WATERSHED MONITORING AND LAND USE EVALUATION FOR THE LAKE DECATUR WATERSHED

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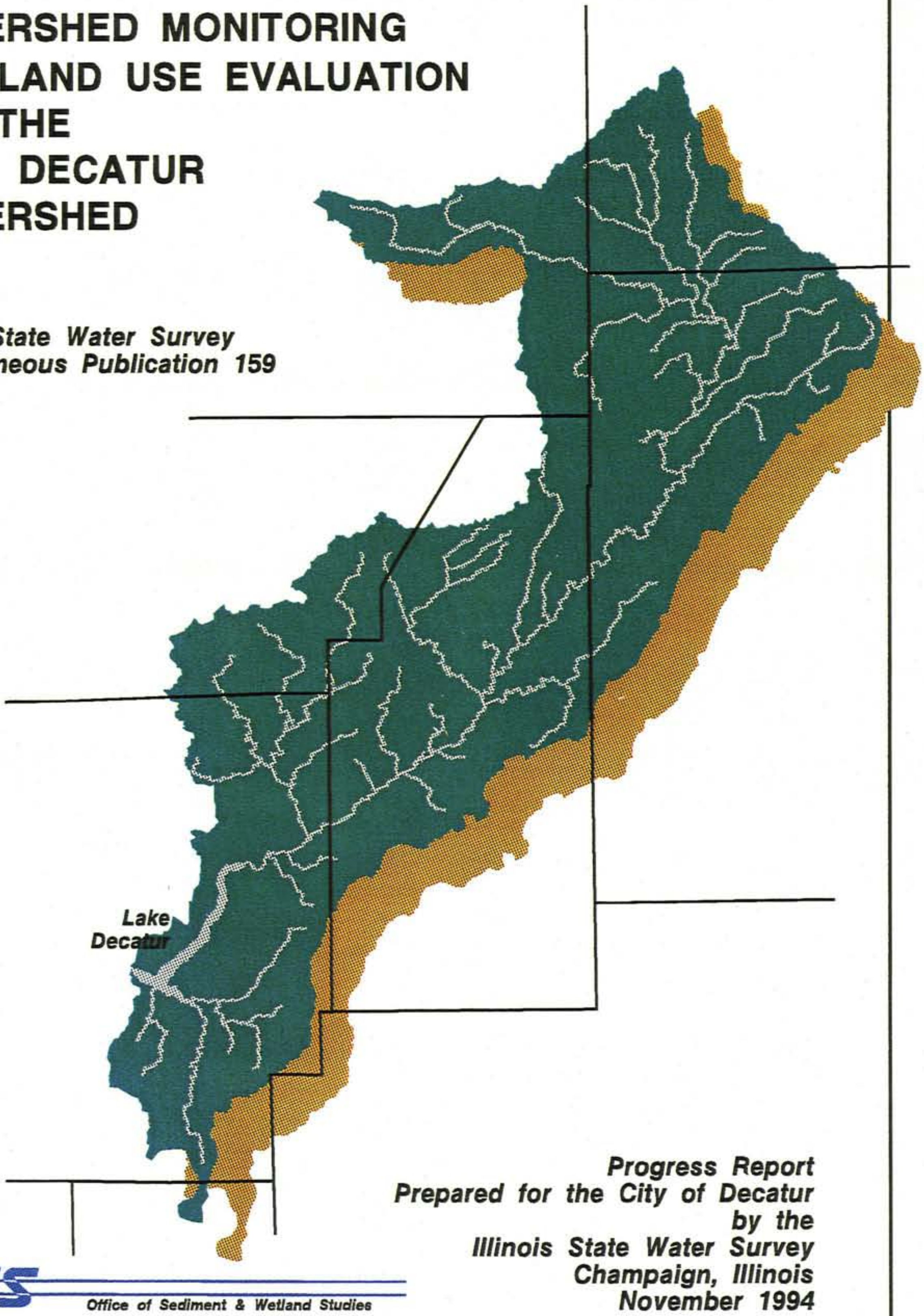

Progress Report
Prepared for the City of Decatur
by the
Illinois State Water Survey
Champaign, Illinois
November 1994

Office of Sediment & Wetland Studies

Watershed Monitoring and Land Use Evaluation for the Lake Decatur Watershed

Annual Progress Report

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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 city has been issued eight nitrate warnings from the Illinois Environmental Protection Agency (IEPA) 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). The nitrate concentrations in the lake started to exceed the MCL starting in 1980. Prior to 1980, the MCL was exceeded only in 1967. Since 1980, the nitrate concentration in Lake Decatur has exceeded the MCL every year except for 1993. 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 under compliance for IEPA drinking water standards.

Review of 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.

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.

The 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 of nitrate 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.

Water quality samples are collected at each of the 11 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 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. In the lower part of the watershed the precipitation for the period was near normal. The runoff as measured by the streamflow at the gaging stations was also above normal for the upper portion of the watershed. Frequency analyses for both precipitation and streamflow have not yet been done to determine their rank based on the historical record, but it is expected that the data collection period is one of the wettest yean on record.

The nitrate concentrations in the main river stations ranged from a low of 3 mg/1 to a high of 12 mg/1, while for the tributary streams the range was from 5 to 15 mg/1. The highest concentrations were measured in April, May, and June. The nitrate concentrations were generally higher at the tributary streams than at the main river stations.

Big Ditch and Goose Creek had the highest nitrate-nitrogen concentrations at 15.3 and 14.1 mg/1, while Friends Creek had the lowest maximum concentration at 11.4 mg/1.

Even though the main water quality concern at the lake is nitrate concentrations, the critical issue for watershed management is nitrate loads. It is impossible to reduce the nitrate concentrations without reducing the nitrate load. Preliminary nitrate load calculations were made based on the first year of data. The calculations and our procedures will be improved as more data are collected.

For the tributary streams, the annual nitrate loads range from a low of 27 pounds per acre (lbs/acre) for Long Creek to a high of 48 lbs/acre for Big Ditch. Next to Big Ditch, Camp Creek generated the highest nitrate load at 46 lbs/acre. The other tributaries, Friends Creek, Goose Creek, and the upper Sangamon upstream of Fisher generated nitrates at almost a uniform rate ranging from 35 to 42 lbs/acre. For the main river stations, the nitrate loads were 37, 37, and 42 lbs/acre at Monticello, Mahomet, and Fisher, respectively. Based on the first-year data, it can be concluded that the source of nitrate in Lake Decatur is truly dispersed throughout the watershed.

As a tool for evaluating the effects of best management practices (BMPs) on nitrate load, a mathematical model known as Agricultural Non-Point Source model (AGNPS) has been selected. The model has already been developed for one of the sub-watersheds, Big Ditch, and is in the process of being implemented for the whole watershed. Once the model is fully implemented, it will be possible to evaluate the cumulative effects of BMPs at several locations in the watershed on the nitrate levels in Lake Decatur.

Another major task of the project is to identify management alternatives that include alternative land use practices and mitigation projects to remedy the nitrate problem. This component of the project is under progress with the cooperation of the county Soil and Water Conservation Districts (SWCDs). The SWCDs are in the process of generating detailed, up-to-date land use information that can be used in the project to identify alternative land use practices. As soon as the data collection and processing are completed, a detailed land use database will be created for the entire watershed. A Technical Advisory Committee will also be created to evaluate the data and information that have been gathered during the project and also to recommend appropriate BMPs for implementation.

Watershed Monitoring and Land Use Evaluation for the Lake Decatur Watershed

by
Illinois State Water Survey
Champaign, IL

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 33 million gallons per day in 1991. 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, and 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. These warnings were issued 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 been given a grant by 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.

This progress report is a product of the first-year of data collection and analysis. Several components under progress are not included in this report, which emphasizes the establishment and results of the monitoring program and general hydrologic analyses for the basin. The report is organized into six sections: Introduction, Background, Hydrology of the Lake Decatur Watershed, Hydrologic and Water Quality Monitoring, Mathematical Modeling, and Management Alternatives. 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 one year of data collection; the section on mathematical modeling presents the progress in the development of a model to evaluate the effects of best management practices (BMPs) on nitrate loading into Lake Decatur; and the section on management alternatives discusses the issue of developing land use management alternatives to solve the water quality problem in Lake Decatur.

Acknowledgments

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

Several other city officials and staff have also been very cooperative and supportive: Erik C. Brechnitz, Mayor; James C. Bacon, Jr., City Manager; Bruce A. McNabb, Public Works Director; Stephen F. John, Council Member; James R. Mayhugh, Sr., Water Production Manager; and John A. Smith, Plant Maintenance Manager.

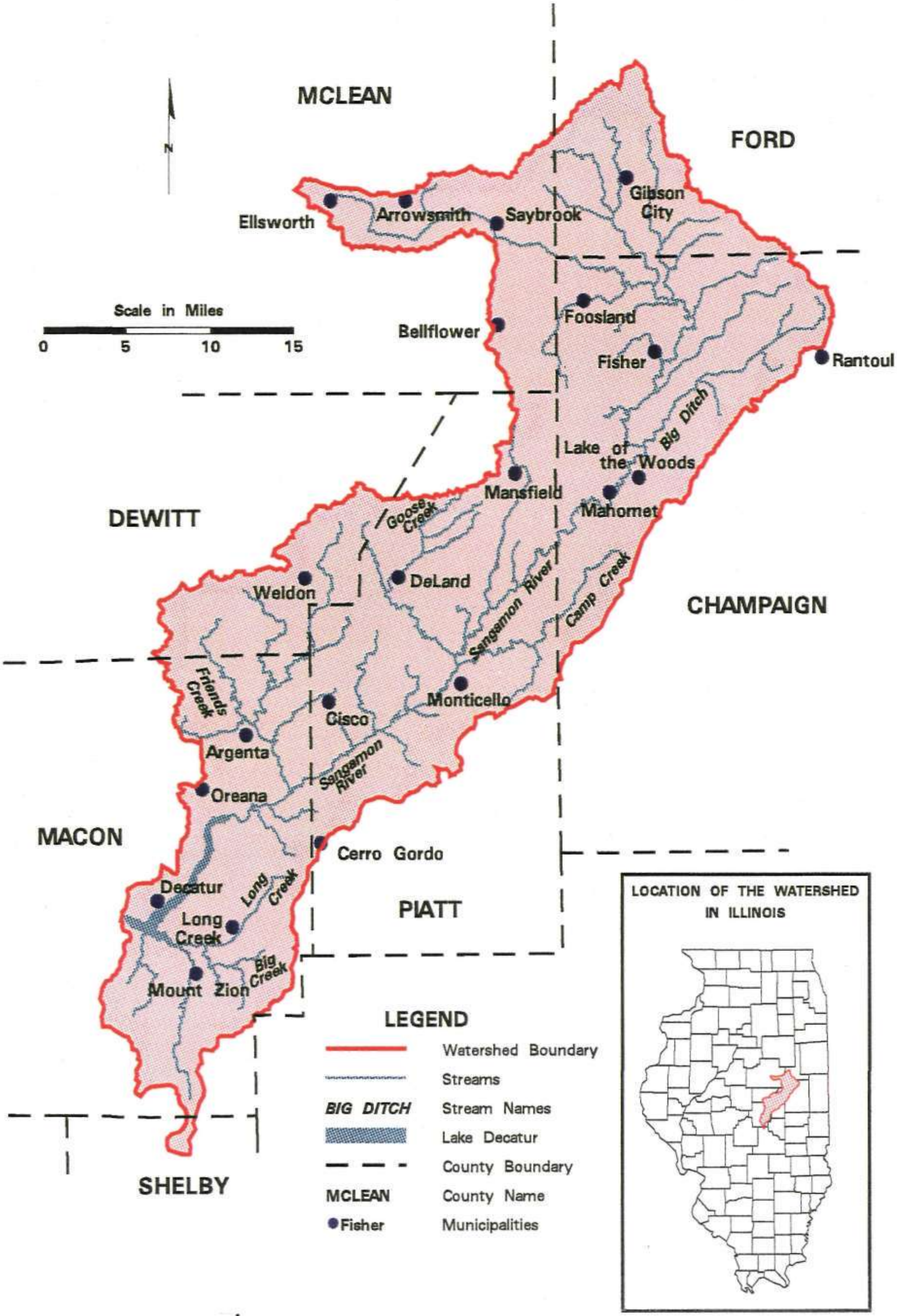


Figure 1. Location of the Lake Decatur watershed

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

We gratefully acknowledge the laboratory analyses performed by the chemists in the Office of Analytical & Water Treatment Services at the Illinois State Water Survey in Champaign. Assistance in data entry and analysis was provided by Heather Karr and David Preston, undergraduate students in computer engineering at the University of Illinois at Urbana-Champaign. Brett Ward, an undergraduate in Geography at Illinois State University, provided the Geographic Information System (GIS) work presented in this report. Becky Howard typed and assisted in the production of the report; Eva Kingston and Sarah Hibbeler edited it; and Linda Hascall provided advice on illustration layout.

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 installing 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 is 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, all the nitrate concentration data collected by the city since 1967 are plotted in figure 2, which 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

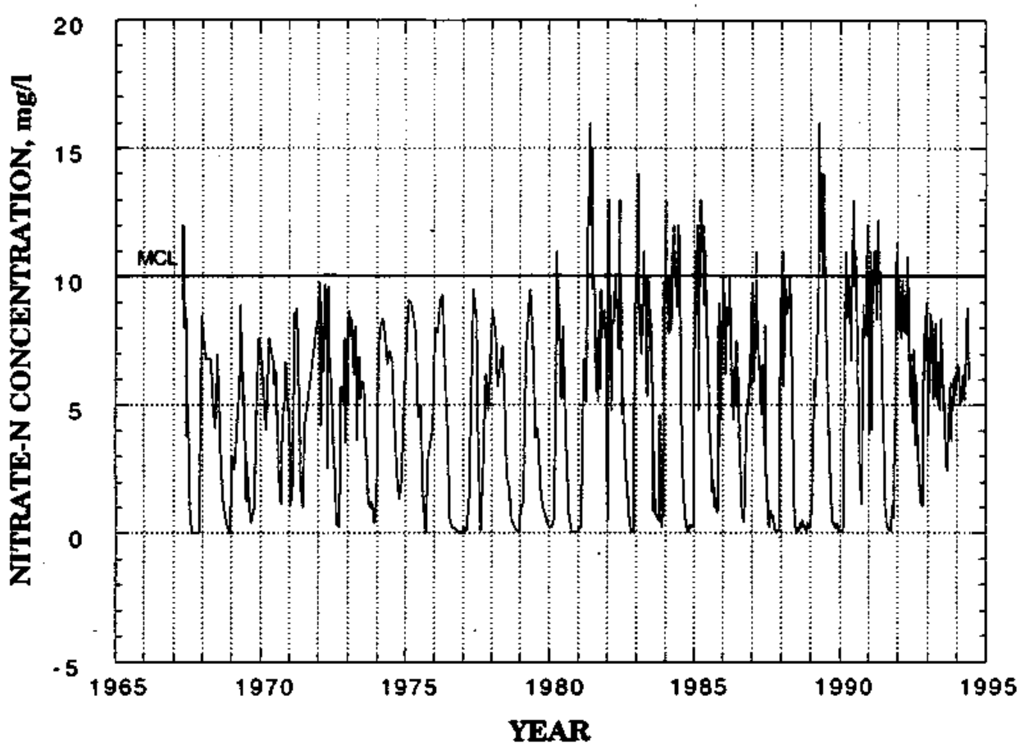


Figure 2. Nitrate concentrations in Lake Decatur from 1967-1994

exceeded only in 1967. Since 1980, the maximum nitrate concentration has equaled or exceeded the 10 mg/1 maximum contamination level (MCL), except for 1993. This fact is clearly illustrated in figure 3, which shows the annual maximum, minimum, and average nitrate concentrations in Lake Decatur for the last 27 years (City of Decatur, 1992). 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 thirteen years. The most recent warning was issued onJanuary 6, 1992, and rescinded on July 14, 1992 (City of Decatur, 1991).

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 1994. 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 and eventually in controlling the nitrate problem in Lake Decatur. One of the major tasks of this project is to collect relevant land use data that will provide better understanding of the correlation between land use and nitrate concentrations and loads. General data and a discussion of land use in the Lake Decatur watershed are presented in the following section. Much

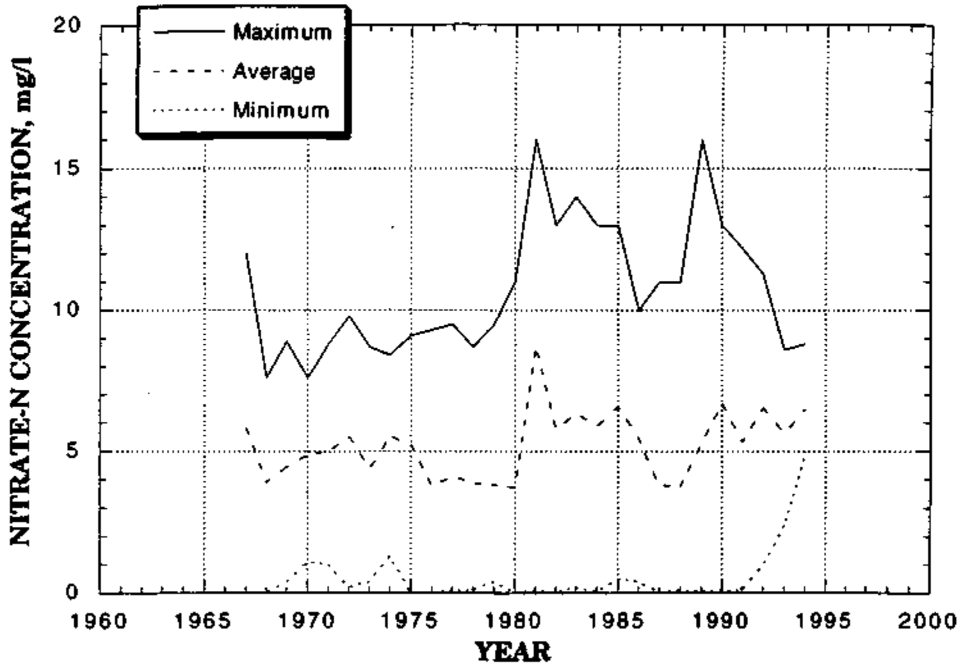


Figure 3. Annual maximum, minimum, and average nitrate concentrations in Lake Decatur from 1967-94

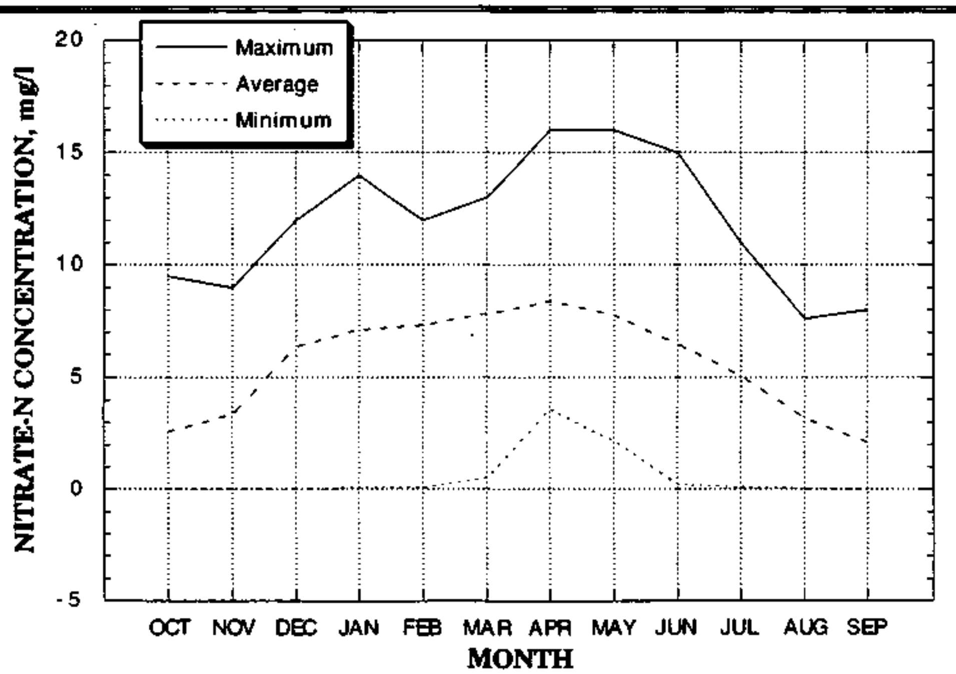


Figure 4. Monthly maximum, minimum, and average nitrate concentrations in Lake Decatur from 1967-94

more detailed land use data are being collected by the Soil and Water Conservation Districts for each county in the watershed.

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 1990 and 1991 varies from 54.2 to 33.5 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 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.

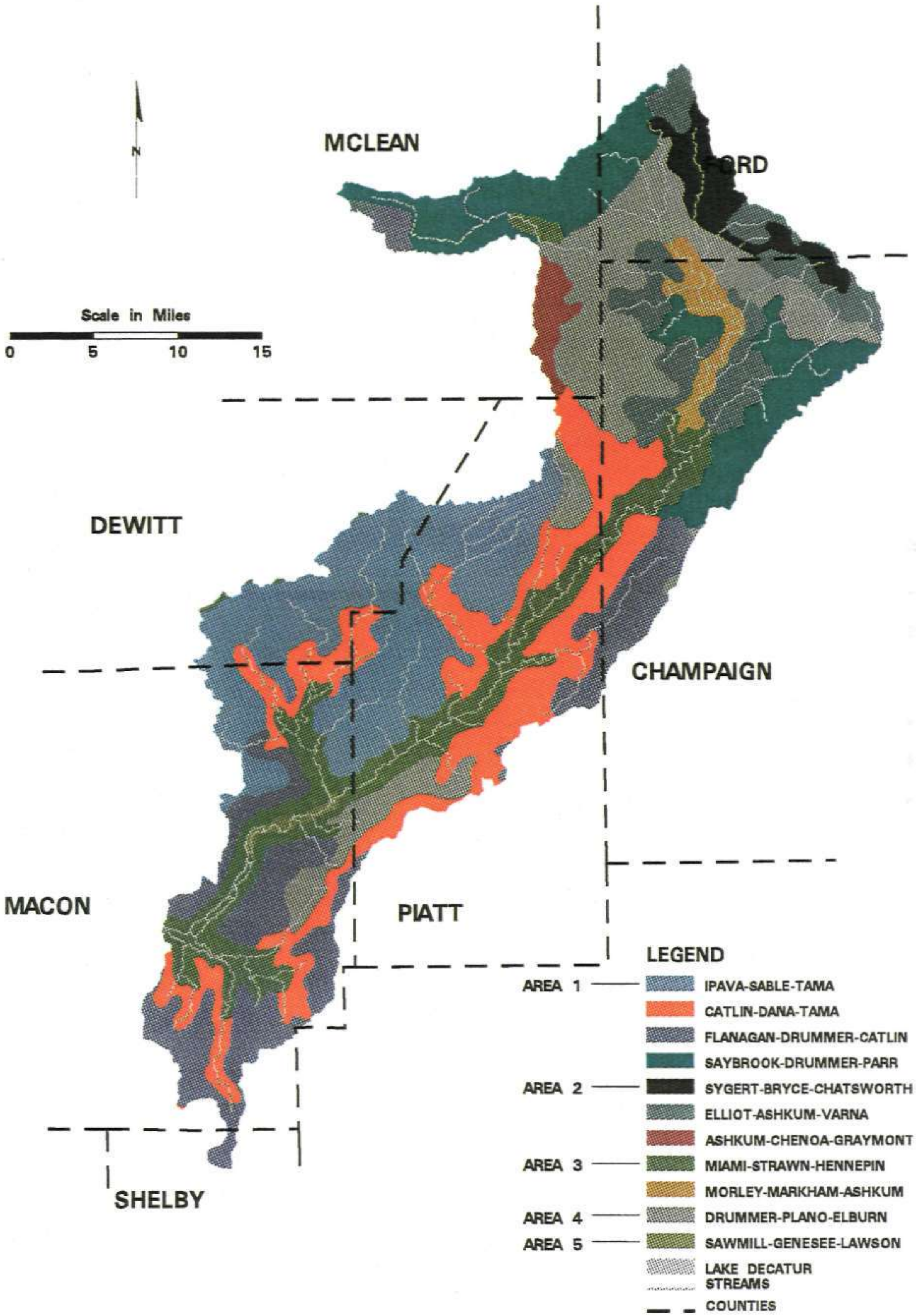


Figure 5. Map of soil association groups in the Lake Decatur watershed

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 1922-1983. 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.

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	-

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

Land Use in the Lake Decatur Watershed

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 6 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 in soybean acreage is a mirror image of 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 1992.

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 7 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 at the present.

The discussion on land use presented so 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 and major land uses, detailed information is lacking. Therefore, a more detailed investigation of all land uses in the watershed should include all potential sources of nitrate. The six Soil and Water Conservation Districts (SWCDs) in 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* developed by the Illinois Department of Agriculture (EDOA) and the 98 SWCDs in the state. The Transect Survey's purpose is "to gather information on the

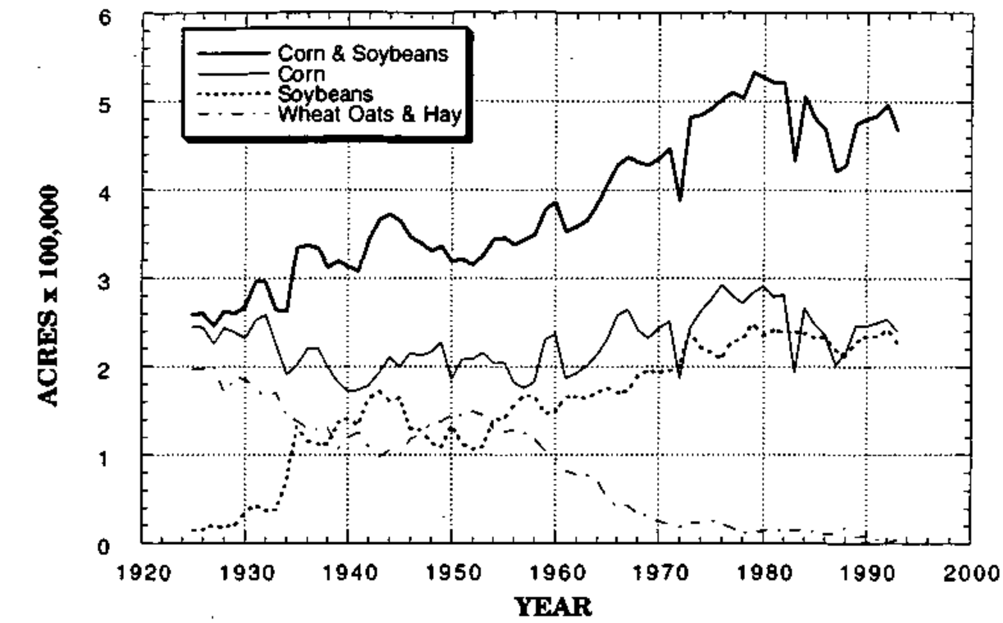


Figure 6. Acreages of selected crops in the Lake Decatur watershed based on Illinois Agricultural Statistics (IAS) data

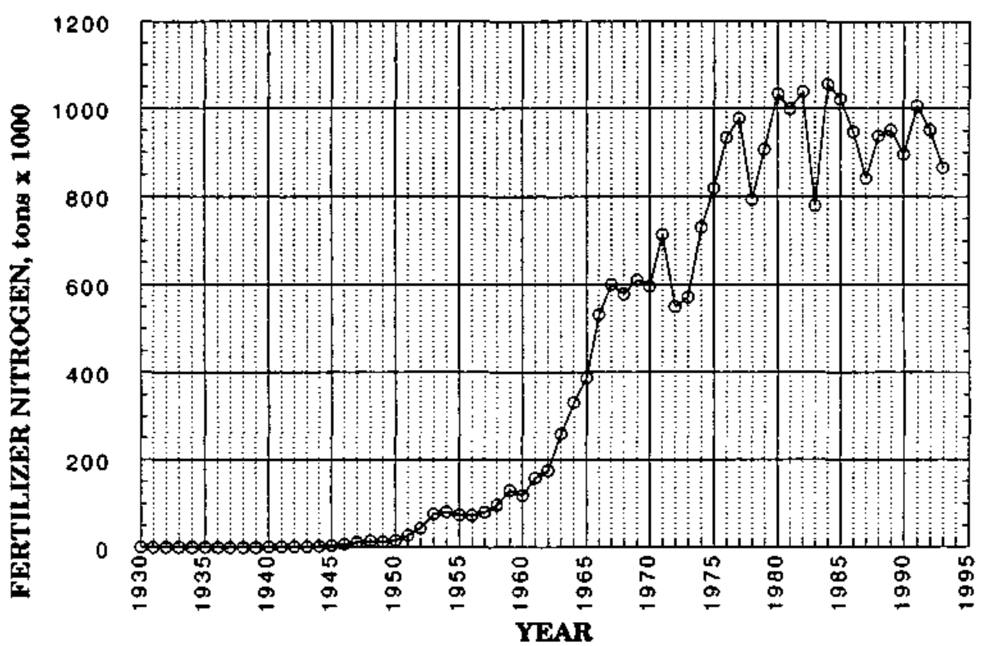


Figure 7. Total nitrogen fertilizer application in Illinois 1930 - 1993.

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." Each county retrieves a minimum of 456 sample sites along the route and collects only data for agricultural related land. The parameters collected are: present crop, previous crop, tillage system, percent slope, contouring factor, ephemeral erosion factor, T level, K factor, residue cover, slope length and P factor (terrace/strip cropping). Since this study encompasses all land use types, the ISWS subcontracted to the SWCDs 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 to include these areas, thereby attempting to evenly distribute the sampling route (IDOA, 1994). These additional data were collected only for that portion of the counties within the Lake Decatur watershed.

The actual collection of the data is near completion and the data are in the process of being forwarded to the ISWS. In the second year of this study, the data will be inspected, compiled, analyzed, and then input into the mathematical model to best represent existing land uses and their locations in the watershed and how this information relates to the concentrations and load.

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, we will use the mass balance concept 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 or 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 lightning 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. 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. Nitrates from natural sources reach surface waters as a result of precipitation, atmospheric deposition, surface runoff, and leaching from soils. 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 become more prominent than 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 here, and a more detailed review will be included in the final project report.

Inorganic nitrogen fertilizer is applied to soils in a form containing either nitrate (NO3") or ammonium (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 in soils is lost to the atmosphere by processes known as denitrification and volatilization. Denitrification is a process by which nitrate (NO3") is reduced to nitrogen (N2) and nitrous oxide (NO2) gases by denitrifying microorganisms. Volatilization of ammonia (NH3) is a process by which nitrogen escapes to the atmosphere as ammonia gas. The amount of nitrogen lost to the atmosphere through denitrification 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 ($NO3^-$), 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 includes 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 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 steams 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.

HYDROLOGY OF THE LAKE DECATUR WATERSHED

One of the major objectives of this project is 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).

Monthly Variations

Table 2 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 8 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

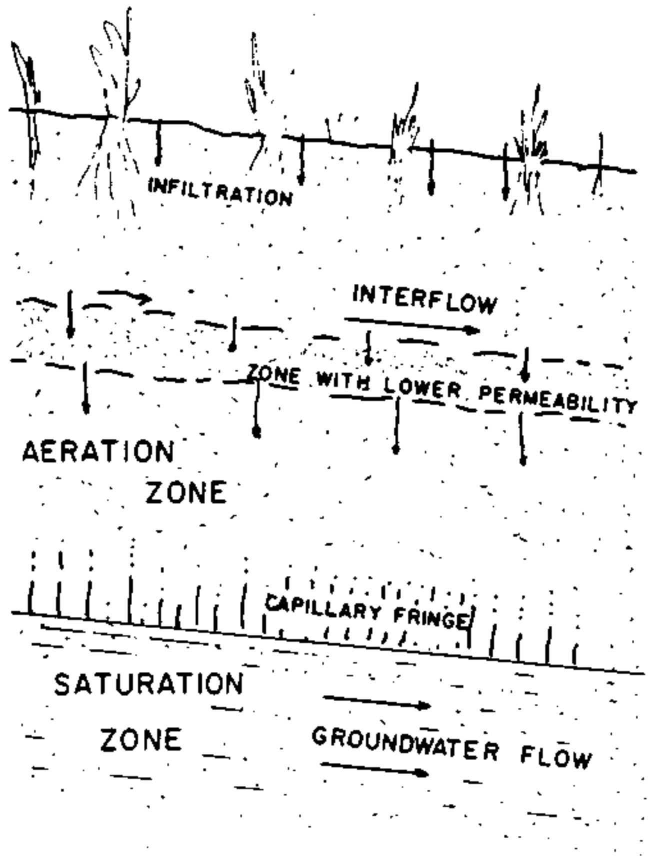


Figure 8. Schematic of flow paths from upland areas to streams

Table 2. Average Monthly Distribution of Precipitation (P), Evapotranspiration (ET), Streamflow (Q), and Change in Subsurface Storage (DS)

Month	*P*	*ET*	*Q*	*DS*
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

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 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 3 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

Table 3. 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

hybrid of the Chemical, Runoff, and Erosion from Agricultural Management System (CREAMS) water budget model. There is somewhat less water yield from watersheds having high percentage of pasture and forest cover compared to areas in row crops.

Figures 9 and 10 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 10 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 11 and in table 4. Table 4 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 and a greater percentage of the streamflow originates from

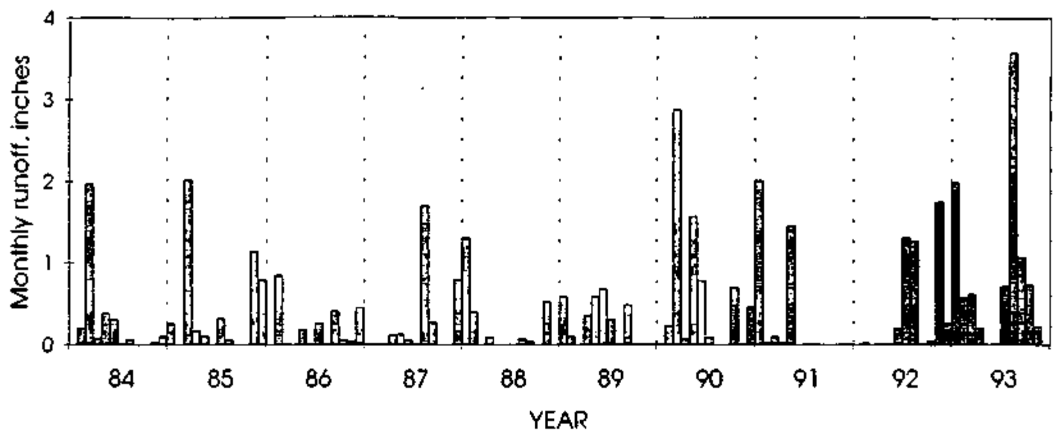


Figure 9. Estimates of monthly direct surface runoff, 1984-1993

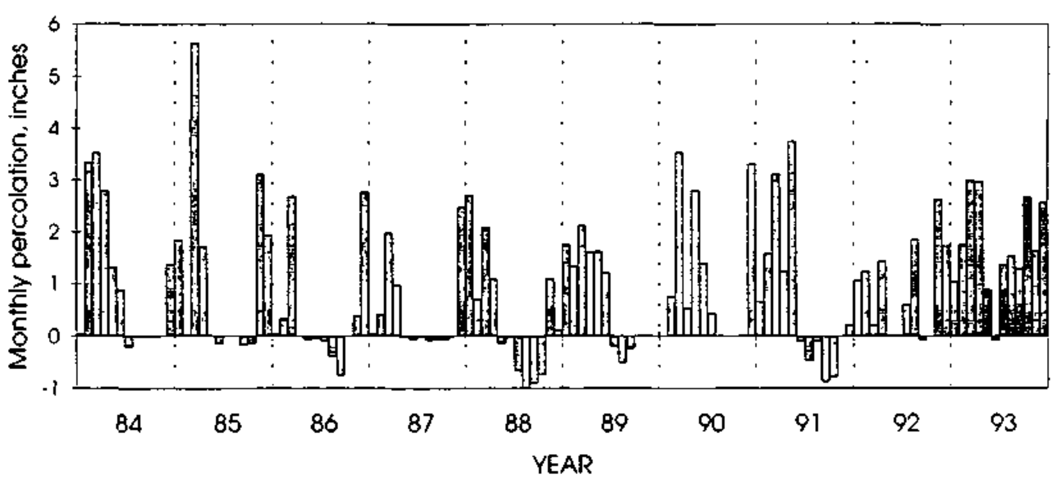


Figure 10. Estimates of monthly percolation through the soil, 1984-1993

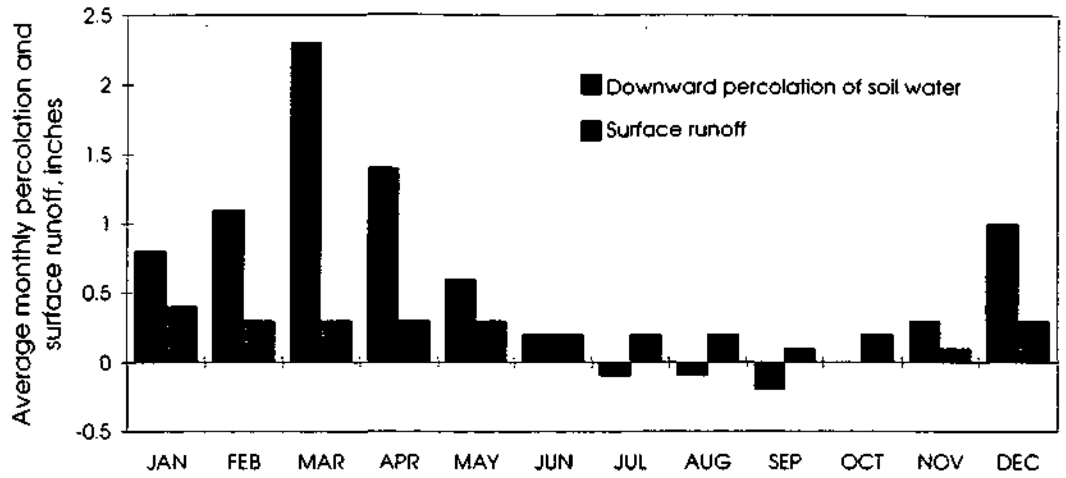


Figure 11. Monthly average percolation through the soil and surface runoff, 1949-1993

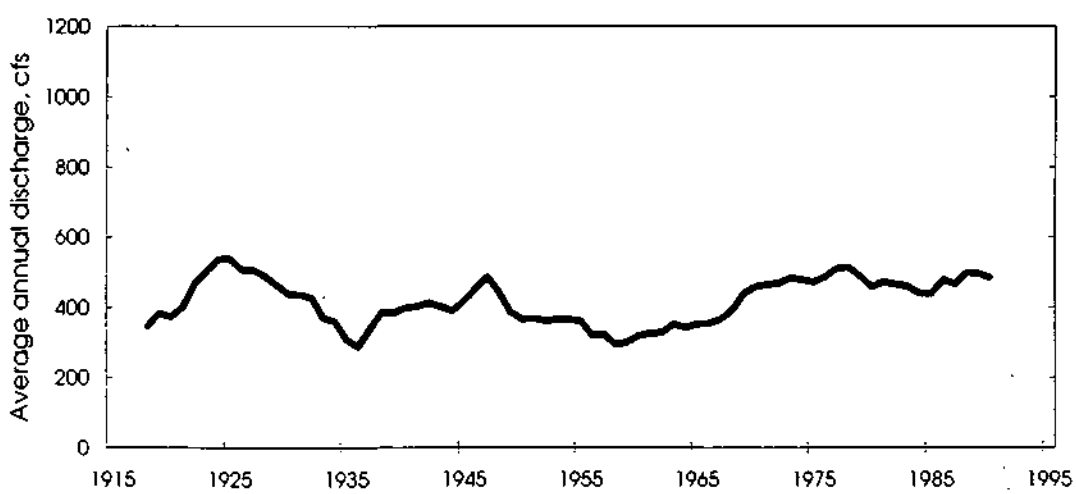


Figure 12. Annual series of average streamflow (shaded) and the 10-year average flow (dark line) for the Sangamon River at Monticello

Table 4. 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

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 5 lists the historical streamgaging records from the Lake Decatur watershed prior to the additional gages that were installed last year. The streamgages listed in table 5 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 a 79-year period of record, which is the longest continuous measurement of any stream in central Illinois.

Figure 12 shows the annual average flows measured at the Sangamon River at Monticello 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 13 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

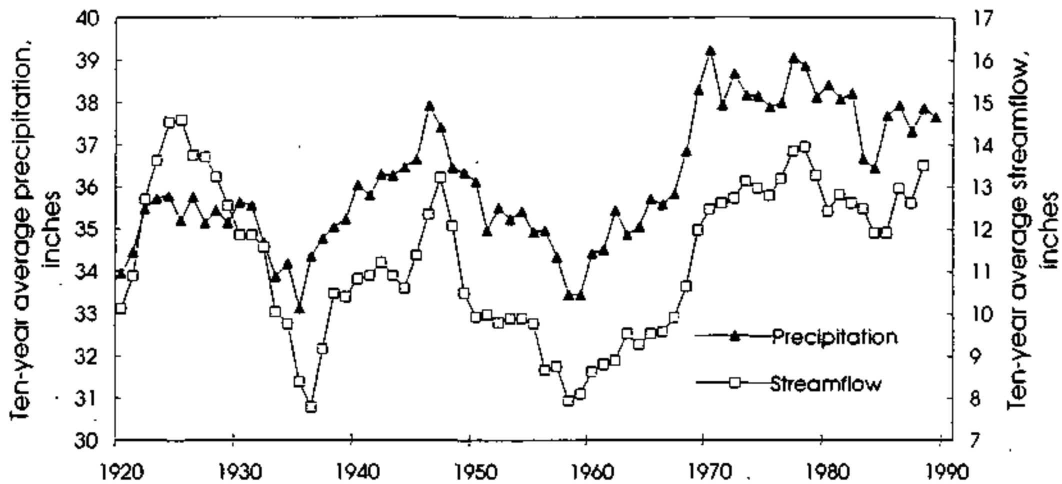


Figure 13. Comparison of the 10-year average streamflow at Monticello and the concurrent 10-year average precipitation over east-central Illinois

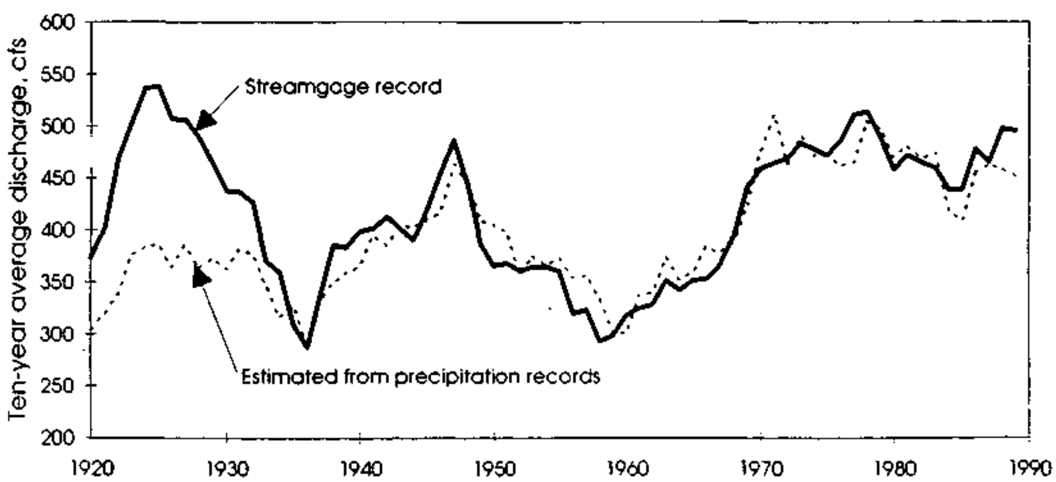


Figure 14. Comparison of the 10-year average streamflow at Monticello, measured versus estimated using precipitation data

Table 5. List of Streamgaging Stations in the Lake Decatur Watershed

Station name	*USGS gage number*	*Years of record*	*Drainage area (sq mi)*
Sangamon River at Fisher	05570910	1978-1993	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	1914-1993	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

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 14, 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 13 and 14, 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.

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 sub-watersheds are located adjacent to each other and their physiographic and soil characteristics are very similar. 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 12-14). 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 be close to 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 conducted 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 (the 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 6 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 15 charts the flow frequencies for three of these stations: Camp Creek, Goose Creek, and Big Ditch. 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.

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 7. As indicated earlier, the gaging 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).

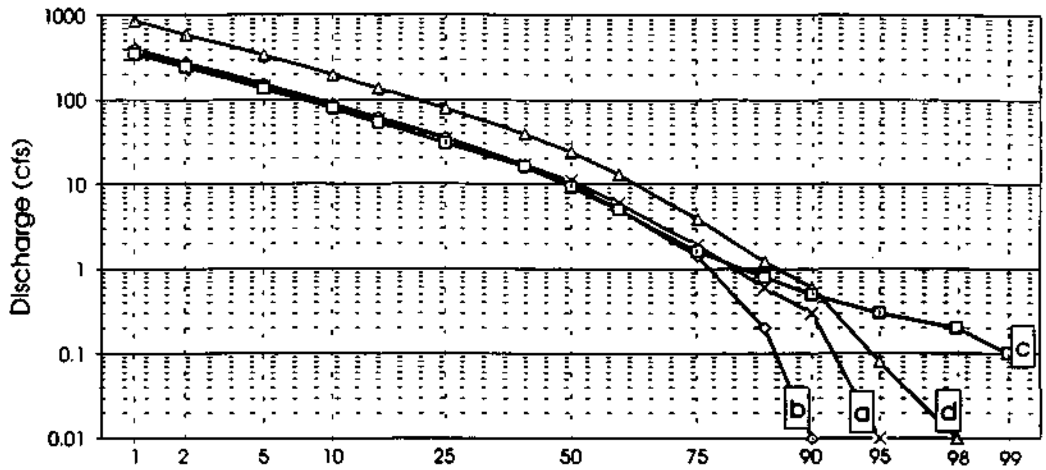


Figure 15. Comparison of long-term flow frequencies for:
a) Goose Creek near Deland, b) Camp Creek near White Heath,
c) Big Ditch near Fisher, and d) Friends Creek near Argenta

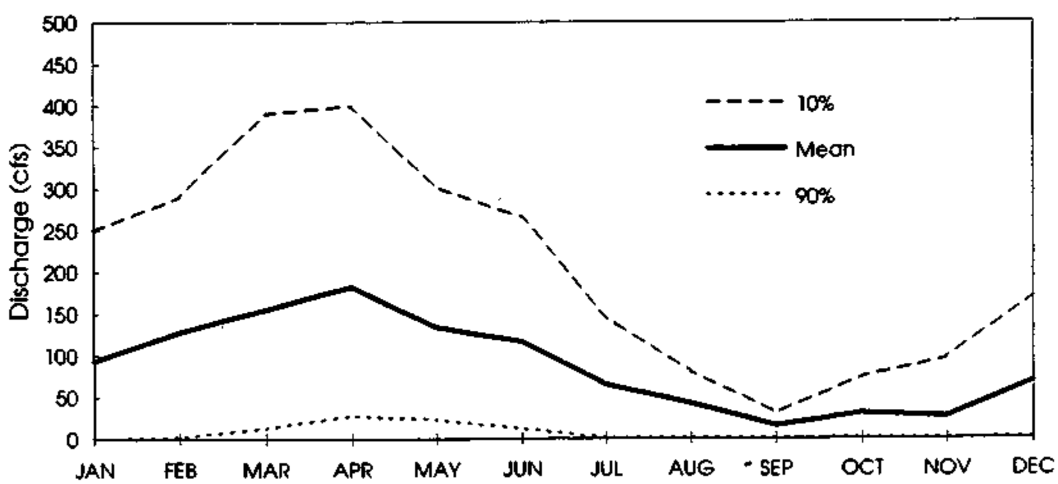


Figure 16. Monthly distribution of flow frequency
for Friends Creek at Argenta

Table 6. Estimates of Long-Term Flow Frequencies for Tributaries to Lake Decatur

Frequency of exceedance (%)	*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	0.0	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	5.3	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
Avg. Permeability (in/hr)	0.93	0.92	0.60	0.58	0.78

Table 7. 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 (%)	*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

Figure 16 illustrates an example of the monthly differences in flows for each of these tributaries 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 17 and table 8 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. The 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.

Table 8. Comparison of Long-term Flow Frequencies for the Sangamon River

Frequency of exceedance (%)	*at Fisher*	*near Mahomet*	*at Monticello*	*Inflow to Lake Decatur*
99	0.2	0.8	2.7	*1.1*
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

The frequency of flows by month for the Sangamon River at Monticello is illustrated in figure 18. Note that this distribution is very similar to that presented in figure

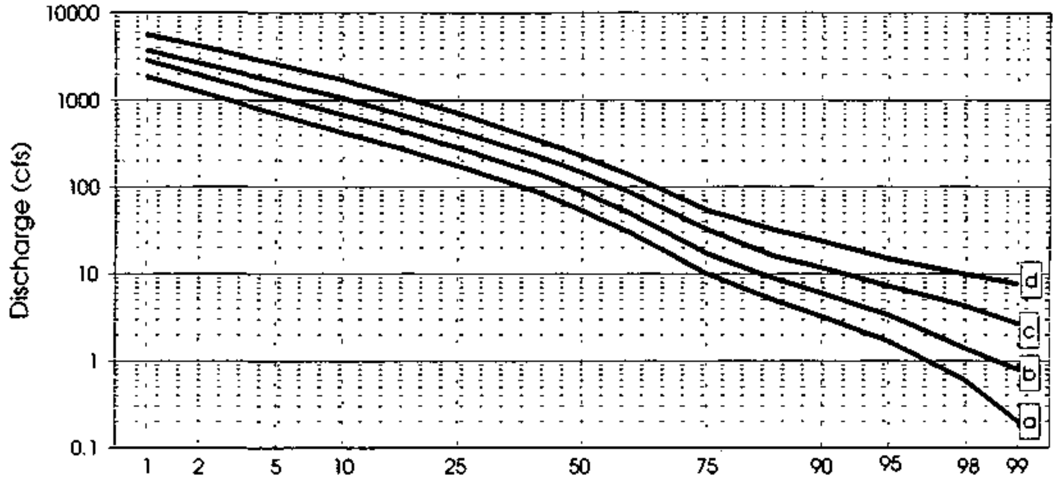


Figure 17. Comparison of long-term flow frequencies for the Sangamon River: a) at Fisher, b) near Mahomet, c) at Monticello, and d) above the Lake Decatur dam

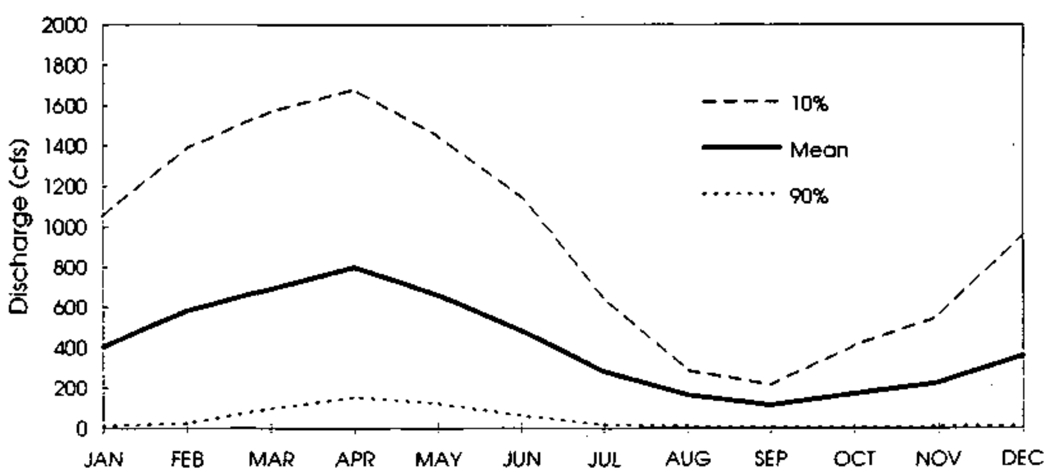


Figure 18. Monthly distribution of flow frequency for the Sangamon River at Monticello.

16 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.

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 19) 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 storm events at each station. The names of the streams, locations of the monitoring stations, and drainage areas are presented in table 9. 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.

Table 9. 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

Hydrologic Monitoring

Continuous hydrologic monitoring at each of the stations allows for 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.

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 20 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 security shelter designed for protection from weather and vandalism. The float and pulley system is enclosed within either a 12-inch aluminum or a 6-inch PVC culvert pipe 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 21. 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. The water level recorders are basically a float and pulley system connected with an electronic encoder and logger. Changes in water level turn the pulley in increments are read by the encoder and sent to the logger every 15 minutes where these data are 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.

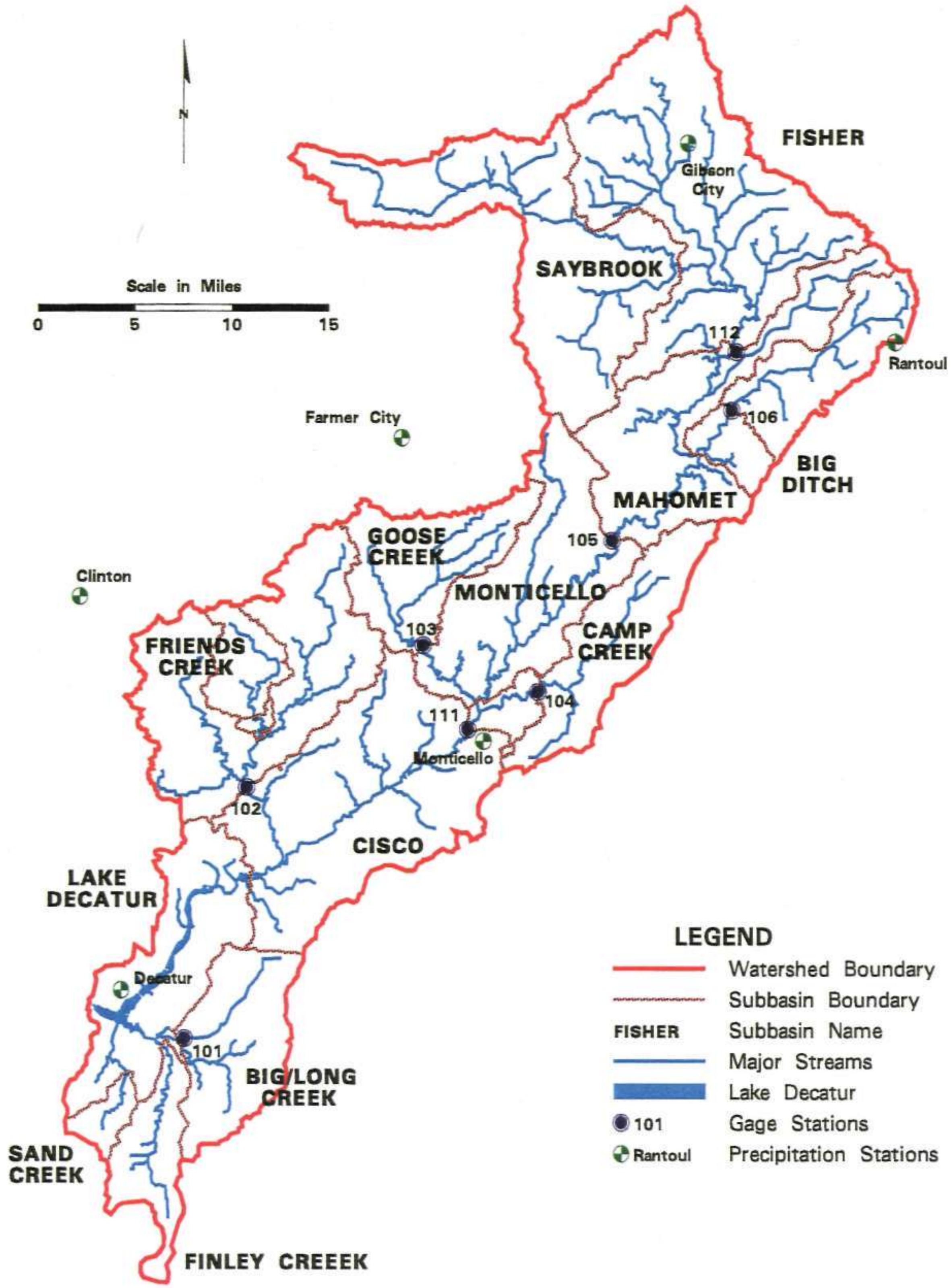


Figure 19. Location map of stream and rain monitoring stations in the Lake Decatur watershed

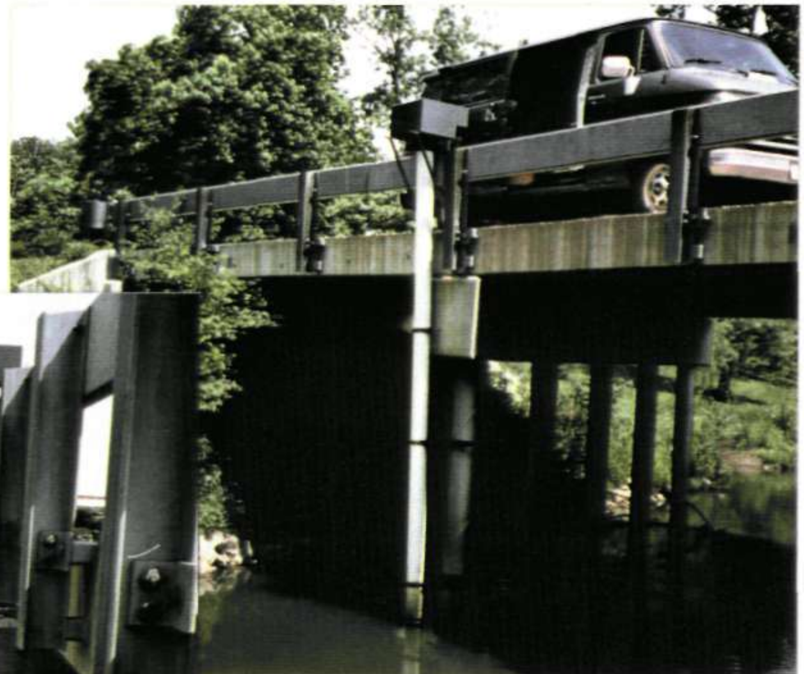



Figure 20. Streamgaging station installation on a bridge over Big Ditch and Camp Creek

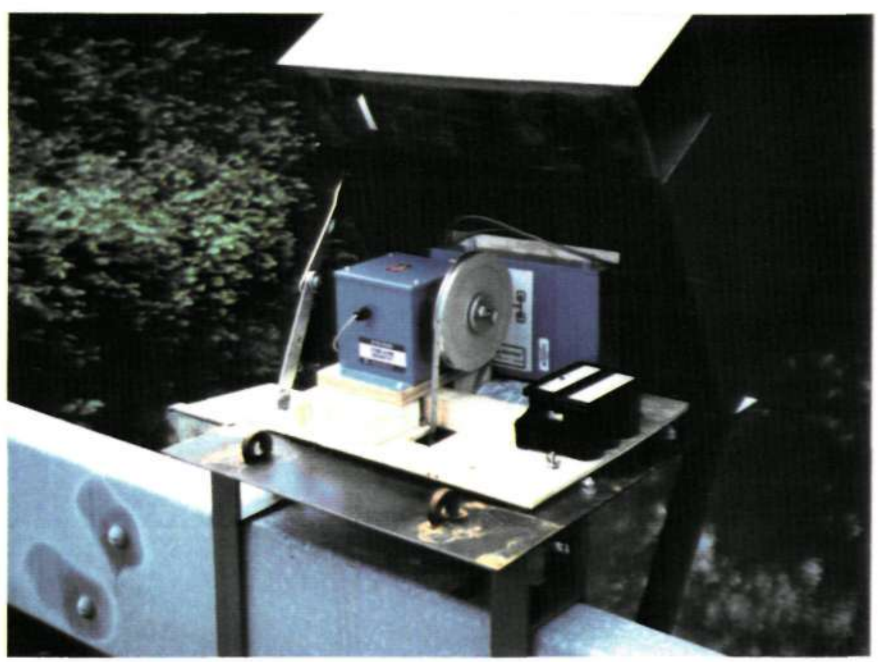


Figure 21. Stevens Type A/F recorder using the float-pulley system

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.

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).

For example, 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 22 and 23). 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 in 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 to develop a stage-discharge curve. Using this curve, the stage data files are then converted to daily discharge. The daily discharge data can then be used to develop daily nutrient load data.

Water Quality Monitoring

Each of the eleven monitoring stations (the eight main stations and the three supplementary stations around the lake) is sampled for water quality. 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 that is lowered on a rope into the stream at the thalweg (figure 24), which is a midpoint 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 25). 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 10 lists the container types, sample size, and preservation and storage practices used for each of the different types of analysis.

Table 10. Sample Collection, Preservation, and Handling

Parameter	*Container*	*Sample size*	*Preservation*	*Maximum holding time*
Nitrate-Nitrogen	Polyethylene bottle	60 ml	0.05% H_2SO_4/4° C (pH<2)	14 days
Ammonium-Nitrogen, TKN	Polyethylene bottle	500 ml	0.05% H_2SO_4/4° C (pH<2)	28 days

Water samples are collected at each of the eleven stations for nitrogen compound analysis on regular weekly visits and during storm/runoff events. Analysis is done for

Figure 22. A rotating bucket current meter

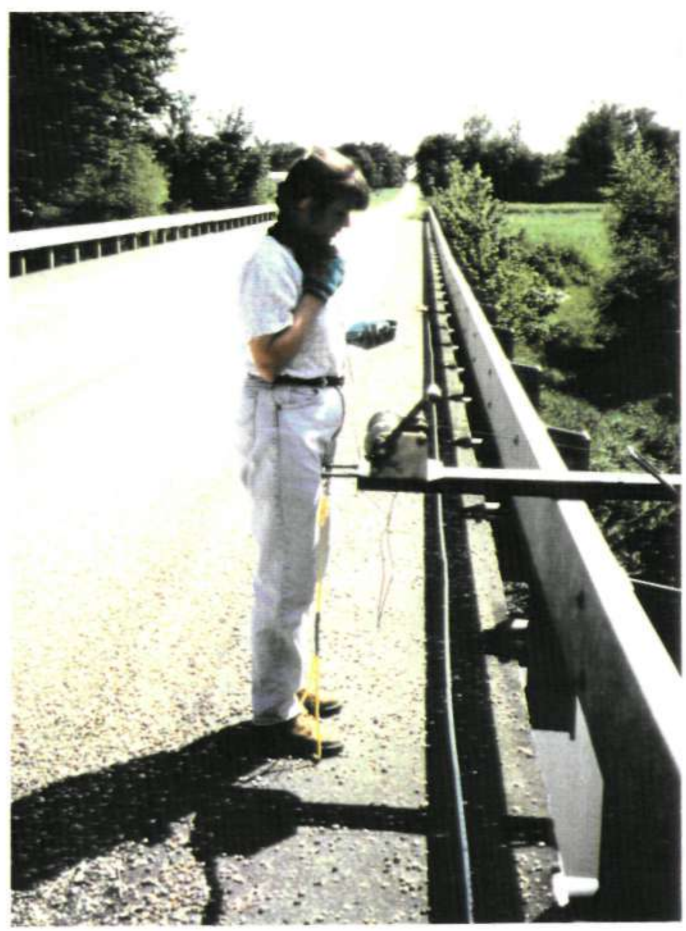


Figure 23. Field technician performing a discharge measurement with a bridge-board cable assembly at the Mahomet station

Figure 24. Typical aluminum sampling basket for retrieving water samples

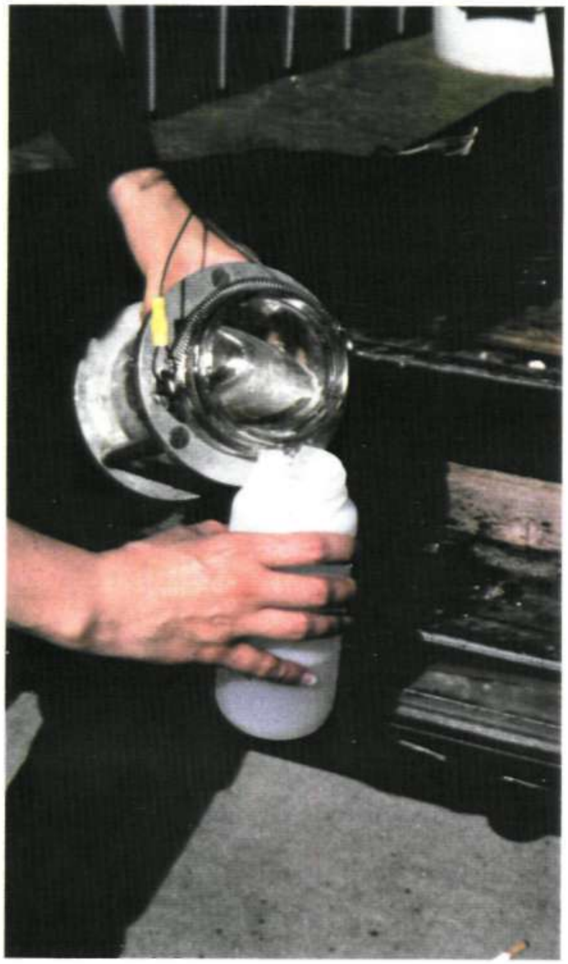


Figure 25. Transfer of retrieved sample to storage bottle for shipping to laboratory for analysis

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 10). A preservative of 0.05 percent sulfuric acid is 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 11 lists the procedures used by the laboratories during analysis of water samples. The table gives the analyte, the IEPA method number, and specifies of the methodology used

Table 11. Methodology for Chemical Analysis of Water Samples

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

QA/QC Procedures

The collection of water samples for water quality analysis follow 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 the actual sample is taken 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 IEPA-certified Environmental Laboratory (Certificate No. 100202), it therefore meets general QA/QC procedures described in Pan 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 (see table 10), and analysis of the samples is within the specified holding times listed in table 10. The ISWS laboratories use the IEPA methods listed in table 11 for each type of analysis.

Results

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. The monthly precipitation was retrieved for April 1993 through March 1994, which is the study period. Figure 26 compares the monthly precipitation in inches between all six stations. Figure 27 presents the annual precipitation totals, long-term means, and deviations from the long-term mean. 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 27 makes it apparent that the stations in the northern region of the watershed have received 35 percent more rainfall on the average compared to the southern region. Gibson City, Rantoul, and Urbana have received 12-13 inches above their long-term means of 35.67, 37.68, and 39.71 inches, respectively. Decatur shows near normal rainfall, with slightly above average rainfall at Clinton (9.9 inches) and Monticello (5.24 inches). This gradient in precipitation amounts will be reflected in the streamflow runoff data which follows.

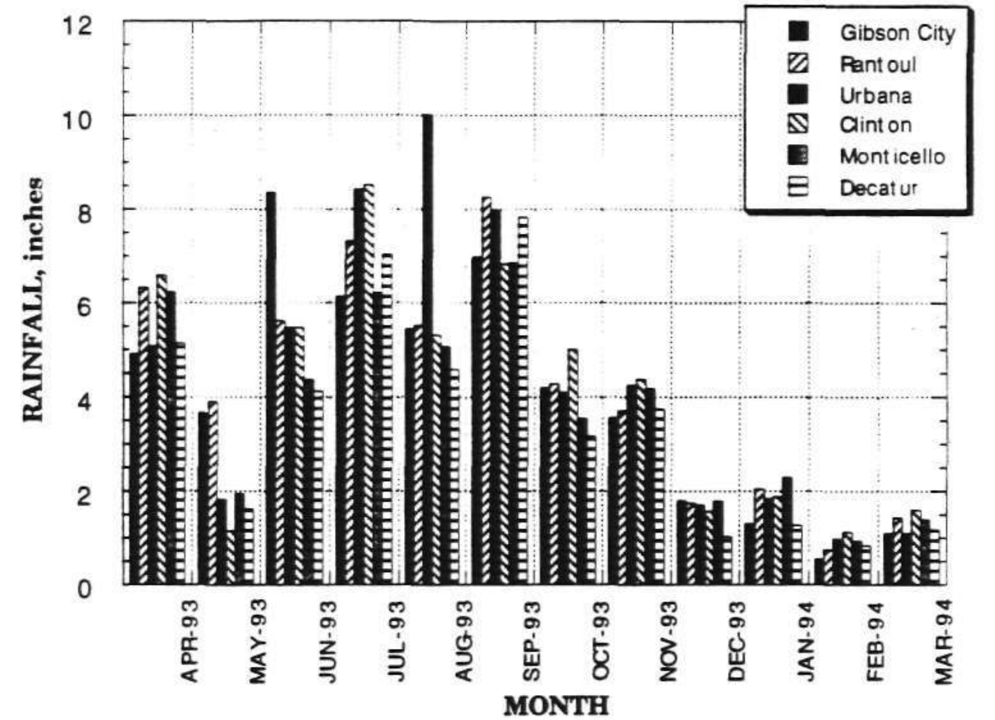


Figure 26. Monthly precipitation for April 1993-March 1994

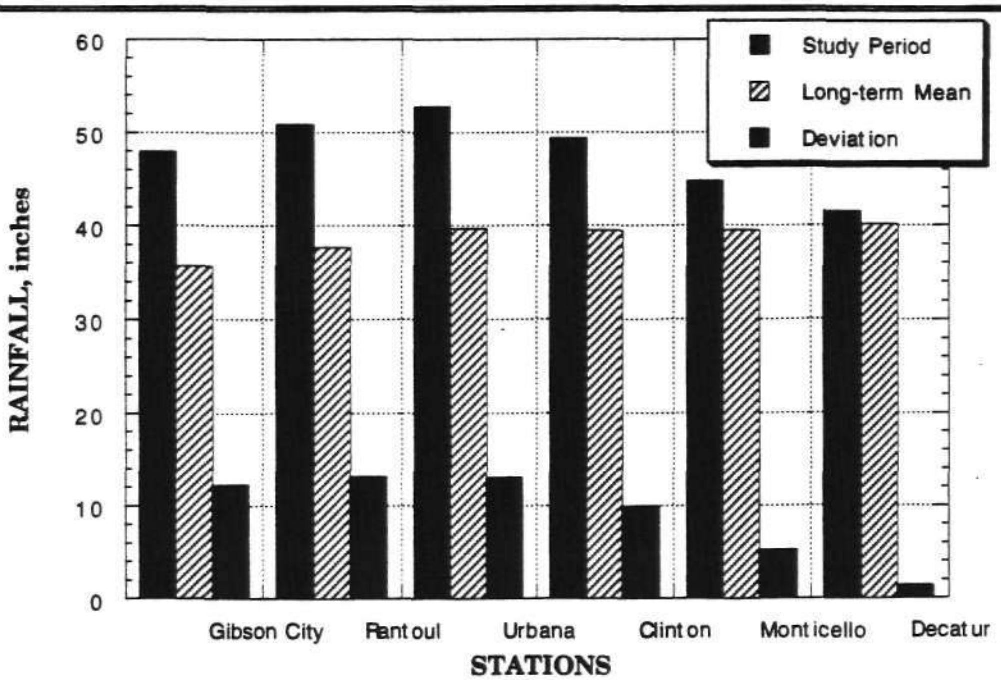


Figure 27. Annual precipitation for April 1993-March 1994

Streamflow

The streamflow data collected for this report represent the period from April 1993 through March 1994. The data were originally collected as stage 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 1993 to March 1994 for these two stations were retrieved from the USGS before being officially published and are therefore considered provisional at this time.

The discharge data results are illustrated in figures 28 and 29. Figure 28 shows the monthly discharge for the stations located on tributaries of the Sangamon River (stations 101, 102, 103, 104, 106), and figure 29 shows the stations located on the Sangamon River (stations 111, 105, 112). In figure 28, Friends Creek (station 102) shows the highest discharge during ten of the twelve months presented, which is expected since it drains twice as much watershed as the other stations (71,647 acres). The fall of 1993 (September-December) appears to be the wettest period of the year, and April and October 1993 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.

Figure 29 shows the same trends as the tributary stations for the main river stations. The wettest months appear in the fall (September-December), April, and July of 1993, and the driest months were August 1993, and January and February 1994. January and February 1994 were months where most station sites, if not all, were frozen over and

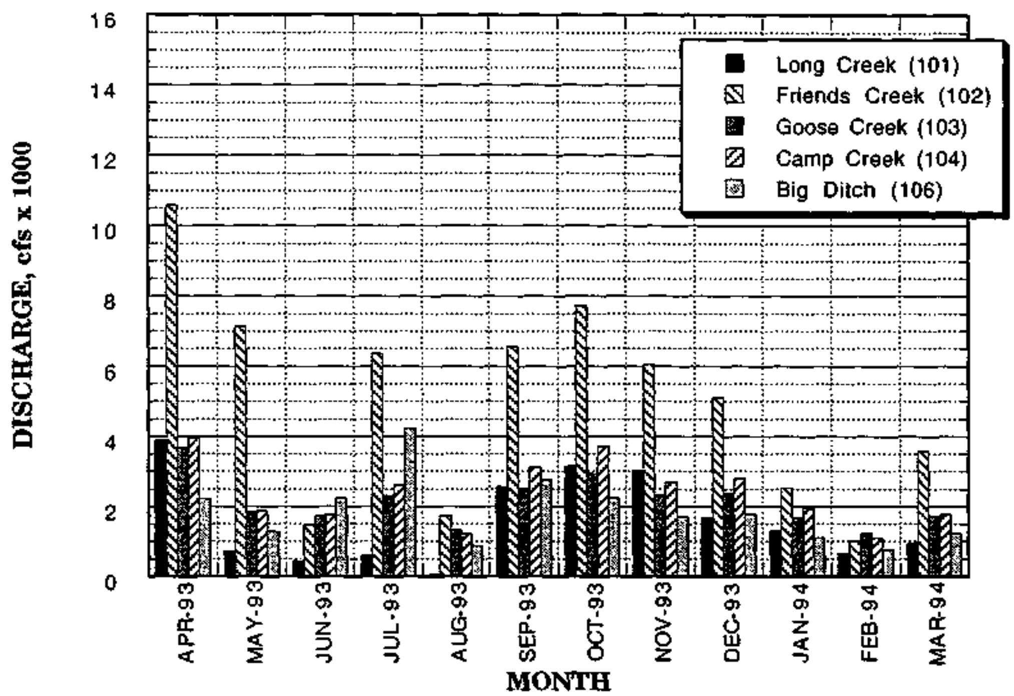


Figure 28. Monthly discharge for tributary stations

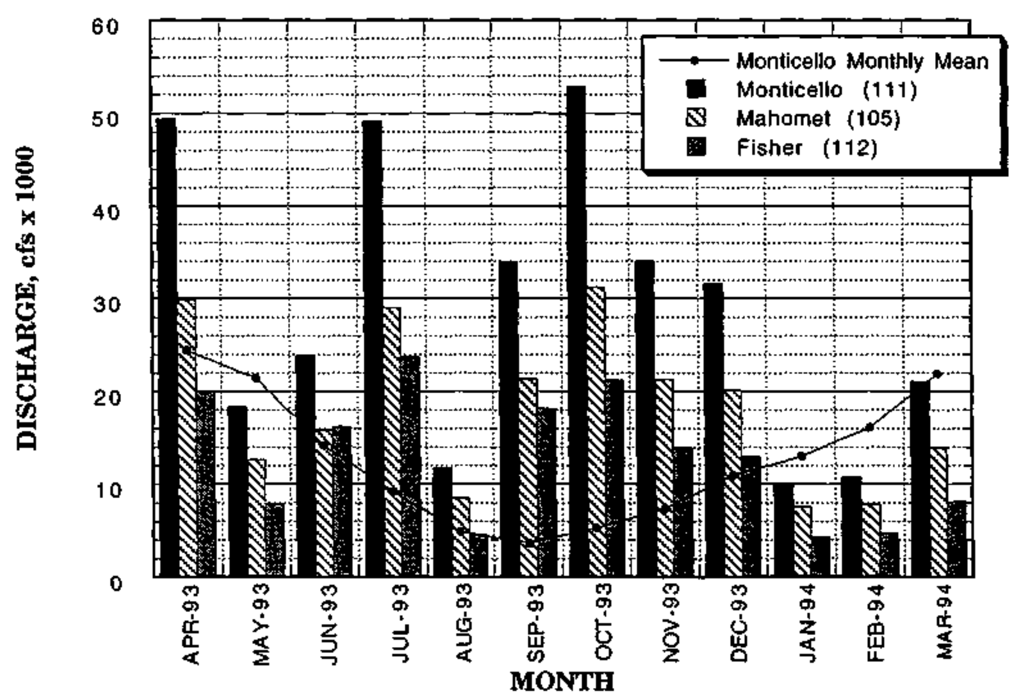


Figure 29. Monthly discharge for Sangamon River stations

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 29 presents the long-term monthly mean discharges for the Monticello station and illustrates that all except four of the months exceeded the mean discharges. Some months exceeded the discharge from two to ten times their long-term mean.

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 30 and 31 show runoff in inches for the tributary and Sangamon River stations, respectively. Streamflows vary between the stations due to the spatial variability of rainfall events throughout the watershed. The highest monthly tributary streamflow was at the Big Ditch station in July 1993 with 4.11 inches, and the lowest at Long Creek in August 1993 with 0.04 inches. For all eight stations, April, July, and September through December had the most significant monthly streamflows, with all averaging around or above 2 inches of runoff. Precipitation during these months reflects this by averaging or exceeding 4 inches of rainfall at all the raingages, with July and September exceeding 6 inches (see figure 24).

Annual runoff for the tributary and Sangamon River stations are presented in figures 32 and 33, respectively. As can be seen in figure 32, the streamflow increases for each tributary as you move upstream through the watershed. This correlates very well with the rainfall measurements shown in figure 27. The rainfall deviation from the long-term mean increases when proceeding from the southernmost station in Decatur to the northernmost one at Gibson City. Fisher had the highest annual runoff at 23.64 inches, with Camp Creek (22.47 inches) and Big Ditch (21.84 inches) following very closely. Long Creek had 15.39 inches, the lowest streamflow. The Sangamon River stations varied from 22.15 to 23.75 inches at Mahomet and Monticello, respectively.

Nitrogen Concentrations

The nitrogen compounds sampled for this study are nitrate-N, ammonium-N, and TKN. The nitrogen samples were collected from the eight major stations located around

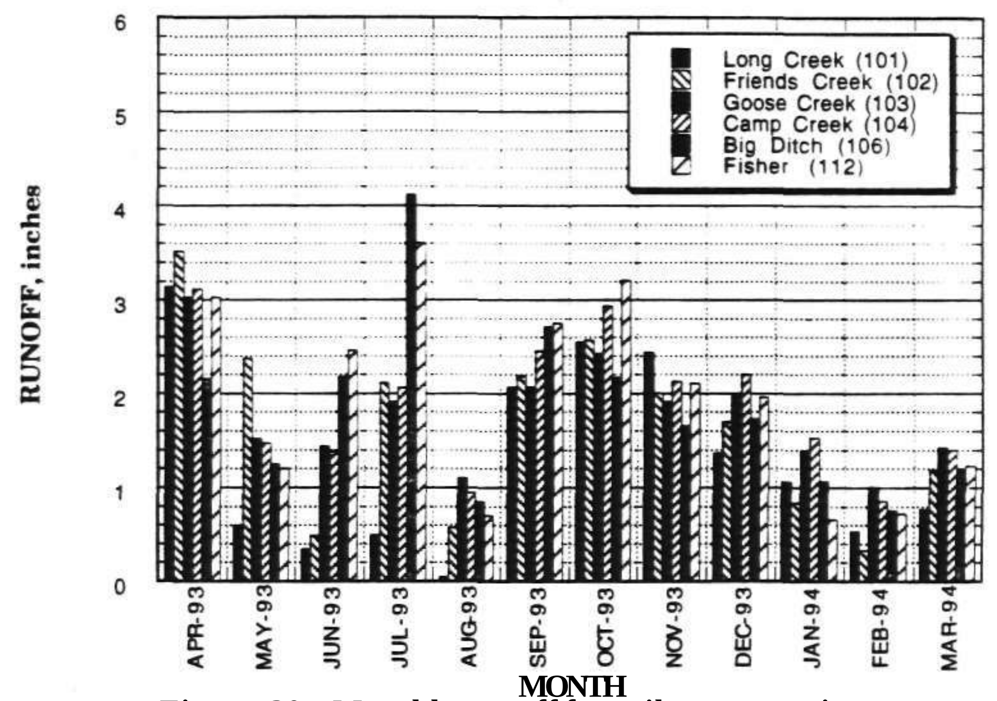


Figure 30. Monthly runoff for tributary stations

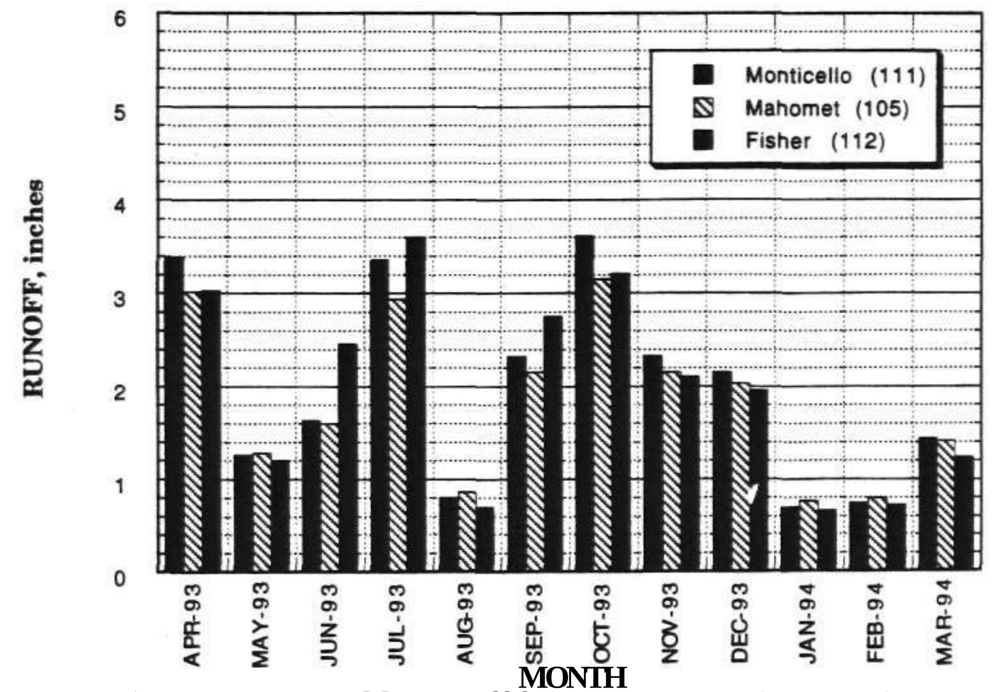


Figure 31. Monthly runoff for Sangamon River stations

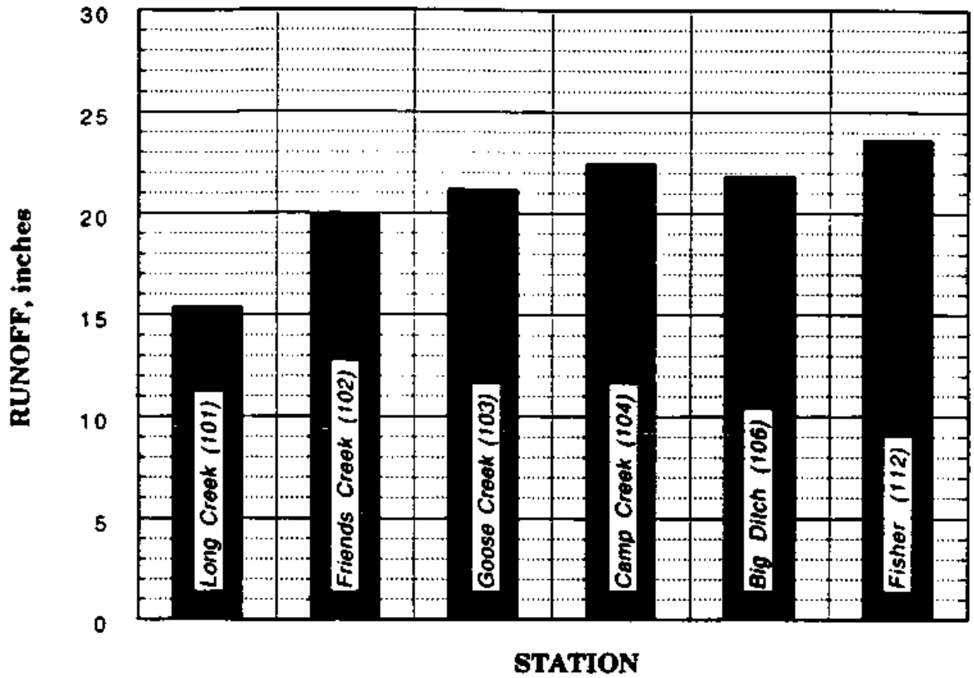


Figure 32. Annual runoff for tributary stations

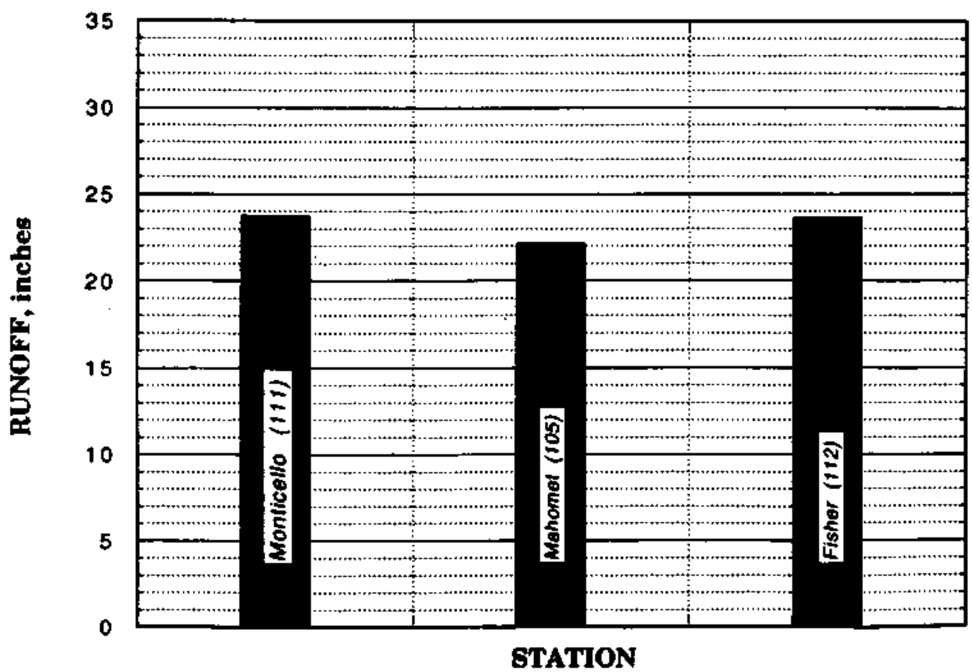


Figure 33. Annual runoff for Sangamon River stations

the watershed and from three additional sites located in urban areas of Decatur that drain directly into Lake Decatur. These three urban sites are 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)

Nitrate. The nitrate-N concentration sample results **are** presented in figures 34 and 35 for the tributary and Sangamon River stations, respectively. As can be seen in both figures, the seasonal fluctuations in concentration are parallel between all eight stations The range of nitrate-N concentrations at the tributary stations hovers around 5 to 15 mg/1, while 3 to 12 mg/1 is the range for the river stations. Nitrate-N concentrations started out at their highest levels between April and June, steadily decreased until September, varied slightly until they rose a little in late November/December, and then dropped back to previous levels. Figure 34 shows several data points for Long Creek that are at a much lower concentration than other stations during August when Long Creek experienced almost zero streamflow at 0.04 inches runoff as shown in figure 30.

The results of the data collected at the urban sites are presented in figure 36. Residential (station 201) and Golf Course (station 202) had nitrate-N concentrations that typically stayed near or below 2 mg/1. A sharp increase at Residential (station 201) in early November to 7.3 mg/1 was the rare exception. Industrial (station 203) had levels that varied between 3 to 6 mg/1, with spring and early summer months 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 water used for cooling, 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 37, it can be seen that Industrial (station 203) does indeed match or fall below the prevailing nitrate-N levels in the lake.

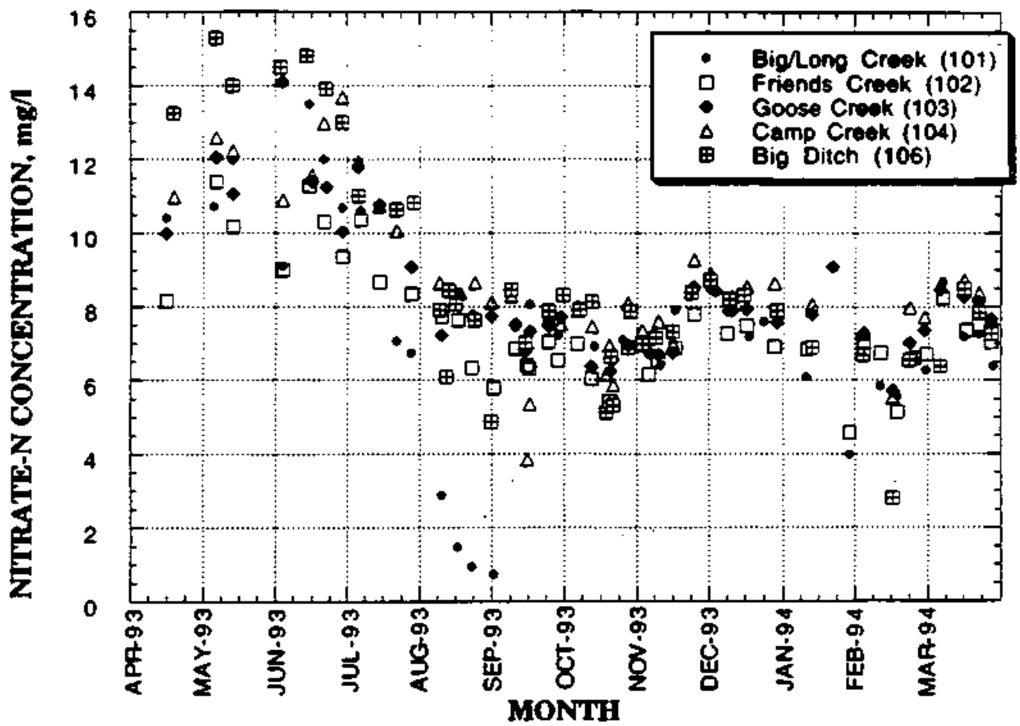


Figure 34. Nitrate - N concentrations for tributary stations

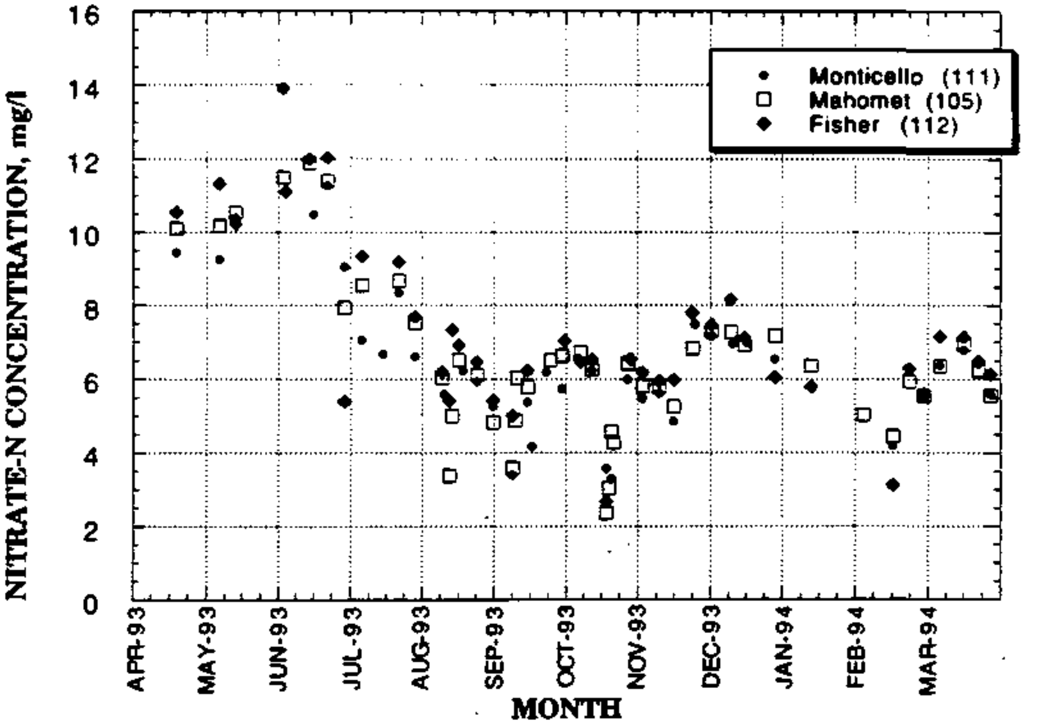


Figure 35. Nitrate - N concentrations for Sangamon River stations

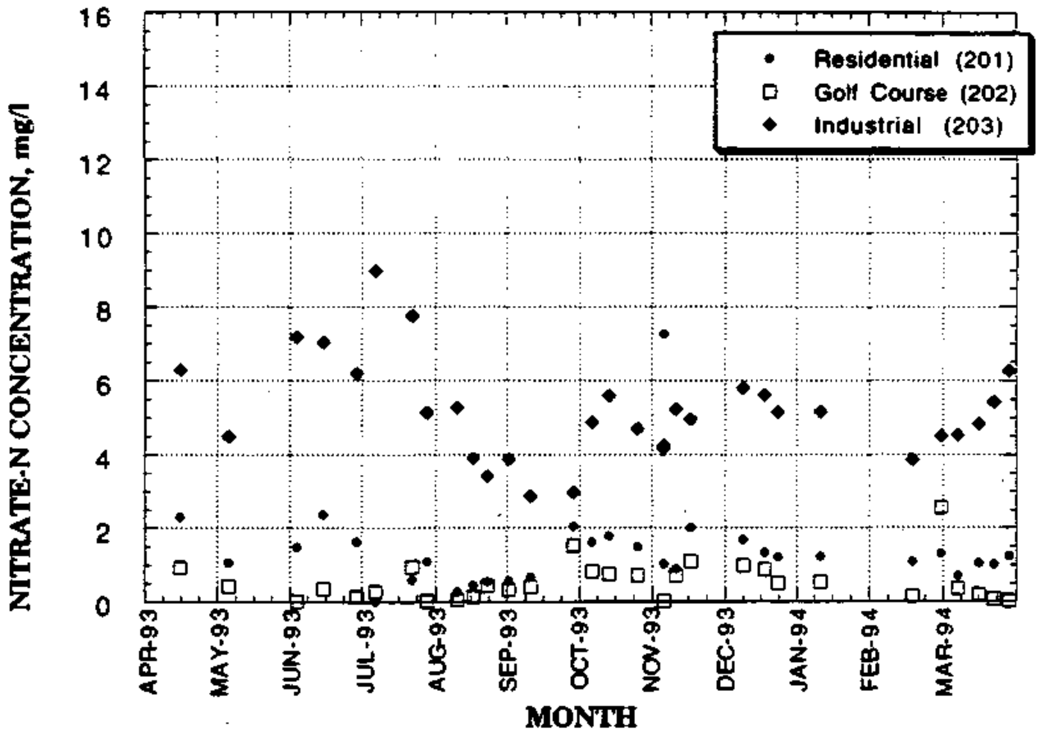


Figure 36. Nitrate-N concentrations for urban stations

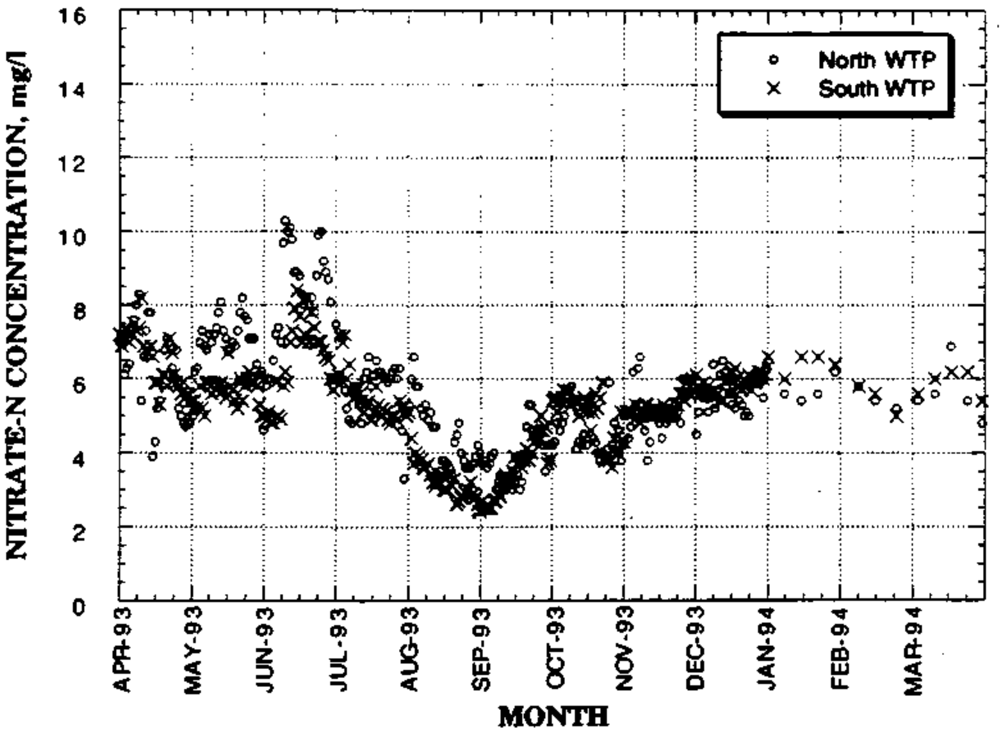


Figure 37. Nitrate-N concentration readings from north and south water treatment plant (WTP) lake intakes

Ammonium and TKN. The nitrogen compounds ammonium-N and TKN were collected at all stations on a biweekly basis. Figures 38-39 and 40-41 show the ammonium-N concentration results for the tributary and river stations, respectively Figures 42-43 show the ammonium-N and TKN results for the urban stations Both compounds stayed typically low at all stations throughout the study period The only serious deviation for both compounds occurred during a mid-winter thaw in February 1994, during which Lake Decatur experienced some of the highest ammonium-N concentrations in recent years. It was reported by the city of Decatur that turbidity levels were also seriously high that same month. The Big Ditch and Fisher stations had the highest readings of both ammonium-N and TKN during February. Ammonium-N was 5.5 and 2.3 mg/1, while TKN was 7.2 and 4.4 mg/1 at Big Ditch and Fisher, respectively

Figures 44-46 show the maximum, average, and minimum concentrations of all three nitrogen compounds sampled at the eight main stations in the watershed. As illustrated by figure 44, 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, while Friends Creek had the lowest maximum concentration of 11.4 mg/1. Big Ditch had the highest ammonium-N concentrations at 5.06 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 45 shows the average nitrogen concentrations for the study period. No stations really stand out for any of the three compounds shown. All eight stations average a nitrate-N concentration of 7.7 ± 1.1 mg/1. Average TKN values range from 0.9 to 1.3 mg/1, while ammonium-N never exceeds 0.35 mg/1. The minimum nitrogen concentrations encountered appear in figure 46. TKN and ammonium-N were always below their minimum detection limit (MDL) of <0.33 and <0.02 mg/1, respectively. Goose Creek and Camp Creek had 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 from Friends Creek at 0.2 mg/1.

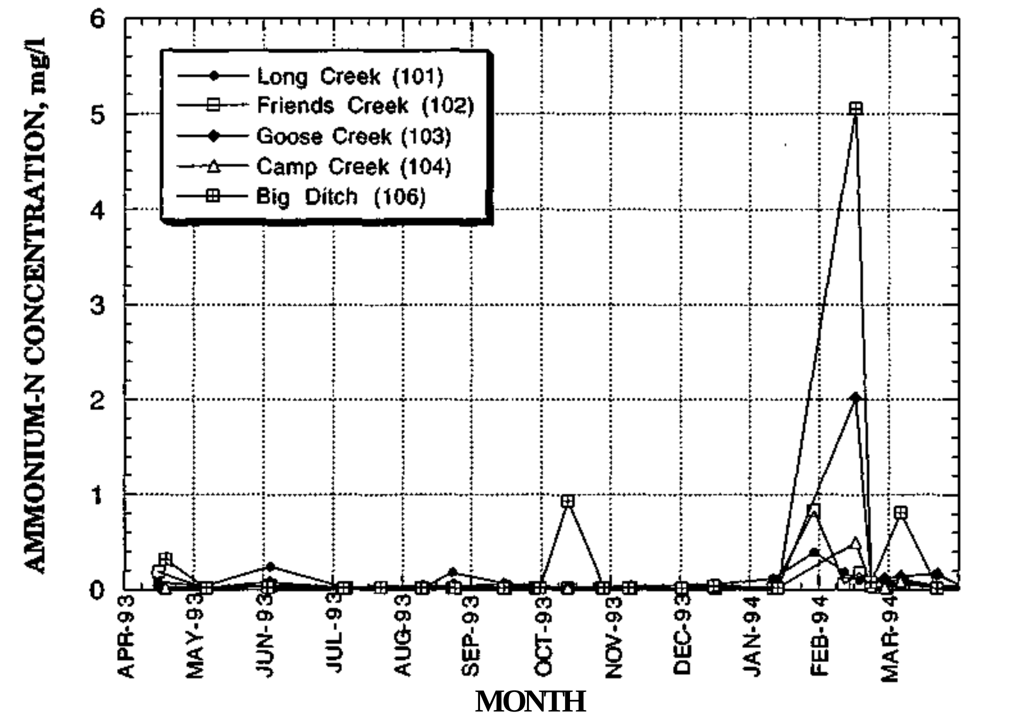


Figure 38. Ammonium-N concentrations for tributary stations

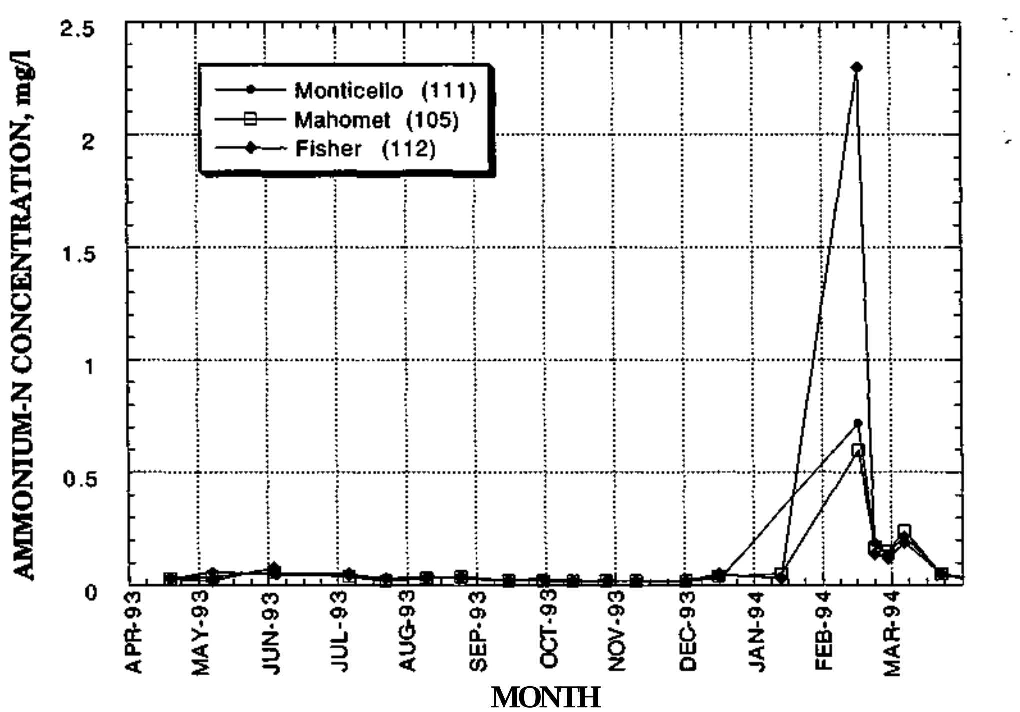


Figure 39. Ammonium-N concentrations for river stations

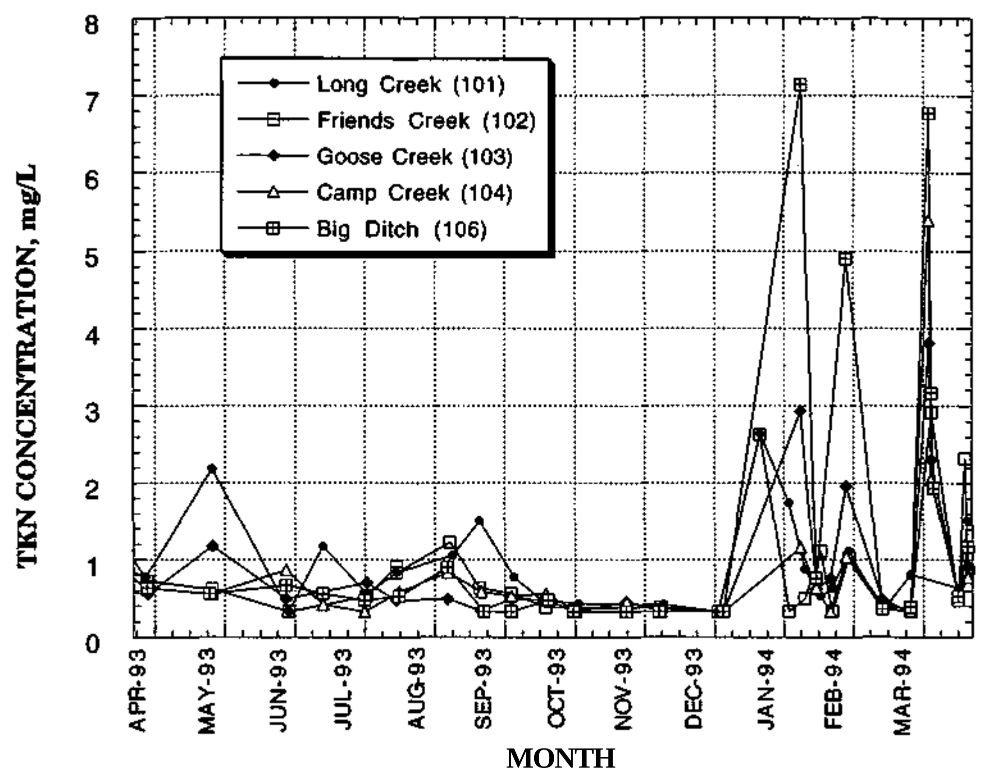


Figure 40. TKN concentrations for tributary stations

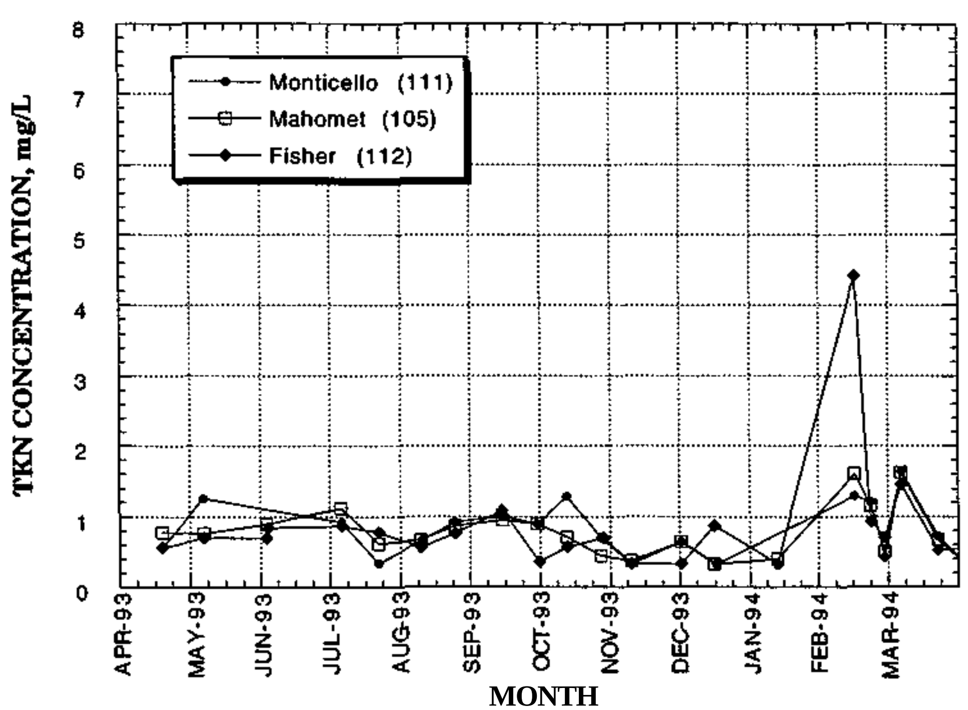


Figure 41. TKN concentrations for river stations

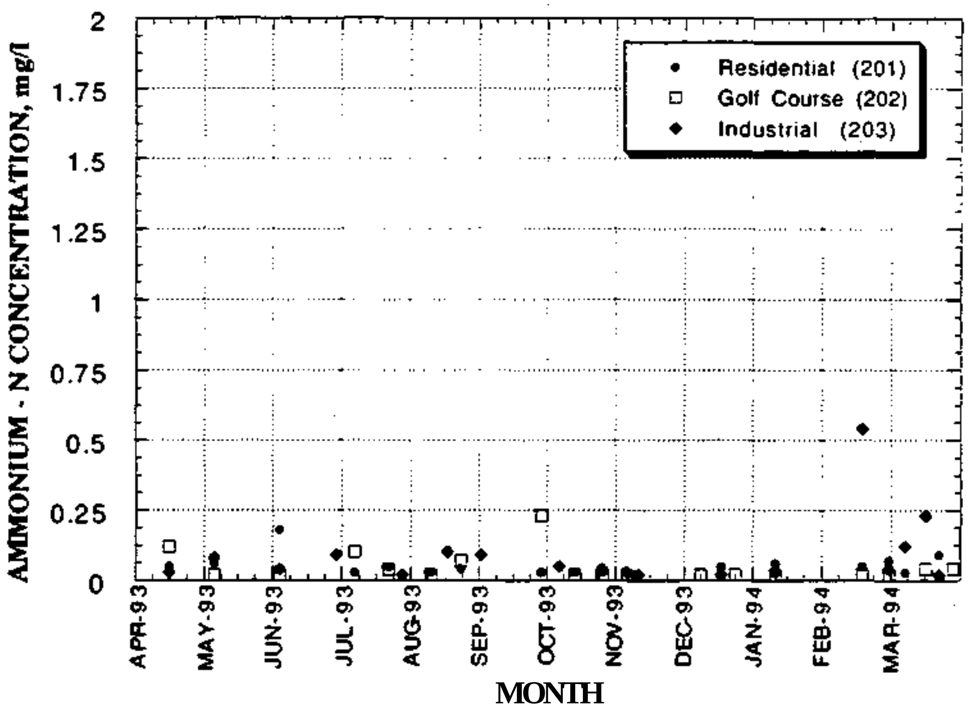


Figure 42. Ammonium-N concentration results for urban stations

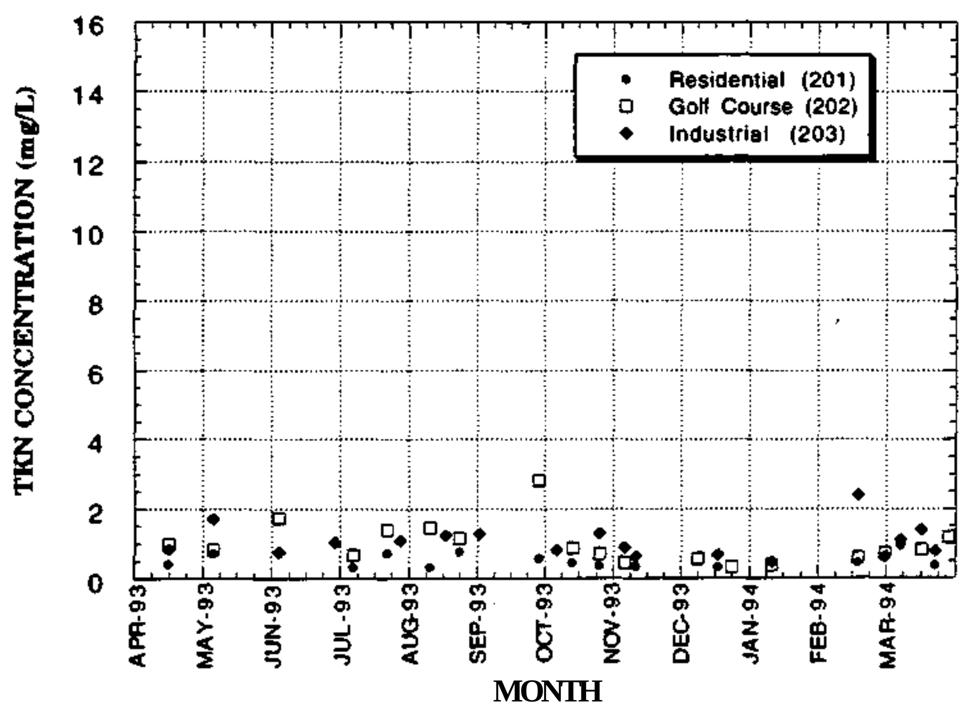


Figure 43. TKN concentrations for urban stations

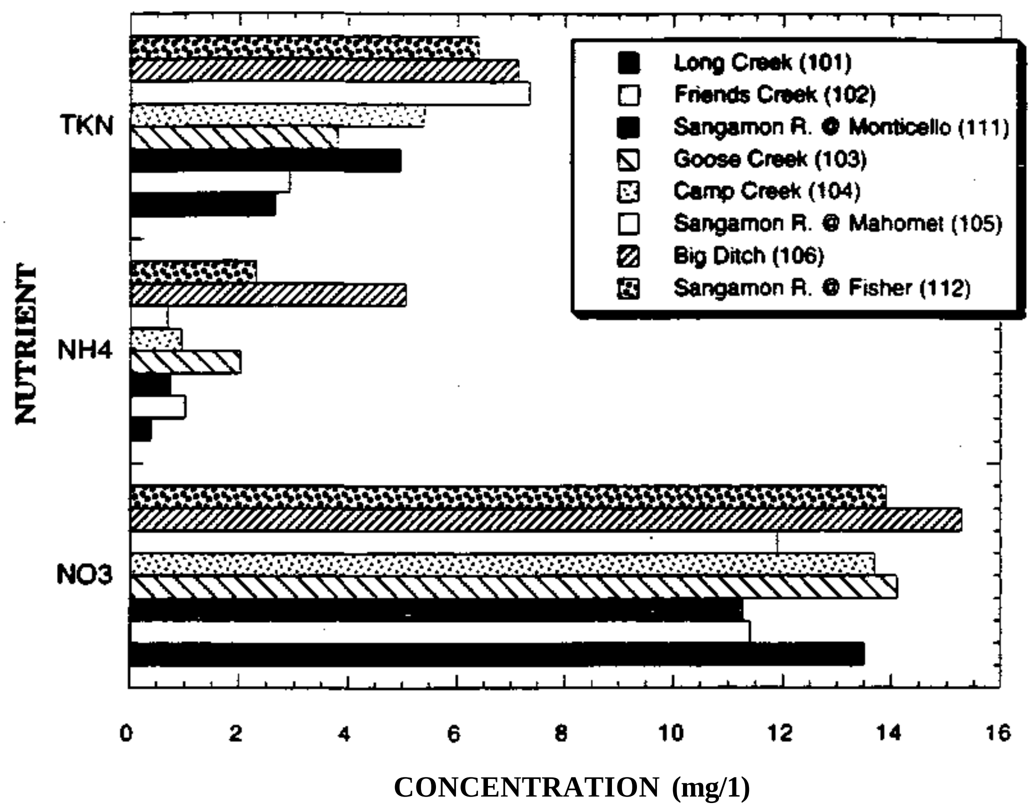


Figure 44. Maximum nitrogen concentrations during study period

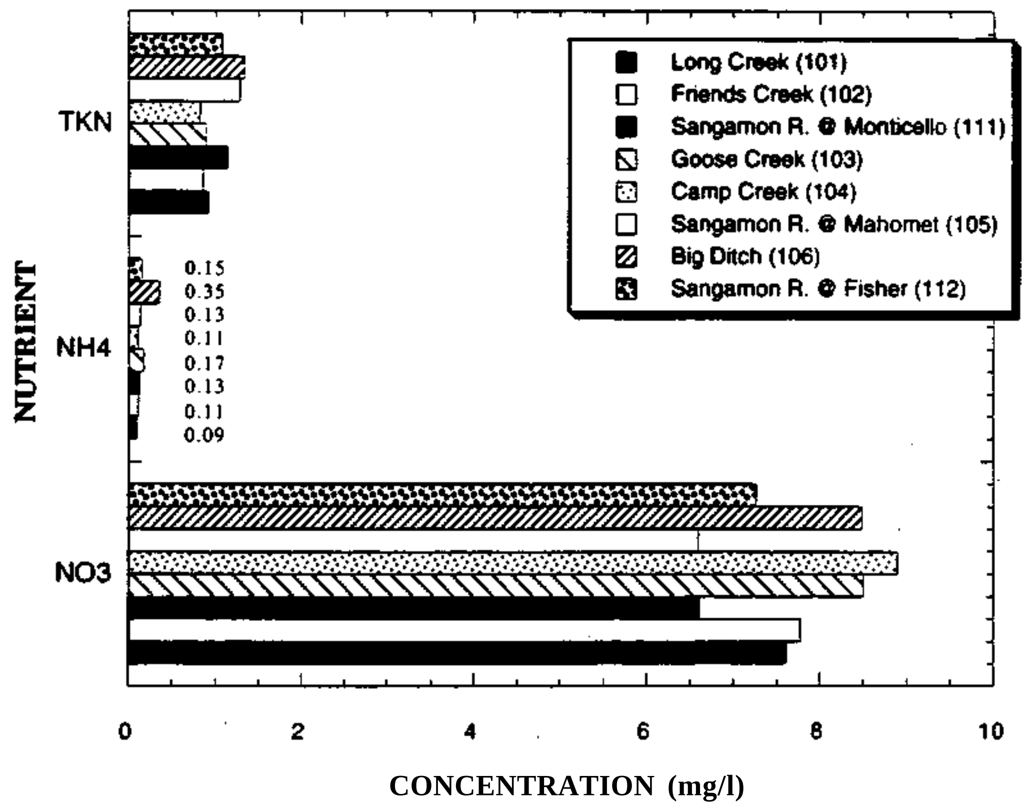


Figure 45. Average nitrogen concentrations during study period

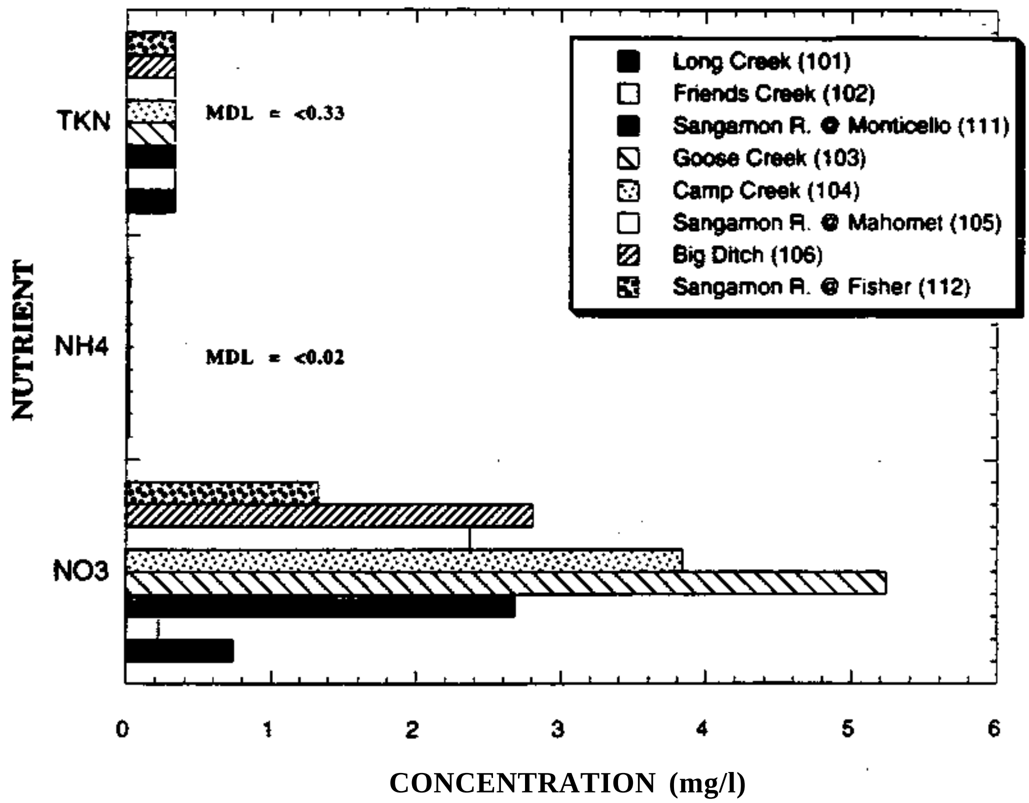


Figure 46. Minimum nitrogen concentrations during study period

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 Therefore, we will present preliminary nitrate load calculations based on the first year of data These calculations will be revised as we collect more data that enable us to calculate loads with better accuracy. There are two factors that should be noted when evaluating the nitrate loads. The first is the fact that the data collection year was extremely wet and may be atypical. The second factor is that the loads were calculated based on limited data, and thus their absolute value might not be exact, but their use to compare different sub-watersheds within the Lake Decatur watershed is valid, because they were computed in a consistent manner for all the stations.

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. Preliminary calculations of monthly nitrate yields have been made for all eight main stations and are presented in figures 47 and 48.

Figure 47 shows the monthly contribution of nitrate-N in lbs/acre for the tributary stations. The Sangamon River at the Fisher station (station 112) has been added as a tributary watershed because it monitors the headwaters of the Sangamon River. It is also presented with the main river stations at Monticello (station 111) and Mahomet (station 105) in figure 48 to give a perspective of how the loads vary along the river from upstream to downstream. When compared to the monthly runoff (figures 30 and 31), the loads parallel the same fluctuations throughout the year, with April, July, and September

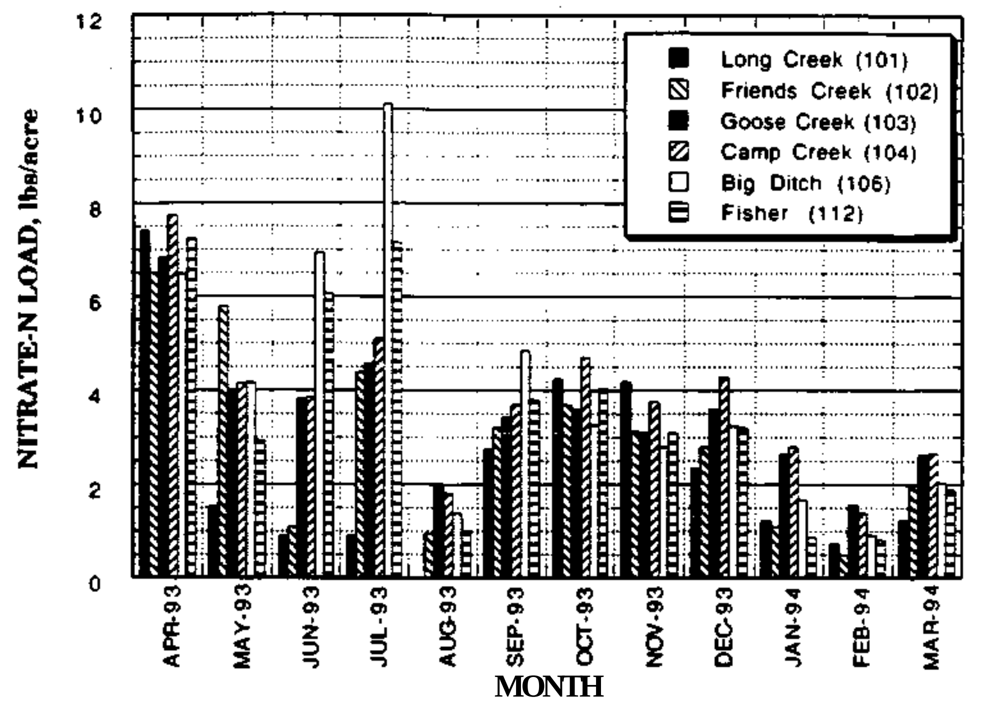


Figure 47. Monthly nitrate-N loads for tributary stations

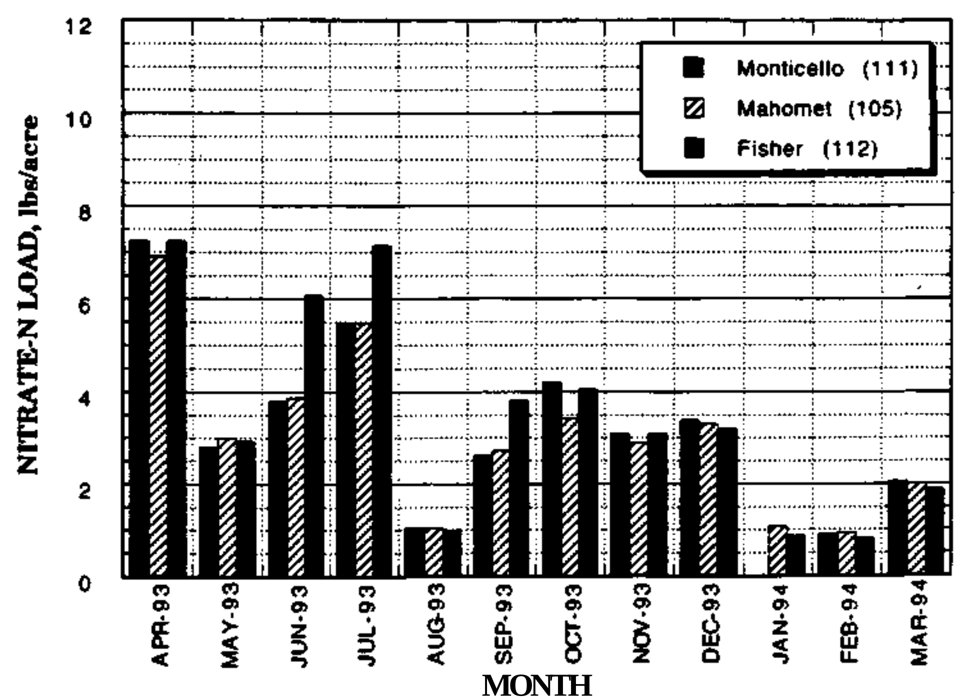


Figure 48. Monthly nitrate-N loads for river stations

through December being the months during which all the stations have uniformly high yields. The highest monthly nitrate load for a tributary and river station occurred at Big Ditch and at the Sangamon River at Fisher with 10.1 and 7.2 lbs/acre, respectively. The lowest loads were at Long Creek in August (0.02 lbs/acre). Figure 48 shows the Sangamon River at Monticello with no load during January 1994, because the site was completely frozen over that month, making it impractical to retrieve water samples The Sangamon River at Fisher (112) had the lowest river nitrate load during February 1994 (0.8 lbs/acre).

Annual Nitrate Loads. The annual nitrate loads at all the stations monitored are summarized in table 12 and presented in figure 49. 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 ranges from a low of 27 lbs/acre for Long Creek to a high of 48 lbs/acre for Big Ditch. Next to Big Ditch, Camp Creek generates the highest nitrate load at 46 lbs/acre. The other tributaries, Friends Creek, Goose Creek, and the upper Sangamon upstream of Fisher, generate nitrate at almost a uniform rate ranging from 35 to 42 lbs/acre. We will attempt to explain the variability of nitrate loads from the tributaries after analyzing the detailed land use data being collected by the county SWCDs.

Table 12. Annual Nitrate Loads in the Sangamon River Basin

Station	*Drainage area (acre)*	*Annual nitrate yield (lbs/acre)*
Long Creek (101)	29,539	27
Friends Creek (102)	71,647	35
Goose Creek (103)	28,892	42
Camp Creek (104)	30,242	46
Big Ditch (106)	24,421	48
Sangamon River at Fisher	157,177	42
Sangamon River at Mahomet	235,653	37
Sangamon River at Monticello	347,747	37

For the main river stations, the nitrate load at Monticello is 37 lbs/acre and 37 and 42 lbs/acre at Mahomet and Fisher, respectively. As the drainage area increases, the unit

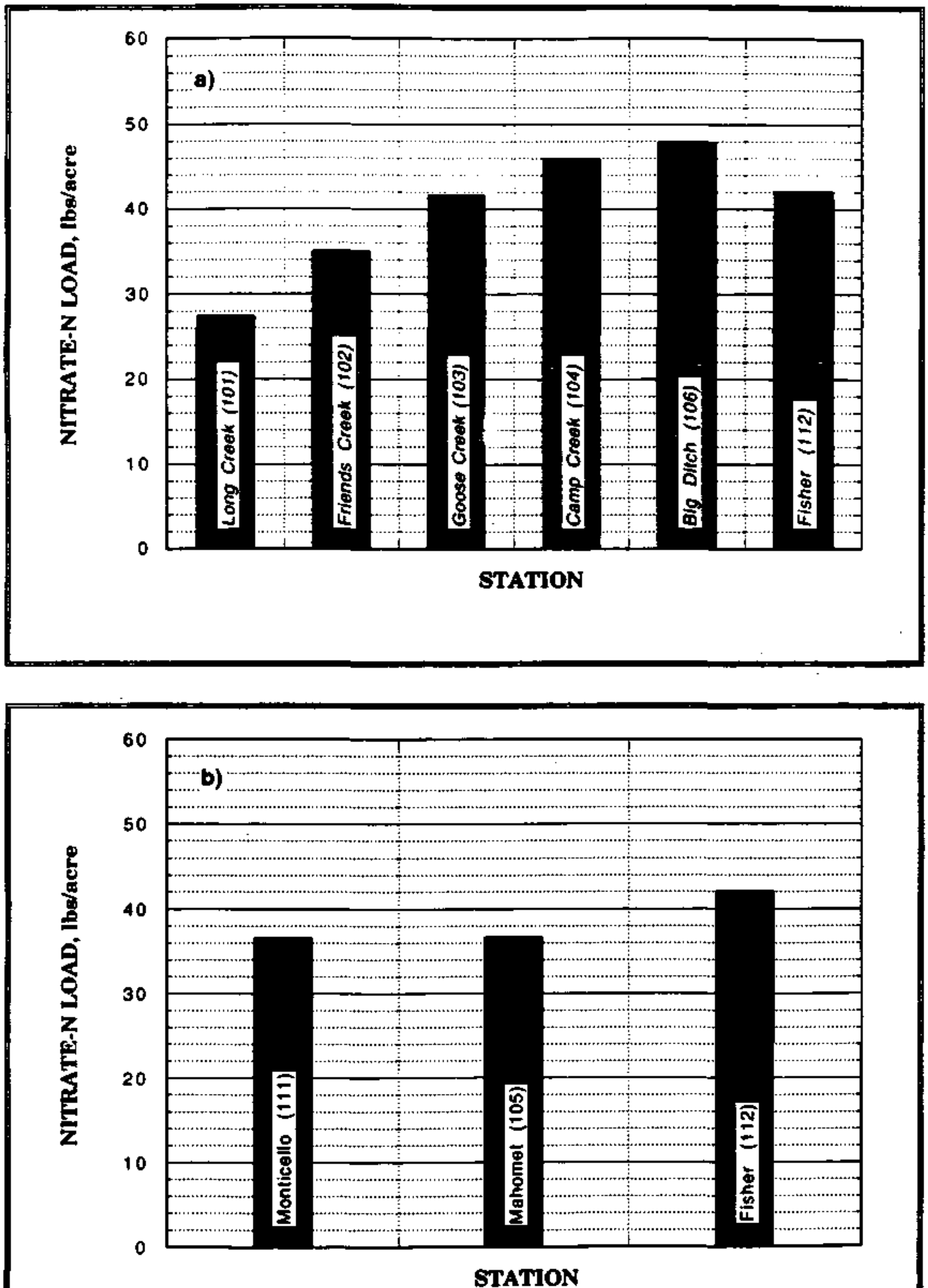


Figure 49. Annual nitrate-N loads for a) tributary and b) river stations

load generally decreases similar to sediment yield. One process in 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 as the discharge increases

Based on the nitrate load data, the preliminary conclusion is that the source of nitrate in the Lake Decatur watershed is truly dispersed throughout the watershed, and thus any mitigation plan should attempt to address the entire watershed rather than a selected few sub-watersheds. Even though the Big Ditch and Camp Creek watersheds were observed to generate relatively higher nitrate loads per unit area than the rest of the watershed, their rates are not significantly higher than the rest. Furthermore, the combined drainage areas of the two watersheds are less than ten 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 BMPs ON NITRATE LOAD

One of the main objectives of this project is 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 will be accomplished through the use of a nonpoint source pollution (NPS) model for agricultural runoff, a computer program that simulates 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 phosphorus) with mathematical expressions. Some of the well-known and widely used nonpoint source models are ARM (Donigan and Crawford, 1976), CREAMS (Knisel, 1980), HSPF (Bicknell et al., 1993), PRZM (USEPA, 1984), BASIN (Heatwole et al., 1989), AGNPS (Young et al., 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 agricultural lands. The results from the application of the AGNPS model will provide useful information for the planning and implementation of effective management alternatives.

The AGNPS model will be calibrated with measured streamflow and water quality data throughout the watershed monitoring network. The calibration process will enable selection of model parameter values suitable for different land uses, soil characteristics, and agricultural management practices. To ensure that the AGNPS model can be used to accurately predict future scenarios of various BMPs, the model will be verified by predicting streamflow and nutrient concentration for several events not used during the calibration process.

Once the model has been calibrated and verified, it will be used to compare the nitrate loading at different locations of the watershed as a result of various alternative land management practices. Critical locations of the watershed will be identified that contribute to nitrate problems more significantly than other locations. An assessment will also be made of how various agricultural practices change the nitrate loadings from different sub-watersheds and quantify the percentage of nitrate reductions at both the sub-watershed and watershed outlets

In addition, the AGNPS model will be applied to two sub-watersheds (Big Ditch and Friends Creek). Through intensive data collection and monitoring of land use, watershed characteristics, and hydrologic and climatic data on these sub-watersheds, it will be possible to determine specific relations between land use practices and nitrate concentrations. This section of the report contains the description of the AGNPS model, the modeling procedure for the Lake Decatur watershed and the two intensely monitored sub-watersheds, and the application of the AGNPS model to Big Ditch sub-watershed to simulate the effect of nutrient management practices (NMPs) on nitrate output from the sub-watershed.

Model Description

The AGNPS model can simulate watershed responses to single storm events. The model subdivides a watershed into cells of uniform square areas comprising upland and channel areas. Runoff, sediment, nutrient, and chemical oxygen demand (COD) are computed for each cell, and then routed stepwise through the cells to the watershed outlet. The nutrients include nitrogen and phosphorus from plants and from other major contributors to surface water pollution such as the leaching of fertilizers from agricultural lands. The AGNPS model also considers water, sediment, nutrients, and COD from point sources such as animal feedlots, springs, and gullies. Water impoundment tile-outlet terraces are considered as areas of deposition of sediment and sediment-associated nutrients in the model.

The parameters required in the input file for the AGNPS model can be classified into five categories:

1. *Land use parameters:* Cropping practices, conservation practices, surface condition, fertilization level, fertilizer availability, COD, and Manning roughness coefficient
2. *Soil parameters.* Soil credibility, soil texture, and SCS curve number
3. *Landscape parameters.* Land slope, slope shape, field slope length, and slope aspect

4 *Channel parameters:* Channel type, channel bed slope, channel side slope, and Manning roughness coefficient

5 *Other parameters:* Point sources, gully sources, and surface impoundment

The definition and range of values of each parameter is given in the AGNPS manual (Young et al., 1987). The AGNPS model has been used in several studies to predict runoff and sediment yield from small agricultural watersheds (Young et al., 1989, Hession, 1990; Engel et al., 1993, Mitchell et al., 1993) The model has also been applied to evaluate the effectiveness of installed BMPs (Hession et al., 1989) and to evaluate the efficiency of erosion and water pollution control strategies (Prato and Shi, 1990) The simulated management practices for water pollution control include vegetation strips along streams, permanent vegetation cover in critical noncropland areas, sediment retention ponds, and manure management and resource management systems comprising combined tillage and farming practices.

The first step in the estimation of the AGNPS parameters is to obtain a topographic map of the watershed showing watershed boundaries, major stream network, stream monitoring locations, and township ranges and sections. The township sections are then subdivided into a grid of square cells. Land use parameters can be obtained from the local SCS office and from field observation. Soil parameters can be estimated from county soil survey manuals and soil maps. Most landscape parameters are estimated from topographic maps and from field observations.

Modeling Procedure

The water quality problem in Lake Decatur is related to the land use practices in the drainage basin. One of the objectives of the nutrient modeling component of this project is to determine different sections of the Lake Decatur watershed that contribute significantly high concentrations of nitrates due to management practices. This objective is accomplished by subdividing the Lake Decatur watershed into 12 sub-basins as shown in figure 19. The sub-basins have been selected based on the location of streamgaging stations along the Sangamon River and its tributaries and on the streams that are discharging directly into the lake. Nine sub-basins are drained by tributary streams into the Sangamon River. Hence the runoff and nitrate loading from these sub-basins are transported through the Sangamon River to the upper section of the lake. However, Big/Long Creek, Sand Creek and Finley Creek drain directly into the lower section of the lake

The AGNPS model is used to compute the runoff and the total nitrogen loading for each of the 12 sub-basins. The runoff and nitrogen loads are then routed through the Sangamon River and tributary streams to Lake Decatur. A flow chart for the simulation procedure is shown in figure 50. By simulating the nitrogen loading at the outlet of each sub-basin, it is possible to evaluate the impact of the contribution of each sub-basin on the total nitrogen load discharged to Lake Decatur. In addition, since the model subdivides the sub-basins into a grid of uniformly sized cells, it is possible to further evaluate the impact of the contribution from different parts of a particular sub-basin on the nitrogen output from the sub-basin. This is particularly useful in identifying critical areas of a sub-basin that are contributing significantly high nitrate loading to the watershed output. The procedure is also useful for the evaluation of the impact of management practices on dissolved nitrates in the runoff from targeted sub-basins.

For the model simulations, the Lake Decatur watershed was subdivided into 922 square cells of 640 acres. Along the Sangamon River and other critical areas, the 640-acre cells were further subdivided into smaller cells of 160 acres. Since each cell may enclose several farm tracks, some of the model parameters were averaged to obtain representative values for each cell.

Five of the streamgaging and water quality sampling stations (figure 19) are located on tributary streams, and three other stations are located on the main stem of the Sangamon River. The locations of the precipitation recording stations are also shown in figure 19. The streamgages are located at the outlet of the gaged sub-basins. The calibration of the AGNPS model involves a systematic adjustment of the values of some of the model parameters such that the model output closely matches the recorded discharge and nitrogen load at each sampling site. The model data input include the total rainfall, the amount of fertilizer available at the soil surface at the beginning of the storm, the antecedent moisture conditions (AMC), the cropping practice factor, and the tillage

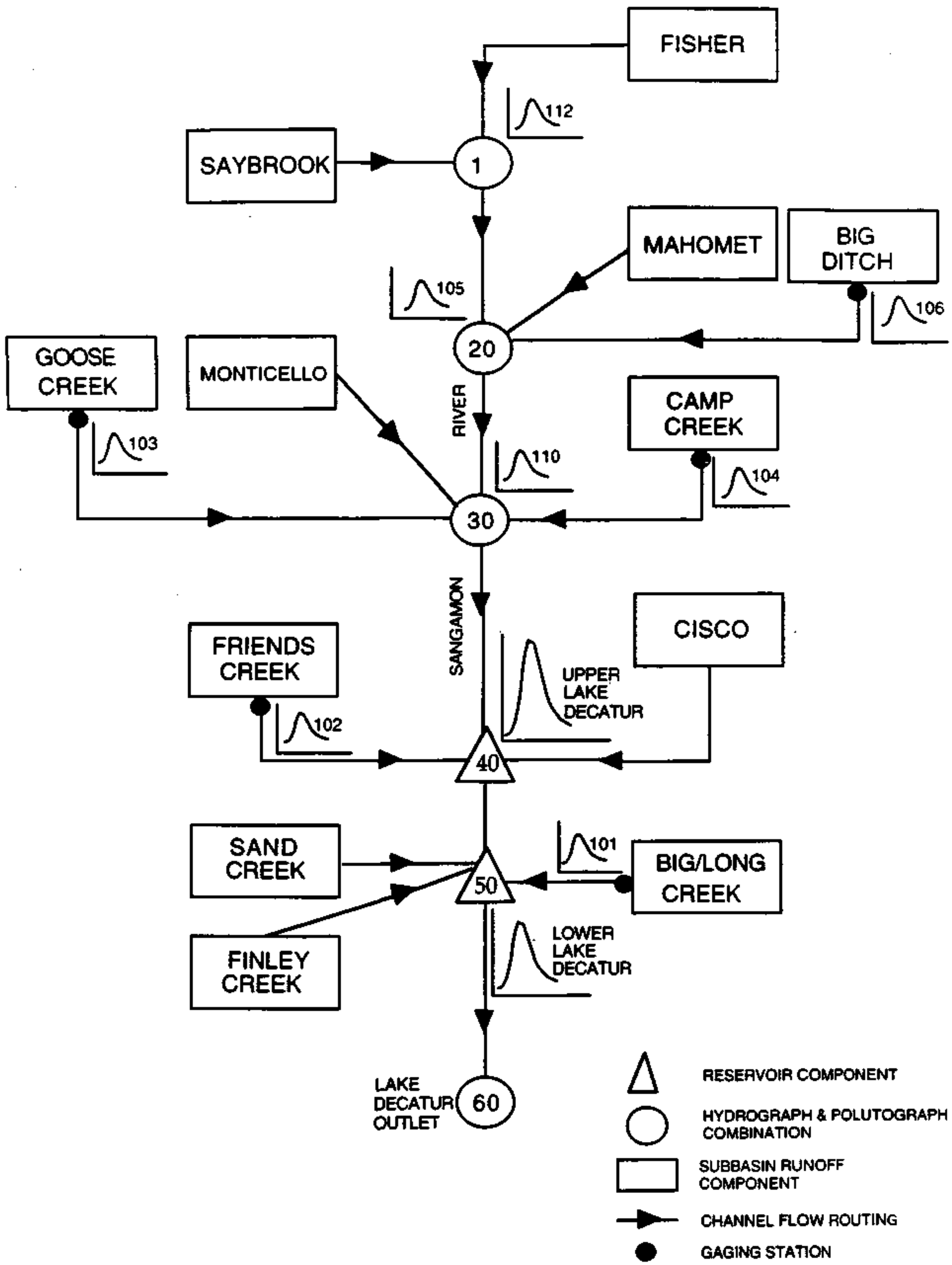


Figure 50. Flow diagram for streamflow, sediment, and nutrient routing on the Lake Decatur watershed

practice factor. The total rainfall depths for each storm are obtained from the daily precipitation records of the nearest precipitation stations (figure 19). The available fertilizer on the soil surface depends on the time elapsed since the fertilizer was first applied, the rate of application, and the method of application Fertilizers are usually applied in the spring or fall on the soil surface or several inches below the surface The AMC is estimated from the rainfall amount occurring within the previous five days This value is used to select the appropriate AMC class. Using the selected AMC group and information on the soil group and land use, the runoff curve number is obtained The runoff curve number is used in the computation of the runoff. The cropping factor depends on whether the fields are plowed in the spring or fall and on the tillage system, crop sequence, and percentage ground cover after planting each crop. The values of some of these parameters are gradually adjusted during the calibration until the model produces the best estimates of the measured discharge and total nitrogen load.

Best Management Practices

Agricultural BMPs are used to control soil erosion and transport of sediment-adsorbed nutrients and pesticides from farmland. They are also used to reduce dissolved nutrients discharged into streams through surface runoff and ground-water discharge. Erosion management practices include implementation of conservation tillage, no-till, and minimum or reduced tillage, and the construction of buffer strips and retention ponds. Nutrient management practices (NMPs), on the other hand, are used to control the rate of fertilizer application, the time of application, and the method of application.

Erosion control strategies are implemented in noncrop areas along creeks and along fields adjacent to the creeks in riparian areas. Soil erosion is reduced by planting grass, trees, and shrubs in these areas. However, recent implementation of management practices usually involves a combination of erosion and nutrient control strategies by selecting appropriate tillage methods, land treatment practices (row crop, contour farming, contour strip cropping, etc.) and a suitable nutrient management program. In addition, buffer strips and retention ponds are installed in critical areas. The impact of these BMPs and NMPs includes reduction of soil loss and nitrogen loading in the surface water.

However, some management practices may result in an increase in the dissolved nitrogen concentration in the ground water.

The efficiency of a management practice can be evaluated by considering the sediment and nutrient loadings of the watershed before and after the management practice is implemented For the nutrient modeling of the Lake Decatur watershed, the dissolved nutrient reduction efficiency will be measured using the following expression:

$$\text{Efficiency} = 1 - \frac{\text{Post - NMP Nutrient Loading}}{\text{Pre - NMP Nutrient Loading}}$$

The nutrient loading will be evaluated at the outlet of each sub-basin and at the discharge points to the lake.

Model Application

As a first step of the modeling effort, the AGNPS model was applied to the Big Ditch watershed to simulate the effect of the management of fertilizer application on nitrate loading reduction at the watershed outlet.

The 50-square-mile drainage area of Big Ditch watershed was subdivided into 824 40-acre cells as shown in figure 51. A streamgage located on Big Ditch also serves as a water quality sampling point. Four cross sections along Big Ditch are shown in figure 52. All of the model input parameters have been estimated or assumed for this simulation exercise. The entire Big Ditch watershed was assumed to be cultivated under a corn-soybean row crop sequence and conventional tillage. The COD for straight-row cropping practice was obtained as 170 mg/1 from the AGNPS manual. The corresponding surface condition constant was 0.05. The estimation of the runoff curve numbers requires information on the associated hydrologic soil groups. Since the Big Ditch watershed is located in Champaign County, the values of some of the model parameters including soil texture, hydrologic group, and credibility factor were taken from the county soil survey manual (SCS, 1982). Figure 5 presents a map of soils associations groups in the Lake Decatur watershed. After identifying the predominant soil type for each cell, the corresponding soil properties were selected from the soil survey manual. The shape factor

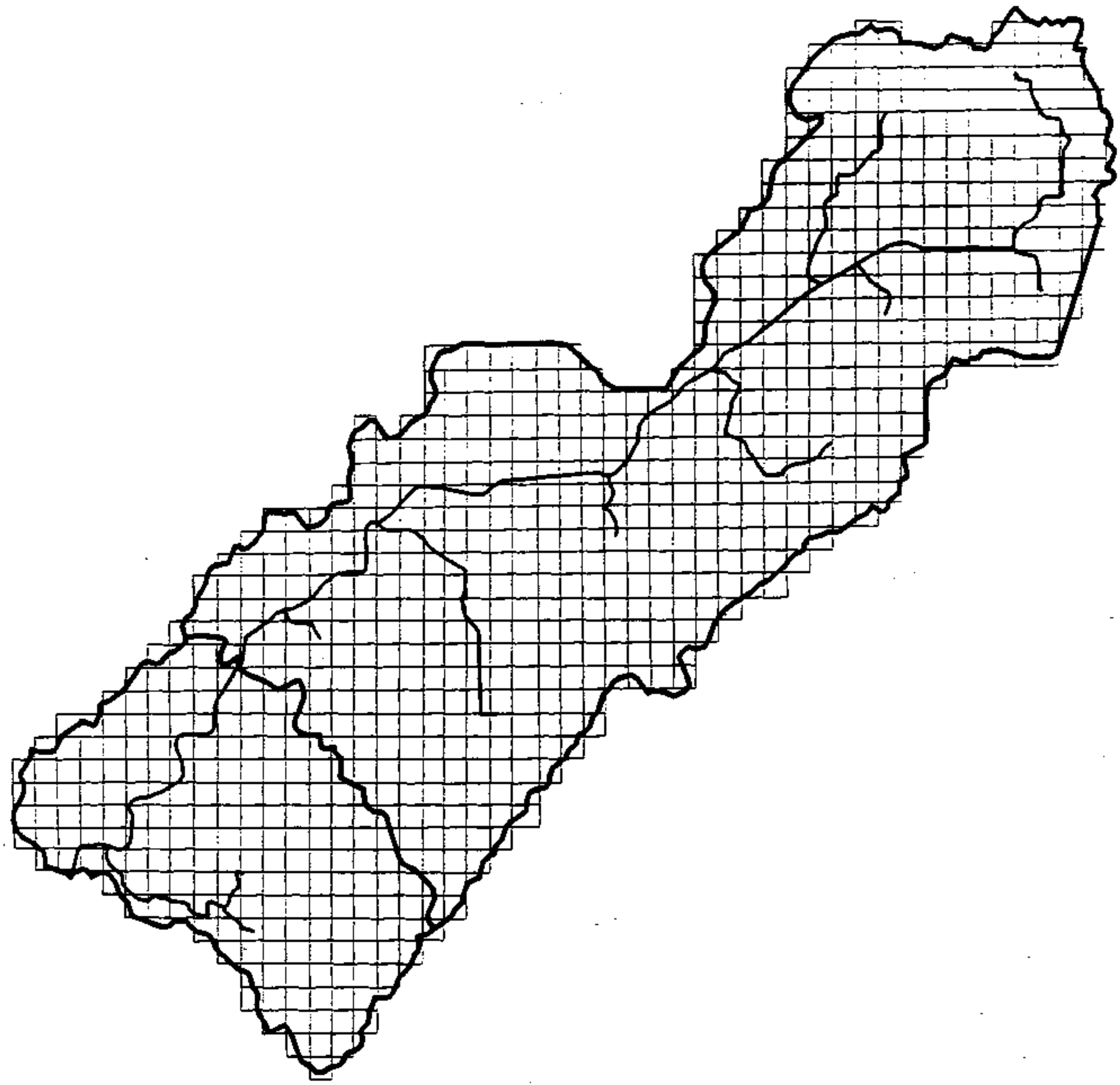


Figure 51. Division of Big Ditch watershed into 64-acre uniform grid cells

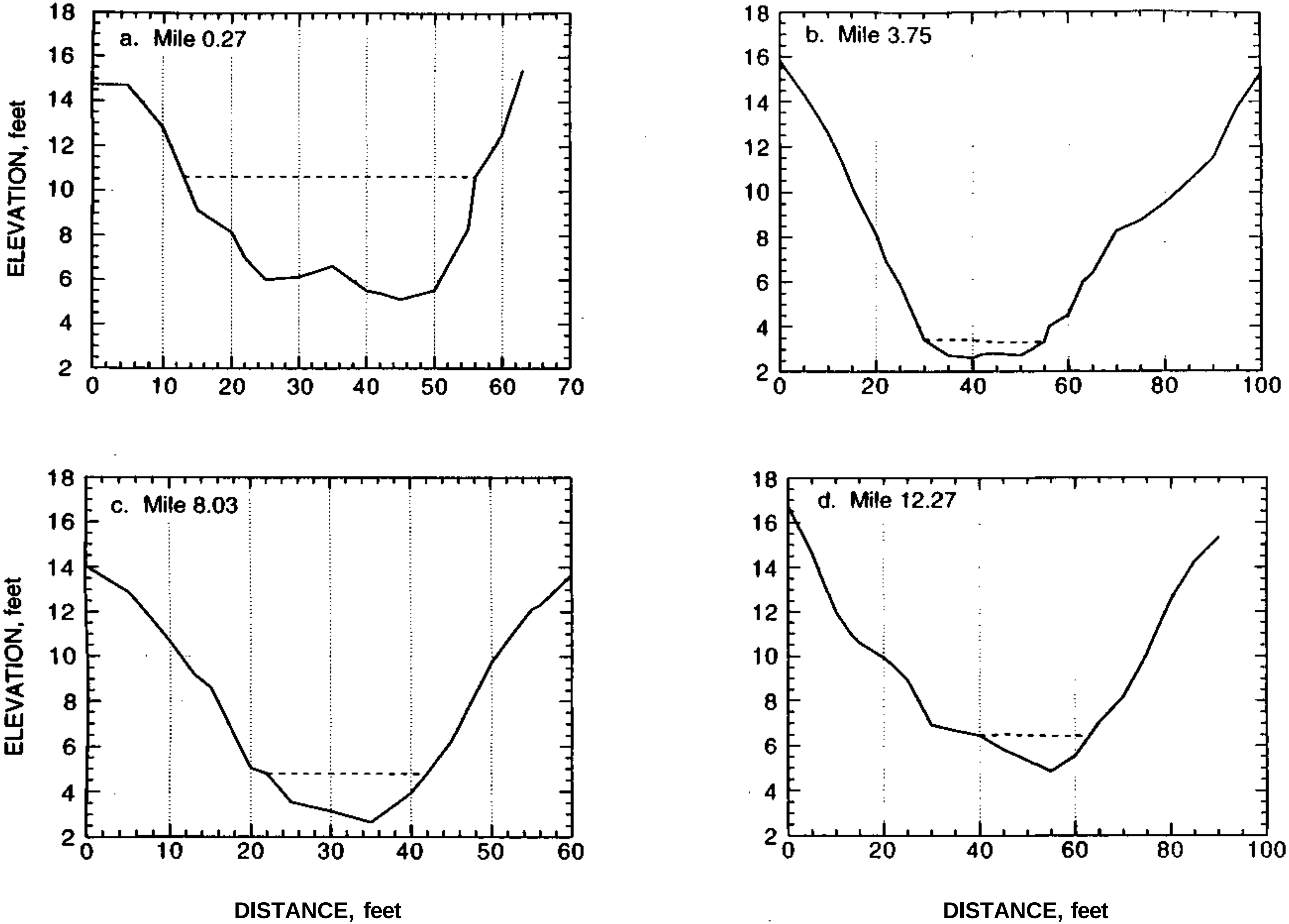


Figure 52. Big Ditch channel cross sections at a) 0.27 mile, b) 3.75 mile, c) 8.03 mile, and d) 12.27 mile

for all the cells was assumed to be uniform and the field slope length was taken as 200 feet. The cropping and practice factors for the corn-soybean row sequence in central Illinois were obtained from Circular 1220 (Walker and Pope, 1983) as 0.4 and 0.5, respectively. An annual fertilizer application rate of 200 lbs/acre was assumed for the entire watershed. This fertilization rate was considered to be typical among the farmers in this sub-basin. The fertilizer availability factor was assumed to be 25 percent.

The estimated values of some of the parameters are shown in table 13. These values will be updated or refined by calibration when sufficient data on streamflow and land use are available from the ongoing data collection efforts. The parameter values used in the simulations were specifically selected to represent the average conditions during the year. They do not necessarily represent conditions during a specific period or storm event. The model has been used to simulate 24-hour design storms with return periods ranging from two months to 25 years, which correspond to rainfall depths varying from 1.0 to 5.32 inches. The parameter values for the 200 lbs/acre fertilization rate representing the typical conditions are listed in table 13 under the corn-soybean conventional tillage column.

Table 13. Model Input for Big Ditch Watershed

Model parameter	*Corn-soybean conventional tillage*	*Baseline (100 percent)*
SCS curve number	78-85	58-71
Slope shape factor	Uniform	Uniform
Field slope length, feet	200	200
Manning roughness coefficient		
for channel	0.04	0.04
for overland area	0.075	0.08
Soil erodibility factor	0.28-0.43	0.28-0.43
Cropping factor	0.4	0.003
Practice factor	0.5	1.0
Surface condition constant	0.05	0.59
Fertilization level (lbs/acre)	100	0.0
Availability factor (%)	25	0.0
COD (mg/l)	170	25

The first simulation runs involved the typical fertilization rate of 200 lbs/acre on the entire Big Ditch watershed. For the next simulation, the fertilization rate was assumed to be reduced to 100 lbs/acre on the lower segment of the watershed, while the upper segment fertilization rate was maintained at the 200 lbs/acre Other conditions simulated include fertilization rates of 100 lbs/acre and 50 lbs/acre on the entire watershed and a baseline scenario of conditions prior to the cultivation of the land by assuming that the watershed was completely covered with prairie grass Table 13 shows the input data for the baseline condition Figure 53 shows the computed nitrogen concentration at the watershed outlet for the pre-NMPs condition, the post-NMPs conditions, and the baseline

These results indicate the range of nitrogen concentration reduction from 6 to 26 mg/1 for the various design storms when the fertilization rate was 200 lbs/acre on Big Ditch watershed. The baseline condition yields a constant concentration of 1 mg/1 for the selected storms. This implies that the actual nitrogen yield on Big Ditch for the 200 lbs/acre fertilization rate varies from 5 to 25 mg/1. The nitrogen concentration in the runoff was reduced by about 50 percent (4 to 13mg/l) when the fertilization rate was reduced to 100 lbs/acre on the entire watershed. The reduction in nitrogen concentrations was approximately 70 percent for the 50 lbs/acre manure application. When the fertilization rate was assumed to be 200 lbs/acre on the upper watershed and 100 lbs/acre on the lower section, the reduction in the nitrogen output varies from 5 to 20 mg/1. This suggests that the efficiency of an NMP on Big Ditch watershed will vary between 17 and 35 percent for the selected design storms.

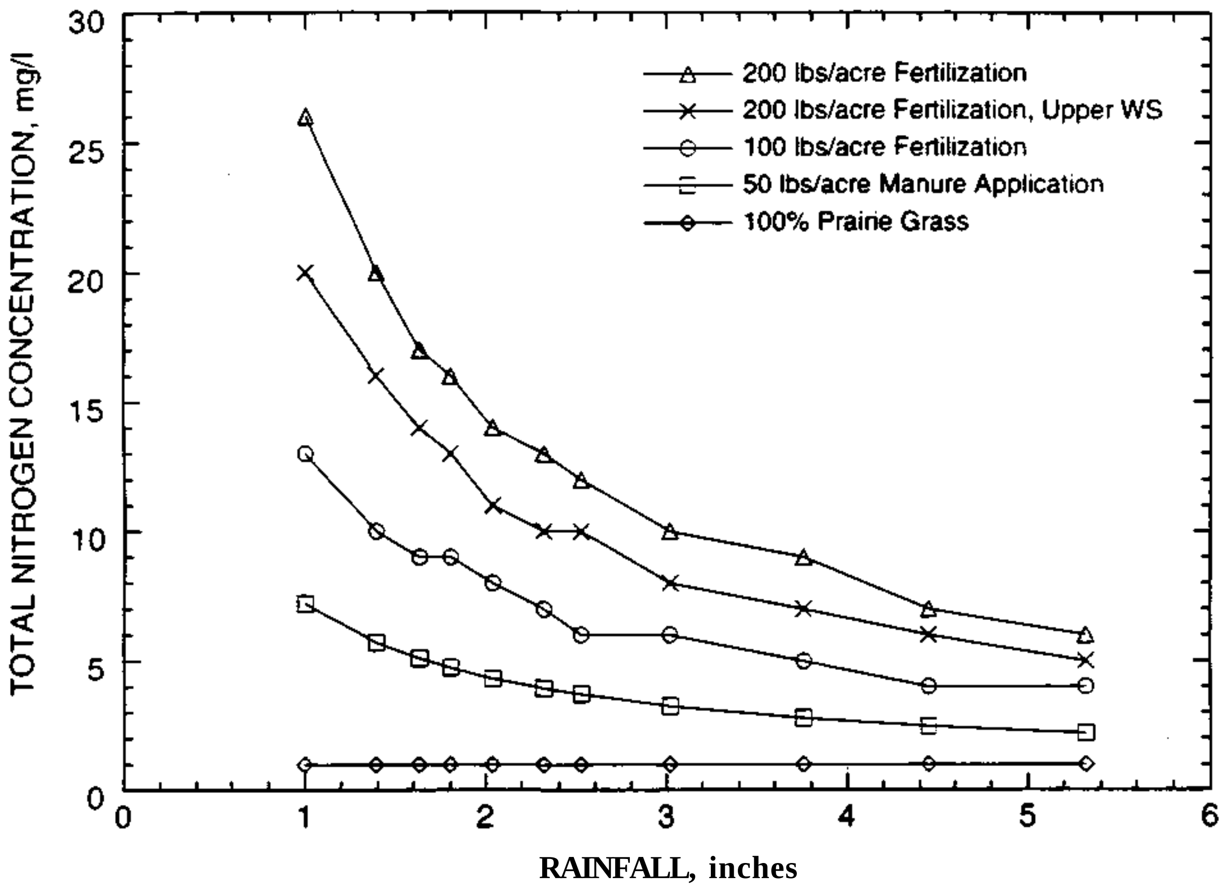


Figure 53. Variation of nitrogen concentration with different fertilization rates

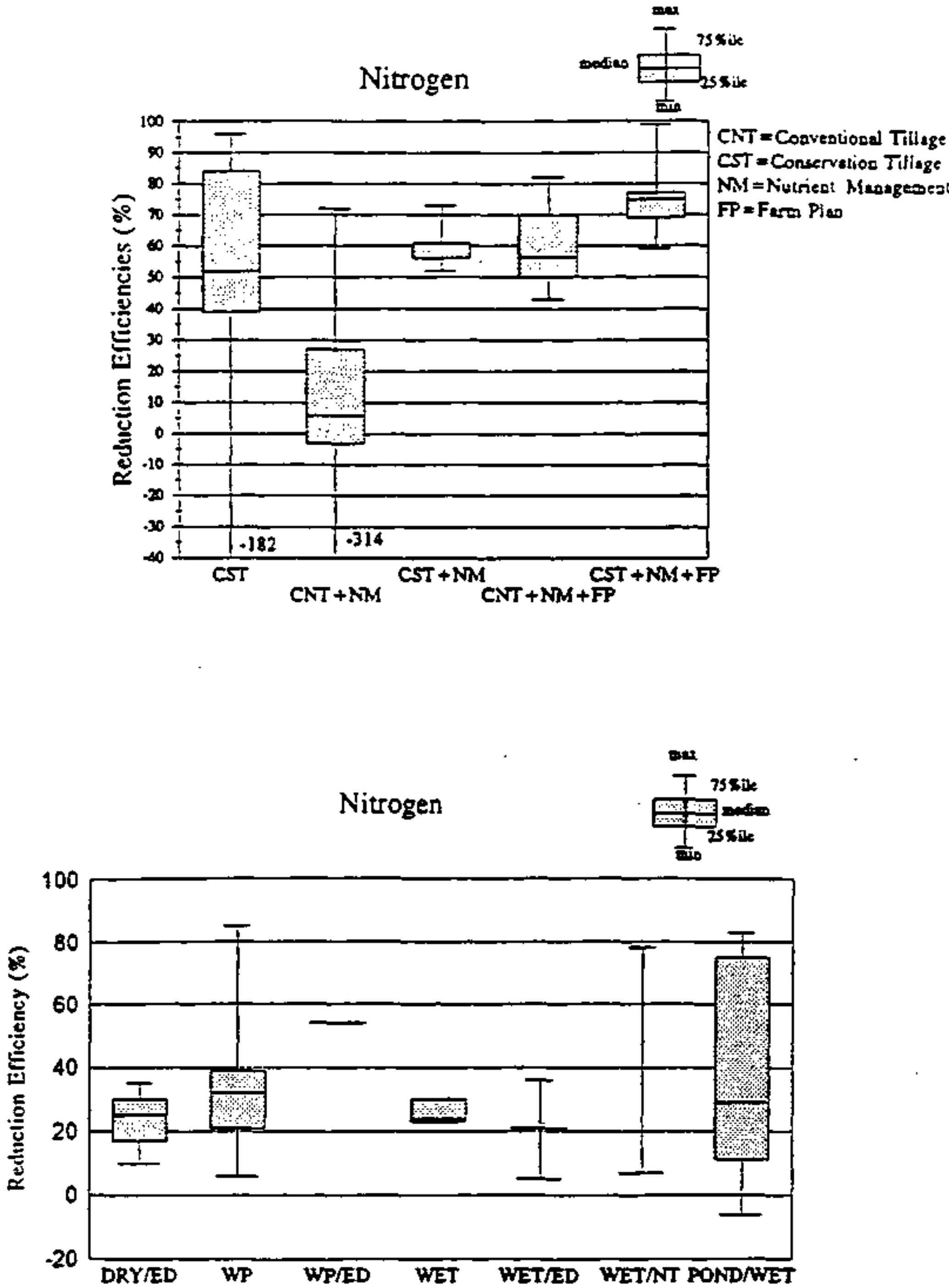
MANAGEMENT ALTERNATIVES

One of the main objectives of this project is to identify management alternatives that include alternative land use practices and mitigation projects to remedy the problem As was presented in the proposal, this component of the project will be conducted in cooperation with the Soil and Water Conservation Districts (SWCDs) within the watershed and a Technical Advisory Committee The cooperative work with the SWCDs was intended to generate reliable and up-to-date land use information for the watershed to establish relationships between land use practices and nitrate levels and to recommend appropriate best management practices (BMPs). Even though it has been a slow process, there has been progress in arranging to obtain the land use data from the SWCDs. Once the data have been processed and compared to the nitrate concentration and load data, then it will be possible to explain why certain sub-watersheds generate more or less nitrates than others. It is hoped that the cooperation with the SWCDs will be long term, since their cooperation and participation will be essential during the planning and implementation phases of any watershed management program.

A Technical Advisory Committee has not yet been formed to avoid starting that phase of the project without benefit of the first-year data and also to avoid projecting an image of knowing what needs to be done without evaluating the field data. After the review of the first-year annual report by the city, the Technical Advisory Committee will be formed and then evaluate the report and start the task of identifying potential BMPs that can be implemented in the watershed.

A literature review has identified several other places, ranging in size from small cities like Danville to large urban areas like New York City, that are having similar problems with nitrates or nutrients in general. In terms of valuable information related to nutrient problems and management issues, the efforts by the Interstate Commission on the Potomac River Basin (ICPRB) to reduce nutrient loads into the Chesapeake Bay Basin proved very educational and valuable. Publications from ICPRB and the Chesapeake Bay Program were reviewed very carefully (Camacho, 1990, 1992; Camacho and Blasenstein, 1992; Thomann, et al., 1994). The reports are results of major data collection and water quality modeling efforts jointly funded by several states and the federal government. The most useful information from these studies was related to nutrient reduction efficiencies of agricultural and "urban" BMPs. Even though the results might be slightly different from region to region, the efficiency factors reported in the literature will provide a starting point in evaluating BMPs and mitigation projects. Figure 54 summarizes the efficiency factors for removing nitrogen by different BMPs and mitigation projects These efficiency factors were compiled from values reported in the literature, and thus show significant variability from negative values to near 100 percent efficiency. In most cases though the reported efficiencies for most BMPs are encouraging For example, the median efficiency for conservation tillage with nutrient management is near 60 percent and the median efficiency of the "urban" BMPs is over 20 percent. These types of efficiency values will make it possible to evaluate what is needed in the watershed to lower the nitrate concentrations below the MCL.

After completion of the review process for the progress report, the data and information gathered through this project and the literature review will be presented to the Technical Advisory Committee so that it can identify and prioritize the BMPs for the Lake Decatur watershed.



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

Figure 54. Nitrogen reduction efficiencies of BMPs (Camacho, 1992)

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