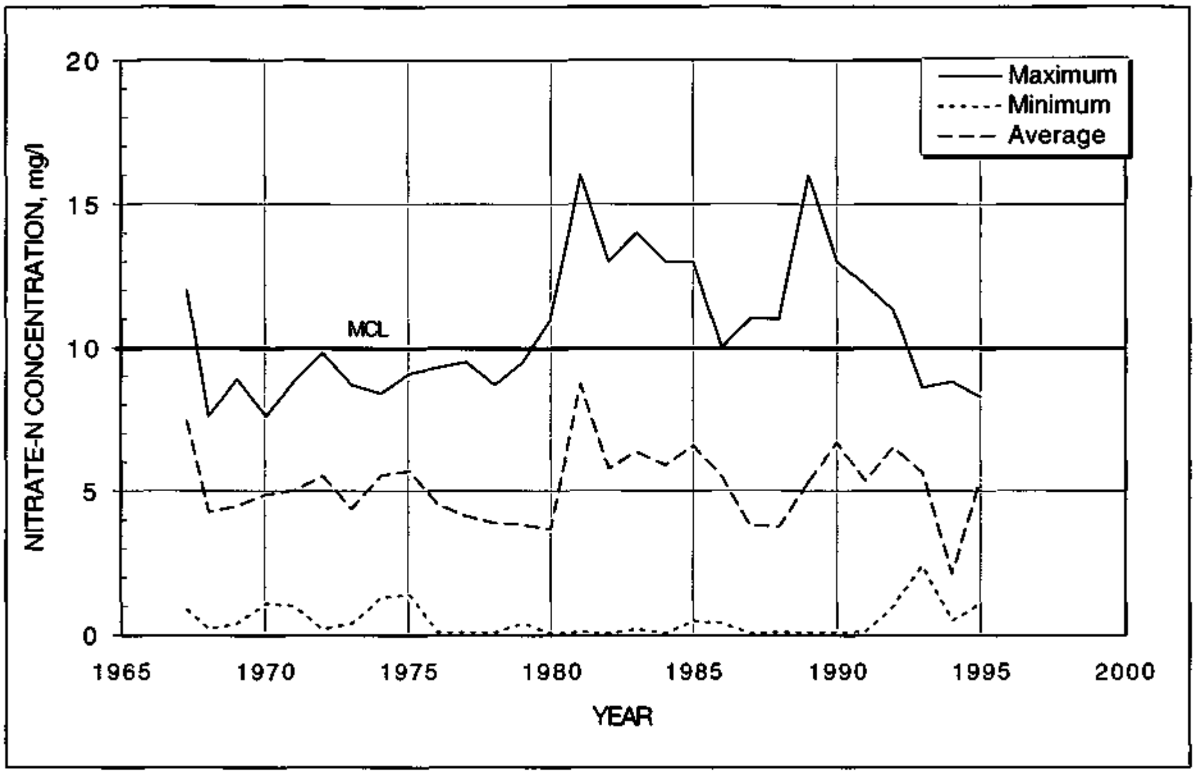


Figure 3. Annual maximum, minimum, and average nitrate concentrations in Lake Decatur from 1967-1995

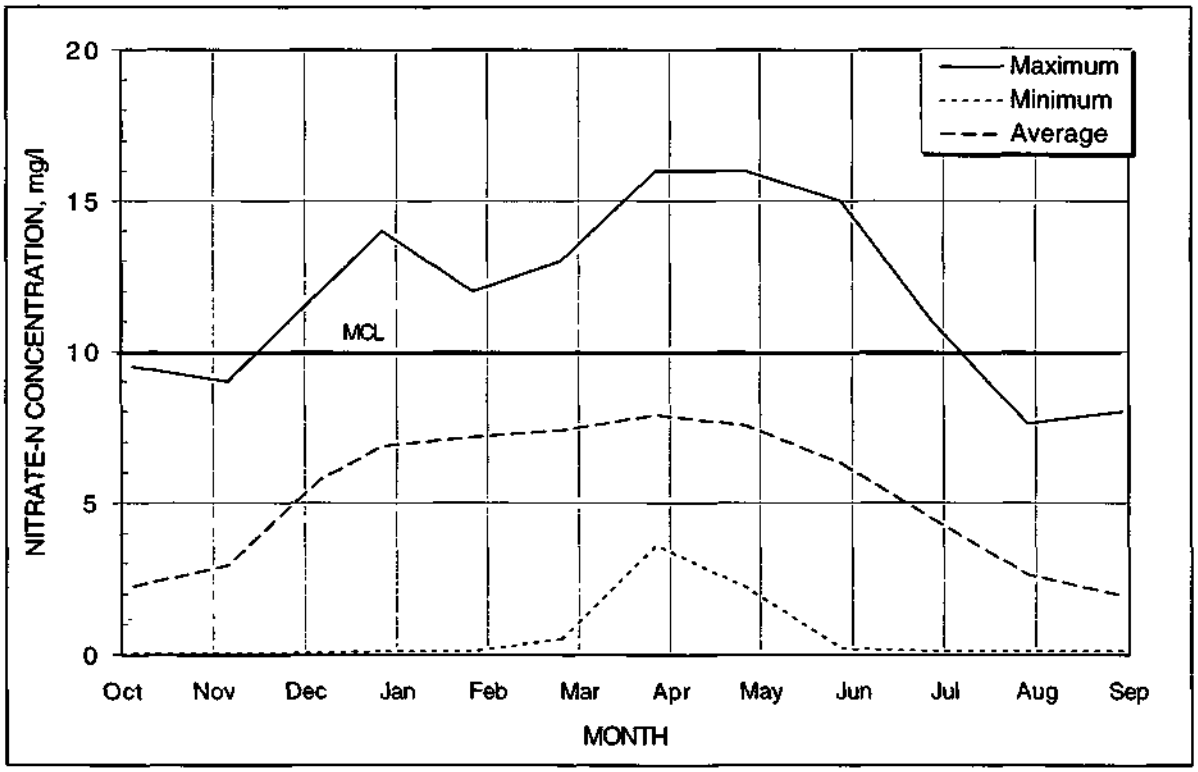


Figure 4. Monthly maximum, minimum, and average nitrate concentrations in Lake Decatur from 1967-1995

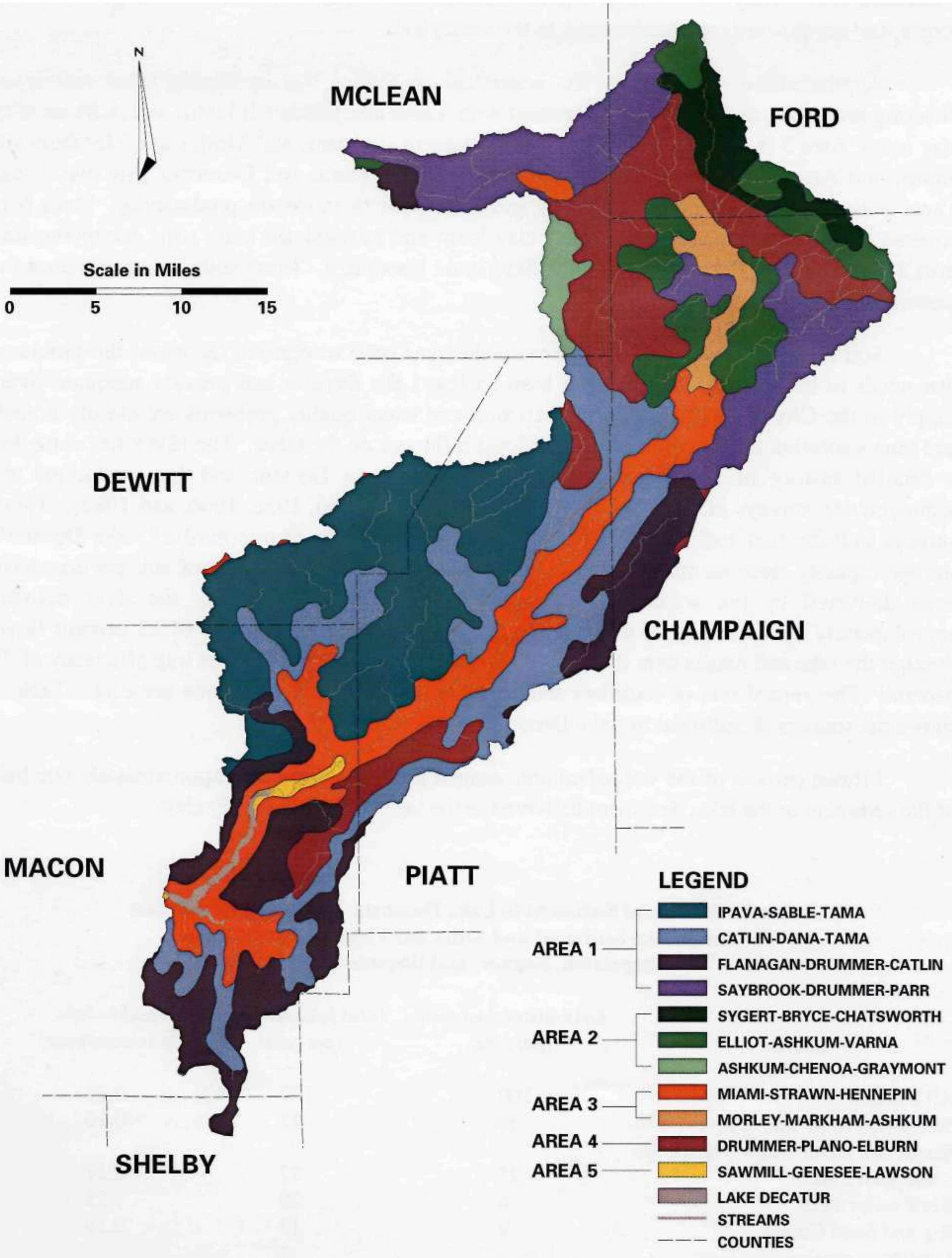


Figure 5. Map of soil association groups in the Lake Decatur watershed

poorly drained Flanagan and Ipava silt loams. These soils account for almost 60 percent of the watershed area. They have a high organic content and a high resistance to drought, are very fertile, and are the most productive soils in the watershed.

Approximately one-third of the watershed is divided equally among three soil types covering areas 2, 3, and 4. Area 2 is covered with Varna and Elliott silt loams and Ashkum silty clay loam; Area 3 is covered with Miami and Hennepin silt loams and Morley and Markham silt loams; and Area 4 is covered with Piano and Elburn silt loams and Drummer silty clay loam. These soils are used for cultivated crops and have poor to moderate productivity. Area 5 is covered with Sawmill and Genesee silty clay loam and Lawson silt loam soils occupying less than 3 percent of the watershed along the Sangamon floodplain. These soils are mostly used for pasture, hay, and woodlands.

Soil erosion in the Lake Decatur watershed has been recognized as one of the problems that needs to be controlled in the long term so that Lake Decatur can provide adequate water supply to the City of Decatur. The soil erosion and water quality problems are closely linked, and thus a solution to one will have a significant influence on the other. The ISWS has compiled a detailed history of the sedimentation problem in Lake Decatur and has performed six sedimentation surveys in Lake Decatur (1931-1932, 1936, 1946, 1956, 1966, and 1983). These surveys indicate that sedimentation has contributed to the loss of one-third of Lake Decatur's storage capacity since its construction in 1922. On the average, 21.4 tons of soil per acre have been delivered by the watershed between 1922 and 1983. Annually the river delivers approximately 200,000 tons of sediment to the lake, of which an average of 23 percent flows through the lake and passes over the dam. The lake has an average sediment trap efficiency of 77 percent. The annual rate of sediment accumulation in the lake is 0.27 tons per acre. Table 1 shows the sources of sediment to Lake Decatur.

Fifteen percent of the watershed area nearest the lake contributes approximately one half of the sediment in the lake. Sediment delivered to the lake is predominantly clay.

Table 1. Sources of Sediment to Lake Decatur: Estimated Proportion of Total Lake Sediment and Sediment Yield by Source Area (Fitzpatrick, Bogner, and Bhowmik, 1987)

Source	*Lake watershed area (percent)*	*Total lake sediment (percent)*	*Yield to lake (tons/acre/year)*
All Sources	100	100	0.27
Sangamon River above Monticello	59	22	0.10
Sangamon River below Monticello and above lake	25	27	0.29
Bluff watersheds	6	29	1.25
Big and Sand Creeks	9	19	0.56
Lakeshore erosion	-	2	-

Stream Profiles

The slope of a stream is an indicator of erosion and stream velocity. Table 2 provides the mean stream slopes for the Sangamon River and four main tributaries. The distances and corresponding changes in elevation for each stream can be plotted to visually show the slopes of the streams relative to each other. Figure 6 is a plot of the profiles for the Sangamon River and four major tributaries in the Lake Decatur watershed.

According to table 2, the Sangamon River within the Lake Decatur watershed has the greatest slope between its headwaters near Ellsworth to the first sampling station, Fisher (0.084 percent). After this point the slope decreases, ranging from 0.017 to 0.028 percent. The slope for the entire Sangamon River above Lake Decatur is 0.049 percent. The tributary with the greatest slope is Big Ditch (0.138 percent) and the least slope is Camp Creek (0.071 percent). However, it should be noted that the first three of the 18 miles of Big Ditch has a 0.538 percent slope whereas the remaining distance has the lowest slope of all tributaries of 0.053 percent. Consequently, Goose (0.088 percent) and Friends (0.074 percent) Creeks have the greatest slope.

Land Use in the Lake Decatur Watershed

Agricultural Land Use Trends

Agriculture is the dominant land use in the six major counties (Champaign, DeWitt, Ford, McLean, Macon, and Piatt) within the Lake Decatur watershed. Row crops (corn and soybeans) cover approximately 87 percent of the total watershed area and have been increasing over the years. Figure 7 shows the changes in acreage for different types of crops in the Lake Decatur watershed from 1925 to 1993. Row crop acreage has more than doubled between 1925 (260,000 acres) and 1979 (530,000 acres) with a slight decline since then. Corn acreage has remained fairly steady, fluctuating between 170,00 and 300,000 acres, while soybean acreage has significantly increased from virtually zero acres in 1925 to 240,000 acres in 1993. The increase

Table 2. Mean Stream Slopes of the Sangamon River and Four Major Tributaries in the Lake Decatur Watershed

Location	*Mean (percent)*
River Reach:	
Sangamon River headwaters near Ellsworth to near Oakley	0.049
Sangamon River from headwaters to Fisher (112)	0.084
Sangamon River at Fisher (112) to near Oakley	0.025
Tributaries:	
Big Ditch	0.138
Lower (confluence to north fork)	0.053
Upper (north fork)	0.538
Goose Creek	0.088
Camp Creek	0.071
Friends Creek	0.074

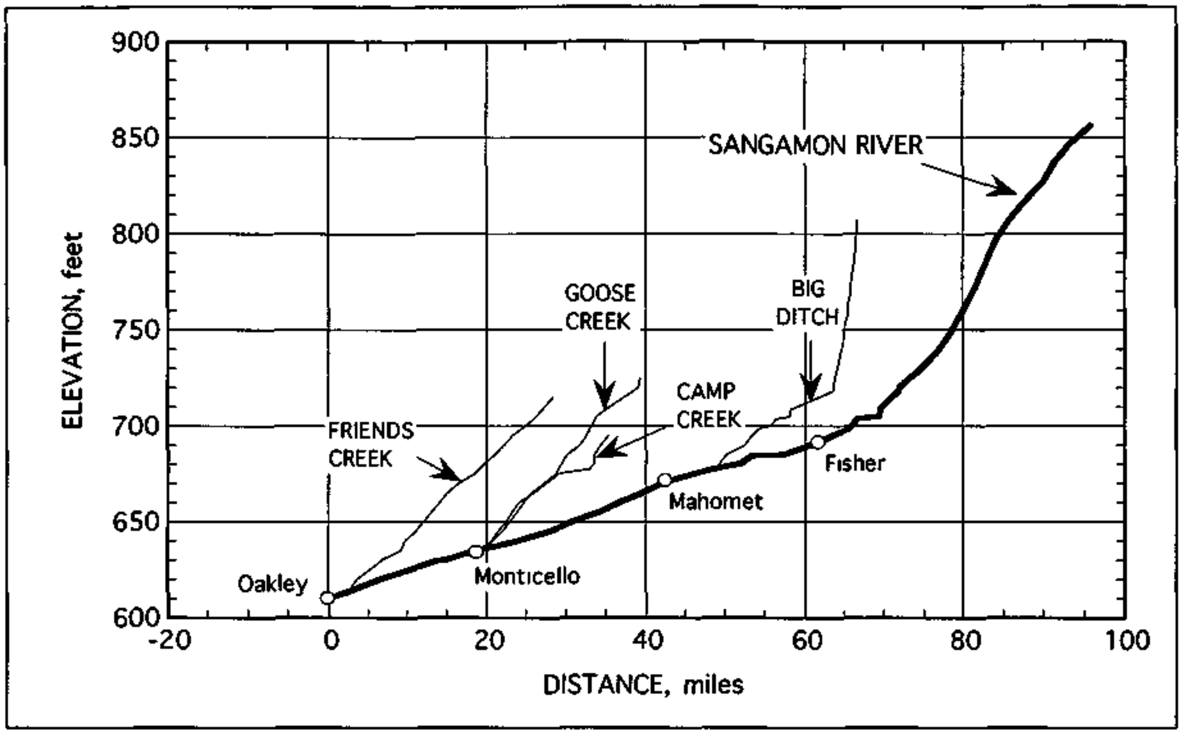


Figure 6. Stream profiles of the Sangamon River above Lake Decatur and selected tributaries

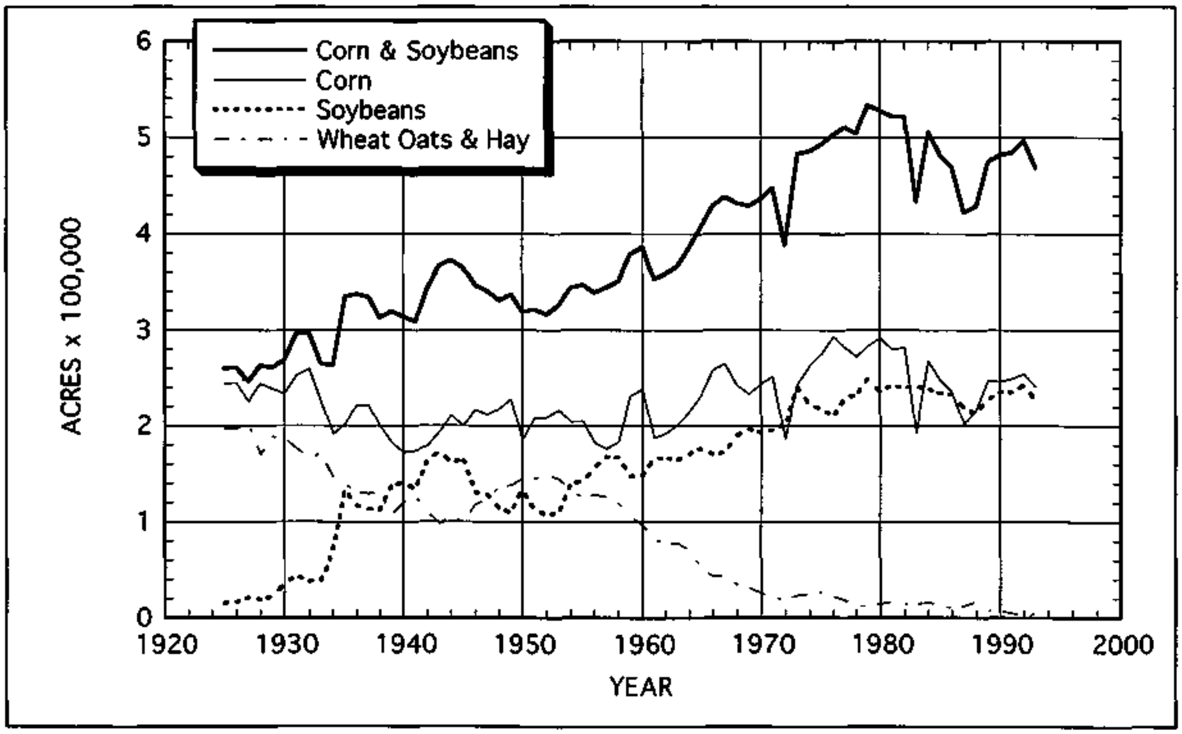


Figure 7. Acreages of selected crops in the Lake Decatur watershed based on Illinois Agricultural Statistics (IAS) data

in soybean acreage is an inverse relationship to the decrease in acreage for grassy crops such as wheat, oats, and hay. These grassy crops have virtually disappeared from the Lake Decatur watershed, declining from a high of 200,000 acres in 1927 to near zero in 1993.

Agricultural and Nonagricultural Land Uses

The discussion on land use presented thus far is based on the Illinois Agricultural Statistics (IAS) data for each county in the watershed. Even though it provides a good perspective on the general trend of major land uses, detailed information is lacking. Therefore, a more detailed investigation of land uses in the watershed should include all potential sources of nitrate. The six Soil and Water Conservation Districts (SWCDs) in the majority of the watershed have been working in cooperation with the ISWS to collect more current and extensive land use data.

The procedure used to collect the land use data is known as the *T by 2000 Transect Survey* (IDOA, 1994) developed by the Illinois Department of Agriculture (IDOA) and the 98 SWCDs in the state. The transect survey's purpose is "to gather information on the extent and current status of soil erosion in Illinois...." and uses a statistical sampling technique whereby each SWCD maps a route "that will allow for representative sampling of the cropping practices in the county" (IDOA, 1994). Each county retrieves a minimum of 456 sample sites along the route and collects only data for agricultural related land. Each sample site has two data points, which represent the land area observed 100 feet from the road to the right and left of the survey vehicle. The parameters collected are: present crop, previous crop, tillage system, percent slope, contouring factor, ephemeral erosion factor, T level (soil loss), K factor (soil erodibility), residue cover, slope length, and P factor (cropping practice; e.g., terrace/strip cropping). Since this study encompasses all land use types, the ISWS subcontracted to the SWCDs in the watershed- to collect nonagricultural land use data while performing the Transect Survey. The routes used for the transect surveys avoided densely urban or nonagricultural areas where possible. Therefore, the ISWS incorporated additional routes in each SWCD district to include these areas, thereby attempting to evenly distribute the sampling routes throughout the watershed. These additional data were collected only for that portion of the counties within the Lake Decatur watershed.

The Illinois SWCDs are scheduled to do three annual transect surveys, the first of which was done in 1994. Each survey is typically conducted early in the agricultural growing season, usually in the month of June. The data from the 1994 survey are being used in this analysis. This survey includes crops planted for 1994 as well as those planted in 1993 by using the "previous crop" parameter collected. This survey overlaps the watershed study period quite well, which started at the beginning of the 1993 growing season and ended in the 1994 season. A total of 1810 data points were used in this analysis. This is an average of approximately two data points for each square mile of watershed area. A county location for each data point was readily available in the survey; however, for the purposes of this study the location of each data point in its respective tributary watershed was determined and all analyses will be based on this spatial aspect of the data. Sand and Finley Creeks are grouped together as a larger tributary watershed and were included in the analyses even though they were not part of the watershed monitoring network. There are instances where a particular land use is listed as "none" in the analyses. This does not necessarily mean that the land use does not exist, only that it was not observed in the established survey route and should be assumed that the land use covers a very small percentage of the watershed area. The following analysis of the data is divided into two sections. The first section is an analysis of the tributary watersheds (Big Ditch, Camp Creek, Goose Creek, Friends Creek, Long/Big Creek, and Sand/Finley Creeks). The other analysis of the entire watershed is divided into five sections along the Sangamon River above (upstream) each of the following locations: Fisher (112), Mahomet (105), Monticello (111), Oakley blacktop, and the Lake Decatur dam (entire watershed).

As mentioned above, the IAS data showed that approximately 87 percent of the upper Sangamon River watershed is in agricultural production and the transect survey concurs with 87 percent as well. Crops surveyed were corn, row and drilled soybeans, small grains, hay, and other crops. Figure 8 shows the agricultural and nonagricultural land uses in the tributary watersheds during the 1994 growing season. The survey also shows 1993 percentages of crops and will be discussed later in this section. The crop area in the tributary watersheds ranged from 99 to 77 percent in Goose and Long/Big Creek watersheds, respectively. Nonagricultural land uses surveyed include urban, rural (farmsteads, pastures, animal lots, etc.), infrastructure (roads and railroads), woods or open areas (meadows, cemeteries, or grass), and water areas. Figure 9 shows the percent area of nonagricultural land uses surveyed in 1994. The figure shows that urban use was the highest in Long/Big and Sand/Finley Creek watersheds at 13 and 12 percent, respectively, and none was observed on the routes in Big Ditch and Goose Creek. Rural land use was observed more in the Long/Big Creek watershed at 8 percent, but Big Ditch showed none in the route. The Camp Creek watershed shows 6 percent of its area in woods/open areas, with Sand/Finley next at 4 percent. Big Ditch has the least area in woods/open areas (one percent). Infrastructure and water were surveyed to be one percent or less in all the tributary watersheds.

Figure 10 shows the breakdown of selected crops between the growing seasons [Year 1 (1993) and Year 2 (1994)] for tributary watersheds. Corn-soybean rotation is apparent in figure 10. The Long/Big Creek watershed shows very distinctly that in Year 1 corn was planted in 45 percent of the watershed and soybeans 28 percent, while in Year 2 the opposite occurs with soybeans dominating the land area at 46 percent and 27 percent in corn. Long/Big Creek, Friends Creek, and Big Ditch all show corn as the dominant crop planted in Year 1 and soybeans in Year 2. The opposite is true for Goose Creek and Sand/Finley Creeks. Camp Creek had corn nearly even at approximately 44 percent between Year 1 and Year 2, whereas soybeans fell from 40 to 37 percent. Grassy crops (small grain, hay, and other crops) increased from almost none in Year 1 to just over 2 percent in Year 2.

Figure 11 shows the percent area of agricultural and nonagricultural land uses at the five Upper Sangamon River watershed subdivisions. Each subdivision represents the watershed area upstream of the location indicated. For example, the area above Mahomet includes the area between Fisher and Mahomet as well as the area above Fisher. The watershed subdivisions show

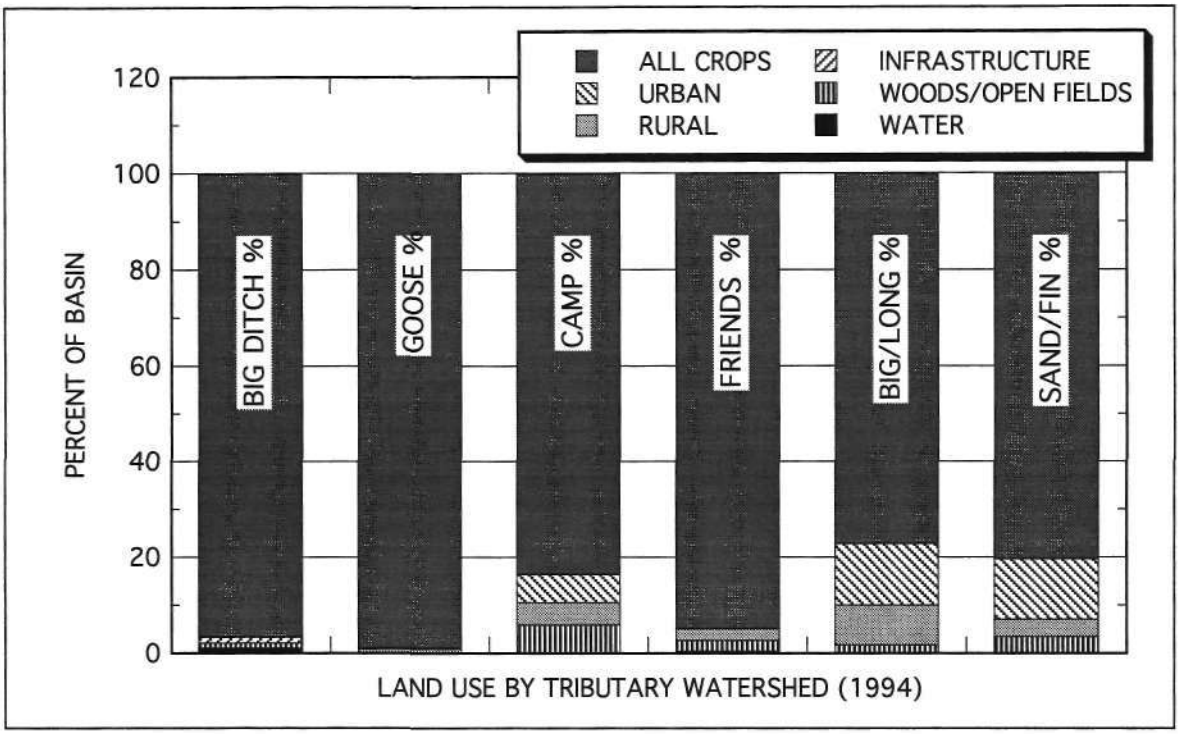


Figure 8. Percent area of land uses in tributary watersheds

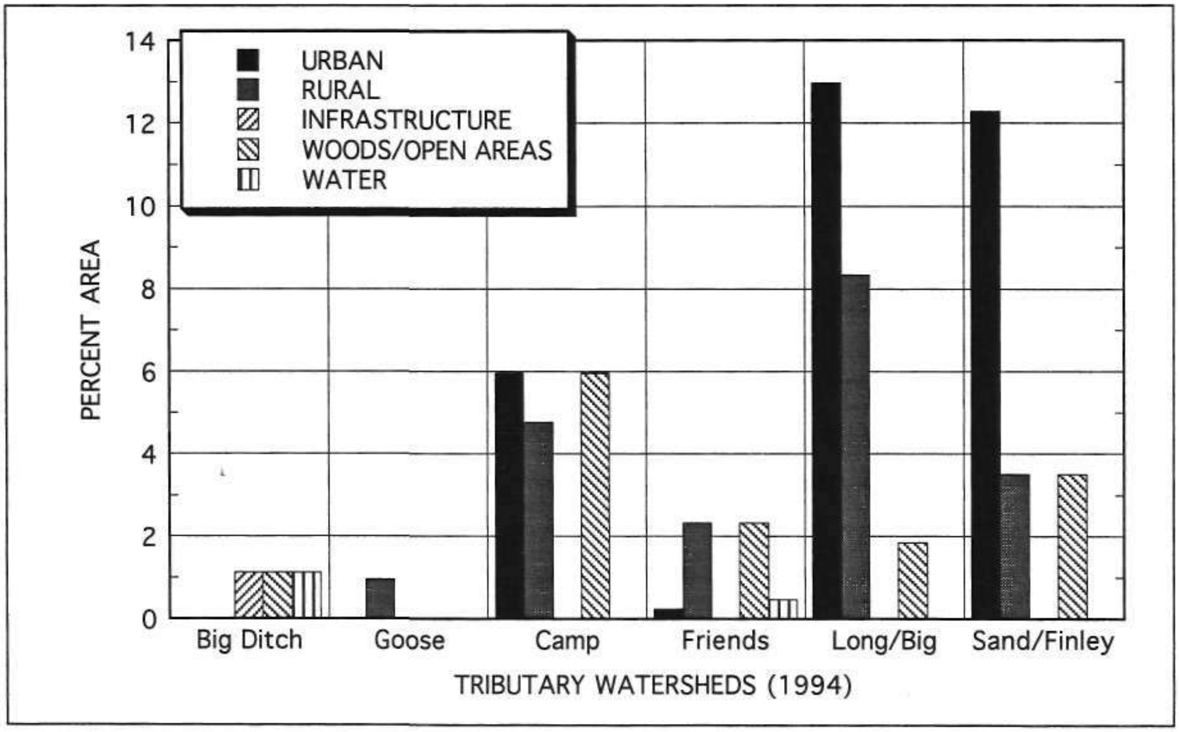


Figure 9. Percent area of all other land uses in tributary watersheds based on IDOA T-2000 Transect Survey data

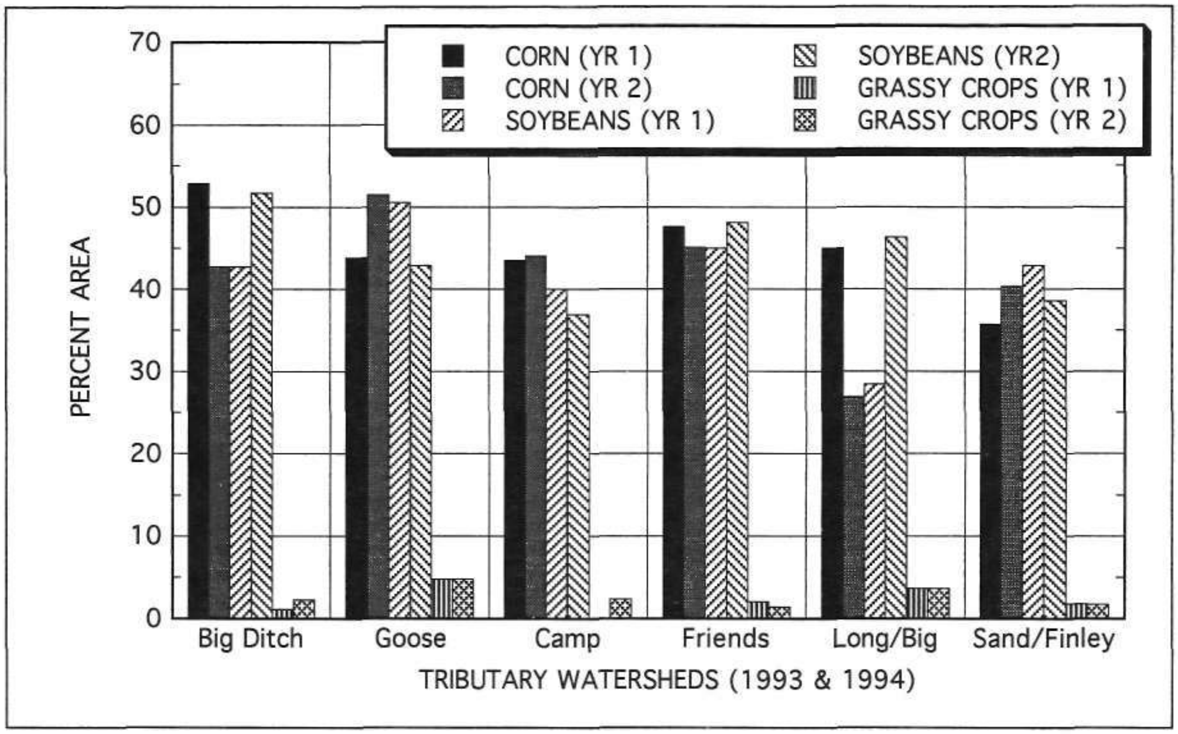


Figure 10. Percent area of selected crops in tributary watersheds based on IDOA T-2000 Transect Survey data

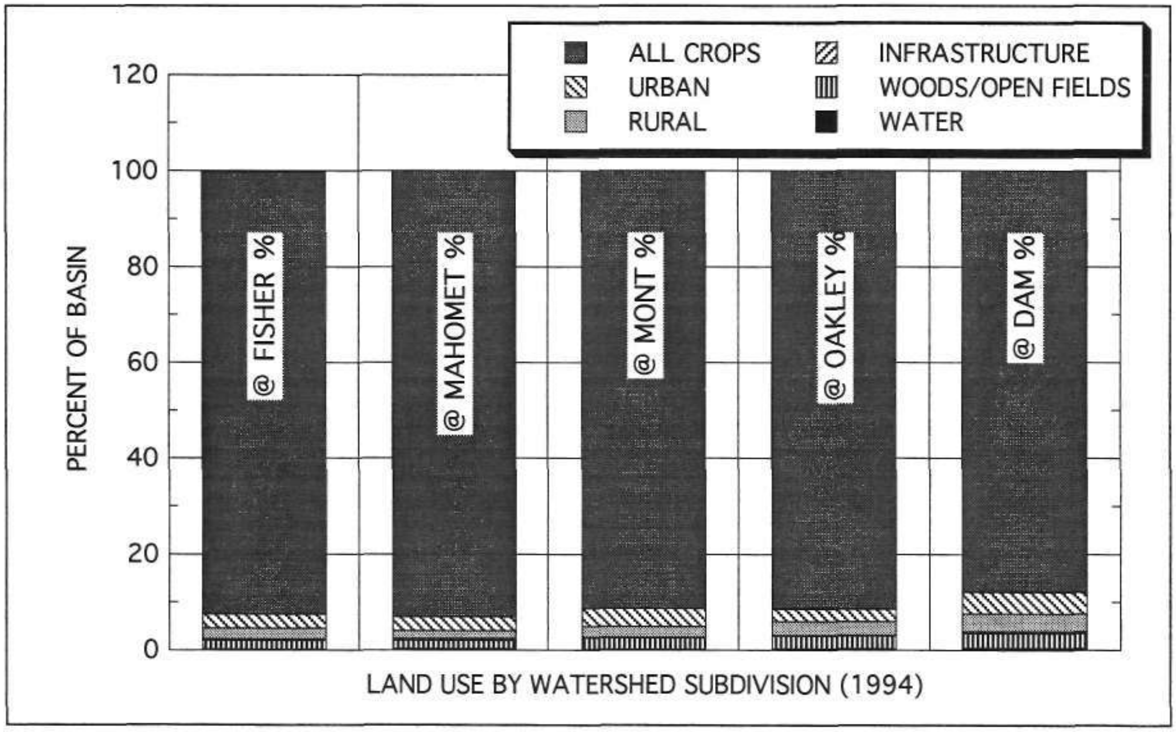


Figure 11. Percent area of land uses in Lake Decatur watersheds subdivisions

agricultural land use decreases. Figure 12 shows that in 1994 nonagricultural land uses totaled 12.3 percent of the land area. Urban, rural, and woods/open areas are the dominant land uses in the entire watershed at 4.5, 3.9, and 3.1 percent, respectively. Infrastructure and water each, occupy approximately 0.4 percent. The difference between selected crops in 1993 and 1994 is shown in figure 13. There appears to be less variability in the watershed between corn and soybeans as indicated in the tributaries. There is less than 5 percent difference in the areas planted in corn and soybeans. The average area of grassy crops is similar to the tributaries at approximately 2.4 percent. In 1994, row crops (corn and soybeans) in the entire watershed covered 85.3 percent of the land area, whereas grassy crops (small grains and hay) covered only 2.4 percent. Corn and soybeans almost equally split the row crop land area at 42.0 and 43.3 percent, respectively.

Residue Cover

The 1994 *T by 2000 Transect Survey* included the observation of residue cover and tillage systems on agricultural lands. Residue cover data are grouped by percent intervals: 0-15 percent, 16-30 percent, 31-50 percent, 51-75 percent, 76-100 percent, and "does not apply". The tillage systems identified in the survey are mulch-till, no-till, ridge-till, conventional-till, and other. Tillage systems were not analyzed because of the subjectivity of transect survey personnel interpretations of the tillage types. Nevertheless, residue cover, the key result of any tillage practice, was analyzed.

Figure 14 shows the percent residue covers for the tributary watersheds. The tributaries have a 0-15 percent residue cover that varies in area from 42 to 70 percent of the watersheds. Big Ditch is the highest at 70 percent and Camp Creek is the lowest at 42 percent. Five of the six tributaries have a 0-15 percent residue cover over 50 percent of the area. The high percentage of watershed area with a 0-15 percent residue cover is most likely the result of intense rainfall during the spring in several tributary watersheds. Many farmers lost seeds to flooding or needed to dry out fields quickly and had to re-till, consequently reducing the residue cover (Leon Wendte, U.S. Department of Agriculture, Natural Resources Conservation Service, personal communication, 1995; Marilyn Parker, Macon County Soil and Water Conservation District, personal communication, 1995). The 16-30 percent residue cover occurs more often in the Goose Creek watershed (33 percent watershed area) and least in the Long/Big Creek watershed (7 percent). Residue covers of 0-15 and 16-30 percent are generally associated with conventional and reduced tillage systems, respectively. The mulch tillage system usually produces anywhere from 31-50 percent residue cover. A greater than 50 percent residue cover can represent a no-till system, however, this is dependent on the previous crop. When planting a field that was in soybeans the previous year, only 20 percent residue cover is obtainable, where 60 percent or more is representative of corn as the previous year's crop. Camp and Sand/Finley Creeks had 13 and 11 percent, respectively, of their watershed area in a residue cover of 31-50 percent. Goose and Long/Big Creeks had some of the lowest percent areas in residue cover of 31-50 percent (3 percent each), and Big Ditch had none. Residue covers of 50 percent or greater were found more often in the Friends Creek watershed at 10 percent and Big Ditch at 8 percent. Long/Big and

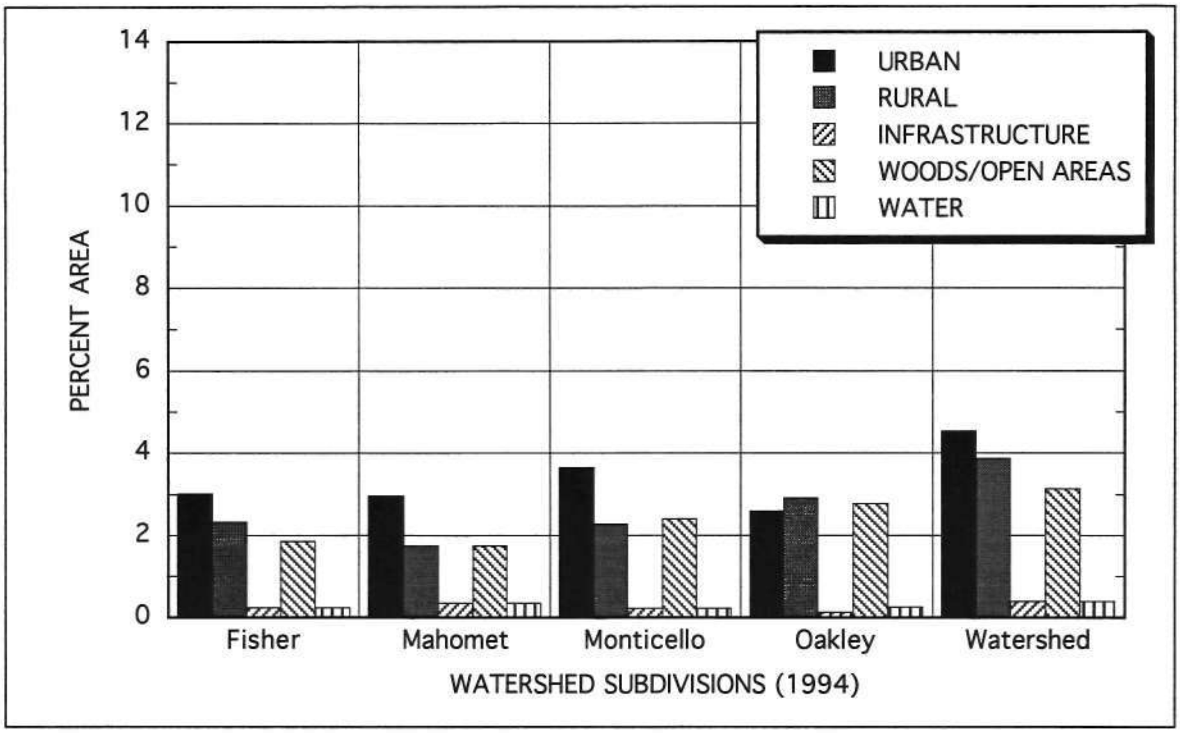


Figure 12. Percent area of all other land uses in watershed subdivisions based on IDOA T-2000 Transect Survey data

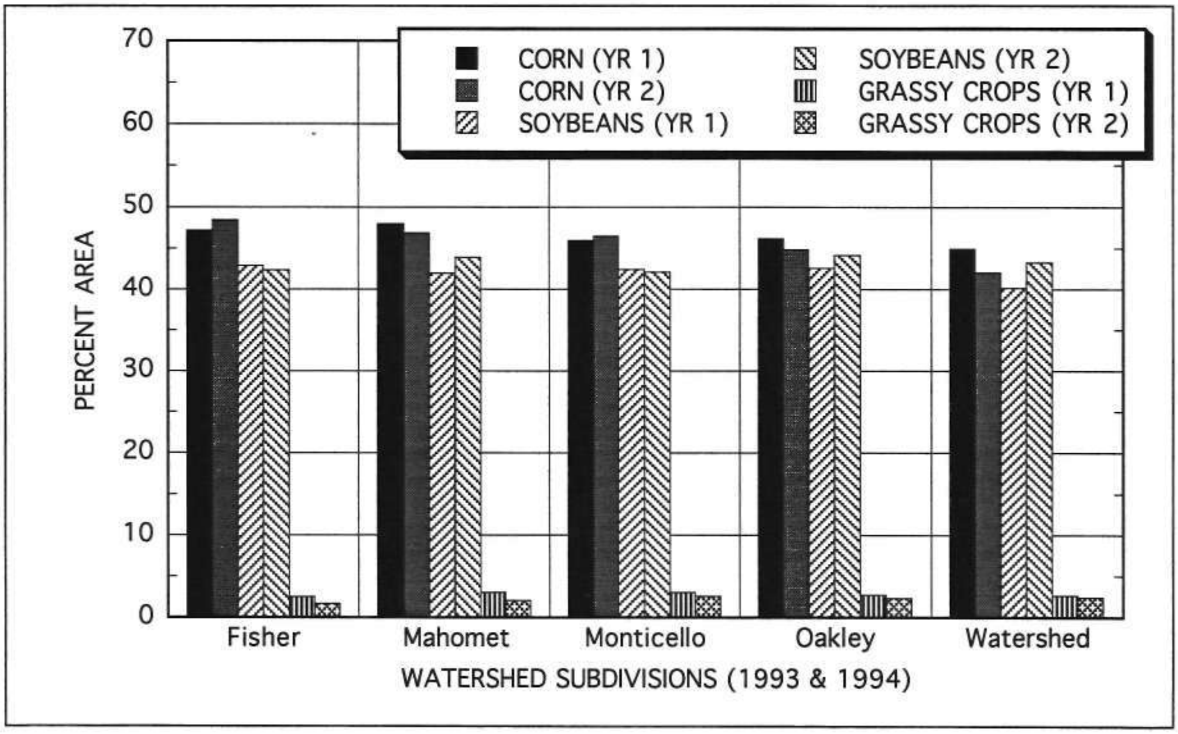


Figure 13. Percent area of selected crops in watershed subdivisions based on IDOA T-2000 Transect Survey data

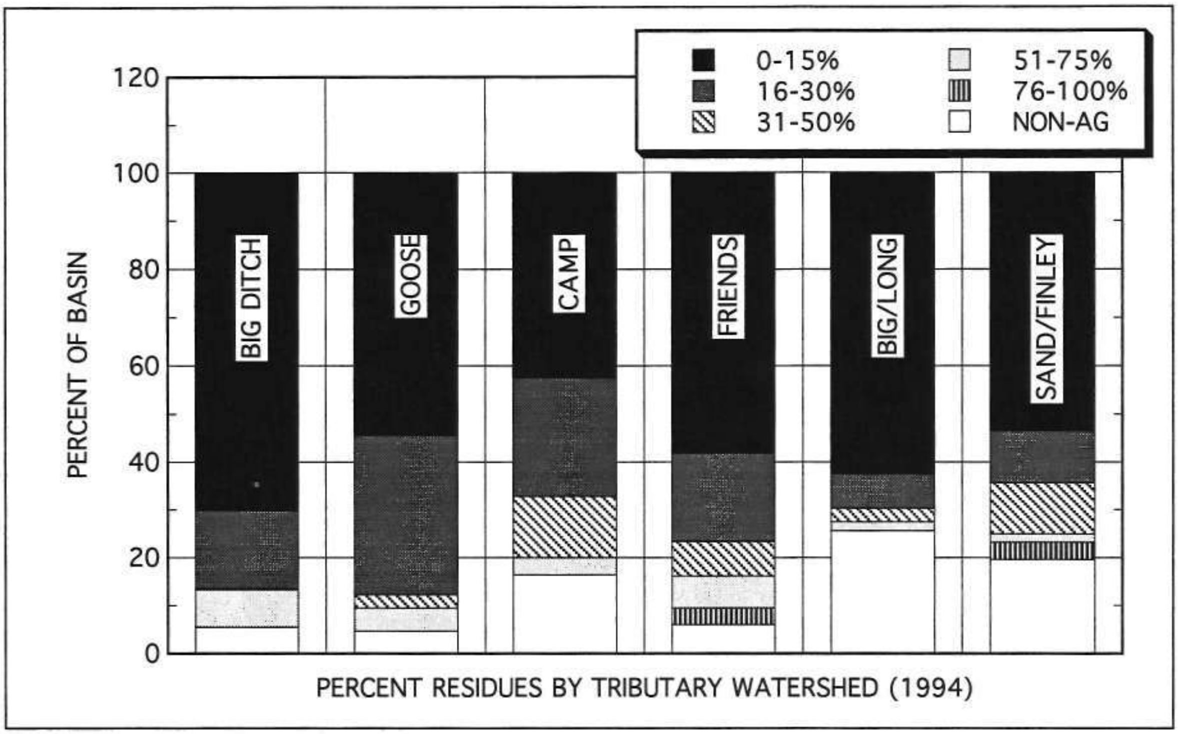


Figure 14. Percent areas of residue covers in tributary watersheds

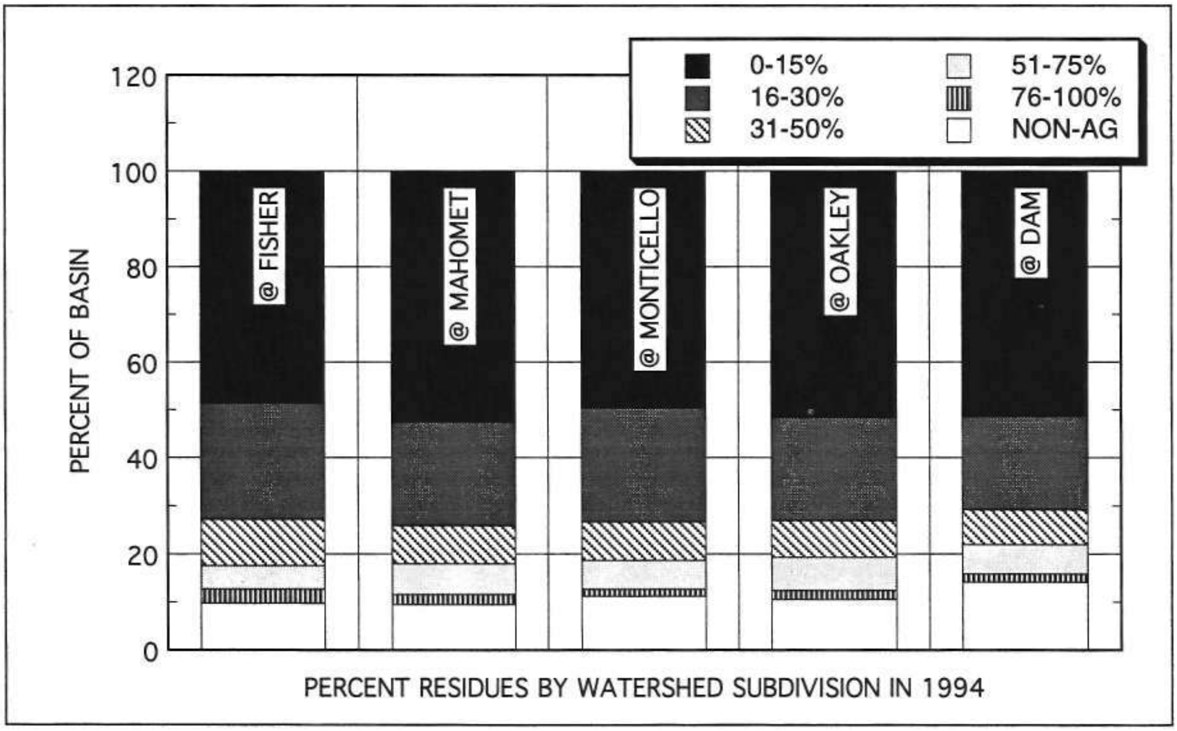


Figure 15. Percent areas of residue covers in river watershed subdivisions

Sand/Finley Creeks were the lowest at 2 percent. Friends and Sand/Finley Creeks were the only watersheds that the occurrence of the 76-100 percent residue cover was noted (approximately 3.5 percent each).

Figure 15 shows the percent residue covers for the watershed subdivisions. As can be seen, there is very little difference in the percent residue covers between each subdivision. The average percent watershed area in each subdivision for each percent residue cover is as follows: 50.6 percent for 0-15 percent residue, 22 percent for 16-30 percent residue, 8.1 percent for 31-50 percent residue, 6.1 percent for 51-75 percent residue, and 2 percent for 76-100 percent residue.

Fertilizer Use

The increase in total acreage of row crops and the corresponding increase in total and per-acre fertilizer application in the watershed is a major factor in the increase of nitrates in Lake Decatur. Figure 16 illustrates the significant increase in fertilizer application in Illinois from the 1950s to the present. The general trend for the state is most likely applicable to the Lake Decatur watershed. As shown in the figure, fertilizer application in Illinois has increased from practically zero in 1950 to more than a million tons in 1980. Since 1980, the increasing trend has ceased and application has fluctuated between 778,000 and 1.05 million tons annually.

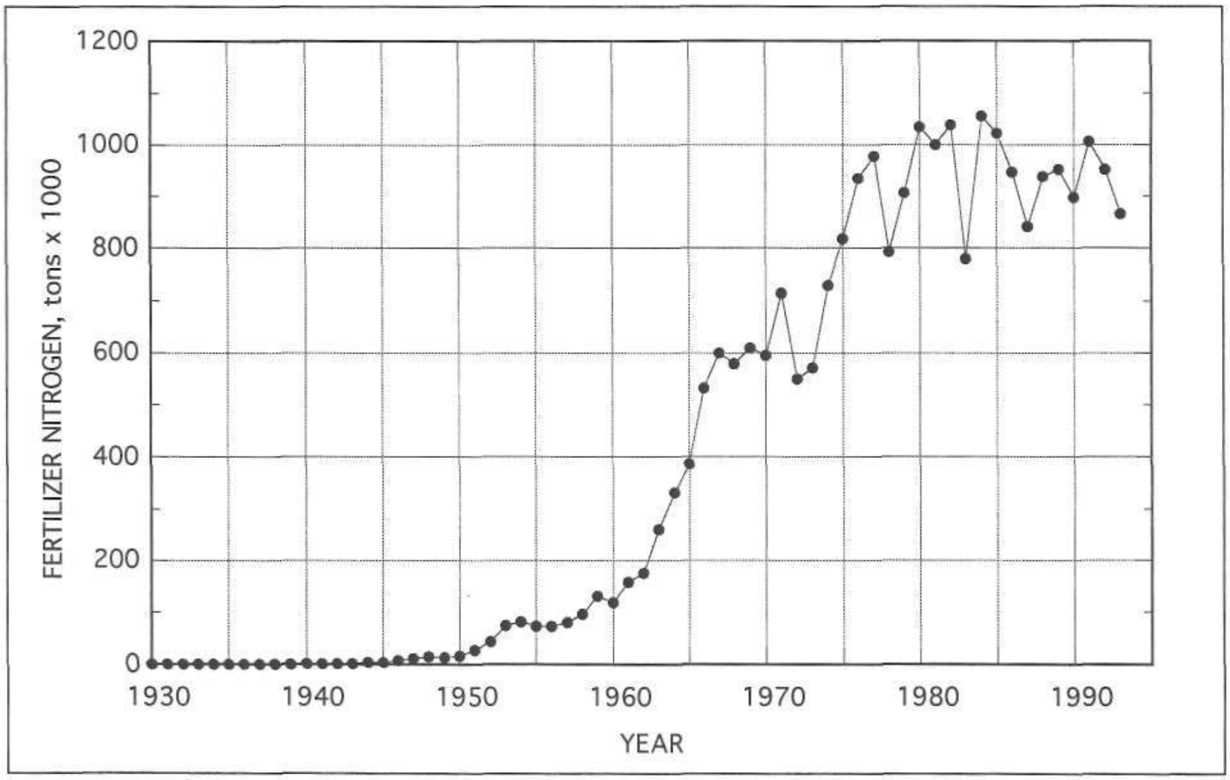


Figure 16. Total inorganic nitrogen fertilizer application in Illinois 1930 - 1993

Sources of Nitrate and Nitrogen Transformations

The sources of nitrate in the Lake Decatur watershed could be viewed either from a spatial perspective, which evaluates sub-watersheds and tributary streams for their relative contribution to the total nitrate load to the lake or from a mass balance perspective, which evaluates the input and output of nitrate to the whole watershed. Mass balance analysis is generally very difficult to conduct for large watersheds because of the difficulty in obtaining reliable quantification of the different sources of nitrate to accurately establish a balance sheet for nitrogen. The spatial approach is generally used for large watersheds to identify and quantify sources of nitrates from different parts of the watershed, and this general approach is being used for the Lake Decatur watershed project. Even though the mass balance approach is difficult to implement for large watersheds, the concept is important in understanding how nitrate is generated and introduced into the watershed and then how it is stored or removed from the watershed. In this section of the report, the mass balance concept is used to briefly explain how nitrogen is introduced, generated, and transformed in Lake Decatur.

Nitrate in the Lake Decatur watershed is generated from natural and anthropogenic (human) sources. Natural processes that generate nitrate in the environment include nitrogen fixation by bacteria, whereby atmospheric nitrogen is converted to organic matter by bacteria, and lightening in the atmosphere whereby nitrogen gas is oxidized to nitrate and particulate nitrogen in the atmosphere. These natural processes generate background or undisturbed nitrate concentrations or loads. Nitrates from natural sources reach surface waters as a result of precipitation, atmospheric deposition, surface runoff, and leaching from soils. For ground water the background level is generally assumed to be less than 3 mg/1, for surface waters it is highly variable from region to region and season to season. Nitrate concentrations in pristine environments with limited human activities are consistent with the natural processes in those environments, are generally low, and are not sources of environmental or health concerns.

In developed environments, the contribution of nitrate from human activities generally becomes more prominent than that from natural sources. Sources of nitrate from human activities include fertilizer applications, wastewater discharge, septic systems, animal waste, and some industrial plants. In most agricultural watersheds, fertilizer application is the most dominant source of nitrate.

The application, uptake, and leaching of nitrogen in agricultural watersheds is sometimes evaluated by an input-output model. A simplified conceptual model includes the input of nitrogen into the soil from all sources: natural and human-induced. Once nitrogen is incorporated into the soil, it is either stored in the soil or lost to the atmosphere and to surface and ground waters, or removed from the watershed through harvesting of crops. During these different processes, nitrogen undergoes several transformations. Some of these transformations are complex and are major areas of research throughout the world because of their implication on food production and environmental quality. Some of the basic processes are summarized in figure 17 adapted from Stevenson (1982).

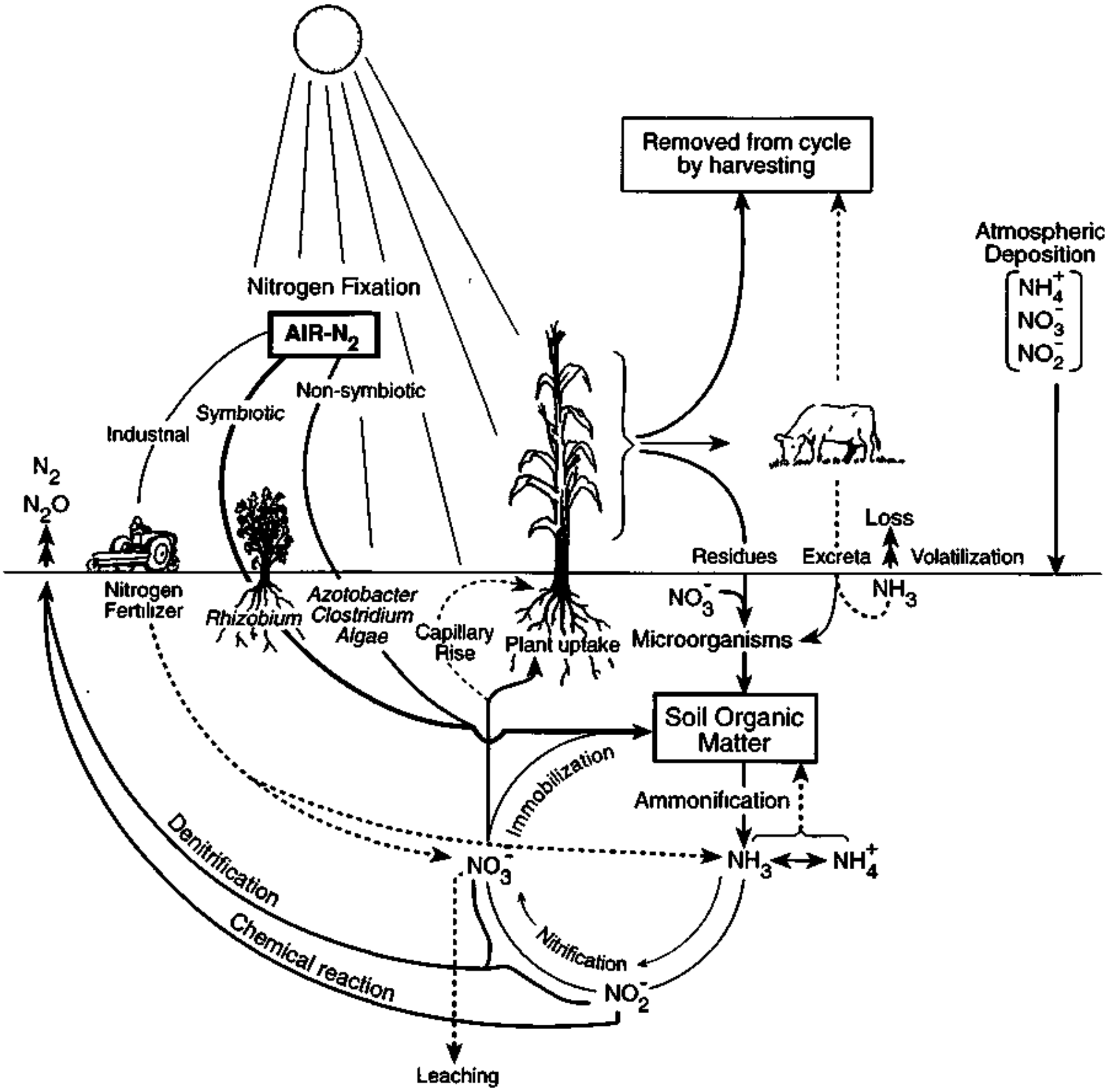


Figure 17. Nitrogen transformations in agricultural soils (adapted from Stevenson, 1982)

The input of nitrogen into soils comes primarily from three sources: atmospheric deposition, biological nitrogen fixation, and inorganic nitrogen applied as fertilizer. The relative significance of each source varies from region to region and on land use practices.

Atmospheric Input

The input of nitrogen into soils from atmospheric precipitation can be in the form of ammonium (NH_4^+), nitrate ($N0_3^-$), nitrite ($N0_2^-$) and nitrogen bound to particles. The contribution of atmospheric sources was expected to be relatively small as compared to inputs from biological nitrogen fixation and inorganic fertilizer nitrogen. This assumption was supported by data collected by the National Atmospheric Deposition Program (NADP). This program uses the National Trends Network (NTN), which has been collecting data since 1978 throughout the United States. The NADP has its Central Analytical Laboratory (CAL) at the Illinois State Water Survey (ISWS) in Champaign, Illinois. Each year the ISWS receives thousands of precipitation samples collected at 200 sites by the NTN. The data retrieved by the network represent a cumulative, weekly precipitation sample collected by special precipitation collectors that cover the sample bucket between rainfall events to avoid evaporation and contamination. Each site has a raingage that graphically records the timing and amounts of rain for each seven-day sample period (Lynch et al., in press).

There are four NTN sampling sites in Illinois. The Bondville site (IL11), located just west of Champaign, is the closest station to the Lake Decatur watershed and should represent the conditions in the watershed. Figure 18 shows the a) nitrate-N and b) ammonium-N concentrations from 1979 to present at the Bondville station. The nitrate-N concentrations rarely exceed 1.5 mg/1 and generally average 0.5 mg/1. Ammonium-N has a wider variability in concentration, which ranges from the minimum detection level (MDL) of 0.02 mg/1 to 3.8 mg/1 and averages of 0.4 mg/1 Lynch, Bowersox, and Simmons (in press) have calculated recent trends for nitrate-N concentrations. Their analysis states that from 1980-1993 nitrate-N concentrations have decreased by approximately 20 percent, whereas ammonium-N concentrations show almost no change.

Biological Nitrogen Fixation

Atmospheric nitrogen is incorporated into soils by natural processes mediated by living microorganisms in soils. The process whereby molecular nitrogen (N2) is converted into other forms of combined nitrogen is generally referred to as biological nitrogen (N_2) fixation. Microorganisms that fix nitrogen are grouped into symbiotic and nonsymbiotic microorganisms to recognize the differences between microorganisms that fix nitrogen only by a symbiotic relationship with plants (primarily leguminous plants) and those free-living microorganisms that fix nitrogen without association with plants. The symbiotic fixation of nitrogen is facilitated by root nodule bacteria referred to as Rhizobium that exists in a symbiotic relationship with legume plants such as soybeans, cowpeas, clover, alfalfa, and many other varieties found throughout the world. In most developing countries where inorganic fertilizers are not heavily used, legumes are the most important nitrogen fixers.

Nonsymbiotic nitrogen fixation is facilitated by free-living microorganisms that include various species of blue-green algae, photosynthetic bacteria, and aerobic bacteria. These types of organisms can convert molecular nitrogen (N2) into combined nitrogen under the proper soil conditions including sufficient source of energy such as organic residue, neutral pH, and low levels of available N in the soil among other conditions.

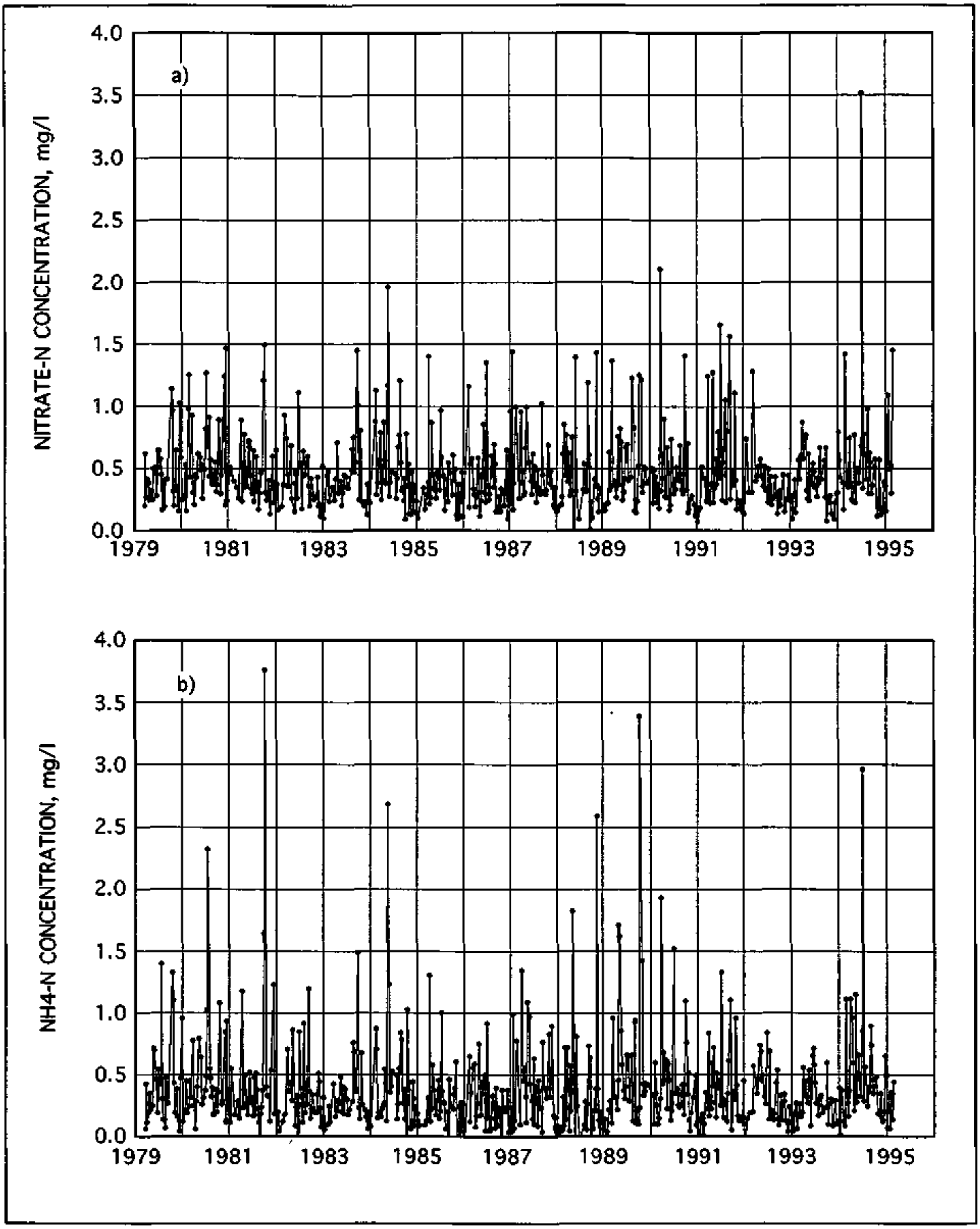


Figure 18. Atmospheric deposition of a) nitrate-N and b) ammonium-N data at Bondville, Illinois from 1979-present

Nitrogen Input from Fertilizer Application

Inorganic nitrogen fertilizer is applied to soils in a form containing either nitrate (NO3) or ammonium (NH_4+). Fertilizer is applied either in the fall, in the spring before planting, or after planting (side-dress). Anhydrous ammonia, ammonium nitrate, urea, and urea-ammonium nitrate are the common forms of commercial nitrogen fertilizer. Anhydrous ammonia is the most commonly applied fertilizer in Illinois (McKenna and Bicki, 1990). Ammonium is not the most stable form of inorganic nitrogen and usually oxidizes to form nitrate. Nitrification occurs in virtually all soils where NH_4^+ is present and conditions are favorable with respect to the major factors of temperature, moisture, pH, and aeration. Stevenson (1982) explains that the use of NH_4^+ and NO_3^- for plant growth corresponds to events in the soils. In early growth stages, roots are largely in the surface layer and the NH_4^+ form predominates because nitrification is limited by low temperatures. As the soil becomes warmer, nitrification proceeds, the root system extends, and the amount and uptake of NO_3^- predominates over NH_4^+. It is estimated that plants take up less than 50 percent of the fertilizer nitrogen and transform it into organic nitrogen (Bouchard et al., 1992). The remainder is either stored in the soil as organic or inorganic nitrogen or lost to the atmosphere or water. Nitrogen available as ammonium in the soil is eventually oxidized to form nitrate, which is more stable. This process is known as nitrification.

Nitrogen Losses

Nitrogen in soils is lost to the atmosphere by processes known as denitrification and volatilization. Denitrification is a process by which nitrate (NO_3^-) is reduced to nitrogen (N_2) and nitrous oxide (NO_2) gases by denitrifying microorganisms. For denitrification to occur in soils there must be anaerobic conditions (oxygen depleted), a proper soil temperature and pH, and the presence of a carbon source (soil organic matter content and plant residue) (Pierzynski et al., 1994). In addition, ammonia (NH_3) and nitrite (NO_2) are sometimes transformed to nitrogen gases by chemical reaction. Volatilization of ammonia (NH_3) is a process by which nitrogen escapes to the atmosphere as ammonia gas. The amount of nitrogen lost to the atmosphere through denitrification, chemical reaction, and volatilization depends on many factors such as the amount and type of fertilizer nitrogen applied, the amount of organic matter available, the pH of the soil and water, temperature, and drainage.

Nitrogen is lost from the soil to either ground or surface water by the processes of surface runoff and leaching. In terms of water quality impacts, the process of leaching is the most dominant mechanism by which nitrate is transported from soils to surface waters, even though surface runoff during fertilizer application periods could transport significant inorganic and organic nitrogen. During the process of leaching, percolating waters transport dissolved nitrogen in the form of nitrate (NO_3), ammonium (NH_4^+), or nitrite (NO_2) to either ground or surface waters. Even though dissolved nitrogen that reaches surface waters could include ammonium and traces of nitrite, it is mostly in the form of nitrate. Surface runoff erodes and transports particulate nitrogen associated with sediment and dissolved nitrogen available at the land surface during storm events. The amount of nitrogen removed by surface runoff including soil erosion depends on several factors such as storm intensities, land cover, soil type, and timing of storm events with respect to fertilizer applications. Particulate organic nitrogen transported into lakes and streams generally settles to the bottom of lakes with sediment and becomes a source of nitrate over a longer period of time.

Once nitrate reaches free-flowing stream channels, it is transported downstream to lakes without significant losses. However, much research is being conducted to facilitate denitrification and uptake of nitrate by aquatic plants through creation of wetlands and detention basins along stream corridors.

Nitrogen transformations in aquatic environments such as streams, lakes, wetlands, or floodplains that are inundated by water are more complicated than those in well drained agricultural soils. The major nitrogen transformations in submerged soil or sediment are illustrated in figure 19 (Patrick, 1982). The major controlling factor is the availability or lack of oxygen in the soil or sediment layers. The top soil or sediment layer is generally expected to be aerobic because of constant supply of oxygen from the water column. This is not, however, always the case. Below the aerobic layer, there is an anaerobic layer where oxygen is in short supply or absent. The importance of these aerobic/anaerobic layers is because of the fact that the transformation of ammonium (NH_4^+) to nitrate (NO_3), which only takes place in the aerobic layer where there is sufficient oxygen, whereas nitrate (NO_3) is readily denitrified in the anaerobic layer (Patrick, 1982). Other nitrogen transformations such as nitrogen fixation by microorganisms and bacteria, loss of nitrogen by volatilization of ammonia, denitrification of nitrate into N_20 and N_2, and leaching of nitrate to surface and ground water are the same as discussed earlier.

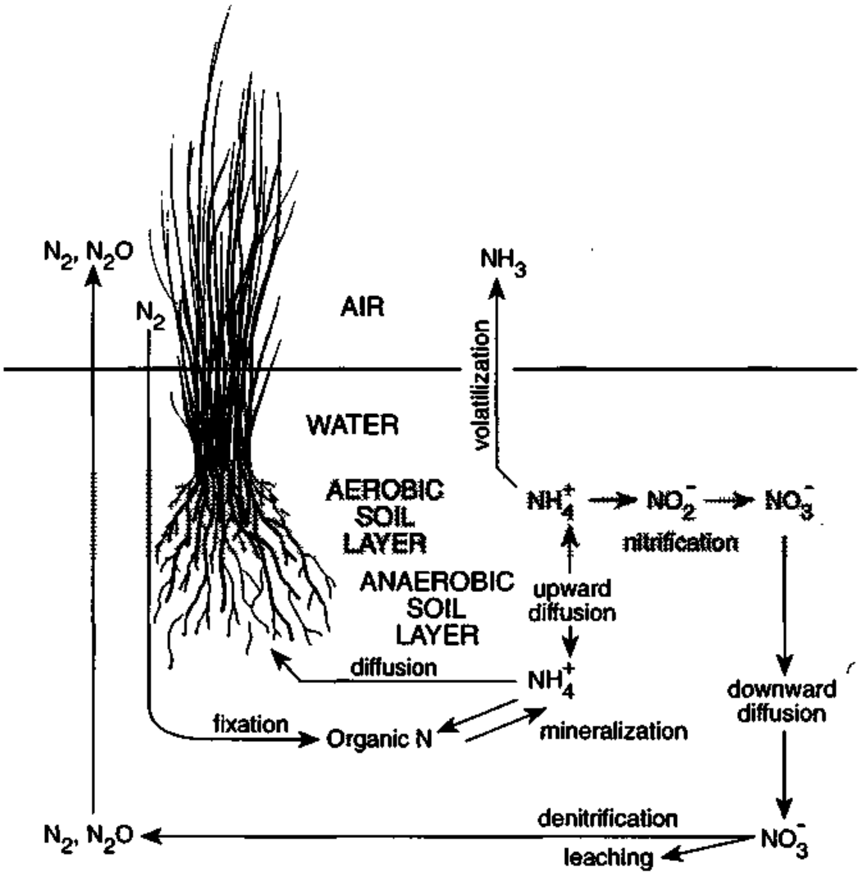


Figure 19. Nitrogen transformations in submerged soils (adapted from Patrick, 1982)

Hydrology of the Lake Decatur Watershed

One of the major objectives of this project was to better characterize the hydrology of the Lake Decatur watershed in order to quantify when and where the water and nutrients flowing into Lake Decatur originate. A hydrologic investigation of a watershed provides information on the spatial and temporal variation of precipitation, evapotranspiration, and streamflow. Any watershed management program cannot be properly planned, implemented, and evaluated without a proper understanding of the watershed hydrology.

The present data collection program only reflects the conditions during a narrow window of time in which the climatic and hydrologic conditions might not reflect a typical or normal period. Thus it is important to analyze historical hydrologic data and place the present data collection period in the correct perspective. It is also very difficult to quantify the characteristics of streams based on limited data so it is crucial to base the hydrologic characterization of the watershed on all available data over a longer period of time.

This section discusses the hydrology of the Lake Decatur watershed based on historical precipitation and streamflow data. The detailed hydrologic data being collected for this project will be presented in the section on hydrologic and water quality monitoring.

Water Budget of the Lake Decatur Watershed

Average Precipitation, Evapotranspiration, and Streamflow

The average annual precipitation for the Lake Decatur watershed over the last 100 years (1895-1993) is approximately 37.5 inches, ranging from about 36.5 inches in the northern edge of the watershed to 38.5 inches in the southeastern part of the watershed. During the past three decades, 1961-1990, the average precipitation over the watershed was 38.5 inches, or approximately 3 percent greater than the long-term average. As will be discussed later, the precipitation increase over the last 30 years has resulted in a coincident increase in average streamflow. A major portion of the precipitation that occurs over the watershed is returned to the atmosphere through evapotranspiration, which includes evaporation from the land surface and transpiration by crops and other vegetation. The average annual evapotranspiration over the watershed is approximately 27.3 inches.

The long-term average streamflow over the Lake Decatur watershed is 10.2 inches of runoff over the watershed, roughly equivalent to the difference between the long-term average precipitation and evapotranspiration. The geographic distribution of average streamflow is fairly uniform, being greatest in the eastern fringes of the watershed (10.5 inches) and least in the western and northwestern part of the watershed (9.6 inches).

Table 3. Average Monthly Distribution of Precipitation (P), Evapotranspiration (ET), Streamflow (Q), and Change in Subsurface Storage (DS)

Month	*P (inches)*	*ET (inches)*	*Q (inches)*	*DS (inches)*
January	2.1	0.1	0.8	+1.2
February	1.9	0.2	1.1	+0.6
March	3.2	0.9	1.5	+0.8
April	3.7	2.2	1.6	0.0
May	4.0	3.3	1.4	-0.7
June	4.0	4.3	1.0	-1.4
July	3.8	5.9	0.6	-2.7
August	3.6	4.9	0.3	-1.6
September	3.1	3.0	0.2	-0.1
October	2.9	1.6	0.4	+0.9
November	2.8	0.7	0.5	+1.6
December	2.4	0.2	0.8	+1.4
TOTAL	37.5	27.3	10.2	0.0

Monthly Variations

Table 3 provides the typical distribution of precipitation (P), evapotranspiration (ET), and streamflow (Q) over the Lake Decatur watershed for each month of the year. Over long periods, the sum of the average streamflow and evapotranspiration will equal the average precipitation, but this is never the case in any one month due to the effect of subsurface storage of water in the soil and shallow ground water (DS). Evapotranspiration is noticeably greater than precipitation during the height of the growing season (June through August) when the greatest reduction in subsurface water storage occurs. The lowest streamflow rates are expected near the end of the growing season (September and October) when soil moisture and ground water are at their minimum. Average runoff is highest in March and April when the soil is frequently saturated.

Movement of Water to Streams

The flow in streams can be classified as having three origins: 1) direct surface runoff, 2) interflow, and 3) baseflow. Figure 20 illustrates these three processes. Surface runoff occurs when rain falls at a rate that exceeds the infiltration capacity of the soil. The movement of water through the interflow and baseflow processes first requires that the water percolate downward through the soil column. Interflow is the relatively quick movement of water toward the stream through air pockets, cracks, tile drains, and other openings in the shallow layers beneath the soil. Baseflow is flow through the shallow ground-water matrix that sustains the flow in the stream during late summer and fall as well as during drought years. Baseflow to a stream often increases directly after a rain event, and as a result it may appear as if the ground water is moving quickly from the uplands to the stream. In reality, it is usually the ground water immediately adjacent to the stream that is released to the stream, and it may take years for a particular mass of

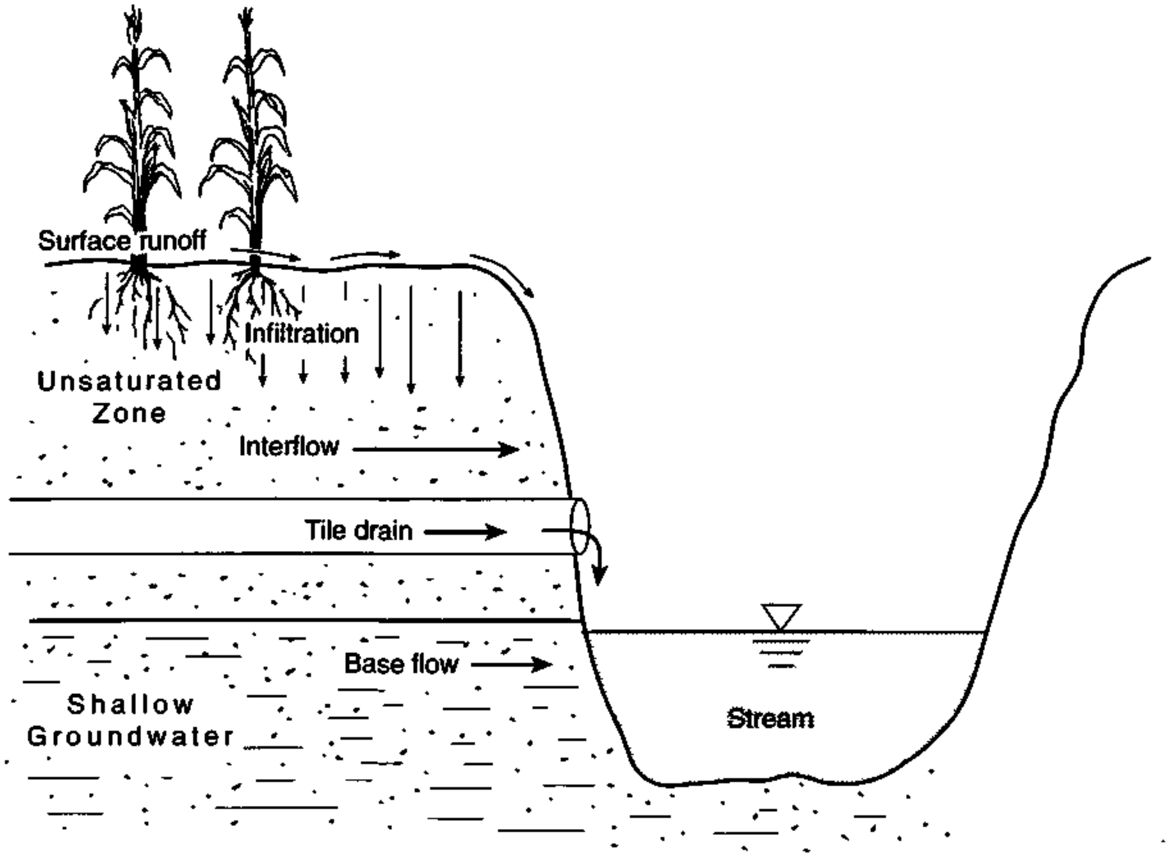


Figure 20. Schematic of flow paths from upland areas to streams

water and its dissolved constituents to reach the stream from upland areas. The division between interflow and baseflow is also not as clear-cut as what is presented above. The movement of subsurface water to the streams can take many different paths, and occurs over a continuum of temporal and spatial scales.

An examination of the water budgets of the soils typical to the Sangamon River basin indicates that more water reaches the stream via the combined effects of interflow and baseflow (i.e., by first percolating through the soils into the subsurface) than from direct surface runoff. The relative contribution to streamflow from direct surface runoff and the subsurface differs depending on the soil permeability, drainage characteristics, and, to a lesser extent, land use. Soils established on more permeable parent material generally have a greater and better sustained contribution of baseflow to the stream. Table 4 compares the relative amounts of seepage and surface runoff depending on different soil conditions. These values were estimated using the PACE (Precipitation Augmentation for Crops Experiment) soil moisture balance model (Durgunoglu et al., 1987), which is a hybrid of the Chemical, Runoff, and Erosion from Agricultural Management System (CREAMS) water budget model (Knisel, 1980). There is somewhat less water yield from watersheds having a high percentage of pasture and forest cover compared to areas in row crops.

Table 4. Examples of Annual Distribution of Surface Runoff and Subsurface Flow (in inches) for Different Soil Groupings

	SCS Hydrologic Group		
	B	*C*	*D*
Surface runoff	2.9	3.5	5.6
Subsurface flow	7.3	6.8	4.9
Total water yield	10.2	10.3	10.5

Figures 21 and 22 show modeled estimates of monthly direct surface runoff and percolation for hydrologic soil group B in which group most of the soils within the Lake Decatur watershed are classified. Figure 22 illustrates that most of the percolation occurs in the winter and spring each year (November through April), generally when the soil is saturated, whereas the surface runoff is more sporadically distributed throughout the year. The distributions of these processes over an "average" year, simulated using climatic data from 1949-1993, are shown in both figure 23 and in table 5. Table 5 also shows estimates of the storage of shallow ground water, which generally increases from December through May and is then depleted the rest of the year. During March nearly half of the water that percolates through the soil appears to go to ground-water storage. Much of the percolated water that is not stored in shallow ground water is assumed to reach the stream as interflow. Interflow is greatest during March through May, the same time that baseflow is highest. The amount of interflow may be a particularly significant portion of the water budget in areas drained by tiles.

As the shallow ground-water storage increases during the spring, so does the release of baseflow to the stream. There is generally a high volume of baseflow into the streams from early spring through mid-summer. From late summer through fall, the amount of baseflow is lower

Table 5. Average Monthly Distribution of Direct Surface Runoff (QD), Change in Soil Moisture (DSM), Percolation through Soil (SP), Change in Shallow Ground-water Storage (DG), and Total Subsurface Flow to Streams (QG) for Hydrologic Soil Group B

Month	*QD*	*DSM*	*SP*	*DG*	*QG*
January	0.4	+0.6	0.8	+0.4	0.4
February	0.3	+0.2	1.1	+0.3	0.8
March	0.3	-0.6	2.3	+1.1	1.2
April	0.3	-0.4	1.4	+0.1	1.3
May	0.3	-0.5	0.6	-0.5	1.1
June	0.2	-0.8	0.2	-0.6	0.8
July	0.2	-1.2	-0.1	-0.5	0.4
August	0.2	-0.6	-0.1	-0.1	0.1
September	0.1	+0.1	-0.2	-0.2	0.1
October	0.2	+1.1	0.0	-0.2	0.2
November	0.1	+1.3	0.3	-0.1	0.4
December	0.3	+0.8	1.0	+0.5	0.5
TOTAL	2.9	0.0	7.3	0.0	7.3

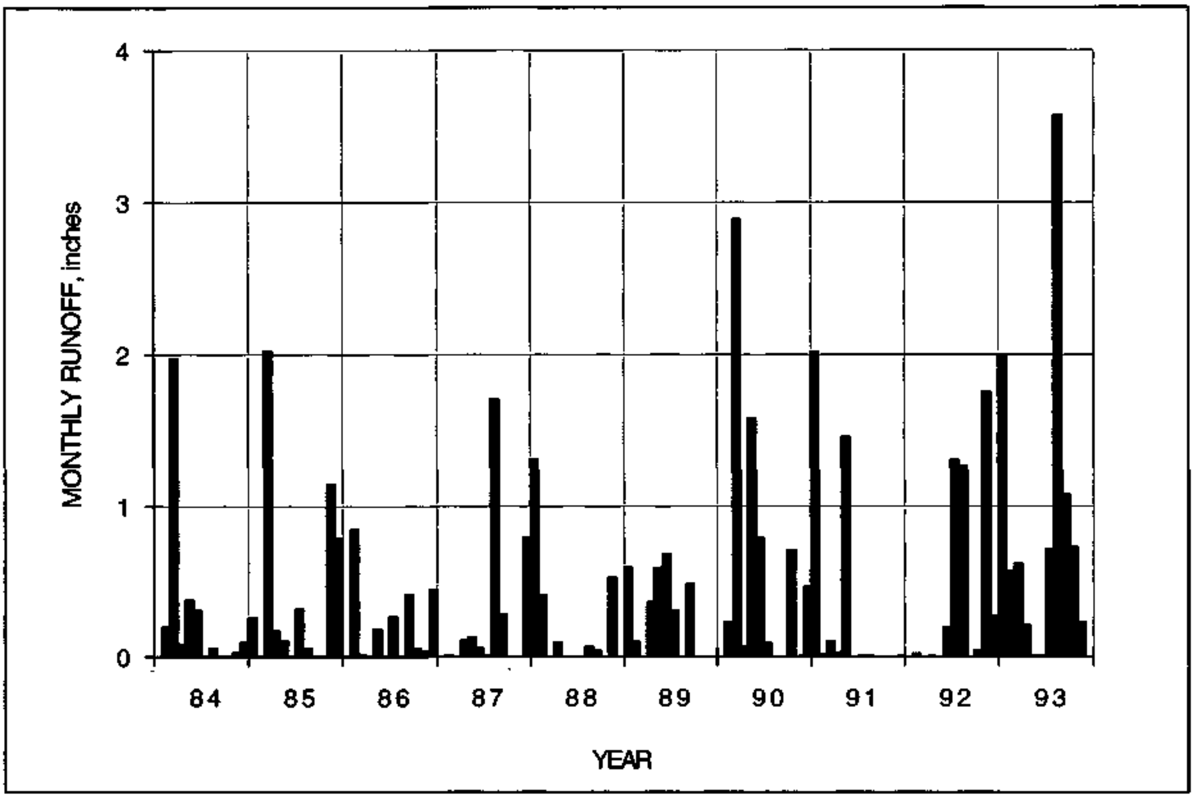


Figure 21. Estimates of monthly direct surface runoff, 1984 -1993

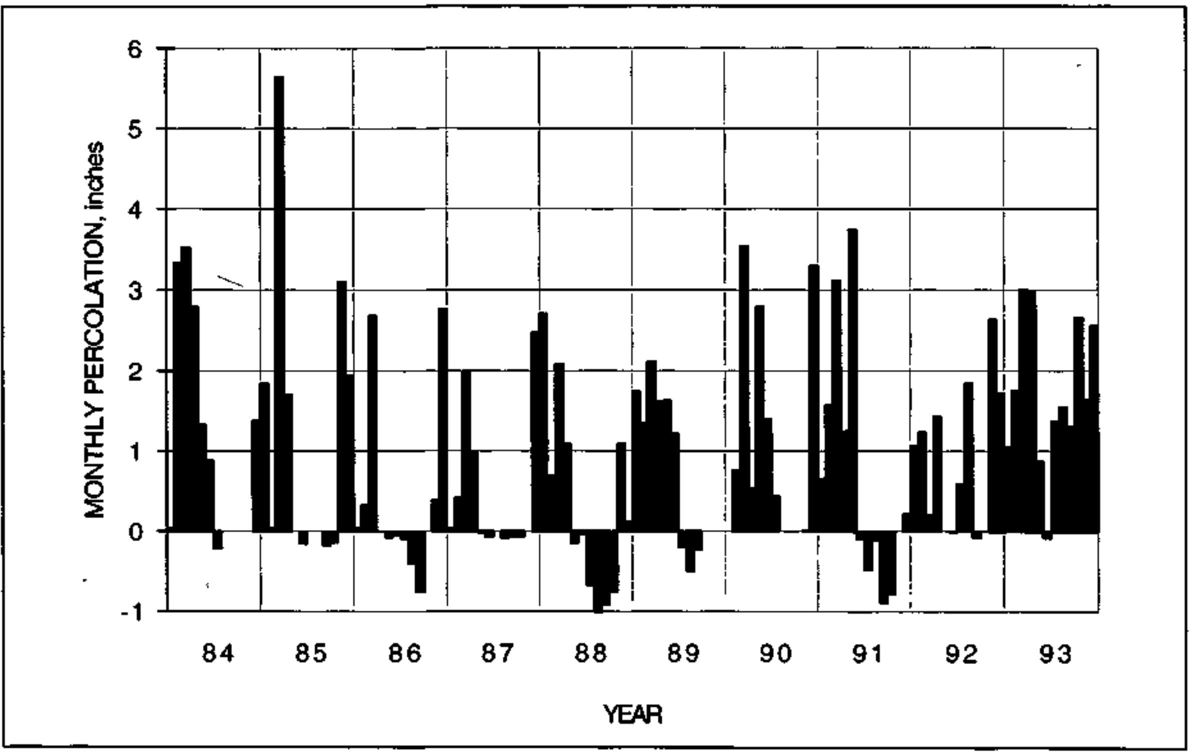


Figure 22. Estimates of monthly percolation through the soil, 1984 -1993

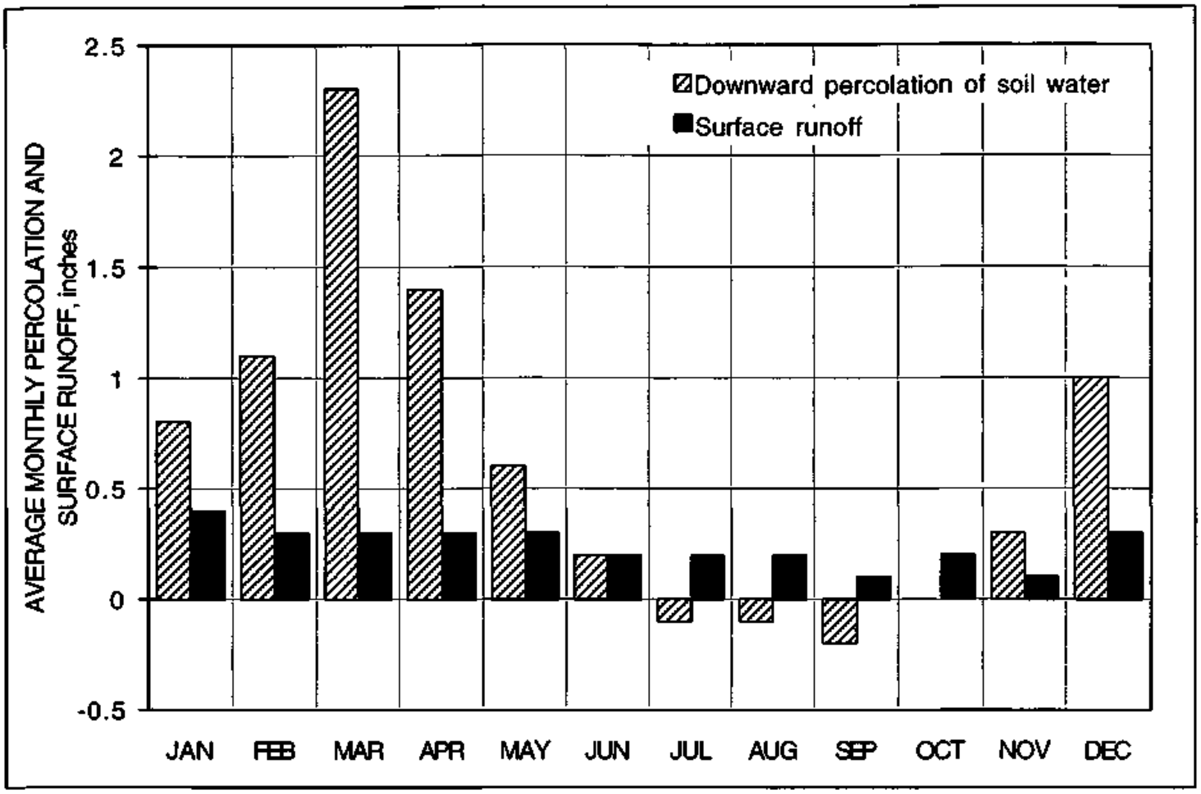


Figure 23. Monthly average percolation through the soil and surface runoff, 1949-1993

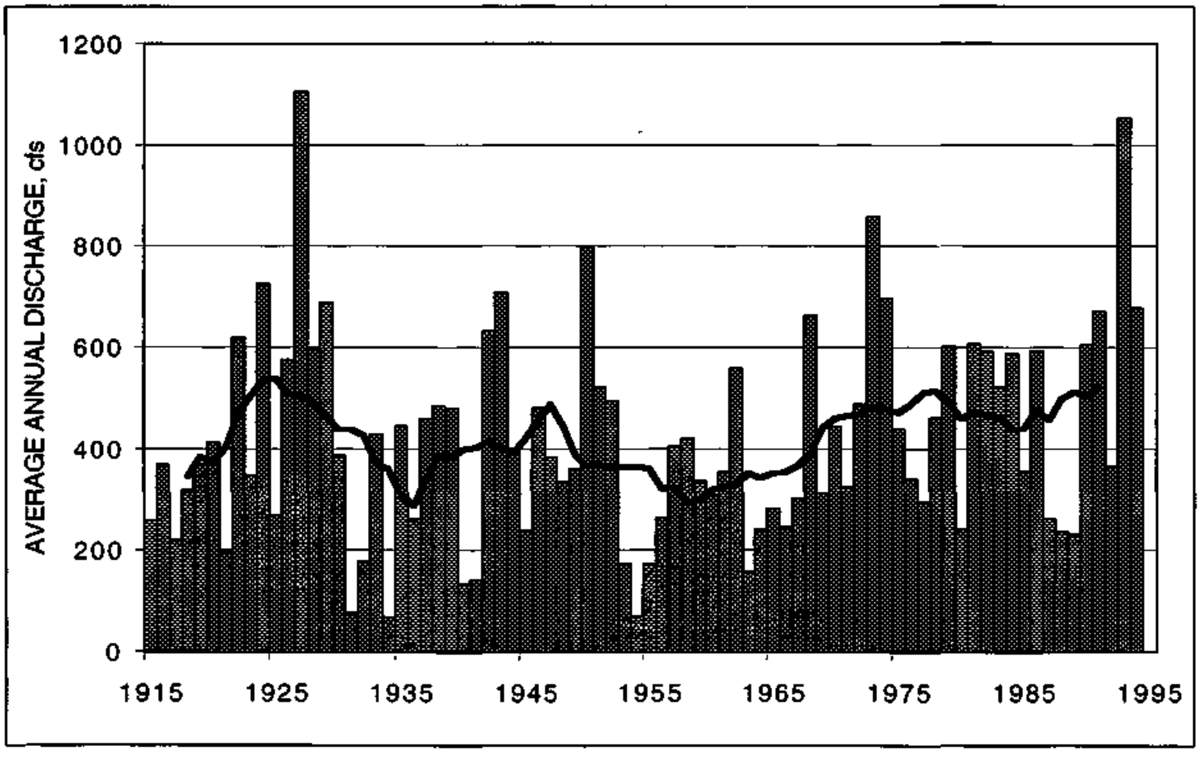


Figure 24. Annual series of average streamflow (shaded) and the 10-year average flow (dark line) for the Sangamon River at Monticello

and a greater percentage of the streamflow originates from, direct storm runoff. It is highly significant that the spring period when percolation, interflow, and baseflow are at their greatest corresponds to the season when the average nitrate concentrations in streams are at their highest.

Historical Streamflow Records in the Watershed

Table 6 lists the historical streamgaging records from the Lake Decatur watershed prior to the additional gages that were installed at the beginning of this study. The streamgages listed in table 6 have been operated by the U.S. Geological Survey (USGS) with cooperative funding from various federal, state, and local agencies, including the City of Decatur. The gaging station on the Sangamon River at Monticello has an 81-year period of record, which is the longest continuous measurement of any stream in central Illinois.

Figure 24 shows the annual average flows measured at the Sangamon River at Monticello gage since 1915. During the last 25 years the Sangamon River has experienced an increase in its average flow, with flow rate greater than 13 percent above the long-term average. Similar increases in average flow have been experienced by most rivers in central Illinois. The major cause for this increase appears to be climate variability.

Figure 25 compares the average precipitation over the watershed with the average streamflow over the period of record at Monticello. Since the 1930s the ten-year average precipitation and streamflow correlate very well, with a correlation coefficient of 0.94. The correlation between average precipitation and streamflow is further illustrated by figure 26, which compares the observed ten-year average streamflow with an estimate of that flow using the average precipitation over the same time period. The lack of a similar correlation for the period prior to 1930 may be caused by inconsistencies in either the streamflow or precipitation measurements.

As shown in figures 25 and 26, the observed increases in streamflow over the last 60 years appear to be explained almost entirely from concurrent increases in precipitation. The total volume of streamflow has not been affected in any significant way by changes in land use or other practices in the watershed.

Table 6. Streamgaging Stations in the Lake Decatur Watershed

Station name	*USGS gage number*	*Years of record*	*Drainage area (sq mi)*
Sangamon River at Fisher	05570910	1978-1995	240.0
Sangamon River at Mahomet	05571000	1948-1978	362.0
Goose Creek near Deland	05571500	1951-1959	47.9
Sangamon River at Monticello	05572000	1914-1995	550.0
Friends Creek at Argenta	05572450	1966-1982	111.0
Sangamon River near Oakley	05572500	1951-1956	774.0
High flows only	05572500	1956-1977	774.0

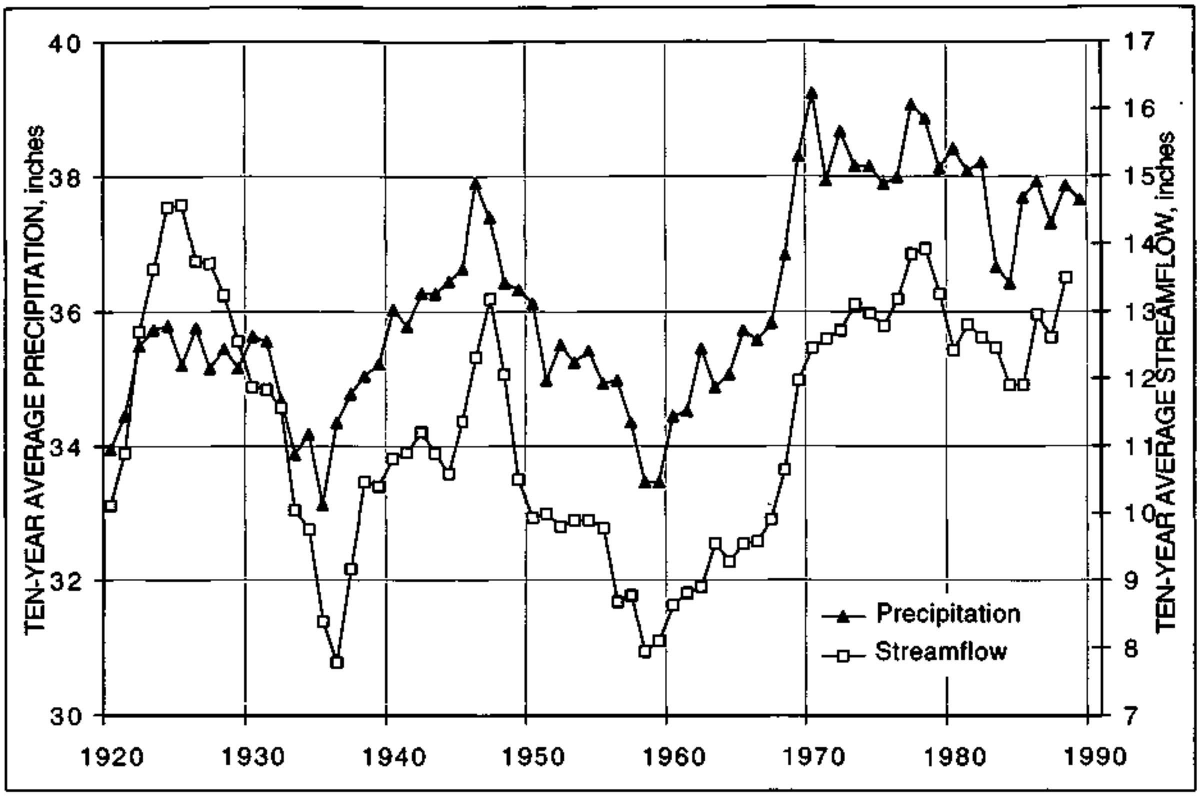


Figure 25. Comparison of the 10-year average streamflow at Monticello and the concurrent 10-year average precipitation over east-central Illinois

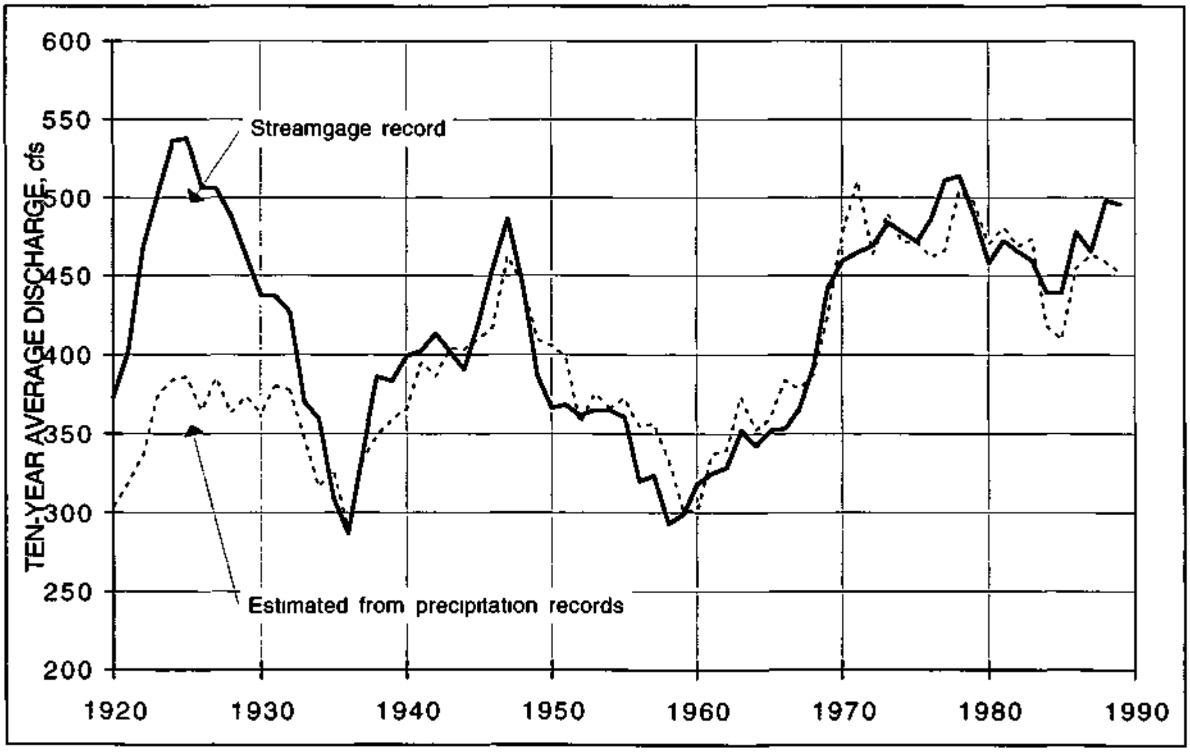


Figure 26. Comparison of the 10-year average streamflow at Montixcello, measured versus estimated using precipitation data

For purposes of estimating long-term streamflow conditions, it is assumed that the above-normal climatic conditions experienced over the past 25 years will not continue indefinitely, and therefore future streamflow conditions are best approximated using the historical long-term average from the period of record at the Monticello gage. Because most of the streamflow records in the watershed cover a significantly shorter period than the Monticello record, it is quite possible, and even expected in many cases, that these shorter gaging records will not provide estimates of streamflow frequency consistent with the expected long-term conditions.

Historical streamflow records in the watershed are available for several other locations on the Sangamon River, but records are available for only two gaging stations on tributaries to the Sangamon River: Friends Creek at Argenta and Goose Creek near Deland. These two adjacent sub-watersheds have very similar physiographic and soil characteristics. Over a concurrent period of gaging, it is expected that the runoff characteristics from the two sub-watersheds would also be very similar (assuming there is some account of the difference in drainage areas). However, the gaging periods for Friends Creek (1966-1982) and Goose Creek (1951-1959) represent significantly different hydrologic periods, one wet and the other one dry. The occurrence of these wet and dry periods can easily be verified by examining the concurrent condition at the Monticello gage (figures 24-26). The average streamflow per square mile for the Friends Creek and Goose Creek records is 0.89 and 0.53 cubic feet per second (cfs), respectively. The long-term average flow for both streams is expected to approximate 0.73 cfs per square mile.

Estimated Flow Frequencies for the Sangamon River and Tributaries

Methodology

Long-term streamflow characteristics for all the tributaries in the Lake Decatur watershed were computed using regional equations developed from analysis of streamgage records in central Illinois (Knapp, 1994). Similar regional analyses of streamflow characteristics have been con-ducted by the ISWS for numerous watersheds in Illinois (Knapp, 1988, 1990). These studies indicate that two major watershed characteristics show consistent strong correlations to differences in streamflow frequency: 1) drainage area and 2) the permeability of the lower layers of soils in the watershed. The second characteristic is a surrogate parameter to represent the relative rate at which water moves laterally through the subsoil toward the stream.

Numerous other watershed characteristics (amount of tile drainage, entrenchment of the stream, land use, amount of wetland area, watershed shape, channel slope, and land slope) also conceptually influence the magnitude and frequency of flows from a watershed. Demissie and Khan (1993), for example, indicated that the presence of wetlands could decrease high flows and increase low flows in a watershed. The relationships between all these various watershed characteristics and streamflow frequency are continuing to be evaluated in other research projects, but their impacts have yet to be incorporated into regional streamflow equations.

The hydrologic characteristics over the Lake Decatur watershed are fairly uniform for a watershed its size. Small differences in physiography and soils occur between the upper part of the watershed (north of Mahomet) and that portion of the watershed downstream of Mahomet. The upstream portion has a higher percentage of less permeable, poorly drained soils (falling in hydrologic soils groups C and D). However, the overall range of topography and soil conditions throughout the watershed is relatively small. Given the limited flow data available from the watershed, it is expected that the downstream portions of the watershed may have slightly higher contributions of flow during dry climatic conditions. But for the most part, the flow frequencies from the various sub-watersheds are likely to be very similar.

Flow Frequency for Tributaries

Table 7 presents the expected long-term flow frequency, computed by the regional flow equations, for each of the five gages on tributaries to the Sangamon River currently being monitored. The regional equations suggest that all five tributaries are expected to have similar flow characteristics. The flow values for Goose Creek, Camp Creek, Big Ditch, and Long Creek are similar because these gages have similar drainage areas. The flow values for Friends Creek are noticeably different only because the drainage for this gage is larger.

Figure 27 charts the flow frequencies for four of these stations: Camp Creek, Goose Creek, Big Ditch, and Friends Creek. The regional equations suggest that the only systematic differences in flow will occur for extreme low flows (less than 1 cfs). Camp Creek is expected to have the lowest flows in dry periods. Big Ditch has sustained flow during dry periods because of wastewater effluents discharged to that stream from Rantoul.

Table 7. Estimates of Long-Term Flow Frequencies for Tributaries to Lake Decatur

Frequency of exceedance (percent)	*Friends Creek*	*Goose Creek*	*Camp Creek*	*Big Ditch*	*Long Creek*
99	0.0	0.0	0.0	0.1	0.0
98	0.0	0.0	0.0	0.2	0.0
95	0.1	0.0	0.0	0.3	0.0
90	0.2	0.1	0.01	0.5	0.2
85	0.8	0.4	0.2	0.7	0.4
75	3.9	1.9	1.4	1.6	1.6
70	6.1	2.9	2.3	2.5	2.5
60	13.0	6.0	5.1	5.0	5.3
50	24.0	11.0	9.9	9.2	9.7
40	39.0	17.0	17.0	16.0	16.0
25	79.0	34.0	35.0	30.0	33.0
15	137.0	59.0	61.0	53.0	57.0
10	196.0	85.0	88.0	78.0	83.0
5	335.0	144.0	153.0	134.0	141.0
2	600.0	255.0	279.0	245.0	253.0
1	858.0	362.0	400.0	351.0	363.0
Average flow	81.1	35.1	36.6	31.8	34.1
Drainage area (sq mi)	111.0	47.9	48.2	41.1	46.7
Average permeability (in/hr)	0.93	0.92	0.60	0.58	0.78

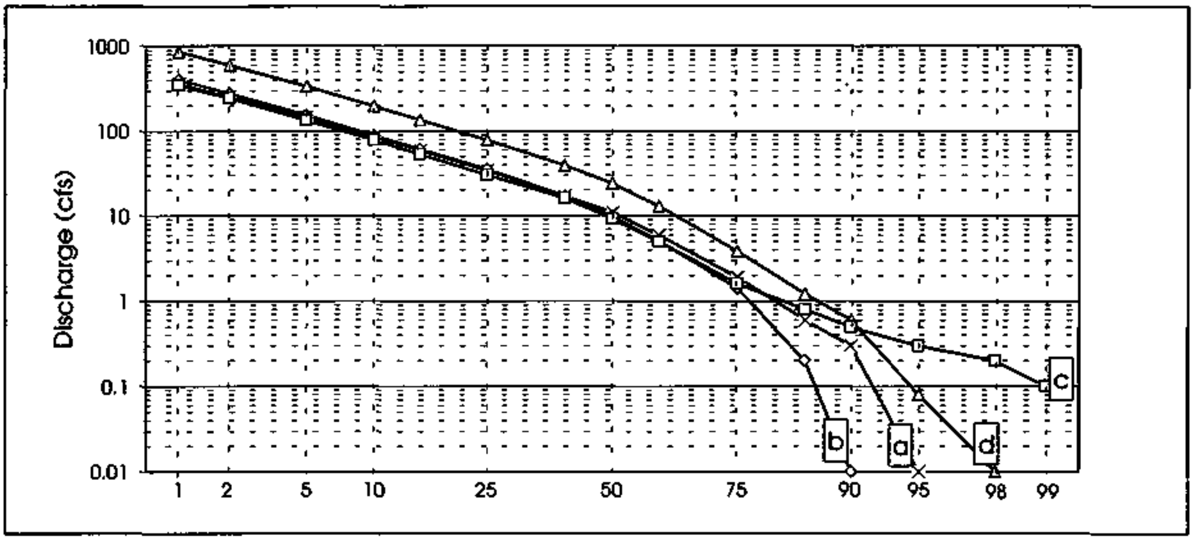


Figure 27. Comparison of long-term flow frequencies for: a) Goose Creek near Deland, b) Camp Creek near White Heath, c) Big Ditch near Fisher, and d) Friends Creek near Argenta

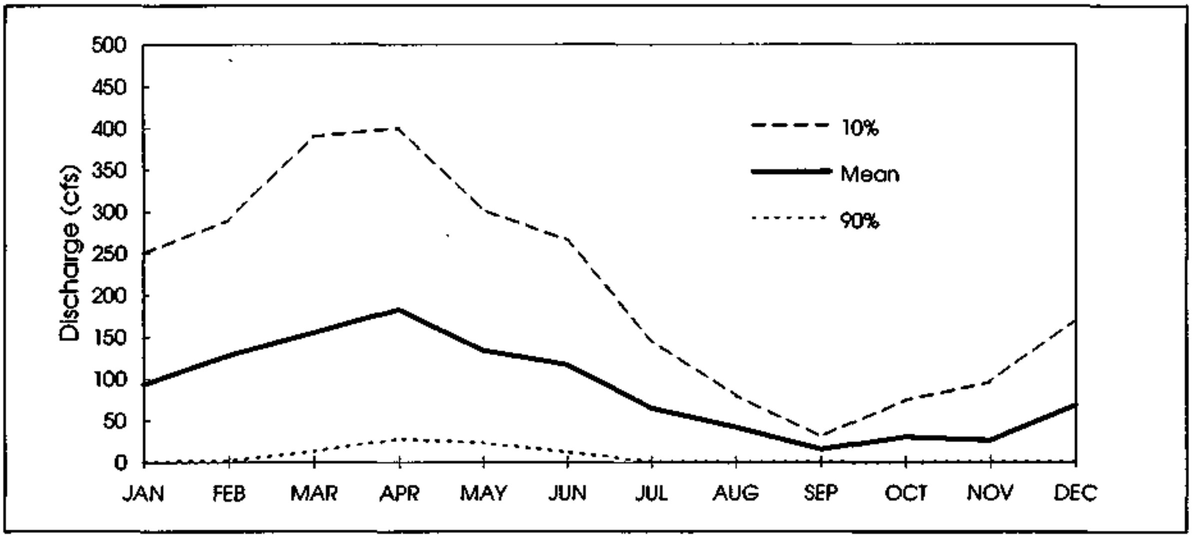


Figure 28. Monthly distribution of flow frequency for Friends Creek at Argenta

The long-term flow estimates from the regional equations differ from those computed from the gaging records on Friends Creek and Goose Creek, as indicated in table 8. As indicated earlier, the record for the Friends Creek gage represents wetter-than-normal conditions that existed from 1966 to 1982; and drought conditions existed when Goose Creek was gaged (1951-1959).

Figure 28 illustrates an example of the monthly differences in flows for the tributary streams and presents those values for Friends Creek at Argenta. As can be seen in this figure, a large portion of the streamflow occurs during the first six months of the calendar year. Low flows during August through November are the norm, rather than the exception.

Mainstem Sangamon River

Figure 29 and table 9 provide estimates of long-term flow conditions on the main stem of the Sangamon River. Values for Monticello and near Mahomet are in accordance with the USGS gaging records for these locations. Estimates for the Fisher gage were adjusted from the 14-year USGS record to more closely reflect the expected long-term flow conditions at that location. The inflow to Lake Decatur was estimated using data from two sources: the regional equations and the flow record at Monticello.

The frequency of flows by month for the Sangamon River at Monticello is illustrated in figure 30. Note that this distribution is very similar to that presented in figure 28 for Friends Creek, although the changes from month to month appear to be smoother. Again, there is a considerable difference in the flows expected in the wet season (February through May) versus the dry season (August through November). The high probability of low flows in the dry season emphasizes the need for reservoir storage to provide water supply at Decatur.

Table 8. Comparison of Flow Frequencies for Friends Creek at Argenta and Goose Creek near Deland: Gaging Record versus Expected Long-term Average (in cfs)

Frequency of exceedance (percent)	*Friends Creek at Argenta*		*Goose Creek near Deland*	
	Gaging record	*Long-term*	*Gaging record*	*Long-term*
99	0.01	0.0	0.0	0.0
98	0.03	0.0	0.0	0.0
95	0.08	0.01	0.0	0.0
90	0.2	0.2	0.0	0.1
85	0.8	0.8	0.0	0.4
75	6.4	3.9	0.0	1.9
70	12.0	6.1	0.4	2.9
60	24.0	13.0	1.3	6.0
50	37.0	24.0	4.1	11.0
40	57.0	39.0	9.0	17.0
25	105.0	79.0	24.0	34.0
15	170.0	137.0	48.0	59.0
10	245.0	196.0	72.0	85.0
5	412.0	335.0	119.0	144.0
2	690.0	600.0	190.0	255.0
1	911.0	858.0	247.0	362.0
Average flow	98.3	81.1	25.4	35.1

Table 9. Comparison of Long-term Flow Frequencies for the Sangamon River (in cfs)

Frequency of exceedance (percent)	*At Fisher*	*Near Mahomet*	*At Monticello*	*Inflow to Lake Decatur*
99	0.2	0.8	2.7	7.7
98	0.6	1.4	4.3	9.9
95	1.7	3.4	7.3	15.0
90	3.3	6.1	12.0	24.0
85	5.0	8.9	16.0	32.0
75	10.0	17.0	32.0	53.0
60	30.0	50.0	87.0	137.0
50	53.0	88.0	146.0	226.0
40	89.0	145.0	230.0	356.0
25	176.0	284.0	442.0	711.0
15	302.0	485.0	737.0	1180.0
10	418.0	672.0	1052.0	1700.0
5	697.0	1100.0	1650.0	2630.0
2	1250.0	1940.0	2670.0	4180.0
1	1850.0	2850.0	3690.0	5640.0
Average flow	175.0	277.0	411.0	660.0

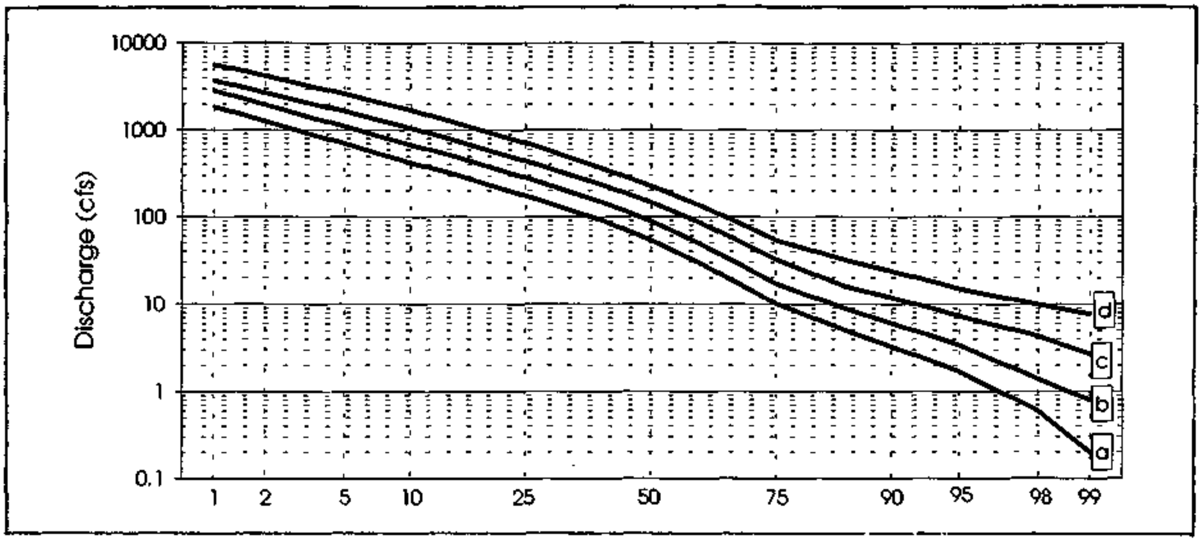


Figure 29. Comparison of long-term flow frequencies for the Sangamon River: a) at Fisher, b) near Mahomet, c) at Monticello, and d) above the Lake Decatur dam

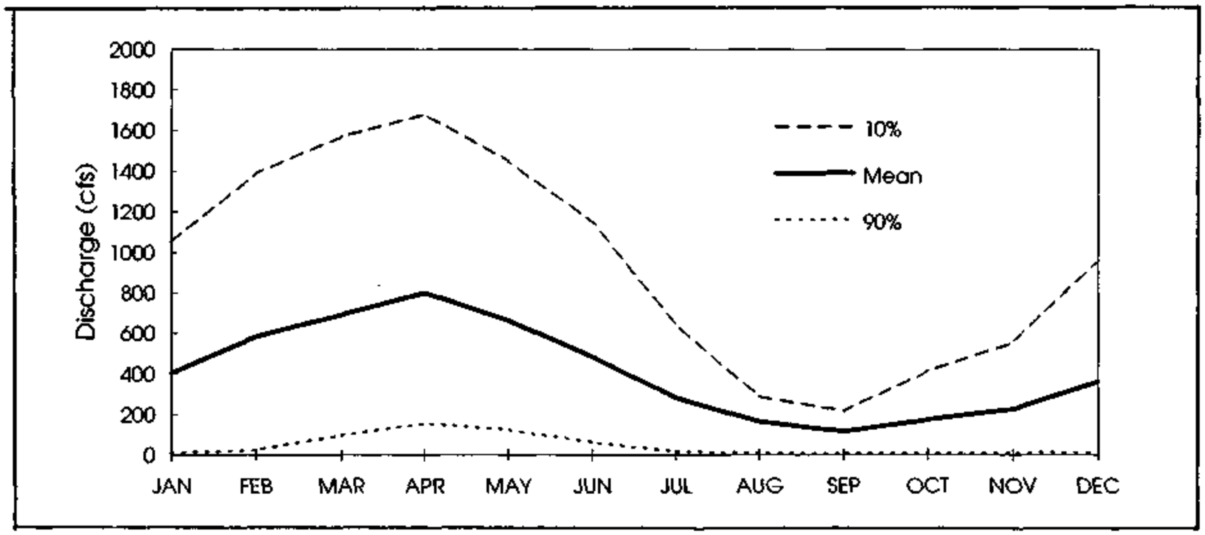


Figure 30. Monthly distribution of flow frequency for the Sangamon River at Monticello

Hydrologic and Water Quality Monitoring

A watershed monitoring network has been established to provide streamflow and water quality data for the Sangamon River and its tributaries upstream of Lake Decatur for the purpose of establishing the sources of nitrate throughout the watershed. The network mainly comprises eight stations (see figure 31) at which stage is continuously recorded and discharge is measured periodically. Water samples are collected and analyzed for nitrogen compounds on a weekly basis and during storm events at each station. The names of the streams, locations of the monitoring stations, and drainage areas are presented in table 10. Three additional stations have been established in the immediate vicinity of Lake Decatur and are monitored for nitrogen compounds from urban drainage. Water levels and samples are noted weekly for these sites.

Hydrologic Monitoring

Continuous hydrologic monitoring at each station facilitates the calculation of continuous streamflow for the entire study period. This is essential for establishing the nitrate contribution to Lake Decatur from the Sangamon River and its tributaries. The procedures used to collect hydrologic data at the monitoring stations are discussed in the following sections.

Precipitation

Precipitation data for selected locations around the watershed have been retrieved from the Midwestern Climate Center database, which is operated by the ISWS. Six stations were selected from within and around the Lake Decatur watershed: Gibson City, Rantoul, Urbana, Clinton, Monticello, and Decatur. Their locations are shown in figure 31. The monthly precipitation was retrieved for May 1993 through April 1995. Figure 32 compares the monthly precipitation in inches between all six stations. Figure 33 presents the annual precipitation totals

Table 10. Streamflow and Stage Monitoring Stations in the Lake Decatur Watershed

Station number	*Location*	*Drainage area (sq mi)*
101	Long/Big Creek at Twin Bridge Road	46.2
102	Friends Creek at Rte 48 near Argenta	111.9
103	Goose Creek near DeLand	45.1
104	Camp Creek near White Heath	47.2
105	Sangamon River at Shively Bridge near Mahomet	368.2
106	Big Ditch near Fisher	38.2
111	Sangamon River at Monticello	543.4
112	Sangamon River at Fisher	245.6

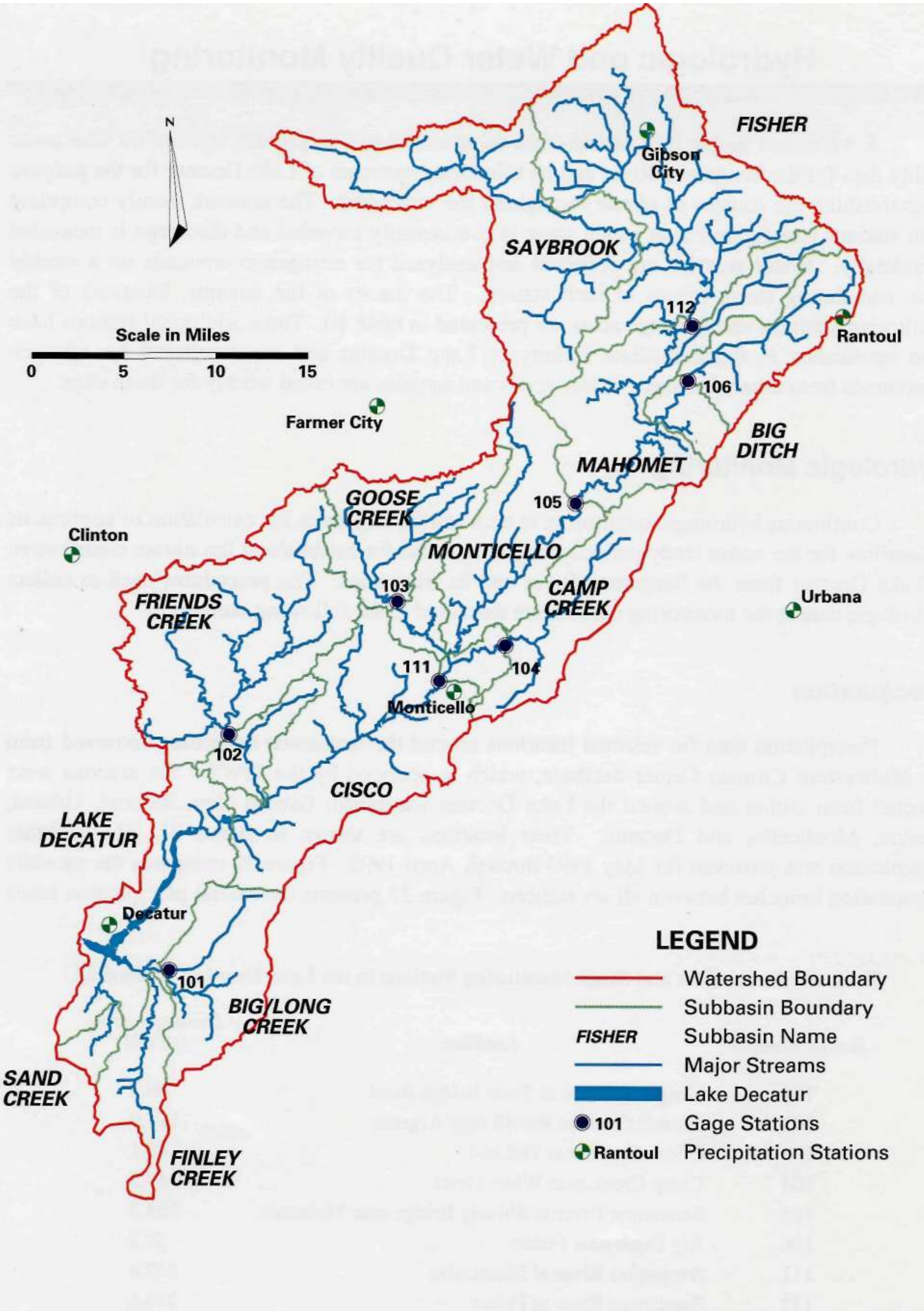


Figure 31. Location map of stream and rain monitoring stations in the Lake Decatur watershed

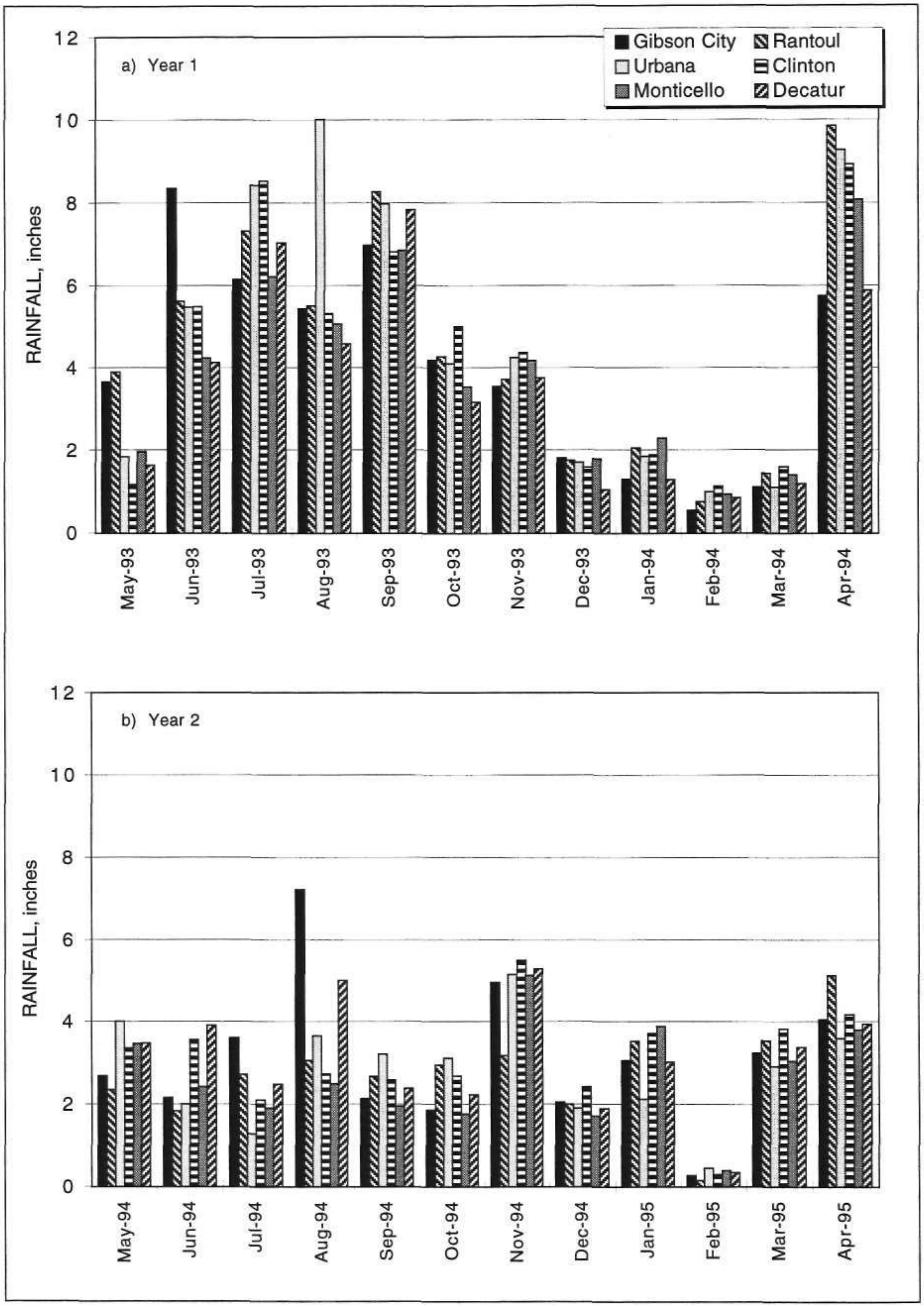


Figure 32. Monthly precipitation for study periods

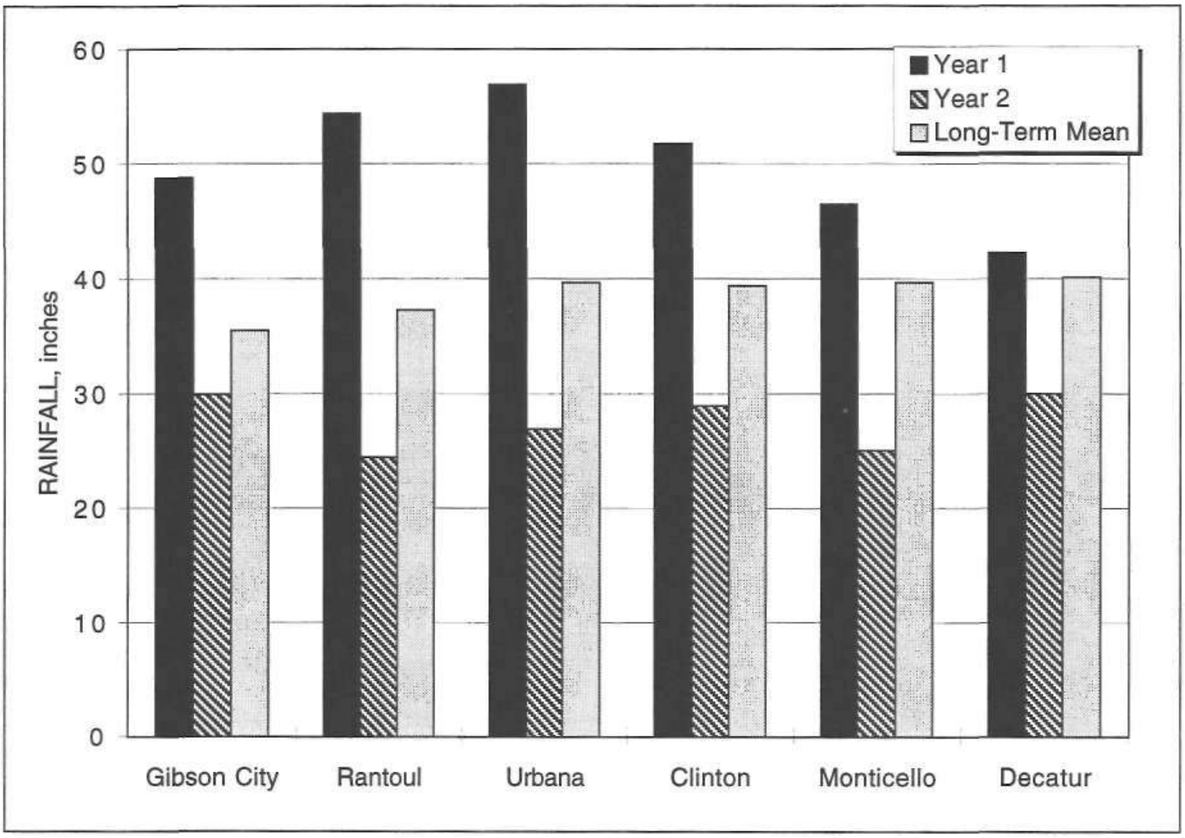


Figure 33. Annual precipitation for study periods

and long-term means. It should be noted that the stations are presented as they are located in the watershed from north to south (Gibson City is the station closest to the north end of the watershed, and Decatur is the farthest south).

Figure 32 shows the differences between each station as well as the changes in overall precipitation from month to month. The high precipitation in the summer and fall months of 1993 as well as April 1994, stand out in Figure 32a. The highest monthly precipitation was in Urbana during August of 1993 at 10.02 inches. More than half of the rain fell on August 12 with 5.32 inches. Figure 32b shows that the second year precipitation amounts vary from near normal to much below normal. The month of February 1995 was more than 75 percent below normal. Other much below normal months are June, July, and December 1994. November 1994 was the only month above normal. Gibson City was above normal during August 1994, because of an isolated thunderstorm on August 2 with 3.8 inches of rain.

Figure 33 shows the difference in rainfall between the two monitoring years. The first year of the study period is very much above the long-term mean, whereas the precipitation was below normal during the second year. It is also apparent that the stations in the northern region of the watershed have received nearly 40 percent more rainfall on the average compared to the southern region during the first year. Gibson City, Rantoul, Urbana, and Clinton received 12-17 inches above their long-term means of 35.50, 37.29, 39.67, and 39.41 inches, respectively. Decatur shows slightly above normal rainfall (2.18 inches above normal), with above average rainfall at Monticello (6.76 inches above normal). This gradient in precipitation amounts will be reflected in the streamflow runoff data that follow. Unlike the first year, there seems to be no clear tendency in rainfall variability among different regions of the watershed. In fact, all the stations except Gibson City (5.56 inches) were anywhere from 10 to 14 inches below the long-term mean.

Stream Stage

Stage is a measurement of the elevation of the water surface in the stream. A stage record allows the determination of the quantity (volume) of water carried by a stream for a given time through the application of a stage-to-discharge calibration curve for a station.

The main network stations are each outfitted with continuous recording streamgaging equipment. Six of these gaging stations were designed and built by the ISWS for this investigation. The other two stations (Monticello and Fisher) are part of the USGS long-term monitoring network. Figure 34 shows gaging stations at Big Ditch and Camp Creek (Station numbers 106 and 104, respectively), illustrating a typical setup for the ISWS sites. The recorders are housed in an ISWS designed security shelter for protection from weather and vandalism. The float and pulley system is enclosed within either a 12-inch aluminum culvert pipe or a 6-inch PVC stilling well, which protects the float system from debris carried by the stream.

These streamgaging sites are equipped with water-level recorders that continuously monitor the stage of the streams. A photograph of a recorder installed on Camp Creek is shown in figure 35. The type of water-level recorder used is a Leupold & Stevens Type A/F data logger and encoder powered by a 12-volt rechargeable lead acid battery. A Stevens data card is used to store data. Each water-level recorder is basically a float and pulley system connected to an electronic encoder and logger. Changes in water level turn the pulley in increments, are read by the encoder, and are sent to the logger every 15 minutes and converted to water-level information. Water-level history is recorded on a removable data card module, which is retrieved on a regular schedule and downloaded to a computer. The continuous output of the stream water level obtained from these recorders is used to determine the quantity of water moving through the stream channel. The "Streamflow" section in this report discusses the procedure used to convert the streamgage record to stream discharge.

Instantaneous stage data are collected at the three urban sites. These data are recorded during the regular weekly visits and during storm/runoff events. To measure stage, a steel tape is lowered until it just touches the water surface, and a reading is made at a known datum on a culvert or bridge rail.

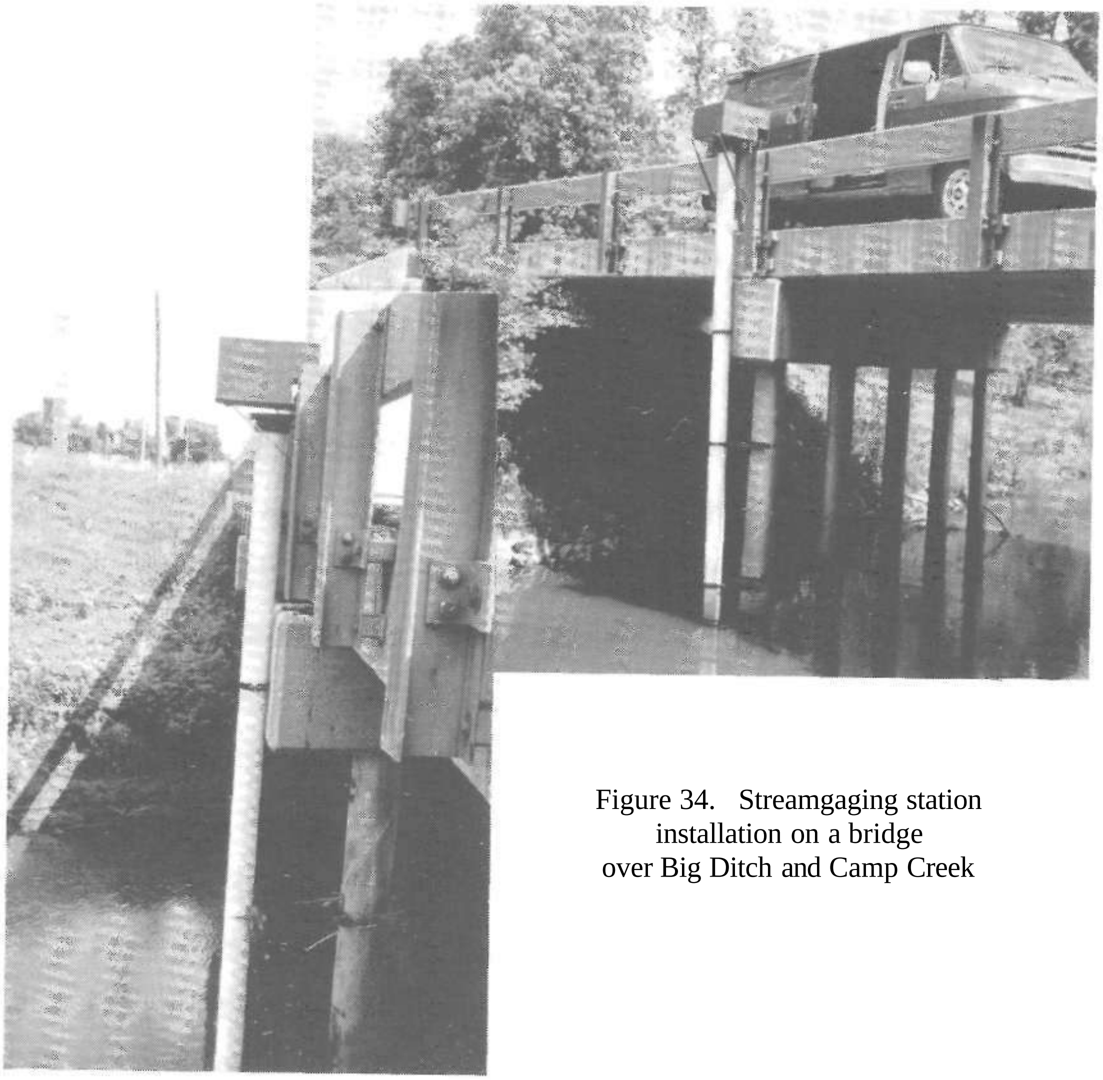


Figure 34. Streamgaging station installation on a bridge over Big Ditch and Camp Creek

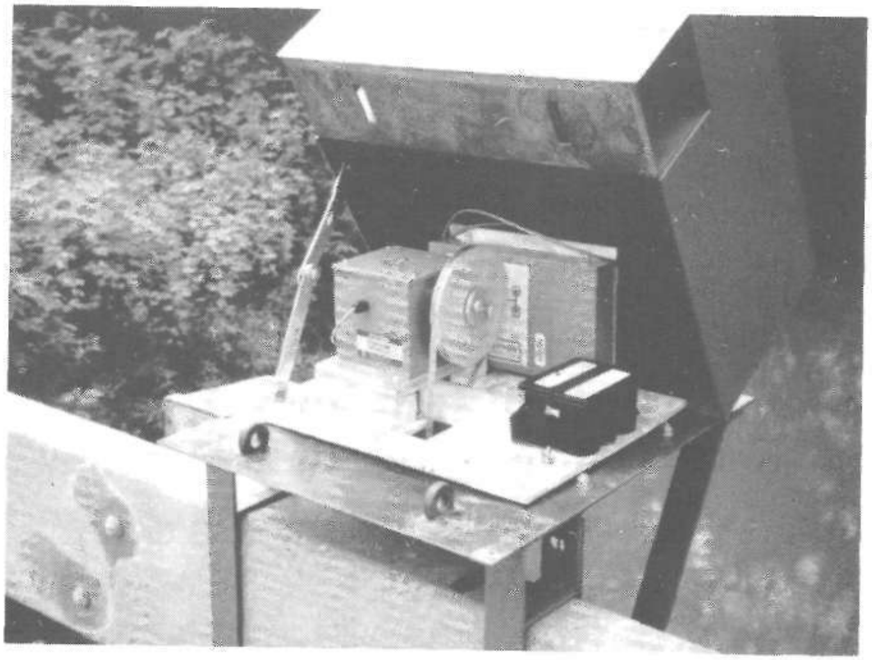


Figure 35. Stevens Type A/F recorder using the float-pulley stystem

Streamflow

Streamflow data are generated from the stage record for each of the monitoring stations. Stage data are converted to streamflow data by applying a stage-to-discharge calibration curve. The stage-to-discharge calibration is developed by taking several detailed field measurements of the stream discharge at known stages. The discharges are plotted with corresponding stages, and a stage-to-discharge curve is developed for each station.

Stream Discharge Measurements. The stream discharge measurement techniques used in this study were established by the USGS (Buchanan and Somers, 1969) and the American Society for Testing and Materials (standard practice for Open-Channel Flow Measurement of Water by Velocity-Area Method, designation: D3858-79). Stream discharge is determined by subdividing a cross section of a stream at a bridge crossing, into partial sections 2 to 10 feet wide. A standard rotating bucket mechanical velocity meter (current meter), suspended by a cable/winch/crane assembly (A-reel and bridgeboard), is lowered into the stream at the midpoint of each partial section (figures 36 and 37). A depth gage built into the winch reads the total depth of the stream at the midpoint of the partial section. This depth is recorded and later used to calculate the flow area of the partial section. Velocity measurements are then made vertically at the midpoint of the partial section. The meter is positioned beneath the water surface at 0.2 and 0.8 percent of the total depth (for total depths greater than 2.5 feet) or at 0.6 percent of the total depth (for total depths less than 2.5 feet). The number of times the meter's bucket rotates in 40 seconds determines the velocity of the stream at these measured points. An average velocity of the partial sections is then calculated. The partial section discharge is calculated by multiplying the average velocity by the flow area. These discharges are then summed to determine the total discharge for the stream. Each stream discharge is then plotted with a corresponding stage todevelop a stage-discharge curve. Using this curve, the stage data files are then converted to daily discharge. The discharge data can then be used to develop nutrient load data.

Streamflow Data. The streamflow data presented in this report are for the period from May 1993 through April 1995. The data were originally collected as stage data from continuous recording streamgaging instruments. The stage data are converted to discharge (streamflow) using discharge rating curves, as discussed in the preceding section. Rating curves were developed for Long Creek at Twin Bridge Road (station 101), Friends Creek at Route 48 near Argenta (station 102), Goose Creek near DeLand (station 103), Camp Creek near White Heath (station 104), the Sangamon River at Shively Bridge near Mahomet (station 105), and Big Ditch near Fisher (station 106). Discharge data from the USGS continuous streamgaging stations already exist for the Sangamon River at Route 136 (station 112) and at Monticello (station 111). The discharge data from October 1994 to April 1995 for these two stations were retrieved from the USGS before being officially published and are therefore considered provisional.

The discharge data results are illustrated in figures 38 and 39. Figure 38 shows the monthly discharge for the stations located on tributaries of the Sangamon River (stations 101, 102, 103; 104, 106), and figure 39 shows the stations located on the Sangamon River (stations 111, 105, 112). In figure 38a, Friends Creek (station 102) shows the highest discharge during 11

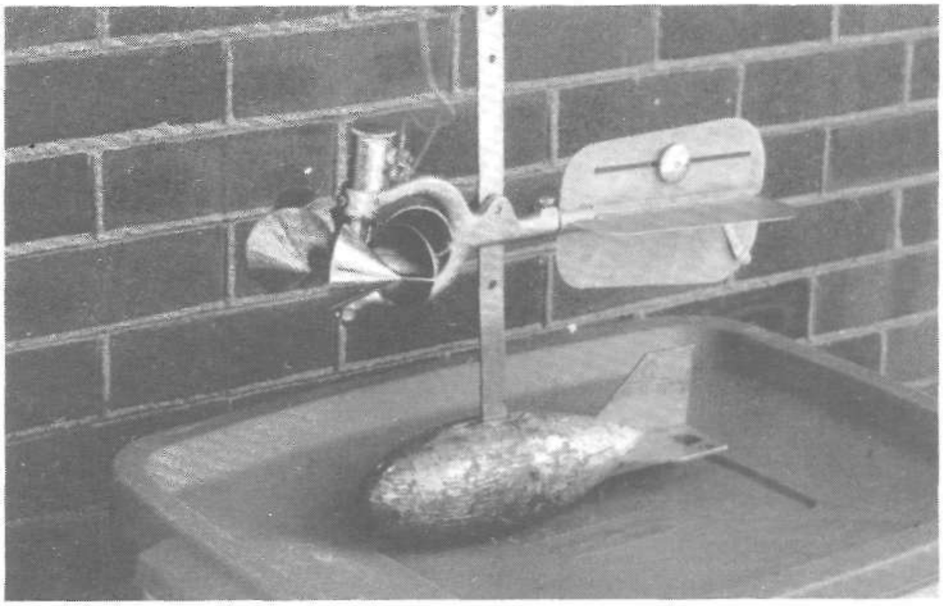


Figure 36. A rotating bucket current meter

Figure 37. Field technician performing a discharge measurement with a bridgeboard cable assembly at the Mahomet station

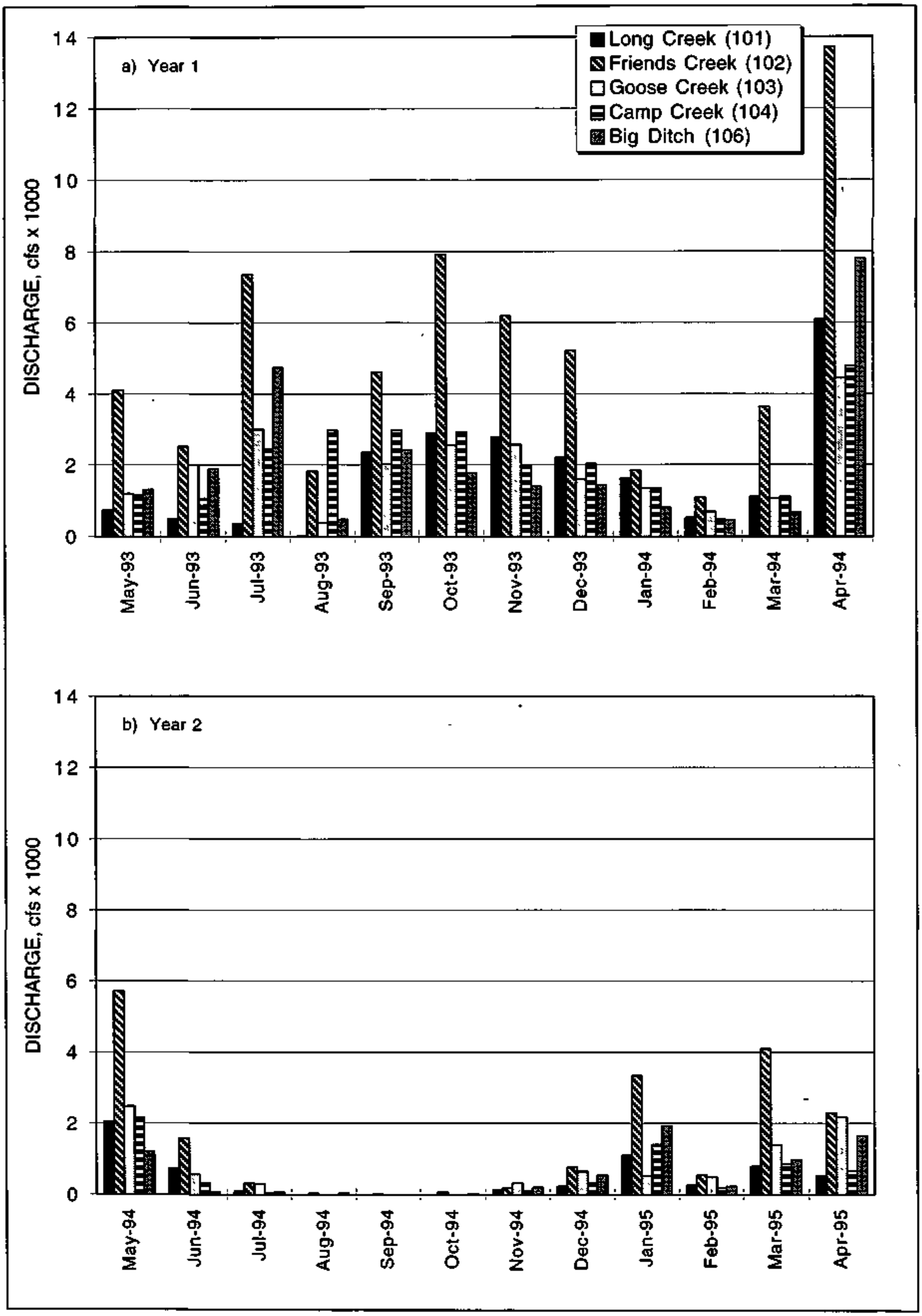


Figure 38. Monthly discharge for tributary stations

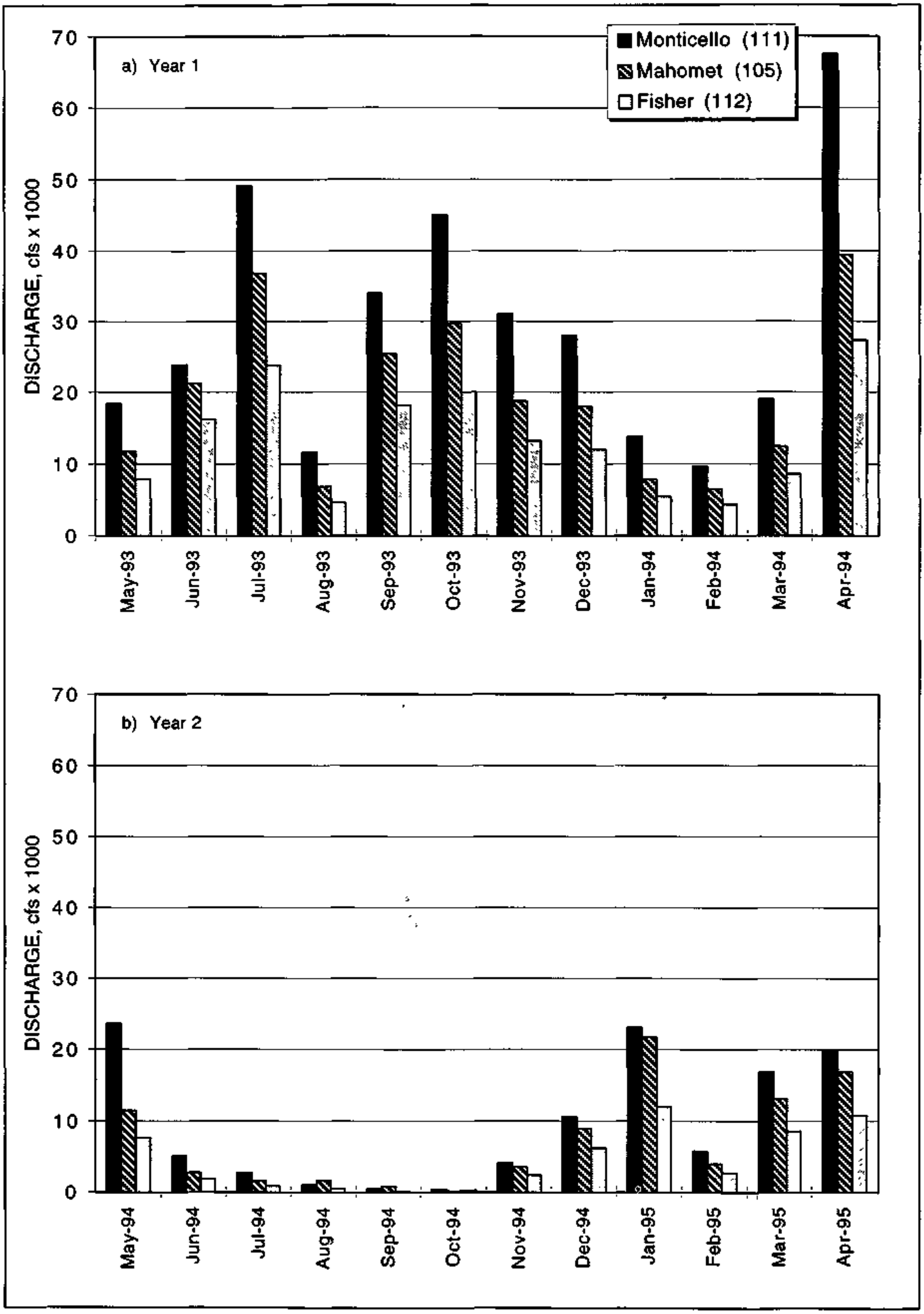


Figure 39. Monthly discharge for Sangamon River stations

of the 12 months presented, which is expected since it drains twice as much watershed as the other stations (71,647 acres). Late summer to fall of 1993 (August-December) appears to be the wettest period of the year, and April and October 1993 and April 1994 were the wettest months. During the dry months, Long Creek (station 101) experienced the lowest flows and had almost zero flow in August. This would indicate that the extreme southeastern corner of the watershed was receiving much less rainfall during the first year of data collection. Figure 38b shows that the discharge amounts in the second year are significantly lower than those from the first year. Friends Creek produced the highest discharges due to its drainage area. The months of July through November 1994 suffered extreme low flow. April 1995 has very low flows compared to the previous year.

Figure 39a shows the same trends as the tributary stations for the main river stations for the first year of monitoring. The wettest months appear in late summer to fall (August-December), July 1993, and April 1994; and the driest months were August 1993, and January and February 1994. Most station sites, if not all, were frozen over in January and February 1994, and flows remained low. Monticello consistently had the highest discharges because it drains the largest watershed area at 347,747 acres (543.4 square miles). Figure 39b shows the low discharges during the second year of the study period in comparison with the first year. The summer and fall months were the lowest flow months, whereas May 1994 and January, March, and April 1995 were relatively higher.

Discharge is sometimes converted to inches for the purposes of comparing runoff to rainfall. The monthly discharge is divided by the drainage area upstream of the streamgaging station to determine the streamflow in inches. Figures 40 and 41 show runoff in inches for thetributary and Sangamon River stations, respectively. Streamflows vary between the stations due to the spatial variability of rainfall events throughout the watershed. Figure 40 shows the highest monthly tributary runoff was at the Big Ditch station in April 1994 with 7.68 inches. All tributary stations experienced none to nearly no runoff during the months of August through October of the second year. Figure 41 reflects the same trends in runoff for the main river stations as in the tributary stations. The lowest runoffs were experienced during July through October 1994 at 0.2 inches and below. During the entire study period, 12 of the months had stations that averaged 1 inch or greater runoff, half of those averaged 2 inches or more, and only two had more than 3 inches. April 1994 exhibited the highest runoff at 4 inches or more, with July 1993 being the next highest at about 3.5 inches.

Annual streamflow for the tributary and Sangamon River stations is presented in figure 42. As can be seen in figure 42a, the streamflow increases for each tributary as you move upstream through the watershed during the first year. This correlates very well with the rainfall measurements shown in figure 33. The rainfall deviation from the long-term mean increases when proceeding from the southernmost station at Decatur to the northernmost one at Gibson City. Big Ditch had the highest annual streamflow at 24.73 inches, with Fisher (24.71 inches) just about even. Long Creek had 17.21 inches, the lowest streamflow.

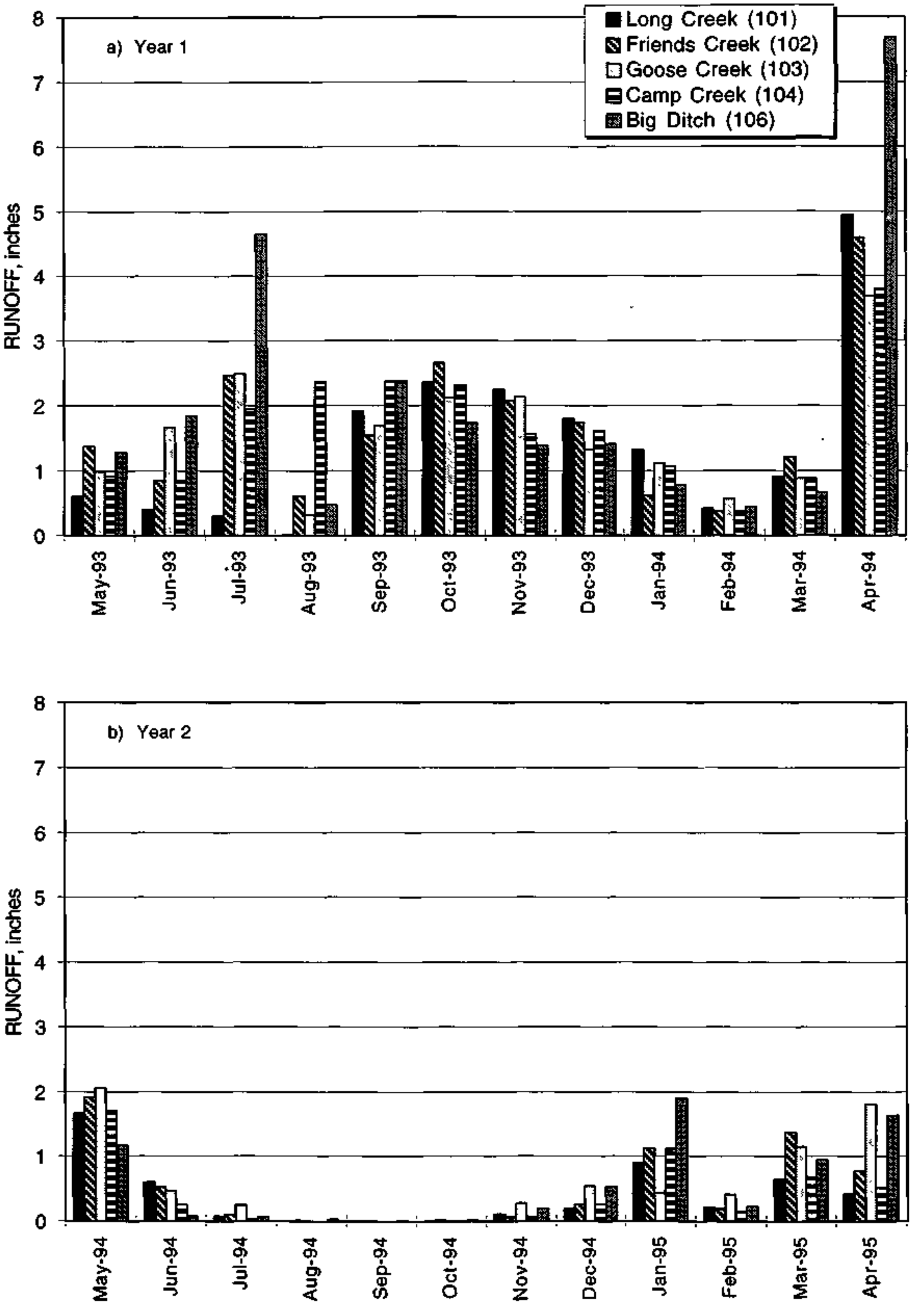


Figure 40. Monthly runoff for tributary stations

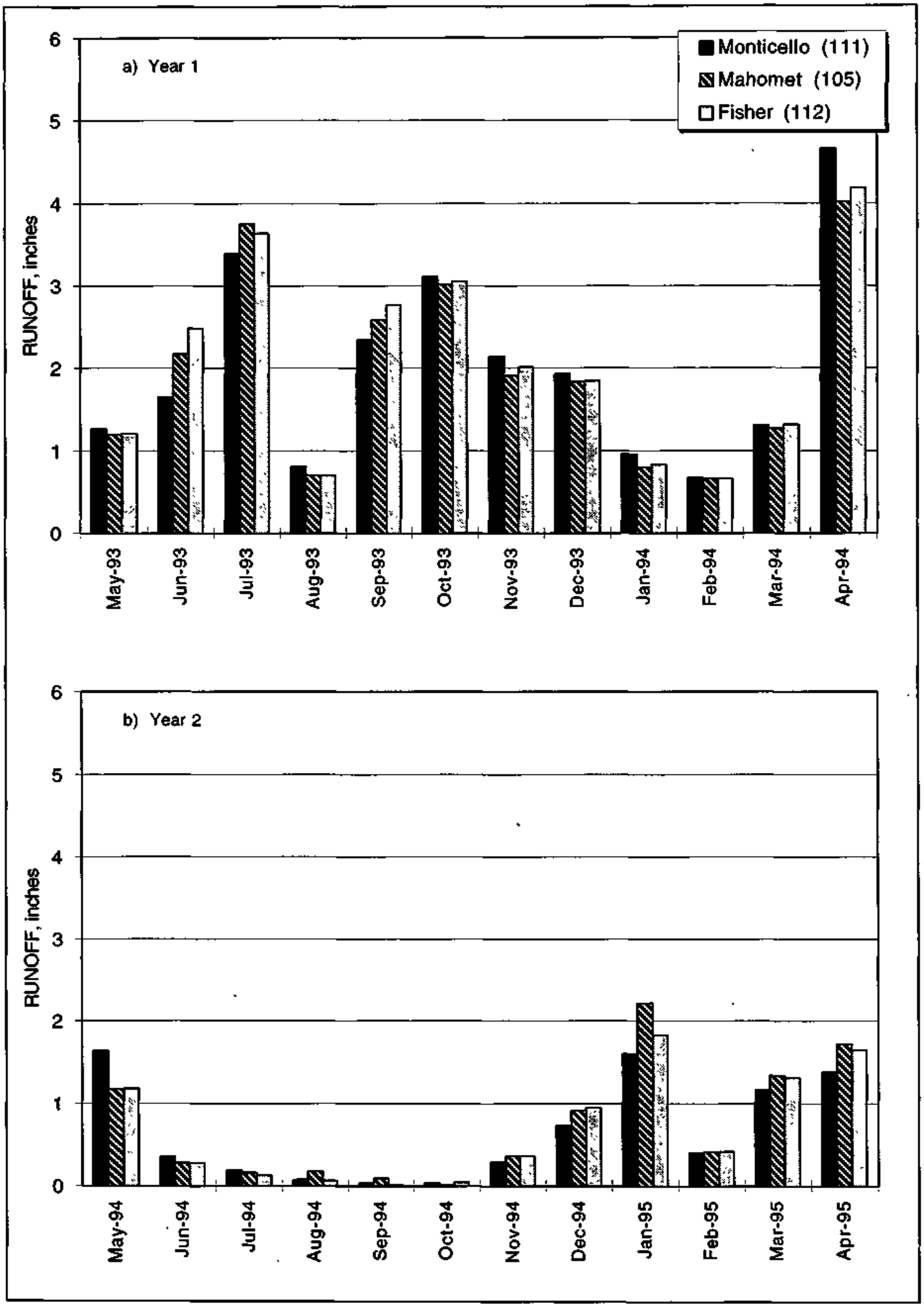


Figure 41. Monthly runoff for Sangamon River stations

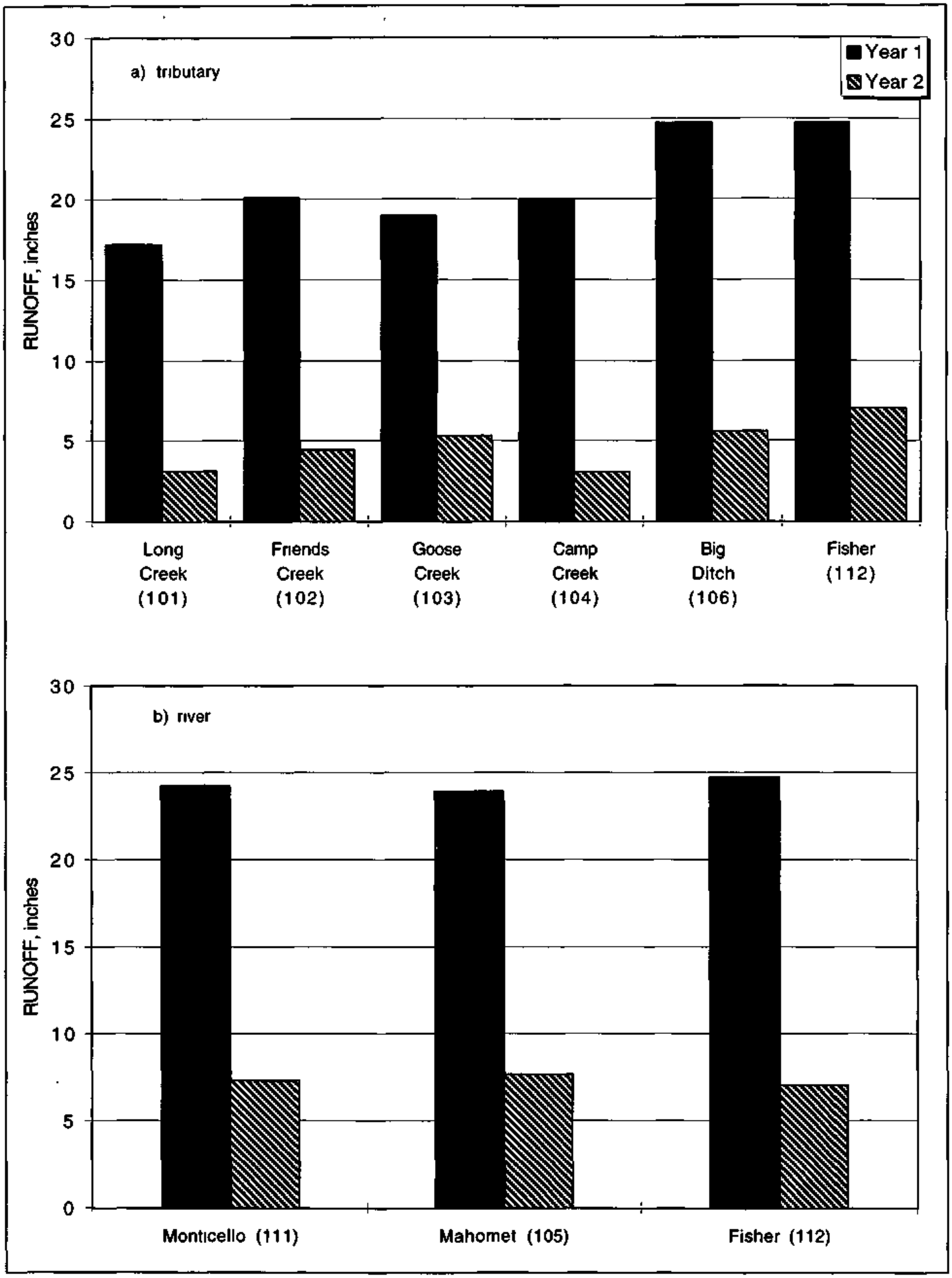


Figure 42. Annual runoff for a) tributary stations and b) Sangamon River stations

The second year streamflows in the tributaries were nowhere near the amounts of the first year. The highest streamflow was at Fisher (7.03 inches), and the lowest was at Camp and Long Creeks at 3.05 and 3.11 inches, respectively. Streamflow at the Sangamon River stations during the first year ranged from a high of 24.71 inches at Fisher to 23.92 at Mahomet. As figure 42b shows, the second year streamflows were considerably less than those in the first year. The differences in streamflow among the main river stations are a little more than 0.5 inch. Mahomet had the highest annual streamflow at 7.66 inches.

Comparison of Streamflows during Monitoring Period with Long-term Records

Table 11 compares the average streamflow measured during each year of the monitoring period with the expected long-term average flow. Examination of table 11 confirms that the first year of monitoring, May 1993-April 1994, was an extremely wet hydrologic period. The northern portion of the basin, in particular, had extremely high average streamflow rates during the first year, with the Sangamon River at Fisher experiencing flow 153 percent above normal. All of the streamgages on the main stem of the Sangamon River reflect the high amount of flow coming from the upstream portion of the watershed. For Monticello, the average flow rate for this period, 963 cfs, is surpassed only twice in that station's 81-year period of record (that being in 1926-1927 and 1981-1982).

The flooding that occurred during April 1994 is the greatest along the Sangamon River in 50 years. The peak discharges observed at the Fisher and Mahomet gages surpass any measured during those stations' period of record, and the peak discharge, observed at Monticello is the fourth highest on record and the highest discharge since 1943.

Another significant aspect of the streamflows during this first year is the lack of any significant low-flow period. The 7-day low flow observed at Monticello, 149 cfs, is the highest such low-flow period ever recorded, surpassing by a considerable margin the previous maximum low flow of 69 cfs, which occurred in April 1981. This illustrates the considerable contribution of baseflow and interflow to the flow in the Sangamon River during this period.

Table 11. Comparison of Annual Average Streamflow over the Monitoring Period with the Long-Term Average

	Average streamflow, cfs		
Location	*First year*	*Second year*	*Long term*
Sangamon River at Fisher	443.0	147.0	175.0
Sangamon River at Mahomet	643.0	238.0	277.0
Sangamon River at Monticello	963.0	354.0	411.0
Big Ditch	68.9	18.8	31.8
Goose Creek	62.6	24.3	35.1
Camp Creek	69.1	16.4	36.6
Friends Creek	164.0	51.9	81.1
Long Creek	58.0	16.1	34.1

Streamflow conditions during the second year of monitoring, May 1994 to April 1995, were near normal for the northern portion of the watershed, and as much as 50 percent below normal for some of the tributaries in the southern portion of the watershed. Still, the average flow for the composite two-year period was above normal, substantially so for the northern portion of the watershed.

The flow duration curves for tributary streams for each year of monitoring are compared to the long-term curve in figure 43, which illustrates the large flow differences between the two monitoring years, and how both of them differ from the long-term mean. The composite flow duration curve for the two-year period is slightly above the long-term curve shown in figure 43. The flow duration curves for the main stem Sangamon River stations are also compared to the long-term curves in figure 44, where significant differences between the two years of monitoring are observed. But in this case the flows from the second year of monitoring are very similar to the long-term average. The values of the flow duration curve for the two-year period, 1993-1995, are noticeably greater than that for the long-term condition.

The most apparent difference in streamflows between the two-year monitoring period and the expected long-term conditions is in the low flows. As shown in figure 44, the low flows during the first year of monitoring are record amounts, and are considerably greater than the long-term low flows for the same frequency of occurrence.

Water Quality Monitoring

Water quality is sampled at each of the 11 monitoring stations (the eight main stations and the three supplementary stations around the lake). Parameters analyzed include nitrate-nitrogen (nitrate-N), ammonium-nitrogen (ammonium-N), and total Kjeldahl nitrogen (TKN). Nitrate-N is the parameter of most concern, although ammonium-N and TKN concentrations can give insight to the dynamics of nitrate as it is created and assimilated throughout the course of the watershed.

Sample Collection, Preservation, and Handling

All water samples are initially collected in a 1-liter glass jar held inside an aluminum frame basket (figure 45) that is lowered on a rope into the stream at the midpoint of the channel where the stream velocity is greatest. The glass jar is rinsed once with deionized water and once with the resident (stream) water before the samples are taken and brought back to the field vehicle for preparation. A water temperature reading is taken using a standard Fahrenheit thermometer, and the sample is transferred to a storage bottle and labeled (figure 46). The sample number, date and time of collection, and water temperature are recorded. Preservatives, if necessary, are added to the water sample, which is placed in a cooler kept at < 4°C and transported to the laboratory for analysis. Table 12 lists the container types, sample size, and preservation and storage practices used for each of the different types of analysis.

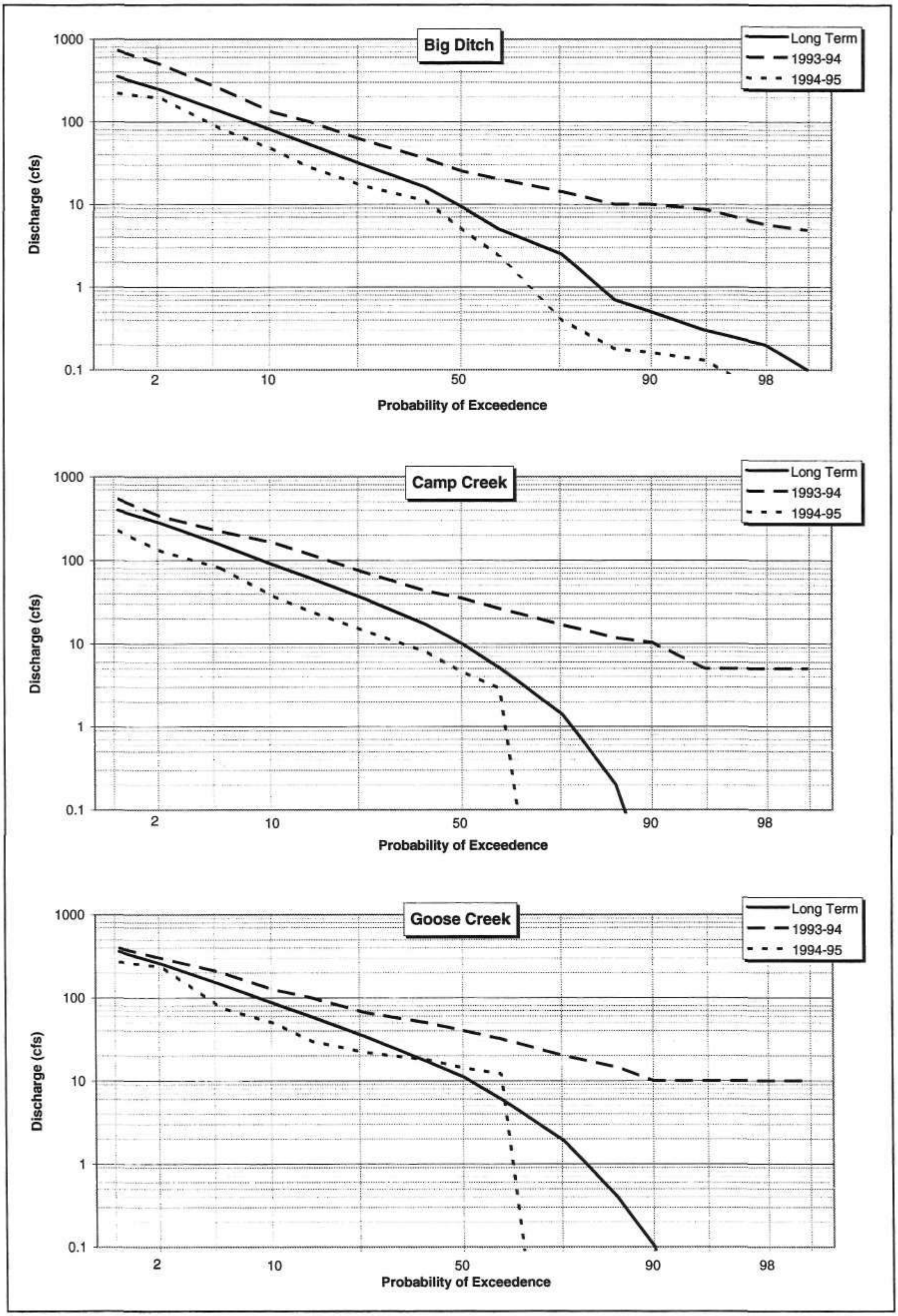


Figure 43. Flow frequencies during study period as compared to long-term conditions at tributary stations

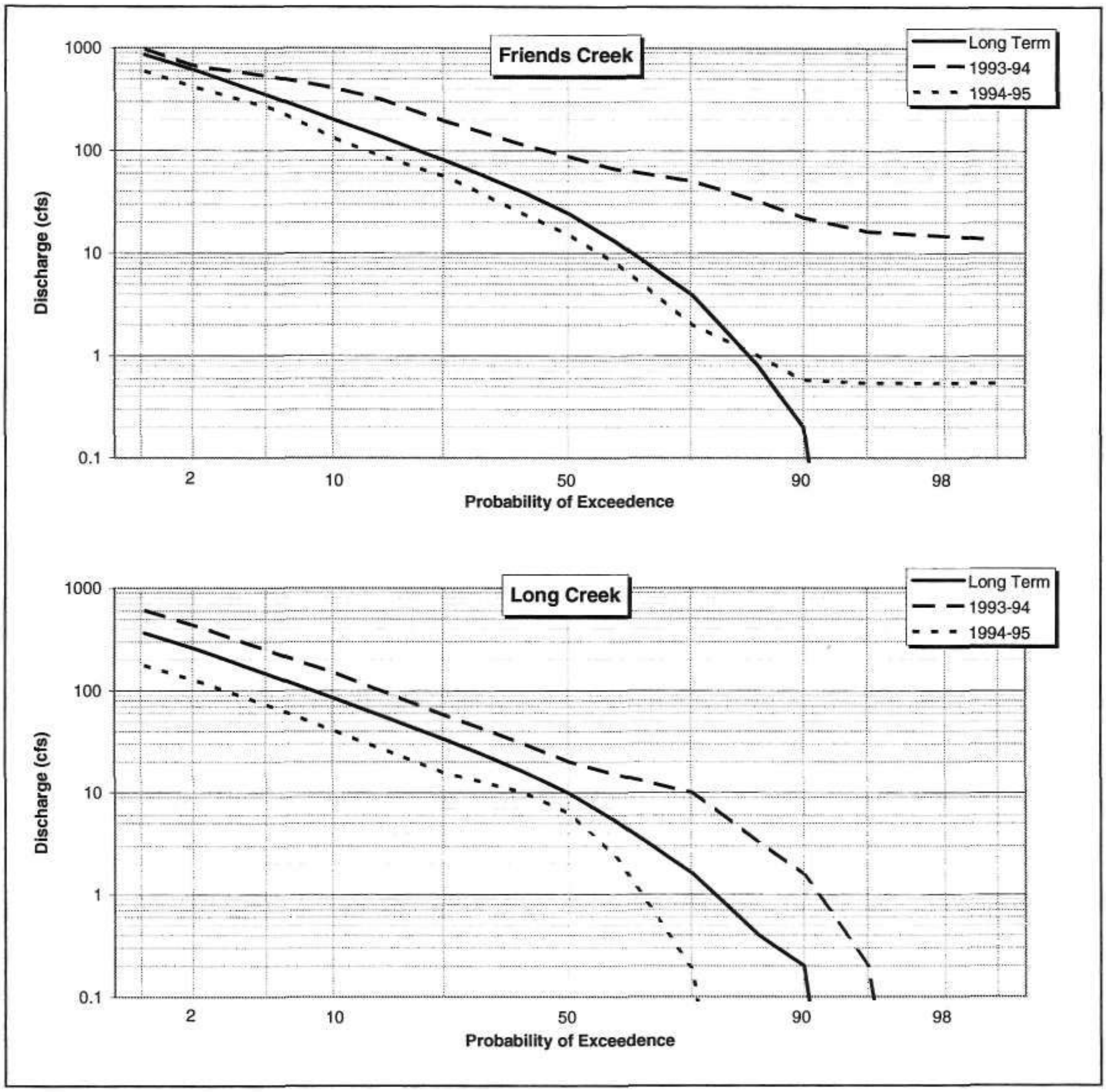


Figure 43. Concluded

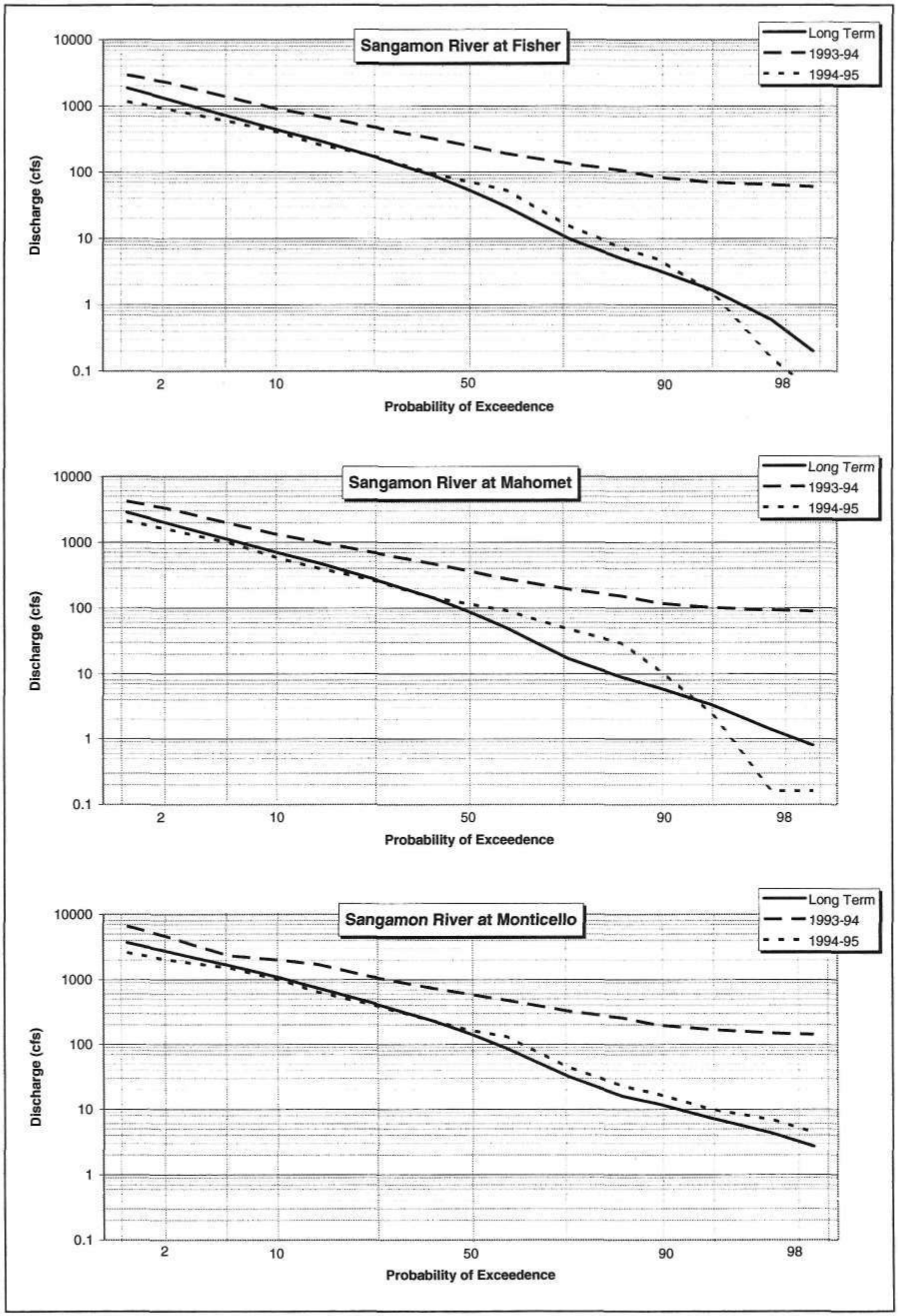


Figure 44. Flow frequencies during study period as compared to long-term conditions at river stations

Figure 45. Typical aluminum sampling basket for retrieving water samples

Figure 46. Transfer of retrieved sample to storage bottle for shipping to laboratory for analysis

Table 12. Sample Collection, Preservation, and Handling

Date	*Analyte*	*Container*	*Sample size*	*Preservation*	*Maximum holding time*
4/16/93 to 5/23/94	NO_3-N	Polyethylene bottle	60 ml	0.05% H_2SO_4/ 4°C (pH<2)	14 days
5/24/94 to present	NO_3-N	Polyethylene bottle	60 ml	4°C	2 days
4/16/93 to present	NH_4-N, TKN	Polyethylene bottle	500 ml	0.05%H_2SO_4/4°C (pH<2)	28 days

Water samples are collected at each station for nitrogen compound analysis on regular visits and during storm/runoff events. Analysis is done for nitrate-N on a weekly basis and all three nitrogen compounds on an biweekly basis. A 500-milliliter polyethylene bottle is used for storage of the nitrogen compounds sample, and a 60-ml polyethylene bottle is used for the nitrate-N only sample (see table 12). A preservative of 0.05 percent sulfuric acid was used to reduce the pH of the sample to less than 2. This stops any further biological processes that may alter the nitrate concentration of the sample.

Analytical Procedures

The ISWS laboratories at the Champaign facility are certified by the IEPA. Table 13 lists the procedures used by the laboratories during analysis of water samples. The table gives the analyte, the IEPA method number, and the methodology used.

Table 13. Methodology for Chemical Analysis of Water Samples

Analyte	*IEPA method number*	*Methodology*
Nitrate-Nitrogen	300.0	Ion chromatography
Ammonium-Nitrogen	350.1	Colorimetric
Total Kjeldahl Nitrogen	351.3	Titrimetric

When the Lake Decatur study began in April of 1993, the preservation of nitrate samples was done according to Section 8.2 of EPA Method 300.0 (August 1991 revision). This method called for the adjustment of nonchlorinated samples (as would be the case for surface water samples) to a pH of less than 2 using concentrated sulfuric acid. This procedure was also the protocol recommended in Title 35, Subtitle A, Chapter II, Part 183 of the State Rules and Regulations (1983). Therefore, nitrate samples for the Lake Decatur project were preserved accordingly. During the first year of the project, occasional dilutions of the preserved samples were run parallel with undiluted samples. A dilution is performed by taking a portion of a sample and mixing it with a measured volume of deionized water, which allows for back-calculations to find the true concentration (mg/1) of a sample. Calculated values from the diluted samples were found to be consistently higher than the corresponding values of the undiluted samples. In April 1994, nitrate samples were collected, both preserved and unpreserved, so that a comparison of results could be made between preserved undiluted, preserved diluted, and unpreserved samples. A study of the results of the analysis of the preserved samples showed undiluted values were an average of 13 percent lower than the diluted values. A conclusion was made that the preservative was having an interference effect with the analysis. Although dilution seemed to decrease the interference, it can be shown by comparing preserved diluted samples to unpreserved samples that it did not totally eliminate it. A comparison showed values from the preserved diluted samples to be an average of 8 percent lower than the values for the unpreserved samples.

During the first year of the study, the USEPA revised Method 300.0 (Revision 2.1, August 1993) calling for the preservation of nitrate samples by storing at 4°C and analysis within 48 hours. In May 1994 the Illinois Administration Code Title 35 Part 183 was also revised. In Subtitle A, Chapter n, Section 183.235, it is noted that chemically suppressed ion chromatography (USEPA Method 300.0) cannot be used with the sulfuric acid preservative. Because of the observed preservative interferences and the change in both the USEPA Method and the Illinois Administrative Code, the use of sulfuric acid as a preservative for the nitrate samples was discontinued (as of Sample #0684, May 23, 1994).

QA/QC Procedures

The collection of water samples for water quality analysis follows several quality assurance/quality control (QA/QC) procedures. Each glass sample jar used to collect samples is rinsed first with deionized water and then with the resident water before taking the actual sample at each station. This helps prevent any cross-contamination between stations. Each bottle used for storing samples is precleaned according to the IEPA specifications for each type of analysis.

Every week, one field blank and two field splits are taken of the nitrogen compound samples. Analysis of the field blanks can determine if contamination of the sample bottles has occurred, and field splits are a blind test to ensure lab consistency. One out of every ten nitrogen samples that the laboratory analyzes is also duplicated in a lab split. This gives the laboratory a way to test the precision of the analysis and to make changes and retest if results between two lab splits differ.

Because the ISWS laboratory is an EEPA-certified Environmental Laboratory (Certificate No. 100202), it therefore meets general QA/QC procedures described in Part 183, Joint Rules of the Illinois Environmental Protection Agency and the Illinois Department of Public Health: Certification and Operation of Environmental Laboratories. All samples are preserved and stored as specified by the IEPA for each type of analysis, and analysis of the samples is within the specified holding times listed in table 12. The ISWS laboratories use the IEPA methods listed in table 13 for each type of analysis.

Nitrogen Concentrations

The nitrogen compounds sampled for this study were nitrate-N, ammonium-N, and TKN. Nitrogen samples were collected from the eight major stations located around the watershed, three additional sites located in urban areas of Decatur that drain directly into Lake Decatur, and several locations in the Friends Creek and Big Ditch tributaries. The three urban sites were monitored for water level and nitrogen on a weekly basis and were chosen to obtain representative samples of the types of nitrate-N concentrations coming from residential neighborhoods, golf courses, and industrial areas. These sites will be referred to in this report as Residential (station 201), Golf Course (station 202),and Industrial (station 203). Sampling sites in the Friends Creek and Big Ditch sub-watersheds were positioned at several locations upstream of the main streamgaging stations (102 and 106). Several sites sampled tile drainage water in the Friends Creek tributary.

Nitrate. Nitrate-N concentration data for the two-year study period and for all of the monitoring stations are presented in figures 47-53. To clearly present the data and facilitate their discussion, the data were grouped into six categories as follows: tributary streams (figure 47), Sangamon River stations (figure 48), urban stations (figure 49), Friends Creek sites (figure 51), Friends Creek tiles (figure 52), and Big Ditch sites (figure 53). Discussion of the results for each category follows.

Tributary Streams. Nitrate concentrations at the five tributary stream stations for the two-year period are presented in figure 47. The first-year concentrations are presented in figure 47a while the second year concentrations are presented in 47b. The first major observation is the significant difference between the two years of data collection. The first year was a wet year resulting in high nitrate concentrations throughout the year, even during the summer months. The second year was a dry year, with near zero concentrations during the summer months. The significance of this difference in nitrate input into Lake Decatur will be discussed later in the section on nitrate loads.

The other major observation is how the data points from the different tributaries are closely clustered and generally follow similar trends even when the concentrations are different. This indicates the general similarities in climate, hydrology, and land use for most of the sub-watersheds in the region.

For the first year of data collection (figure 47a), the nitrate concentrations were generally above 4 mg/1 except for Long Creek in August, two data points for Big Ditch in February and April, and one point for Camp Creek in September. The highest concentrations were in May and June 1993 when concentrations above 14 mg/1 were measured. The highest concentration for the first year, 15.3 mg/1, was measured in Big Ditch on May 7, 1993. The lowest concentration, 0.94 mg/1, was measured in Long/Big Creek on September 1, 1993. For a period of almost nine months from August to April, nitrate concentrations at all the stations were generally between 4 to 10 mg/1. The concentrations stayed elevated even during the summer months when they were expected to have dropped significantly.

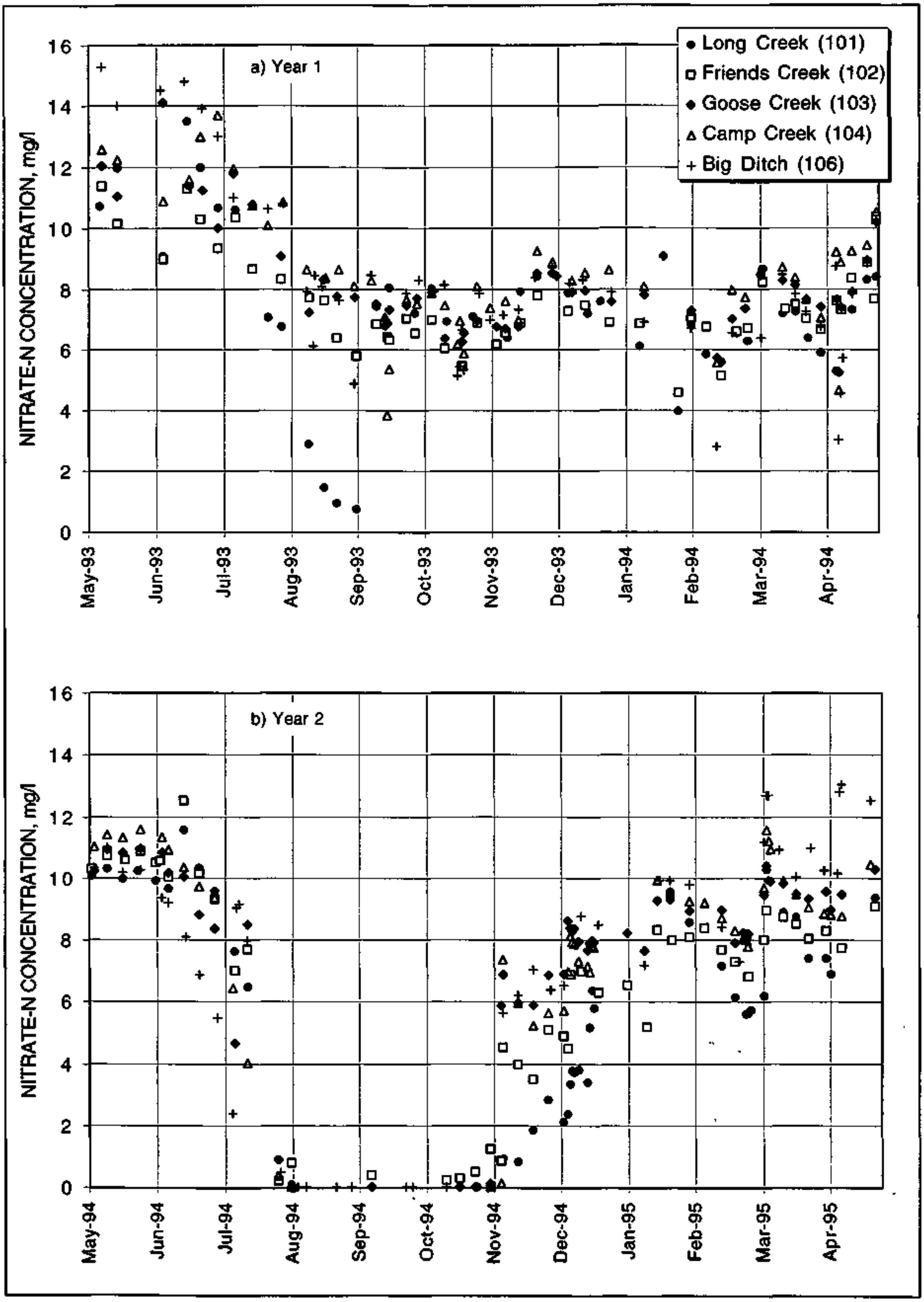


Figure 47. Nitrate - N concentrations for tributary stations

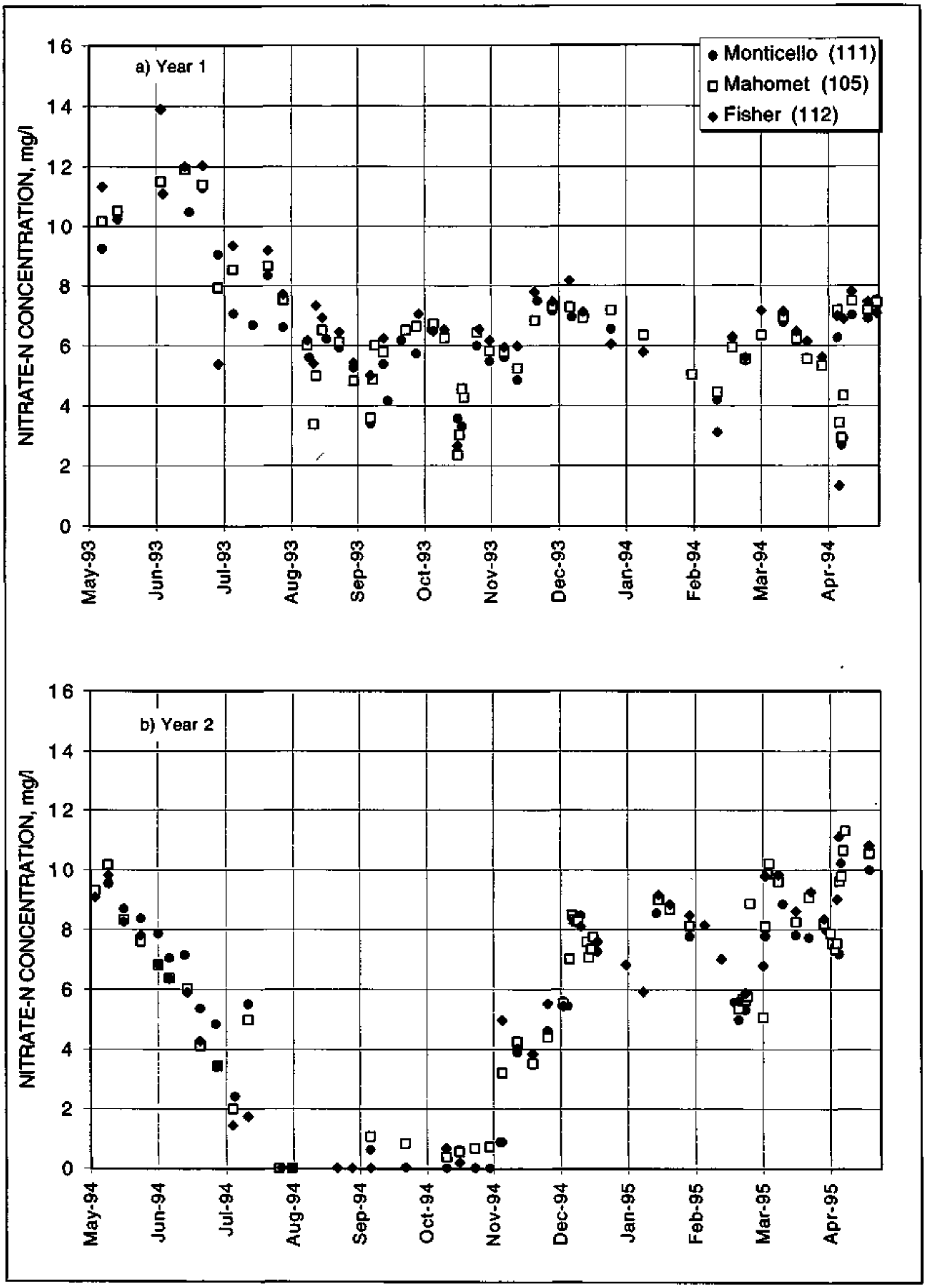


Figure 48. Nitrate - N concentrations for Sangamon River stations

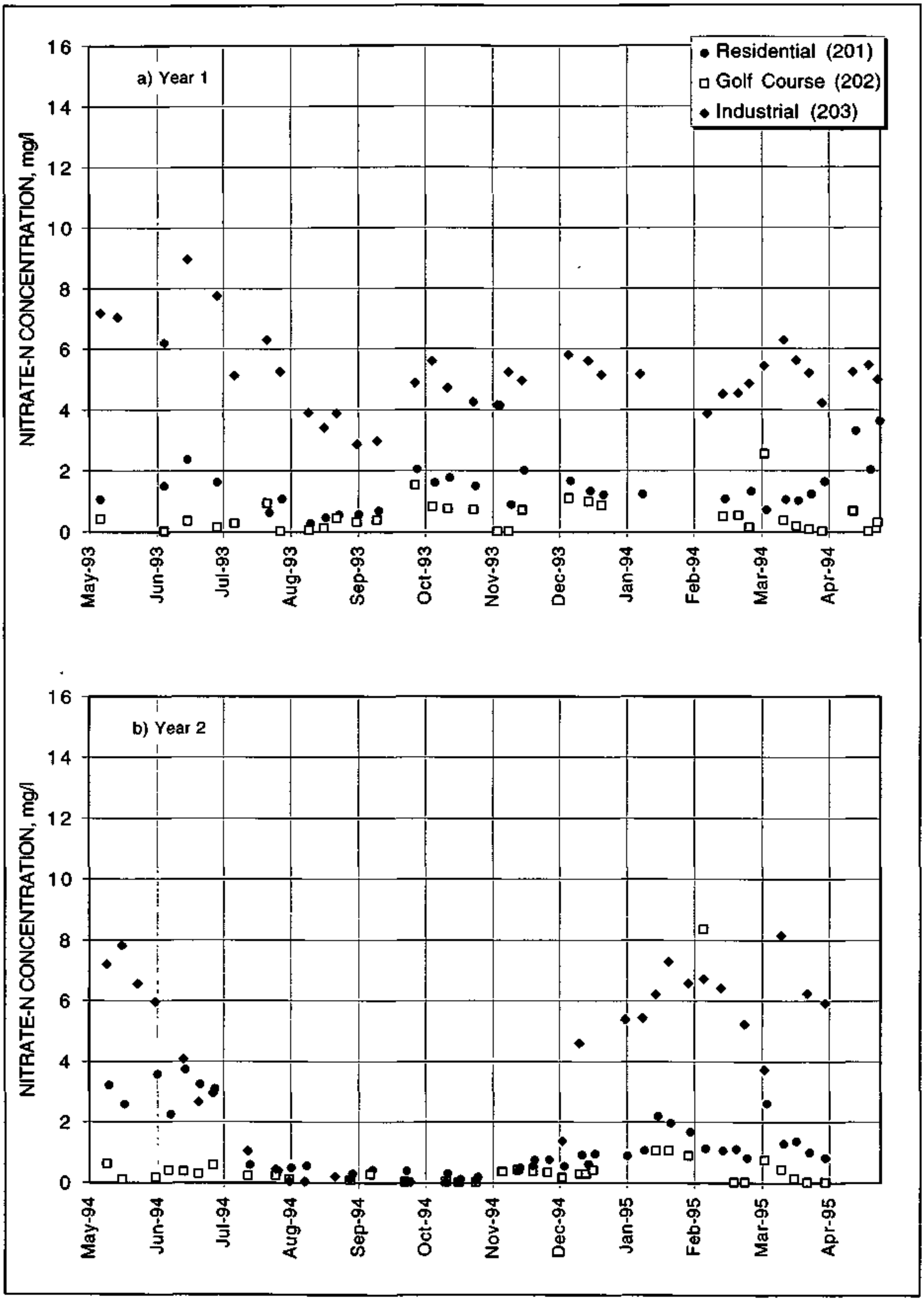


Figure 49. Nitrate - N concentrations for urban stations

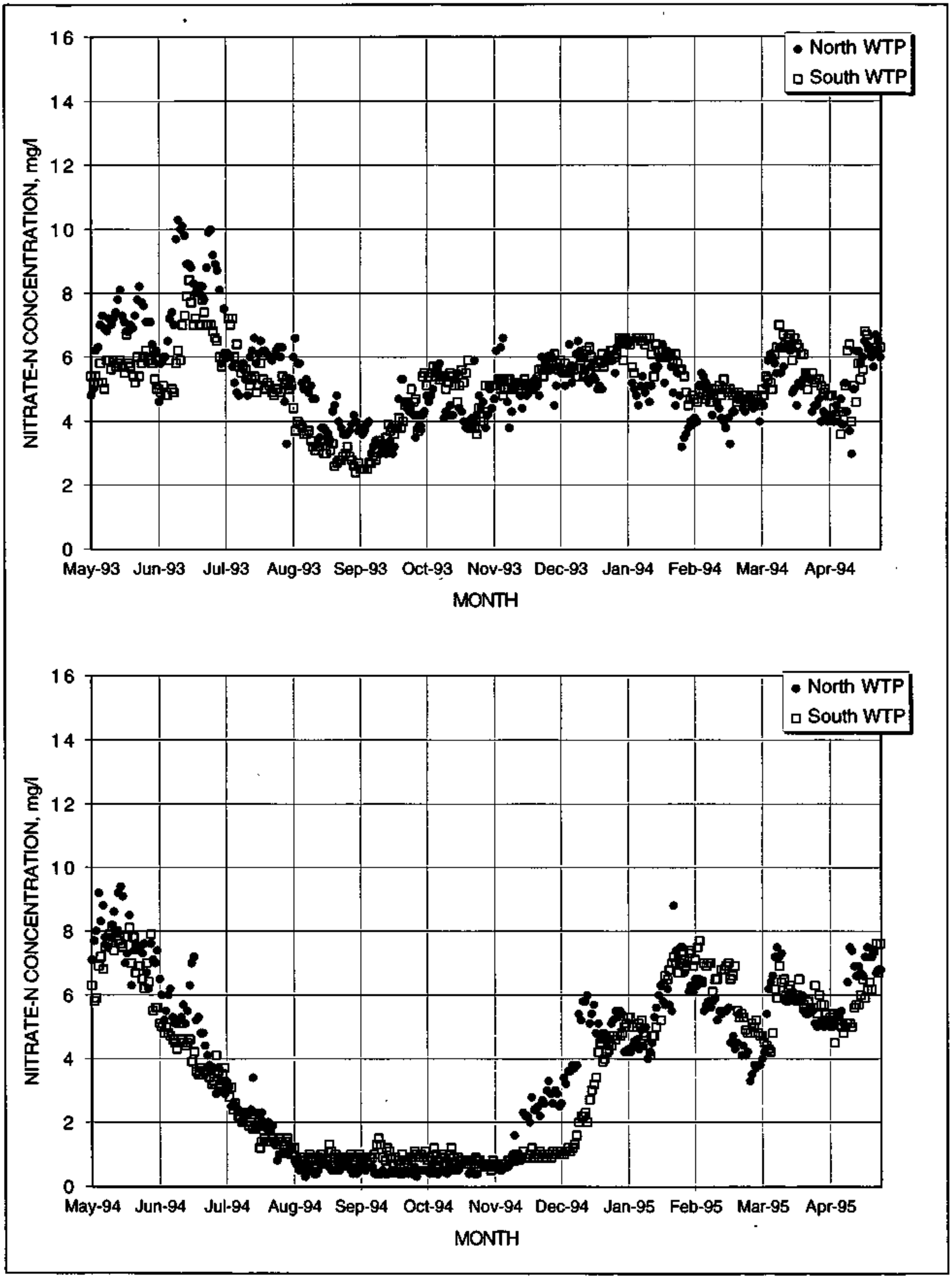


Figure 50. Nitrate-N concentration readings from north and south water treatment plant (WTP) lake intakes

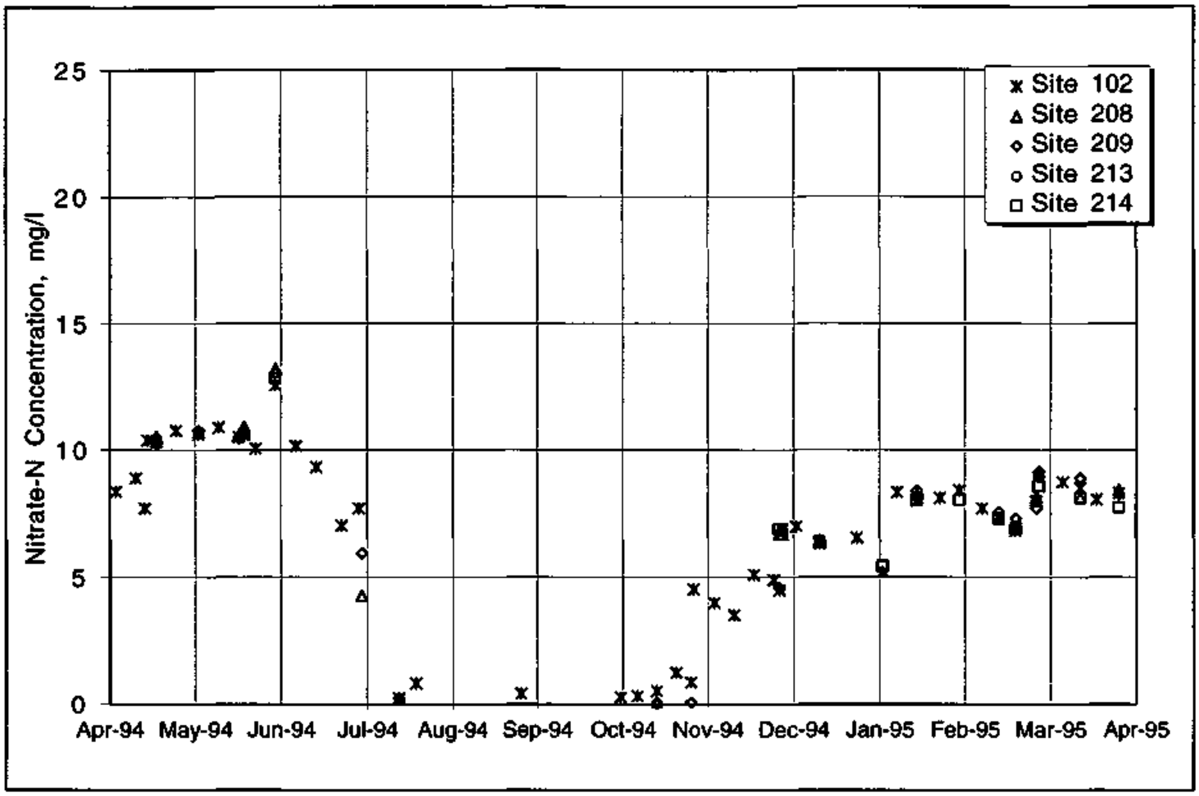


Figure 51. Nitrate-N concentrations at Friends Creek sites

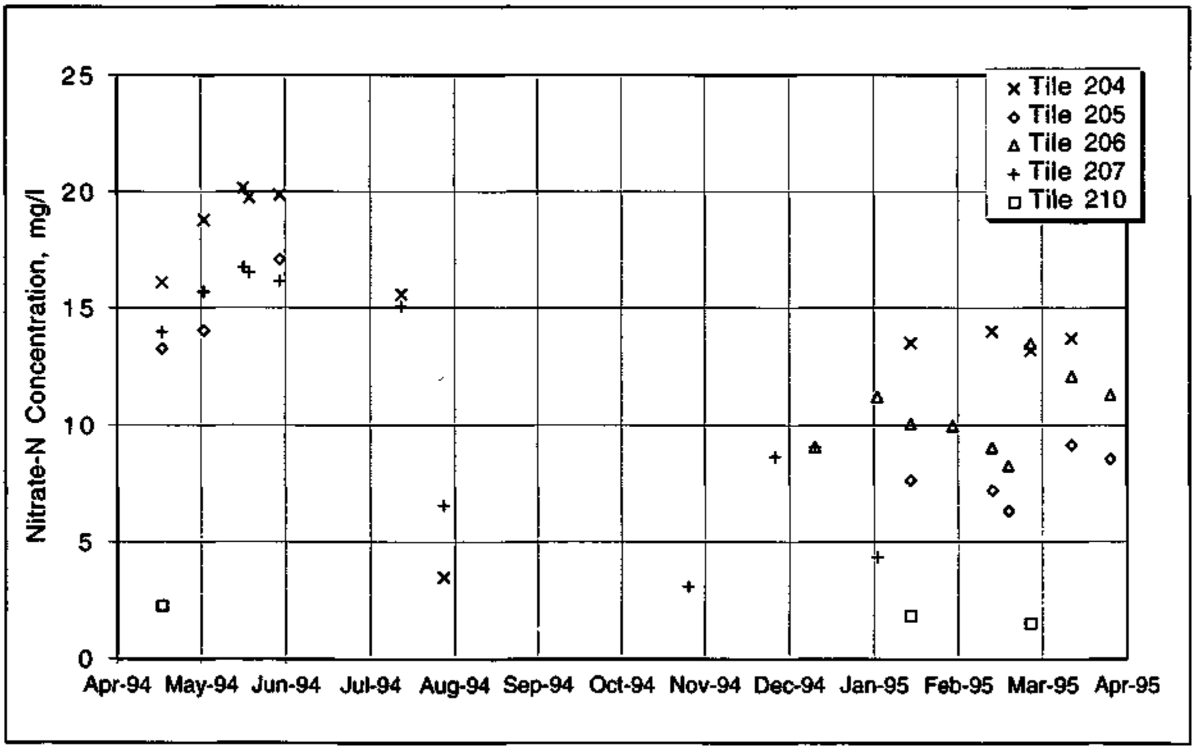


Figure 52. Nitrate-N concentrations at Friends Creek tiles

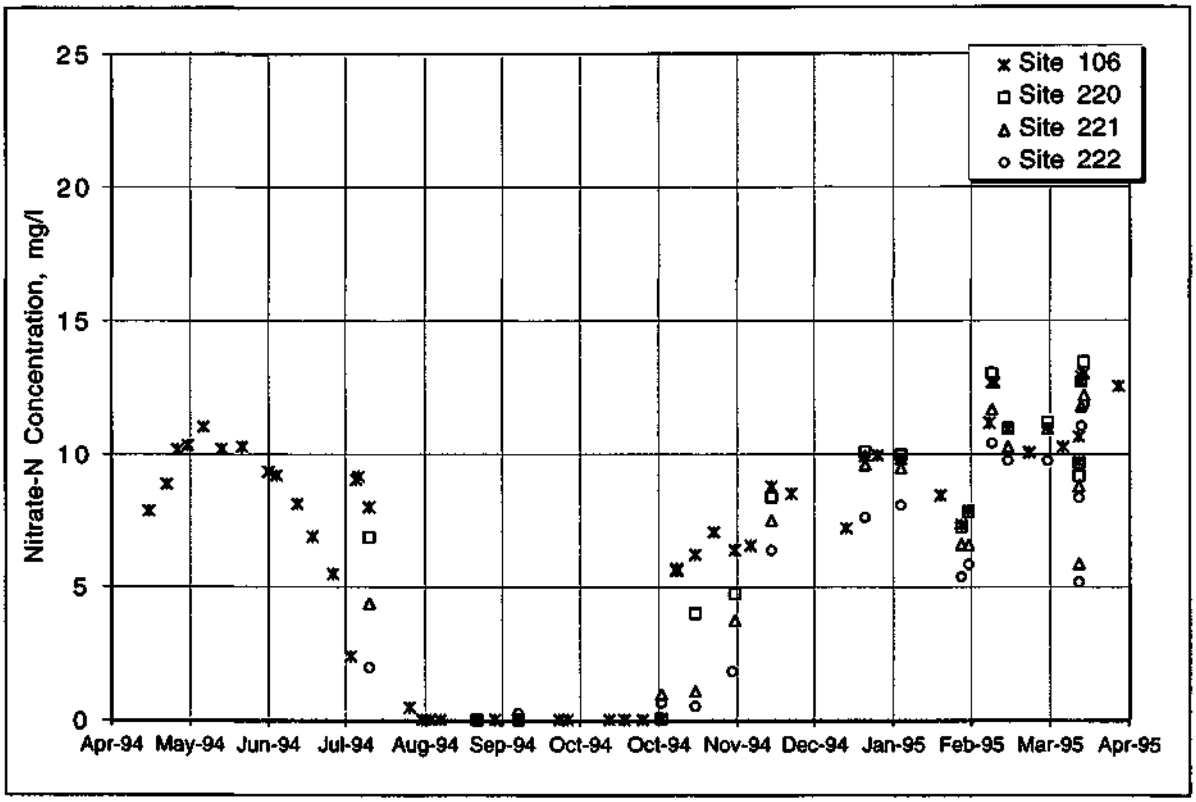


Figure 53. Nitrate-N concentrations at Big Ditch sites

During the two months of high nitrate concentrations in May and June, the highest concentrations were measured at the Big Ditch station, while the lowest concentrations were measured at the Friends Creek station. For the rest of the year there was no consistent pattern except that Camp Creek tended to stay on the high side, while Long/Big Creek and Friends Creek tended to stay on the lower side. During the month of August, nitrate concentrations at the Long/Big Creek station were consistently lower than at the other stations. This could be explained by the extreme low flow, only 0.04 inches runoff for the month (figure 40) in Long/Big Creek.

As previously mentioned, the pattern of nitrate concentrations monitored in the second year (figure 47b) was different than that of the first year. For three-and-a-half months, from mid-July to the end of October, nitrate concentrations were near zero at all of the monitoring stations. The low concentrations combined with the extreme low flows during the same period resulted in insignificant nitrate inflow into Lake Decatur. Nitrate concentrations were generally lower in the second year than the first year except during March and April when second-year concentrations were higher. The maximum concentration measured in the second year, 13.04 mg/1, was at the Big Ditch station on April 12, 1995. This is lower than the 15.3 mg/1 measured during the first year at the same station. The period of relatively high nitrate concentration for the second year was longer from March to June, as compared to the months of May and June for the first year.

The highest concentrations in the second year were measured in March and April as opposed to May and June for the first year. The highest concentrations were again measured at the Big Ditch station. Except for the months of May and June, the Big Ditch station tends to show higher concentrations and Long/Big Creek tends to show lower concentrations.

Sangamon River Stations. Nitrate concentrations at the three Sangamon River stations for the two-year monitoring period are presented in figure 48. The first-year data are presented in figure 48a, and the second year data are presented in figure 48b. The first observation that can be made is the significant difference between the first- and second-year data similar to the conditions observed in the tributary streams. During the first-year data collection, nitrate concentrations never fell below 2 mg/1 except once at Fisher in April 1994. During the second year, nitrate concentrations were zero or near zero for three-and-a-half months from mid-July to the end of October.

During the first year, nitrate concentrations were high at all three stations for the months of May and June, started to drop in July, and essentially stayed between 2 and 8 mg/1 for the rest of the year. The highest concentration, 13.9 mg/1, was measured at Fisher on June 3, 1993. The lowest concentration, 1.33 mg/1, was also measured at Fisher on April 12, 1994. The 10 mg/1 level was exceeded only in May and June. In general, the nitrate concentrations at Fisher, the upstream station, were higher than at Mahomet or Monticello and lower at Monticello than at Mahomet or Fisher. This is not, however, always the case as indicated with the lowest concentration at Fisher in April.

Data for the second year (figure 48b) differ from data for the first year in several respects. The low concentrations in the summer during the second year have already been pointed out. Another major difference was the higher nitrate concentrations during the second year as compared to the first year for the period from December 1994 to April 1995. Nitrate concentrations were consistently higher in the Sangamon River during the second year from December 1994 through April 1995. During this period, concentrations were between 5 to 12 mg/1 in the second year as compared to 2 to 8 mg/1 for the first year. The highest concentration for the second year was 11.1 mg/1 at Fisher on April 11, 1995 as compared to 13.9 mg/1 in the first year. The highest concentrations were measured in April 1995 for the second year as opposed to June 1993 for the first year. High concentrations were higher during the first year, while low concentrations were lower in the second year. In terms of comparing concentrations at the three stations for the second year, it is difficult to determine where the concentrations were consistently higher or lower because the pattern and the concentrations for all three stations are very similar.

Urban Sites. The results of the data collected at the urban sites (Residential, Golf Course, and Industrial) are presented in figure 49. Residential (station 201) and Golf Course (station 202) had nitrate-N concentrations that typically stayed near or below 2 mg/1 during the first year and below 4 mg/1 during the second year. The major exception is a concentration of 8.4 mg/1 at Golf Course on February 8, 1995. Industrial (station 203) levels varied between near 0 to

9 mg/1, with the spring/early summer months in both years and the winter months in year 2 showing the same elevated concentrations as the rest of the watershed. It should be noted that the Industrial (station 203) samples collected reflect local drainage from an industrial area as well as the return of cooling water from an industrial plant, which was originally pumped from Lake Decatur. If there is no additional contribution of nitrogen compounds from the local drainage, then it would be reasonable to expect the concentrations from the cooling water to at least match the prevailing lake nitrate levels. When compared with figure 50, it can be seen that Industrial (station 203) does indeed match or fall below the prevailing nitrate-N levels in the lake. Therefore, no additional nitrates are coming from this industrial site.

Friends Creek Sites. Based on the first year of nitrate-N sampling in the Lake Decatur watershed and slope profiles, the Friends Creek and Big Ditch tributary watersheds were selected for more detailed sampling. The Friends Creek watershed is the largest of all the tributary watersheds being monitored in this study. Therefore, five collection points were selected and positioned at sites that would best sample a large portion of the watershed. As can be seen in figure 51, the nitrate-N concentrations vary slightly between these sites. It should be noted that few samples were taken from mid-July to mid-October 1994 because of extreme low-flow conditions.

Friends Creek Tiles. A second aspect of the detailed sampling in Friends Creek was the sampling of agricultural tile drains. Tiles were selected based on different agricultural land uses in order to determine their relative nitrate-N concentrations. Five sites were selected and sampled on a biweekly basis when water was flowing. The criterion for tile selection was that it should drain a fairly small area (approximately a quarter of a section); when the drained area had more than one crop, at least one crop had to significantly dominated the area; and the tile had to be reasonably accessible for sampling (for time efficiency and safety reasons). Tile 204 had three activities in its drainage area; corn-mulch, soybean-mulch, and cattle pasture. Corn was the dominant crop, however, pasture land is the last area drained before the tile outlet. Tile 205 drained a terraced soybean-mulch area. Tiles 206 and 207 both drained corn. Tile 206 was in a no-till system using N-serve (denitrification inhibitor), while 207 was a chisel system with a small surface inlet for ponding. Tile 210 drains an area that had been previously farmed but has been in the Conservation Reserve Program (CRP) for the last eight years.

As can be seen in figure 52, there was a large range in nitrate-N concentrations measured at the tile outlets. The highest concentration was 20.15 mg/1 at tile 204, and the lowest was 1.5 mg/1 at the 210 tile. Tile 204, except for one sample, never dropped below 13 mg/1. Tiles 207 and 205 ranged from 3.09 to 16.75 and 6.32 to 17.1 mg/1 of nitrate-N, respectively. Tile 210 never rose above 2.25 mg/1. Figure 52 shows a seasonal pattern in the nitrate-N levels similar to the one encountered at the eight main stations of the watershed monitoring network.

Big Ditch Sites. Big Ditch had three additional sites selected for nitrate-N sampling and were located upstream of the streamgage (106). Station 222 is the farthest upstream, 220 is upstream of 106, with 221 in between. Figure 53 shows a pattern of nitrate-N concentrations increasing in the downstream direction. In only a few cases, concentrations at station 220 were slightly higher than at station 106. The highest nitrate-N concentration was 13.06 mg/1 at station 220 and the lowest concentration was 0.02 mg/1 at all stations. The minimum detection level (MDL) for nitrate-N is 0.02 mg/1.

Ammonium and TKN. The nitrogen compounds of ammonium-N and TKN were collected at all stations on a biweekly basis. Figures 54-56 show the ammonium-N concentration and figures 57-59 show the TKN results for the tributary, river, and urban stations, respectively. Ammonium-N concentrations stayed quite low for the majority of the study period. Higher concentrations occurred more often during the first year than the second year. The highest concentrations were 5.5, 2.3, and 0.5 mg/1 for the tributary, river, and urban stations, respectively. All stations had samples at the MDL of 0.02 mg/1. One serious deviation occurred during a mid-winter thaw in February 1994, during which Lake Decatur experienced some of the highest ammonium-N concentrations in recent years. The City of Decatur reported that turbidity levels were also seriously high that same month. A smaller peak occurred in April 1994 for all but the urban stations. Only Friends Creek experienced an ammonium-N peak in fall 1994. All stations experienced a small rise in March 1995.

TKN concentrations also stayed low but had more oscillations throughout the study period than ammonium-N. Major peaks occurred during the months of February, March, and April 1994 at the tributary stations and February and April 1994 at the river stations. Again a small peak occurred in March 1995 at all stations and only Friends Creek in October 1994. The highest TKN concentrations were at Big Creek and Mahomet (7.14 and 7.36 mg/1). All stations fell to the MDL of 0.33 mg/1.

Figures 60-62 show the maximum, average, and minimum concentrations of all three nitrogen compounds sampled at the eight main stations in the watershed during the study period. As illustrated by figure 60, out of all the tributary stations, Big Ditch and Goose Creek had the highest nitrate-N readings at 15.3 and 14.1 mg/1, respectively, while Friends Creek had the lowest maximum concentration of 11.4 mg/1. Big Ditch had the highest ammonium-N and TKN concentrations at 5.06 and 7.14 mg/1. Fisher had the maximum river station nitrate-N and ammonium-N concentrations at 13.9 and 2.3 mg/1, while Mahomet read 7.4 mg/1 for TKN. Figure 61 shows the average nitrogen concentrations for the study period. None of the stations stand out for the ammonium-N and TKN compounds. All eight stations average a nitrate-N concentration of 6.4 and 7.6 mg/1 for the first and second years, respectively. Average TKN values range from 0.6 to 1.4 mg/1, while ammonium-N never exceeds 0.4 mg/1. The minimum nitrogen concentrations encountered appear in figure 62. Ammonium-N was always at the minimum detection limit (MDL) of <0.02 mg/1. TKN concentrations were at or below 0.33 mg/1. Goose Creek and Camp Creek had the highest minimum concentrations of 5.2 and 3.8 mg/1 for the tributary stations, while Monticello and Mahomet read 2.7 and 2.4 mg/1, respectively. The lowest nitrate-N concentration was 0.02 mg/1 for all stations except Friends Creek.

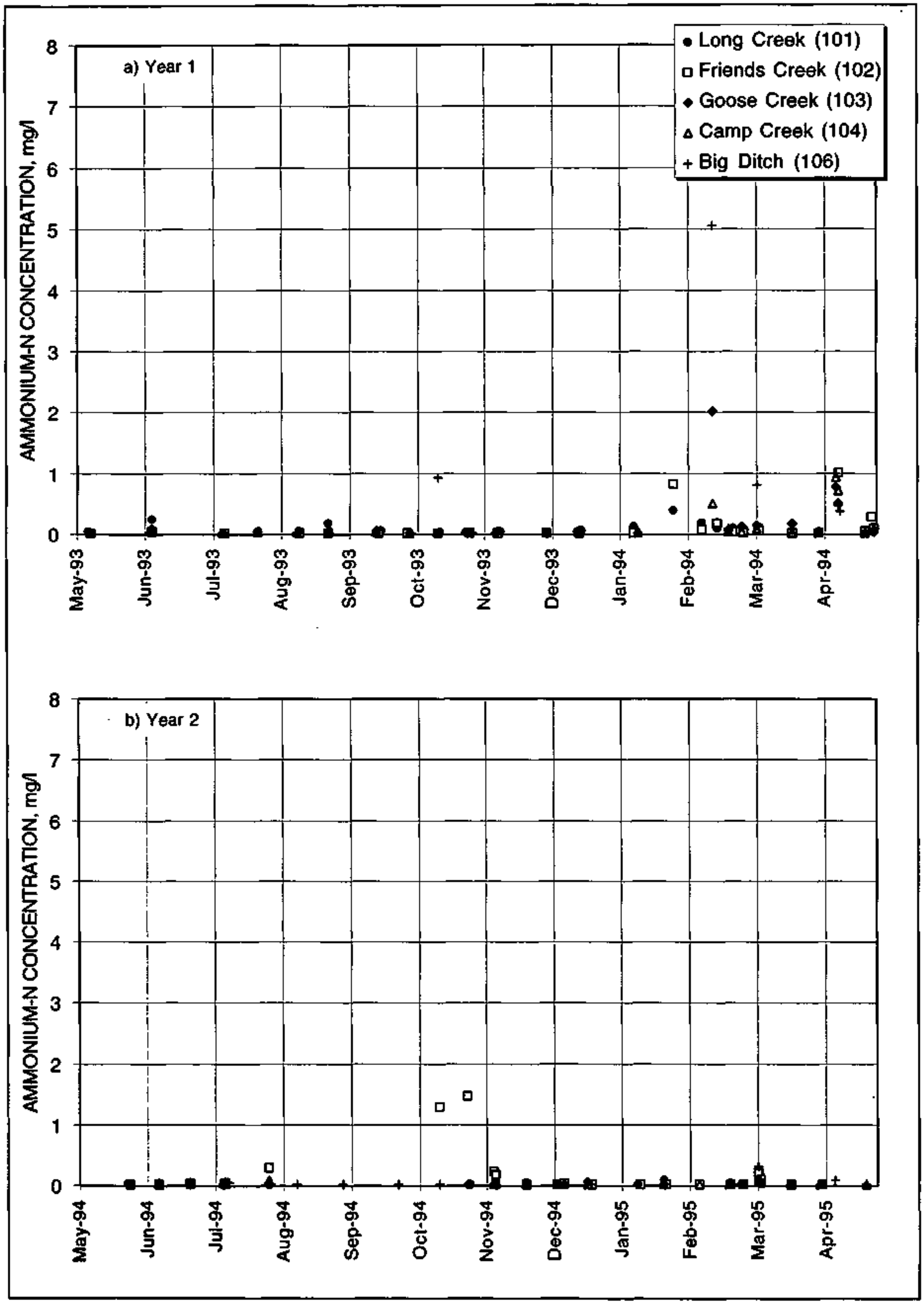


Figure 54. Ammonium-N concentrations for tributary stations

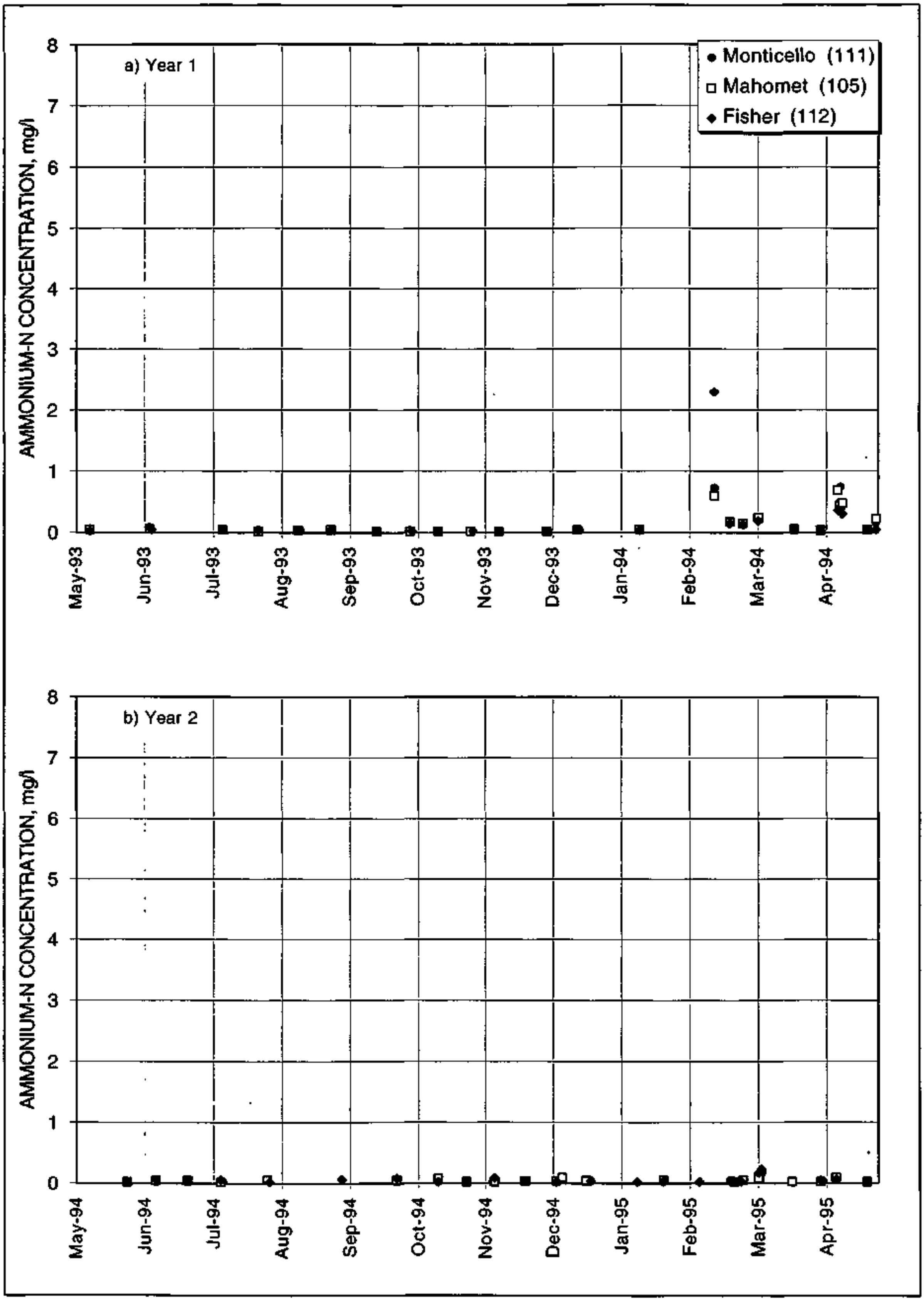


Figure 55. Ammonium-N concentrations for river stations

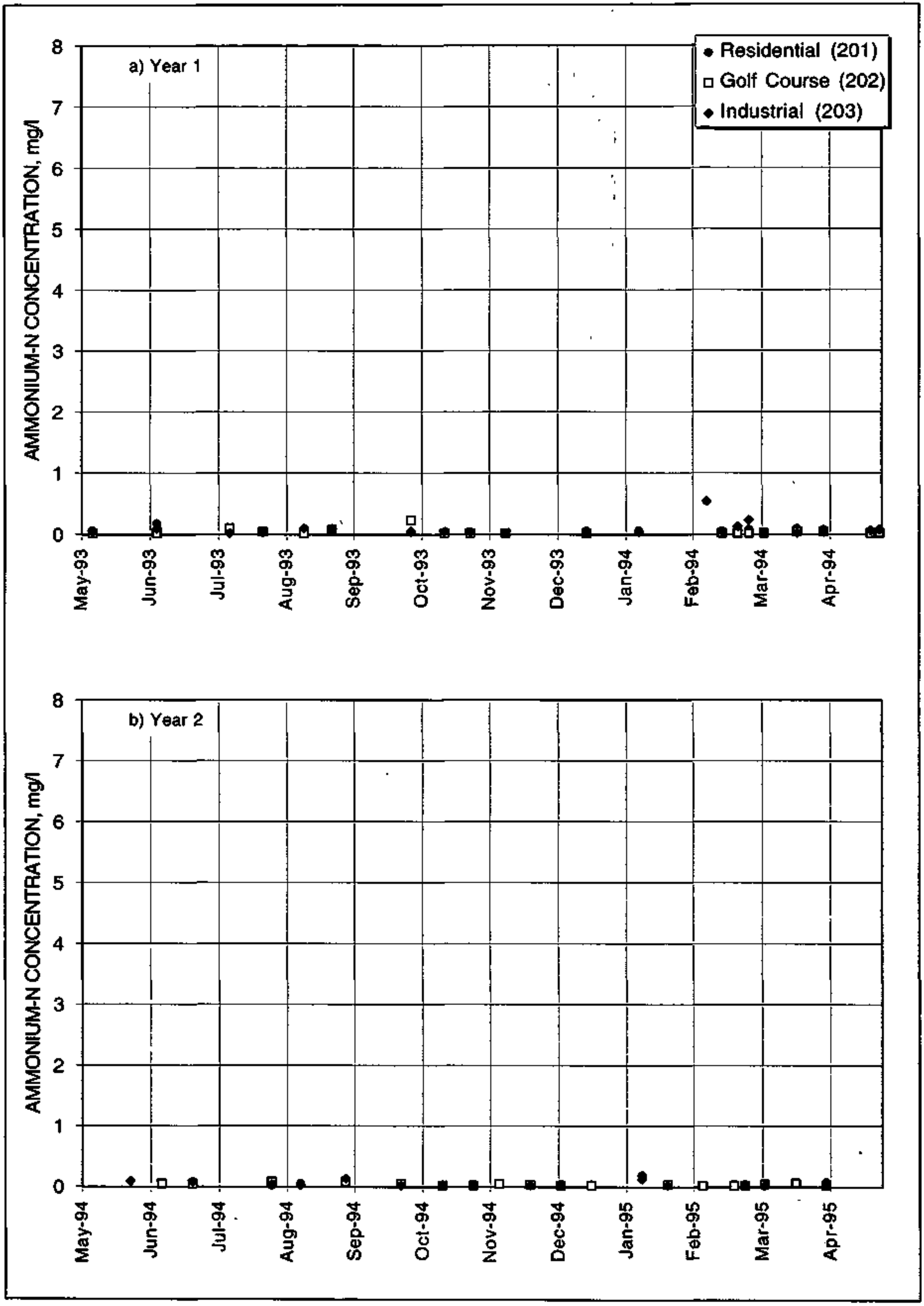


Figure 56. Ammonium-N concentrations for urban stations

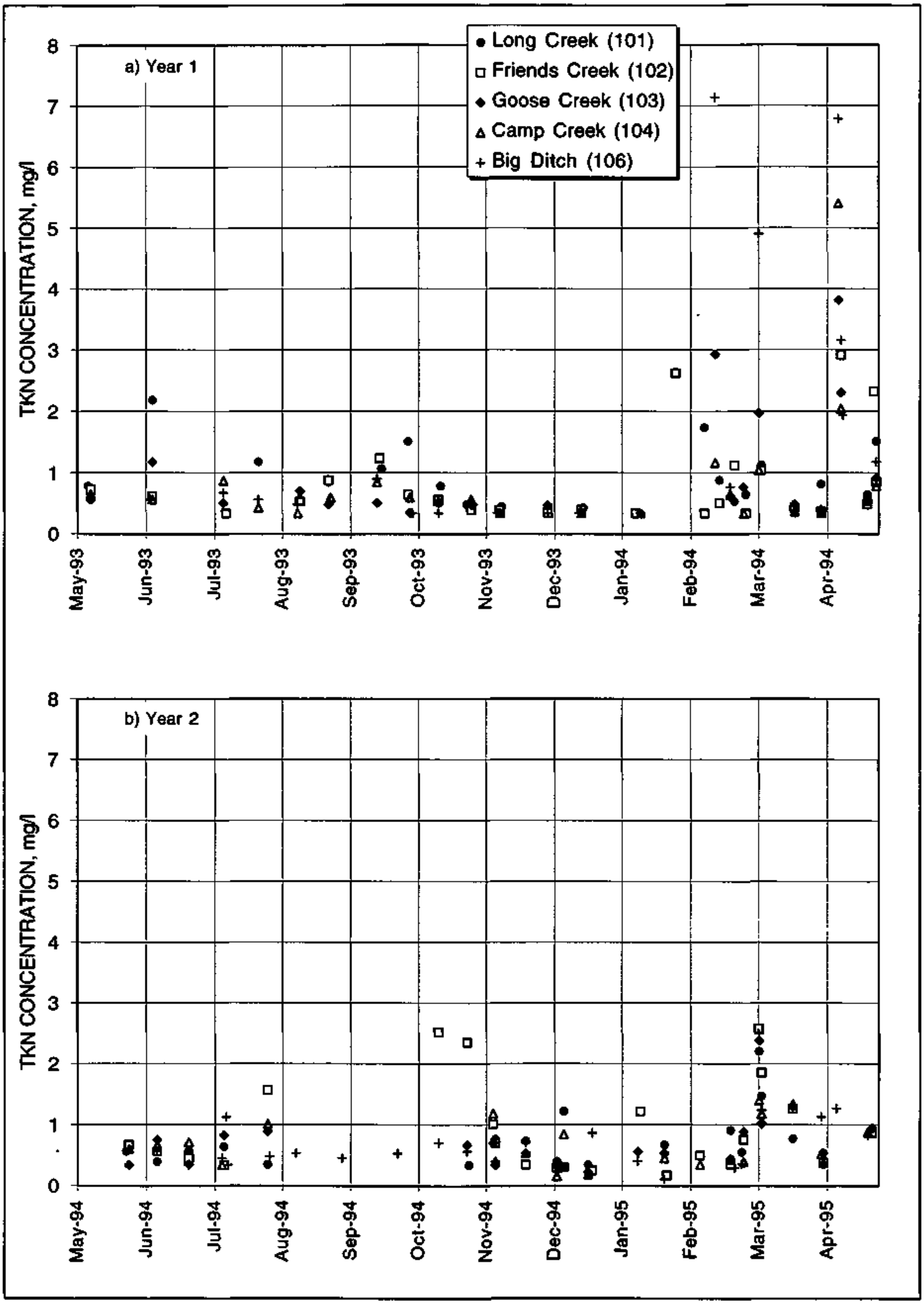


Figure 57. TKN concentrations for tributary stations

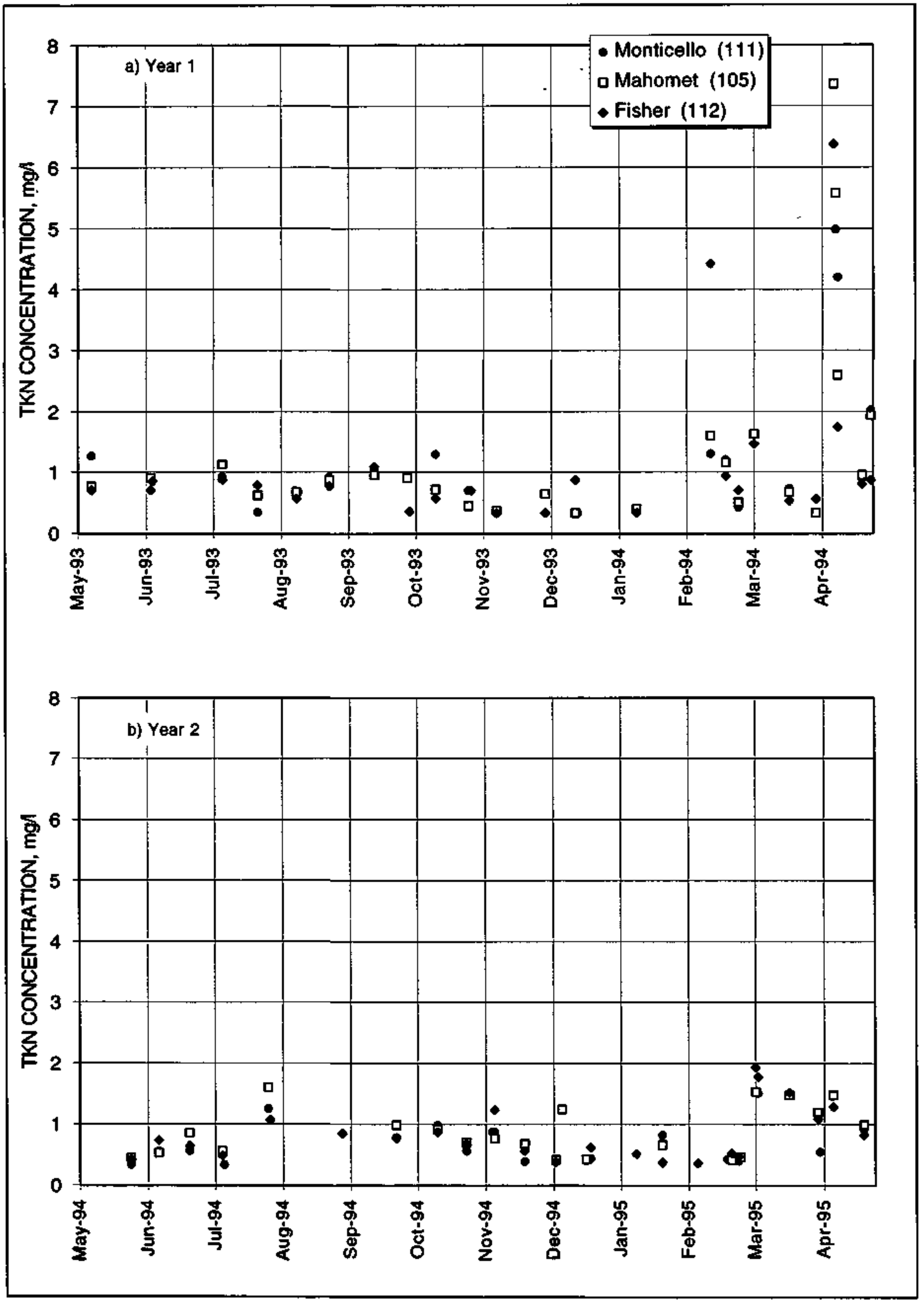


Figure 58. TKN concentrations for river stations

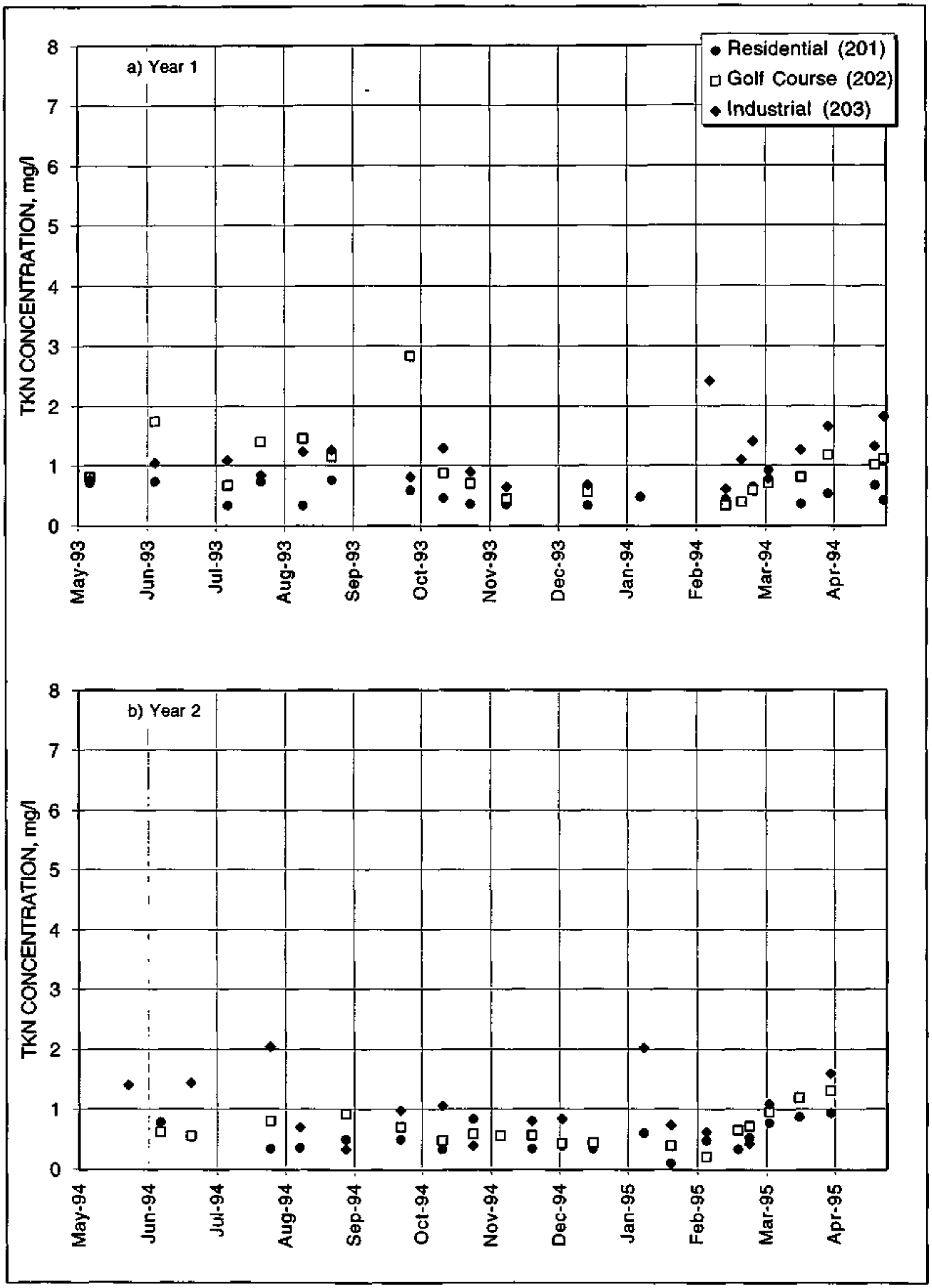


Figure 59. TKN concentrations for urban stations

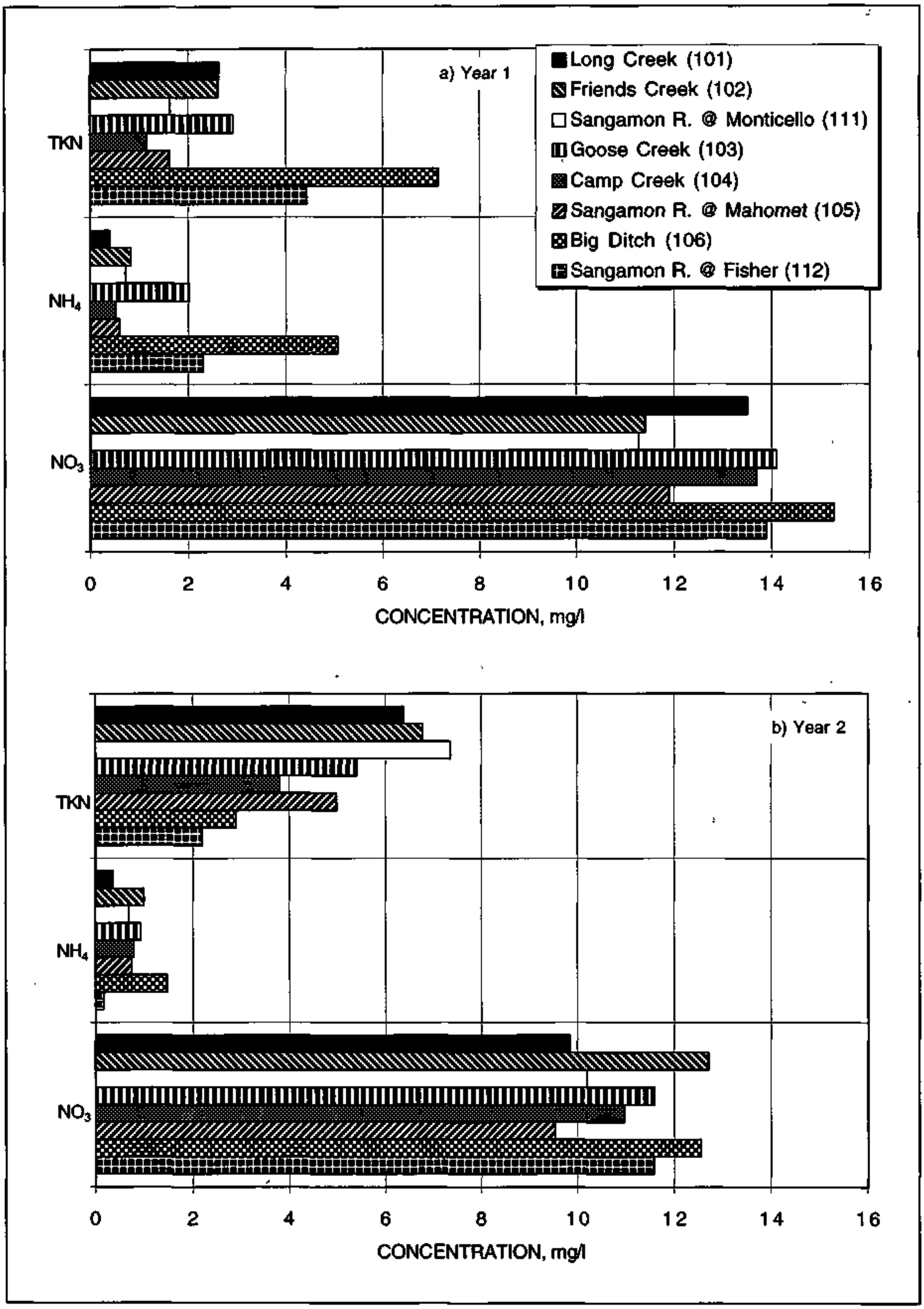


Figure 60. Maximum nitrogen concentrations during study period

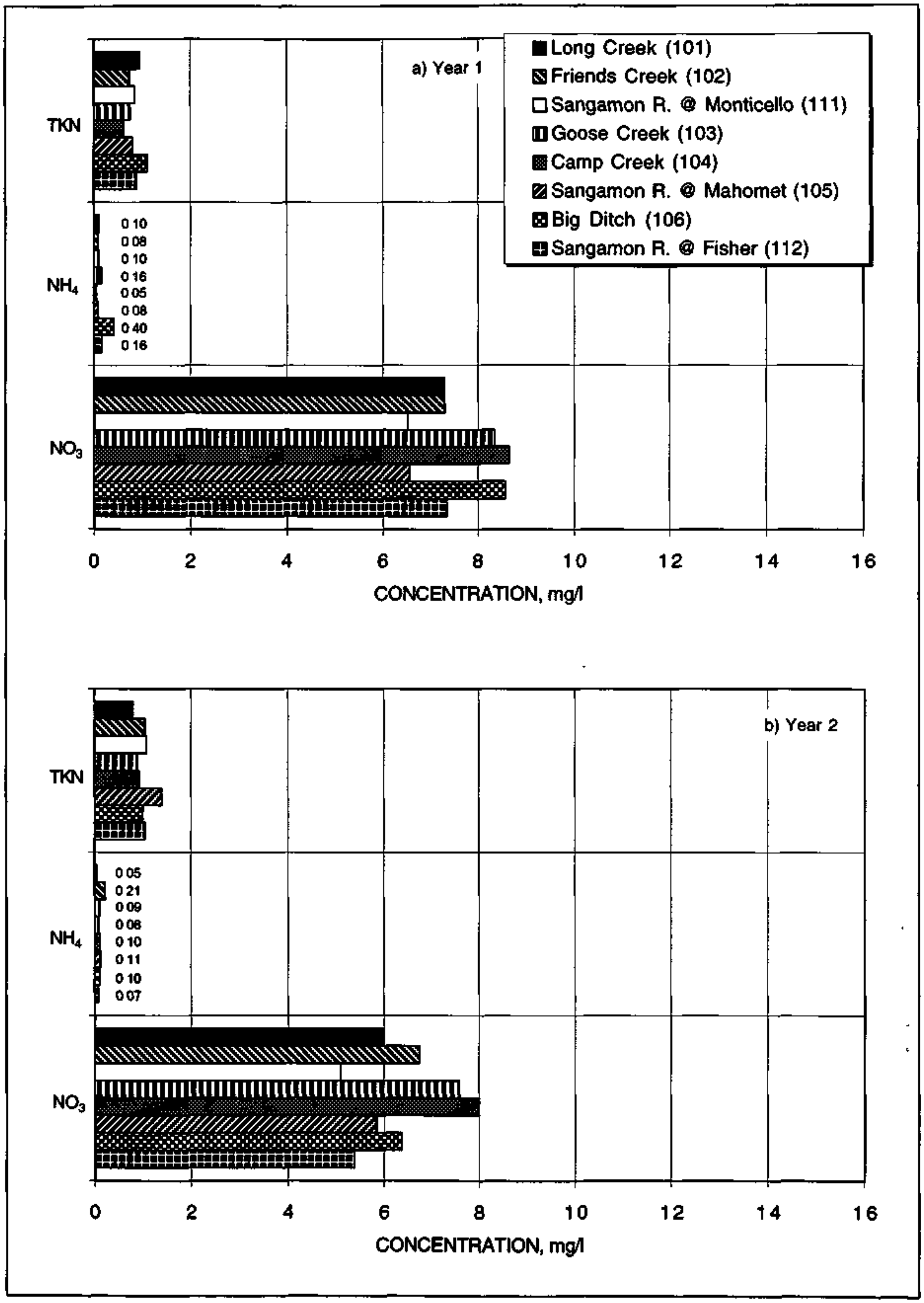


Figure 61. Average nitrogen concentrations during study period

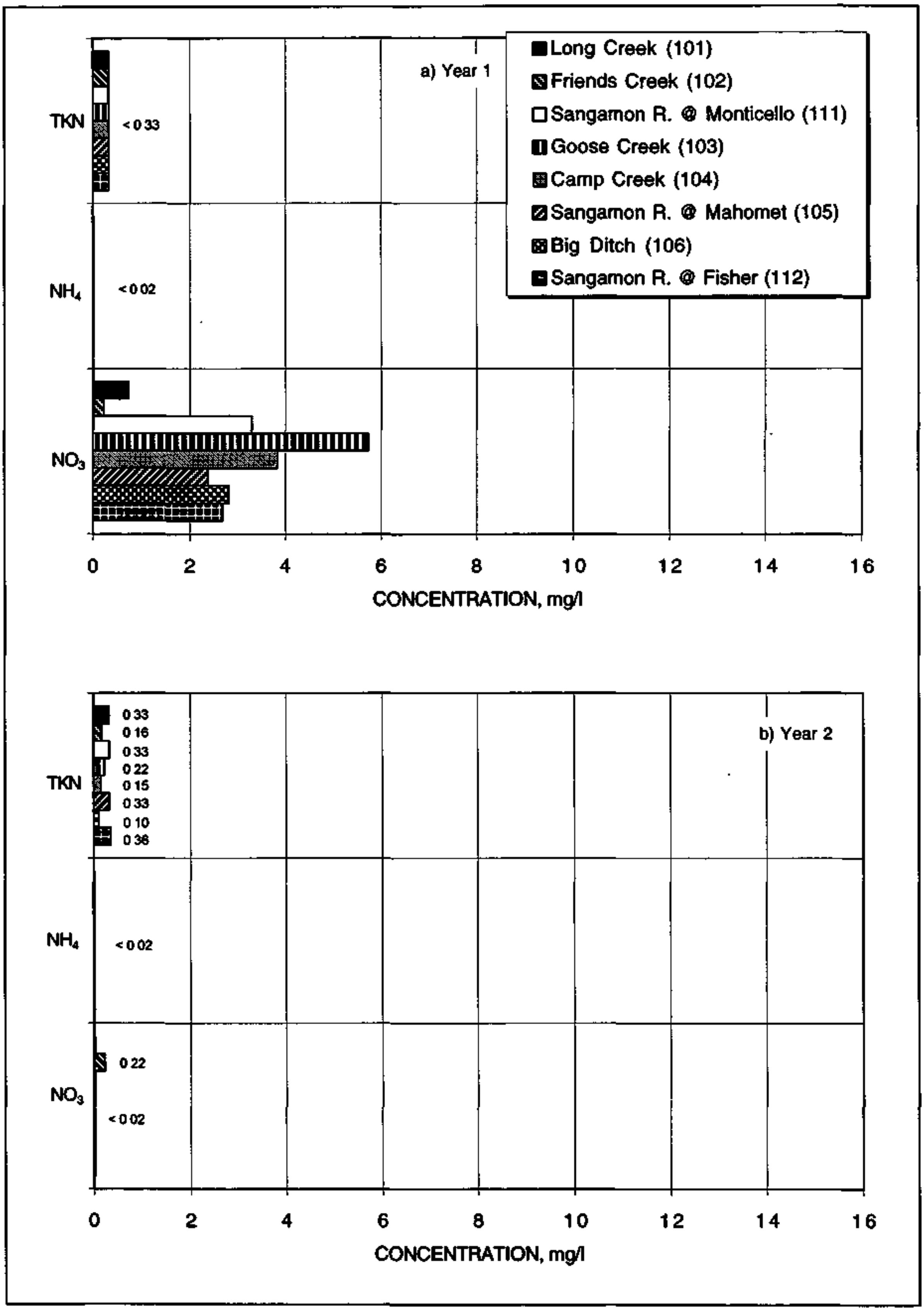


Figure 62. Minimum nitrogen concentrations during study period

Nitrate Loads

Even though the main water quality concern at Lake Decatur is nitrate concentrations, the critical issue for watershed management is nitrate loads. It is impossible to reduce the nitrate concentration without reducing the nitrate load into the lake. Management alternatives are more easily understood in terms of load reduction than reduction in concentration.

The calculation of nitrate loads, or yields, is necessary to determine the contribution of different areas to the total nitrate input into the lake. Nitrate concentrations are used for regulatory purposes but are not sufficient to determine the relative contribution of nitrates from different areas. The nitrate load combines the effect of concentration and discharge and thus provides a more accurate picture of the relative contribution of different areas. For example, a tributary may have some of the highest nitrate concentrations, but if it is also one of the smallest sub-watersheds, its total delivery of nitrates to the lake could be quite small as compared to other sub-watersheds and thus not a significant contributor. Calculations of monthly nitrate loads have been made for all eight main stations and are presented in figures 63 and 64.

Figure 63 shows the monthly nitrate-N load in pounds per acre (lb/acre) for the five tributary stations. Since the loads are calculated as a product of the monthly discharges and the average nitrate concentrations, the loads presented in figure 63 show the combined effect of the streamflows and concentrations. Therefore because of the higher streamflows during the first year, the monthly loads for the first year are significantly higher than for the second year. The overall average monthly nitrate load for all the stations was 3.1 lb/acre for the first year as compared to 1.16 lb/acre for the second year. The main factor for the extremely low loads in the second year was the near zero monthly loads for nearly five months (July to November) as a result of either no flow or near zero nitrate concentrations during the period.

The highest load for each of the tributaries was in April 1994 when extremely high flows combined with moderately high concentrations resulted in loads ranging from 6.5 lb/acre for Goose Creek to 12.0 lb/acre for Big Ditch. Big Ditch had another high load of 11.3 lb/acre in July of 1993 as a result of high flows and concentrations.

The monthly nitrate loads for the three Sangamon. River stations are presented in figure 64. Similar to the tributary streams, the loads were significantly higher during the first year than the second year. The average monthly load for the three stations was 3.1 lb/acre for the first year as compared to 1.2 lb/acre for the second year. This is because of the near zero loads for nearly six months during the second year. The highest monthly load at Fisher (7.2 lb/acre) and Mahomet (7.0 lb/acre) occurred in July 1993. At the Monticello station, the highest monthly load (5.8 lb/acre) occurred in April 1994.

During the first year, the monthly loads were the highest at the Fisher station most of the time. The lowest monthly loads were either at the Monticello station or at the Mahomet station. During the second year, the loads were much smaller with only four months showing any significant load greater than 2 lb/acre.

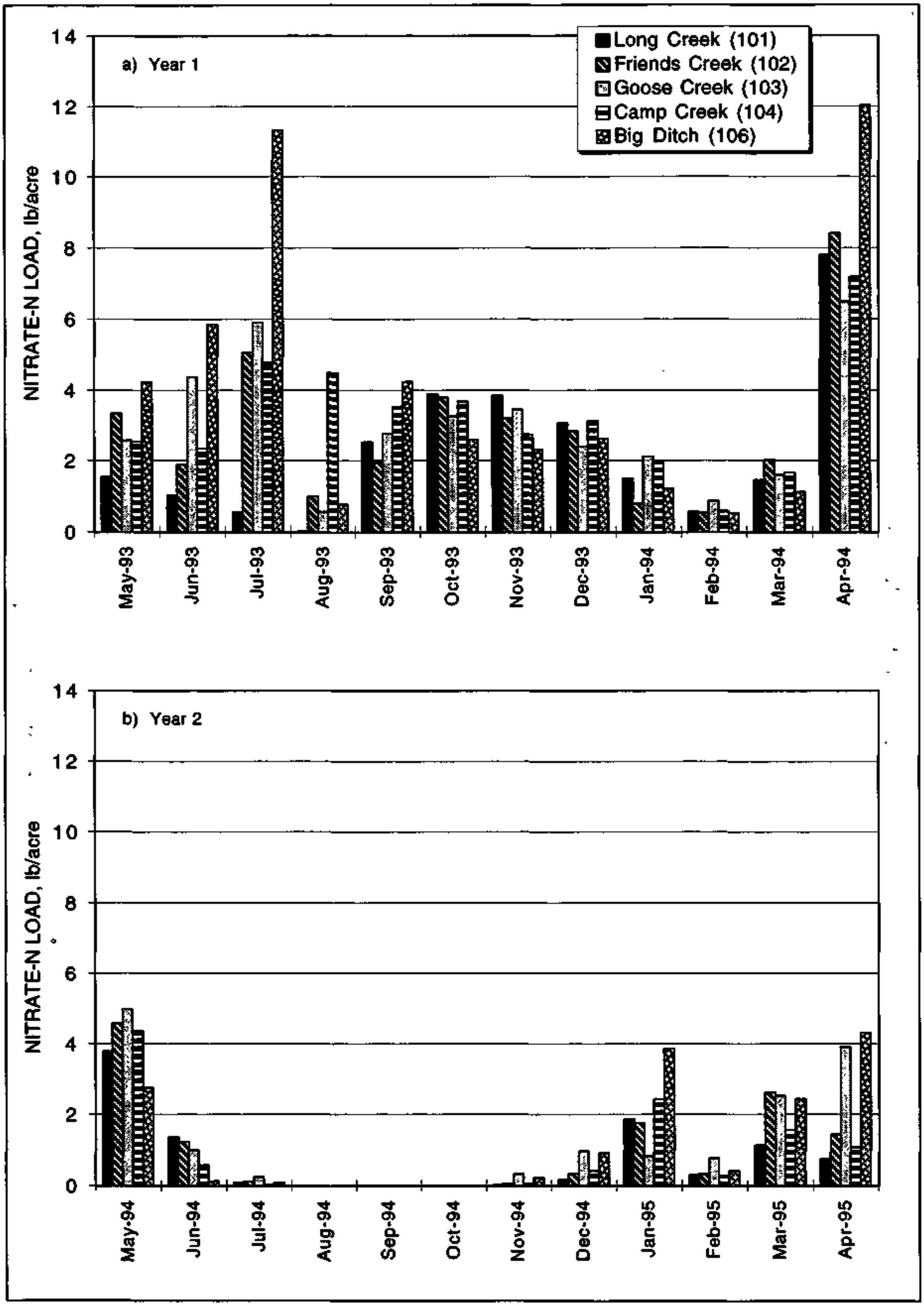


Figure 63. Monthly nitrate-N loads for tributary stations

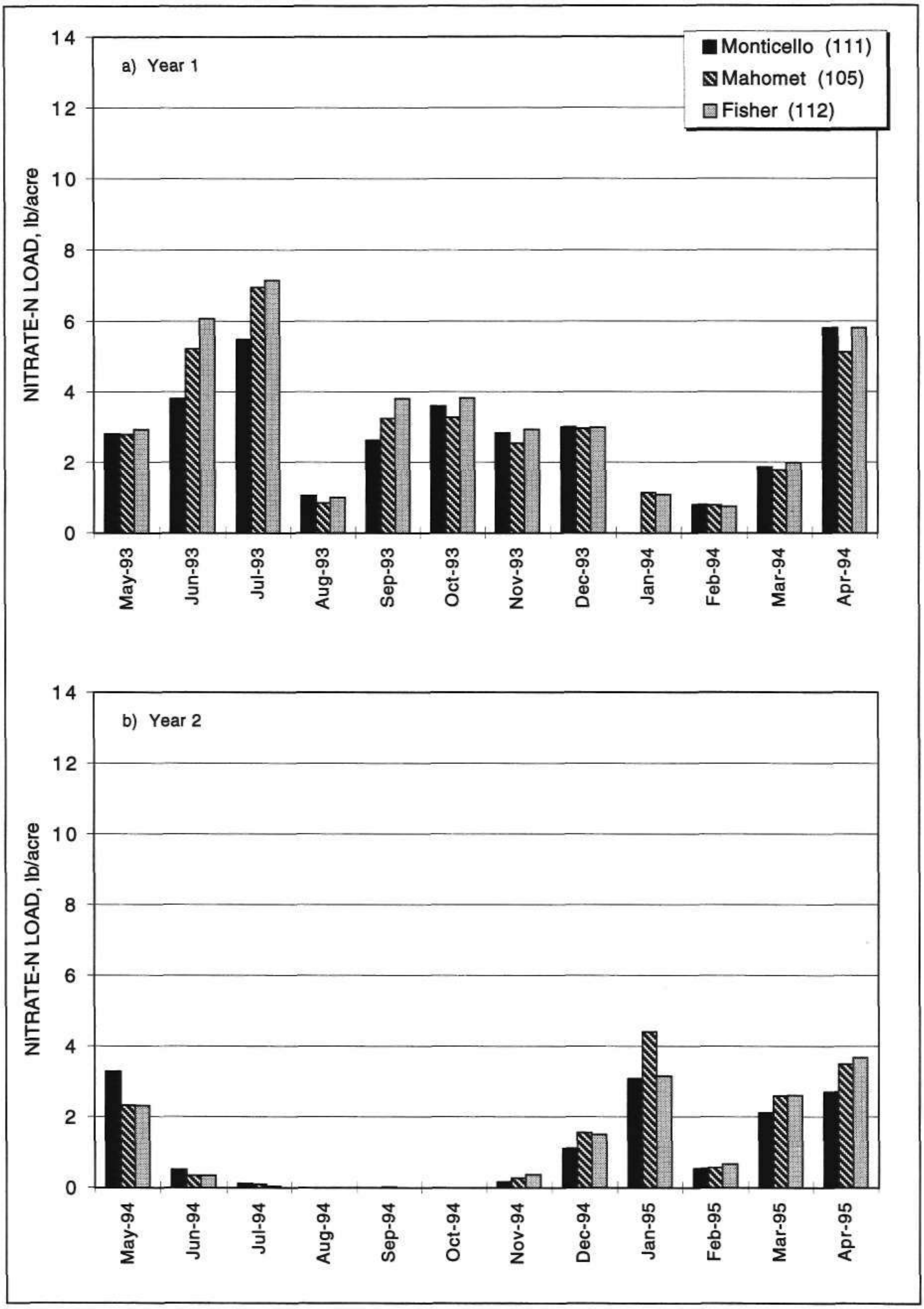


Figure 64. Monthly nitrate-N loads for river stations

Table 14. Annual Nitrate Loads in the Sangamon River Basin

Station	*Drainage area (acre)*	*Annual nitrate yield* *Year 1 (lb/acre)*	*Year 2 (lb/acre)*	*Average (lb/acre)*
Tributary stations:				
Long Creek (101)	29,539	28	9	19
Friends Creek (102)	71,647	44	19	32
Goose Creek (103)	28,892	36	16	26
Camp Creek (104)	30,242	39	11	25
Big Ditch (106)	24,421	49	15	32
Main river stations:				
Sangamon River at Fisher	157,177	40	15	28
Sangamon River at Mahomet	235,653	37	16	27
Sangamon River at Monticello	347,747	34	14	24
Total inflow into Lake Decatur	586,868	33	13	23

Annual Nitrate Loads. The annual nitrate loads at all the stations monitored are summarized in table 14 and presented in figure 65. The results are grouped into two figures for the purpose of comparing tributary streams separately from main river stations. For the tributary streams, the annual nitrate load for year 1 ranges from a low of 28 lb/acre for Long Creek to a high of 49 lb/acre for Big Ditch. Next to Big Ditch, Friends Creek generated the highest nitrate load at 44 lb/acre. The other two tributaries, Goose Creek and Camp Creek, generated nitrate at almost a uniform rate of 36 to 39 lb/acre.

The average annual load for all the tributaries for the first year was 39.2 lb/acre. The annual nitrate loads for the tributary streams were much smaller the second year than the first-year. The overall average annual load for the second year was 14 lb/acre as compared to the 39.2 lb/acre for the first year. First year loads were almost three times greater than those of the second year. Loads for the second year ranged from a low of 9 lb/acre for Long Creek to a high of 19 lb/acre for Friends Creek.

The annual nitrate loads for the three Sangamon River stations are presented in figure 65b. Similar to the tributary streams, the loads during the first year are significantly greater than those for the second year. The overall average annual load for the main river stations for the first year was 37 lb/acre as compared to 15 lb/acre for the second year, more than double the second year loads. During the first year, the annual loads ranged from a low of 34 lb/acre at the Monticello station to a high of 40 lb/acre at the Fisher station. For the second year, the loads fell within a narrow range from a low of 14 lb/acre at the Monticello station to a high of 16 lb/acre at the Mahomet station. The variability in annual load among the stations for the second year is not significant.

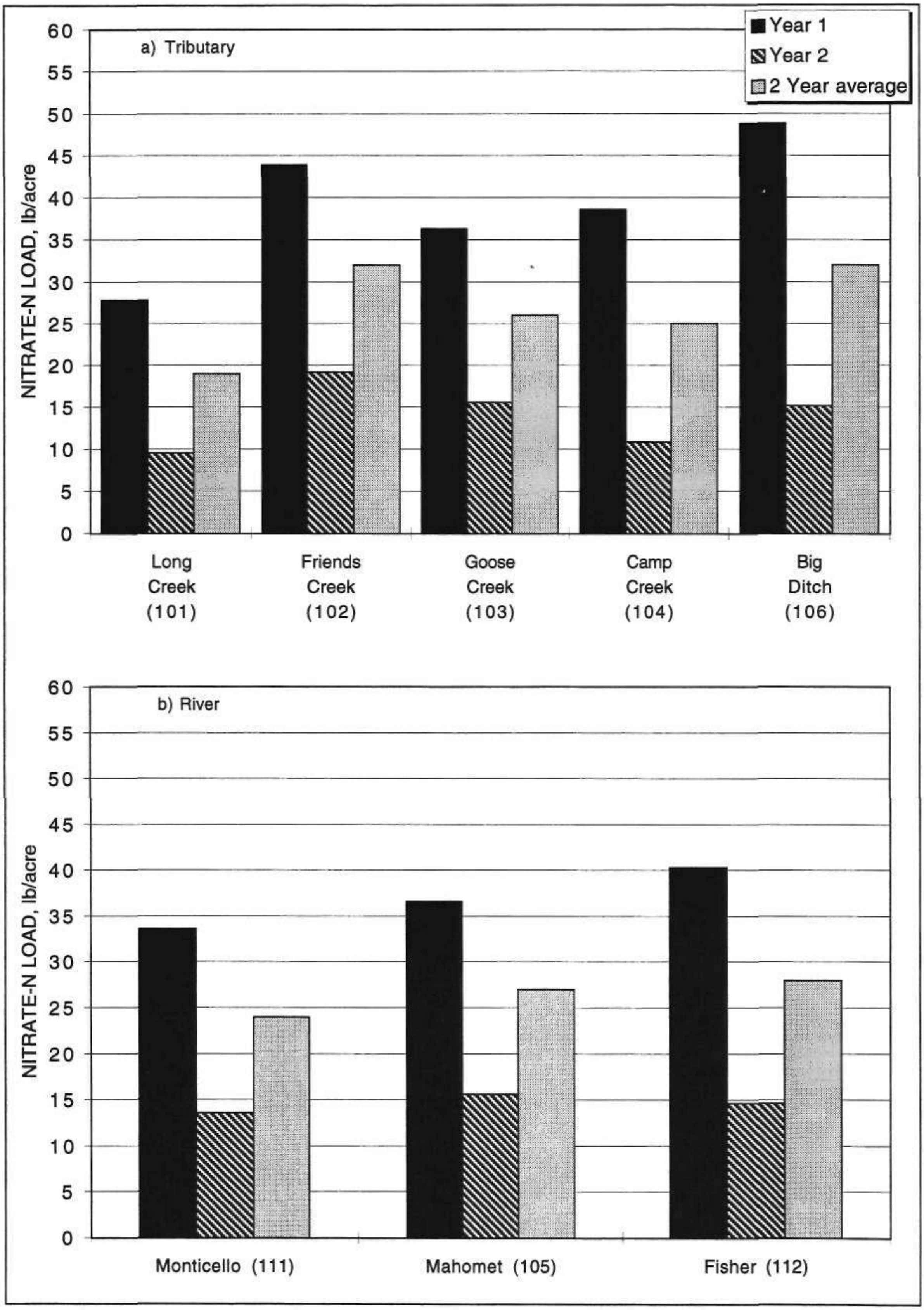


Figure 65. Annual nitrate-N loads for a) tributary and b) river stations

Based on the first-year data, it can be concluded that as the drainage area increases, the unit load generally decreases similar to sediment yield. The nitrate load is the highest at Fisher and the lowest at Monticello. One process by which the unit load decreases with increasing drainage area is the mixing of runoff of higher concentrations with runoff of lower concentrations. For sediment, channel and floodplain storage account for the decrease in unit area yields as drainage area increases, but for nitrate there must be some losses in the stream channel and floodplain as the drainage area increases.

Based on the nitrate load data, we can conclude that the source of nitrate in the Lake Decatur watershed is truly dispersed throughout the watershed. There are no "hot spots" generating most of the nitrate that flows into Lake Decatur. Even though the Big Ditch and Friends Creek watersheds were observed to generate relatively higher nitrate loads per unit area during the first year, their rates were not significantly higher than the rest of the watershed. Furthermore, the combined drainage areas of the two watersheds are approximately 16 percent of the whole watershed. More than 80 percent of the drainage area yields nitrate at almost a uniform rate.

Mathematical Modeling to Evaluate the Effects of Best Management Practices on Nitrate Load into Lake Decatur

One of the main objectives of this project was to evaluate the potential effects of alternative agricultural best management practices (BMPs) at different locations of the Lake Decatur watershed on nitrate level reduction at Lake Decatur. This was to be accomplished through the use of a nonpoint source pollution (NPS) model for agricultural runoff, a computer program that uses mathematical formulas to simulate the movement of water, sediment, and pollutants from agricultural lands by representing the physical processes of release mechanisms and transport of water, sediment, and nutrients (nitrogen and phosphorous). Some of the well-known and widely used nonpoint source models were found to be ARM (Donigian and Crawford, 1976), CREAMS (Knisel, 1980), HSPF (Bicknell et al., 1993), PRZM (USEPA, 1984), BASIN (Heatwole et al., 1989), AGNPS (Young et al., 1987; 1989), and SWRRB (Arnold et al., 1990). Based on the project requirements, the AGNPS model was selected as the most suitable model for quantitative evaluation of the effects of alternative management practices on nonpoint source pollution from the Lake Decatur watershed.

The AGNPS (Agricultural Nonpoint Source Pollution) model for agricultural watersheds was used to simulate nitrate movement in the Lake Decatur watershed. This model has been developed and distributed by the North Central Soil Conservation Research Laboratory of the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS), Morris, Minnesota (Young et al., 1987, 1989). All NPS models are not well documented and are not applicable to large agricultural and rural watersheds, but the AGNPS model has complete documentation and wide applications. The latest version of the model, Version 4.03, was completed in September 1994 and is recommended for use in watersheds ranging in size from a few acres to hundreds of square miles.

The model was first applied to two of the Lake Decatur sub-watersheds (Big Ditch and Friends Creek) and then to the entire Lake Decatur watershed using estimated input data and model parameters to determine a suitable model grid size and the most sensitive model parameters and variable input data for simulations of surface water runoff and soluble nitrogen. Based on these findings, the model was applied to the entire Lake Decatur watershed using input data and parameter values that were estimated based on measured and published data. A search of single-event storms from the observation period produced two storms that approximately matched the model assumptions. Since these two storms occurred during two completely different seasons, spring and fall, the model was calibrated separately for each storm. Using the parameters for the spring storm, the model was run for a 1-year, 12-hour rainfall event, chosen as the base storm, to study the impact of different BMP scenarios in reducing nitrogen (N) concentrations entering Lake Decatur.

BMP scenarios in four broad categories were evaluated: (1) nutrient management, (2) mitigation projects, (3) conservation practices, and (4) a combination of nutrient management and conservation practices. While evaluating nutrient management, the fertilizer application rate was varied in each of the selected sub-watersheds and combinations of sub-watersheds, one at a time, and changes of N concentrations throughout the watershed and at the lake were analyzed. Mitigation projects, such as wetlands, buffer strips, and detention ponds, could be implemented in the watershed to reduce the nitrate level in Lake Decatur. Because such projects could change the N decay rate, the impact of these projects was evaluated by varying the decay parameter. Conservation practices such as conservation tillage increase land cover, thus reducing the Soil Conservation Service (SCS) curve number. Conservation practices were simulated by varying the SCS curve number. Finally, the fertilizer application rate and the SCS curve number were simultaneously varied to study the combined effects of nutrient management and conservation practices.

The following sub-sections present descriptions of the AGNPS model; test run applications of the model to Big Ditch and Friends Creek sub-watersheds and the entire Lake Decatur watershed with estimated input data and parameter values for determining a suitable model grid size, sensitive model parameters, and sensitive input variables; application of the model to the entire Lake Decatur watershed with the selected grid size and estimated input data; calibration of the sensitive model parameters for each sub-watershed; and 72 model runs to evaluate effects of different BMP scenarios on nitrate load into Lake Decatur. All model results are presented and discussed.

AGNPS Model Description

The AGNPS model simulates runoff, sediment, and nutrient transport of nitrogen (N) and phosphorous (P) from agricultural watersheds, as well as chemical oxygen demand (COD). Basic model components include hydrology, erosion, and transport of sediment and chemicals.

The watershed is divided into uniformly square areas (cells). Water, sediment, and pollutants are routed through the cells beginning at the uppermost cell and ending at the watershed outlet. The model expresses all watershed characteristics and inputs at the cell level.

The model computes runoff volume using the SCS runoff curve number method (USDA-SCS, 1972). The method requires rainfall depth and a value for the curve number that depends upon land use, soil type, and hydrologic soil condition. Peak runoff rate for each cell is computed using an empirical relationship proposed by Smith and Williams (1980), which is based on drainage area, channel slope, runoff volume, watershed length-width ratio, and empirical coefficients determined from field measurements.

The chemical transport part of the model estimates transport of N, P, and COD throughout the watershed using procedures adapted from Frere et al. (1980) and Young et al. (1982). Chemical transport computations are divided into soluble and sediment-adsorbed phases. Nutrient yield in the sediment adsorbed phase is empirically calculated using total sediment yield from a cell, nutrient (N or P) content of the soil, and an enrichment ratio, as described by Young et al. (1987).

Soluble nutrient estimates consider the effects of nutrient levels in rainfall, fertilization, and leaching. Soluble N or P contained in runoff is computed simply by multiplying an extraction coefficient of N and P and the mean concentration of soluble N or P at the soil surface during runoff with total runoff.

The model accounts for nutrient contributions from point sources, such as feedlots, springs, and wastewater treatment plants, and estimated sediment contributions from streambank, streambed, and gully erosion.

Sediment and runoff routing through impoundments is done using procedures described by Laflen et al. (1978). Impoundments reduce peak discharges, sediment yield, and yield of sediment-attached chemicals.

Input data and parameters required by the AGNPS model are as follows:

1. SCS curve number
2. Land slope
3. Overland Manning's coefficient
4. Surface condition constant
5. Universal Soil Loss Equation (USLE) slope shape indicator
6. USLE topographic (slope length) factor
7. USLE soil-erodibility (K) factor
8. USLE cropping-management (C) factor
9. USLE conservation practice (P) factor
10. Soil texture indicator
    a) Soil nitrogen
    b) Soil phosphorus
    c) Pore water N concentration
    d) Pore water P concentration
    e) N extraction coefficient for runoff
    f) P extraction coefficient for runoff
    g) N extraction coefficient for leaching
    h) P extraction coefficient for leaching
    i) Percent organic matter in soil
11. Fertilizer indicator
    a) N application rate
    b) P application rate
    c) N availability factor
    d) P availability factor
12. Pesticide indicator (application rate)
13. Point source indicator
14. Additional erosion
15. Impoundment indicator
16. Channel indicator
    a) Type
    b) Slope

    - c) Side slope
    - d) Length
    - e) Manning's coefficient
    - f) Nutrient decay rate
17. Storm data
    - a) Precipitation depth
    - b) Nitrogen concentration in rainfall
    - c) Rainfall duration
    - d) Storm type
    - e) Peakflow calculation option

Model Sensitivities to Grid/Cell Size, Parameters, and Input Variables

Model test runs were made for the Big Ditch and Friends Creek sub-watersheds and the entire Lake Decatur watershed to test model applicability, and to determine sensitivities of grid or cell size, parameters, and input variables. Input data and parameter values were based on U.S. Geological Survey (USGS) topographical and U.S. Department of Agriculture-Soil Conservation Service (USDA-SCS) soil survey maps covering the 925-square-mile Upper Sangamon River (draining to Lake Decatur), field measurements, published information, and model default values derived from published data. Some of the data used in these test runs were approximate values.

Figure 66 is a schematic diagram of the Upper Sangamon River with all the major tributaries, their catchment basins, and Lake Decatur. The figure shows relative sizes of the tributary and mainstem sub-basins (sub-watersheds).

The model was first applied to the Big Ditch sub-watershed having a drainage area of approximately 40 square miles. The sub-watershed was divided into 641 cells, each with an area of 40 acres. The rainfall event of April 11-12, 1994, was selected for these model runs. With the estimated rainfall depth, rainfall duration, and the parameters, the model was run by uniformly varying the fertilizer application rate, N availability factor, SCS runoff curve numbers, N extraction coefficients, and N decay factors. The summary results at the outlet of the sub-watershed showed that the model was sensitive to all the above five input variables and parameters in computing N load and N concentrations in runoff. The SCS curve number was also sensitive to runoff volume and peakflow. Channel shape was sensitive to only sediment yield. Uniform soil texture of silt, and uniform-average values of SCS runoff curve number, USLE slope length factor, and USLE cover factor were adequate to represent the sub-watershed because of uniformity or homogeneity of hydrologic conditions throughout the sub-watershed, or hydrologic balancing at the outlet of this large catchment.

Then the model was applied to the entire Lake Decatur watershed, which was divided into 992 cells, each with an area of 640 acres or 1 square mile. In order to contain most of the Lake Decatur watershed within the boundary of the area being modeled, cells at the watershed boundary that contain only a small portion of the watershed were included as part of the watershed that was modeled, resulting in 992 cells. Thus the area of the modeled watershed

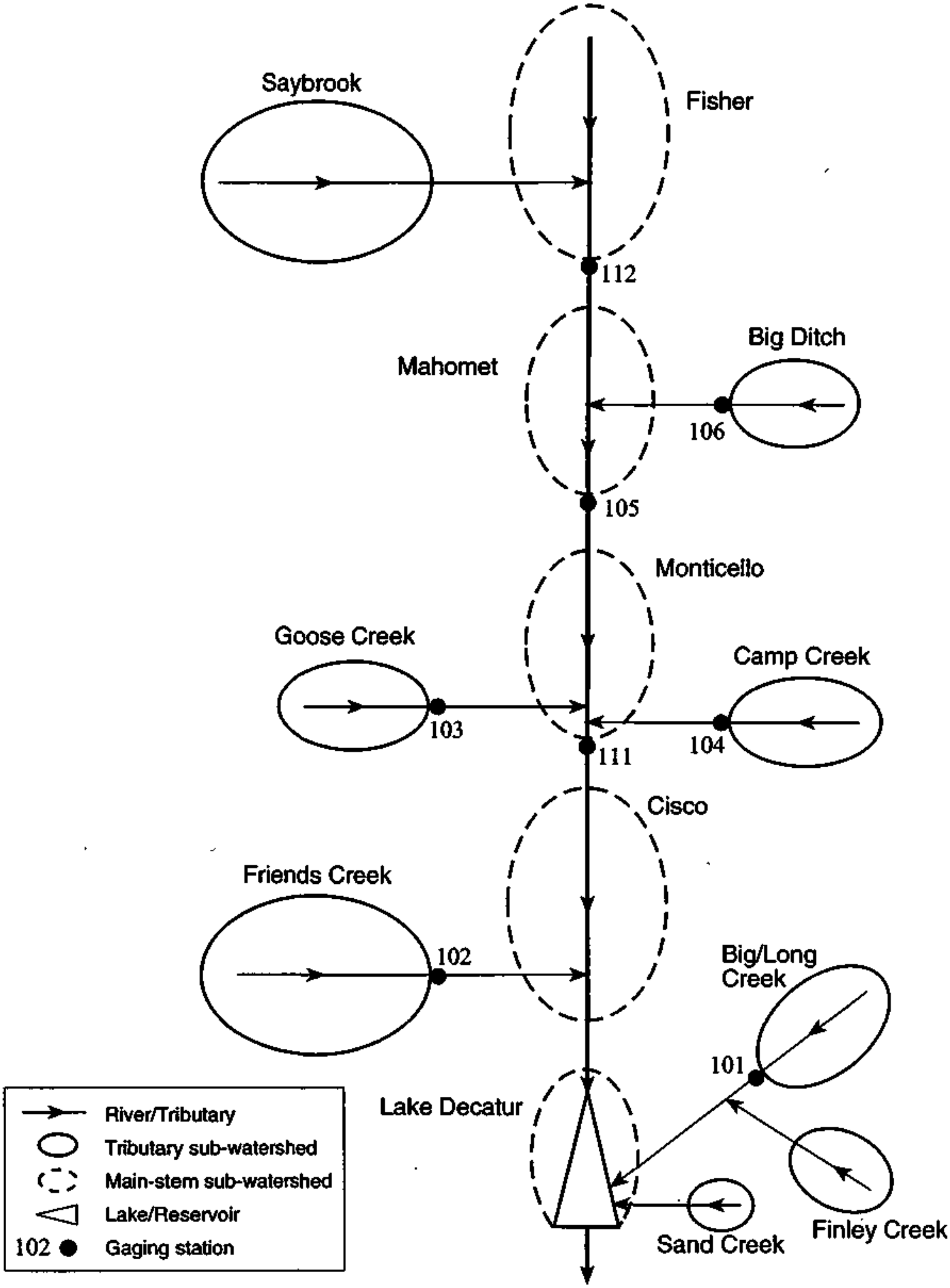


Figure 66. Schematic diagram of the Upper Sangamon River with its major tributaries and sub-watersheds draining into Lake Decatur

shown in figure 67 is greater than the actual drainage area of the Lake Decatur watershed by 67 square miles (7 percent). In this grid representation, Big Ditch sub-watershed covered 46 cells. Model results at the outlet of Big Ditch sub-watershed for the same storm showed minor and acceptable differences with the results obtained earlier with fine grid representation. The differences, the result of a 15 percent increase in the Big Ditch sub-watershed size due to the coarse grid representation, can be avoided by carefully discretizing to match the two grid representations.

Finally, sensitivity test runs were made on a sub-watershed in the Friends Creek basin. This sub-watershed was represented by 332 fine (40-acre) cells covering a 21-square-mile area. Within the coarse-cell representation of the entire Lake Decatur watershed, this sub-watershed was represented by 24 cells, each with 640 acres or 1 square mile of area. Model results at the outlet of this sub-watershed using both fine and coarse grid/cell representations showed minor and acceptable differences for the same storm.

In the above test runs, it was noticed that some changes in results did occur due to changes in grid sizes. Although the changes were not unacceptable, they were the result of different physical representations of the basin including basin size changes during conversion of grid sizes. Since the physical representations were different, hydrologic responses were also expected to be different. In order to balance such differences, different representative values of parameters must be estimated or calibrated for different grid/cell representations. It was concluded from these analyses that a 640-acre (1-square-mile) grid/cell representation of the 925-square-mile Lake Decatur watershed was adequate for the current modeling study as long as the model with this cell/grid representation was calibrated with field-observed data. It was also concluded from the test runs that the AGNPS model was adequate for the current modeling study as long as the simulating storms were uniformly distributed throughout the 925-square-mile watershed.

The test runs showed that the tributary drainage basins could be assumed as individual homogeneous sub-watersheds of the entire Lake Decatur watershed with uniform hydrologic characteristics. Uniform representative values of the model parameters would be sufficient to simulate the hydrologic processes within each individual sub-watershed.

From the sensitivity analyses, the most sensitive model parameters and input variables for simulations of surface water runoff and soluble nitrogen were found to be:

1. SCS runoff curve number
2. N extraction coefficient for runoff
3. N extraction coefficient for leaching
4. N decay rate
5. N application rate
6. N availability
7. Rainfall depth and duration

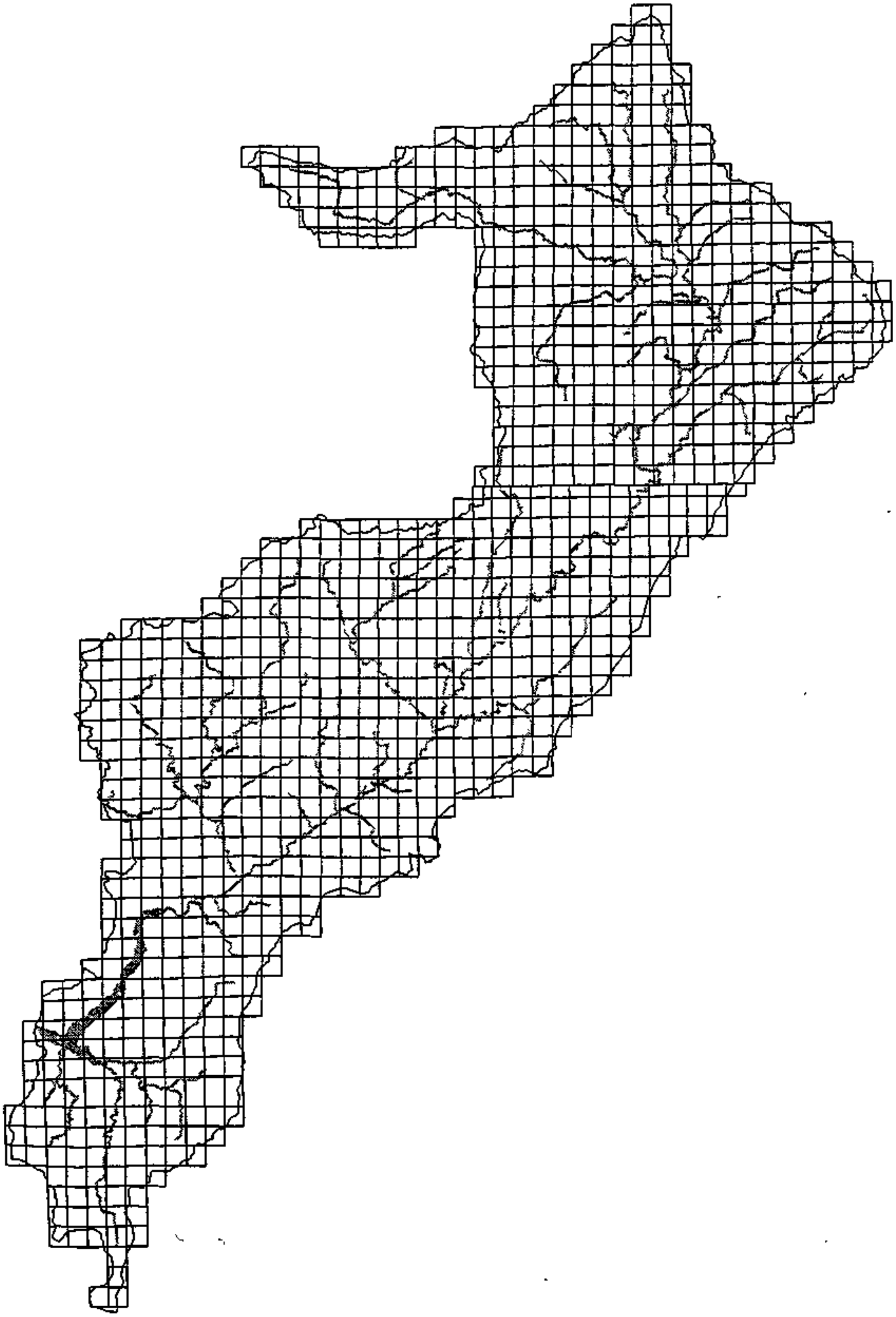


Figure 67. Lake Decatur watershed covering the Upper Sangamon River and divided into 992 cells, each with an area of 640 acres or 1 square mile

Modeling of the Lake Decatur Watershed

The entire Lake Decatur watershed, covering the Upper Sangamon River basin, was modeled using AGNPS. The watershed was divided into 992 square cells, each having an area of 640 acres or 1 square mile. Figure 67 shows the entire Lake Decatur watershed, the Upper Sangamon River, its major tributaries, and Lake Decatur. The watershed was delineated based on USGS topographical maps. The Upper Sangamon River originates at the uppermost corner of the watershed and flows through the watershed, first towards the south and then towards the southwest until it flows through and exits Lake Decatur in the west.

Figure 66 shows a schematic view of the main stem of the Upper Sangamon River, major tributaries, the associated sub-watersheds, Lake Decatur, and the gaging stations established during this study. Sub-watersheds were drawn to approximate their relative sizes.

Assumptions

Based on the model test runs made earlier and reported above, the following assumptions were made:

1. Model representation of the Lake Decatur watershed with coarse grid cells of 640 acres was adequate.
2. The AGNPS model was applicable to the entire 925-square-mile watershed of the Upper Sangamon River as long as the watershed was divided into smaller sub-watersheds and model parameters were calibrated for each sub-watershed independently by matching the model results with observed data.
3. Uniform parameter values, as determined through calibration, were adequate to represent a sub-watershed of the Lake Decatur watershed.
4. The computed runoff volume and nutrient load at the lake exit, which included runoff and nutrient contributions from the entire Lake Decatur watershed, were considered as the runoff and nutrient load coming into the lake.

Watershed Data Preparation

Watershed data used to run the AGNPS model were based on USGS topographical maps, USDA-SCS soil survey maps, field measurements, and data available in-house and from the literature. The 992 cells of the Lake Decatur watershed were numbered from left to right, top to bottom, and ending at the lowermost right cell. All data listed earlier in the AGNPS model description, except storm data, were entered for each cell using the spread sheet routine that came with the model. As required by the model, storm data were provided separately for the entire watershed. Consequently, the model is applicable only to spatially uniform rainfall events.

SCS curve number, USLE factors, overland and channel Manning coefficients, surface condition constant, and soil texture indicator for each cell were estimated based on USDA-SCS soil survey maps, field observations, and guidelines given in the AGNPS user's manual, USDA-SCS (1972), Wischmeier and Smith (1978), and Circular 1220 of the Cooperative Extension Service, University of Illinois (1983). Land slope, channel slope, and channel length within each cell were estimated based on USGS topographical maps and field measurements. Triangular channel side slopes were computed based on an equivalent triangular section having the measured bankfull top width and cross-sectional area. Model default values, based on nationwide literature data, were used for soil nutrient contents and parameters. Based on the sensitivity analyses presented earlier, the sensitive parameters, which were SCS curve number, N extraction coefficients for runoff and leaching, and N decay rate were adjusted during calibration. Fertilizer application rates were used based on interviews with farmers, soil and water conservation districts, local agriculture-related agencies, and fertilizer dealers. N availabilities were based on tillage practices discovered during field observations and interviews and guidelines given in the AGNPS user's manual.

Storm Selection and Data Processing

The Lake Decatur watershed has been monitored for flow and concentrations of NO3, NH4, and TKN starting in spring 1993. As shown in figure 66, most of the gaging stations (five) are located at the tributary sub-watershed outlets, and the rest (three) on the mainstem of the Sangamon River. Available flow and nutrient records were collected from all the gaging stations during the period of April 1993 - March 1995. Rainfall data from National Weather Service stations at Urbana, Rantoul, Farmer City, Decatur, and Sullivan were collected for the same period. Both flow and rainfall data were simultaneously reviewed to find single-event storms generating significant amounts of rainfall depth and flow, and uniformly distributed over the entire watershed. Such a storm would have approximately the same rainfall depth and duration at all raingages, and peakflows occurring at all the tributary and mainstem gaging stations on the same day of rainfall or the following day. Such rainfall events are difficult to find for a large watershed such as the 925-square-mile Lake Decatur watershed, but the AGNPS model is limited to this type of storm. Only two storms were found from the nearly two years of monitored data that closely matched the above criterion, and those were the rainfall events on April 11-12, 1994 and September 14, 1993. The April 1994 storm better matched the above assumptions and criterion than the September 1993 storm.

Figure 68 shows cumulative rainfall depths at the five raingages resulting from the April 11-12, 1994 storm, which produced heavy rainfall at all the stations in spite of some variations in the amounts. Sullivan is located further south from the watershed and had the lowest rainfall depth. Urbana and Farmer City are located close to the watershed boundary. Rantoul and Decatur are the only stations located inside the watershed. Figure 68 also shows the average cumulative rainfall depth at the center of the watershed, computed based on the reciprocal-distance-squared method (Wei and McGuinness, 1973). From this average curve, a representative uniform rainfall depth of 5 inches for a duration of 24 hours was selected for simulating this storm. Similar

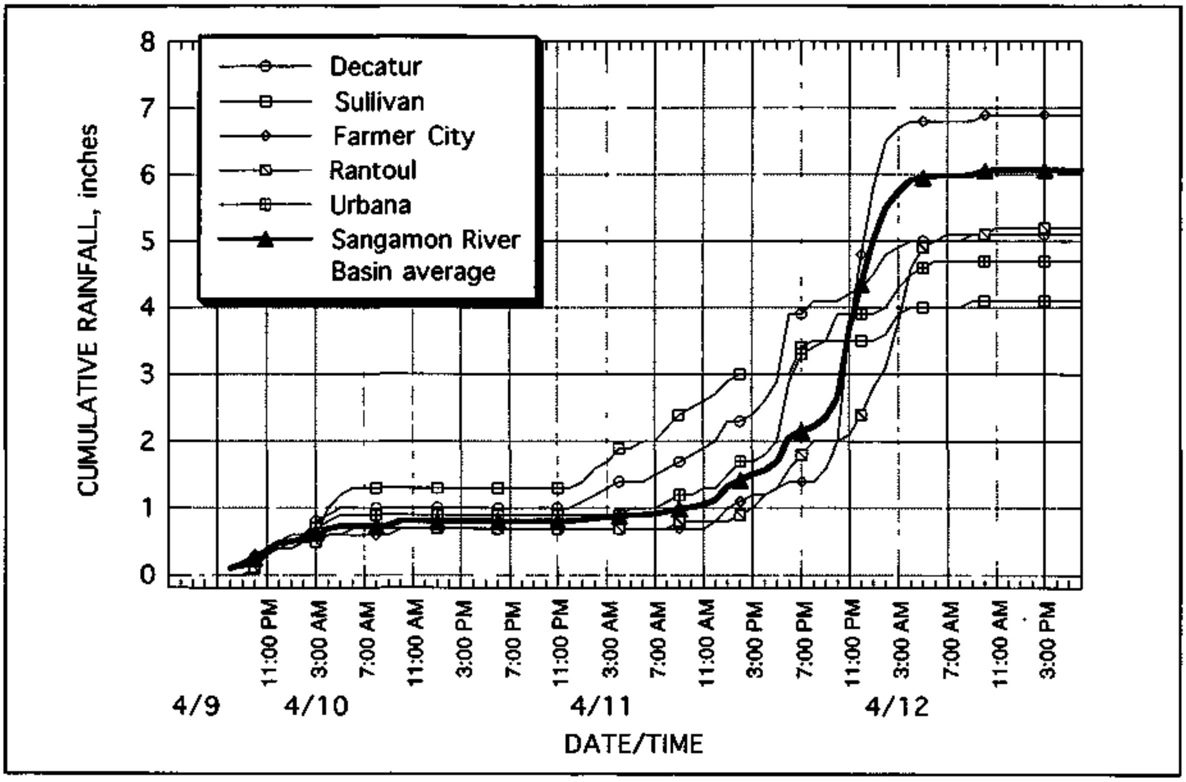


Figure 68. Cumulative rainfall at rainfall gaging stations and Upper Sangamon River basin average before, during, and after April 11-12, 1994 storm

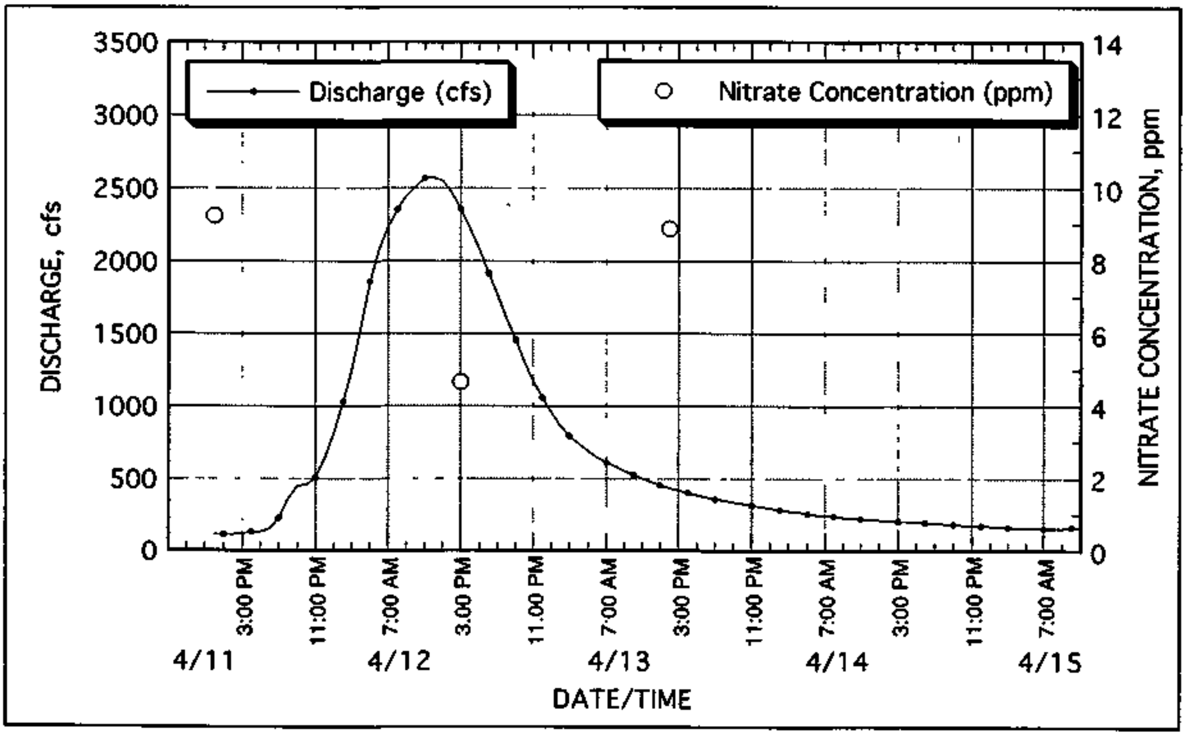


Figure 69. Hydrograph and nitrate concentrations measured at Camp Creek gaging station during and after April 11-12, 1994 storm

analyses were done for the September 14,1993 storm, and a representative uniform rainfall depth of 2.10 inches for a duration of 12 hours was selected to simulate that storm.

Flow hydrographs and nitrate concentrations recorded at all the gaging stations during the storm events were plotted and analyzed for computations of storm runoff volumes and average nitrate concentrations. Figure 69 shows flow hydrograph and nitrate concentrations observed at the outlet of Camp Creek, (Station 104) resulting from the April 11-12, 1994 storm. This is a typical plot of observed flow hydrograph and nitrate concentrations. The observed data indicated that concentrations of NH4 and TKN were very small in comparison to concentrations of nitrate. Also, nitrate is available in dissolved form, but NH4 and TKN are also adsorbed with sediment. Therefore, a simulation of only nitrate was considered in this project. The AGNPS model predicts dissolved N load and concentration, and sediment-adsorbed N load. The predicted N concentrations were assumed to be nitrate concentrations.

Observed runoff volume contributed at a gaging station during a storm was computed from the flow hydrograph by subtracting the baseflow, if any. Baseflows for tributary stations, such as Camp Creek, were insignificant. However, baseflows could be significant at the mainstem stations, and sometimes at the large tributary stations, such as Friends Creek. Baseflows were assumed to be linear from the first rising point of the hydrograph to a reasonable point on the tail of the recession curve where surface runoff was assumed to cease and flow was assumed to continue only from sub-surface contributions. Surface runoff volume was computed from the area between the hydrograph and the linear baseflow curves using trapezoidal rule. In order to match the runoff volume unit used by AGNPS, the computed volume was divided by the drainage area and expressed in inches of runoff depth.

Observed runoff volumes at all gaging stations during the storm events of April 11-12, 1994 and September 14, 1993 are shown in tables 15 and 16, respectively. These tables also show observed nitrate concentrations, flow and nitrate concentrations predicted by the AGNPS model, and percent differences of predicted and observed values, which are discussed later in the report. As shown in these tables, flow data from the mainstem station at Mahomet and station on Goose Creek were not available for these storms. The number in parentheses next to the station names indicate the gaging station identification number and model cell number containing that gaging station, respectively.

More involved procedures and judgments were used to estimate average nitrate concentrations at the gaging stations during the flow durations of the two storms. Only two or three nitrate concentration measurements were available for most stations during flow duration periods of both storms, while some stations had only one measurement and one had four. Figure 69 shows three nitrate concentration measurements at Camp Creek station during the flow period of the April 11-12, 1994 storm. If a station had three or more nitrate concentration measurements during the storm flow period, as shown in figure 69, a nitrate load graph was developed by multiplying the concentration with the corresponding flow, then the total nitrate load for the storm was computed using trapezoidal rule, and finally average nitrate concentration for the

Table 15. Comparisons of Model Predictions with Observations for April 11-12,1994 Storm (rainfall 5.00 inches, duration 24 hours)

	Runoff volume			*N concentration*		
Gaging stations	*Observed (inches)*	*Predicted (inches)*	*Difference (percent)*	*Observed (ppm)*	*Predicted (ppm)*	*Difference (percent)*
Fisher (112/275)	2.92	2.89	-1	3.37	3.63	8
Big Ditch (106/330)	2.79	2.89	4	4.49	3.96	-12
Mahomet (105/423)	No data	2.89	-	4.47	4.38	-2
Goose Creek (103/588)	No data	1.88	-	6.77	6.10	-10
Camp Creek (104/651)	1.59	1.65	4	5.26	5.21	-1
Monticello (111/697)	2.79	2.69	-4	4.23	4.60	9
Friends Creek (102/752)	1.90	1.88	-1	7.33	7.73	5
Long/Big Creek (101/918)	1.74	1.73	-1	5.29	5.54	5

Note:
The first number in parentheses is the gaging station identification number, and the second number is the model cell number.

Table 16. Comparisons of Model Predictions with Observations for September 14,1993 Storm (rainfall 2.10 inches, duration 12 hours)

	Runoff volume			*N concentration*		
Gaging stations	*Observed (inches)*	*Predicted (inches)*	*Difference (percent)*	*Observed (ppm)*	*Predicted (ppm)*	*Difference (percent)*
Fisher (112/275)	0.24	0.23	-4	6.24	5.88	-6
Big Ditch (106/330)	0.59	0.62	5	4.81	5.12	6
Mahomet (105/423)	No data	0.32	-	5.79	5.20	-10
Goose Creek (103/588)	No data	0.23	-	6.99	6.48	-7
Camp Creek (104/651)	0.49	0.43	-12	4.81	4.13	-14
Monticello (111/697)	0.31	0.34	10	4.16	4.47	7
Friends Creek (102/752)	0.22	0.23	5	6.37	6.35	<1
Long/Big Creek (101/918)	0.26	0.28	8	8.06	7.93	-2

Note:
The first number in parentheses is the gaging station identification number, and the second number is the model cell number.

storm was computed by dividing the total nitrate load by the total runoff weight (surface runoff and baseflow). This procedure was used to estimate observed nitrate concentrations at stations of Big Ditch, Camp Creek, Fisher, and Monticello for the April 1994 storm, and at stations of Camp Creek, and Friends Creek for the September 1993 storm.

For the station having only one measurement and showing good correlation of flow and nitrate concentration with another station having three or more measurements, the nitrate concentration was estimated based on the correlation. The nitrate concentration at Big Ditch for the September 1993 storm was estimated based on Camp Creek data. For stations with no flow record, it was simply the arithmetic mean of the measured concentrations. Mahomet and Goose Creek were those stations for both storms. For the remaining stations and storms, the only measured concentration was used to represent the average concentration for that station: Friends Creek and Long/Big Creek for the April 1994 storm, and Fisher, Monticello, and Long/Big Creek for the September 1993 storm. Nitrate concentrations at the gaging stations, estimated using the above procedures and the measured data during the two rainfall events, are given in tables 15 and 16.

Model Calibration and Verification

There were only two suitable storms available to calibrate and verify the AGNPS model for the entire Lake Decatur watershed. As discussed above, these two storms (April 11-12, 1994 and September 14, 1993) occurred in two completely different seasons having completely different antecedent soil moisture and ground cover conditions, and different soil nutrient contents. The sensitive model parameters, determined earlier, depend on these factors, and therefore, the model must be calibrated for both storms separately. However, the relative values of the parameters and their seasonal trends, resulting from both calibrations, would indicate validity of the model and its parameters on the Lake Decatur sub-watersheds. Also, comparisons of model predictions with observed data at an independent station, such as Monticello, would validate the model.

Using the observed runoff volumes and nitrate concentrations at the gaging station, as discussed above, the AGNPS model was calibrated for the corresponding drainage basins or sub-watersheds, each independent of the others. Since the total surface runoff volume of a storm has more impact on the average nitrate concentration generated during the storm than the peakflow, it was decided that predicted and observed runoff volumes would be matched in calibrating representative model parameters.

Model runs were made by adjusting the sensitive model parameters in each sub-watershed, one at a time, until the predicted runoff volume and N concentration compared reasonably well with the observed runoff volume and nitrate concentration. Adjustment of the SCS curve number was made first to match the runoff volumes, then adjustments of the runoff and leaching extraction coefficients were made to match the N concentrations. Tables 17 and 18 show the calibrated values of these parameters along with the decay factor, fertilizer application

Table 17. Calibrated "AGNPS" Parameters and Key Inputs for April 11-12,1994 Storm

Sub-watershed	*Curve number*	*Runoff extraction coefficient*	*Leaching extraction coefficient*	*Nutrient decay (percent)*	*N application rate (lb/acre)*	*N availability factor (percent)*
Fisher	80	0.05	0.35	1	200	60
Big Ditch	80	0.05	0.35	1	200	60
Mahomet	80	0.05	0.25	1	200	60
Goose Creek	68	0.05	0.20	1	200	60
Camp Creek	65	0.05	0.20	1	200	60
Monticello	80	0.05	0.25	1	200	60
Friends Creek	68	0.05	0.18	1	200	60
Cisco	75	0.05	0.20	1	200	60
Lake Decatur and adjacent creeks	66	0.05	0.20	1	200	60

Table 18. Calibrated "AGNPS" Parameters and Key Inputs for September 14,1993 Storm

Sub-watershed	*Curve number*	*Runoff extraction coefficient*	*Leaching extraction coefficient*	*Nutrient decay (percent)*	*N application rate (lb/acre)*	*N availability factor (percent)*
Fisher	68	0.05	0.20	1	50	60
Big Ditch	80	0.05	0.30	1	50	60
Mahomet	75	0.05	0.25	1	50	60
Goose Creek	68	0.05	0.20	1	50	60
Camp Creek	75	0.05	0.30	1	50	60
Monticello	75	0.05	0.25	1	50	60
Friends Creek	68	0.05	0.20	1	50	60
Cisco	75	0.05	0.25	1	50	60
Lake Decatur and adjacent creeks	70	0.05	0.18	1	50	60

rate, and N availability factor for the sub-watersheds (figure 66) and determined for the two storms. During these calibrations, the Saybrook and Fisher sub-watersheds (figure 66) were combined as Fisher, and Long/Big Creek, Finley Creek, Sand Creek, and Lake Decatur were combined into one sub-watershed as Lake Decatur and the adjacent creeks because of their geographic and gaging station locations.

Tables 15 and 16 compare observed and predicted runoff volumes and N concentrations, along with the percent differences. The matches between observed and predicted values were very good with mostly one-digit percent differences, and only a few two-digit differences with a maximum of -14 percent.

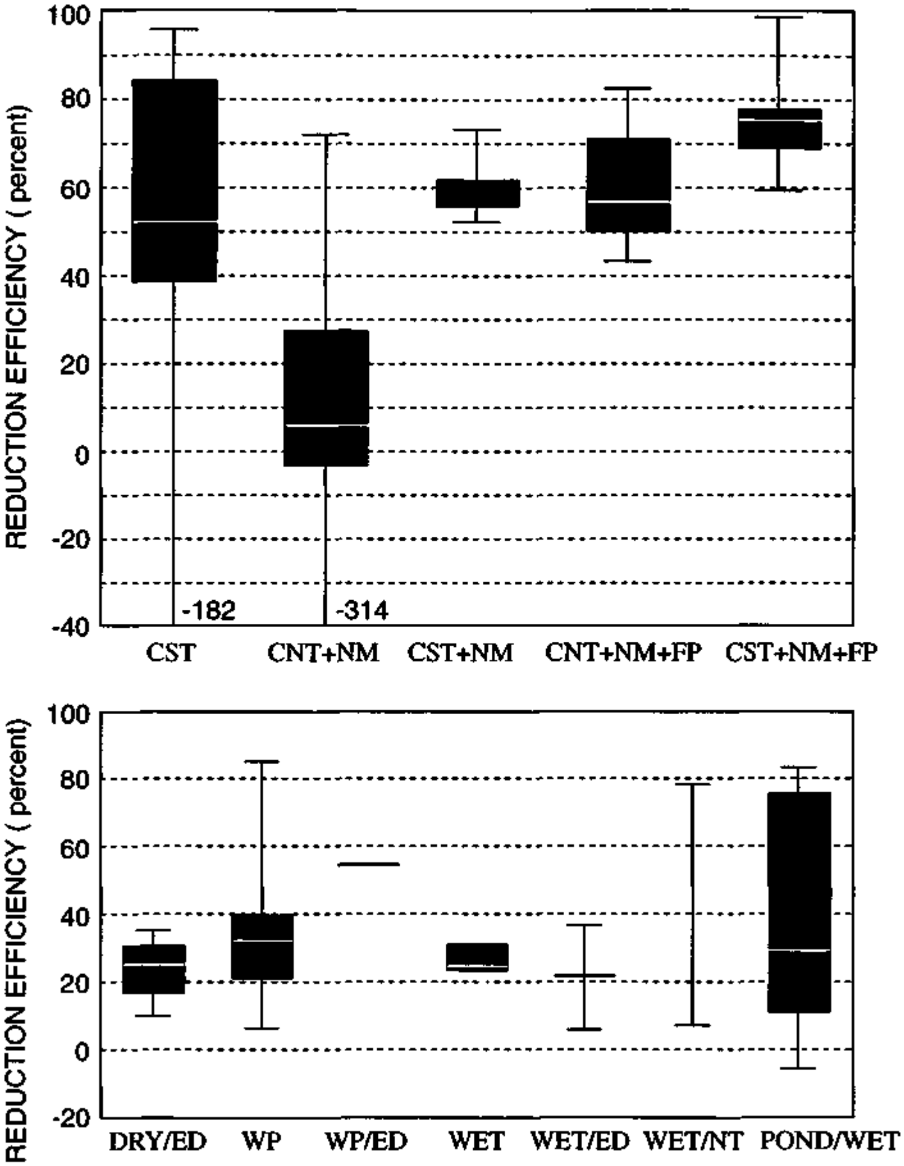
As may be seen in tables 17 and 18, changes in the SCS curve numbers between the two storms follow the expected trend, higher during spring season due to high antecedent moisture conditions and lower in the fall season due to drier conditions. There were a few exceptions, for example in Camp Creek and Long/Big Creek, that might have been due to spatial variations or limited data used in the calibration. However, the overall trend is there. The runoff and leaching extraction coefficients were mostly model default values, as suggested by the model developers based on their experiences in model applications. Slight adjustments were made for a few of the sub-watersheds. The decay factor was kept fixed at 1, a low value, since no guidelines were available as to its determination. Fertilizer application rates were used based on field investigations and interviews with farmers, relevant local, state, and private agencies, and fertilizer dealers. The N availability factor was based on tillage practices used in the watershed and guidelines given in the model users' manual.

Comparisons of predicted and observed outputs at Station 111, which is located at Monticello, were essentially verifications of model performance in the upstream portion of the watershed. Model results at this station were the cumulative responses of all upstream sub-watersheds. No additional adjustments of parameters could have been made to match the runoff volumes and N concentrations at Monticello. Therefore, comparisons of predicted and observed outputs at Monticello were an independent verification of model performance in the upstream sub-watersheds, individually and in combinations of more than half of the entire Lake Decatur watershed. The model performed very well with variations of results at.Monticello only -4 percent to 10 percent (tables 15 and 16).

Based on the satisfactory model performance upstream of Monticello and good matches of predicted values with the observations at Friends Creek and Long/Big Creek (tables 15 and 16), it was concluded that the model performed reasonably well in the entire Lake Decatur watershed.

Effects of BMPs on Nitrate Load into Lake Decatur

The major objective of this modeling study was to evaluate the effects of different BMP scenarios in reducing nitrate loadings into Lake Decatur. In order to accomplish such objectives, the BMPs must be incorporated into the model through changing values of the model parameters affected by the BMPs. There is no detailed guideline in the literature for such parameter changes. However, reduction efficiencies studied in agricultural fields and small watersheds are available from the literature. Efforts by the Interstate Commission on the Potomac River Basin (ICPRB) to reduce nutrient loads into the Chesapeake Bay basin proved very valuable. The efforts included a major data collection program and water quality modeling studies, as published by Camacho (1990, 1992), Camacho and Blasenstein (1992), and Thomann et al. (1994). The most useful information from these studies was related to nutrient reduction efficiencies of agricultural and urban BMPs. Even though the results might differ slightly from region to region, the efficiency factors for evaluating BMPs reported in the literature provide a starting base derived from field experience. Figure 70 summarizes the efficiency factors for removing N by individual BMPs and BMP combinations. These efficiencies could provide some guidelines for the individual agricultural fields and small sub-watersheds in the Lake Decatur watershed. However, relationships between N reduction efficiencies in Lake Decatur and N reduction efficiencies at



CNT = Conventional tillage
CST = Conservation tillage
NM = Nutrient management
FP = Farm plan

DRY/ED = Dry extended detention ponds
WP = Wet ponds
WP/ED = Wet ponds/extended detention
WET = Stormwater wetlands
WET/ED = Extended detention wetlands
WET/NT = Natural wetlands
POND/WET = Pond wetlands systems

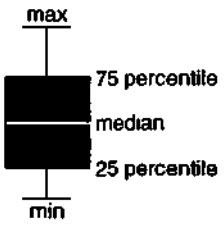


Figure 70. Nitrogen reduction efficiencies of BMPs (Camacho, 1992)

different sub-watersheds of the Lake Decatur watershed due to different types of BMPs and their combinations must be established. Such relationships were developed using the calibrated AGNPS model.

As described above, the AGNPS model was calibrated reasonably well for moisture and land cover conditions in the spring and the fall. Historical data showed that nitrate concentrations in Lake Decatur were higher during the spring season and during more frequent storms with low rainfall intensities. Therefore, model parameters calibrated using the April 11-12, 1994 storm were representative of the watershed conditions during spring, and would be suitable for BMP evaluations. However, the storm of April 11-12, 1994 was an extreme event, resulting in lower concentrations of nitrate (<10 ppm) throughout the Lake Decatur watershed (table 15) due to the dilution effects of high water volumes. Therefore, the rainfall depth and duration of the storm was not used for a base run to compare reductions of nitrate loadings into Lake Decatur due to different BMP scenarios. A more frequent and low-intensity rainfall would produce high N concentrations comparable to historical high observations, and would be more appropriate for such a base run. A 1-year, 12-hour rainfall event, expected during the spring season, was selected as a base storm event for evaluating BMPs. Based on the historical frequency distributions of rainstorms in Central Illinois, rainfall depth for such a storm was found to be 2.17 inches (Huff and Angel, 1989).

The AGNPS model was run for the base storm using the calibrated parameters for the spring storm. This base storm produced reasonably high nitrate concentrations, comparable to historical records, at most of the gaging stations. However, the concentrations at a few stations were even higher compared to historical high values. Therefore, a few parameters were slightly revised to produce reasonably high nitrate concentrations at all the stations, and the revised parameters are shown in table 19. As may be seen from this table, the curve number and leaching extraction coefficient for Goose Creek, Camp Creek, Friends Creek, and Lake Decatur and adjacent creeks were revised from those presented in table 17.

Table 19. Revised "AGNPS" Parameters and Key Inputs for the 1-Year, 12-Hour Base Storm

Sub-watershed	*Curve number*	*Runoff extraction coefficient*	*Leaching extraction coefficient*	*Nutrient N decay (percent)*	*application N rate (Ib/ac)*	*N availability factor (percent)*
Fisher	80	0.05	0.35	1	200	60
Big Ditch	80	0.05	0.35	1	200	60,
Mahomet	80	0.05	0.25	1	200	60
Goose Creek	75	0.05	0.30	1	200	60
Camp Creek	75	0.05	0.30	1	200	60
Monticello	80	0.05	0.25	1	200	60
Friends Creek	75	0.05	0.30	1	200	60
Cisco	75	0.05	0.20	1	200	60
Lake Decatur and adjacent creeks	75	0.05	0.30	1	200	60

A few sub-watersheds and combinations of sub-watersheds (see figure 66 for their orientations), located evenly throughout the Lake Decatur watershed were selected to apply the BMPs and analyze reductions and reduction efficiencies of nitrate loadings into Lake Decatur. These sub-watersheds and sub-watershed combinations were:

1. Big Ditch
2. Friends Creek
3. Upstream of Fisher
4. Upstream of Monticello
5. Downstream of Monticello
6. Entire Lake Decatur watershed

Four broad types of BMPs were evaluated: nutrient management, mitigation projects, conservation practices, and a combination of nutrient management and conservation practices. Different scenarios of these four BMPs were applied to the above listed sub-watersheds and combinations of sub-watersheds, and reductions and reduction efficiencies of nitrate loadings into Lake Decatur were computed. Each BMP category is discussed below.

Nutrient Management

In this category, the fertilizer application rate was varied in each of the six sub-basins and sub-basin combinations, one at a time, and changes in N concentrations throughout the watershed and the watershed outlet, as predicted by the AGNPS model, were computed. N concentration computed at the watershed outlet was used to calculate the nitrate loading into Lake Decatur. Therefore, the primary focus during these evaluations was the N concentrations at the watershed outlet.

Four nutrient application rates were studied: starting with the base application rate of 200 pounds per acre (lb/ac), then with the application rate of fertilizer reduced by 25 percent, 50 percent, and 75 percent. These reductions do not necessarily mean reduction of total yearly application, and could be due to nutrient application several times during the year, which would reduce effective application rate or.nutrient availability before a storm event.

In all, 18 nutrient management runs were made. In the base run, a fertilizer application rate of 200 lb/ac, uniformly applied throughout the watershed, was used (table 19). The three fertilizer reduction rates (25 percent, 50 percent, and 75 percent) were applied individually to the six sub-watersheds and sub-watershed combinations. Table 20 shows N concentrations from the base run and from the 18 management runs at Lake Decatur (watershed outlet) and some selected stations. All the results are not shown, and N concentrations only at the key locations (stations) are shown for clarity and emphasis. Table 20 also presents the corresponding N reduction efficiencies (in parentheses), which were computed as percentage differences of N concentrations under a BMP scenario (called post-BMP N-loading) with respect to N concentrations from the base run (called pre-BMP N-loading). The N concentration and efficiency results are also shown graphically in figures 71a and 71b, respectively.

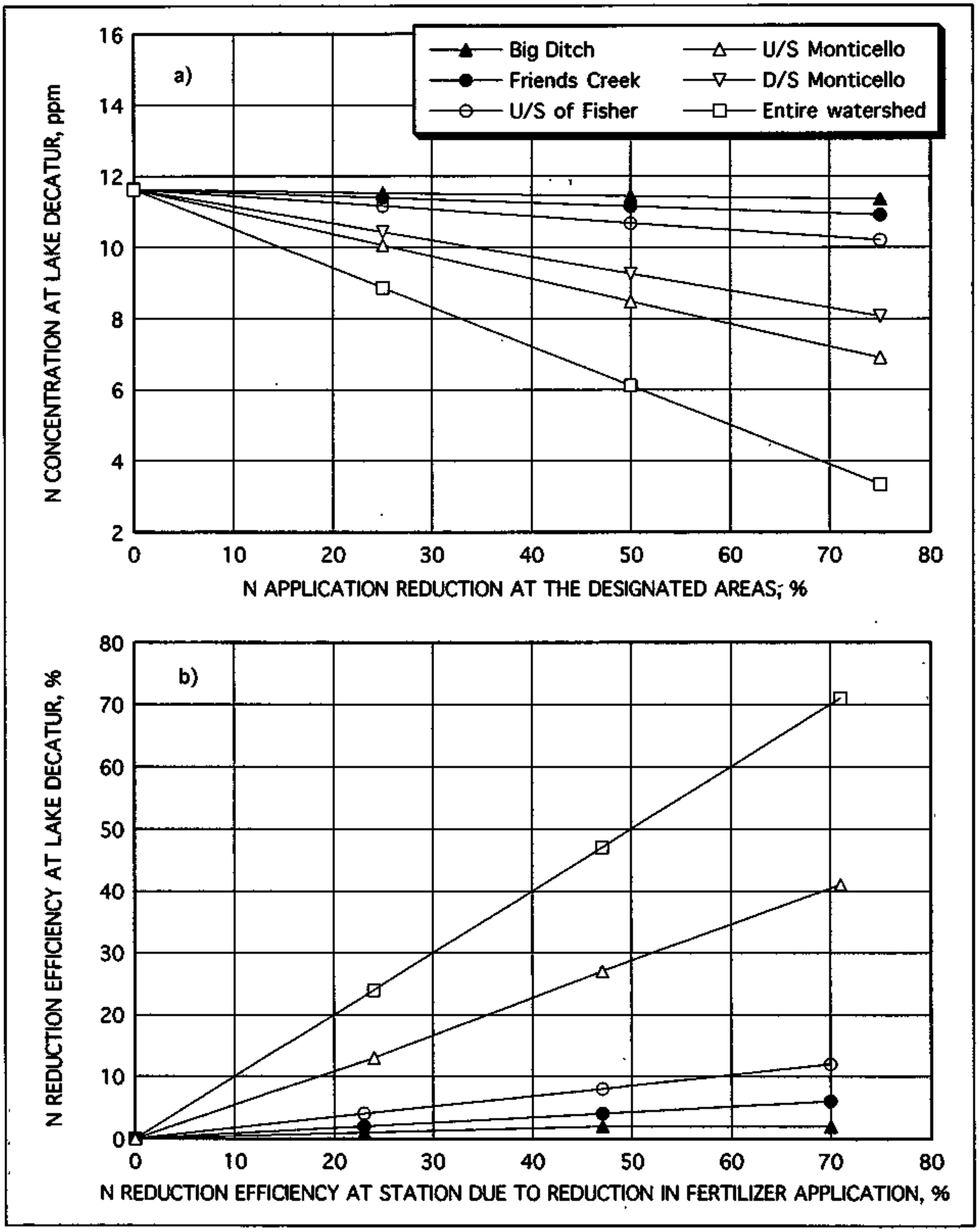


Figure 71. Effects of nutrient management in the Lake Decatur watershed: a) variations of N loading to Lake Decatur and b) relationships of N reduction efficiencies

Table 20. Variations of Nitrogen Concentrations and Reduction Efficiencies in the Lake Decatur Watershed due to Reductions in Fertilizer Applications at Various Sub-watersheds (one-year storm: rainfall 2.17 inches, duration 12 hours)

Fertilizer application sub-watershed	*Reduction of fertilizer applications (percent)*	*N concentration in ppm (and reduction efficiency in percent)*				
		Big Ditch	*Friends Creek*	*Fisher*	*Monticello*	*Lake Decatur*
Entire watershed (base run)	0	12.64	12.78	11.53	12.66	11.63
Big Ditch	25	9.69(23)				11.53 (1)
Friends Creek	25		9.79(23)			11.39 (2)
Upstream of Fisher	25			8.84(23)		11.16 (4)
Upstream of Monticello	25				9.66(24)	10.06 (13)
Downstream of Monticello	25					10.44 (10)
Entire watershed	25					8.87 (24)
Big Ditch	50	6.74(47)				11.44 (2)
Friends Creek	50		6.80(47)			11.15 (4)
Upstream of Fisher	50			6.15(47)		10.68 (8)
Upstream of Monticello	50				6.66(47)	8.48 (27)
Downstream of Monticello	50					9.25 (20)
Entire watershed	50					6.11 (47)
Big Ditch	75	3.79(70)				11.35 (2)
Friends Creek	75		3.81 (70)			10.91 (6)
Upstream of Fisher	75			3.45(70)		10.21 (12)
Upstream of Monticello	75				3.65(71)	6.91 (41)
Downstream of Monticello	75					8.07 (31)
Entire watershed	75					3.35 (71)

Figure 71a shows reduction functions of N concentration loadings to Lake Decatur with respect to reduction of fertilizer application rate at different sub-watersheds. The functions were linear, inversely proportional to application reduction in a specific sub-watershed. The lake nitrogen loadings were also inversely proportional to the area of nutrient management. For example, nutrient management in the entire watershed had the highest impact, followed by upstream of Monticello, downstream of Monticello, upstream of Fisher, Friends Creek, and Big Ditch. Figure 71b also confirms the hypothesis of linear N reductions at Lake Decatur with respect to nutrient application rate and surface area of nutrient management within the Lake Decatur watershed. In this report, N concentration of the inflowing water into Lake Decatur is referred to as N concentration at Lake Decatur.

Mitigation Projects

This scenario is for the evaluation of mitigation projects that could be implemented in the watershed to reduce nitrate loading to Lake Decatur. Such projects could include wetlands, buffer strips, detention ponds, etc. Camacho (1992) reported nitrate removal efficiencies by these projects (figure 70). These projects would definitely affect some of the sensitive model parameters, which would be shown in the model results. Unfortunately, these effects are not yet quantified. Mitigation projects would definitely affect the N decay factor, since these types of projects provide longer retention time of the runoff water, and create environments for degradation of the nutrients. The N decay factor represents percent reduction of N in the water while flowing through the cell. Therefore, effects of mitigation projects were studied by varying the N decay factor at the six sub-watersheds and combinations of sub-watersheds.

The base run decay rate was 1 percent uniform throughout the watershed (table 19). Due to mitigation projects, this rate was accelerated to factors of 2, 3, and 5, independently in each of the six sub-watersheds and combinations of sub-watersheds. These N decay factors were selected based on sensitivity analysis of the AGNPS model. The N concentrations at the key stations and at Lake Decatur under these 18 scenarios, as predicted by the AGNPS model, are shown in table 21, and plotted in figure 72a. As can be seen in figure 72a, the N reduction function is nonlinear and inversely proportional to multiple factor of the decay rate. The function is also inversely proportional to the area of mitigation projects. An exception is seen in figure 72a where projects downstream of Monticello are more effective than projects upstream although total upstream area is larger. This indicates that mitigation projects close to the lake might have a more direct impact and thus be more effective in comparison to projects further away from the lake. Similar responses were noticed in cases of conservation practices, as discussed later.

Table 21. Variations of Nitrogen Concentrations and Reduction Efficiencies in the Lake Decatur Watershed due to Accelerated Decay of Nitrogen Resulting from Mitigation Projects at Various Sub-watersheds (one-year storm: rainfall 2.17 inches, duration 12 hours)

Mitigation project sub-watershed	*Increase in N decay (factor)*	*N concentration in ppm (and reduction efficiency in percent)* *Big Ditch*	*Friends Creek*	*Fisher*	*Monticello*	*Lake Decatur*
Entire watershed (base run)	1	12.64	12.78	11.53	12.66	11.63
Big Ditch	2	11.85 (6)				11.60(0.3)
Friends Creek	2		11.61 (9)			11.53 (1)
Upstream of Fisher	2			9.76(15)		11.32 (3)
Upstream of Monticello	2				9.57(24)	10.01(14)
Downstream of Monticello	2					9.28(20)
Entire watershed	2					8.02(31)
Big Ditch	3	11.12(12)				11.58(0.4)
Friends Creek	3		10.55(17)			11.45 (2)
Upstream of Fisher	3			8.28(28)		11.06 (5)
Upstream of Monticello	3				7.41(41)	8.87(24)
Downstream of Monticello	3					7.42(36)
Entire watershed	3					5.76 (50)
Big Ditch	5	9.78(23)				11.54 (1)
Friends Creek	5		8.71(32)			11.30 (3)
Upstream of Fisher	5			6.01(48)		10.66 (8)
Upstream of Monticello	5				4.74(63)	7.48(36)
Downstream of Monticello	5					4.77 (59)
Entire watershed	5					3.29 (72)

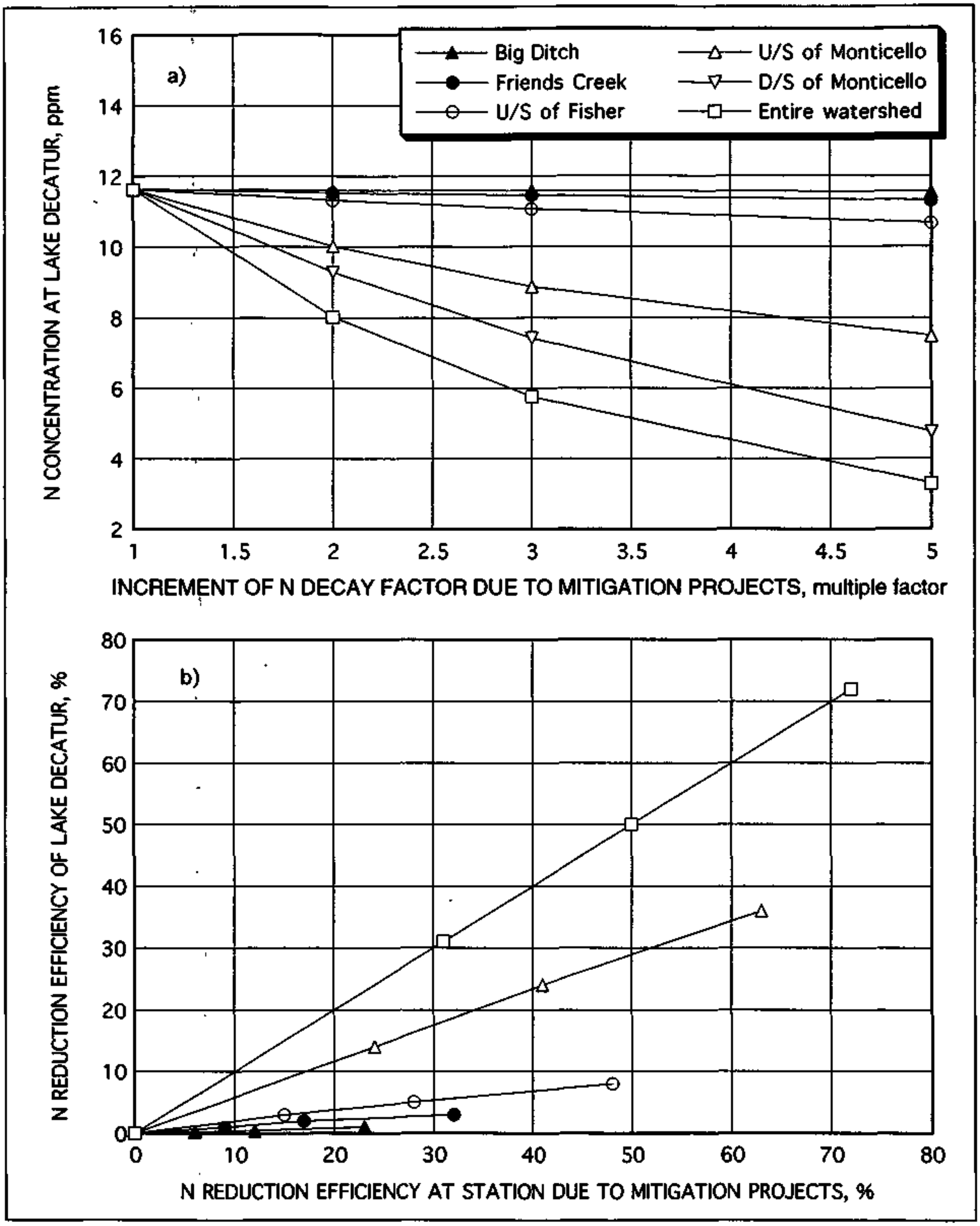


Figure 72. Effects of mitigation projects in the Lake Decatur watershed: a) variations of N loading to Lake Decatur and b) relationships of N reduction efficiencies

Table 21 also shows the N reduction efficiencies at Lake Decatur and the corresponding sub-watersheds with mitigation projects. These efficiencies are shown graphically in figure 72b and are approximately linear. This agrees with figure 71b, reduction efficiencies due to nutrient management. It means, in general, that there is a direct correlation of N reduction efficiency within a certain area of the watershed with the reduction efficiency at Lake Decatur, regardless of BMPs. It must be noted that the BMPs considered so far are assumed to affect the N loading only and not runoff. This assumption was made to simplify the evaluation of BMPs without including several factors at once. The effect of runoff reductions will be discussed next in relation to conservation practices.

Conservation Practices

Conservation practices such as conservation tillage increase land cover and preferential flow paths through the undisturbed and unsaturated soil zone causing increased infiltration, and thus reducing runoff potential. This results in the reduction of the SCS runoff curve number. As per SCS data (USDA-SCS, 1972), curve number reduction from poor to good cover conditions ranges from 2 to 19 percent. The reduction could go up to 87 percent in the case of pasture and range lands with contouring. Tillage practice affects N availability at the surface due to different mixing of nutrient and the soil. There is no guideline available on the N availability factor for conservation tillage. However, based on cover conditions, conservation practices were evaluated by varying the curve numbers.

Here also, 18 scenarios were evaluated by reducing the curve numbers 10 percent, 20 percent, and 30 percent in each of the six sub-watersheds and combinations thereof. These scenarios were completely different from the scenarios evaluated above. The earlier scenarios simply reduced nitrate loadings, not runoff. However, the conservation practice scenarios reduced runoff and affected nitrate loading. Concentration depends on contaminant load and water volume. Because water volume had been affected in these scenarios, N concentrations were either reduced or increased depending upon the amounts of N load and runoff volume. As a result, N concentrations at Lake Decatur were mixed, reduced, and increased, due to reduction of curve numbers.

Table 22 and figure 73a show the changes in runoff volumes due to the changes in curve numbers. Table 23 and figure 73b show N concentration in Lake Decatur with the corresponding concentrations in the sub-watersheds where conservation practices were applied. Figure 74 and table 23 (numbers in parentheses) show the N concentration reduction efficiencies. As indicated above, there were negative efficiencies of N reduction, which were more pronounced in cases of conservation practices in upstream sub-watersheds. As shown in figure 73b, the conservation practices were more effective when these were applied either to the entire watershed or downstream of Monticello.

Table 22. Variations of Runoff Volumes in the Lake Decatur Watershed due to Reductions in SCS Curve Numbers at Various Sub-watersheds Resulting from Conservation Practices (one-year storm: rainfall 2.17 inches, duration 12 hours)

Conservation practice sub-watershed	*Reduction curve number (percent)*	*Runoff volumes in inches* *Big Ditch*	*Friends Creek*	*Fisher*	*Monticello*	*Lake Decatur*
Entire watershed (base run)	0	0.67	0.47	0.67	0.63	0.57
Big Ditch	10	0.37				0.55
Friends Creek	10		0.24			0.54
Upstream of Fisher	10			0.37		0.49
Upstream of Monticello	10				0.34	0.39
Downstream of Monticello	10					0.48
Entire watershed	10					0.30
Big Ditch	20	0.16				0.54
Friends Creek	20		0.09			0.52
Upstream of Fisher	20			0.16		0.43
Upstream of Monticello	20				0.15	0.28
Downstream of Monticello	20					0.42
Entire watershed	20					0.13
Big Ditch	30	0.04				0.54
Friends Creek	30		0.01			0.51
Upstream of Fisher	30			0.05		0.40
Upstream of Monticello	30				0.04	0.21
Downstream of Monticello	30					0.39
Entire watershed	30					0.03

Table 23. Variations of Nitrogen Concentrations and Reduction Efficiencies in the Lake Decatur Watershed due to Reductions in SCS Curve Numbers at Various Sub-watersheds Resulting from Conservation Practices (one-year storm: rainfall 2.17 inches, duration 12 hours)

Conservation practice sub-watershed	*Reduction curve number (percent)*	*N concentration in ppm (and reduction efficiency in percent)* *Big Ditch*	*Friends Creek*	*Fisher*	*Monticello*	*Lake Decatur*
Entire watershed (base run)	0	12.64	12.78	11.53	12.66	11.63
Big Ditch	10	8.06(36)				11.66 (-0.3)
Friends Creek	10		9.60(25)			11.54 (1)
Upstream of Fisher	10			7.39(36)		12.04 (-4)
Upstream of Monticello	10				8.80(30)	10.83 (7)
Downstream of Monticello	10					10.28 (12)
Entire watershed	10					8.48 (27)
Big Ditch	20	6.03(52)				11.76 (-1)
Friends Creek	20		7.97(38)			11.62 (0.1)
Upstream of Fisher	20			5.54(52)		12.94 (-11)
Upstream of Monticello	20				6.94(45)	12.03 (-3)
Downstream of Monticello	20					9.89 (15)
Entire watershed	20					6.81 (41)
Big Ditch	30	5.10(60)				11.84 (-2)
Friends Creek	30		7.23(43)			11.71 (-1)
Upstream of Fisher	30			4.69(59)		13.74 (-18)
Upstream of Monticello	30				6.01(53)	14.15 (-22)
Downstream of Monticello	30					9.84 (15)
Entire watershed	30					5.61 (52)

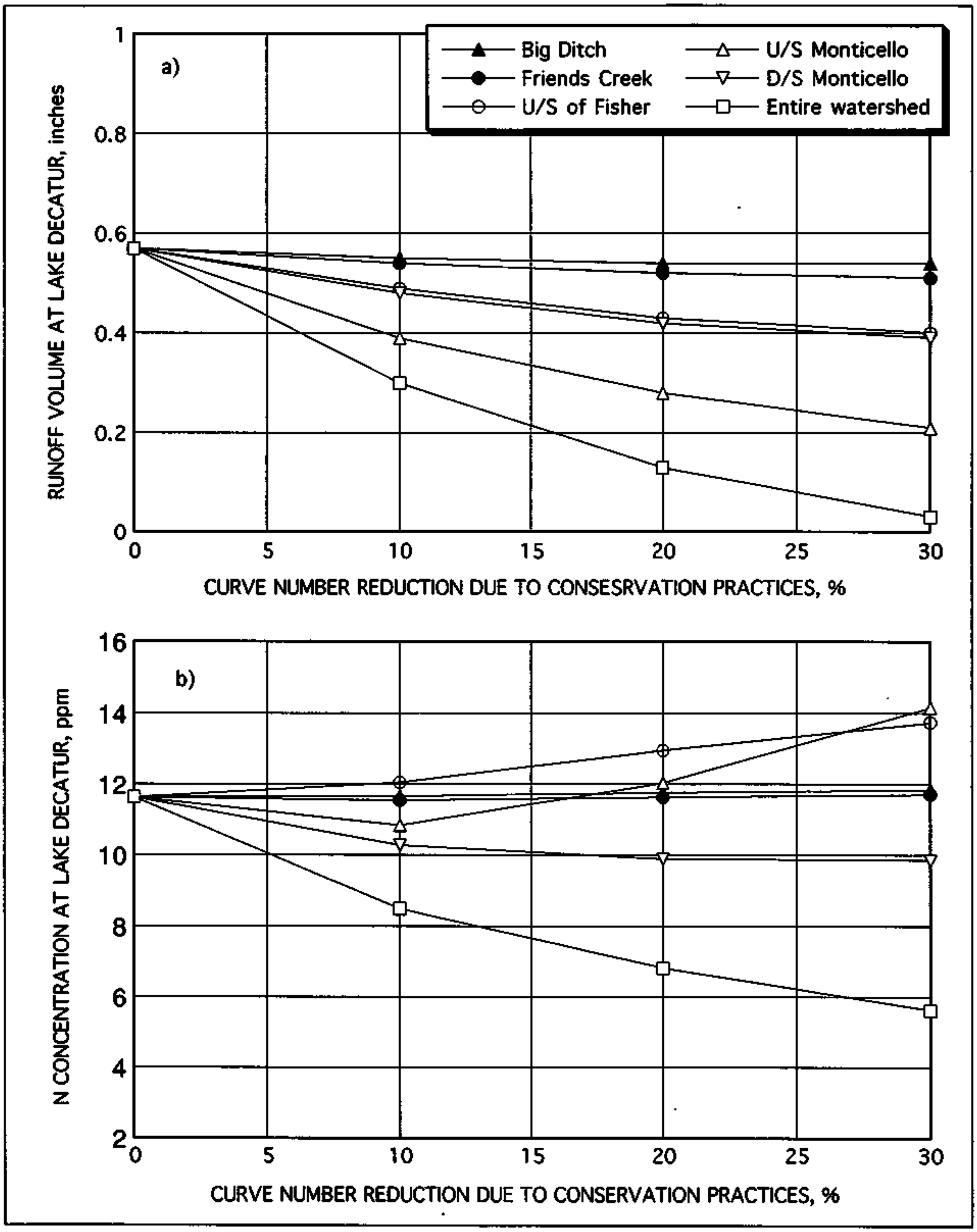


Figure 73. Effects of conservation practices in the Lake Decatur watershed on:
a) runoff volume and b) N loading to Lake Decatur

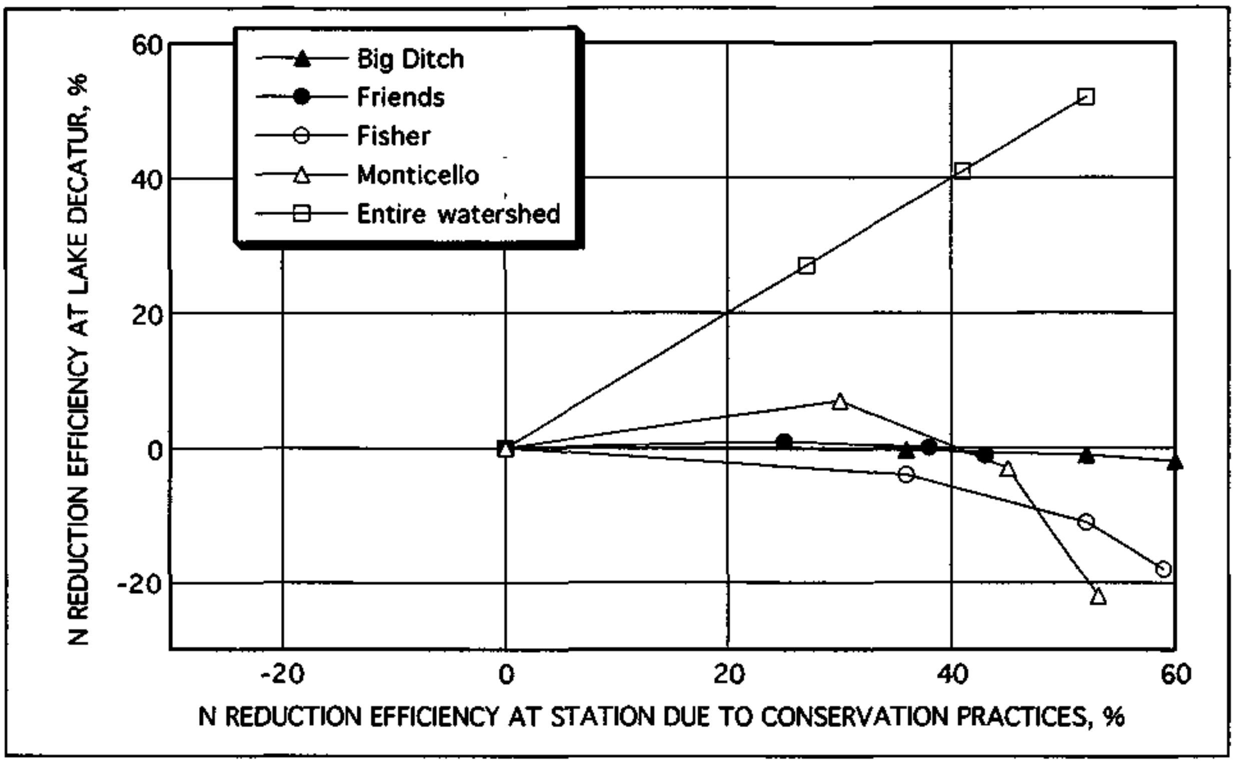


Figure 74. Relationships on N reduction efficiencies caused by conservation practices on sub-watersheds of the respective stations

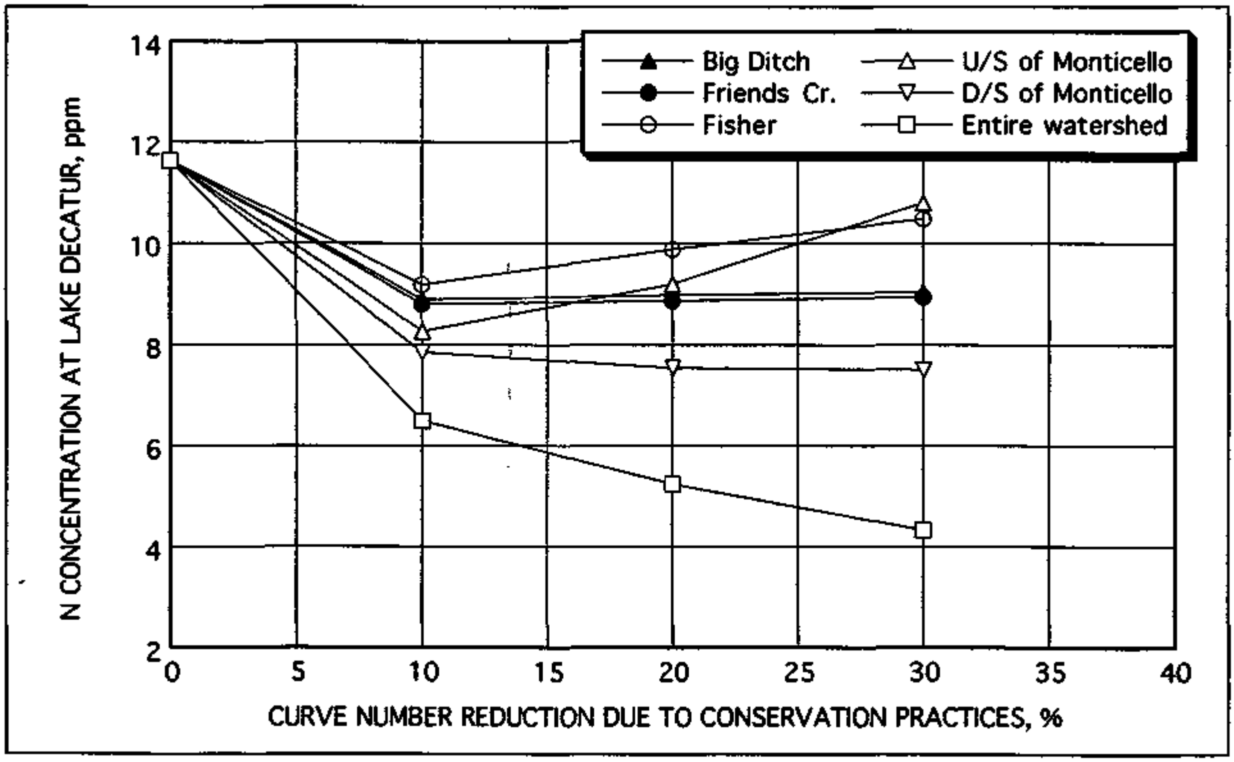


Figure 75. Variations of N loading to Lake Decatur due to combinations of 25 percent fertilizer reduction in the entire watershed and conservation practices in sub-watersheds

Therefore, thorough investigation and great care must be taken in implementing conservation practices that affect both runoff and nitrate. These practices are definitely effective in reducing runoff, as well as flooding. However, based on model results, they might not necessarily be effective in reducing N concentrations due to different mixing and dilution rates. Historically, conservation practices were introduced to reduce soil erosion, increase soil moisture retention in agricultural lands, and reduce flooding. These practices were not intended to reduce concentrations of agricultural chemicals carried by storm water runoff.

Combination of Nutrient Management and Conservation Practices

When conservation practices were combined with nutrient management, the results became more effective. The above conservation runs were repeated in combination with a 25 percent reduction of fertilizer application throughout the entire Lake Decatur watershed. The results are shown in table 24 and figure 75. As can be seen, the N concentrations were much lower than the base values and never exceeded them.

Table 24. Variations of Nitrogen Concentrations in the Lake Decatur Watershed due to Combinations of 25 Percent Fertilizer Reduction in the Watershed and Conservation Practices in the Sub-watersheds Reducing SCS Curve Numbers (one-year storm: rainfall 2.17 inches, duration 12 hours)

	Reduction	*N concentration in ppm*				
Conservation practice sub-watershed	*curve number (percent)*	*Big Ditch*	*Friends Creek*	*Fisher*	*Monticello*	*Lake Decatur*
Entire watershed (base run)	0	12.64	12.78	11.53	12.66	11.63
Big Ditch	10	6.26				8.89
Friends Creek	10		7.40			8.80
Upstream of Fisher	10			5.73		9.18
Upstream of Monticello	10				6.76	8.27
Downstream of Monticello	10					7.85
Entire watershed	10					6.50
Big Ditch	20	4.73				8.97
Friends Creek	20		6.18			8.86
Upstream of Fisher	20			4.34		9.87
Upstream of Monticello	20				5.36	9.19
Downstream of Monticello	20					7.55
Entire watershed	20					5.25
Big Ditch	30	4.03				9.03
Friends Creek	30		5.63			8.93
Upstream of Fisher	30			3.71		10.47
Upstream of Monticello	30				4.66	10.79
Downstream of Monticello	30					7.51
Entire watershed	30					4.34

Summary

The AGNPS model was reasonably calibrated for the Upper Sangamon River basin draining into Lake Decatur and generated useful results for evaluation of different BMP scenarios within the watershed in reducing N loading into Lake Decatur. Nutrient management was found to be the most effective and reliable BMP in reducing nitrate loading into the lake. Nitrate loading into the lake was directly proportional to the amount and area of nutrient application. Similarly, mitigation projects that remove nitrate were also effective in reducing nitrate loading into the lake. However, it is difficult to quantify the extent to which mitigation projects are needed.

Conservation practices reduced runoff but could either reduce or increase N concentrations in the lake depending upon their locations of applications with respect to the lake. Conservation practices applied over the entire watershed and over areas closer to the lake reduce nitrate concentrations in the lake. Conservation practices applied over areas further away from the lake tend to increase nitrate concentrations in the lake if nutrient applications remain the same. However, when conservation practices are combined with nutrient management they are found to be very effective.

The N reduction efficiencies shown in figure 70 (Camacho, 1992) are based on field observations and modeling in agricultural fields and small watersheds in the Chesapeake Bay basin. These efficiencies provide a general guideline on expected N reductions from different BMPs and their combinations, which could be combined with efficiency results shown in figures 71b, 72b, and 74 to find optimum locations or areas of a specific BMP or combinations of BMPs to reduce nitrate loadings into Lake Decatur.

Bibliography

American Society for Testing and Materials. 1982. *Annual Book of ASTM Standards, Part 31, Water.*

Arnold, J.G., J.R. Williams, A.D. Nicks, and N.B. Sammons. 1990. *SWRRB - A Basin Scale Simulation Model for Soil and Water Resources Management,* Texas A & M Press. 210 p.

Bicknell, B.R., J.C. Imhoff, J.L. Kittle, Jr., A.S. Donigan, Jr., and R.C. Johanson. 1993. *Hydrologic Simulation Program - FORTRAN (HSPF) User's Manual for Release 10.* Report No. EPA/600/R-93/174.

Bouchard, D.C., M.K. Williams, and R.Y. Surampalli. 1992. Nitrate Contamination of Groundwater: Sources and Potential Health Effects. *Journal of AWWR,* pp. 85-90.

Buchanan, T.J., and W.P. Somers. 1969. Discharge Measurements at Gaging Stations, Book 3, Chapter A8. In *Techniques of Water Resources Investigations of the United States Geological Survey,* U.S. Government Printing Office, Washington, DC.

Camacho, R. 1990. *Agricultural BMP Nutrient Reduction Efficiencies: Chesapeake Bay Watershed Model BMPs.* ICPRB Report 90-7, Rockville, MD.

Camacho, R. 1992. *Chesapeake Bay Program Nutrient Reduction Strategy Reevaluation. Report #8: Financial Cost Effectiveness of Point and Nonpoint Source Nutrient Reduction Technologies in the Chesapeake Bay Basin.* ICPRB Report 92-4, Rockville, MD.

Camacho, R., and A. Blasenstein. 1992. *Potomac River Basin Model Project: Second Progress Report.* ICPRB, Report 92-3, Rockville, MD.

City of Decatur, Water Production Division, Public Works Department. 1995. *1994 Annual Report.* Decatur, EL.

Cooperative Extension Service, University of Illinois. 1983. *Estimating Your Soil Erosion Losses with the Universal Soil Loss Equation (USLE).* Circular 1220, Cooperative Extension Service, College of Agriculture, University of Illinois at Urbana-Champaign, IL.

Demissie, M., and A.Q. Khan. 1993. *Influence of Wetlands on Streamflow in Illinois.* Illinois State Water Survey Contract Report 561, Champaign, IL.

Donigian, A.S., Jr., and N.H. Crawford. 1976. *Modeling Pesticides and Nutrients on Agricultural Lands.* Report No. EPA-600/2-76-043, USEPA, Athens, GA.

Durgunoglu, A, H.V. Knapp, and S.A. Changnon. 1987. *PACE Watershed Model (PWM): Volume 1, Model Development.* Illinois State Water Survey Contract Report 437, Champaign, IL.

Engel, B.A., R. Srinivasan, J. Arnold, C. Rewerts, and S.J. Brown. 1993. *Nonpoint Source (NPS) Pollution Modeling Using Models Integrated with Geographic Information Systems (GIS).* Proceedings, IAWQ 1st International Conference on Diffuse (Nonpoint) Pollution: Sources, Prevention, Impact, Abatement, Chicago, IL, September 19-24, pp. 685-690.

Fitzpatrick, W.P., W.C. Bogner, and N.G. Bhowmik. 1987. *Sedimentation and Hydrologic Processes in Lake Decatur and Its Watershed.* Illinois State Water Survey Report of Investigation 107, Champaign, IL.

Frere, M.H., J.D. Ross, and L.J. Lane. 1980. *The Nutrient Submodel. CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems.* Conservation Research Report 26, Agricultural Research Service, U.S. Department of Agriculture, Washington, DC, pp. 65-85.

Heatwole, CD., A.B. Bottcher, and K.L. Campbell. 1989. BASIN: A Basin-scale Nutrient Delivery Model for Coastal Plain Flatwoods. In *Application of Water Quality Models for Agricultural and Forested Watersheds,* D.B. Beasley and D.L. Thomas (eds.). Southern Cooperative Series Bulletin 38.

Hession, W.C. 1990. *Geographic Information System Technology and Water Quality Modeling: An Interface.* Proceedings, Application of Geographic Information Systems, Simulation Models, and Knowledge-based Systems for Land Use Management, Virginia Polytechnic and State University, Blacksburg, VA, November 12-14, pp. 339-349.

Hession, W.C, S. Mostaghimi, V.O. Shanholtz, P.W. McClellan, and K.L. Huber. 1989. *BMP Effectiveness Evaluation Using AGNPS and GIS,* American Society of Agricultural Engineers International Winter Meeting, New Orleans, LA.

Huff, F.A., and J.R. Angel. 1989. *Frequency Distributions and Hydroclimatic Characteristics of Heavy Rainstorms in Illinois.* Illinois State Water Survey Bulletin 70, Champaign, IL.

Illinois Department of Agriculture. 1994. *Illinois' T By 2000 County Transect Survey Procedures.* Springfield, IL.

Illinois Environmental Protection Agency. 1978. *Assessment and Classification of Illinois Lakes.* Volume 1, 208 Water Quality Management Planning Program, Springfield, IL.

Keeney, D.R., and T.H. DeLuca. 1993. Des Moines River Nitrate in Relation to Watershed Agricultural Practices: 1945 Versus 1980s. *Journal of Environmental Quality* 22:267-272.

Klepper, R. 1978. Nitrogen Fertilizer and Nitrate Concentrations in Tributaries of the Upper Sangamon River in Illinois. *Journal of Environmental Quality* 7(1): 13-22.

Klepper R., et al. 1974. *Fertilizer Application Rates and Nitrate Concentrations in Illinois Surface Waters.* Illinois Institute for Environmental Quality, Chicago, IL.

Knapp, H.V. 1988. *Fox River Basin Streamflow Assessment Model: Hydrologic Analysis.* Illinois State Water Survey Contract Report 454, Champaign, IL.

Knapp, H.V. 1990. *Kaskaskia River Basin Streamflow Assessment Model: Hydrologic Analysis.* Illinois State Water Survey Contract Report 499, Champaign, IL.

Knapp, H.V. 1994. *Sangamon River Basin Streamflow Assessment Model: Revised Analysis.* Study currently in progress.

Knisel, W.G., ed. 1980. *CREAMS: A Field-scale Model for Chemicals, Runoff, and Erosion from Agricultural Management System.* Conservation Research Report 26, USDA-SEA, Washington, DC. 640 p.

Laflen, J.M., H.P. Johnson, and R.O. Hartwig. 1978. Erosion Modeling on Impoundment Terraces. *Transactions of the ASAE* 21(6): 1131-1135.

Lynch, J.A., V.C. Bowersox, and C. Simmons. (In press.) *Precipitation Chemistry Trends in the United States: 1980-1993, Summary Report.* NADP, Nat. Res. Ecol. Lab, Colorado State University, Fort Collins, CO.

McKenna, D.P., and T.J. Bicki. 1990. *An Initial Evaluation of the Impacts of Pesticides on Groundwater in Illinois.* Illinois State Geological Survey/Illinois State Water Survey Cooperative' Groundwater Report 12. Illinois Department of Energy and Natural Resources.

Mitchell, J.K., B.A. Engel, R. Srinivasan, and S.S. Yang. 1993. Validation of AGNPS for Small Watersheds Using Integrated AGNPS/GIS System. *Water Resources Bulletin* 29(5):833-842.

Park, S.W., and J.T. Kim. 1995. *Validating AGNPS Model with Complex Topography in Central Korea.* Paper No. 952702. ASAE, 2950 Niles Rd., St. Joseph, MI.

Patrick, W.J., Jr. 1982. *Nitrogen Transformations in Submerged Soils.* American Society of Agronomy, Inc., Agronomy Series Number 22, Madison, WI.

Pierzynski, G.M., J.T. Sims, and G.F. Vance. 1994. *Soils and Environmental Quality.* Lewis Publishers, Ann Arbor, MI.

Prato, T., and H. Shi. 1990. A Comparison of Erosion and Water Pollution Control Strategies for an Agricultural Watershed. *Water Resources Research* 26(2): 199-205.

Smith, R.E., and J.R. Williams. 1980. Simulation of Surface Water Hydrology. In *CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems,* Conservation Research Report 26, Agricultural Research Service, U.S. Department of Agriculture, Washington, DC.

Soil Conservation Service. 1982. *Soil Survey of Champaign County, Illinois.* U.S. Department of Agriculture in cooperation with the Illinois Agricultural Experimental Station, Champaign, IL.

Stevenson, F.J. 1982. *Nitrogen in Agricultural Soils.* American Society of Agronomy, Inc., Agronomy Series Number 22, Madison, WI.

Thomann, R.V., J.R. Collier, A. Butt, E. Casman, and L.C. Linker. 1994. *Response of the Chesapeake Bay Water Quality Model to Loading Scenarios.* Chesapeake Bay Program Office, Annapolis, MD.

U.S. Department of Agriculture-Soil Conservation Service. 1972. Hydrology. In *National Engineering Handbook,* U.S. Department of Agriculture, Soil Conservation Service, Washington, DC.

U.S. Environmental Protection Agency. 1975. *Report on Lake Decatur, Macon County, Illinois.* Corvallis Environmental Research Laboratory and Environmental Monitoring and Support Laboratory, Las Vegas, Nevada, USEPA Region V, National Eutrophication Survey Working Paper Series No. 302., Chicago, IL.

U.S. Environmental Protection Agency. 1984. *Users Manual for Pesticide Root Zone Model (PRZM).* Report No. EPA/600/3-84-109.

Walker, R.D., and R.A. Pope. 1983. *Estimating Your Soil Erosion Losses with the Universal Soil Loss Equation (USLE).* Circular 1220, Agricultural Extension Service, College of Agriculture, University of Illinois at Urbana-Champaign.

Wei, T.C., and J.L. McGuinness. 1973. *Reciprocal Distance Squared Method, A Computer Technique for Estimating Area Precipitation,* ARS-NC-8, U.S. Agricultural Research Service, North Central Region, Coshocton, OH.

Wischmeier, W.H., and D.D. Smith. 1978. *Predicting Rainfall Erosion Losses,* Agricultural Handbook 537, U.S. Department of Agriculture, Washington, DC.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1987. *AGNPS, Agricultural Nonpoint Source Pollution Model: A Watershed Analytical Tool.* U.S. Department of Agriculture Conservation Research Report 35.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1989. AGNPS: A Nonpoint Source Pollution Model for Evaluating Agricultural Watersheds. *Journal of Soil and Water Conservation* 44(2): 168-173.

Young, R.A., M.A. Otterby, and A. Roos. 1982. A Technique for Evaluating Feedlot Pollution Potential. *Journal of Soil and Water Conservation* 37(1): 21-23.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