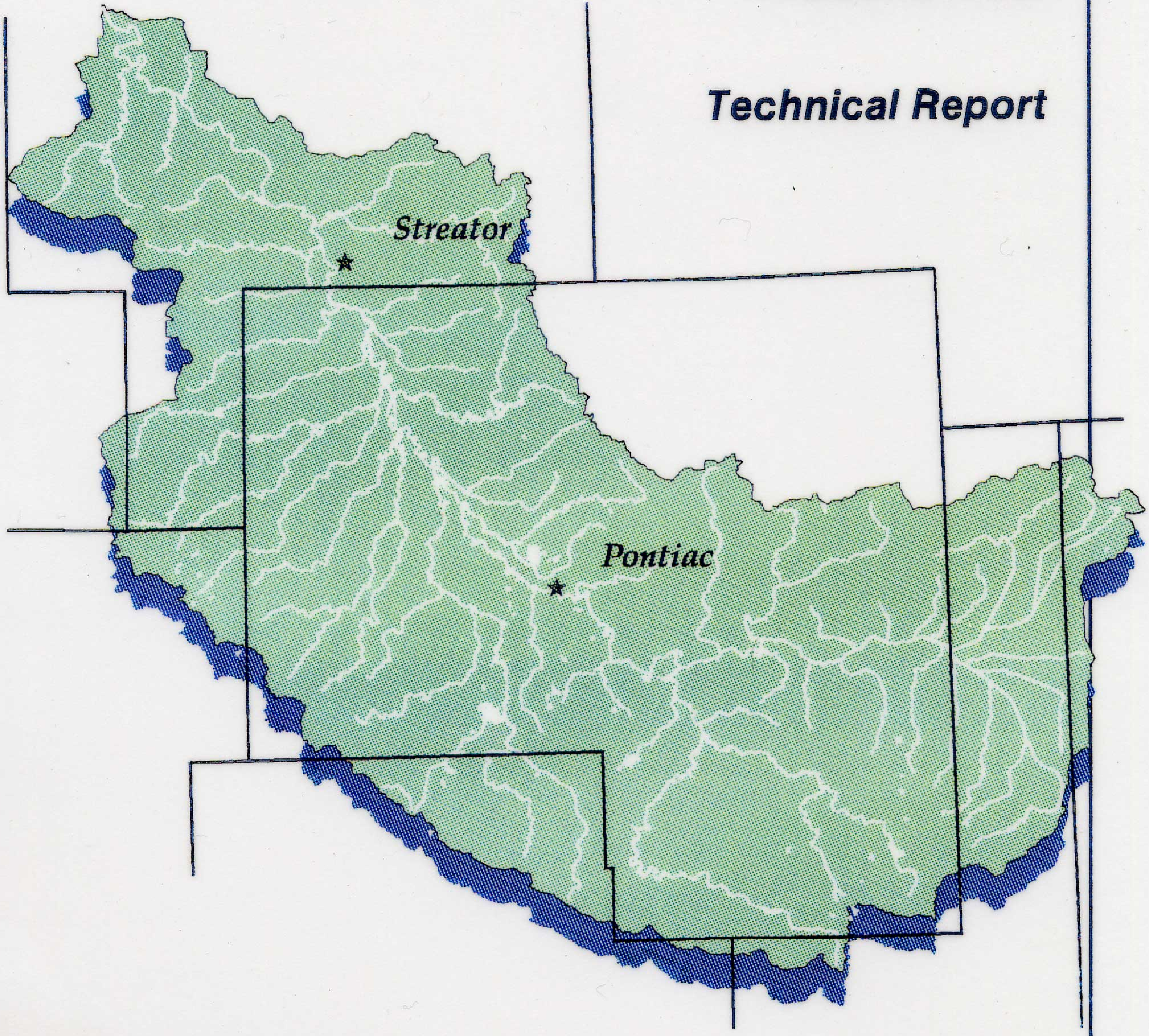
Watershed Monitoring and Land Use Evaluation for the Vermilion River Watershed

Technical Report



Illinois State Water Survey
Miscellaneous Publication 176

Prepared for the
Northern Illinois Water Corporation
June 1996

Watershed Monitoring and Land Use Evaluation for the Vermilion River Watershed

Technical Report

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Report Prepared for the:

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June 1996

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Watershed Monitoring and Land Use Evaluation for the Vermilion River Watershed

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Introduction

The Vermilion River, located in north-central Illinois, serves as a source of drinking water for the cities of Pontiac and Streator. Northern Illinois Water Corporation (NIWC) continuously withdraws water from the river for distribution to these communities. The annual water usage in 1994 and 1995 was 0.85 and 0.8 billion gallons for Streator and 0.74 and 0.76 billion gallons for Pontiac, respectively. The drainage area of the Vermilion River at the confluence with the Illinois River is 1,322 square miles. The watershed includes portions of seven counties in north-central Illinois as shown in figure 1. Agriculture is the predominant land use in the watershed, and some of the major urban areas are Streator, Pontiac, Fairbury, Forrest, and Chatsworth.

In recent years, NIWC has experienced problems related to nutrients in the water supply and had to implement measures to manage these problems. At the present time the major problem is related to high levels of nitrates during certain periods of the year. The nitrate problem is not unique to the Vermilion River and has become a major drinking water quality problem in central Illinois communities such as Decatur, Bloomington-Normal, and Danville. NIWC was able to address the nitrate problem in Pontiac's drinking water supply by storing river water with low nitrate concentration in old quarries for blending when nitrate exceeds the 10 milligram per liter (mg/1) maximum contamination level (MCL) in the river. In August of 1993, NIWC signed a Letter of Commitment (LOC) with the Illinois Environmental Protection Agency (IEPA) in which NIWC agreed to analyze the nitrate problem at Streator and implement a solution. One requirement of the LOC specifies that a two-year watershed monitoring study be conducted to determine nitrate sources and make recommendations that will reduce nitrate to levels below the MCL at the Streator water intake.

The Illinois State Water Survey (ISWS) conducted the two-year watershed monitoring and land use evaluation study for NIWC to monitor and identify the sources and causes of high nitrate concentrations in the Vermilion River basin. The watershed monitoring component of the study established seven stations at selected locations to monitor the nitrogen in the river system and flow of water at six of those stations. This technical report is the product of that study. It discusses the background of the nitrate issue and land uses in the Vermilion River watershed and nitrogen transformations. It also presents the hydrologic and water quality monitoring data collected during the study.

Based on the data collected in the Vermilion River basin and additional information from the literature review and other similar projects, the ISWS will prepare a set of recommendations for implementation in the watershed to reduce the nitrate concentrations in the Vermilion River below the maximum allowable contamination level (MCL) of 10 mg/1.

Acknowledgments

This work was supported by Northern Illinois Water Corporation (NIWC). Mark Johnson, Vice President, served as project manager, and his cooperation and assistance are greatly appreciated.

Several other NIWC staff have also been very cooperative and supportive: Duane Cole, President; Larry Goldsmith, Streator plant; Tim Tuley and John Shirkey, Pontiac plant; and Barry Suits, Champaign office.

We would also like to acknowledge the cooperation and support we have received from the following county Soil and Water Conservation Districts: Livingston: Carol Sweeden and Mark Baran; LaSalle: Melissa Whalen; Ford: Dale Hoogstraat; and McLean: Jackie Kraft and Jim Rutherford.

We gratefully acknowledge the assistance of several ISWS staff. Loretta M. Skowron, Lauren F. Sievers, Daniel L. Webb, Saada E. Hamdy, Sue R. Bachman, Troy Foster, Todd Peter, Matt Lowell, and Lavanya Reddy, Office of Analytical & Water Treatment Services, performed the laboratory analyses. Susan Shaw, Steven Tarte, and Darin Strako, Office of Sediment & Wetland Studies, provided assistance in the field. Eric Richardson and Kingsley Allan, Office of Surface Water Information: Systems, Information, & GIS, provided the Geographic Information System (GIS) work presented in this report. Becky Howard produced the report, which was edited by Eva Kingston; and Linda Hascall and David Cox produced some of the figures and provided expert advice on illustration layout.

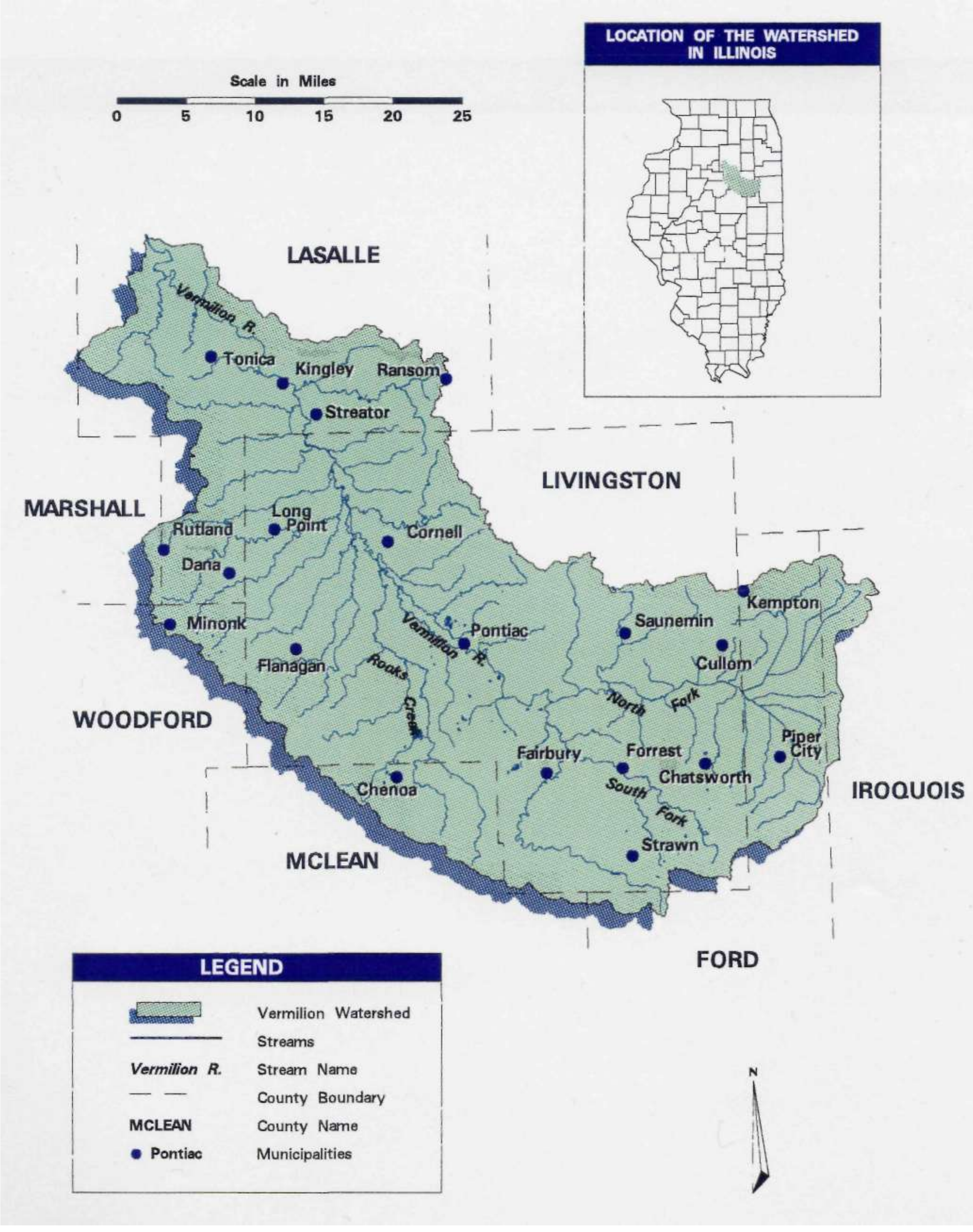


Figure 1. Location of the Vermilion River Watershed

Background

Water Quality Problems in the Vermilion River Watershed

The cities of Pontiac and Streator have been experiencing high nitrate levels in their drinking water for many years, and nitrate concentrations have been periodically exceeding the maximum contamination level (MCL) of 10 milligrams per liter (mg/1) specified by the Safe Water Drinking Act (SWDA). Presently, NIWC-Pontiac has been able to solve this problem by acquiring old stone quarries near the city for storage of river water containing low concentrations of nitrate. This water supply has a dual purpose: 1) for blending with the river water when concentrations exceed the MCL and 2) as a possible emergency water supply during drought. The Illinois Environmental Protection Agency (IEPA) has issued warnings of noncompliance of nitrate for Streator and subsequently brokered a Letter of Commitment (LOC) with NIWC to reduce the nitrate concentrations in Streator to acceptable levels. The agreement required NIWC to investigate several nitrate-reducing options, including the installation of expensive water treatment technologies at the water treatment plant, finding other reliable sources of water with low concentrations of nitrate, or determining the source of the nitrate in the Vermilion River watershed and instituting a watershed management plan. NIWC has tested a pilot ion exchange treatment system at the Streator plant, and found it to be an expensive option. Through a study-conducted by the Illinois State Geological Survey (ISGS), it was determined that there are insufficient viable ground water resources in the vicinity. Since signing the LOC, NIWC has been able to better manage a small reservoir at the Streator plant to be used for blending water. However, because of the low capacity of this reservoir, it will be quite difficult to continue blending if nitrate concentrations remain high in the Vermilion River for long periods of time. In order to determine nitrate sources in the watershed, NIWC contracted the ISWS to conduct a two-year watershed monitoring study.

The design of this watershed monitoring study was based on a very similar study currently being conducted in the Upper Sangamon River watershed. The Vermilion River watershed study was designed to characterize the spatial and temporal distribution of nitrate in the Vermilion River watershed and to collect reliable baseline, hydrologic, and nitrogen data in the watershed to determine and characterize the nitrate sources. However, the Upper Sangamon River study was much more detailed in its monitoring and modeling of nitrates in the watershed. The purpose of that expanded work was to determine the relative characteristics of nitrate behavior throughout the seasons, various climatic events, and land use practices. Consequently, the ISWS determined that the Vermilion River watershed could benefit from the Upper Sangamon River study, which is why the detailed monitoring aspect of the Upper Sangamon River watershed study was not replicated for the Vermilion River watershed.

Since the early part of the century, the Illinois State Water Survey (ISWS) has collected and analyzed water samples from the Vermilion River starting in 1910. Inspection of ISWS and IEPA records indicates that there has been some nitrate analysis over the years. Even though the sampling frequency has not been regular and frequent, the results provide valuable insights to the nitrate problem in the Vermilion River. Historical data retrieved from ISWS and IEPA files for the Vermilion River at Streator are plotted in figure 2. The first samples on record were collected and analyzed for nitrate in 1906 at Streator. Data were collected approximately every ten days from August 1906 through July 1907, and the highest nitrate samples were found during March through June. The highest concentration was approximately 6 milligrams per liter (mg/1) nitrate-nitrogen. The mean nitrate-nitrogen concentration for the one year period was approximately 2.5 mg/1. The earliest samples for the Vermilion River at Pontiac were collected in 1913. These data are presented here for general background information.

One conclusion that can be made from the data is that nitrates are increasing at both locations on the Vermilion River. The Vermilion River at Streator and Pontiac exceeded the 10 mg/1 concentration starting in the 1960s and 1970s. However, since the 1980s, nitrate levels at both locations are higher than during earlier periods. The Vermilion River at Pontiac seems to have had higher concentrations than Streator during the 1980s.

Figure 3a presents an analysis of the annual maximum, average, and minimum nitrate values from 1981-1995 for the Streator data presented in figure 2a. Between 1983 and 1994, the data show an increase in concentrations, with a drop in 1995. Figure 3b shows the monthly maximum, average, and minimum nitrate concentrations from 1906 to 1995. The figure indicates that the nitrate levels reach their highest concentrations in the spring, fall to near zero by late summer/early fall, and then rise during winter, a pattern consistent with other rivers in central Illinois. The available data therefore indicate that nitrate concentrations in the Vermilion River have been increasing over a long period of time and are now exceeding the maximum allowable contamination level (MCL) of 10 mg/1 on a regular basis.

Watershed Characteristics

The Vermilion River watershed is predominantly located within the four central Illinois counties of Livingston, LaSalle, Ford, and McLean, with small portions around the perimeter in Iroquois, Marshall, and Woodford Counties (figure 1). The watershed is situated within the Bloomington Ridged Plain physiographic subdivision of Illinois as defined by Leighton et al. (1948) with a small portion of the eastern headwaters lying within the Kankakee Plain subdivision. These subdivisions are composed of till and outwash deposits left by the Wisconsin Glaciation. They also comprise a portion of the Till Plains Section of the Central Lowland Physiographic Province of the central United States. The Bloomington Ridged Plain is "characterized by low, broad morainic ridges with intervening wide stretches of relatively flat or gently undulating ground moraine." The glacial deposits are generally thick and natural drainage is poorly developed. The Vermilion River flows from the southeast to the northwest along a northward curving valley. The basin is bounded on the north by the Marseilles morainal complex and on the south by the Middle Cropsey moraine. There are 17 different soil associations within the watershed (figure 4). The four major associations (IL018; IL016 and IL081; IL017; IL010

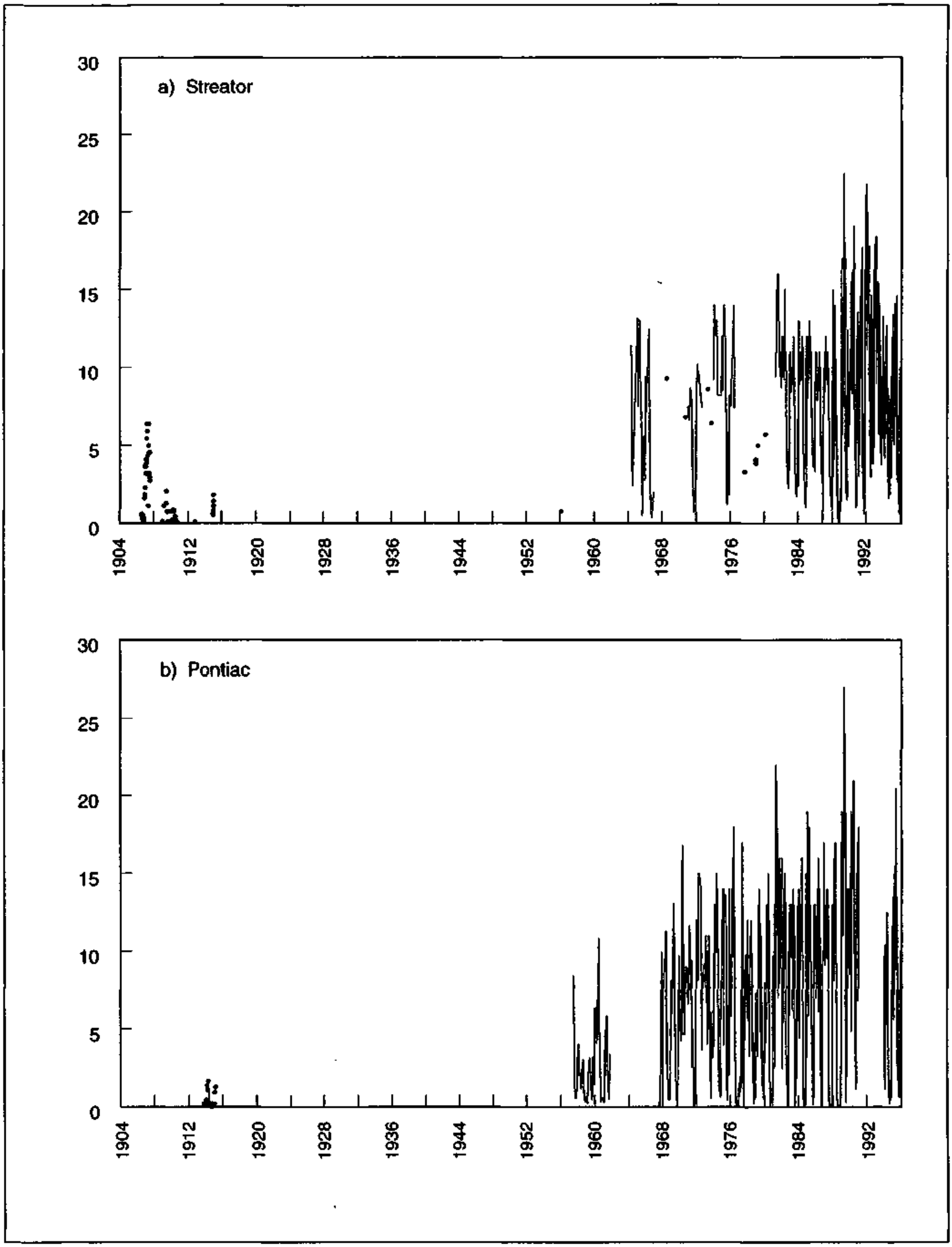


Figure 2. Historical nitrate concentrations in a) Streator and b) Pontiac

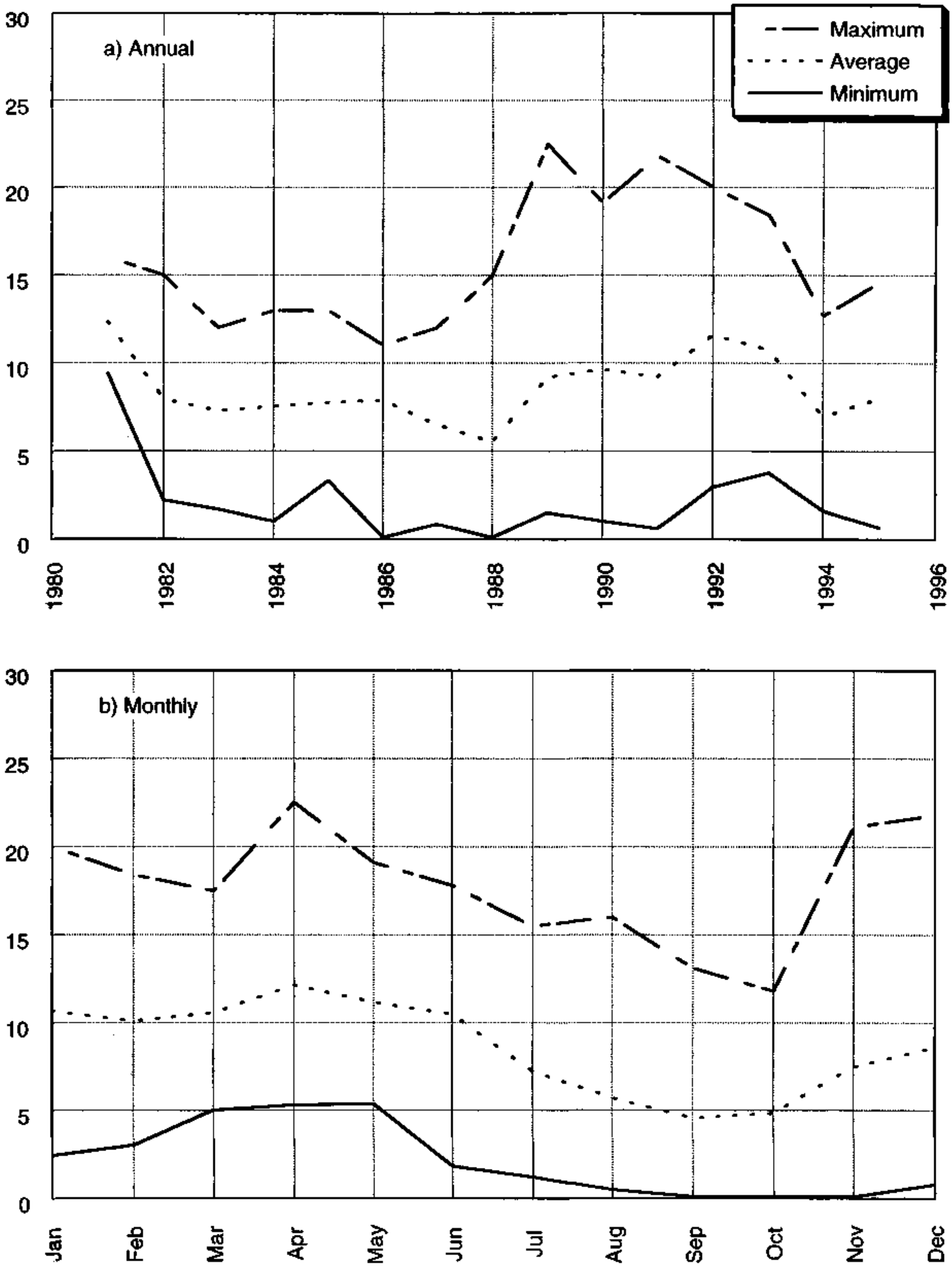


Figure 3. Maximum, minimum, and average nitrate concentrations at Streator, a) annual and b) monthly

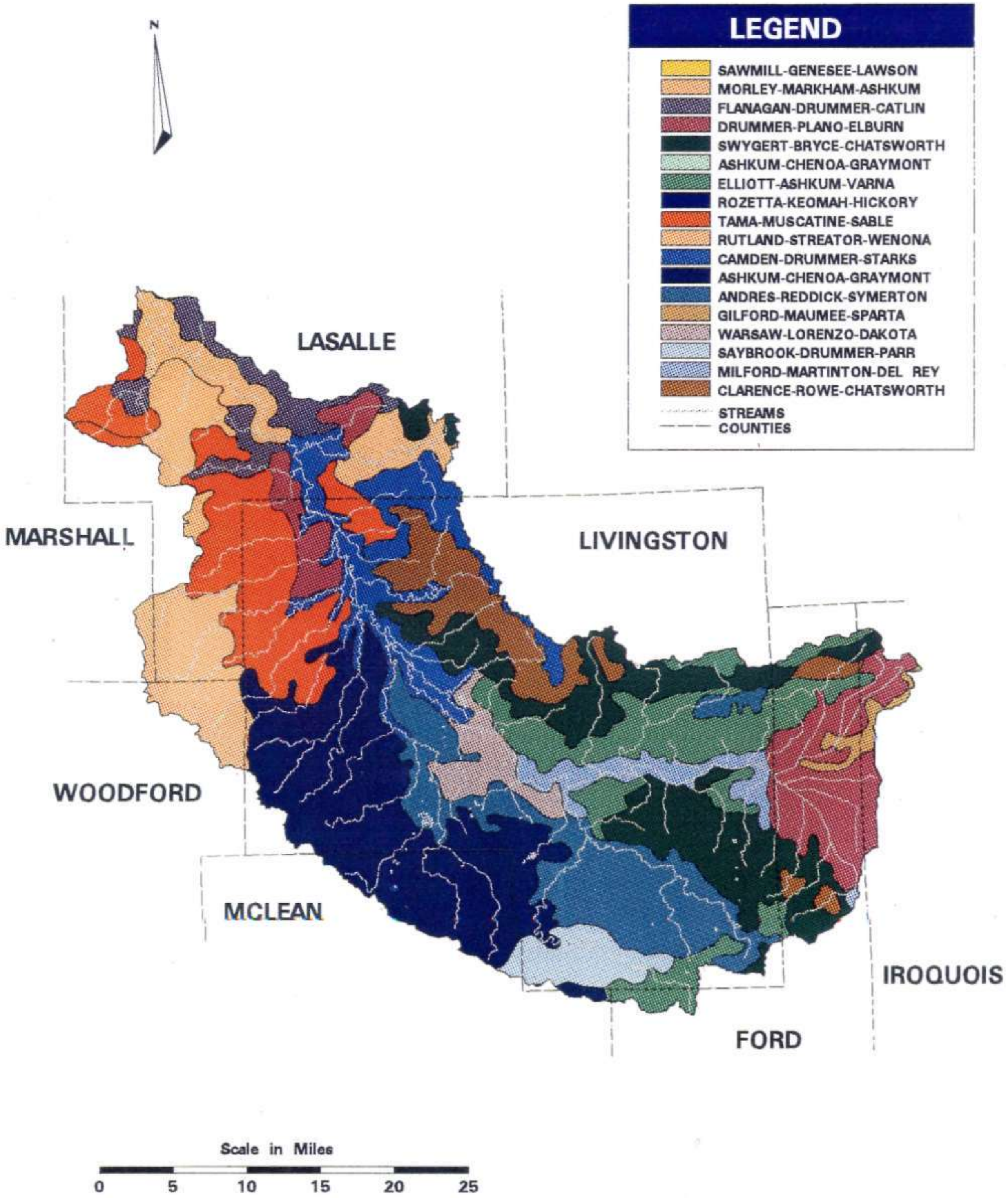


Figure 4. Map of soil association groups in the Vermilion River watershed

and IL012) are characterized by dark-colored soils with permeability ranging from very slow to moderate. The origin of three of the soil types is thin loess with the fourth (IL017) originating from medium- to fine-textured alluvial deposits. The soils are classified as very productive with some drainage problems that likely resulted from extensive man-made drainage networks.

The Vermilion River watershed drains approximately 1,322 square miles (sq mi) and joins the Illinois River at river mile 226.3 near LaSalle-Peru. The length of the Vermilion River is approximately 114.7 miles with a total change in elevation of approximately 224 feet. Table 1 shows river mile, elevation, drainage area, and profile data for the monitoring stations and important features in the basin. The river profile is contrary to that of most river systems: higher gradients occur in the lower reaches of the basin rather than in the upper reaches.

Table 1. Vermilion River Profile along Main Channel

Station name/number	*River mile*	*Elevation (approximate feet above MSL)*	*Drainage area (sq mi)*	*Gradient to next downstream station (ft/mi)*
Confluence with Illinois R.	226.3 on Illinois R.	435	1322	-
Near Leonore (608)	17.2	522	1244	5.1
Route 17 (607)	35.4	576	1044	3.0
Pontiac (604)	60.3	620	576	1.8
Junction of Forks	75.9	632	504	0.8
Near Chatsworth (606)	89.3	636	199	0.3
Drainage Divide	114.7	659	-	0.9

Table 2 presents information on the four tributary watersheds monitored for this project. The largest tributary watershed, the North Fork, drains approximately 320 sq mi of the eastern headwaters, the portion of the basin that has experienced the greatest amount of channelization. Long Point Creek, the smallest of the four tributary watersheds, drains only 63 sq mi. All the profiles are more typical with gradients decreasing in the downstream direction. Significant differences exist between the tributary watersheds (including basin shape, drainage area, and gradient), which affect their respective response times and transport competence. Rooks Creek and South Fork are the most similar, while Long Point Creek and North Fork represent the extremes in basin characteristics of the four tributary watersheds monitored (see table 2).

In general, all of these streams are relatively low-energy systems with gradual slopes and small amounts of impervious surface. All of the watersheds are dominated by row crop land use. Channel maintenance and straightening are apparent in all parts of the Vermilion River watershed, but they are most evident in the headwater regions where gradients are lowest.

Table 2. Characteristics of Four Tributary Watersheds within the Vermilion River Watershed

Station name/number	*River mile*	*Elevation (approximate feet above MSL)*	*Drainage area (sq mi)*	*Gradient to next downstream station (ft/mi)*
Long Point Creek at:				
Confluence	37.1*	577	91	-
Station 602	4.3	582	63	1.2
Divide	25.9	763	-	8.4
Rooks Creek at:				
Confluence	48.9*	594	134	-
Station 603	5.6	615	127	3.8
Divide	32.6	787	-	6.4
South Fork at:				
Confluence	75.9*	632	185	-
Station 605	6.7	660	163	4.2
Divide	28.2	804	-	6.7
North Fork at:				
Confluence	75.9*	632	320	-
Station 606	13.9	636	199	0.3
Divide	39.0	659	-	0.9

Note: * River mile on the Vermilion River

Land Use in the Vermilion River Watershed

Agricultural Land Use Trends

Agriculture is the dominant land use in the seven counties (Ford, Iroquois, LaSalle, Livingston, McLean, Marshall, and Woodford) within the Vermilion River watershed. Four of the counties (Livingston, LaSalle, Ford, and McLean) comprise 95 percent of the land area in the watershed, and one county, Livingston, accounts for 60 percent of that area. Therefore Livingston County was selected for general analysis of the agricultural land use practices in the watershed. Approximately 816.4 sq mi of Livingston County is within the Vermilion River watershed and about 70 percent of that area is in agricultural production. Figure 5 shows the changes in acreages for major crops planted in Livingston County from 1925 to 1993. Row crop (corn and soybean) acreage nearly doubled between 1925 (280,000 acres) and 1979 (533,000 acres), with a decline to 468,000 acres in 1993. Corn acreage has remained fairly steady at a median of 278,100 acres, fluctuating from 198,000 to 321,000 acres. Soybean acreage, however, has made significant increases from virtually zero (800 acres) in 1925 to 267,000 acres in 1993, with a maximum of 293,000 acres reached in 1979. The increase in soybean acreage is a mirror

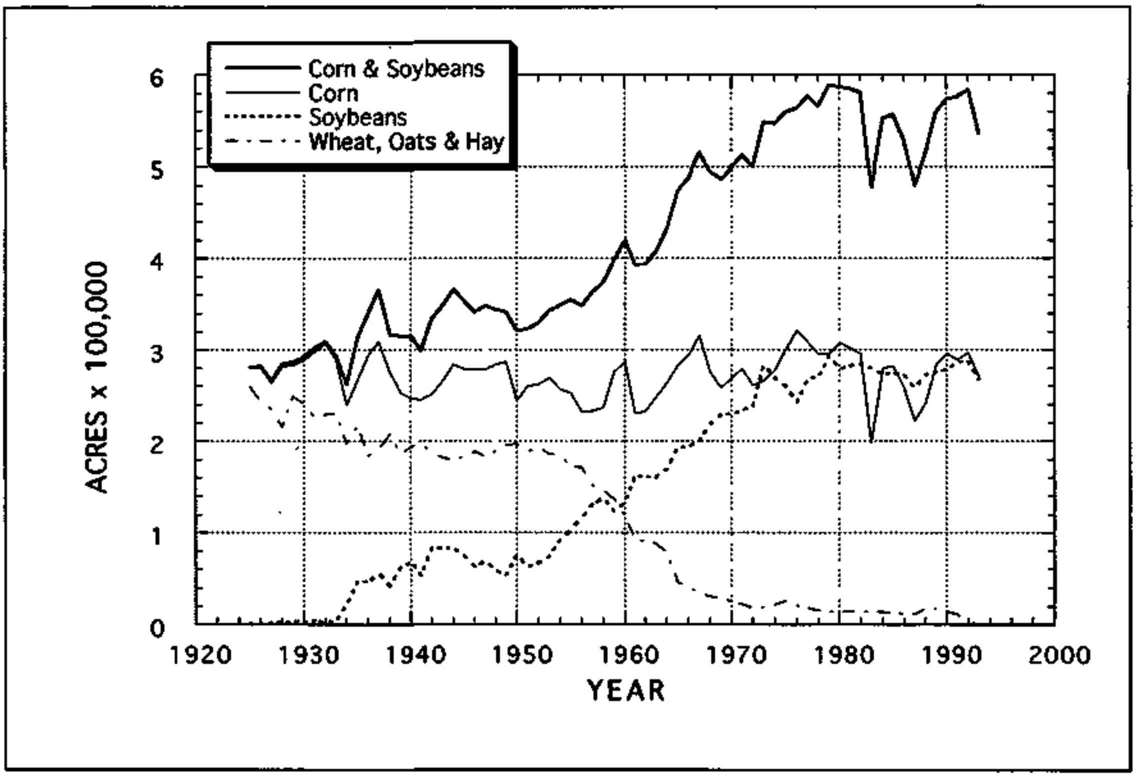


Figure 5. Acreages of selected crops in Livingston County based on Illinois Agricultural Statistics (IAS) data

image of the decrease in grassy crop acreage such as wheat, oats, and hay. These crops have virtually disappeared from the county, declining from a high of 260,000 acres in 1925 to only approximately 10,000 acres in 1993. (Demissie et al., 1996)

Agricultural and Nonagricultural Land Uses

The discussion on land use presented so far is based on the Illinois Agricultural Statistics (IAS) data for only Livingston County. Even though it provides a good perspective on the general trend and major land uses, detailed information is lacking. Therefore, a more thorough investigation of land uses in the watershed should include all potential sources of nitrate. Four Soil and Water Conservation Districts (SWCDs) in the watershed (Livingston, LaSalle, Ford, and McLean) worked in cooperation with the ISWS to collect more current and extensive land use data.

The procedure used to collect these data is known as the *T by 2000 Transect Survey* developed by the Illinois Department of Agriculture (IDOA) and the 98 SWCDs in the state. The transect survey's purpose is "to gather information on the extent and current status of soil erosion in Illinois..." by using 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 samples a minimum of 456 sites along the route and collects data only 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 with the SWCDs to also collect nonagricultural land use data while performing the transect survey. The routes used for the transect survey 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 Vermilion River watershed. (Demissie et al., 1996)

The Illinois SWCDs are scheduled to do three annual transect surveys, the first of which was done in 1994. Each survey is typically conducted early in the agricultural growing season, usually in the month of June. The data from the 1994 survey were used in this analysis. This survey includes crops planted in 1994 as well as those planted in 1993 by using the "previous crop" parameter collected. This survey overlapped the watershed study period by one year, which started at the beginning of 1994 and concluded at the end of 1995. A total of 1203 data points, an average of less than one data point for each square mile of watershed area, were used in this analysis. A county location for each data point was readily available in the survey; however, for the purposes of this study the location of each data point in its respective tributary watershed was determined and all analyses are based on this spatial aspect of the data. There are instances where a particular land use is listed as "none" in the analyses. This does not necessarily mean that the land use did not exist, only that it was not observed in the established survey route and should be assumed to cover a very small percentage of the watershed area. The following analysis of the data is divided into two sections. The first section is an analysis of the tributary watersheds (Long Point Creek, Rooks Creek, South Fork, and North Fork). The other analysis is of the entire watershed divided into five sections along the Vermilion River above (upstream) each of the following locations: Pontiac (604), Rt. 17 (607), Streator Dam (601), Leonore (608), and the entire watershed at the confluence with the Illinois River.

T by 2000 data showed that approximately 91 percent of the Vermilion River watershed is in agricultural production. Crops surveyed were corn, row and drilled soybeans, small grains, hay, and other crops. Figure 6 shows the agricultural and nonagricultural land uses in the tributary watersheds during the 1994 growing season. The survey also shows 1993 percentages of crops and will be discussed later in this section. The crop area in the tributary watersheds ranged from 97 to 89 percent in North Fork and South Fork watersheds, respectively. Nonagricultural land uses surveyed include urban, rural (farmsteads, pastures, animal lots, etc.), infrastructure (roads and railroads), woods/open areas (meadows, cemeteries, or grass), and water areas. Figure 7 shows the percent of the total area occupied by nonagricultural land uses only. The figure shows that of all nonagricultural land uses, urban use was the highest in Rooks Creek watershed at 40 percent, 31 percent at North Fork and South Fork, and no nonagricultural land uses were observed on the routes in Long Point Creek. Rural land use of 60 percent was observed in the Rooks Creek and Long Point Creek watersheds, and the other tributaries ranged from 23 to 31 percent. The North Fork and Long Point Creek watersheds show 46 and 40 percent area in woods/open areas, but no such areas in Rooks Creek. Infrastructure and water were surveyed to be less than one percent in all the tributary watersheds except in the South Fork watershed where water covered 8 percent of the area surveyed.

Figure 8a shows the percentage of agricultural land used for crops by types of crops surveyed. North Fork is the only watershed illustrated because all the crop percentages in the tributary watersheds were virtually the same. The values for the following crops are shown in the accompanying table: corn, soybeans, small grains, hay, and other. Corn and soybeans are almost evenly split in the watersheds, averaging 48 percent for corn and 45 percent for soybeans. There seem to be some small variations between small grains, hay, and other crops.

Figure 8b shows the breakdown of selected crops between the growing seasons in 1993 and 1994 for tributary watersheds. Corn-soybean rotation is apparent in most of the watershed. North Fork, South Fork, and Rooks Creek show corn planted in a slightly smaller percentage of the watershed than soybeans during 1993 and vice versa for 1994. Long Point Creek shows slightly more area planted in corn than soybeans during both years.

Figure 9 shows the percent area of agricultural and nonagricultural land uses at the five Vermilion River watershed subdivisions. Each subdivision represents the watershed area upstream of the location indicated. For example, the area above Rt. 17 includes the area between Pontiac and Rt. 17 as well as the area above Pontiac. The watershed subdivisions show agricultural land use slightly decreases in the downstream direction. In 1994 nonagricultural land uses covered almost 9 percent of the total land area. Figure 10 shows the percent total area occupied by nonagricultural land uses only in each subdivision, but all values for each land use in

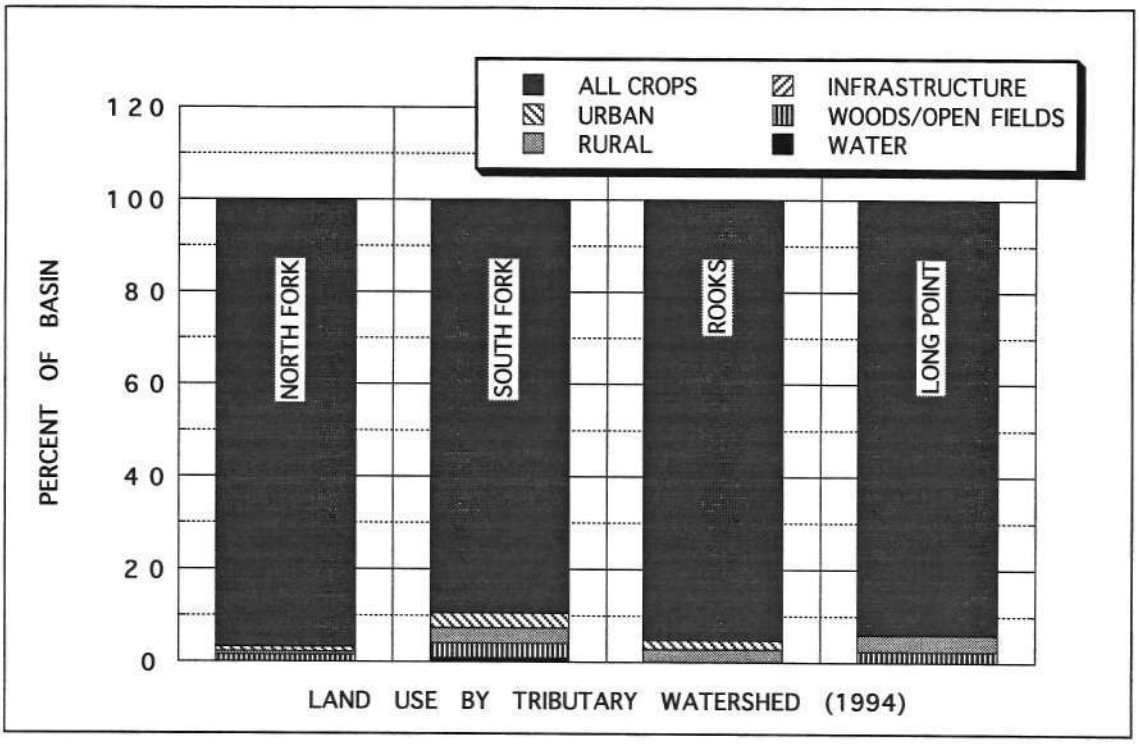


Figure 6. Percent area of land uses in tributary watersheds

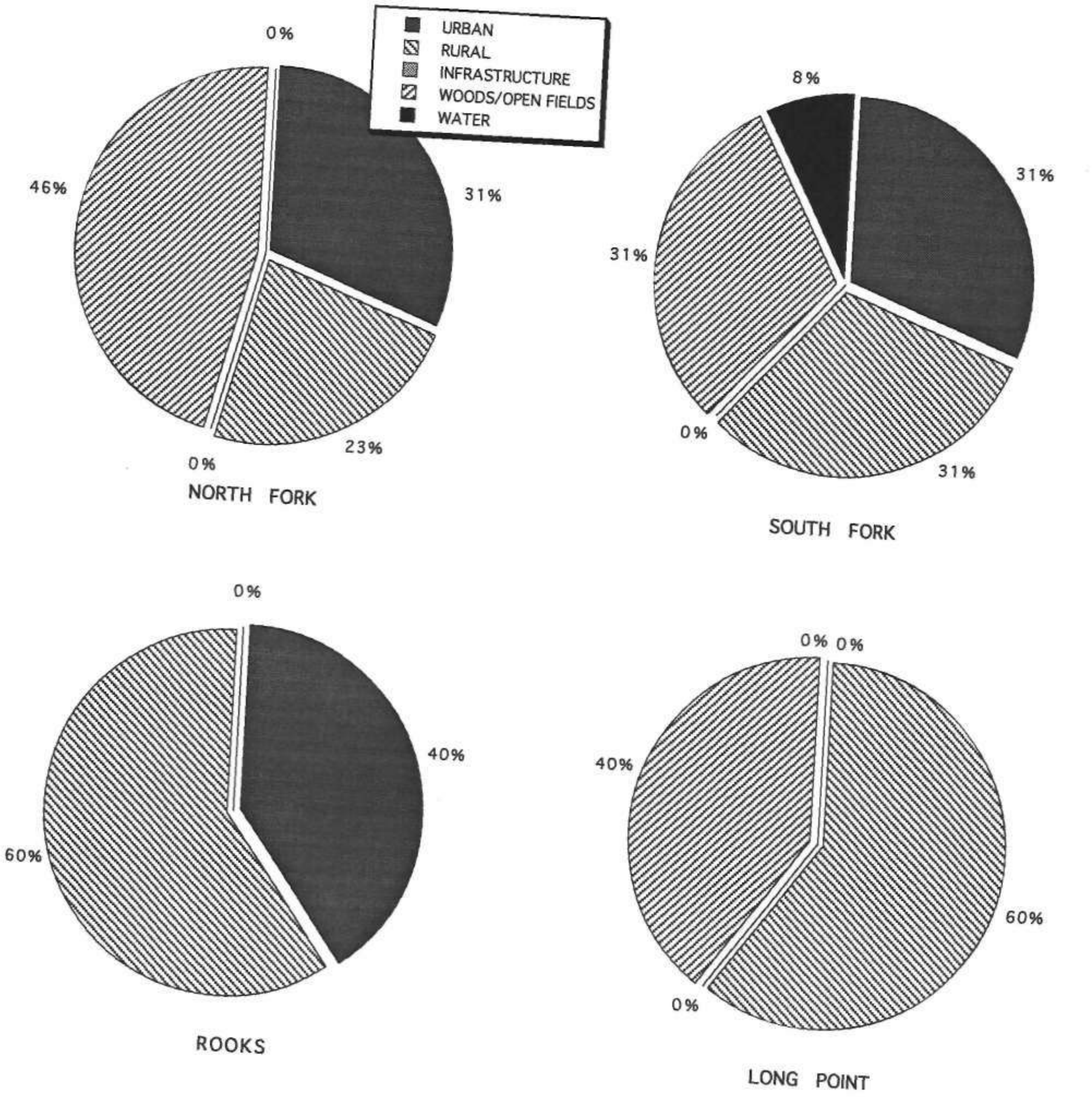
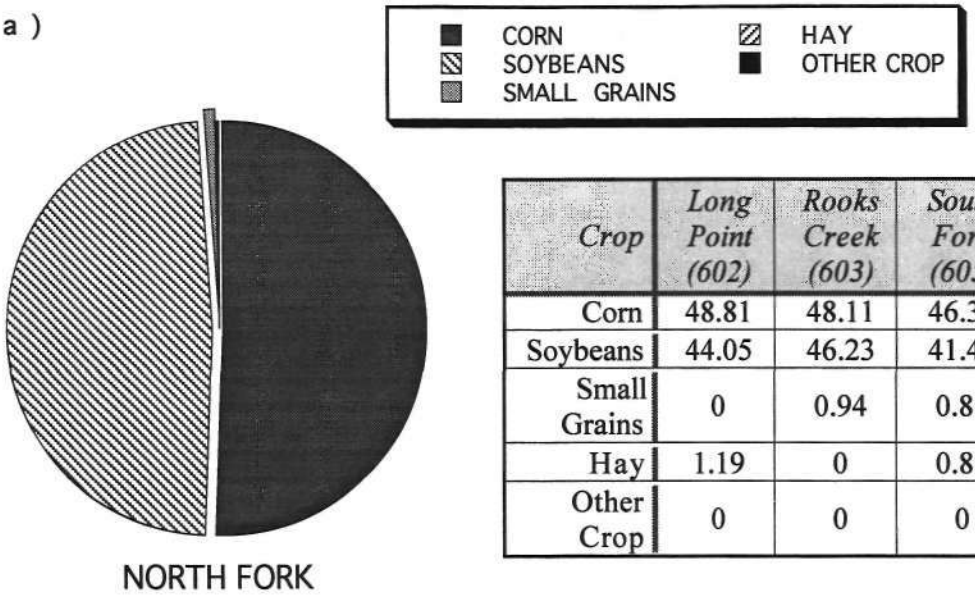


Figure 7. Percent area of all other land uses in tributary watersheds based on IDOA T by *2000* Transect Survey data

a)



Crop	*Long Point (602)*	*Rooks Creek (603)*	*South Fork (605)*	*North Fork (606)*
Corn	48.81	48.11	46.34	48.91
Soybeans	44.05	46.23	41.46	46.97
Small Grains	0	0.94	0.81	0.73
Hay	1.19	0	0.81	0
Other Crop	0	0	0	0.24

b)

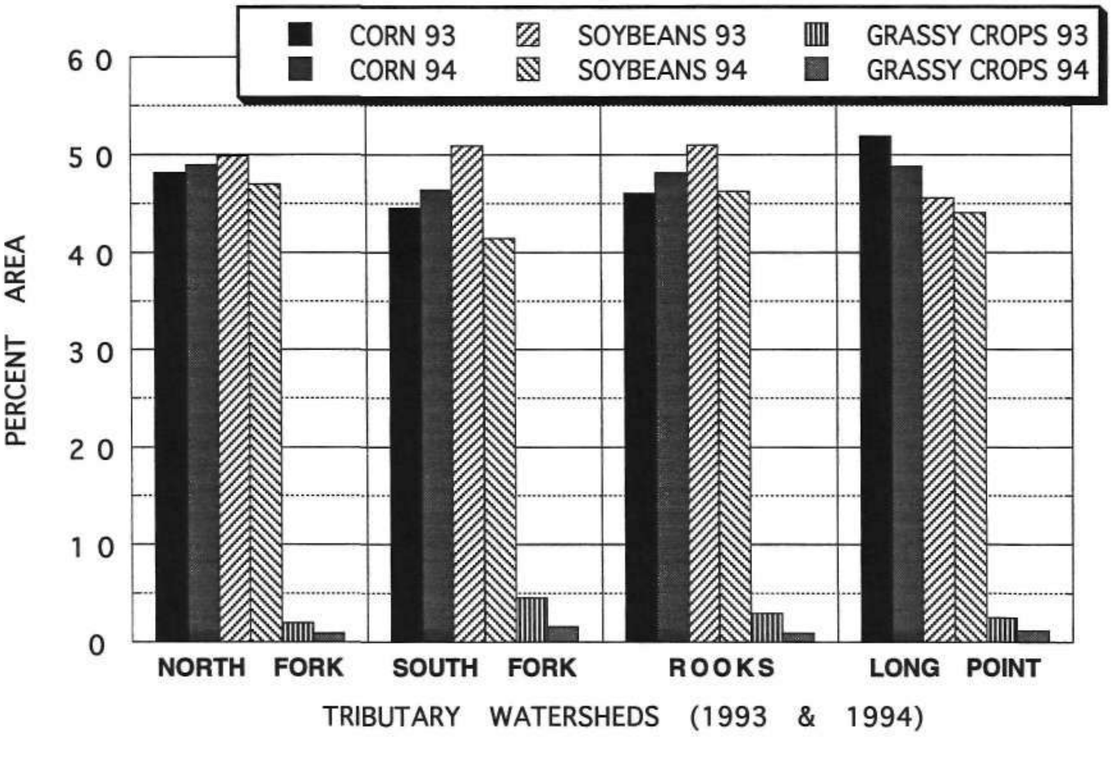


Figure 8. Percent area of selected crops in tributary watersheds based on IDOA *T by 2000* Transect Survey data: a) 1994 crops, b) 1993 crops based on residue observed in field with 1994 growing crops

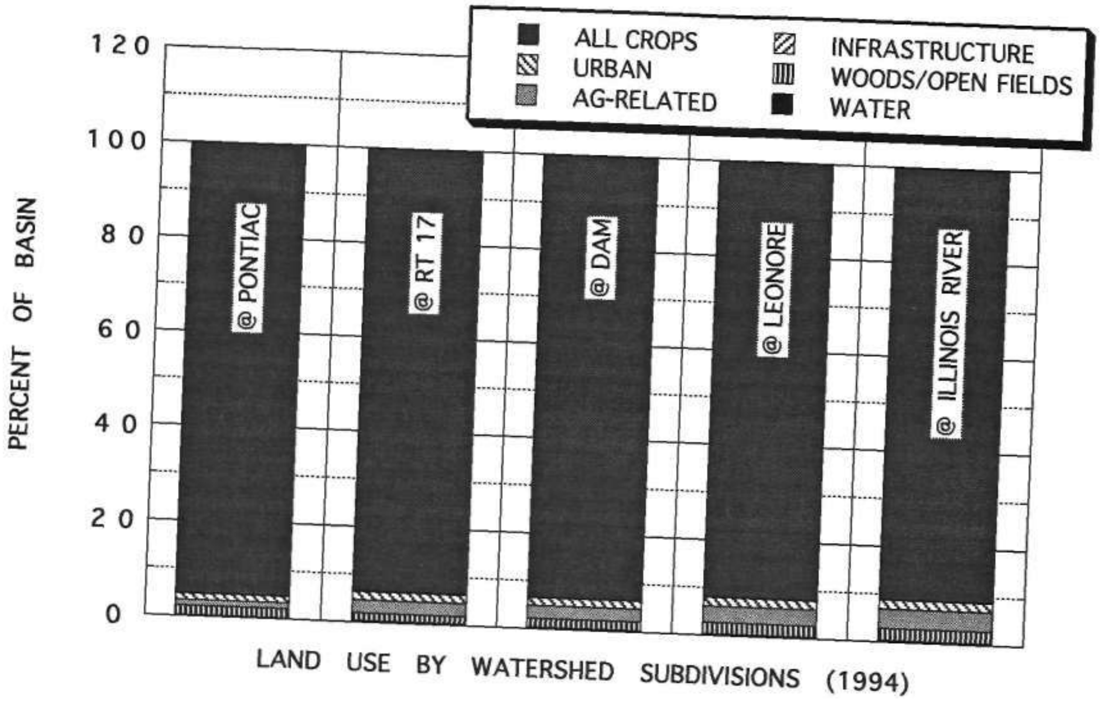
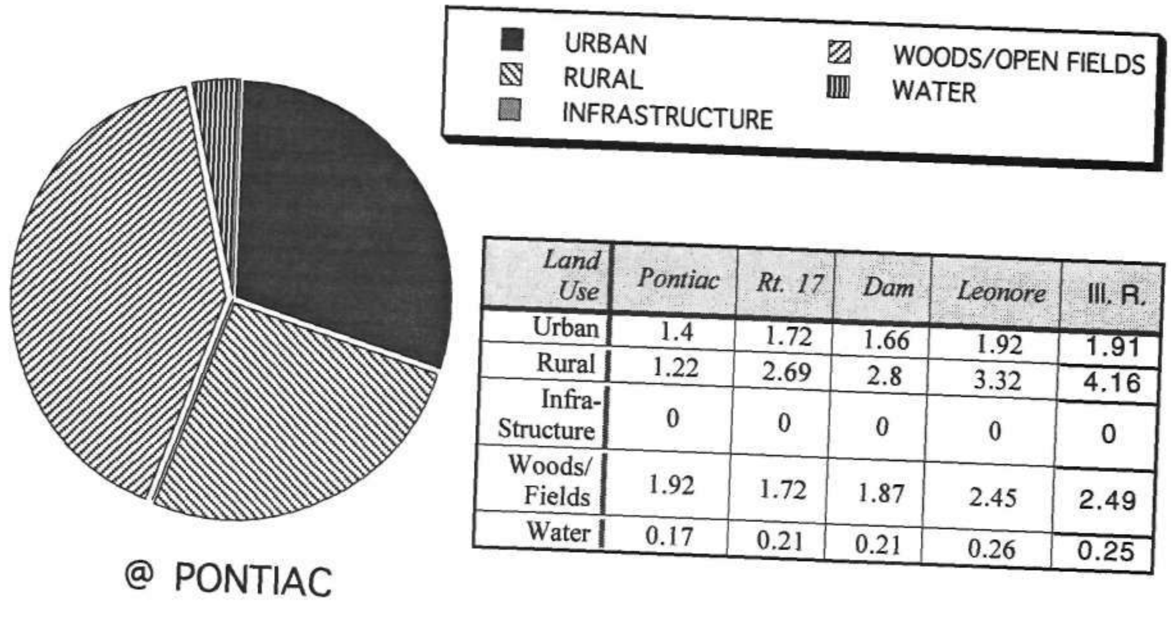


Figure 9. Percent area of land uses in Vermilion River watershed subdivisions based on IDOA *T by 2000* Transect Survey data



Land Use	*Pontiac*	*Rt. 17*	*Dam*	*Leonore*	Ill. R.
Urban	1.4	1.72	1.66	1.92	1.91
Rural	1.22	2.69	2.8	3.32	4.16
Infra-Structure	0	0	0	0	0
Woods/ Fields	1.92	1.72	1.87	2.45	2.49
Water	0.17	0.21	0.21	0.26	0.25

Figure 10. Percent area of all other land uses in Vermilion River watershed subdivisions based on IDOA *T by 2000* Transect Survey data

each subdivision are illustrated in the accompanying table. The pie chart shows the Pontiac subdivision as a representation of the different nonagricultural land uses with respect to each other. As can be seen, urban, rural, and woods/open fields are generally evenly distributed. Rural areas account for approximately 4 percent of the entire watershed, woods/open areas at 2.5 percent, less than one percent area of water, and no infrastructure.

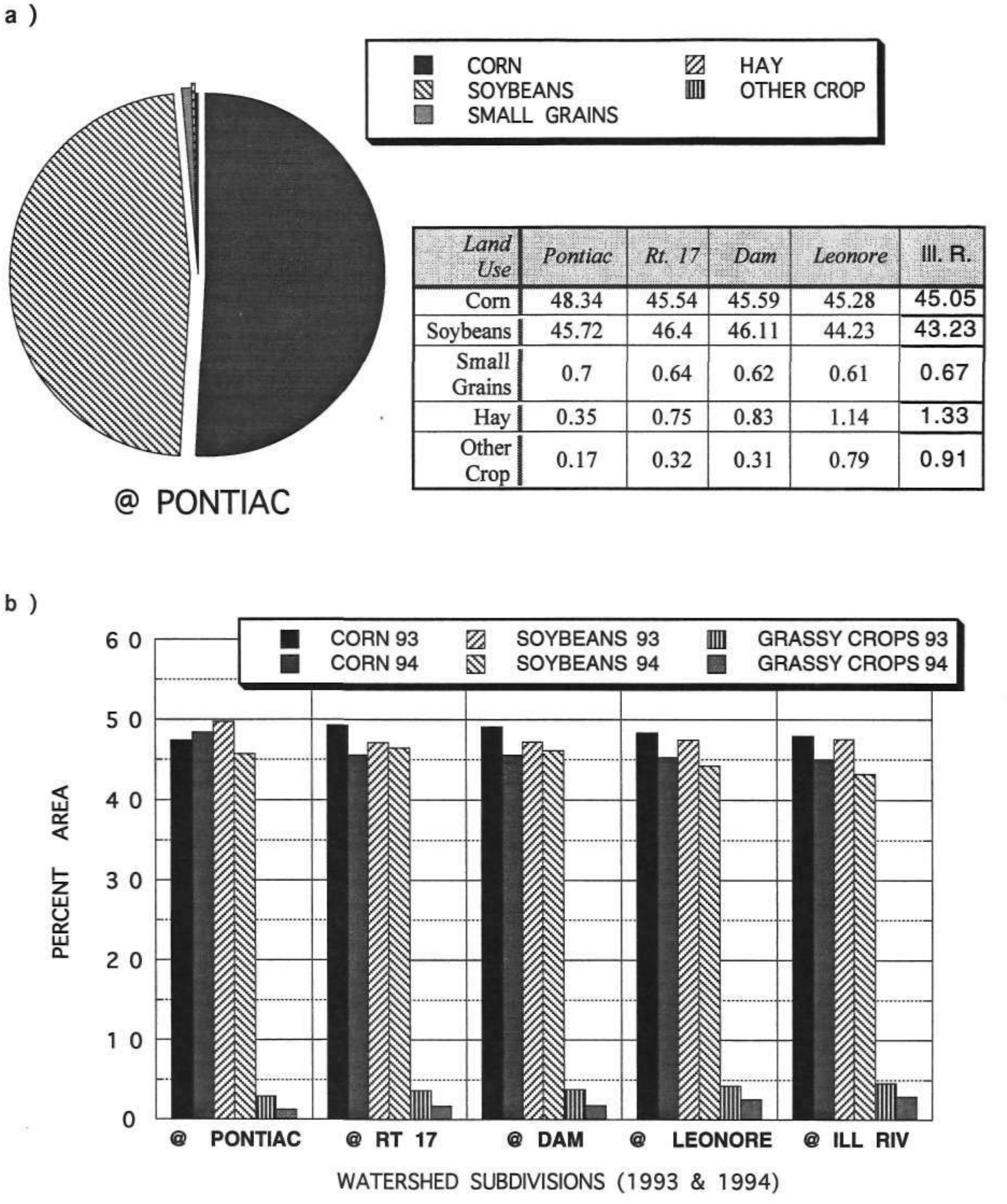
Figure 11a shows another pie chart and the accompanying table shows the breakdown of the crops surveyed in each watershed subdivision. Similar to the tributary watersheds, corn and soybeans are almost evenly observed at 45 and 43 percent, respectively. There appears to be less variability in the watershed subdivisions between corn and soybeans as indicated in the tributaries (figure 11b). Corn appears to be the more dominant crop planted every year with soybean percentage area very close to the corn. The average area of grassy crops is similar to that in the tributaries. In 1994, row crops (corn and soybeans) in the entire watershed covered 88.3 percent of the land area, whereas grassy crops (small grains and hay) covered only 2.9 percent.

Residue Cover

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

Figure 12a shows the percent residue covers for the tributary watersheds. The tributaries have a 0-15 percent residue cover that varies in area from 40 to 52 percent of the watersheds. North Fork is the highest at 52 percent, and Rooks Creek and Long Point Creek are the lowest at 40 percent each. The 16-30 percent residue cover occurs more often in the Long Point Creek watershed (35 percent watershed area) and least in the South Fork watershed (22 percent). Residue covers of 0-15 and 16-30 percent are generally associated with conventional and reduced tillage systems, respectively. The mulch tillage system usually produces anywhere from 31-50 percent residue cover. A greater than 50 percent residue cover can represent a no-till system, however, this is dependent on the previous crop. When planting a field that was in soybeans the previous year, only 20 percent residue cover is obtainable, whereas 60 percent or more is representative of corn as the previous year's crop. All the tributary watersheds averaged 15 percent of the cropped area in a residue cover of 31-50 percent. Residue covers of 51-75 percent or greater were found highest in the Long Point and Rooks Creek watersheds at 6 percent and the lowest at North Fork at 3 percent. All watersheds except Long Point were observed with 76-100 percent residue cover (approximately 3.2 percent each).

Figure 12b shows the percent residue covers for the watershed subdivisions. As can be seen, there is very little difference in the percent residue covers between each subdivision. The



Land Use	*Pontiac*	*Rt. 17*	*Dam*	*Leonore*	Ill. R.
Corn	48.34	45.54	45.59	45.28	45.05
Soybeans	45.72	46.4	46.11	44.23	43.23
Small Grains	0.7	0.64	0.62	0.61	0.67
Hay	0.35	0.75	0.83	1.14	1.33
Other Crop	0.17	0.32	0.31	0.79	0.91

Figure 11. Percent area of selected crops in Vermilion River watershed subdivisions based on IDOA *T by 2000* Transect Survey data: a) 1994 crops, b) 1993 crops based on residue observed in field with 1994 growing crops

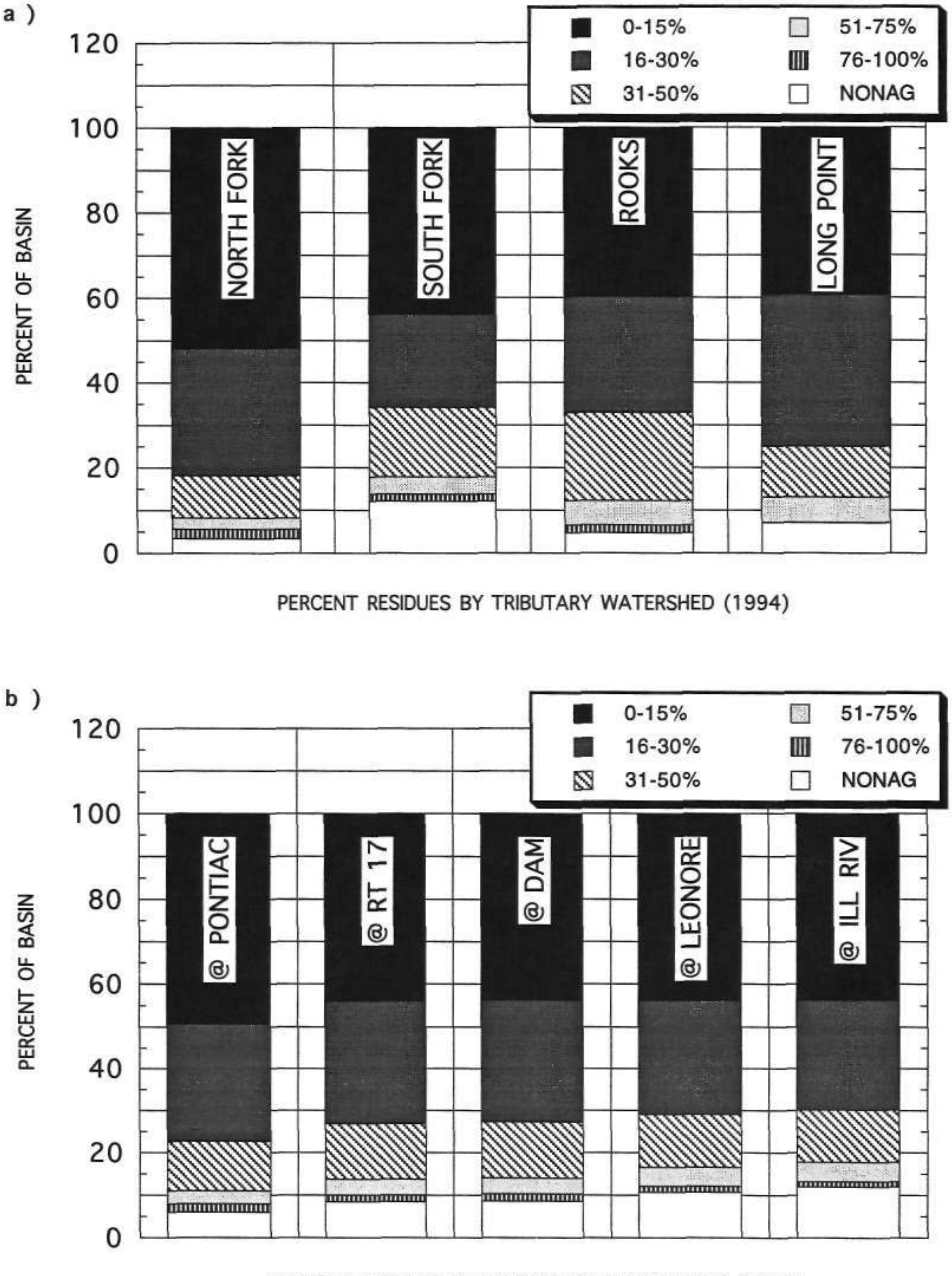


Figure 12. Percent area of residue covers in a) tributary watersheds and b) river watershed subdivisions

average percent watershed area in each subdivision for each percent residue cover is as follows: 44.9 percent for 0-15 percent residue, 27.8 percent for 16-30 percent residue, 12.5 percent for 31-50 percent residue, 3.9 percent for 51-75 percent residue, and 1.6 percent for 76-100 percent residue.

Fertilizer Use

The increase in total acreage of row crops and the corresponding increase in total and per-acre fertilizer application in the watershed is a major factor in the increase of nitrates in the Vermilion River. Figure 13 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 Vermilion River watershed. As shown in the figure, fertilizer application in Illinois has increased from practically no application in 1950 to more than a million tons in 1980. Since 1980, application has fluctuated between 778,000 and 1.05 million tons annually. (Demissie et al., 1996)

Sources of Nitrate and Nitrogen Transformations

The following discussion was taken and revised from the ISWS Miscellaneous Report 169 titled *Watershed Monitoring and Land Use Evaluation for the Lake Decatur Watershed* (Demissie et al., 1996).

The sources of nitrate in the Vermilion River 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 river 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 Vermilion River watershed study. Even though the mass balance approach is difficult to implement for large watersheds, the concept is important in understanding how nitrate is generated and introduced into the watershed and then how it is stored or removed from the watershed. In this section of the report, the mass balance concept is used to briefly explain how nitrogen is introduced, generated, and transformed in the watershed.

Nitrate in the Vermilion River watershed is generated from natural and anthropogenic (human) sources. Natural processes that generate nitrate in the environment include nitrogen fixation by bacteria, whereby atmospheric nitrogen is converted to organic matter by bacteria, and 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. Nitrates from natural sources reach surface waters as a result of

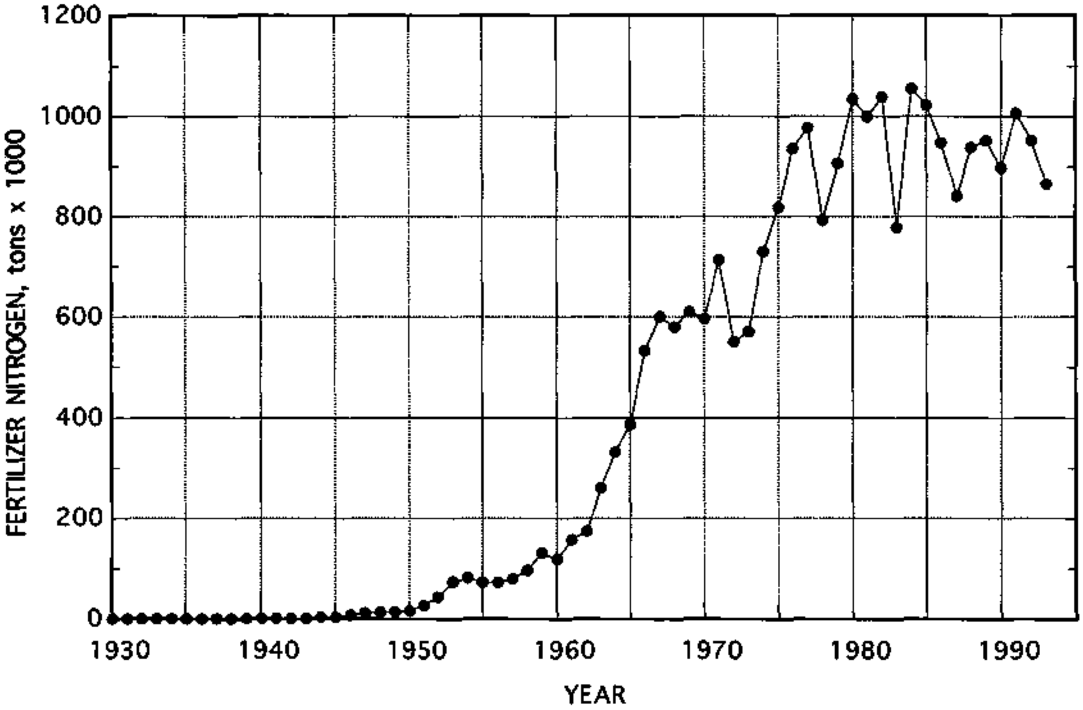


Figure 13. Total inorganic nitrogen fertilizer application in Illinois, 1930-1993

precipitation, atmospheric deposition, surface runoff, and leaching from soils. For ground water the background level is generally assumed to be less than 3 mg/1, for surface waters it is highly variable from region to region and season to season. Nitrate concentrations in pristine environments with limited human activities are consistent with the natural processes in those environments, are generally low, and are not sources of environmental or health concerns.

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

The application, uptake, and leaching of nitrogen in agricultural watersheds is sometimes evaluated by an input-output model. A simplified conceptual model includes the input of nitrogen into the soil from all sources: natural and human-induced. Once nitrogen is incorporated into the soil, it is either stored in the soil or lost to the atmosphere and to surface and ground waters, or removed from the watershed through harvesting of crops. During these different processes, nitrogen undergoes several transformations. Some of these transformations are complex and are major areas of research throughout the world because of their implication on food production and environmental quality. Some of the basic processes are summarized in figure 14 adapted from Stevenson (1982).

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

Atmospheric Input

The input of nitrogen into soils from atmospheric precipitation can be in the form of ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-) and nitrogen bound to particles. The contribution of atmospheric sources was expected to be relatively small as compared to inputs from biological nitrogen fixation and inorganic fertilizer nitrogen. This assumption was supported by data collected by the National Atmospheric Deposition Program (NADP). This program uses the National Trends Network (NTN), which has been collecting data since 1978 throughout the United States. The NADP has its Central Analytical Laboratory (CAL) at the Illinois State Water Survey (ISWS) in Champaign, Illinois. Each year the ISWS receives thousands of precipitation samples collected at 200 sites by the NTN. Data retrieved by the network represent a cumulative, weekly precipitation sample collected by special precipitation collectors that cover the sample bucket between rainfall events to avoid evaporation and contamination. Each site has a raingage that graphically records the timing and amounts of rain for each seven-day sample period (Lynch et al., in press).

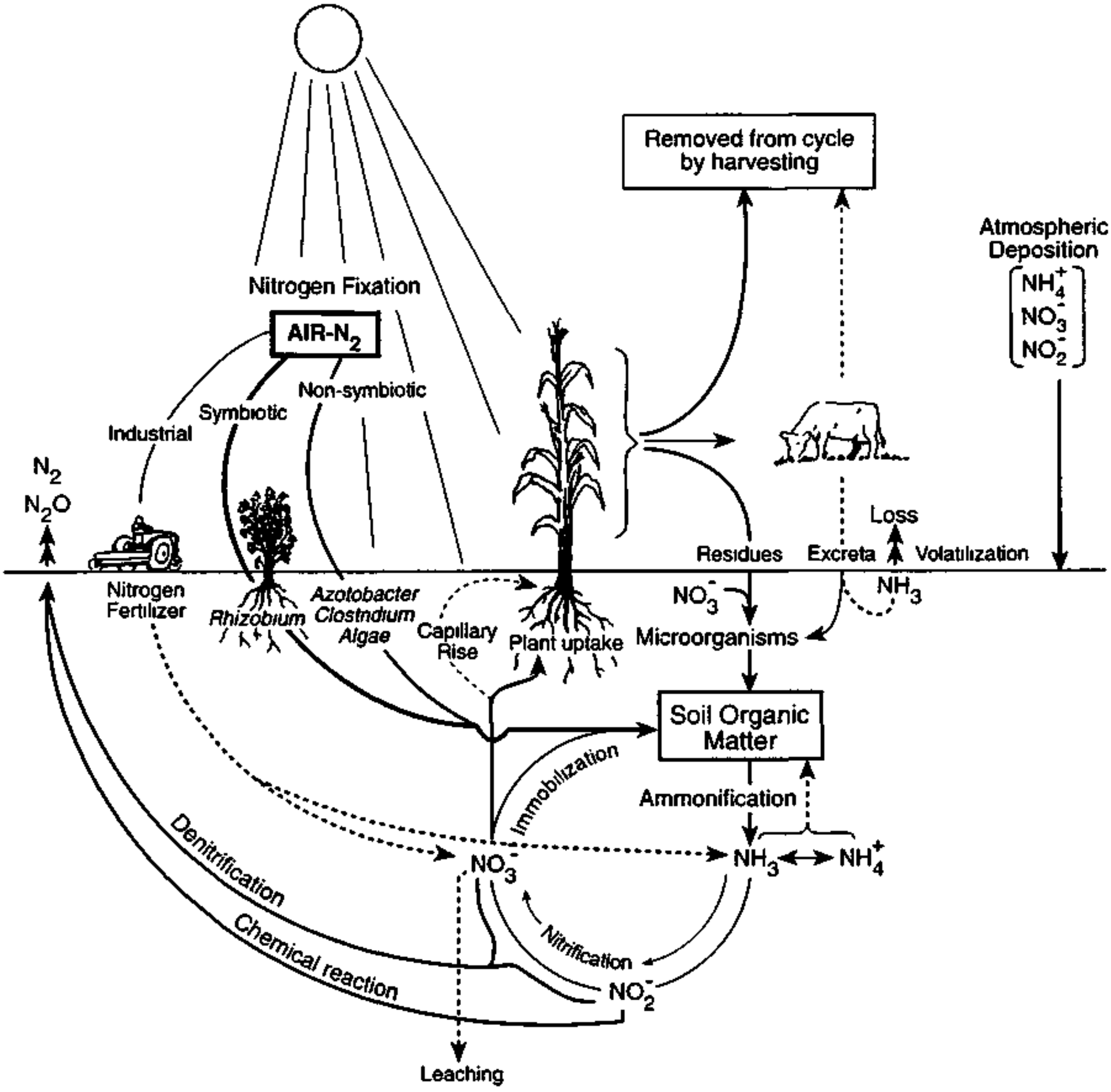


Figure 14. Nitrogen transformations in agricultural soils (adapted from Stevenson, 1982)

Illinois has four NTN sampling sites. The Bondville site (IL11), located just west of Champaign, was used to represent the conditions in the watershed. Figure 15 shows the a) nitrate-N and b) ammonium-N concentrations 1979-1995 at the Bondville station. The nitrate-N concentrations rarely exceed 1.5 mg/1 and generally average 0.5 mg/1. Ammonium-N has a wider variability in concentration, which ranges from the minimum detection level (MDL) of 0.02 mg/1 to 3.8 mg/1 and averages of 0.4 mg/1. Lynch et al. (in press) have calculated recent trends for nitrate-N concentrations. Their analysis states that from 1980-1993 nitrate-N concentrations have decreased by approximately 20 percent, whereas ammonium-N concentrations show almost no change.

Biological Nitrogen Fixation

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

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

Nitrogen Input from Fertilizer Application

Inorganic nitrogen fertilizer is applied to soils in a form containing either nitrate (NO_3^-) or ammonium (NH_4^+). Fertilizer is applied either in the fall, in the spring before planting, or after planting (side-dress). Anhydrous ammonia, ammonium nitrate, urea, and urea-ammonium nitrate are the common forms of commercial nitrogen fertilizer. Anhydrous ammonia is the most commonly applied fertilizer in Illinois (McKenna and Bicki, 1990). Ammonium is not the most stable form of inorganic nitrogen and usually oxidizes to form nitrate. Nitrification occurs in virtually all soils where NH_4^+ is present and conditions are favorable with respect to the major factors of temperature, moisture, pH, and aeration. Stevenson (1982) explains that the use of NH_4^+ and NO_3^- for plant growth corresponds to events in the soils. In early growth stages, roots are largely in the surface layer and the NH_4^+ form predominates because nitrification is limited

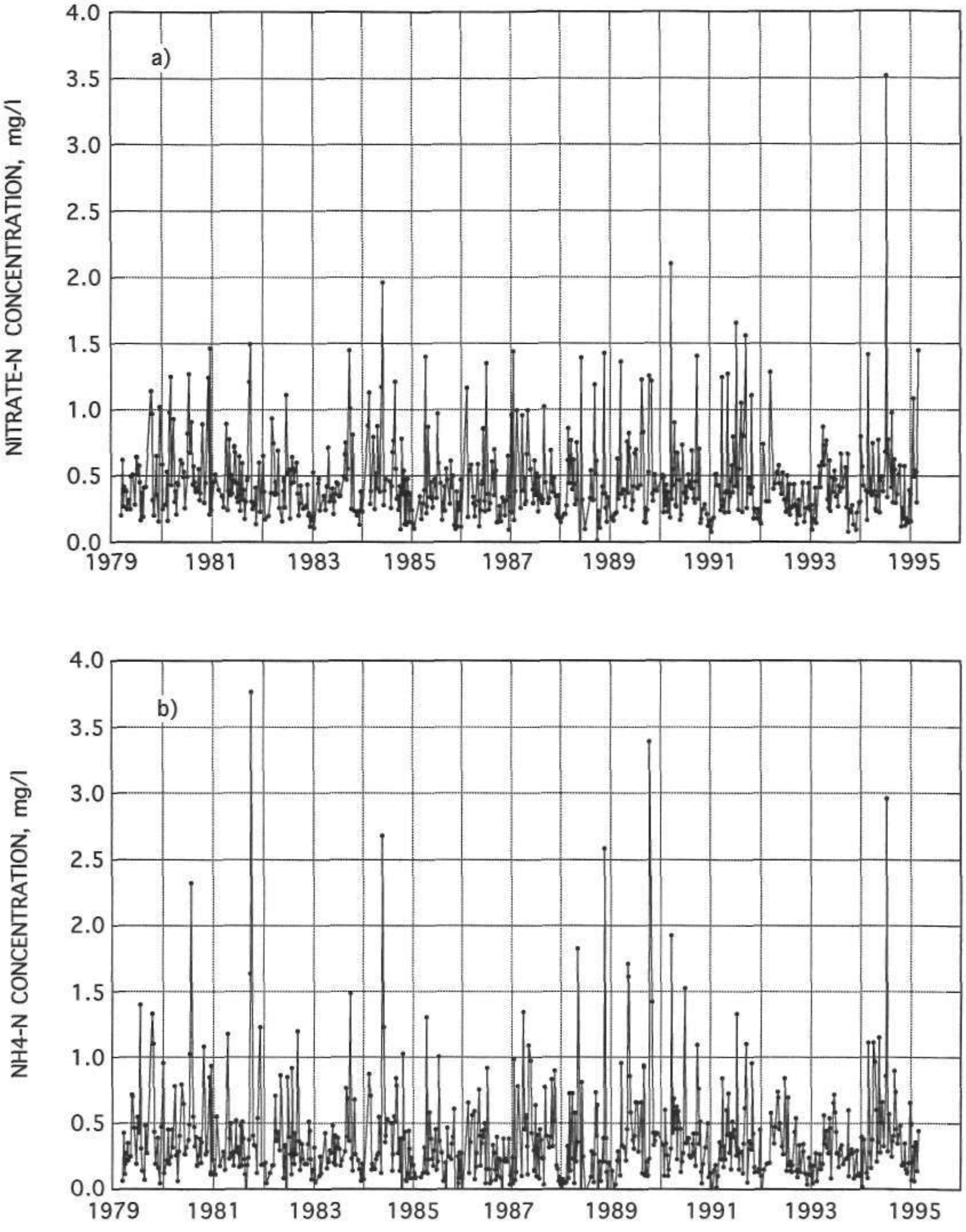


Figure 15. Atmospheric deposition of a) nitrate-N and b) ammonium-N at Bondville, Illinois, 1979-1995

by low temperatures. As the soil becomes warmer, nitrification proceeds, the root system extends, and the amount and uptake of NO_3^- predominates over NH_4^+. It is estimated that plants take up less than 50 percent of the fertilizer nitrogen and transform it into organic nitrogen (Bouchard et al., 1992). The remainder is either stored in the soil as organic or inorganic nitrogen or lost to the atmosphere or water. Nitrogen available as ammonium in the soil is eventually oxidized to form nitrate, which is more stable. This process is known as nitrification.

Nitrogen Losses

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

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

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

Nitrogen transformations in aquatic environments such as streams, lakes, wetlands, or floodplains that are inundated by water are more complicated than those in well drained agricultural soils. The major nitrogen transformations in submerged soil or sediment are illustrated in figure 16 (Patrick, 1982). The major controlling factor is the availability or lack of oxygen in the soil or sediment layers. The top soil or sediment layer is generally expected to be aerobic because of constant supply of oxygen from the water column. This is not, however, always the case. Below the aerobic layer, there is an anaerobic layer where oxygen is in short supply or absent. The importance of these aerobic/anaerobic layers is because of the fact that the transformation of ammonium (NH_4^+) to nitrate (NO_3^-), which only takes place in the aerobic layer where there is sufficient oxygen, whereas nitrate (NO_3^-) is readily denitrified in the anaerobic layer (Patrick, 1982). Other nitrogen transformations such as nitrogen fixation by microorganisms and bacteria, loss of nitrogen by volatilization of ammonia, denitrification of nitrate into N_2O and N_2, and leaching of nitrate to surface and ground water are the same as discussed earlier.

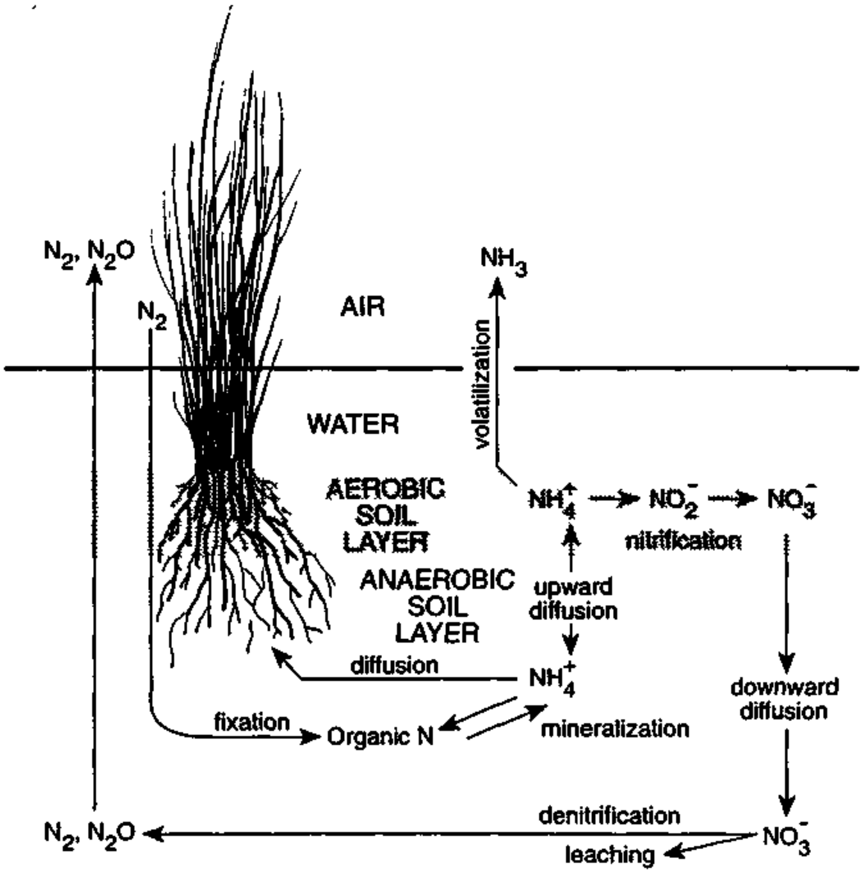


Figure 16. Nitrogen transformations in submerged soils (adapted from Patrick, 1982)

Hydrologic and Water Quality Monitoring

A watershed monitoring network was established to provide streamflow and water quality data for the Vermilion River and its tributaries. Seven stations (figure 17) comprise the network from which stage (water surface) measurements are taken either continuously (stations 608, 604, and 605) or periodically (stations 607, 602, 603, and 606), and water samples were collected and analyzed for the nitrogen compounds of nitrate, TKN, and ammonium. Discharge measurements were also taken to develop stage discharge calibration curves for use in estimating total nitrate loads over time at six of the stations. Table 3 presents names of the streams, locations of the monitoring stations, and drainage area for each station.

Table 3. Streamflow and Stage Monitoring Stations in the Vermilion River Watershed

Station number	*Location*	*Drainage area (sq mi)*
608	Vermilion River at Leonore	1244
607	Vermilion River at Route 17	1044
602	Long Point Creek at Route 23	63
603	Rooks Creek at County Road 1100N	127
604	Vermilion River at Pontiac	576
605	South Fork at County Road 1000N	163
606	North Fork at County Road 3100E	199

Hydrologic Monitoring

Hydrologic monitoring at each station facilitates the calculation of streamflow for the study period. This is essential for establishing the nitrate contribution to the Vermilion River and its tributaries. Procedures used to collect hydrologic data at the monitoring stations are discussed in the following sections.

Precipitation

Precipitation data for selected locations around the watershed were retrieved from the Midwestern Climate Center databases operated by the ISWS. Seven stations (see figure 17 for locations) were selected from within the watershed for the period beginning in January 1994 through December 1995: Piper City, Gibson City, Fairbury, Chenoa, Pontiac, Streator, and Peru. Figure 18 shows the monthly precipitation at each station while figure 19 compares the annual precipitation and the 30-year (1961-1990) long-term mean. The figures present the stations in the order in which they are located in the watershed from the headwaters to the mouth (southeast to northwest).

Figure 17. Location map of precipitation and gaging stations in the Vermilion River watershed

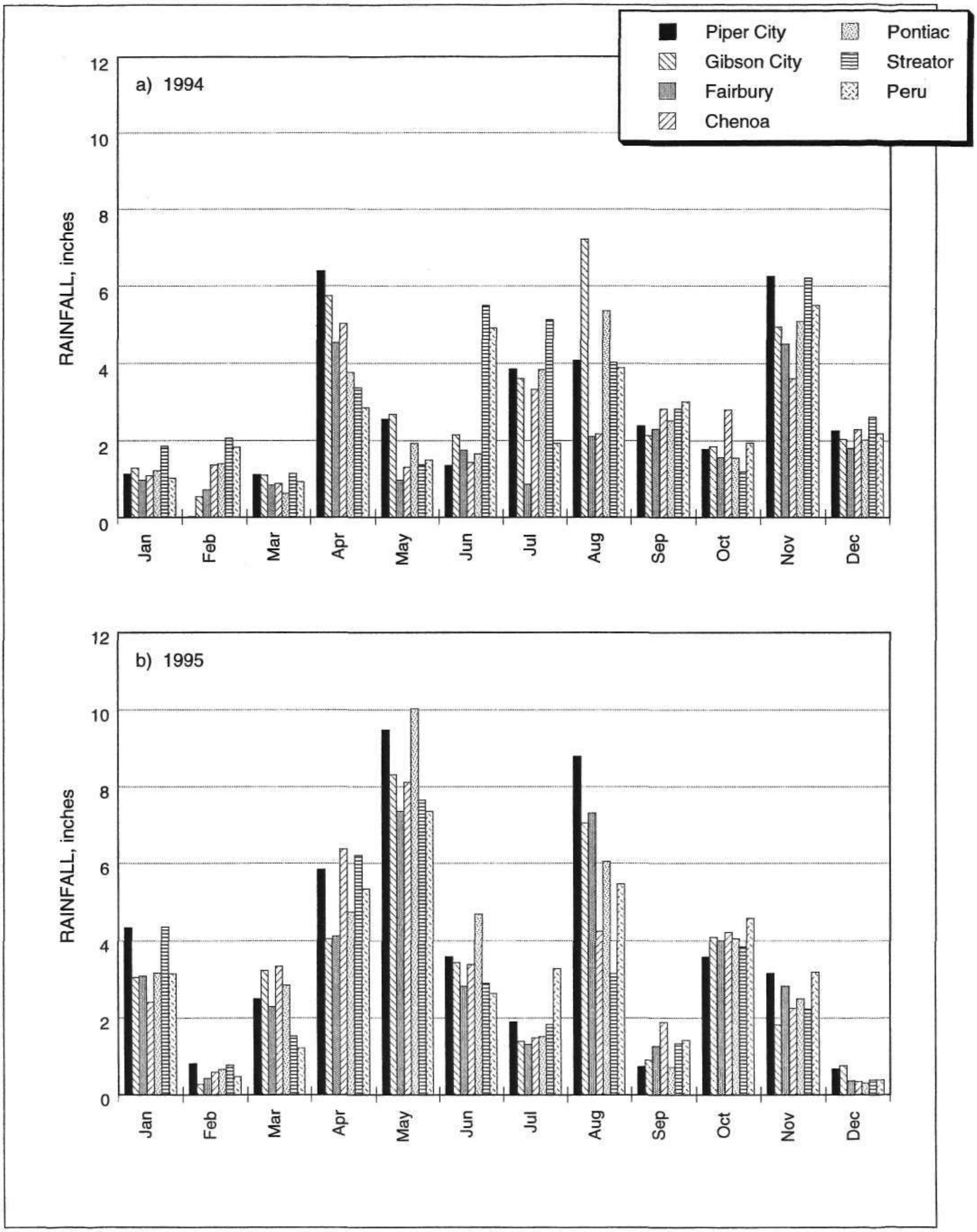


Figure 18. Monthly precipitation during study period

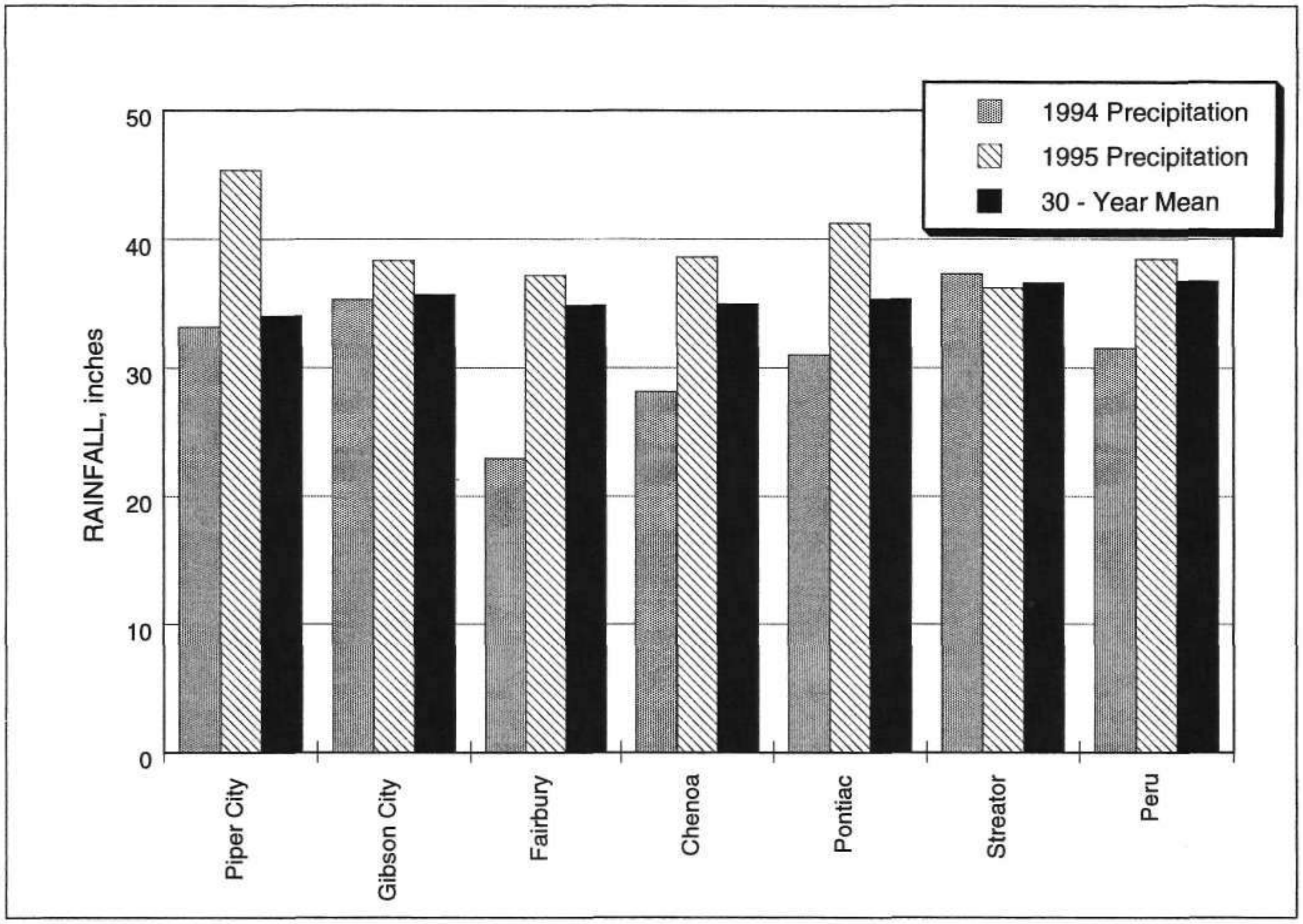


Figure 19. Annual precipitation during study period

Figure 18a shows the monthly precipitation totals for the seven stations during 1994, the first year of monitoring in the watershed. The year started out low during the first three months in which only one station exceeded 2 inches of rainfall at any one time. During April, June, July, August, and November, some stations received 4 inches or more of rainfall, and others received 6 inches or more during April, August, and November. The highest monthly rainfall total was 7.2 inches in August 1994 at Gibson City. The lowest monthly total for the year, 0 inches, was in February at Piper City. The second year of monitoring, 1995, was somewhat different as compared to 1994 (figure 18b). Typical high precipitation occurred at most stations during spring rains in April and May, with slightly reduced rainfall the remainder of the summer, except for August until the fall rainy season in October and November. The highest monthly precipitation measured 10 inches at Pontiac in May. The lowest monthly precipitation total, 0.3 inches, was at Gibson City in February.

Figure 19 shows the annual precipitation totals for 1994 and 1995 as compared to their respective 30-year (1961-1990) long-term means. Precipitation was below normal the first year (figure 19a) at stations located in the upstream region of the watershed and near normal to above normal in the downstream region. Precipitation was either near normal or above normal the second year at all stations (figure 19b). Some of the extremes reported in the watershed show that Fairbury and Chenoa experienced below normal precipitation in 1994, approximately 12 and 7 inches, respectively, whereas Piper City experienced above normal precipitation in 1995, 11 inches. Precipitation at Streator was at or near normal both years.

Some of these rainfall totals might give the wrong impression when compared to the results of the runoff calculations for the monitoring stations in the watershed, which will be presented later in this chapter. For example, even though Piper City had near normal precipitation in 1994, further inspection shows that only two months (April and November) had above average precipitation and the other ten months had below average precipitation, and from May through December, there were only five days with rainfall over one inch.

Stream Stage

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

Three of the network stations were outfitted with continuous recording streamgaging equipment. One of these gaging stations was designed and built by the ISWS especially for this investigation. The other two stations (Leonore and Pontiac) are part of the U.S. Geological Survey (USGS) long-term monitoring network. At the ISWS station, South Fork (605), a float and pulley system is enclosed within an 8-inch PVC stilling well, which protects the float system from debris carried by the stream. Figure 20 shows photos of this station at (a) low flow and (b) high flow. Figure 20b also shows the equipment shelter and stilling well. The float and pulley system is connected to a data logger housed within a shelter positioned over the top of the stilling

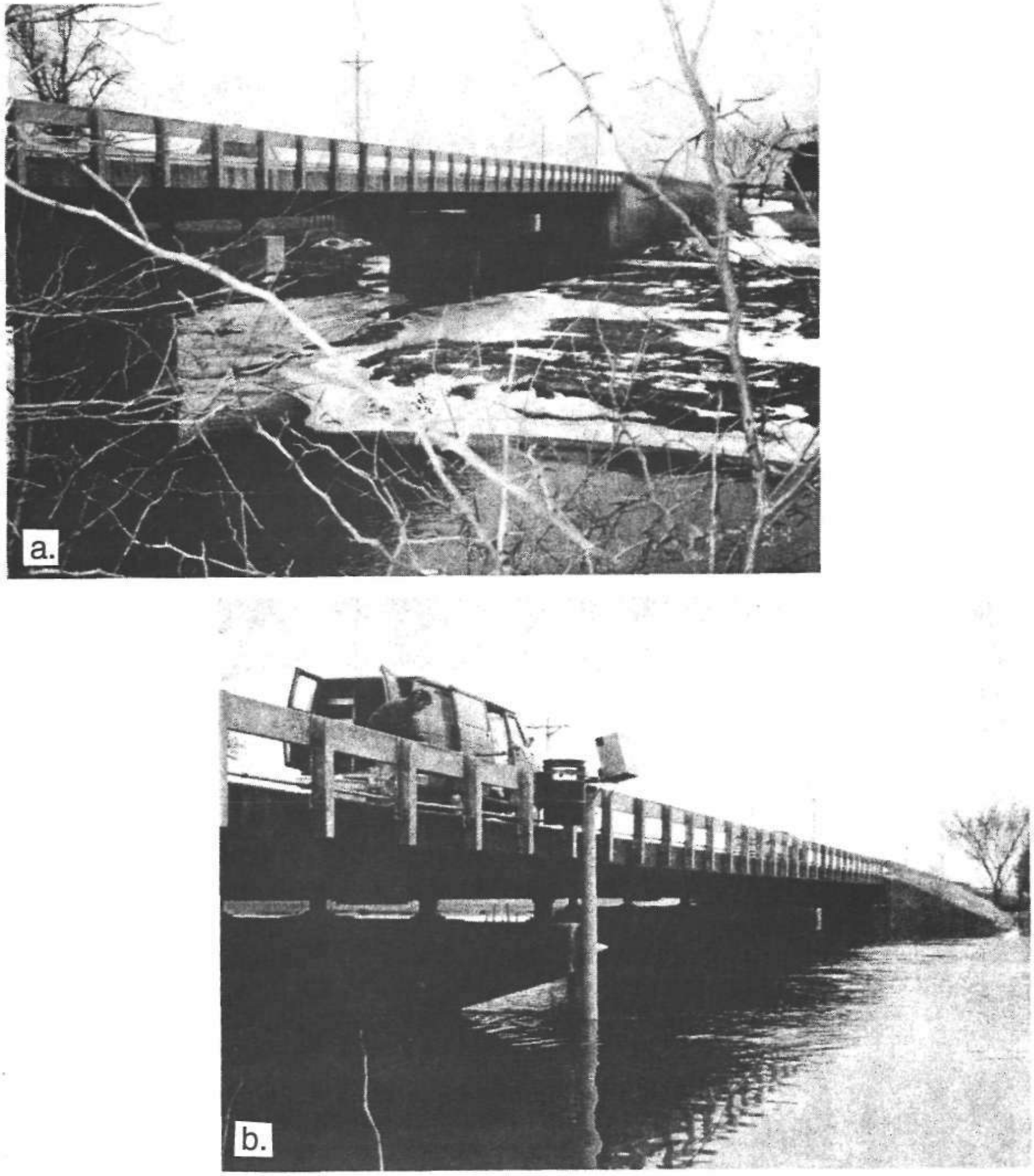


Figure 20. Station 605 on the South Fork Vermilion River at
a) low flow and b) high flow

well. The water level was registered by a Handar 436-B2 shaft encoder and then recorded in a Campbell Scientific BDR320 data logger powered by a 12-volt rechargeable lead acid battery. Changes in water level were recorded every 15 minutes in the data logger and downloaded to a computer on a regular basis. A similar stage monitoring apparatus is used at the USGS gaging stations (608 and 604). These continuous records of stream stage were used in conjunction with discharge measurements to develop a rating curve to estimate the quantity of water moving through the stream channel over time.

Instantaneous stage data were collected at the other four sites and were recorded during the regular visits and storm/runoff events. Stage is measured using a steel tape lowered to the water surface, and a reading is taken at a known datum on a bridge rail. Three of the four sites were outfitted with staff gages either mounted on a fence post driven into the stream channel or secured to a bridge pier. The stage could then be read directly off the staff gage as the water level changes.

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 21 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

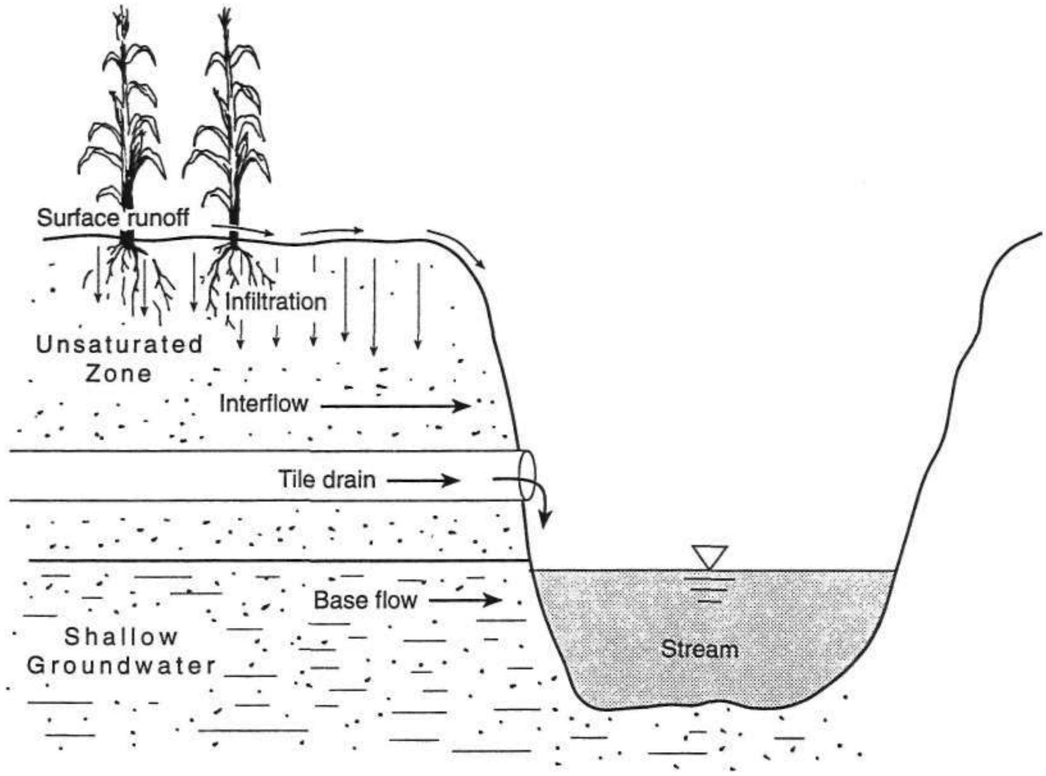


Figure 21. Schematic of flow paths from upland areas to streams

through the interflow and baseflow processes first requires that the water percolate downward through the soil column. Interflow is the relatively quick movement of water toward the stream through air pockets, cracks, tile drains, and other openings in the shallow layers beneath the soil. Baseflow is flow through the shallow ground-water matrix that sustains the flow in the stream during late summer and fall as well as during drought years. Baseflow to a stream often increases directly after a rain event, and as a result it may appear as if the ground water is moving quickly from the uplands to the stream. In reality, it is usually the ground water immediately adjacent to the stream that is released to the stream, and it may take years for a particular mass of 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.

Streamflow

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

Stream Discharge Measurements. The stream discharge measurement techniques used in this study were established by the USGS (Buchanan and Somers, 1969) and the American Society for Testing and Materials (standard practice for Open-Channel Flow Measurement of Water by Velocity-Area Method, designation: D3858-79). Stream discharge is determined by subdividing a cross section of a stream at a bridge crossing into partial sections 2 to 10 feet wide. A standard rotating bucket mechanical velocity meter (current meter), suspended by a cable/winch/crane assembly (A-reel and bridgeboard), is lowered into the stream at the midpoint of each partial section. A depth gage built into the winch reads the total depth of the stream at the midpoint of the partial section. This depth is recorded and later used to calculate the flow area of the partial section. Velocity measurements are then made vertically at the midpoint of the partial section. The meter is positioned beneath the water surface at 0.2 and 0.8 percent of the total depth (for total depths greater than 2.5 feet) or at 0.6 percent of the total depth (for total depths less than 2.5 feet). The number of times the meter's bucket rotates in 40 seconds determines the velocity of the stream at these measured points. An average velocity of the partial sections is then calculated. The partial section discharge is calculated by multiplying the average velocity by the flow area. These discharges are then summed to determine the total discharge for the stream. Each stream discharge is then plotted with a corresponding stage to develop a stage-discharge curve. Using this curve, the stage data files are then converted to daily discharge. The discharge data can then be used to develop nutrient load data. (Demissie et al., 1996)

Streamflow Data. Streamflow data presented in this chapter represent the monitoring period beginning in January 1994 and ending in December 1995. Streamflow was calculated for six of the seven stations in the monitoring network. The seventh station, Vermilion River at Rt. 17 (607), had channel geometry, as well as other physical characteristics, that made discharge measurements inconsistent and unreliable. Nitrate samples were still taken because of the close proximity upstream of the Streator water plant and were determined to have relative value when nitrate data were assessed. Stage data were converted to discharge (streamflow) using discharge rating curves, as discussed in the preceding section. Rating curves were developed by the ISWS for Long Point Creek (602), Rooks Creek (603), South Fork (605), and North Fork (606), whereas discharge data were already available from the U.S. Geological Survey (USGS) for stations at Pontiac (604) and Leonore (608). Discharge data from October 1994 to December 1995 for these two stations were retrieved from the USGS before being officially published and are therefore considered provisional.

Monthly discharge data results for the two monitoring years are presented in figures 22 and 23. Figure 22 shows the monthly discharges for the four Vermilion River tributary watersheds (stations 602, 603, 605, and 606), and figure 23 shows the results for the stations on the Vermilion River (stations 604 and 608). Figure 22a shows uniform and relatively low monthly flows in 1994 when no station exceeded 10,000 cubic feet per second (cfs). Only during the months from February through June, were there stations with monthly flows greater than 5,000 cfs. Rooks Creek (603) had the highest monthly flow during February 1994 at 9,737 cfs. The lowest monthly flows at all stations in 1994 were observed during the months of July and August. Rooks Creek (603) had the lowest monthly flow in August at 336 cfs. Streamflows in 1995 were more dynamic in the spring months (figure 22b). The year begins with relatively normal streamflows for winter months that increase dramatically in March and peak in May. The flows fall to low flows from June and remain that way through the end of the year. All four tributary watersheds have their highest monthly streamflows in May 1995. North Fork (606) is the highest at 29,137 cfs, with Rooks Creek (603), South Fork (605), and Long Point (602) having decreasing flows of 22,630, 17,646, and 9,145 cfs, respectively. Monthly precipitation data presented in figure 18 show relatively uniform rainfall in the watershed (except for the Pontiac station), which demonstrates that the drainage areas of the tributary watersheds would account for the gradation of streamflows observed in May 1995.

As can be seen in figure 23, streamflows at the two Vermilion River stations [Pontiac, (604) and Leonore (608)] mimic the monthly pattern illustrated in figure 22. The first year (1994) begins with a slight increase in streamflow from January to April, slight decreases in May, and then severe decreases from June through October, with slight increases in November and December. May 1995 also has the highest streamflows observed for the two stations with values of 159,727 and 72,606 cfs for Leonore (608) and Pontiac (604), respectively. Leonore (608) consistently has the highest streamflows of the two stations because the drainage area is twice that of Pontiac (604).

Streamflow (discharge) is frequently converted from cfs to inches for the purposes of comparing discharges to rainfall. It is also used to compare streamflow between watersheds on a

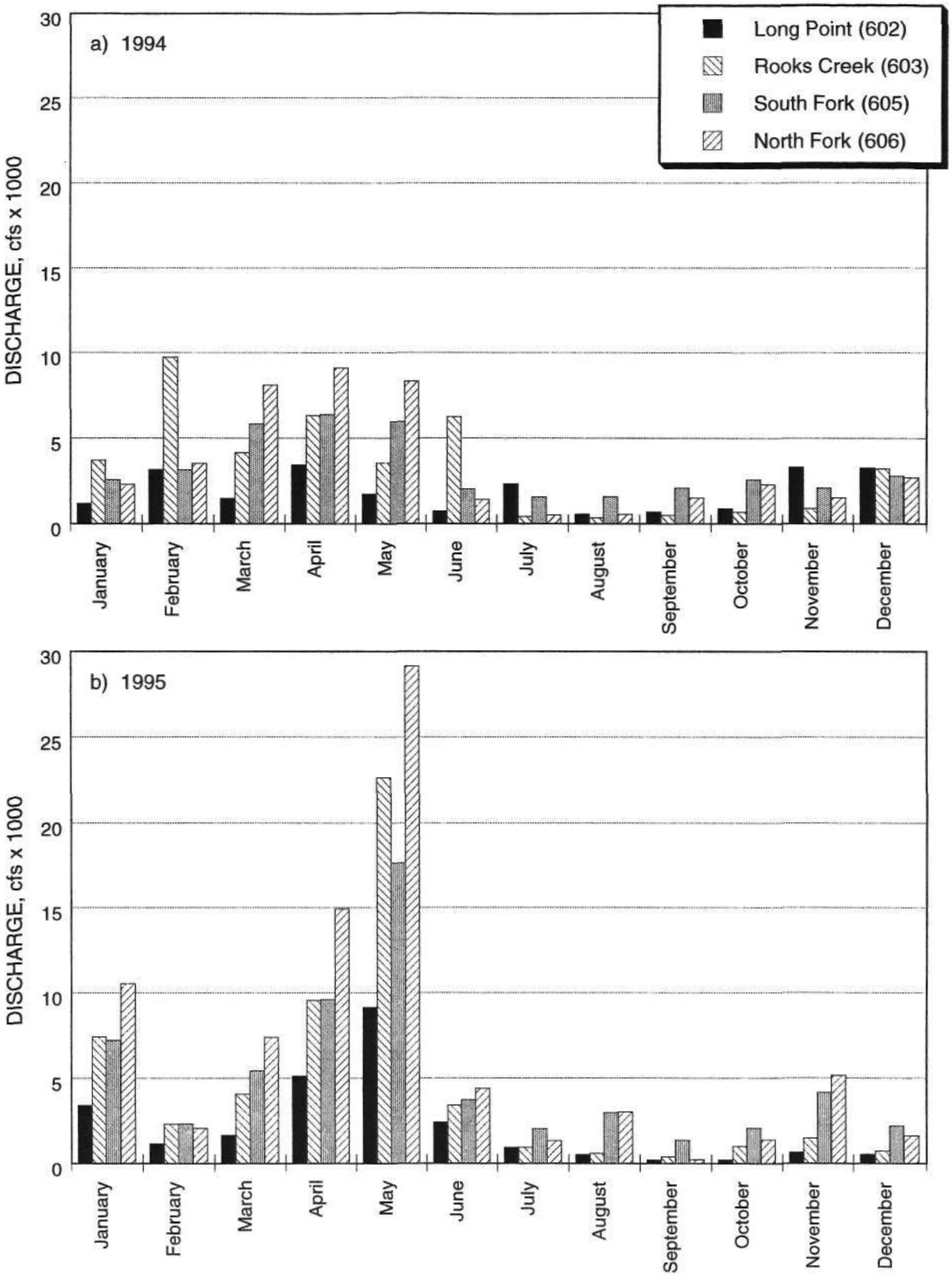


Figure 22. Monthly discharge for tributary stations

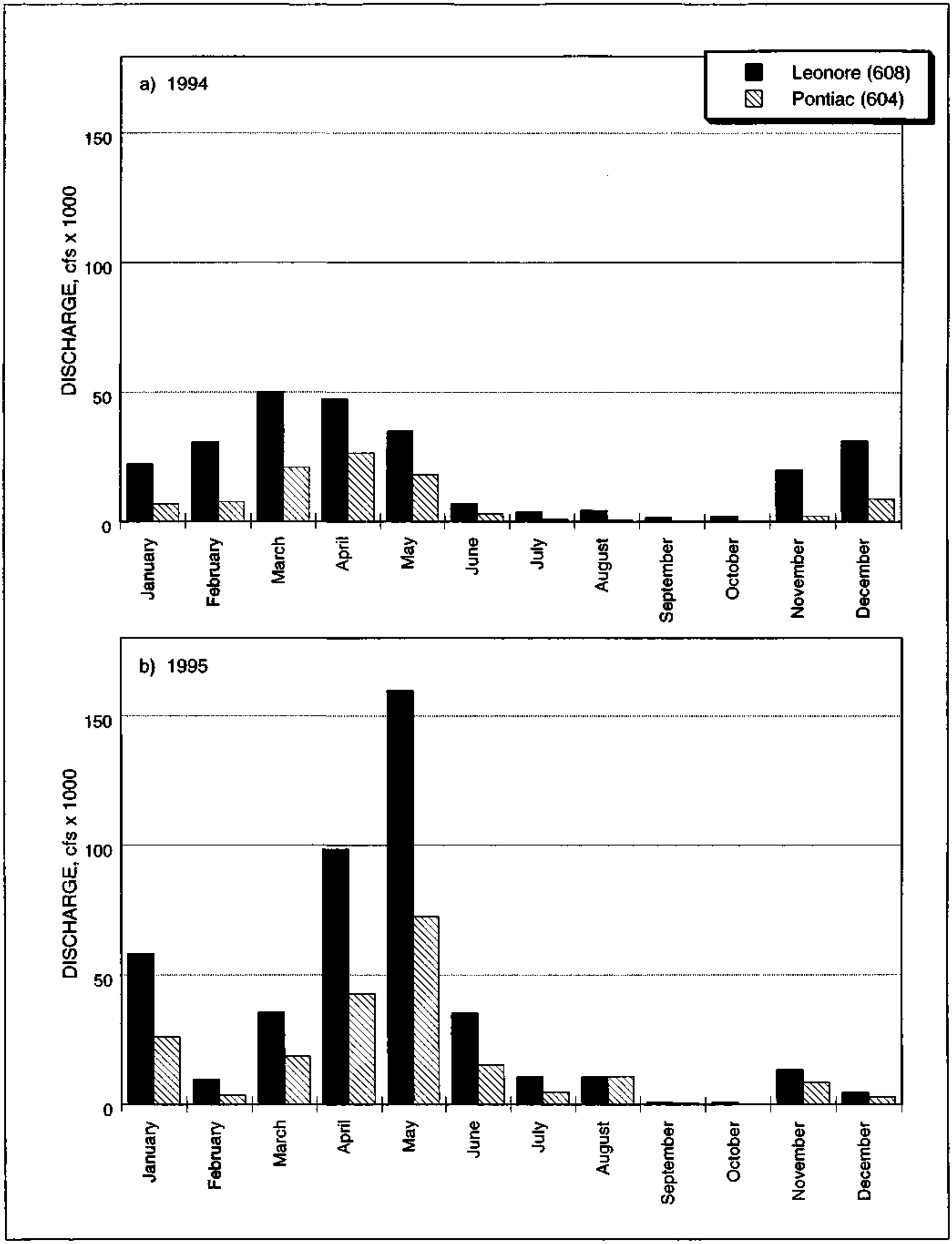


Figure 23. Monthly discharge for Vermilion River stations

relatively equal footing. The streamflow expressed in inches is generally referred to as runoff. The monthly discharge is divided by the drainage area upstream of the streamgaging station to determine the streamflow per unit area. Figures 24 and 25 show runoff in inches for the tributary and river stations, respectively. It should be noted that runoff can vary between stations due to the spatial variability of rainfall throughout the Vermilion River watershed.

Figure 24 shows the same monthly patterns of flow in the tributary watersheds as figure 22, however, Long Point Creek (602) shows higher runoff during July through December of 1994 than the other three stations. This pattern does not continue into 1995. Further inspection of precipitation stations indicated that the Long Point Creek watershed may have received high-volume, localized rainfall events during the narrow period mentioned above. February and April 1994 were the only months in 1994 where two stations [Rooks Creek (603) and Long Point Creek (602), respectively] had observed runoff above 2 inches. Rooks Creek (603) had the highest monthly runoff for 1994, 2.9 inches, in February. Rooks Creek (603) and North Fork (606) had the lowest runoff in July and August 1994. In 1995, stations had runoff above 2 inches during January, April, and May, with runoff above 3 inches in April and above 4 inches at all tributary stations in May. The highest 1995 monthly runoff was 6.7 inches in May at Rooks Creek (603). North Fork (606), Long Point (602), and South Fork (605) had runoff of 5.5, 5.4, and 4.1 inches, respectively, during May 1995. Figure 25 shows little difference in runoff between Pontiac (604) and Leonore (608). During the two-year monitoring period, the highest runoff occurred in May 1995: 4.8 inches at Leonore (608) and 4.7 inches at Pontiac (604). The lowest runoff occurred in September and October for Pontiac (604) and Leonore (608) both in 1994 and 1995.

Figure 26 shows the annual runoff for all stations, comparing runoff during both years between the tributary stations (figure 26a) and river stations (figure 26b). As can be seen in figure 26a, 1995 had higher runoff than 1994; however, 1994 shows a decrease in runoff as you proceed upstream. Runoff between tributaries in 1995 stays relatively uniform. The river station runoff (figure 26b) stays relatively uniform each year, but 1995 was almost double the 1994 runoff. Rooks Creek (603) had the highest annual runoff, 16.1 inches, during the monitoring period, and North Fork (606) had the lowest annual runoff, 7.9 inches. Pontiac (604) and Leonore (608) had virtually the same runoff during the monitoring period: 13.5 and 13.2 inches, respectively. Pontiac (604) had the lowest annual runoff of 6.2 inches.

Water Quality Monitoring

Each of the seven monitoring stations were sampled for nitrogen compounds. Compounds 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 provide insight to the dynamics of nitrate transformations and potential loads within the watershed. The next three sections were taken and revised from the ISWS Miscellaneous Report 169, *Watershed Monitoring and Land Use Evaluation for the Lake Decatur Watershed* (Demissie et al., 1996).

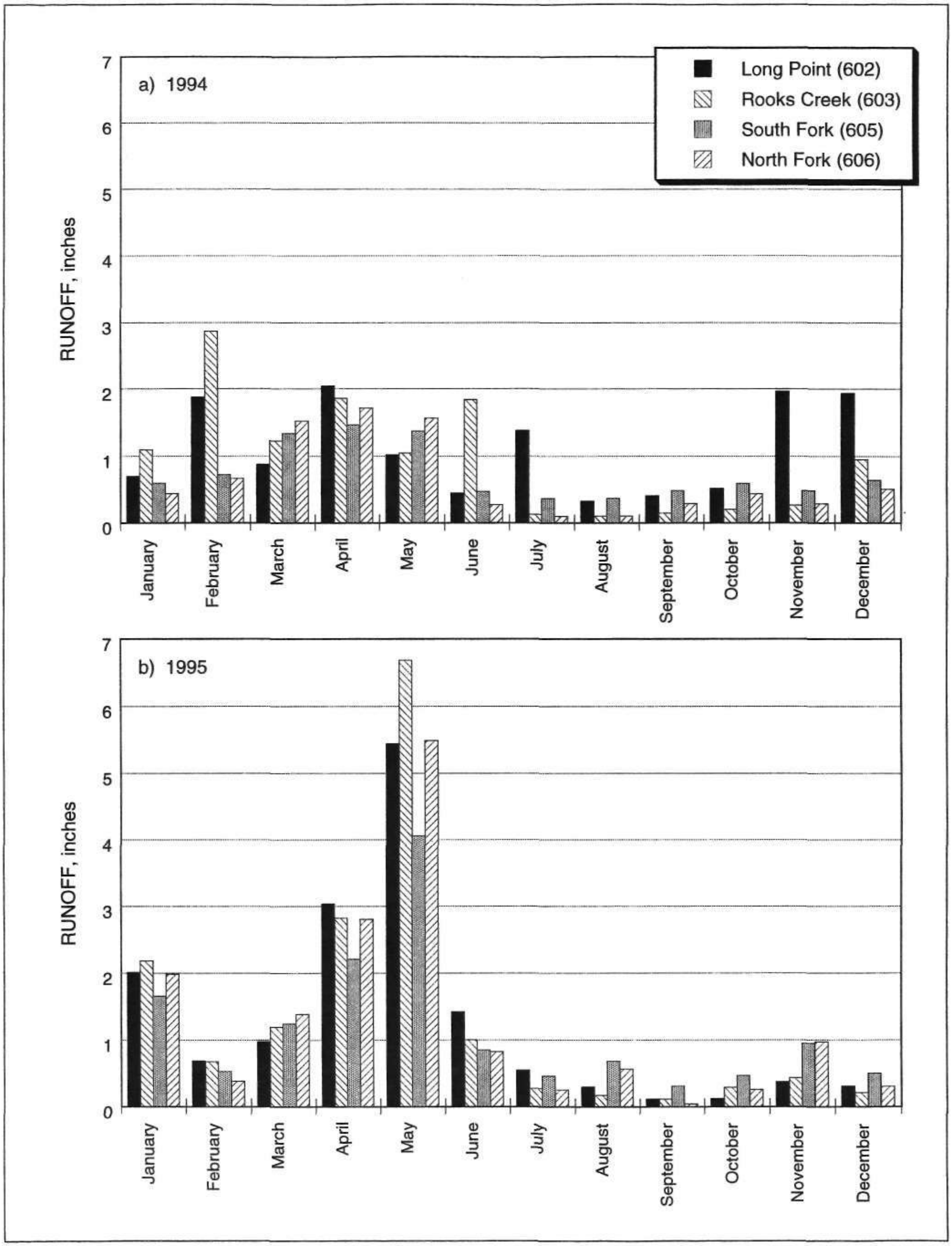


Figure 24. Monthly runoff for tributary stations

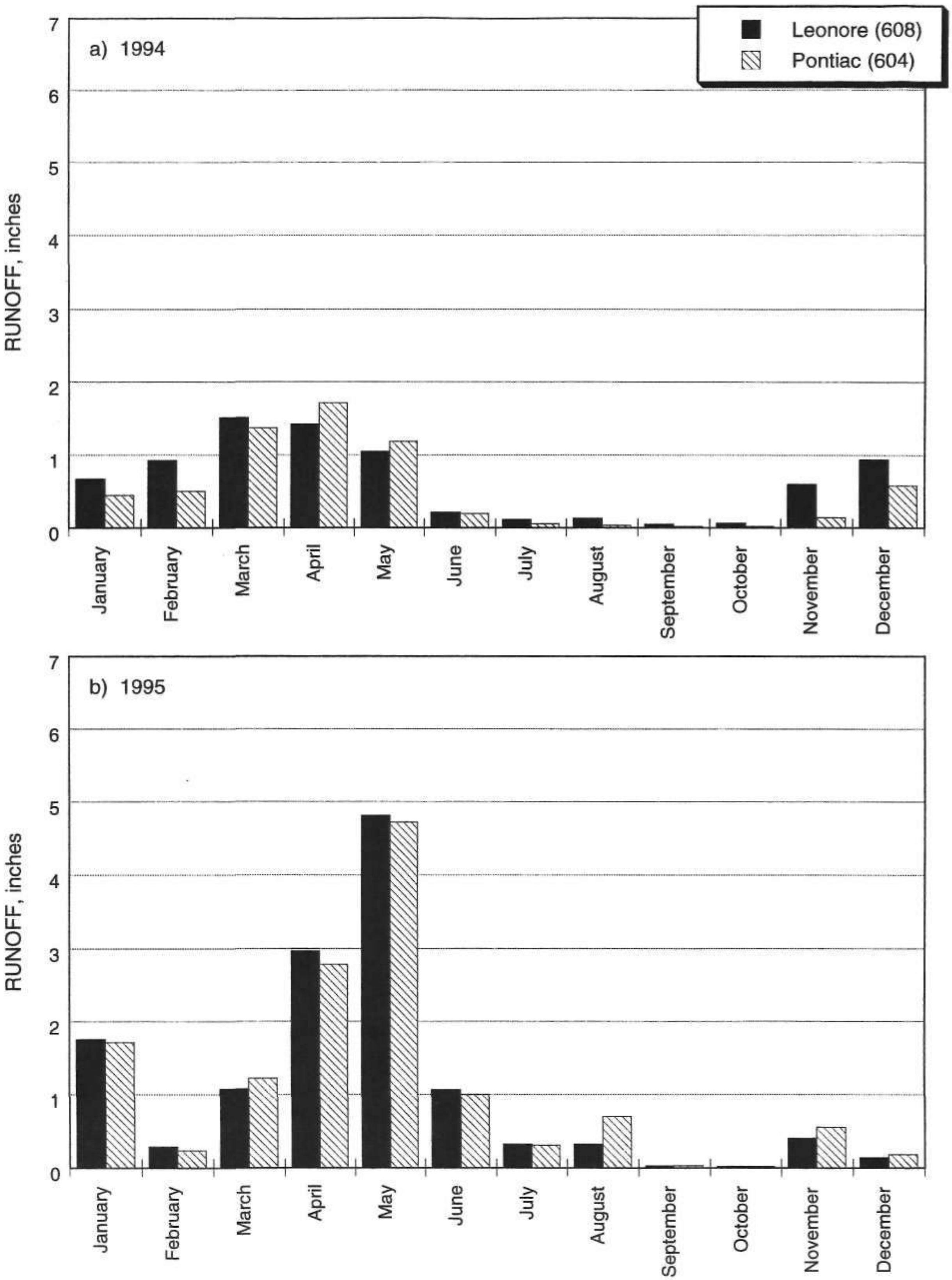


Figure 25. Monthly runoff for Vermilion River stations

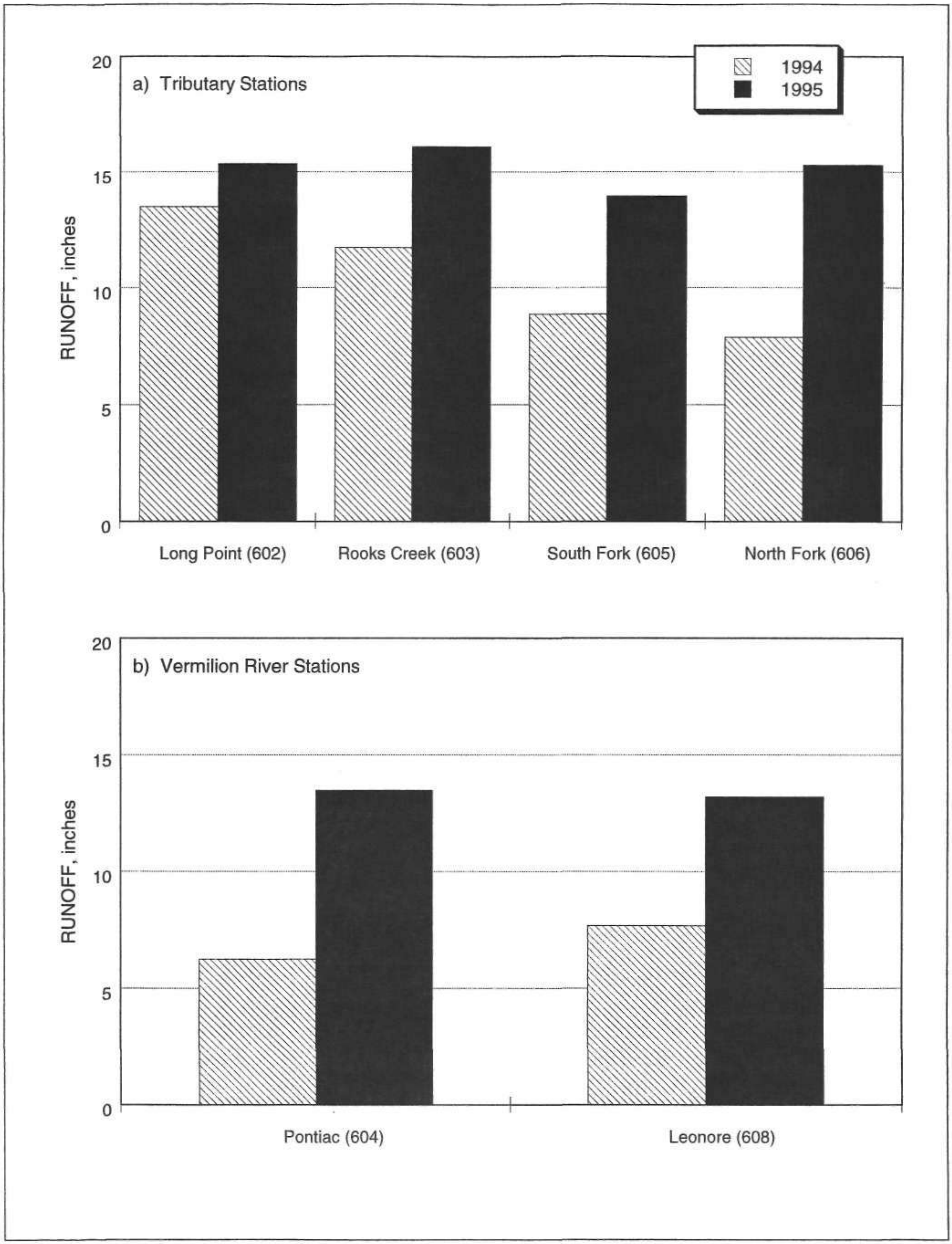


Figure 26. Annual runoff for a) tributary stations and b) Vermilion River stations

Sample Collection, Preservation, and Handling

All water samples are initially collected in a liter glass jar held inside an aluminum frame basket that is lowered on a rope into the stream. The glass jar is rinsed once with deionized water and once with the resident water before the samples are taken and prepared. A water temperature reading is taken using a standard Fahrenheit thermometer, and the sample is transferred to a storage bottle and labeled. Preservatives, if necessary, are added to the water sample (usually sulfuric acid), which is placed in a cooler kept at < 4°C, and transported to the laboratory for analysis. Table 4 lists the container types, sample size, and preservation and storage practices used for each of the different types of analysis.

Table 4. 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 stations for nitrogen compound analysis on regular visits and during storm/runoff events. A 500-ml polyethylene bottle is used for storage of the nitrogen compound samples (ammonium-N and TKN), and a 60-ml polyethylene bottle is used for the nitrate-N sample only. A preservative of 0.05 percent sulfuric acid is used to bring the pH of the sample to less than 2, which stops any further 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 5 lists the procedures used by the laboratories during analysis of water samples. The table gives the analyte, the IEPA method number, and the methodology used.

Table 5. Methodology for Chemical Analysis of Water Samples

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

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

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

QA/QC Procedures

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

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

Because the ISWS laboratory is an IEPA-certified Environmental Laboratory (Certificate No. 100202), it therefore meets general QA/QC procedures described in Part 183, Joint Rules of the Illinois Environmental Protection Agency and the Illinois Department of Public Health: Certification and Operation of Environmental Laboratories. All samples are preserved and stored as specified by the IEPA for each type of analysis, and analysis of the samples is within the specified holding times listed in table 12. The ISWS laboratories use the IEPA methods listed in table 5 for each type of analysis.

Nitrogen Concentrations

Nitrogen compounds sampled in this study were nitrate-N, ammonium-N, and TKN (total Kjeldahl nitrogen). Samples were collected from seven locations around the watershed as described above. Samples were collected on a weekly basis from the beginning of the project at three stations: Leonore (608), Pontiac (604), and South Fork (605). Samples were collected either weekly or biweekly depending on hydrologic conditions at the other stations: Rt. 17 (607), Long Point Creek (602), Rooks Creek (603), and North Fork (606).

Nitrate. In this section, "nitrate-N" (nitrate as Nitrogen) will be referred to as "nitrate" and is not to be confused with the nitrate-NO_3 (nitrate as nitrate) method of reporting. Nitrate concentration data for all stations during the two-year monitoring period are presented in figures 27-29. Figures 27 and 28 represent nitrate samples collected from the tributary and river stations for the two-year monitoring period, respectively. Figure 29 represents nitrate concentration samples taken at the Streator and Pontiac water treatment plants during the same period.

As can be readily seen in the figures, all the stations follow a seasonal pattern for nitrate concentrations. Concentrations steadily rise in January, peak in May or June, drop sharply from July to August, remain very low through October, and begin a steady rise, with periods of fluctuation, to December. Figures 27 and 28 also show that at one time or another all stations exceed the 10 mg/1 MCL and fall to at least below 2 mg/1 during the monitoring period.

Figure 27 represents the nitrate concentration data for the four tributary stations. Figure 27a shows data for the first year of monitoring (1994), and figure 27b shows data for the second year (1995). In general, the tributary stations are relatively clustered for any sampling date and generally follow the seasonal trend except during the summer when the nitrate concentrations become characteristically low and the clusters become very tight. This indicates the general similarities in climate, hydrology, and land use for most of the sub-watersheds in the region. Nitrate concentration data collected from the Upper Sangamon River watershed study exhibited the same clustering tendencies. An exception occurred at Long Point (602) during the summer and early fall of 1994. The concentration dropped in mid-summer but steadily rose while all other stations follow the seasonal trends as described earlier in this section. Runoff values for Long Point in figure 24 show higher flows, thereby providing more opportunity to transport nitrate from the watershed, which is in contrast to the flows of the other tributary stations during the same period. Concentrations were slightly higher at the tributary stations in 1995 during the spring-summer months, but lower in 1994 during the late fall-winter months.

Figure 27a shows that Long Point (602) was the station with consistently high nitrate concentrations throughout 1994. All four stations had their highest concentrations for the first year of data collection in May 1994. The highest nitrate concentration was 14.2 mg/1 at Long Point (602) on May 13, 1994. The lowest concentration for the year was 0.02 mg/1, which is the minimum detection level (MDL) for nitrate. Rooks Creek (603) and North Fork (606) had this low level from July through October 1994. Figure 27b shows no one particular station being consistently higher than the other stations throughout 1995. Also, Long Point (602) concentrations did decrease and stayed low during the summer months; in fact, the nitrate concentrations fell to the MDL. The highest nitrate concentration was 15.3 mg/1 at Rooks Creek (603) on April 20, 1995. The lowest concentration of 0.02 mg/1 (MDL) was read at several stations from August to October 1995. In the months of March, April, and June 1995, concentrations stayed above the MCL for all stations. All stations went below 2 mg/1 during September and October 1995. It was generally observed that South Fork (605) stayed consistently above the MDL by 1 to 2 mg/1 during the summer months while the concentration at the other stations reached the MDL during the same period, with the exception of Long Point (602) in 1994.

Figure 28 represents the nitrate concentrations collected from the three river stations: Pontiac (604), Rt. 17 (607), and Leonore (608). Figure 28a and b show the concentrations for the 1994 and 1995 monitoring years, respectively. Again, just like the tributary stations, the river stations exhibit clustering for any sampling date and generally follow the established seasonal trend. An exception to this clustering is the elevated nitrates at Rt. 17 (607) and Leonore (608) in which the concentrations seem to rise just as they did at Long Point (602) during the summer and early fall of 1994. Inspection of runoff at the two river stations during this period shows extreme low flows. The confluence of Long Point Creek with the Vermilion River is upstream of the Rt. 17 (607) and Leonore (608) stations. It was determined that the combination of the higher runoff and nitrate concentrations at Long Point (602), as compared to Rt. 17 (607) and Leonore (608), may have had an impact on the concentrations observed at these river stations. This phenomenon did not occur again the following summer when runoff and nitrate concentrations at Long Point (602) were significantly lower. Concentrations at the river stations were slightly higher in 1995 during the spring-summer months. Nitrate concentrations peaked in November 1995 but steadily decreased through December, unlike in 1994 in which the concentrations increased.

Figure 28a shows that the highest nitrate concentration observed was 11.2 mg/1 on May 13, 1994 at the Leonore (608) station. The lowest nitrate concentration was 0.02 mg/1 (MDL) at Pontiac (604) during July through October 1994. All the river stations exceeded the MCL during April and May 1994. The clustering characteristic of the concentrations is evident in figure 28b for 1995. All stations dropped below 1 mg/1 from mid-September to mid-October 1995. A high nitrate concentration of 13.8 mg/1 was observed on June 2, 1995 at Pontiac (604), and the lowest nitrate concentration was the MDL for nitrate at Leonore (608) periodically during September and October 1995.

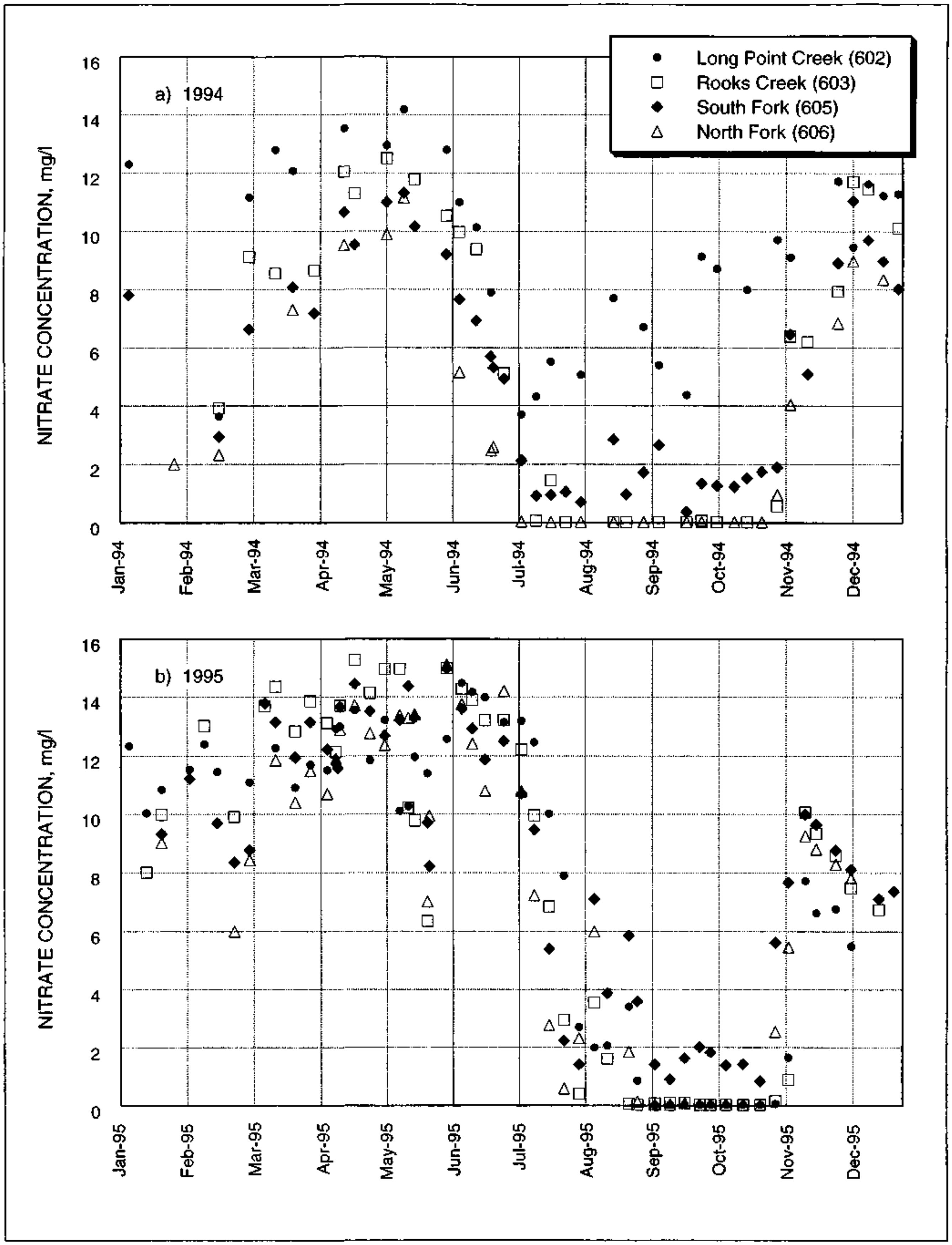


Figure 27. Nitrate-N concentrations for tributary stations

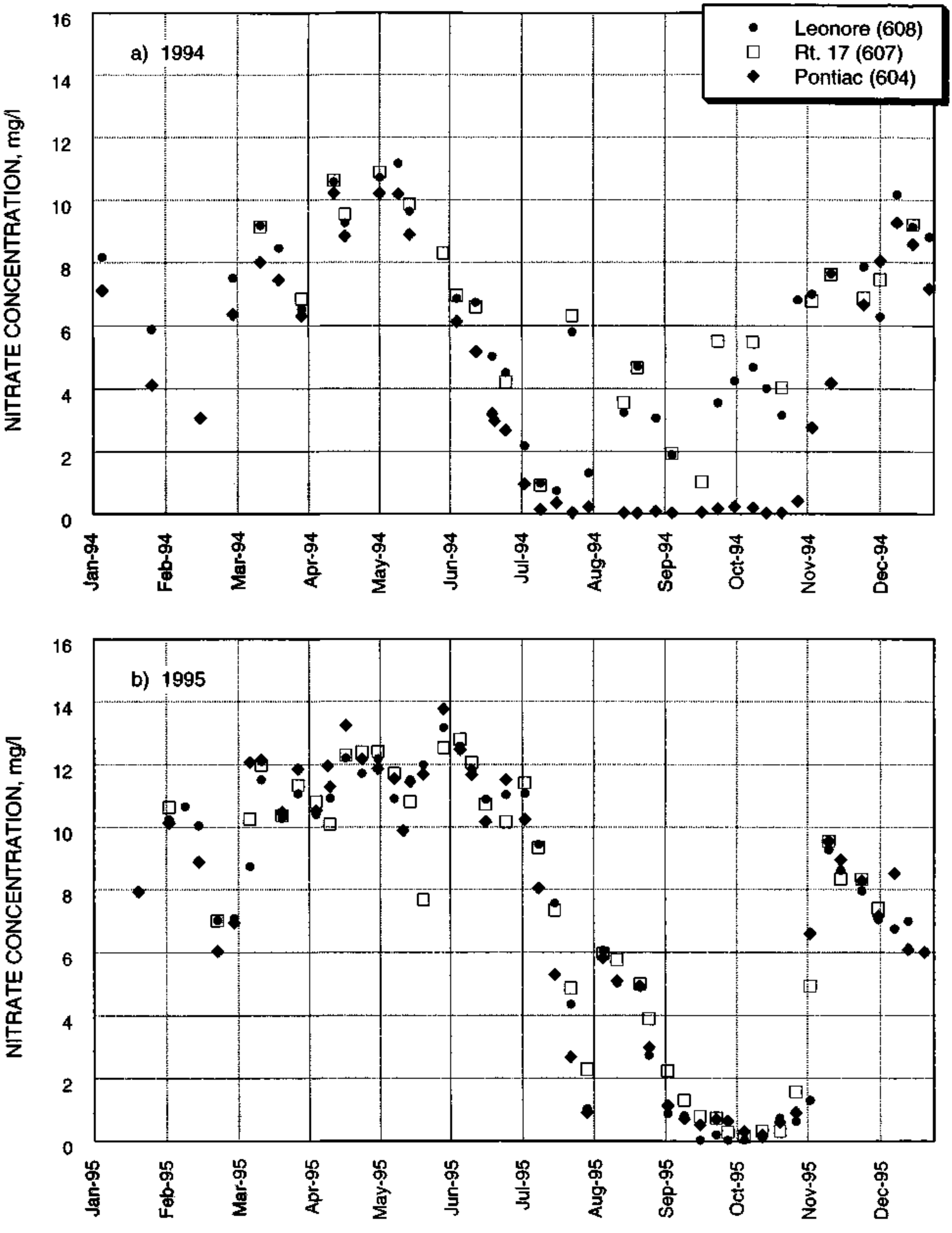


Figure 28. Nitrate-N concentrations for Vermilion River stations

Figure 29 shows the nitrate concentrations observed in the raw water drawn from the Vermilion River in a) 1994 and b) 1995 at the Streator and Pontiac water treatment plants (WTPs). The figure shows concentrations paralleling the levels observed at the river stations of the monitoring network. The seasonal trend is also apparent. The Streator WTP nitrate concentrations are elevated during the summer of 1994 just as the Rt. 17 (607) and Leonore (608) stations. A noted difference between the Pontiac WTP and the Pontiac (604) stations is the higher concentrations during May 1995. Otherwise, all values seem to parallel each other.

Ammonium and TKN. Ammonium-N and TKN are two other nitrogen compounds that were sampled at all stations and at relatively reduced sampling frequency from nitrate-N. Figures 30 and 31 show the ammonium concentrations, and figures 32 and 33 show the TKN concentrations for the tributary and river stations from January 1994 through December 1995.

As figures 30 and 31 show, ammonium stayed below 0.5 mg/1 for most of the study period, except from late January to February of 1994. North Fork (606) had the highest reading (3.6 mg/1) with the next highest reading (2.35 mg/1) at Rooks Creek (603). The highest river station ammonium concentration (2.18 mg/1) was at Pontiac (604). The majority of the ammonium concentrations stayed slightly above or at the minimum detection limit (MDL), which is 0.02 mg/1. The TKN concentrations shown in figures 32 and 33 illustrate the same dramatic increase during January and February 1994. A second spike of TKN concentrations occurred during May 1995 at all of the tributary sites and one of the main river stations [Route 17 (607)]. However, there has been little variation in the remainder of the results in which TKN concentrations did not exceed 2 mg/1.

Figures 34-36 show the minimum, average, and maximum concentrations of all three nitrogen compounds sampled at the seven monitoring stations during the study period. Figure 34 shows that Long Point (602) had the highest minimum concentration of nitrate (3.63 mg/1) during both monitoring years. Otherwise, all nitrogen compounds were observed at very low minimum readings for all the stations. Figure 35 shows that the average concentration for the nitrogen compounds was very uniform during both monitoring years. The noted exception was nitrate during 1994 when 9.2 mg/1 was the highest average reading at Long Point (602) and 3.6 mg/1 was the lowest reading at North Fork (606). The maximum nitrogen concentrations observed during the two-year monitoring period are shown in figure 36. Long Point (602) had the highest nitrate concentration in both years (14.2 and 14.5 mg/1, respectively). The lowest maximum nitrate concentration was 10.2 mg/1 at Pontiac (604). Ammonium-N showed lower maximum concentrations downstream during 1994 but relatively uniform values in 1995. The highest ammonium-N concentration was 3.6 mg/1 at North Fork (606). North Fork (606) had the highest TKN reading at 6.7 mg/1.

Nitrate Loads

Even though the main water quality concern in Streator and Pontiac is nitrate concentration, the critical issue for watershed management is nitrate loads. It is impossible to

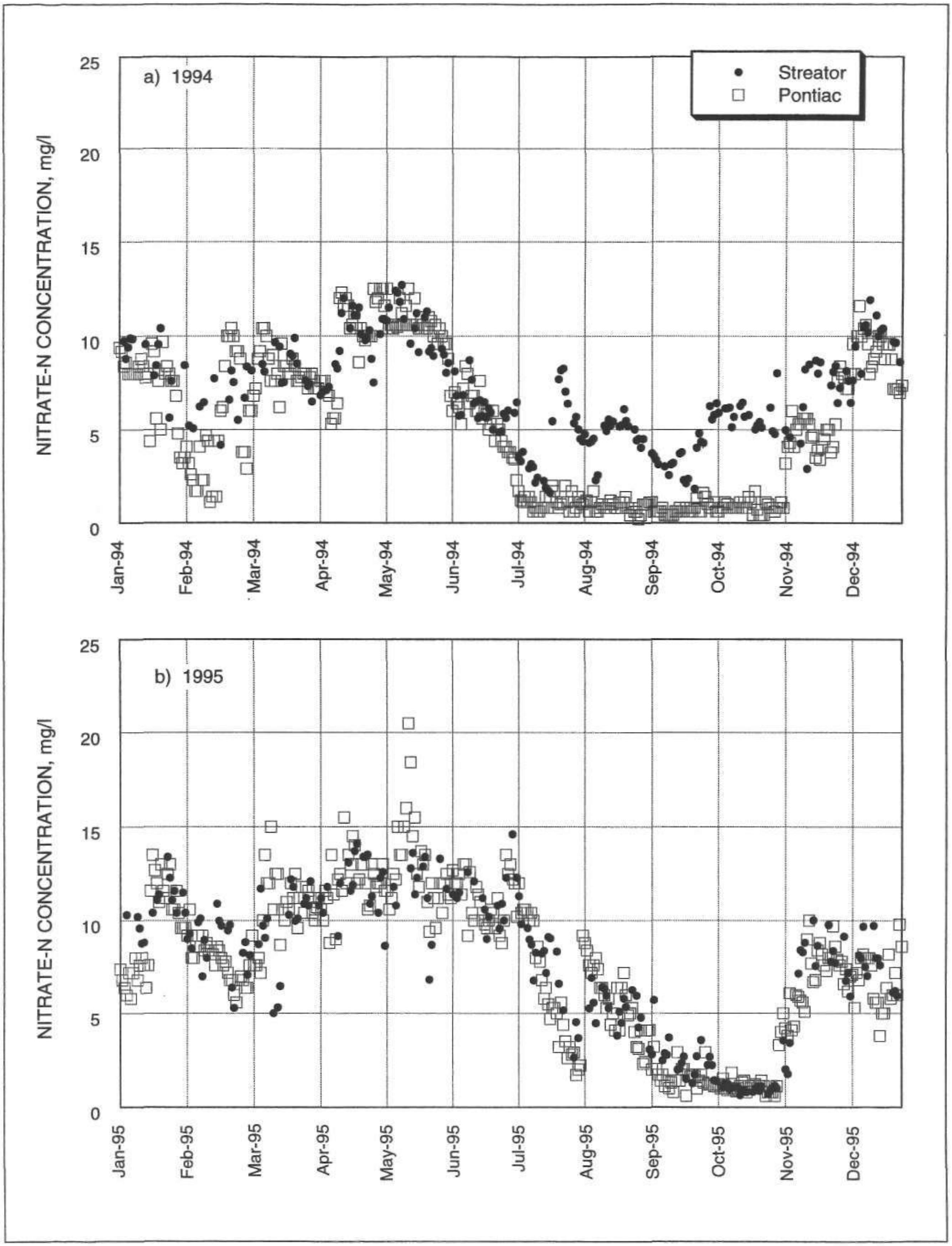


Figure 29. Nitrate-N concentration readings for Streator and Pontiac water treatment plants

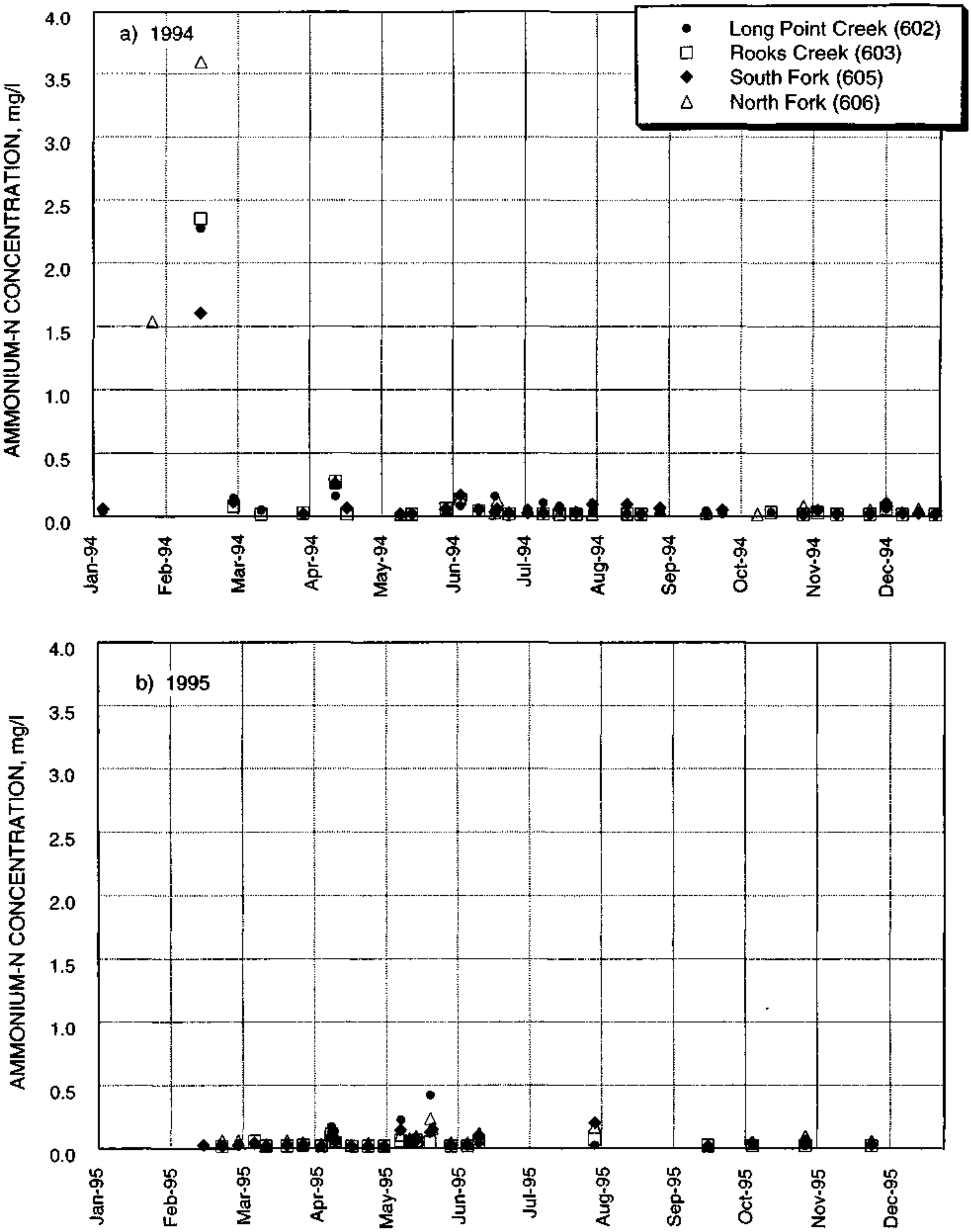


Figure 30. Ammonium-N concentrations for tributary stations

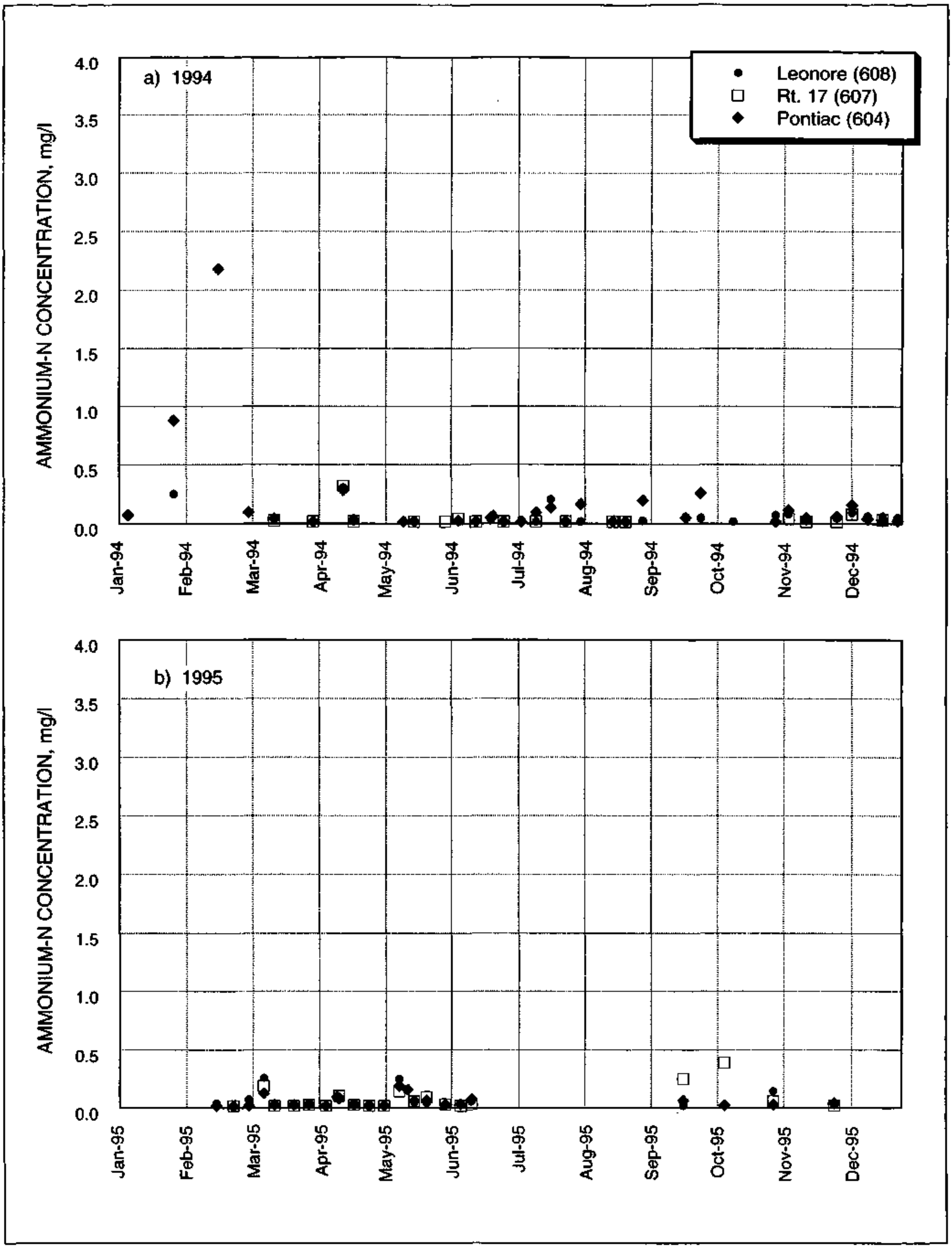


Figure 31. Ammonium-N concentrations for Vermilion River stations

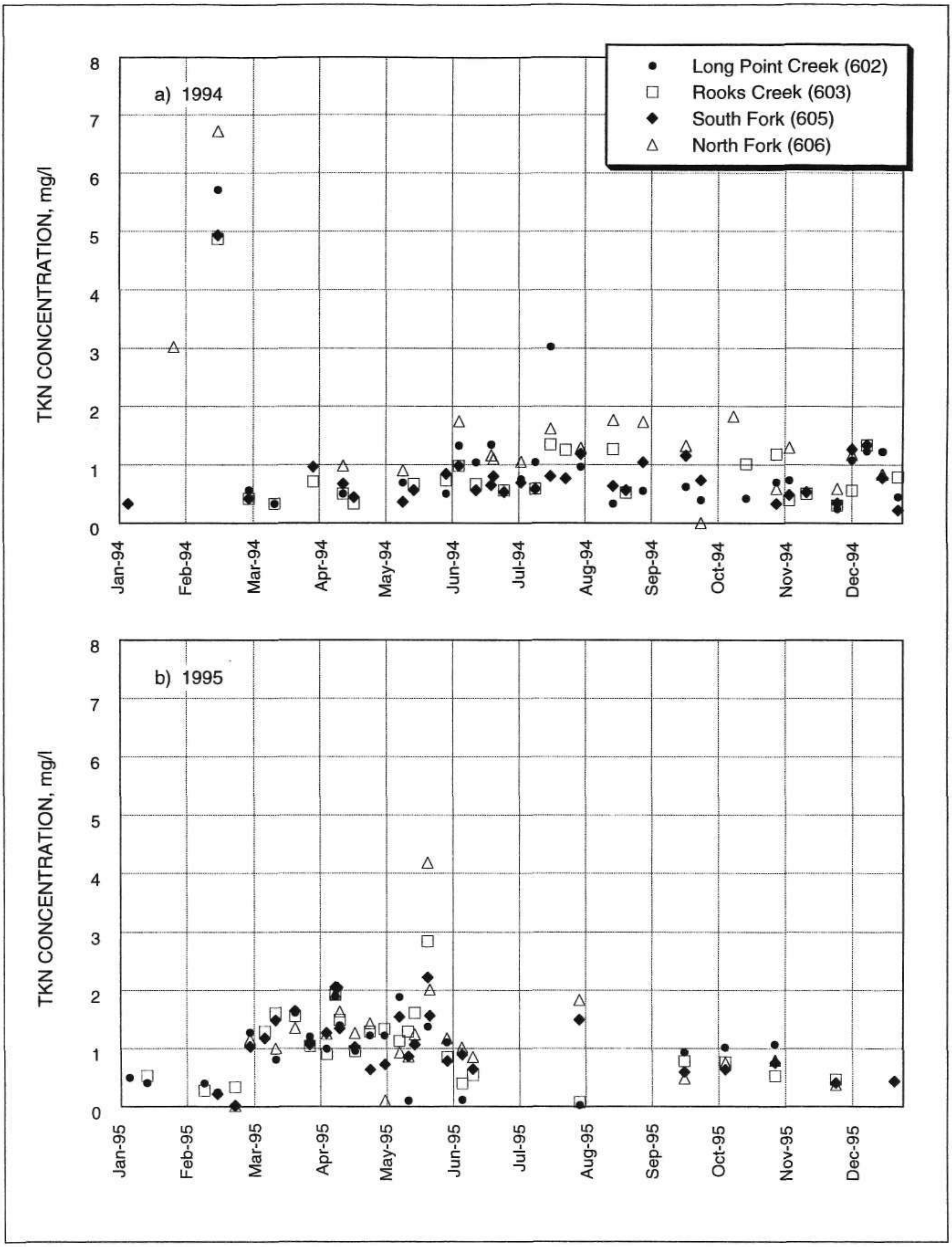


Figure 32. TKN concentrations for tributary stations

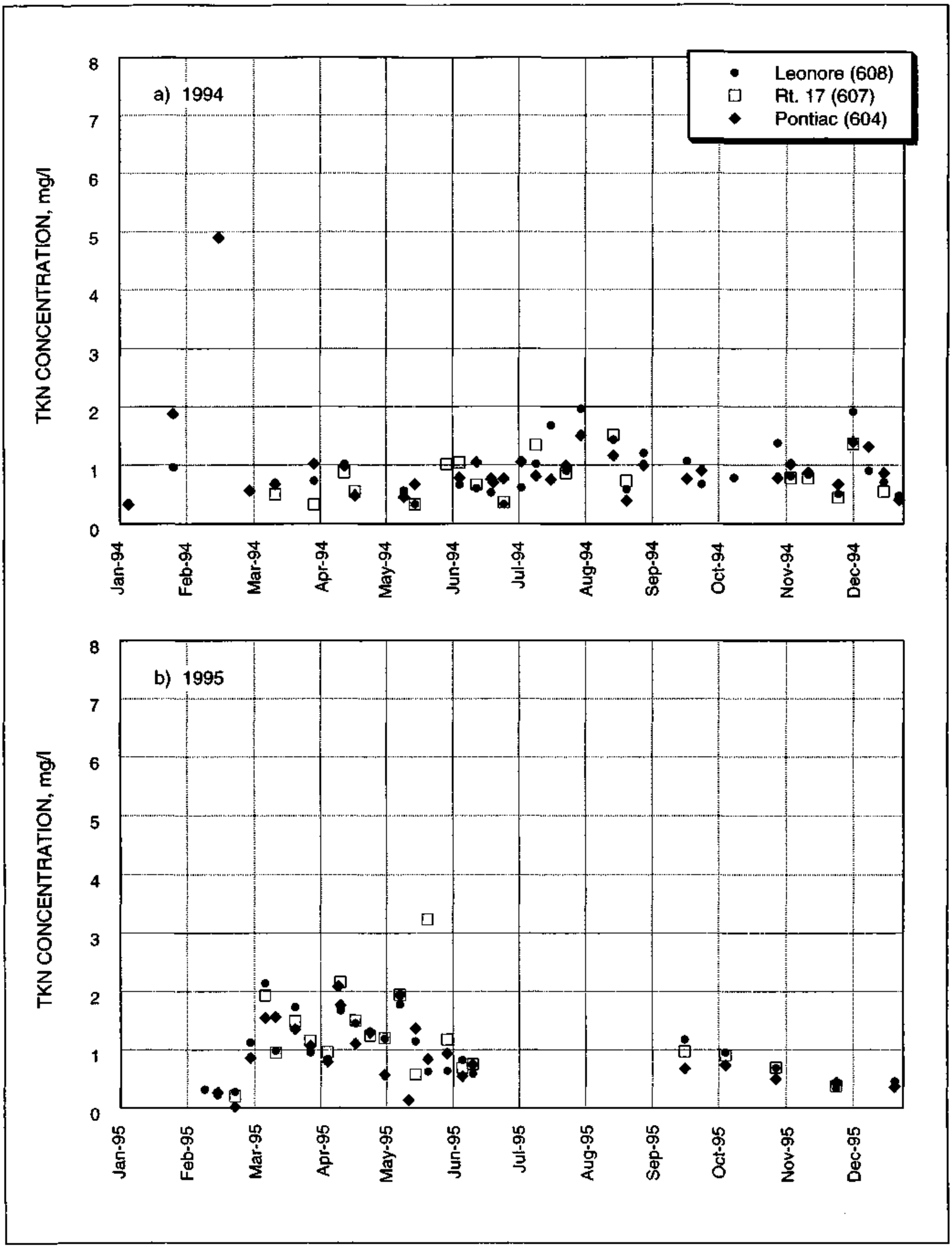


Figure 33. TKN concentrations for Vermilion River stations

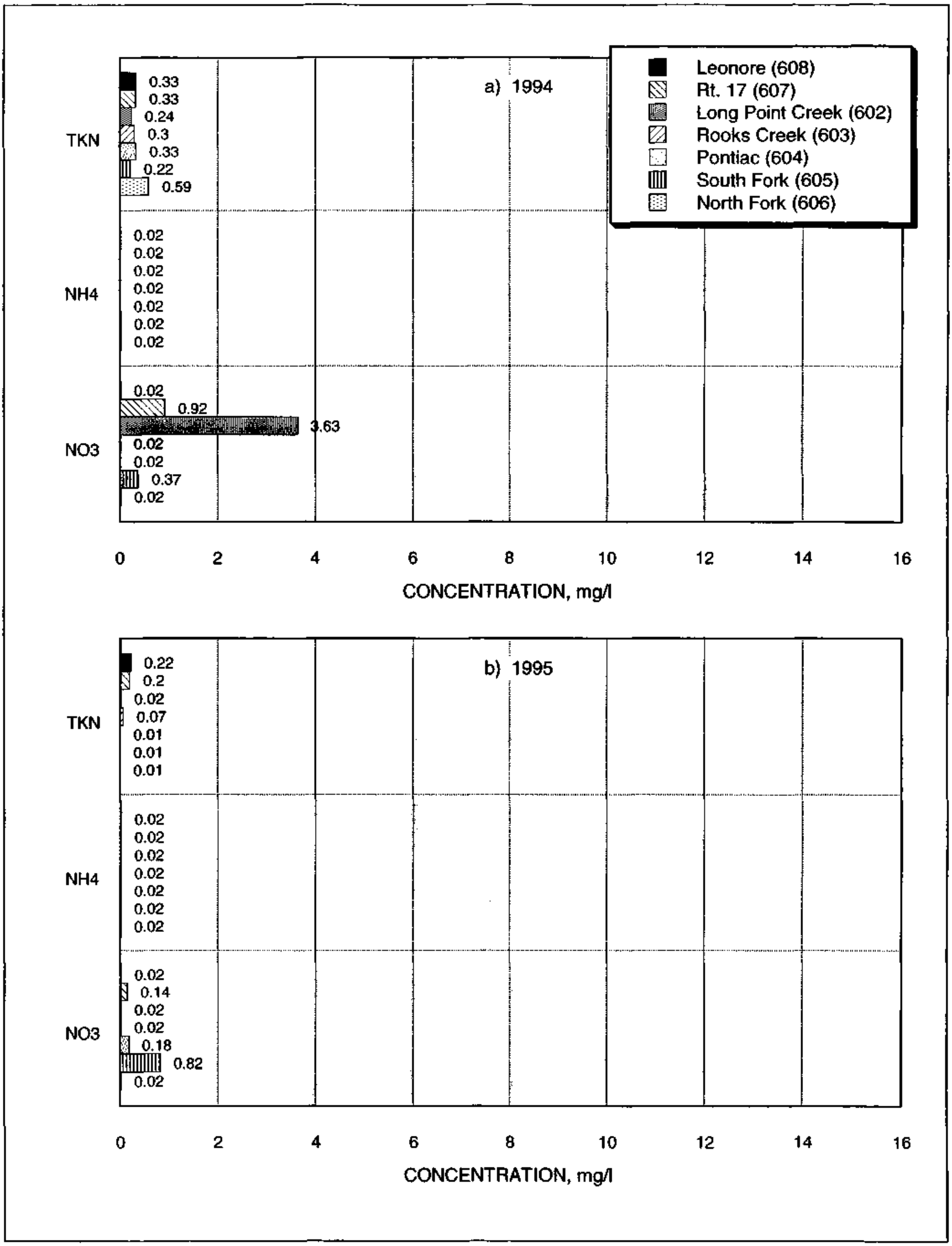


Figure 34. Minimum nitrogen concentrations during study period

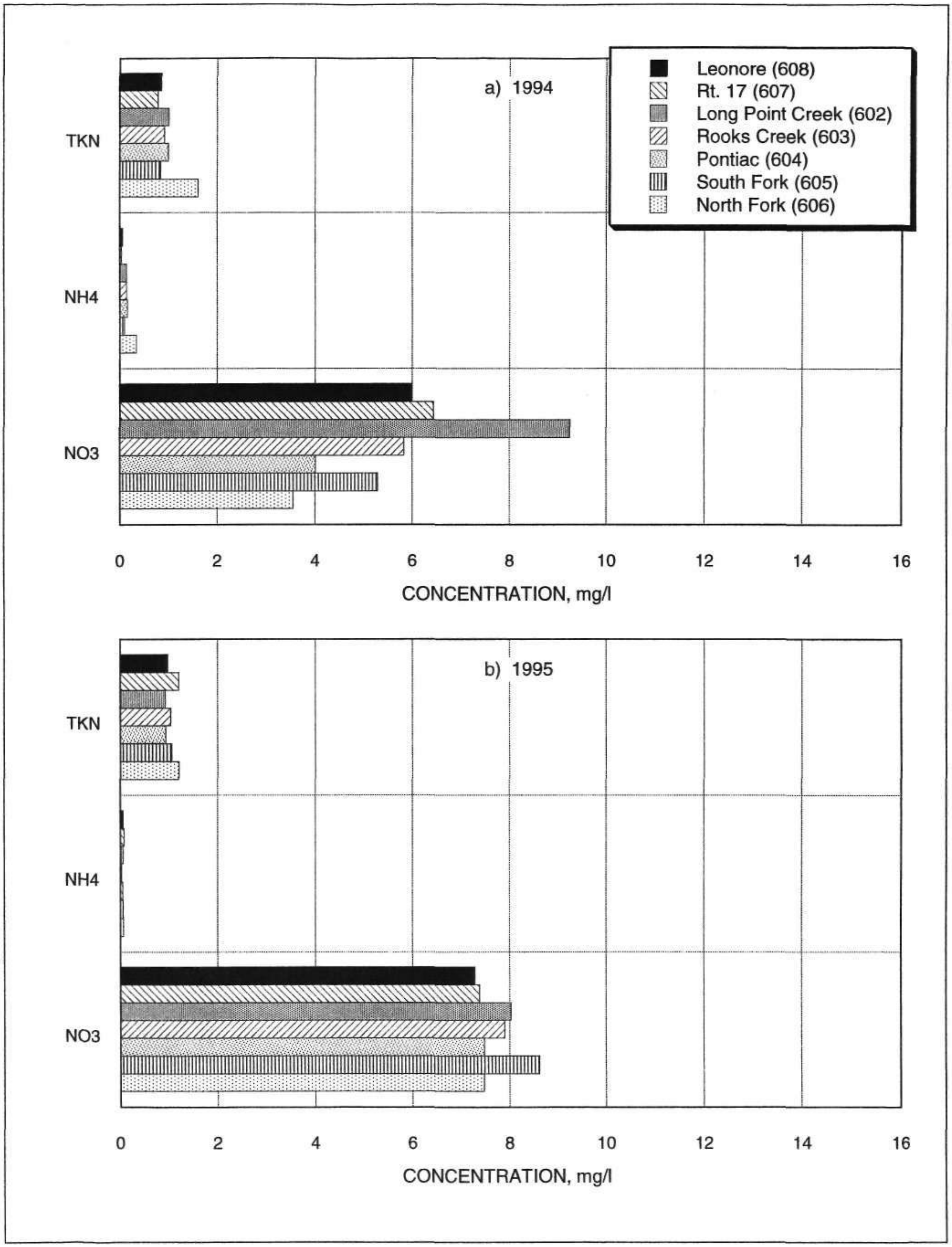


Figure 35. Average nitrogen concentrations during study period

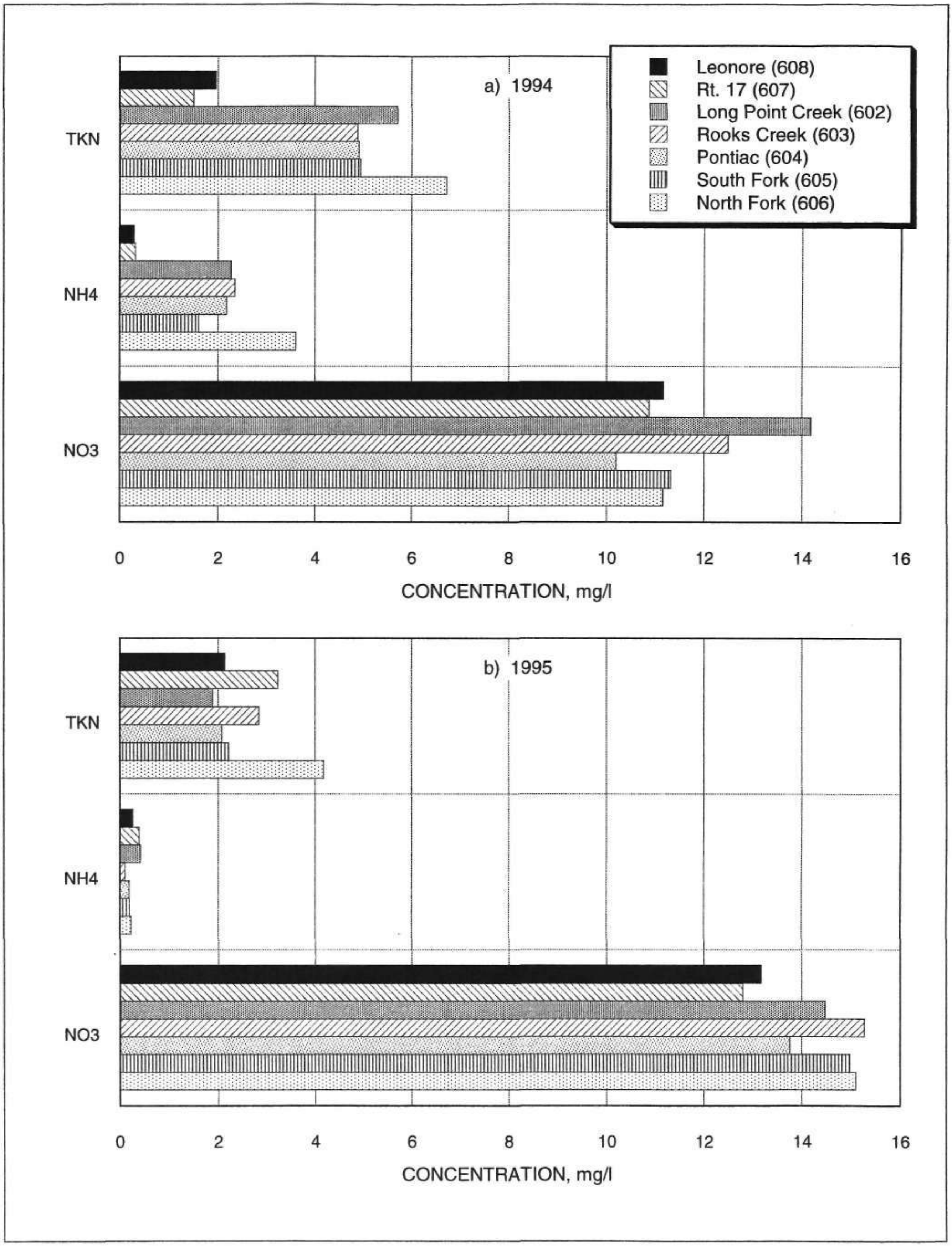


Figure 36. Maximum nitrogen concentrations during study period

reduce the nitrate concentration without reducing the nitrate load to the river. Management alternatives are more easily understood in terms of load reduction than reduction in concentration.

The calculation of nitrate loads, or yields, is necessary to determine the contribution of different areas to the total nitrate input to the river. 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 could be quite small as compared to other sub-watersheds and thus not a significant contributor. Calculations of monthly nitrate loads have been made for six of the stations and are presented in figures 37 and 38.

Figure 37 shows the monthly nitrate-N load in pounds per acre (lb/acre) for the four tributary stations: Long Point Creek (602), Rooks Creek (603), South Fork (605), and North Fork (606). Loads are calculated as a product of the monthly discharges and the average nitrate concentrations, therefore the loads presented in figure 37 show a combined effect of streamflow and nitrate concentration. The monthly loads for the first year are lower than for the second year because of the lower streamflows. The overall average monthly nitrate load for all the stations was 1.5 lb/acre for the first year as compared to 3.0 lb/acre for the second year. In the Upper Sangamon River study, the 1994 average monthly loads for the tributary stations were 1.2 lb/acre as compared to 1.5 lb/acre in the Vermilion River tributary stations. As in the Upper Sangamon River, the main factor for the low loads in the first year was the very low monthly loads for nearly five months (July to November) as a result of either extremely low flow or low nitrate concentrations during the period. In 1994 the highest nitrate load was at Long Point (602) in April with 6.2 lb/acre. The lowest loads (zero lb/acre) were at Rooks Creek (603) and North Fork during July through October. Loads were much higher during 1995 than during 1994. Loads at all stations were above 10 lb/acre during May 1995, with Rooks Creek (603) the highest and South Fork (605) the lowest at 16.9 and 10.9 lb/acre, respectively. All stations were near zero during September and October.

Figure 38 presents the monthly nitrate loads for the two Vermilion River stations. Similar to the tributary streams, the loads were lower during the first year than the second year. The average monthly load for the two stations was 1.0 lb/acre for the first year as compared to 2.6 lb/acre for the second year. Again, the 1994 river stations in the Upper Sangamon River had similar average monthly loads at 1.2 lb/acre. Both stations [Pontiac (604) and Leonore (608)] had their highest loads of 12.0 and 12.6 lb/acre in May, respectively. Loads approaching zero were seen during June through November of 1994 and September through October of 1995.

Annual Nitrate Loads. The annual nitrate loads at all six stations are summarized in table 6 and presented in figure 39. The results are grouped into two figures for the purpose of comparing tributary streams separately from main river stations. For the tributary streams (figure 39a), the annual nitrate load for 1994 ranges from a low of 12 lb/acre for North Fork to a high of

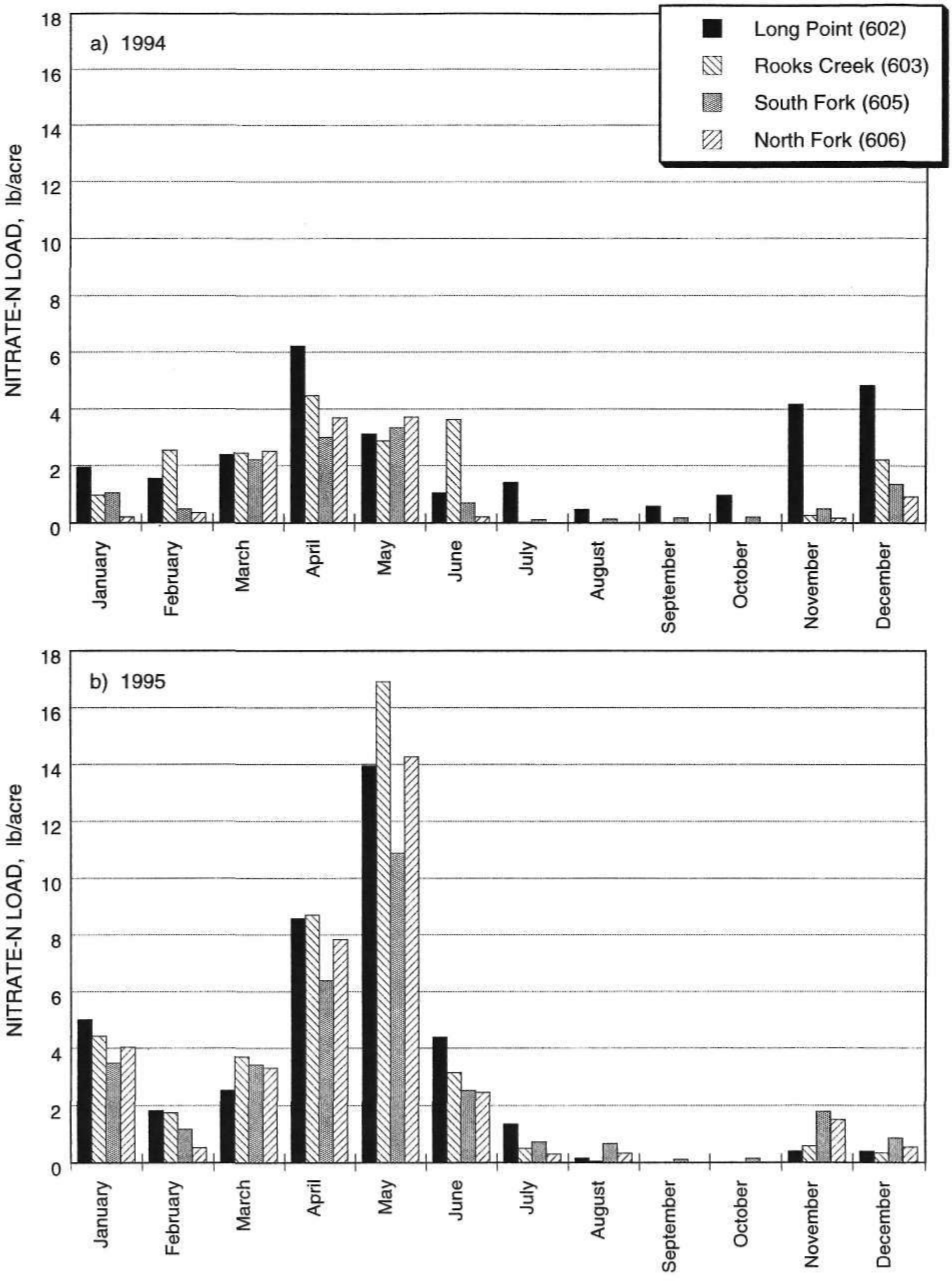


Figure 37. Monthly nitrate-N load for tributary stations

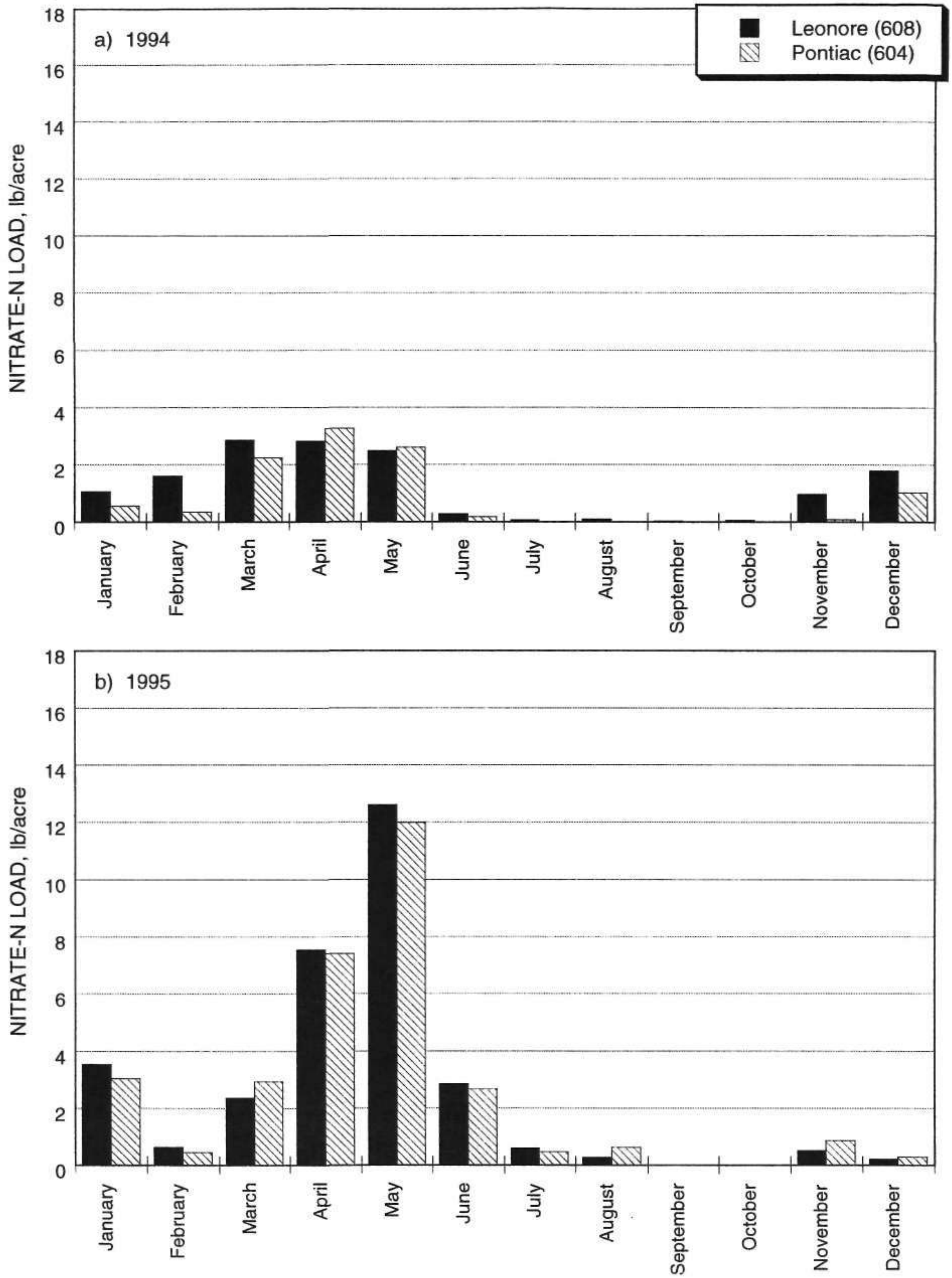


Figure 38. Monthly nitrate-N load for Vermilion River stations

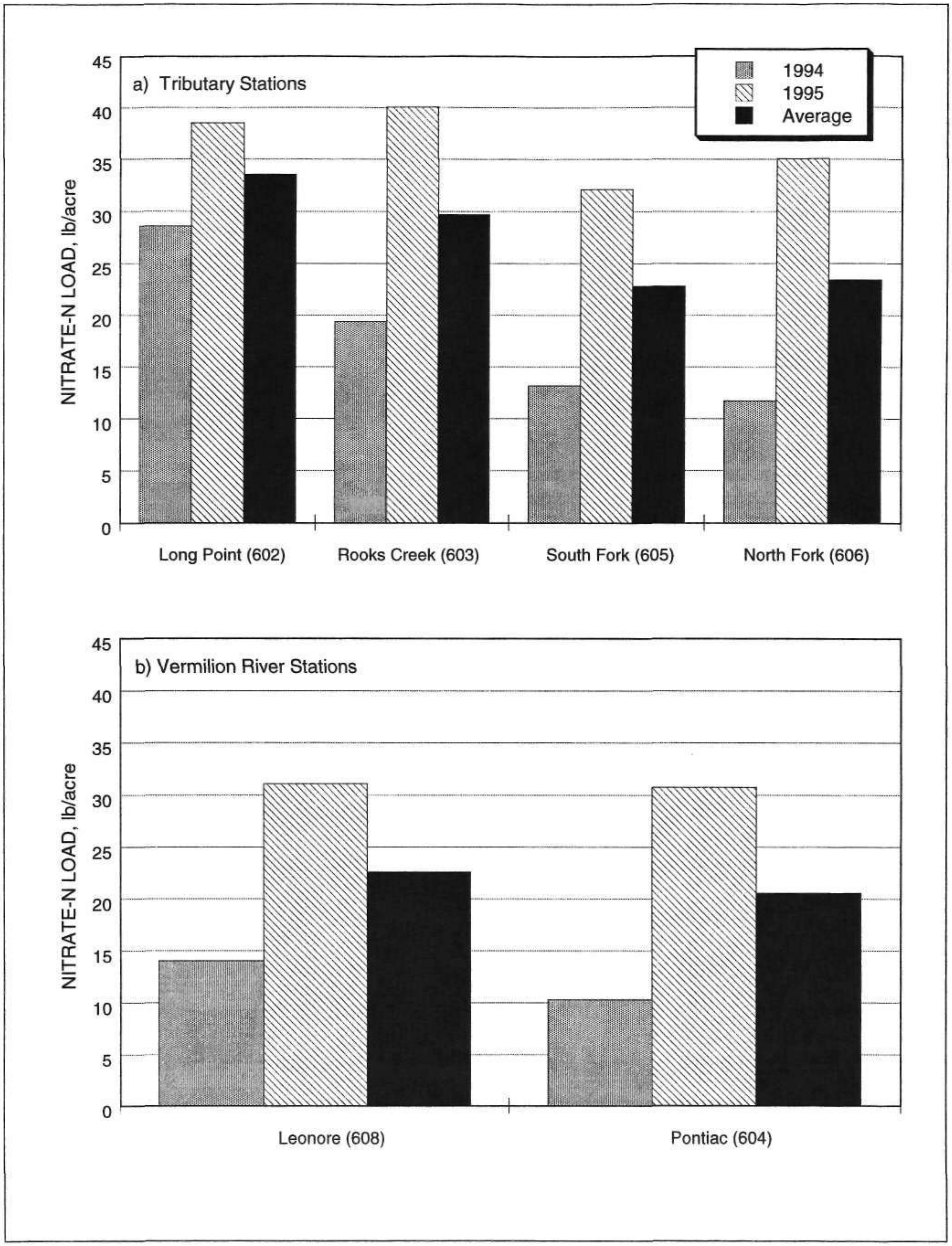


Figure 39. Annual nitrate-N load for a) tributary and b) Vermilion River stations

Table 6. Annual Nitrate Loads in the Vermilion River Basin

Station	*Drainage area (acre)*	*Annual nitrate yield* Year 1 (lb/acre)	*Annual nitrate yield* Year 2 (lb/acre)	*Average (lb/acre)*
Tributary stations:				
Long Point (602)	40,320	29	38	34
Rooks Creek (603)	81,280	19	40	30
South Fork (605)	104,320	13	32	23
North Fork (606)	127,360	12	35	23
Main river stations:				
Vermilion River at Pontiac (604)	368,640	10	31	21
Vermilion River at Leonore (608)	796,160	14	31	23

29 lb/acre for Long Point. Rooks Creek generated the next highest nitrate load at 19 lb/acre and 13 lb/acre for South Fork.

The average annual load for all the tributaries for the first year (1994) was 18 lb/acre as compared to 14 lb/acre in the Upper Sangamon River. The annual nitrate loads for the tributary streams were much smaller the first year than the second year. The overall average annual load for the second year was 36 lb/acre. Second-year loads at some stations were almost three times greater than those of the first year. Tributary loads for the second year were more uniform and ranged from a low of 32 lb/acre for South Fork to a high of 40 lb/acre for Rooks Creek.

Figure 39b presents the annual nitrate loads for the two Vermilion River stations. Similar to the tributary streams, the loads are lower during the first year than the second year. The overall average annual load for the main river stations during the first year (1994) was 12 lb/acre and 31 lb/acre for the second year (1995). The 1994 load in the Upper Sangamon River was 15 lb/acre. During the first year, the annual loads were 10 lb/acre at Pontiac and 14 lb/acre at Leonore. In the second year, the load tripled at Pontiac to a high of 31 lb/acre and nearly double at Leonore to also 31 lb/acre.

It is generally accepted that as drainage area increases, the unit load generally decreases similar to sediment yield. One process by which the unit load decreases with increasing drainage area is the mixing of runoff of higher concentrations with runoff of lower concentrations. For sediment, channel and floodplain storage account for the decrease in unit area yields as drainage area increases, but for nitrate there must be some losses in the stream channel and floodplain as the drainage area increases. The second-year data for the Vermilion River study and the two years of data in the Upper Sangamon River watershed study support this, but the first year Vermilion data seem to be the exception. The data show that Leonore may have had higher loads than Pontiac due to the influence of Long Point Creek.

Based on the nitrate load data, we can conclude that the source of nitrate in the Vermilion River watershed is relatively dispersed throughout the watershed. There are no "hot spots" generating most of the nitrate that flows into the river. Even though the Long Point watershed was observed to generate a much higher nitrate load per unit area during the first year, the load fell within the range of the other watersheds during the second year. The Long Point Creek watershed covers only 5 percent of the monitored Vermilion River watershed area (1,244 sq mi at Leonore). To put this into perspective, 95 percent of the Vermilion River drainage area yields nitrate at a nearly uniform rate, therefore loads contributed by Long Point Creek do not have a significant impact on the Vermilion River except during extreme low flows, as demonstrated by the 1994 data.

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