CONTRIBUTION OF RETURN FLOWS TO STREAMFLOW IN SELECTED STREAM REACHES IN ILLINOIS, 1988-89

by John K. LaTour

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 93-4089

Prepared in cooperation with the

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

Urbana, Illinois

1993

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second

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million gallons per day	1.54723	cubic feet per second

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by John K. LaTour

ABSTRACT

Water returns by sewage-treatment plants and various water users can be a significant part of streamflow, especially during dry seasons. Knowledge of the effect of return flows on streamflow is needed for purposes of assessing stream-water quality and water supply. The results of a study by the U.S. Geological Survey, in cooperation with the Illinois Environmental Protection Agency, are presented to describe the contribution of return flows to streamflow for five stream reaches in Illinois during 1988-89.

The five stream reaches studied were South Branch Kishwaukee River upstream from De Kalb, Mackinaw River upstream from Congerville, Addison Creek upstream from Bellwood, Flag Creek upstream from Willow Springs, and Thorn Creek upstream from Glenwood. The South Branch Kishwaukee River and Mackinaw River reaches flow through mostly rural areas, whereas the Addison Creek, Flag Creek, and Thorn Creek reaches flow through mostly urban areas. The average flows of these streams ranged from 10.0 to 327 Mgal/d (million gallons per day). The drainage areas of the reaches range from 16.5 to 767 square miles.

Annual average return flows from 26 facilities to the 5 study reaches totaled 33.8 Mgal/d in 1988 and 36.7 Mgal/d in 1989. Annual average return flows to each reach ranged from 0.32 to 16.4 Mgal/d during 1988 and 1989. All return flows originated from water sources other than the receiving stream reaches. The median return flows to the reaches were 0.06 and 0.02 Mgal/d in 1988 and 1989, respectively. The median return flows in the entire State of Illinois were 0.08 Mgal/d in 1988 and 0.07 Mgal/d in 1989.

The annual average contributions of return flows to streamflow in each reach ranged from 1 to 99 percent of the annual average streamflow, with the assumption that no water was gained or lost between the return-flow sites and the streamflow-gaging station. Return flows significantly affected streamflows in the Flag Creek and Thorn Creek reaches. Because of the drought during 1988-89, however, the proportion of return flows in streamflow may have been greater than normal.

Return flows exceeded streamflow during at least 1 month during the 1988 drought at all of the study reaches, except the Thorn Creek reach. Because of the drought, streamflow could have been lost between the return-flow sites and the streamflow-gaging station by evaporation and (or) infiltration into the ground. Of the amount of return flows that exceeded streamflow, all reaches lost an estimated 0.01 to 0.34 Mgal/d to evaporation and 0.36 to 1.33 Mgal/d to infiltration.

Flow-duration curves for the Addison Creek, Flag Creek, and Thorn Creek reaches show that streamflows were being sustained by some water source. Because the annual contributions of return flows to streamflows were more significant (33-99 percent of streamflows in 1988-89) for these reaches than for the other reaches, return flows probably sustained streamflows.

Several analyses-of-variance tests of ranked return-flow data were used to evaluate the seasonal variation of return flows in streamflow. An analysis of the test results indicated that median return flows did not differ among seasons at a significance level of 0.05; however, a second analysis indicated that the median proportion of return flows to streamflow did differ seasonally, as would be expected because streamflows usually differ seasonally. In fact, the return flows in the five reaches during July through September 1988-89 constituted a large proportion (67 percent) of the annual streamflows.

Because return flows significantly affected streamflows in some of the reaches, the importance of reliable return-flow data should not be overlooked, especially if minimum streamflow requirements for water supply are mandated in Illinois. Collection of reliable return-flow and streamflow data needs to be continued in order to assess the constantly changing effects of return flows on streamflow.

INTRODUCTION

Water returns by sewage-treatment plants and various water users can be a significant part of streamflow in Illinois, especially during dry seasons. During the summer drought of 1988, flow in many rural streams in Illinois ceased; however, flow in many urban streams of similar size did not (G.W. Curtis, U.S. Geological Survey, written commun., 1988). Flow in urban streams probably was maintained because of the comparatively large concentration of commercial, industrial, power-generation, public-water supply, and sewage-treatment facilities that contributed water returns. An earlier investigation of the Kishwaukee River basin in Illinois indicated that, during low-flow periods, as much as 81 percent of streamflow was from sewage-treatment returns (Allen and Cowen, 1985, p. 19).

This study of water returns was done by the U.S. Geological Survey (USGS), in cooperation with the Illinois Environmental Protection Agency (IEPA), to evaluate the contribution of return flows to streamflow in several stream reaches in Illinois. It also was done to improve return-flow data to better evaluate the effects of return flows in Illinois.

Knowledge of the effect of return flows on streamflow is needed for purposes of assessing stream-water quality and water supply. Minimum streamflows must be adequate for more than 400 facilities that withdraw water from streams in Illinois. Broeren and Singh (1989, p. 2, 17) evaluated the adequacy of 90 surface-water-supply systems in Illinois and found that 24 systems would have an inadequate water source during a 20- to 50-year-recurrence drought. Currently, State laws mandate minimum streamflows only for major transportation waterways. Minimum streamflows or water levels may be mandated in the future to protect stream-water quality, ecology, and aquatic habitats (Broeren and Singh, 1989, p. 13).

Little is known about seasonal variations in return flows and the effects of these variations on streamflow. For example, water use by industrial and power-generation facilities in Illinois is typically greater during summer than during winter because of increased cooling requirements. Because water use often varies by season (Broeren and Singh, 1989, p. 16), it is likely that return flows vary seasonally as well. If return flows are greatest during summer months, they can greatly affect streamflows, which are typically at a minimum during summer in Illinois.

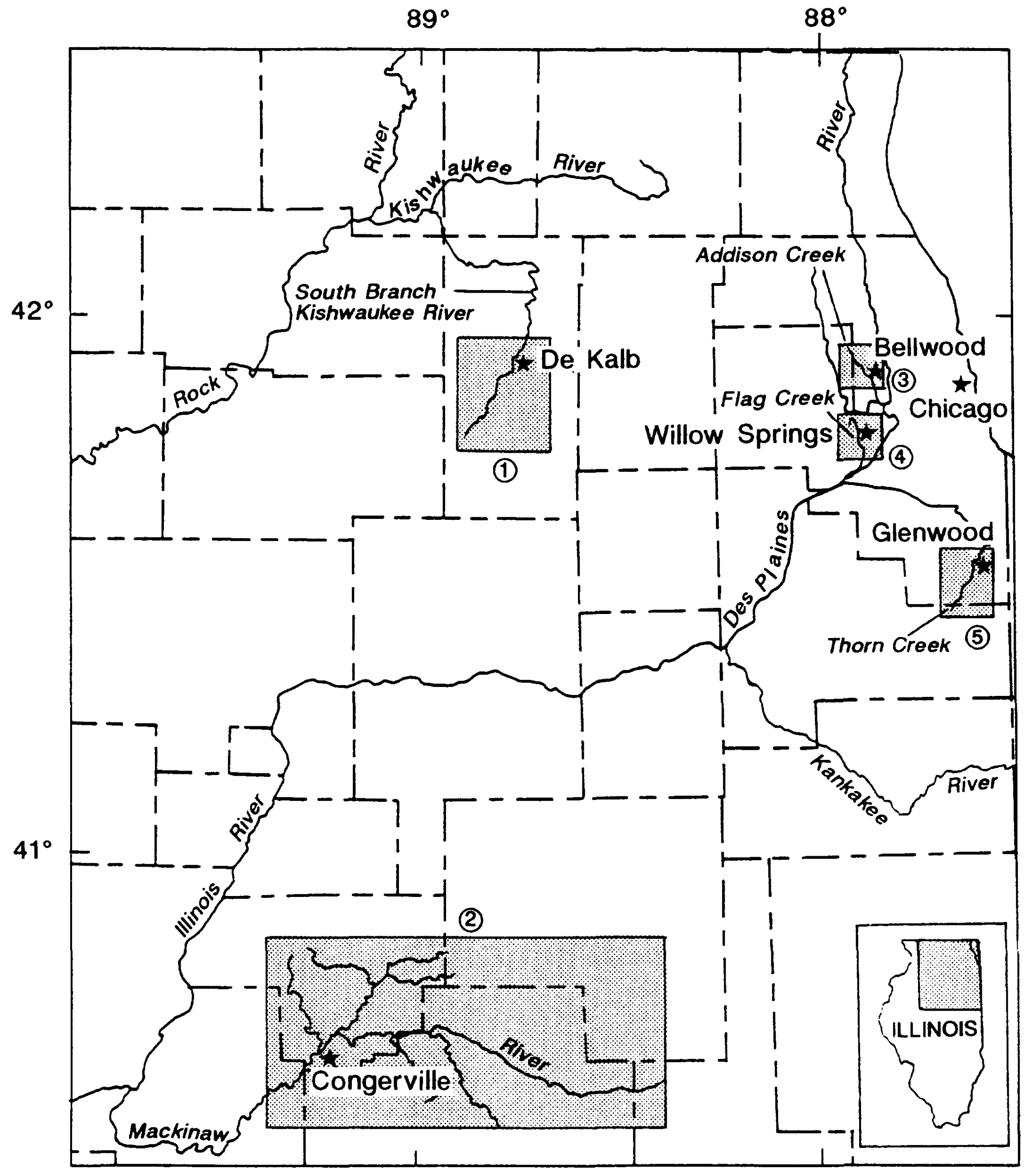
Reliable return-flow data are imperative to the evaluation of the effects of return flows on streamflow. Under the National Pollutant Discharge Elimination System (NPDES) of the U.S. Environmental Protection Agency (USEPA), the quantity and quality of return flows are reported by facilities on discharge-monitoring reports (DMR's) that are submitted to the IEPA. In 1988, there were 2,875 facilities with a total of 4,693 return-flow sites in Illinois. In 1989, there were 2,771 facilities with 4,324 return-flow sites.

Purpose and Scope

This report describes the results of an evaluation of the contribution of return flows to streamflow in Illinois. The report includes a comparison of monthly water returns to streamflows, and a statistical evaluation of the seasonal variation of return flows for five stream reaches during 1988 and 1989. The five reaches selected for the study were South Branch Kishwaukee River upstream from De Kalb, Mackinaw River upstream from Congerville, Addison Creek upstream from Bellwood, Flag Creek upstream from Willow Springs, and Thorn Creek upstream from Glenwood (fig. 1). Water returns in this report consist of water contributed to streams by sewage-treatment plants and various water users that have an NPDES permit. The sources of water for return flows can be from ground water or surface water and can be within or outside the basin in which the water is returned.

Data Collection

Water-return data for commercial establishments, industries, powerplants, public-water suppliers, and sewage-treatment plants in Illinois that are NPDES-permitted facilities were obtained from IEPA computer files and DMR's. Data from IEPA computer files included NPDES permit number, name of permittee, standard-industrial-classification code (U.S. Office of Management and Budget, 1987), location of return sites (latitude, longitude, and legal description), name of the receiving waters, and monthly return-flow data for sewage-treatment and major industrial facilities. An industrial facility is identified as "major" not necessarily by the quantity of returns but according to its pollution potential (Tim Kluge, Illinois Environmental Protection Agency, oral commun., 1991). Monthly return-flow data not in the IEPA computer files were compiled by the U.S. Geological Survey (USGS) from DMR's and facility operators. All data are stored in the Site-Specified Water Use Data System, which is maintained by the USGS.



Base from U.S. Geological Survey
State base map, 1956

0 10 20 30 40 MILES
0 10 20 30 40 KILOMETERS

EXPLANATION

STUDY AREA

① South Branch Kishwaukee River upstream from De Kalb (shown in figure 2)
② Mackinaw River upstream from Congerville (shown in figure 3)
③ Addison Creek upstream from Bellwood (showh in figure 4)
④ Flag Creek upstream from Willow Springs (shown in figure 5)
⑤ Thorn Creek upstream from Glenwood (shown in figure 6)

Figure 1.--Location of the stream reaches studied in Illinois.

Additional descriptive data about return-flow sites were obtained from the Permit Compliance System data base (U.S. Environmental Protection Agency, 1987). The Permit Compliance System is updated by the IEPA and is maintained by the USEPA. The data used included the type of return flow, such as sewage-treatment outfall or noncontact cooling water.

Water-withdrawal data were obtained from the Illinois State Water Survey (ISWS) and one public-water-supply operator. The ISWS provided location and annual withdrawal data for surface-water-withdrawal sites in Illinois. One public-water-supply operator was contacted to obtain monthly withdrawal data.

Stream information was obtained from the USGS computer files (National Water Information System). The stream information included streamflow-gaging-station names and identifiers, location (latitude and longitude) of stations, drainage areas, flow durations, and annual and monthly average streamflows.

Pan-evaporation data were obtained from the National Oceanic and Atmospheric Administration Climatological Data reports (1988 and 1989). The class A pan-evaporation sites closest to the study reaches were used. Neither ground-water elevation nor seepage-run data were available for the reaches.

Stream-Reach Selection

Stream reaches were chosen for this study with regard to minimizing the effects of tributary inflows on streamflows. A stream reach qualified for this study if (1) the reach was upstream from a USGS continuous-record streamflow-gaging station, (2) the reach is the headwaters of a stream, and (3) the reach received return flows during 1988.

Stream reaches that met the qualifications were identified by use of a geographic information system. The location of streams, streamflow-gaging stations, and return-flow sites were merged into a digital file. Of the 84 headwater-stream reaches upstream from a USGS streamflow-gaging station in Illinois, 64 received return flows during 1988.

Five stream reaches were selected by taking a stratified (by annual return flow) random sample of the qualifying reaches. The 64 qualifying reaches were grouped according to their quantity of return flows during 1988. The groups chosen were 0.0 to less than 2.0, 2.0 to less than 4.0, 4.0 to less than 7.0, 7.0 to less than 13.0, and equal to or greater than 13 Mgal/d. There were 35 reaches with return flows in the 0.0 to less than 2.0 Mgal/d group; 12 reaches in the 2.0 to less than 4.0 Mgal/d group; 8 reaches in the 4.0 to less than 7.0 Mgal/d group; 5 reaches in the 7.0 to less than 13.0 Mgal/d group; and 4 reaches in the equal to or greater than 13 Mgal/d group. One reach was randomly selected from each group.

Data Verification

Location data for return-flow sites were verified for each study reach. Latitude-longitude, township-section-range, receiving-water name, city, and county data were checked as to whether the data agreed for each site.

Return-flow data that were questionable or were incomplete were verified by a comparison to the DMR's or by contact with the facility operator. A monthly return-flow value was considered questionable if it differed by more than 10 percent from its previous monthly value. For sites with incomplete records, monthly return flows were estimated to be the average of the reported monthly return flows, with the following exceptions. (1) Incomplete records were checked for over-estimates of return flow. For example, sites with overflows, excess overflows, and bypasses usually have intermittent flows that are often reported as total return flows per month instead of as average return flows per day. Facility operators were contacted to verify return flows for these sites. (2) If no flow data were reported during a year, the operators also were contacted to obtain return-flow data.

Acknowledgments

The cooperation and support provided by Michael Garretson and Kenneth Rogers of the IEPA are greatly appreciated. Detailed return-flow data and background information about the facilities that return water was provided by Tarea Lee of the IEPA. The water-withdrawal data provided by Kenneth Hlinka and Khris Klindworth of the ISWS was helpful.

DESCRIPTION OF STUDY REACHES

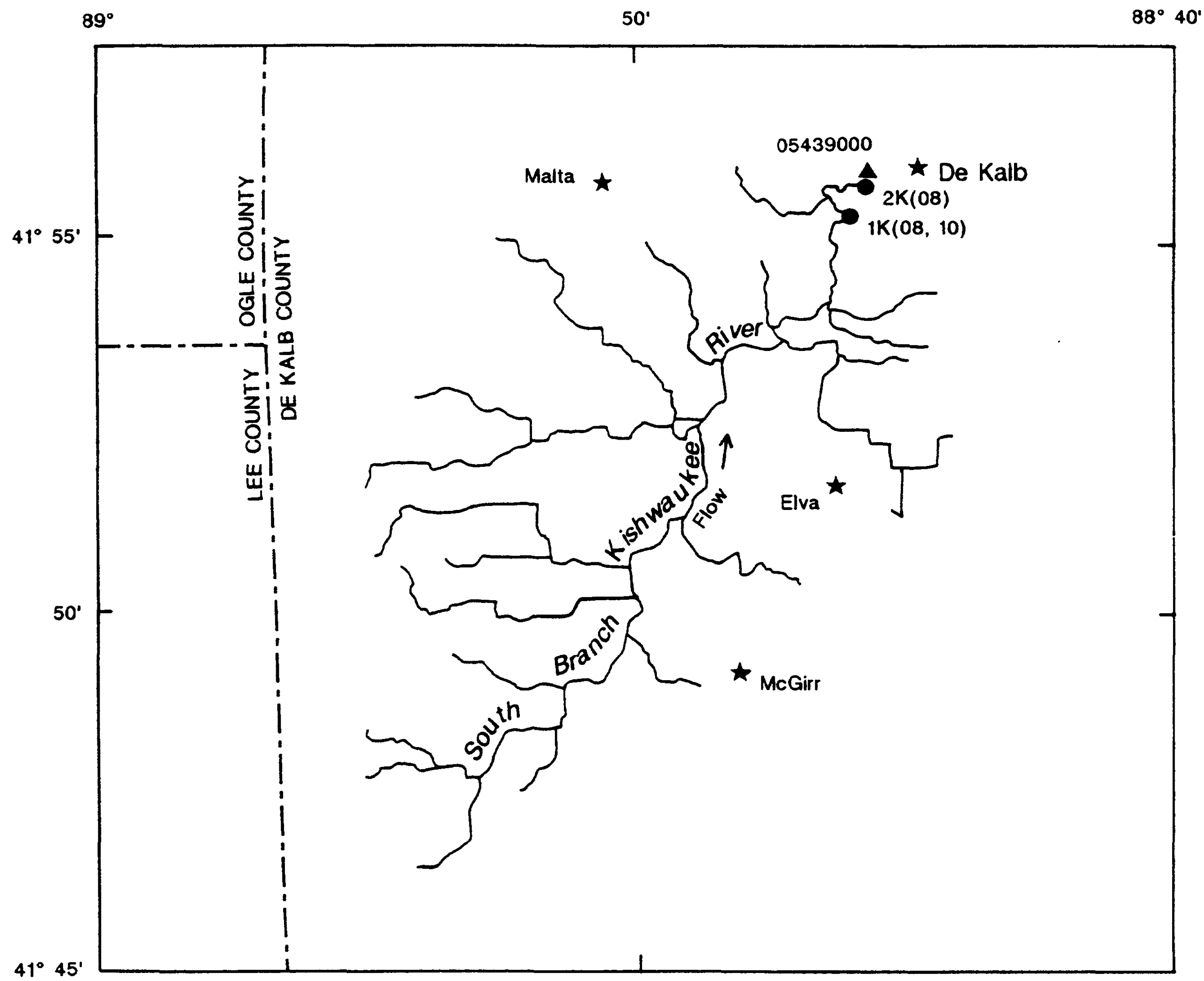
Detailed descriptions of the five study reaches are presented in ascending order by the magnitude of their return flows. Four of the reaches are in northern Illinois; one is in central Illinois.

South Branch Kishwaukee River Upstream From De Kalb

The study reach of the South Branch Kishwaukee River upstream from De Kalb (fig. 2) is in north-central Illinois and has a contributing drainage area of 77.7 mi^2. The river flows to the northeast over Wisconsinan unconsolidated glacial deposits, which overlie bedrock (Allen and Cowen, 1985, p. 3) to the main stem of the Kishwaukee River downstream from the study reach. Soils along the reach consist of thin to moderately thick (24-60 in.) loess or silt on Wisconsinan outwash (Fehrenbacher and others, 1984, map). The streambed at the streamflow-gaging station consists of sand, silt, and gravel.

The USGS streamflow-gaging station (05439000) is at a latitude of 41°55'53" and longitude of 88°45'35" in De Kalb. The average streamflow for the period of record (18 years) is 39.8 Mgal/d.

Land use in the area is mostly agricultural; corn and soybean are the predominant crops. Some of the tributaries in the study reach are drainage ditches, which are used to carry water off of agricultural lands. Communities (fig. 2) in the contributing drainage area of the reach had a combined population of about 32,830; the community of De Kalb accounts for most of this with a population of 31,830 (U.S. Bureau of the Census, 1990).



Base from U.S. Geological Survey
1:1,000,000 Digital Line Graphs
Albers Equal-Area Conic Projection
Standard parallels 33° and 44°, central meridian -89°

EXPLANATION

— - —	COUNTY BOUNDARY	▲ 05439000	STREAMFLOW-GAGING STATION AND NUMBER
★	CITY		POPULATION–Type size is related to population
● 2K(08)	FACILITY AND RETURN-FLOW SITE IDENTIFIER(S)	Malta	Less than 1,000
		De Kalb	31,830

Figure 2.--Return-flow sites discharging to South Branch Kishwaukee River upstream from De Kalb, Ill., 1988-89.

During 1988 and 1989, three industrial facilities along the South Branch Kishwaukee River upstream from De Kalb had a total of five return-flow sites. Of the five return-flow sites, return flows occurred at only three sites at two facilities (table 1 and fig. 2) that are near De Kalb and within 1.5 mi of the streamflow-gaging station, during 1988-89. The return flows originated from ground-water sources. No water was withdrawn from the study reach during 1988-89.

Table 1.--Sites that returned water to South Branch Kishwaukee River upstream from De Kalb, Ill., 1988-89

Facility identifier	Return-flow site identifier	Water-use category	Type of water return
1K	08	Industrial	Treated process water
1K	10	Industrial	Cooling water and condensate
2K	08	Industrial	Contact cooling water

Mackinaw River Upstream From Congerville

The study reach of the Mackinaw River upstream from Congerville (fig. 3) is in central Illinois and has a contributing drainage area of 767 mi^2. Flow is westward to the Illinois River. The Mackinaw River meanders mostly on unconsolidated glacial Wisconsinan drift of loess, 4-12 ft thick, overlying Pennsylvanian bedrock (Willman and others, 1975, p. 21-22); however, about the lower one-half of the main stem of the Mackinaw River is sandy to clayey alluvial sediments on bottomlands (Fehrenbacher and others, 1984, map). The streambed at the streamflow-gaging station is coarse gravel.

The USGS streamflow-gaging station near Congerville (05567500) is 2 mi northwest of Congerville at a latitude of 40°37'25" and longitude of 89°14'30". The average streamflow for the period of record (45 years) is 327 Mgal/d.

Land use in the study area is mostly rural. Land near the reach is forested, but the surrounding areas support grain crops. Communities (fig. 3) in the contributing drainage area of the reach had a total population of about 111,000; the communities of Bloomington and Normal are the largest, with populations of 48,860 and 39,590, respectively (U.S. Bureau of the Census, 1990).

In 1988, 23 facilities along the Mackinaw River upstream from Congerville had a total of 29 return-flow sites. In 1989, one facility became inactive. Of the 29 return-flow sites, return flows occurred at 10 sites at 10 facilities (table 2 and fig. 3) during 1988, but no return flow occurred at one of those sites (7M(08)) during 1989. The most upstream return-flow site (8M(08)) is about 45 mi from the streamflow-gaging station. Of the water returned, nearly 100 percent originated from ground water; less than 1 percent came from Six Mile Creek.

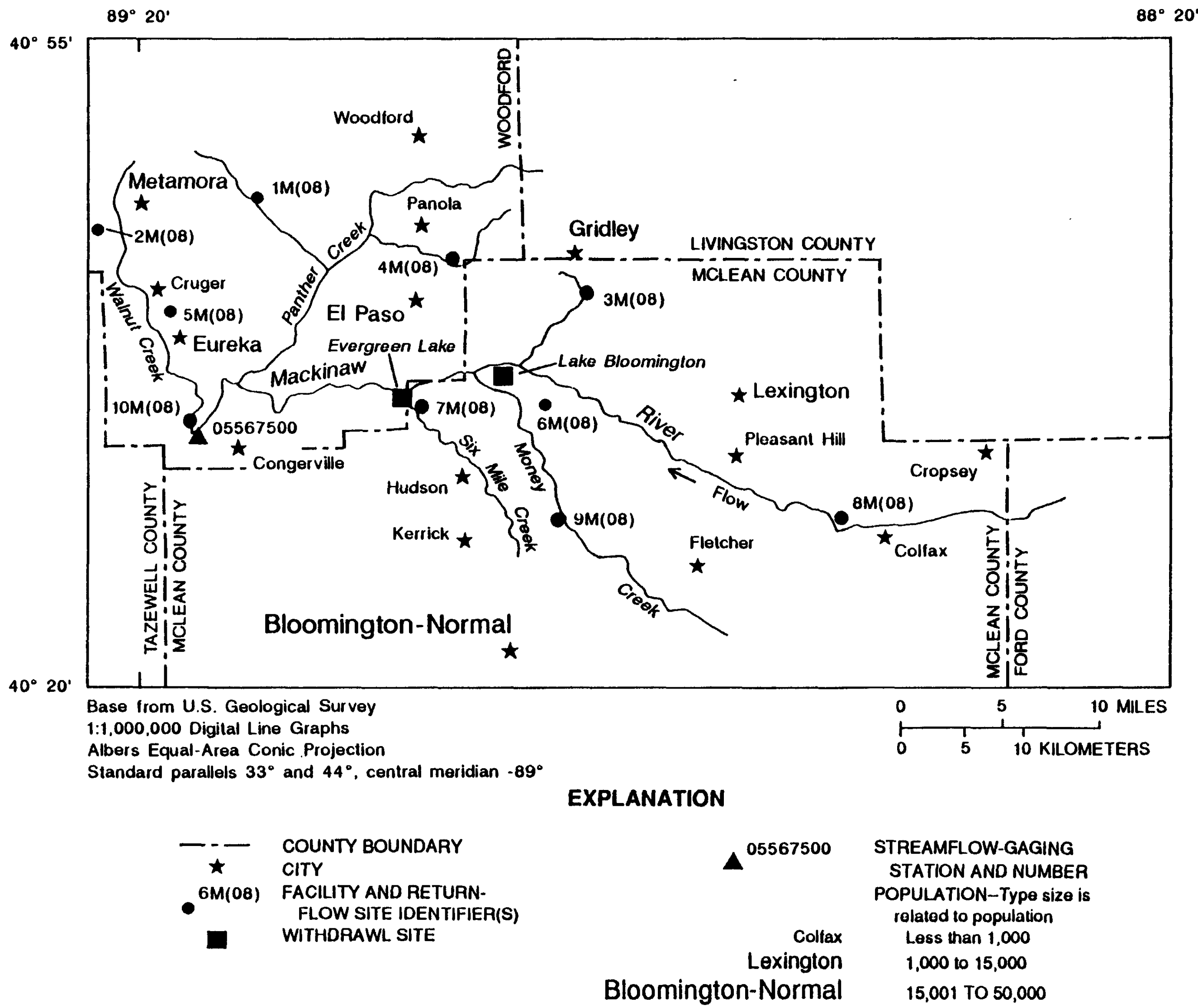


Figure 3.--Return-flow sites discharging to Mackinaw River upstream from Congerville, Ill., 1988-89.

Table 2.--Sites that returned water to Mackinaw River upstream from Congerville, Ill., 1988-89

Facility identifier	Return-flow site identifier	Water-use category	Type of water return
1M	08	Sewage treatment	Cooling water and condensate
2M	08	Sewage treatment	Sewage-treatment outfall
3M	08	Sewage treatment	Sewage-treatment outfall
4M	08	Sewage treatment	Sewage-treatment outfall
5M	08	Sewage treatment	Sewage-treatment outfall
6M	08	Commercial	Sewage-treatment outfall
7M	08	Sewage treatment	Sewage-treatment outfall
8M	08	Sewage treatment	Sewage-treatment outfall
9M	08	Commercial	Sewage-treatment outfall
10M	08	Sewage treatment	Sewage-treatment outfall

Water was withdrawn at several sites (fig. 3) in the study reach. Water was withdrawn for public supply from Lake Bloomington on Money Creek and from Evergreen Lake on Six Mile Creek. According to Ronald Schultz (City of Bloomington Water Department, oral commun., 1991), no streamflow occurred in Money and Six Mile Creeks below both lakes during 1988-89. Therefore, the quantities withdrawn from and returned to these creeks were excluded from the evaluation of the contribution of return flows to streamflow in the Mackinaw River.

Addison Creek Upstream From Bellwood

The study reach of Addison Creek upstream from Bellwood (fig. 4) is in northeastern Illinois and has a contributing drainage area of 17.9 mi^2. The creek flows southeastward over lake deposits, which overlie bedrock of Silurian age (Willman and others, 1975, p. 21). Fehrenbacher and others (1984, map) classified soils in the area as thin loesses (less than 20 in.) and organic materials of peats and mucks. At the streamflow-gaging station, the streambed consists of clay and silt.

The USGS streamflow-gaging station (05532000) is in Bellwood at a latitude of 41°52'48" and longitude of 87°52'07". The average streamflow for the period of record (38 years) is 10.0 Mgal/d.

Land use is urban and consists of residential, commercial, and industrial activities. Total population of the communities (fig. 4) in the contributing drainage area of the reach was about 176,000; the largest community, Elmhurst, had a population of 42,060 (U.S. Bureau of the Census, 1990).

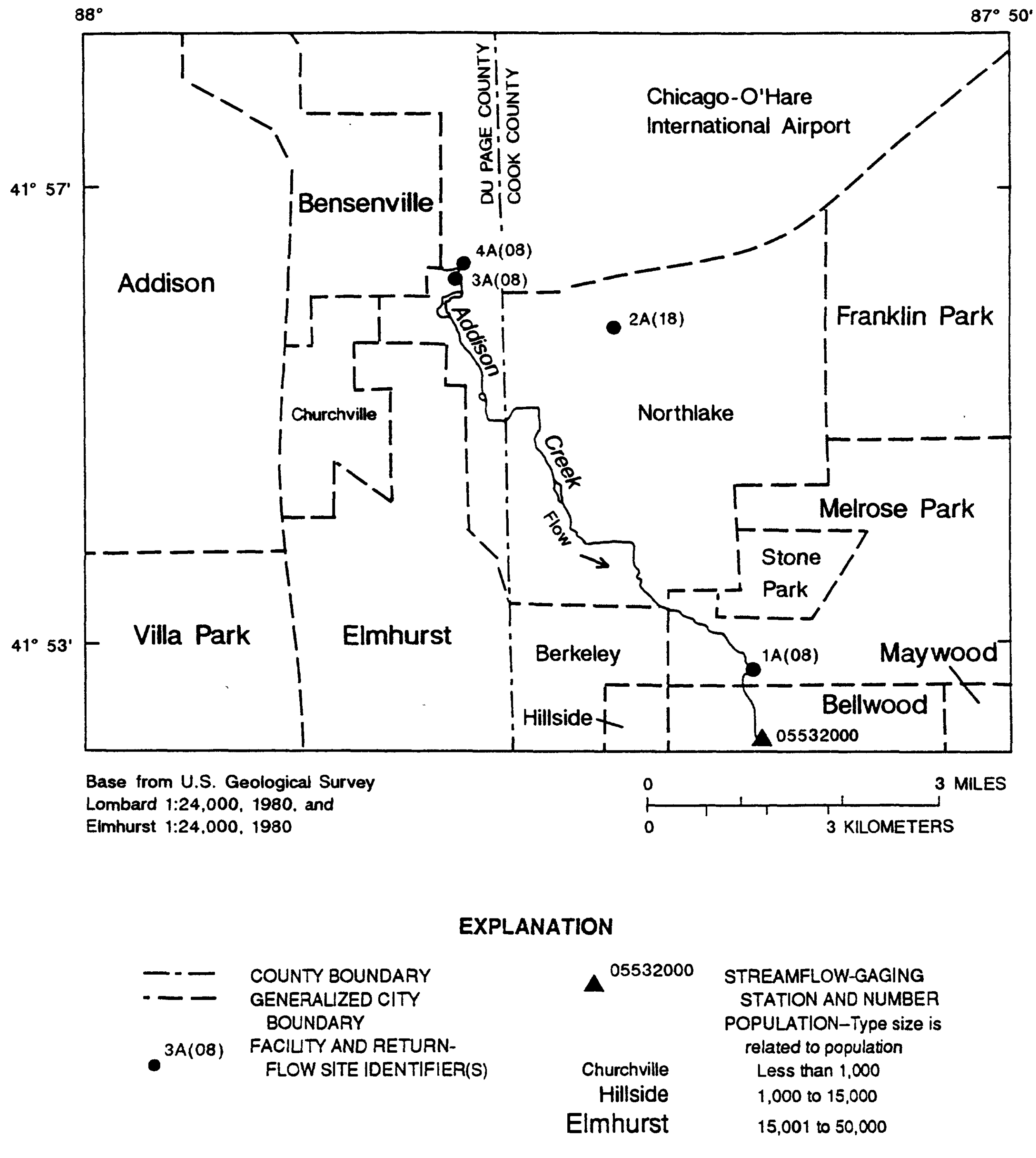


Figure 4.--Return-flow sites discharging in the vicinity of Addison Creek upstream from Bellwood, Ill., 1988-89.

In 1988, 7 facilities along Addison Creek upstream from Bellwood had a total of 10 return-flow sites. In 1989, one facility became inactive. Of the 10 return-flow sites, return flows occurred at 4 sites at 4 facilities (table 3 and fig. 4) that are within 6 mi of the streamflow-gaging station during 1988. Of the four sites, however, no return flows occurred at three of the sites (1A(08), 2A(18), and 4A(08)) during 1989. Of the water returned, about 80 percent originated from ground water and 20 percent from surface water (Lake Michigan). No water was withdrawn from the study reach during 1988-89.

Table 3.--Sites that returned water to Addison Creek upstream from Bellwood, Ill., 1988-89

Facility identifier	Return-flow site identifier	Water-use category	Type of water return
1A	08	Commercial	Stormwater runoff
2A	18	Commercial	Stormwater runoff
3A	08	Sewage treatment	Sewage-treatment outfall
4A	08	Sewage treatment	Sewage-treatment outfall

Flag Creek Upstream From Willow Springs

The study reach of Flag Creek upstream from Willow Springs (fig. 5) is in northeastern Illinois and has a contributing drainage area of 16.5 mi^2. The creek flows southward over glacial drift composed of loess (Wisconsinan age), which overlies bedrock of Silurian age (Willman and others, 1975, p. 22). The creek originates on thin loess (less than 20 in.) overlying silty clay loam and flows downstream over thin loamy or silty materials overlying gravelly Wisconsinan outwash (Fehrenbacher and others, 1984, map). At the streamflow-gaging station, the streambed consists of silt and gravel.

The USGS streamflow-gaging station (05533000) is 1.1 mi northwest of Willow Springs at a latitude of 41°44'20" and a longitude of 87°53'48". The average streamflow for the period of record (38 years) is 12.2 Mgal/d.

Land use throughout the reach is urban. Communities (fig. 5) in the contributing drainage area of the reach had a total population of 80,880; Westmont, the largest community, had a population of 20,710 (U.S. Bureau of the Census, 1990).

During 1988 and 1989, 5 facilities along Flag Creek upstream from Willow Springs had a total of 11 return-flow sites. Of the 11 return-flow sites, return flows occurred at 4 sites at 2 facilities (table 4 and fig. 5) that are within 2 mi of the streamflow-gaging station during 1989. In 1988, return flows occurred at only the three sites at facility 1F. All return flows originated from ground-water sources. No water was withdrawn from the study reach during 1988-89.

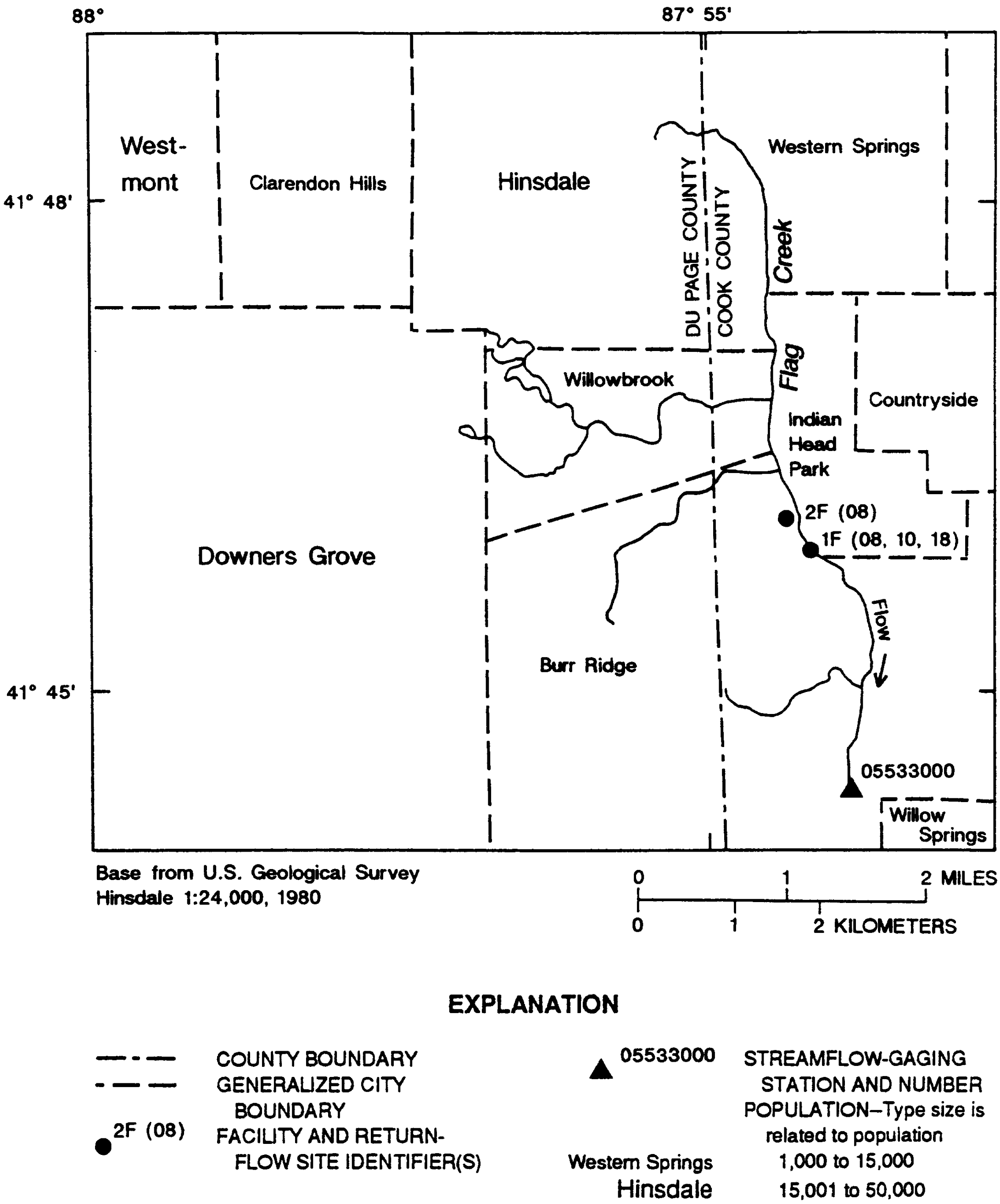


Figure 5.--Return-flow sites discharging to Flag Creek upstream from Willow Springs, Ill., 1988-89.

Table 4.--Sites that returned water to Flag Creek upstream from Willow Springs, Ill., 1988-89

Facility identifier	Return-flow site identifier	Water-use category	Type of water return
1F	08	Sewage treatment	Tertiary lagoon bypass
1F	10	Sewage treatment	Tertiary lagoon bypass
1F	18	Sewage treatment	Sewage-treatment outfall
2F	08	Water supply	Settling lagoon overflow

Thorn Creek Upstream From Glenwood

The study reach of Thorn Creek upstream from Glenwood (fig. 6) is in northeastern Illinois and has a contributing drainage area of 24.7 mi^2. The creek originates near Monee, Ill., and flows to the northeast over glacial drift composed of less than 4 ft of loess of Wisconsinan age overlying bedrock of Silurian age (Willman and others, 1975, p. 22). Fehrenbacher and others (1984, map) classified soils at the headwaters as sandy to clayey alluvial sediments. In the bottomlands, the soils are composed largely of organic materials. At the streamflow-gaging station, the streambed consists of clay, sand, and gravel.

The USGS streamflow-gaging station near Glenwood (05536215) is 0.8 mi southwest of Glenwood at a latitude of 41°31'50" and longitude of 87°36'20". The average streamflow for the period of record (40 years) is 24.2 Mgal/d.

The study reach consists of a wide range of land uses. About 10 percent of the basin in the upper 3 mi^2 of the reach is used for agriculture. Forested areas, which are mostly within 1 mi of Thorn Creek, cover about 30 percent of the basin. Urban areas constitute about 60 percent of the basin. Total population for the communities (fig. 6) in the contributing drainage area of the reach amounted to 82,092; Chicago Heights had the largest population, 35,540 (U.S. Bureau of the Census, 1990).

During 1988 and 1989, 8 facilities near Thorn Creek upstream from Glenwood had a total of 14 return-flow sites. Of the 14 return-flow sites, return flows occurred at 7 sites at 5 facilities (1T, 2T, 4T, 5T, and 6T) during 1988, and at 8 sites at 6 facilities (table 5 and fig. 6) during 1989. All facilities, except facility 1T, are within 2 mi of the streamflow-gaging station. Of the water returned, about 60 percent originated from surface water (Lake Michigan) and the remainder from ground water (James Dawgharty, Thorn Creek Basin Sanitary District, oral commun., 1992). No water was withdrawn from the study reach during 1988-89.

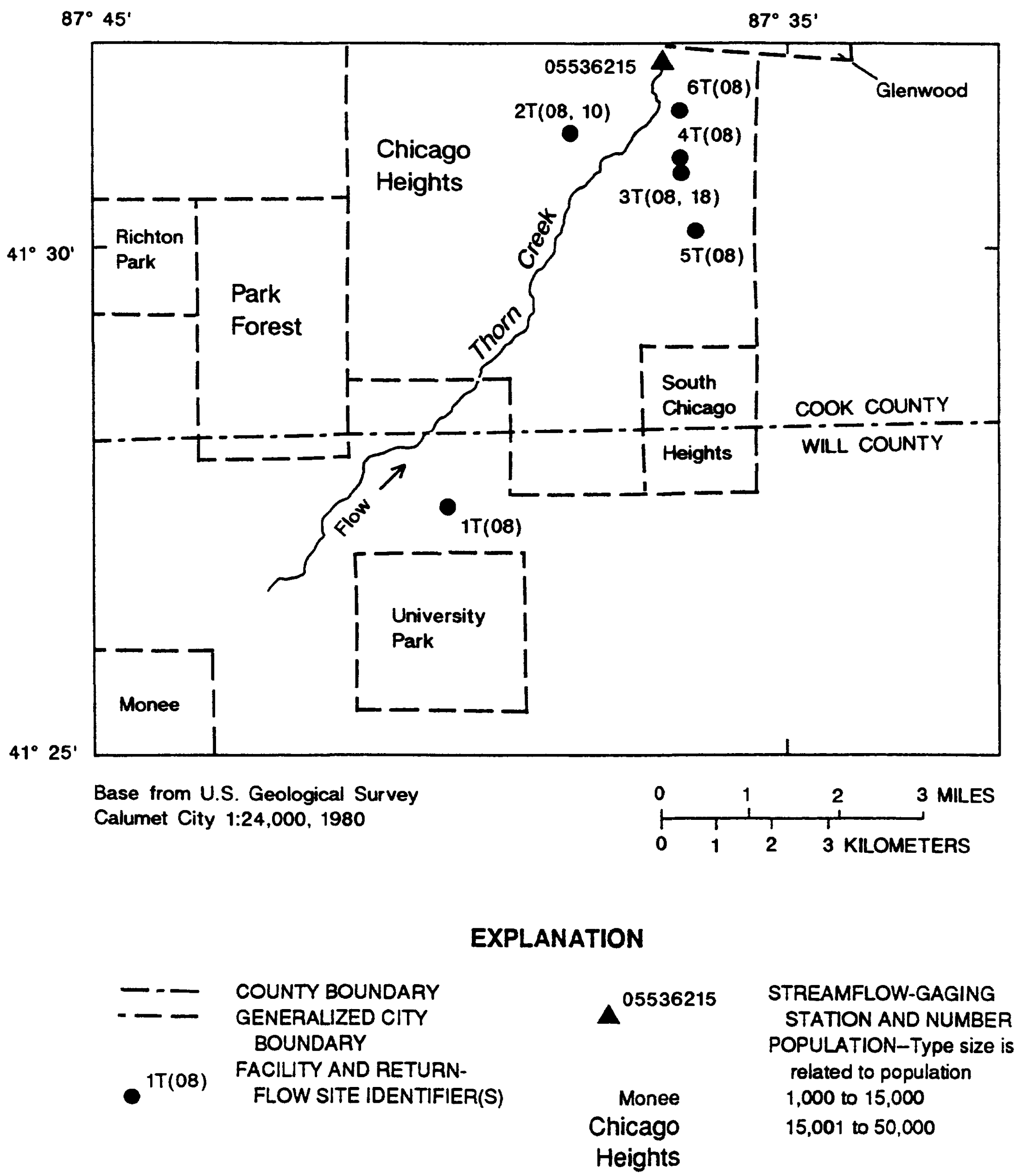


Figure 6.--Return-flow sites discharging in the vicinity of Thorn Creek upstream from Glenwood, Ill., 1988-89.

Table 5.--Sites that returned water to Thorn Creek upstream from Glenwood, Ill., 1988-89

Facility identifier	Return-flow site identifier	Water-use category	Type of water return
1T	08	Industrial	Noncontact cooling
2T	08	Sewage treatment	Sewage-treatment outfall
2T	10	Sewage treatment	Sewage-treatment overflow
3T	08	Industrial	Noncontact cooling and runoff
3T	18	Industrial	Stormwater runoff
4T	08	Industrial	Noncontact cooling and runoff
5T	08	Industrial	Surface and subsurface runoff
6T	08	Industrial	Noncontact cooling

HYDROLOGIC CONDITIONS

The drought of 1988 and 1989 had a significant effect on streamflows in Illinois. Precipitation during 1988 and 1989 was 25 and 14 percent, respectively, below the 112-year (1878-1989) mean (Wendland, 1990, p. 915). Higher-than-average temperatures during 1988 caused evaporation rates to be 50 percent higher than the long-term averages (Broeren and Singh, 1989, p. 18). The drought of 1988 was the third worst drought in Illinois since 1901; its recurrence interval was about 38 years (Wendland, 1990, p. 915). A precipitation drought that exceeds the 20-year recurrence interval is classified as a "severe drought" (Changnon, 1987, p. 11). Record-low streamflows were measured in Illinois at many gaging stations during 1988, and no flow occurred in several streams (G.W. Curtis, U.S. Geological Survey, written commun., 1988). Because of the drought, the proportion of return flows in streamflow may have been greater than normal.

Because of the drought, ground-water discharge to Illinois streams was below normal. Unconsolidated sand and gravel aquifers are present throughout much of Illinois (Bowman and Collins, 1987, p. 5) and, during normal conditions, they provide part of the streamflow for many streams. Water levels in these aquifers can respond rapidly to variations in precipitation and evapotranspiration (Bowman and Collins, 1987, p. 6). A study of the Des Plaines River during 1988 showed that the lack of rainfall during the summer caused dry conditions along parts of the river where ground-water levels fell below the riverbed (Miller and others, 1989, p. 24). Streamflow measurements by Rodger Adams and Edward Delisio (Illinois State Water Survey, written commun., 1988) during the summer (July-September 1988) indicated a water loss of as much as 1.30 Mgal/d from the Des Plaines River.

CONTRIBUTION OF RETURN FLOWS

Annual average return flows from 26 facilities to the 5 study reaches totaled 33.8 Mgal/d in 1988 and 36.7 Mgal/d in 1989. Annual average return flows to each reach ranged from 0.32 to 16.4 Mgal/d (table 6) during 1988 and 1989. All return flows originated from water sources other than the receiving stream reaches. The annual average contributions of return flows to streamflow in each reach ranged from 1 to 99 percent of the annual average streamflow, with the assumption that no water was gained or lost between the return-flow sites and the streamflow-gaging station.

Table 6.--Streamflow-gaging stations, annual average streamflow, and annual average return flow for the studied stream reaches in Illinois, 1988-89

[Mgal/d, million gallons per day]

Streamflow-gaging station		Annual average streamflow (Mgal/d)		Annual average return flow (Mgal/d)	
Number	Name	1988	1989	1988	1989
05439000	South Branch Kishwaukee River at De Kalb	28.7	26.8	0.37	0.32
05567500	Mackinaw River near Congerville	97.7	51.4	[1]2.57	[1]3.10
05532000	Addison Creek at Bellwood	11.2	11.8	4.51	4.00
05533000	Flag Creek near Willow Springs	15.2	13.0	12.3	12.9
05536215	Thorn Creek at Glenwood	22.4	25.2	14.0	16.4

[1]Excluding return flows to Money and Six Mile Creeks.

Of the 46 water-return facilities in 1988, return-flow data were not available from IEPA for 20 of the facilities. Of the 44 facilities in 1989, return-flow data were not available for 18 of the facilities. Facility operators were contacted to obtain the return-flow data. All but one of the operators contacted indicated that no return flows occurred during 1988 and 1989; one provided an estimated return flow of 0.072 Mgal/d for 1989.

Return flows to the South Branch Kishwaukee River upstream from De Kalb were the smallest of the return flows to the five reaches studied. During 1988-89, return flows (table 7) averaged 0.34 Mgal/d, or about 1 percent of the average streamflow (27.8 Mgal/d). Return flows consisted of cooling water (88 percent) and treated process water (12 percent).

Return flows to the Mackinaw River upstream from Congerville (table 8) averaged 2.84 Mgal/d or about 4 percent of the average streamflow (74.6 Mgal/d) in 1988-89. About one-half of the return flows consisted of sewage-treatment discharge, and the other one-half consisted of cooling-water discharge.

Table 7.--Monthly average streamflow and return flow in South Branch Kishwaukee River upstream from De Kalb, Ill., 1988-89

[in million gallons per day]

Month	1988 Streamflow	1988 Return flow	1989 Streamflow	1989 Return flow
January	93.1	0.37	14.3	0.14
February	62.7	.37	7.69	.03
March	40.2	.37	31.9	.10
April	98.3	.37	12.5	1.02
May	22.2	.37	16.0	.23
June	6.46	.37	49.0	.42
July	.98	.28	44.0	.23
August	2.91	.55	63.0	.44
September	.21	.58	61.3	.86
October	1.06	.28	10.7	.19
November	11.1	.37	7.11	.09
December	4.74	.12	3.52	.03
Average	28.7	0.37	26.8	0.32

Table 8.--Monthly average streamflow and return flow[1] in Mackinaw River upstream from Congerville, Ill., 1988-89

[in million gallons per day]

Month	1988 Streamflow	1988 Return flow	1989 Streamflow	1989 Return flow
January	231	2.68	48.3	3.07
February	154	3.74	17.4	3.38
March	189	3.22	79.5	2.61
April	432	3.71	123	3.33
May	93.1	2.08	127	3.35
June	32.1	1.99	71.7	3.13
July	3.94	2.01	16.2	2.90
August	.79	2.28	2.75	3.60
September	1.19	2.19	85.3	3.67
October	1.66	2.03	12.3	3.42
November	11.8	2.50	21.3	2.41
December	21.5	2.36	12.4	2.36
Average	97.7	2.57	51.4	3.10

[1]Excluding return flows to Money and Six Mile Creeks.

Return flows to Addison Creek upstream from Bellwood (table 9) averaged 4.26 Mgal/d or about 37 percent of the average streamflow (11.5 Mgal/d) in 1988-89. Sewage-treatment-plant discharge accounted for 85 percent of the return flows; the remaining 15 percent was stormwater runoff.

Table 9.--Monthly average streamflow and return flow in Addison Creek upstream from Bellwood, Ill., 1988-89

[in million gallons per day]

	1988		1989	
Month	Streamflow	Return flow	Streamflow	Return flow
January	14.5	4.56	8.66	4.12
February	9.95	4.43	4.99	3.39
March	12.6	4.47	12.5	4.13
April	20.1	4.74	7.89	3.53
May	10.0	4.17	7.24	3.56
June	3.32	4.24	10.8	3.80
July	7.50	4.44	16.0	4.45
August	7.63	5.80	14.9	4.75
September	7.76	4.06	19.7	5.73
October	10.3	3.98	20.0	3.80
November	21.6	4.83	13.4	3.74
December	9.57	4.37	5.55	2.94
Average	11.2	4.51	11.8	4.00

Return flows to Flag Creek upstream from Willow Springs (table 10) averaged 12.6 Mgal/d or about 89 percent of the average streamflow (14.1 Mgal/d) in 1988-89. The annual average return flow (12.9 Mgal/d) during 1989 was 99 percent of the annual average streamflow (13.0 Mgal/d). Nearly 100 percent of the return flows were from sewage-treatment-plant discharge.

Return flows to Thorn Creek upstream from Glenwood (table 11) averaged 15.2 Mgal/d or about 64 percent of the average streamflow (23.8 Mgal/d) in 1988-89. More than 95 percent of the return flows were discharges from sewage-treatment plants.

Quantity

The median return flows to the study reaches were 0.06 and 0.02 Mgal/d in 1988 and 1989, respectively. In 1988, return flows at 2,105 return-flow sites in Illinois totaled 15,697 Mgal/d. In 1989, return flows for 2,138 sites in Illinois totaled 15,558 Mgal/d. The median return flows in the entire State of Illinois were 0.08 and 0.07 Mgal/d in 1988 and 1989, respectively. The median return flow for the study reaches in 1988 (0.06 Mgal/d) is similar to the median return flow for Illinois (0.08 Mgal/d).

Table 10.--Monthly average streamflow and return flow in Flag Creek upstream from Willow Springs, Ill., 1988-89

[in million gallons per day]

Month	1988 Streamflow	1988 Return flow	1989 Streamflow	1989 Return flow
January	21.0	13.7	14.8	11.9
February	17.3	13.6	10.1	9.99
March	18.4	17.2	19.1	15.8
April	27.2	15.2	11.8	15.3
May	12.3	9.94	10.3	12.4
June	10.6	9.37	16.7	14.3
July	7.63	9.58	17.6	14.3
August	8.73	10.1	11.9	13.5
September	7.43	9.36	16.7	18.7
October	11.4	11.6	7.82	9.40
November	26.7	16.0	11.8	10.0
December	14.1	12.0	7.89	8.65
Average	15.2	12.3	13.0	12.9

Table 11.--Monthly average streamflow and return flow in Thorn Creek upstream from Glenwood, Ill., 1988-89

[in million gallons per day]

Month	1988 Streamflow	1988 Return flow	1989 Streamflow	1989 Return flow
January	25.9	13.8	30.6	18.7
February	19.5	12.9	16.5	14.1
March	22.8	14.1	30.2	19.9
April	30.0	14.9	23.1	17.4
May	16.2	10.6	22.6	15.6
June	13.0	9.74	58.0	24.1
July	13.2	11.3	24.0	16.3
August	18.0	11.9	13.6	13.3
September	16.2	11.4	27.4	16.5
October	22.9	14.0	16.8	13.0
November	45.0	27.1	22.4	14.8
December	25.9	16.7	17.0	12.8
Average	22.4	14.0	25.2	16.4

Even though there are similarities between median return flows, wide data variability exists within and between the data sets for both the study reaches and the State of Illinois. For example, the standard deviation for the study-reach data is about 3 Mgal/d, whereas that for Illinois is about 60 Mgal/d. Furthermore, the standard error of the mean for the study-reach data is about 0.6 Mgal/d, whereas the standard error for Illinois is about 1.3 Mgal/d. The standard-deviation and standard-error-of-the-mean values for Illinois were greater than those for the study reaches probably because the return-flow data for Illinois include the overestimates for intermittent-flow sites, as described in the "Data Verification" section. Because overestimates were corrected for in the study-reach data, the study-reach statistics probably are more accurate than the Illinois statistics but are not necessarily representative of the return flows for Illinois.

A comparison of return flows and streamflows (figs. 7-11) shows that return flows had a consistently significant effect on streamflows in at least two of the study reaches. Return flows at the Flag Creek and Thorn Creek reaches appear to have greatly affected streamflows, as shown in figures 10 and 11 by the response of streamflows to changes in return flows.

Return flows exceeded streamflow during at least 1 month during the 1988 drought at all of the study reaches, except the Thorn Creek reach (figs. 7-11). One explanation could be the accuracy of return-flow and streamflow data. LaTour (1991, p. 41) measured sewage-treatment-plant return flows at several communities in Illinois and determined that data accuracy ranged from 6 to 9 percent. The accuracy of other return-flow data generally is unknown. Streamflow data generally are considered to be accurate to within ± 5 percent (Rantz and others, 1982, v. 1, p. 181-183; v. 2, p. 547). The accuracy of return-flow and streamflow data, however, does not completely explain why return flows exceeded streamflows; because, if a worst-case adjustment of -20 percent is applied to the return-flow data and +5 percent is applied to the streamflow data, the adjusted data indicate that return flows still exceeded streamflows during some months.

Another explanation could be the drought, as described in the "Hydrologic Conditions" section. Because of the drought, streamflow could have been lost between the return-flow sites and the streamflow-gaging station (figs. 2-6) by evaporation and (or) infiltration into the ground. Class A pan-evaporation data (National Oceanic and Atmospheric Administration, 1988, 1989) were used to estimate the streamflow losses caused by evaporation from surface water. By using the pan-evaporation sites closest to each study reach, evaporation from a reach was estimated by multiplying the pan-evaporation value by the surface-water area of the reach between the return-flow sites and the streamflow-gaging station and then multiplying by a pan-evaporation coefficient of 0.7. Streamflow losses (up to the amount that return flows exceeded streamflow) caused by infiltration was estimated as the remaining amount of losses not evaporated from surface water. Transpiration by plants and trees along the reaches was considered a part of streamflow lost by infiltration to the ground or stream bank.

Table 12 lists (1) stream reaches and months when return flows exceeded streamflow, (2) drainage areas of the reaches, (3) excess return flows (amount of return flows that exceeded streamflow (tables 7-10)), (4) estimated streamflow losses caused by evaporation from surface water, and (5) estimated

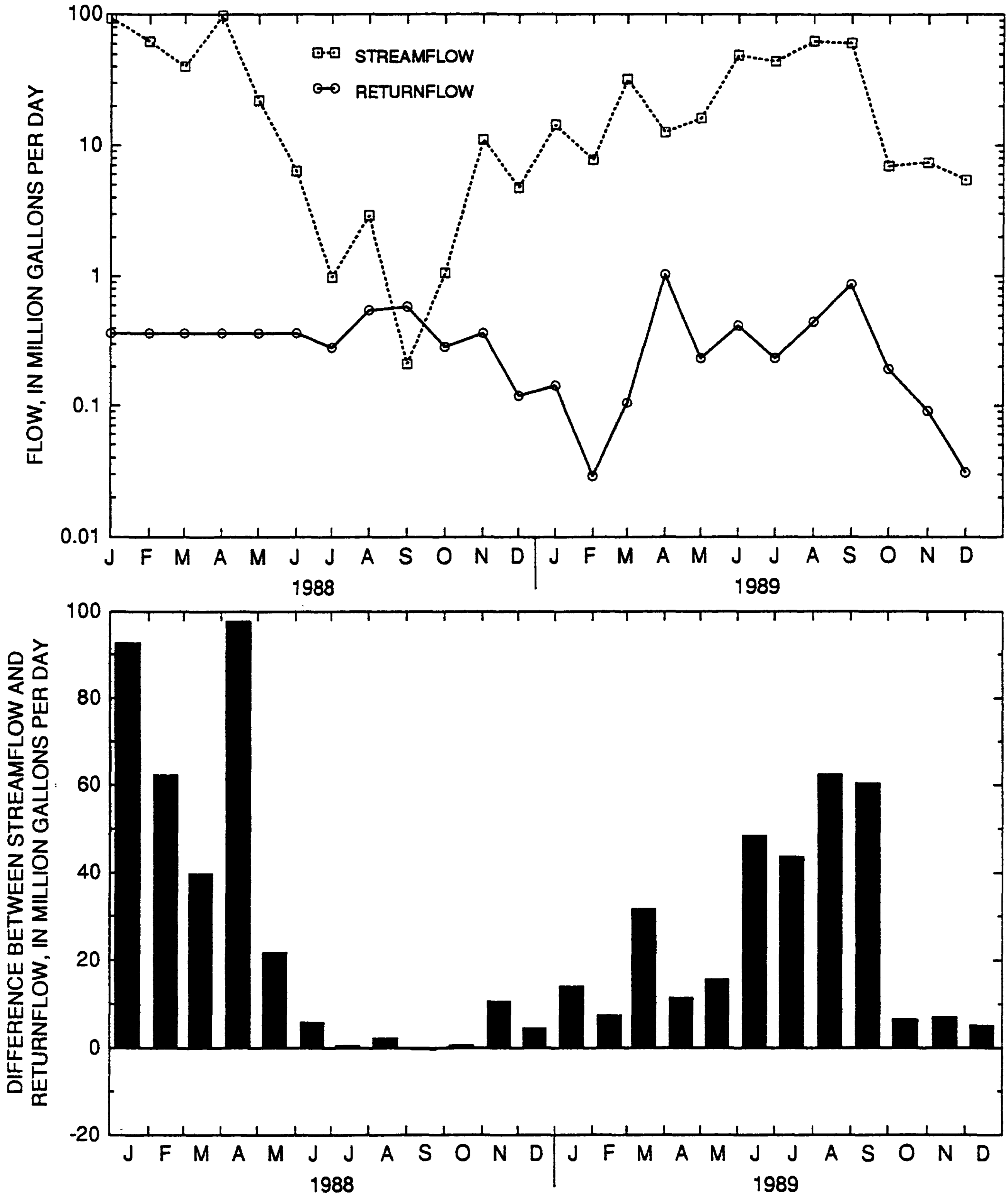


Figure 7.--Streamflow, return flow, and their differences in South Branch Kishwaukee River upstream from De Kalb, Ill., 1988-89.

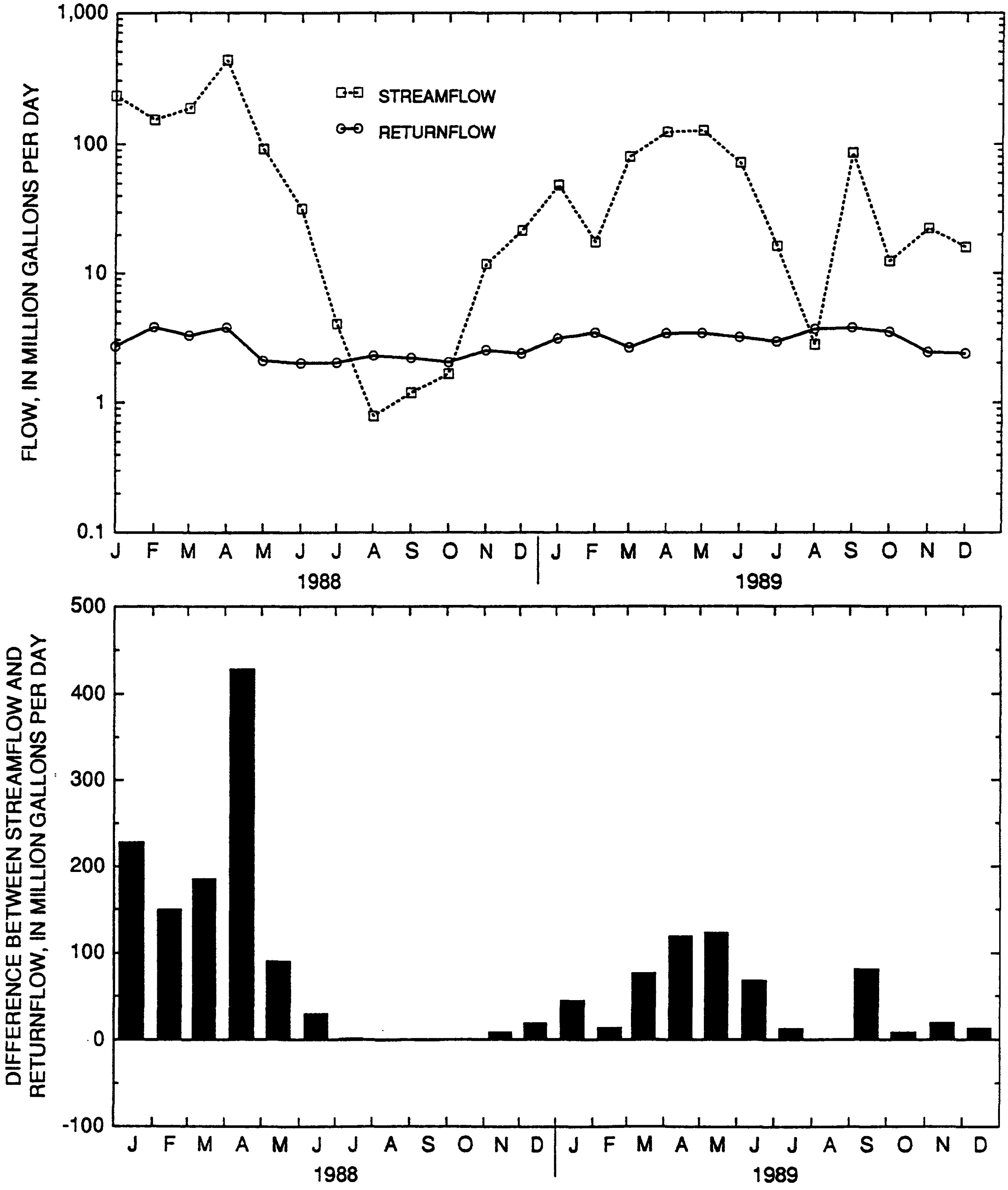


Figure 8.--Streamflow, return flow, and their differences in Mackinaw River upstream from Congerville, Ill., 1988-89.

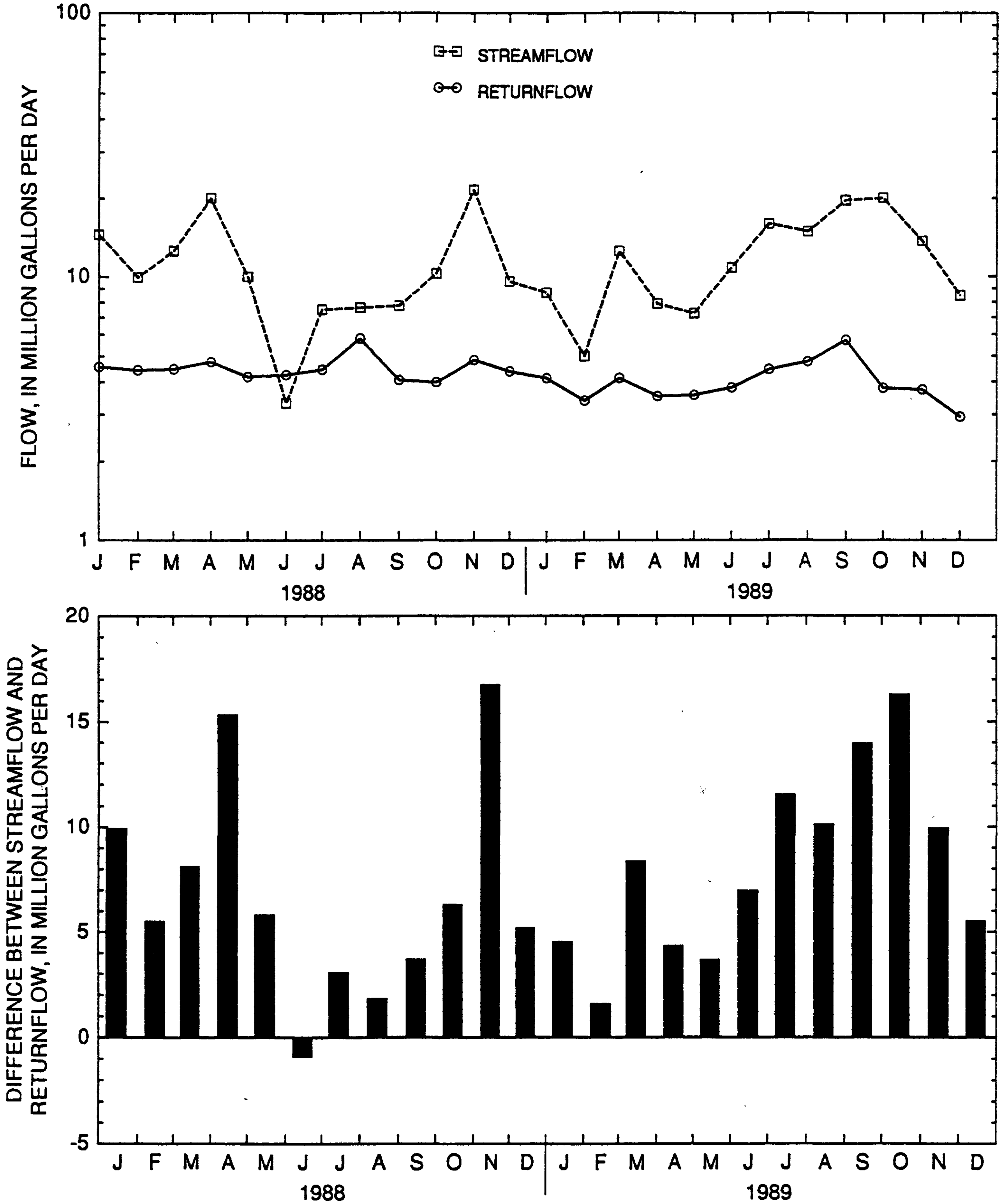


Figure 9.--Streamflow, return flow, and their differences in Addison Creek upstream from Bellwood, Ill., 1988-89.

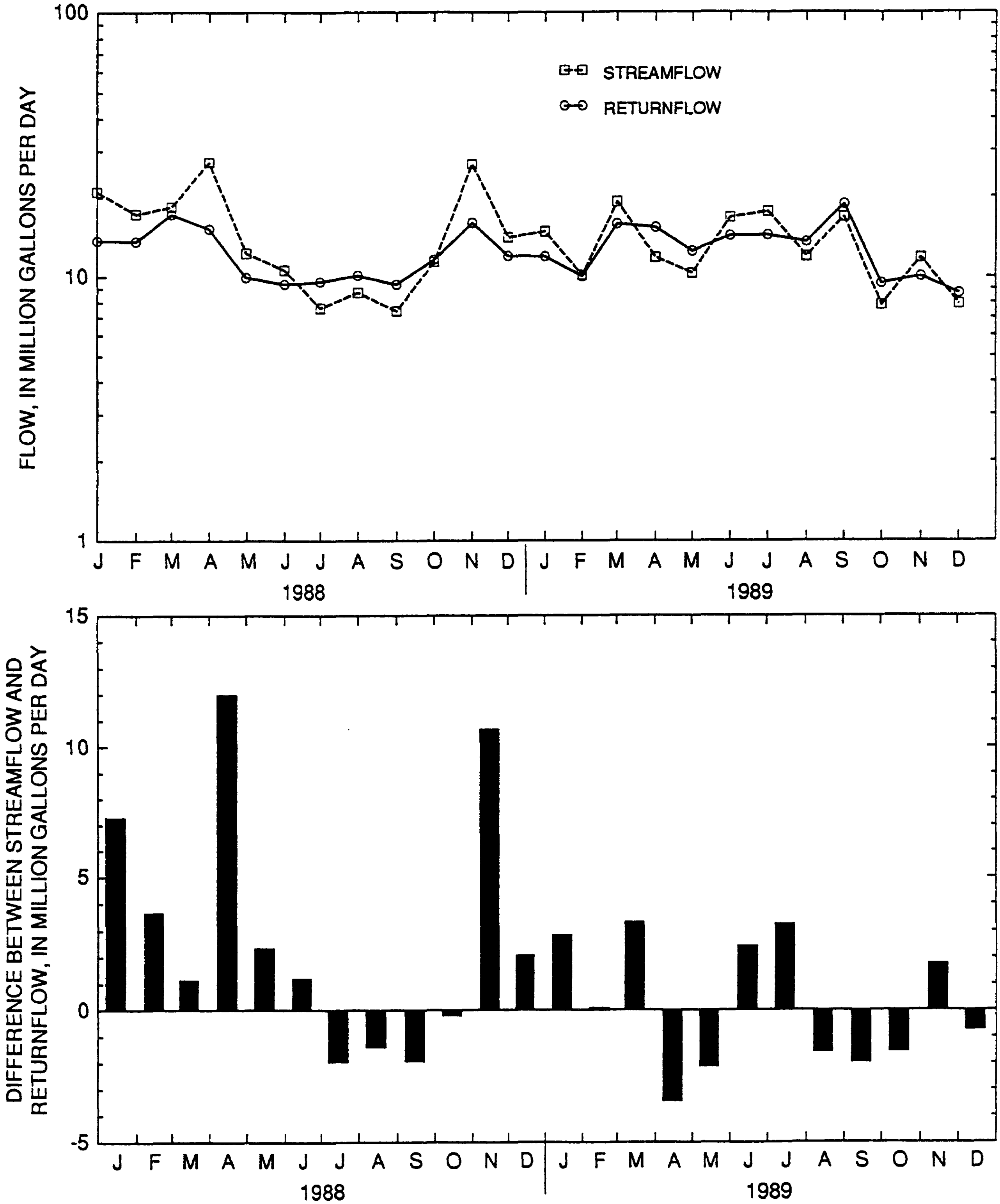


Figure 10.--Streamflow, return flow, and their differences in Flag Creek upstream from Willow Springs, Ill., 1988-89.

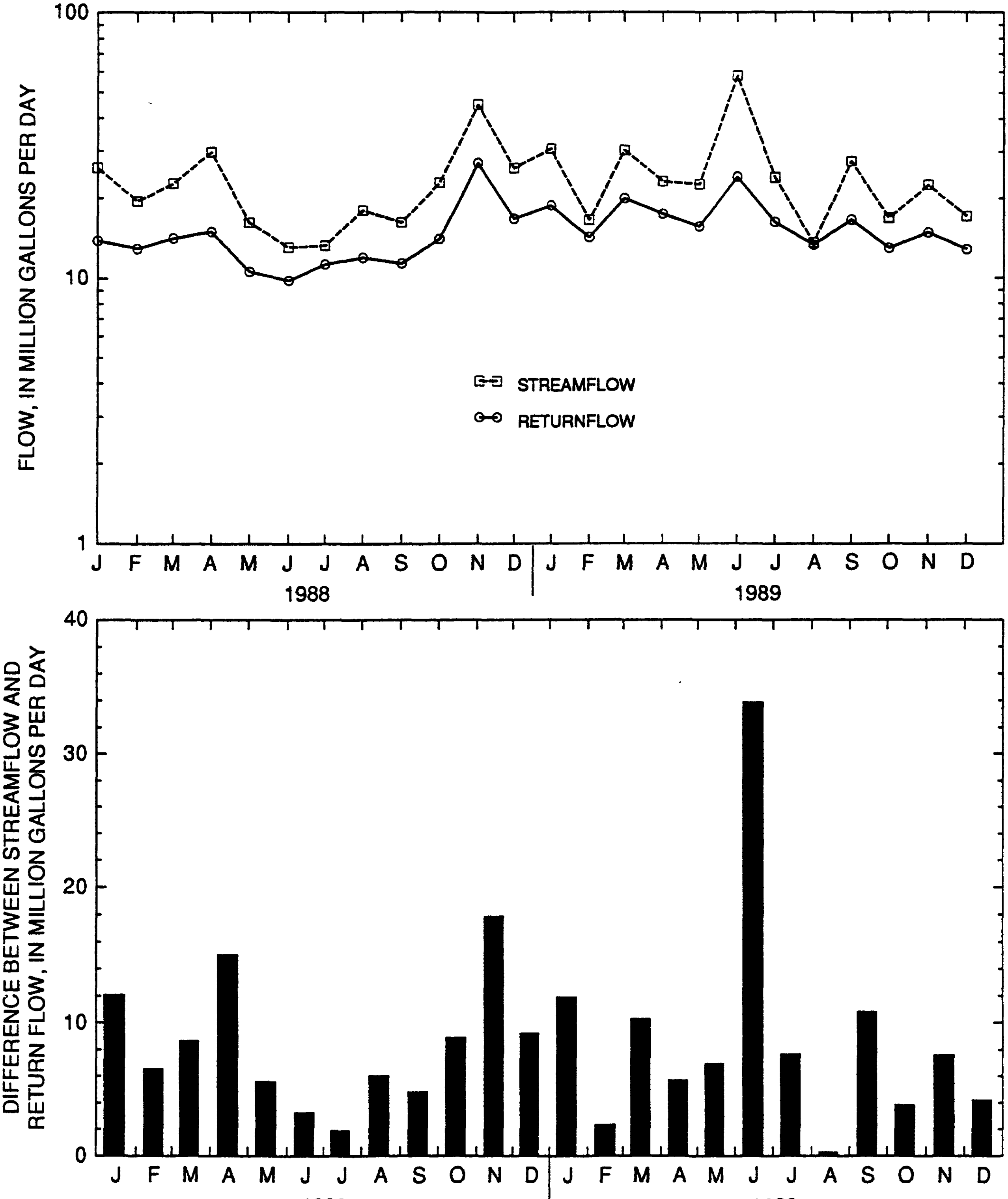


Figure 11.--Streamflow, return flow, and their differences in Thorn Creek upstream from Glenwood, Ill., 1988-89.

streamflow losses caused by infiltration (difference between excess return flows and evaporation). Of the amount of return flows that exceeded streamflow, all reaches lost an estimated 0.01 to 0.34 Mgal/d to evaporation and 0.36 to 1.33 Mgal/d to infiltration. In comparison, streamflow data obtained during the same period by Rodger Adams and Edward Delisio (Illinois State Water Survey, written commun., 1988) indicated that a reach of the Des Plaines River in northeastern Illinois lost as much as 1.30 Mgal/d of streamflow.

Table 12.--Estimates of streamflow losses when return flows exceeded streamflows in the study reaches, 1988

[mi^2, square miles; Mgal/d, million gallons per day]

Stream reach	Months	Drainage area (mi^2)	Excess return flows[1] (Mgal/d)	Estimated streamflow losses caused by: Evaporation from surface water (Mgal/d)	Estimated streamflow losses caused by: Infiltration[2] (Mgal/d)
South Branch Kishwaukee River upstream from De Kalb	September	77.7	0.37	0.01	0.36
Mackinaw River upstream from Congerville	August to October	767	.95	.34	.61
Addison Creek upstream from Bellwood	June	17.9	.92	.13	.79
Flag Creek upstream from Willow Springs	July to October	16.5	1.36	.03	1.33

[1]Amount of return flows that exceeded streamflow. Excess return flows for the several month period for the Mackinaw and Flag Creek reaches were averaged.

[2]Difference between excess return flows and evaporation from surface water.

The slope of flow-duration curves can be used to indicate whether flows in streams were sustained by consistent contributions from some water source. According to Walton (1965, p. 49-53), a flow-duration curve with a small slope indicates that the streamflow is being sustained by contributions from ground water. A small slope, however, also could indicate contributions by return flows. Walton (1965, p. 49-53) determined the slope of flow-duration curves by use of Q_{25}/Q_{75}, where Q_{25} is the streamflow equaled or exceeded 25 percent of the time and Q_{75} is the flow exceeded 75 percent of the time. The slope of the flow-duration curve and the contribution of return flows to streamflows were used to indicate whether return flows sustained streamflows.

The flow-duration curves for the study reaches during water years[1] 1980-89 are shown in figure 12. The curves for Thorn Creek at Glenwood, Addison Creek at Bellwood, and Flag Creek near Willow Springs show that streamflows were being sustained by some water source because the curves are much flatter (smaller slope values) than the other curves. Because the annual contributions of return flows to streamflows were more significant (33-99 percent of streamflows in 1988-89) for these reaches than for the other reaches, return flows probably sustained streamflows.

Seasonal Variation

Seasonal variation of return flows in streamflow was evaluated by the use of two analyses-of-variance (ANOVA) tests. The first analysis was used to determine whether return flows differed seasonally (alternative hypothesis) or whether they did not differ seasonally (null hypothesis). The second analysis was used to determine whether the proportion of return flows to streamflow differed seasonally. A 2-year period (1988 and 1989) of monthly return-flow data for the five study reaches was analyzed.

The variation of return flows by season may be a function of three factors--season, stream reach, and year. The objective was to determine whether returns vary by season; therefore, season would be a factor. The months that were grouped for each season were January-March (winter), April-June (spring), July-September (summer), and October-December (fall). Stream reach was used as a factor so that the differences in return flows among stream reaches did not obscure any seasonal variation of return flows. Year also was used as a factor so that any variations of return flows from year to year did not obscure any seasonal variation of return flows.

All ANOVA tests were done on ranked return-flow data. The assumptions of an ANOVA test are that the data be normally distributed and have equal variance. Seasonally grouped return-flow data are nonnormal and negatively skewed (fig. 13); therefore, ranked return-data were used for the analyses.

The summary of the ANOVA test for whether return flows differed seasonally follows:

[DF, degrees of freedom; SS, sum of squares; MS, median squares; F, F-ratio (ratio of two sample variances); P, P-value; FT, F-distribution test]

Source	DF	SS	MS	F	P	FT
Season	3	179	60	0.61	0.612	2.69
Stream	4	131,539	32,885	333.55	.000	2.46
Year	1	128	128	1.30	.257	2.75
Stream*year	4	1,566	391	3.97	.005	2.46
Error	107	10,549	99			
Total	119	143,962				

[1] Water year is from October 1 to September 30.

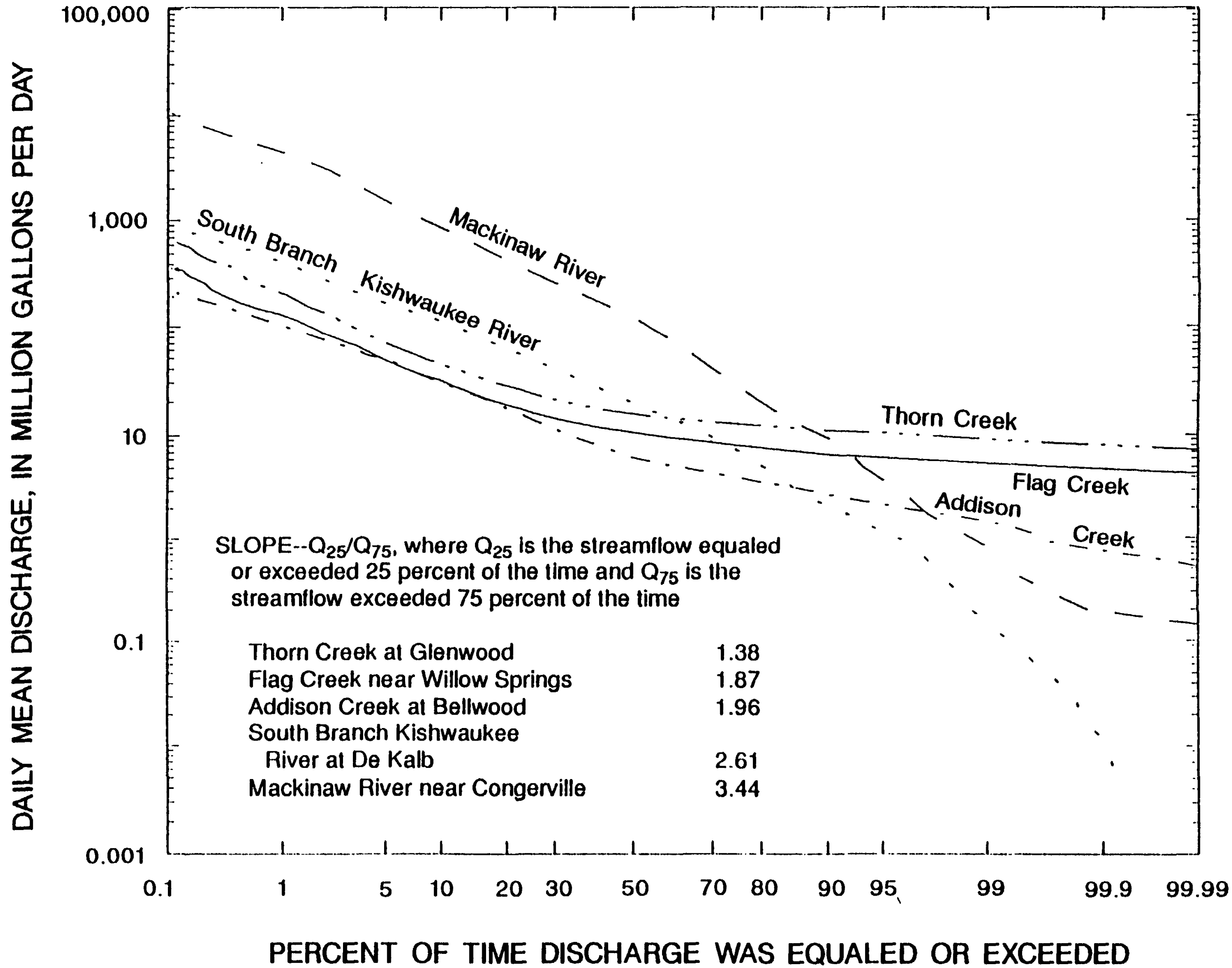


Figure 12.--Flow-duration curves for the five study reaches in Illinois, 1980-89.

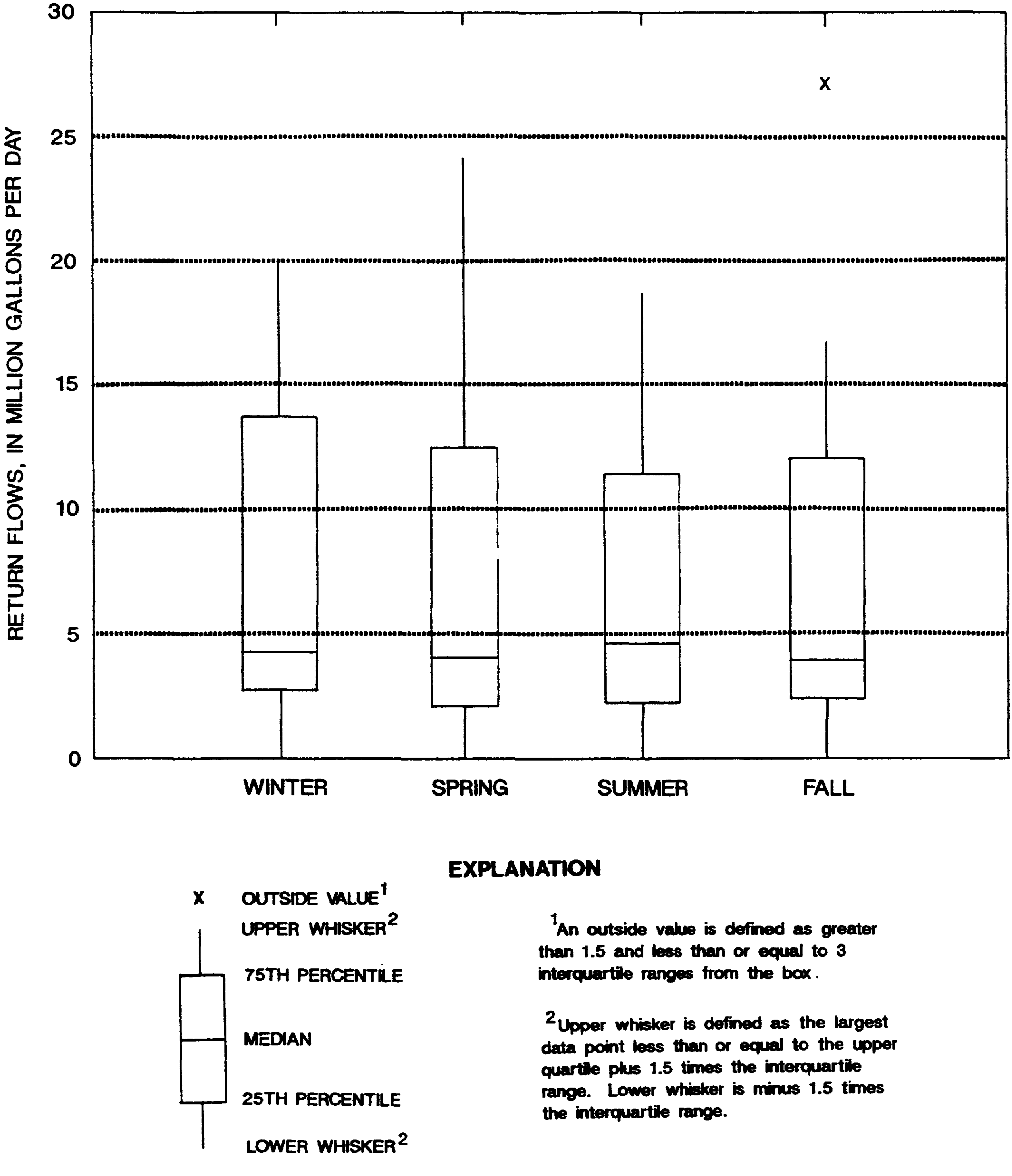


Figure 13.--Distribution of return flows grouped by season for the five study reaches in Illinois, 1988-89.

The analysis indicates that median return flows did not differ among seasons at a significance level of 0.05, because the F-ratio (F) for season was significantly less than the F-distribution test (FT). Furthermore, the P-value (P)--the probability of incorrectly determining that return flows differed seasonally--was much greater than the established significance level of 0.05. The boxplots in figure 13 also show little difference between median return flows each season.

There was strong evidence (low P-value) that return flows differed among streams, which was expected in as much as the study reaches were selected by a stratified sample based on the volumes of return flows. Return flows did not differ significantly among years. The interaction of the stream and year factors (stream*year), however, indicated that return flows differed, probably because of the strong effect of the stream factor.

Another ANOVA test was done to determine whether the proportion of return flows in streamflow varied seasonally. Because it was previously determined that return flows did not vary seasonally, it was expected that the proportion of return flows in streamflow varies seasonally because of typical seasonal variations in streamflow. The results of the ANOVA test on ranked ratios of return flows to streamflow are--

[DF, degrees of freedom; SS, sum of squares; MS, median squares; F, F-ratio (ratio of two sample variances); P, P-value; FT, F-distribution test]

Source	DF	SS	MS	F	P	FT
Season	3	7,585.5	2,528.5	5.78	0.001	2.69
Stream	4	86,915.4	21,728.9	49.68	.000	2.46
Year	1	333.3	333.3	.76	.385	2.75
Stream*year	4	2,359.9	590.0	1.35	.257	2.46
Error	107	46,795.8	437.3			
Total	119	143,990.0				

As expected, results strongly indicate that the median proportion of return flows in streamflow varied seasonally (P-value is 0.001, much smaller than the significance level of 0.05). The return-flow:streamflow ratios for the study reaches show differences among seasons (fig. 14). In fact, return flows in the five reaches during the summer months in 1988 and 1989 constituted a large proportion (67 percent) of the annual streamflows.

SUMMARY AND CONCLUSIONS

Water returns by sewage-treatment plants and various water users can be a significant part of streamflow in Illinois, especially during dry seasons. Knowledge of the effect of return flows on streamflow is needed for purposes of assessing stream-water quality and water supply. This report is an evaluation of the contribution of return flows to streamflow for five stream reaches in Illinois during 1988-89, and includes a comparison of monthly water returns to streamflows and a statistical evaluation of the seasonal variation of return flows.

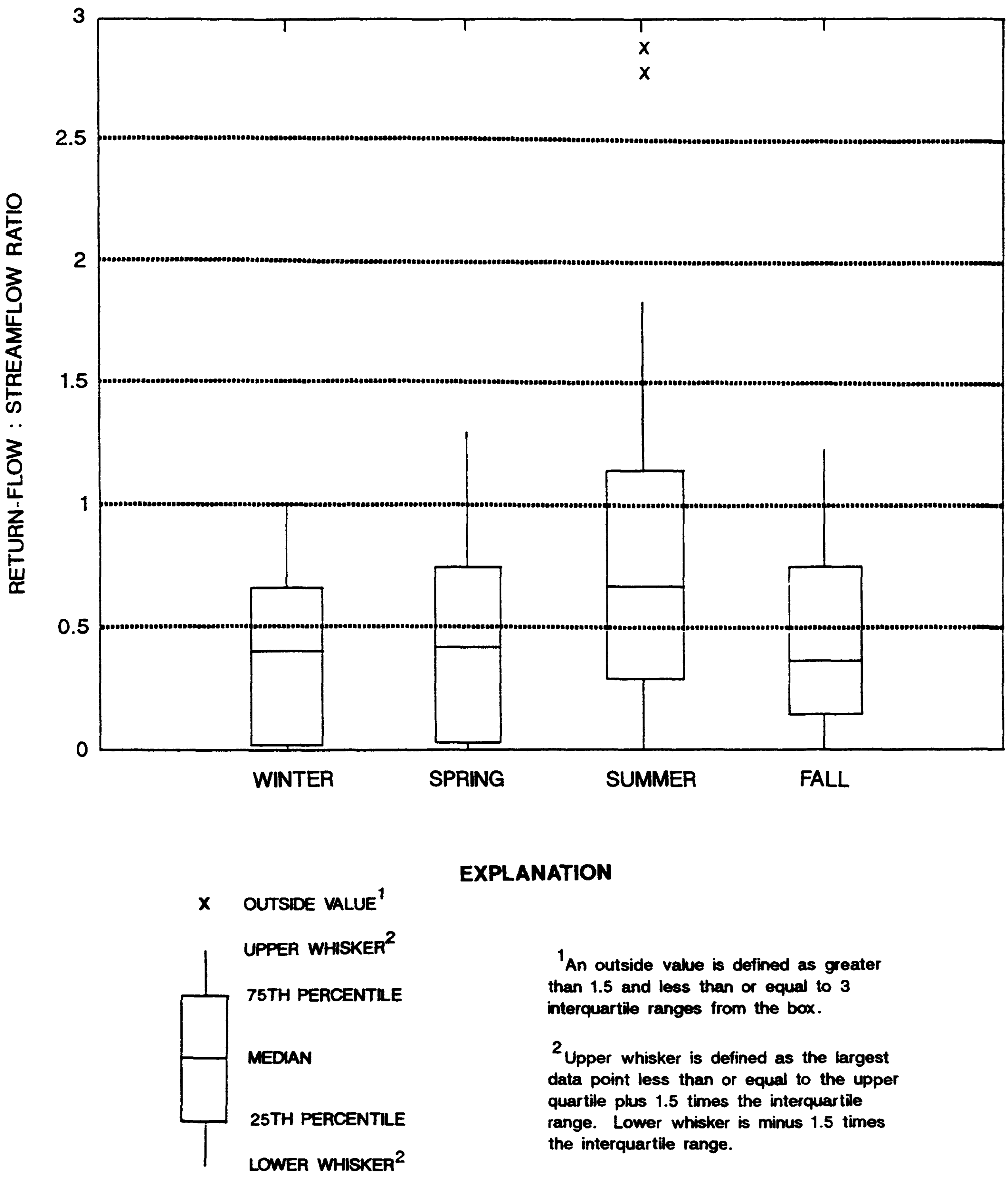


Figure 14.--Distribution of the ratios of return flows to streamflows grouped by season for the five study reaches in Illinois, 1988-89.

Water-return, water-withdrawal, stream, and pan-evaporation data were obtained for the evaluation. Water-return data for commercial establishments, industries, powerplants, public-water suppliers, and sewage-treatment plants in Illinois were obtained from Illinois Environmental Protection Agency computer files, discharge-monitoring reports, and facility operators. Additional descriptive data about return-flow sites were obtained from the Permit Compliance System data base. All return data were stored in the Site-Specific Water Use Data System, which is maintained by the U.S. Geological Survey (USGS). Withdrawal data were obtained from the Illinois State Water Survey and one public-water-supply operator. Stream information was obtained from the USGS computer files (National Water Information System). Pan-evaporation data were obtained from National Oceanic and Atmospheric Administration climatological data reports.

Stream reaches were chosen for this study with regard to minimizing the effects of tributary inflows on streamflows. A stream reach qualified for this study if it was upstream from a USGS continuous-record streamflow-gaging station, if it is the headwaters of a stream, and if it received return flows during 1988. Stream reaches that met the qualifications were identified by use of a geographic information system. Five stream reaches were selected for study by taking a stratified (by annual return flow) random sample of the qualifying reaches in Illinois.

The five reaches selected for study were South Branch Kishwaukee River upstream from De Kalb, Mackinaw River upstream from Congerville, Addison Creek upstream from Bellwood, Flag Creek upstream from Willow Springs, and Thorn Creek upstream from Glenwood. Four of the reaches are in northern Illinois; one is in central Illinois. The South Branch Kishwaukee River and Mackinaw River reaches flow through mostly rural areas, whereas the Addison Creek, Flag Creek, and Thorn Creek reaches flow through mostly urban areas. The average flows of these streams ranged from 10.0 to 327 Mgal/d. The contributing drainage areas of the reaches range from 16.5 to 767 mi^2.

The drought of 1988 and 1989 had a significant effect on streamflows in Illinois. Record-low streamflows were measured in Illinois at many gaging stations during 1988, and no flow occurred in several streams. Because of the drought, the proportion of return flows in streamflow may have been greater than normal.

Annual average return flows from 26 facilities to the 5 study reaches totaled 33.8 Mgal/d in 1988 and 36.7 Mgal/d in 1989. Annual average return flows to each reach ranged from 0.32 to 16.4 Mgal/d during 1988 and 1989. All return flows originated from water sources other than the receiving stream reaches.

The median return flows to the study reaches were 0.06 and 0.02 Mgal/d in 1988 and 1989, respectively. The median return flows in the entire State of Illinois were 0.08 and 0.07 Mgal/d in 1988 and 1989, respectively. The median return flow for the study reaches in 1988 (0.06 Mgal/d) is similar to the median return flow for Illinois (0.08 Mgal/d). Even though there are similarities, wide data variability exists within and between the data sets for both the study reaches and Illinois.

The annual average contributions of return flows to streamflow in each reach ranged from 1 to 99 percent of the annual average streamflow, with the assumption that no water was gained or lost between the return-flow sites and the streamflow-gaging station. Return flows had a consistently significant effect on streamflows in at least two of the study reaches (Flag Creek and Thorn Creek).

Return flows exceeded streamflow during at least 1 month during the 1988 drought at all of the study reaches, except the Thorn Creek reach. Because of the drought, streamflow could have been lost between the return-flow sites and the streamflow-gaging station by evaporation and (or) infiltration into the ground. Class A pan-evaporation data were used to estimate the streamflow losses caused by evaporation from surface water. Streamflow losses (up to the amount that return flows exceeded streamflow) caused by infiltration was estimated as the remaining amount of losses not evaporated from surface water. Of the amount of return flows that exceeded streamflow, all reaches lost an estimated 0.01 to 0.34 Mgal/d to evaporation and 0.36 to 1.33 Mgal/d to infiltration. In comparison, streamflow data obtained during the same period by Rodger Adams and Edward Delisio indicated that a reach of the Des Plaines River in northeastern Illinois lost as much as 1.30 Mgal/d of streamflow.

The slope of flow-duration curves was used to indicate whether flows in the study reaches were sustained by consistent contributions from some water source. Flow-duration curves for the Addison Creek, Flag Creek, and Thorn Creek reaches show that streamflows were being sustained by some water source. Because the annual contributions of return flows to streamflows were more significant (33-99 percent of streamflows in 1988-89) for these reaches than for the other reaches, return flows probably sustained streamflows.

Several analyses-of-variance tests of ranked return-flow data were used to evaluate the seasonal variation of return flows in streamflow. An analysis of the test results indicated that median return flows did not differ among seasons at a significance level of 0.05; however, a second analysis indicated that the median proportion of return flows to streamflow did differ seasonally, as would be expected because streamflows usually differ seasonally. In fact, the return flows in the five reaches during July through September 1988-89 constituted a large proportion (67 percent) of the annual streamflows.

In conclusion, the contribution of return flows to streams significantly affected streamflows in some of the reaches. The importance of reliable return-flow data should not be overlooked, especially if minimum streamflow requirements for water supply are mandated in Illinois. Collection of reliable return-flow and streamflow data needs to be continued in order to assess the constantly changing effects of return flows on streamflow.

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