U.S. Department of the Interior
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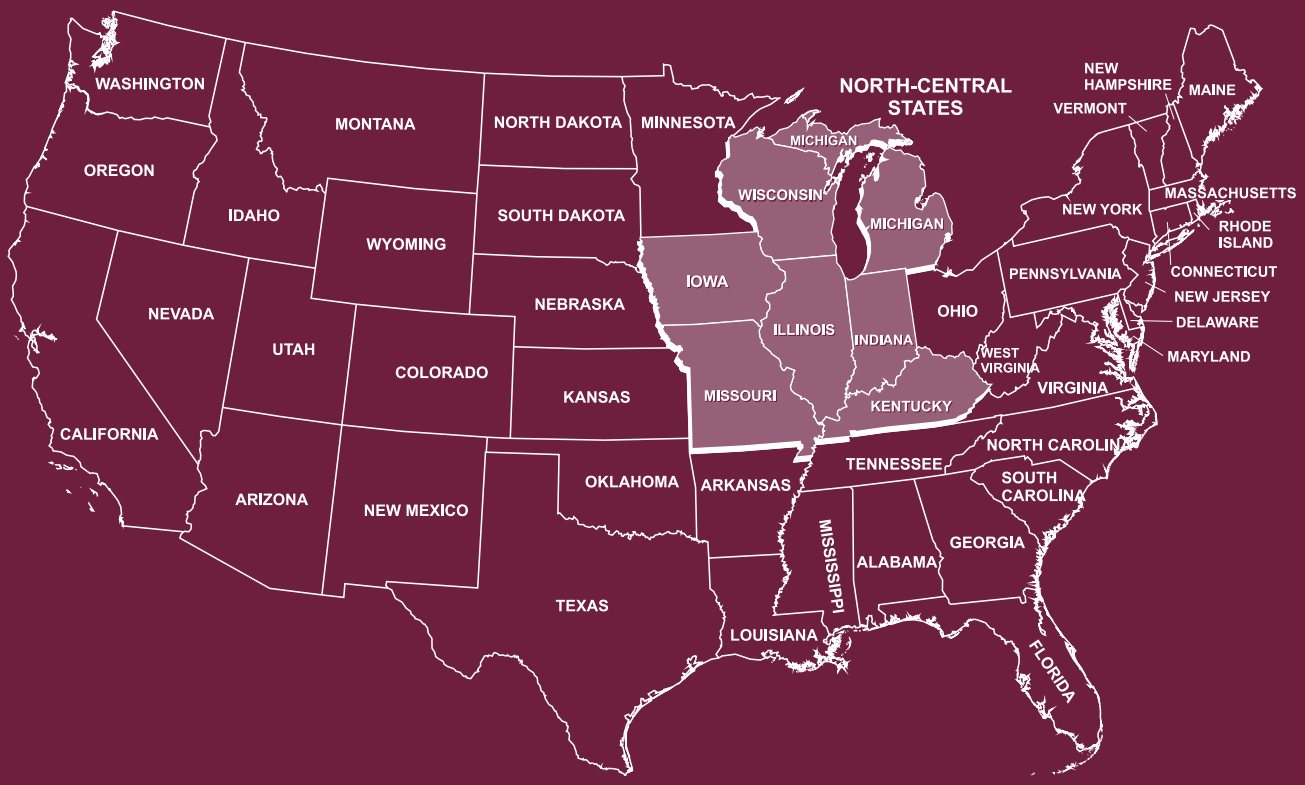
Estimated Water Withdrawals, Water Use, and Water Consumption in Illinois, Indiana, Iowa, Kentucky, Michigan, Missouri, and Wisconsin, 1950-95

Water-Resources Investigations Report 01-4116



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Estimated Water Withdrawals, Water Use, and Water Consumption in Illinois, Indiana, Iowa, Kentucky, Michigan, Missouri, and Wisconsin, 1950-95

By Robert T. Kay

Water-Resources Investigations Report 01-4116

DeKalb, Illinois

2002

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS

Multiply	By	To obtain
gallon per day (gal/d)	3.785	liter per day
million gallons per day (Mgal/d)	0.003785	million cubic meters per day

Estimated Water Withdrawals, Water Use, and Water Consumption in Illinois, Indiana, Iowa, Kentucky, Michigan, Missouri, and Wisconsin, 1950-95

By Robert T. Kay

Abstract

From 1950 through 1995, the U.S. Geological Survey tabulated water withdrawals throughout the United States, including the north-central States of Illinois, Indiana, Iowa, Kentucky, Michigan, Missouri, and Wisconsin. During this period, total water withdrawals increased in each of the north-central States by at least a factor of two. Illinois led the north-central States in total withdrawals, withdrawals from surface water and, typically, withdrawals from ground water. Per capita withdrawals were largest in Indiana or Illinois, however, the disparity in per capita withdrawals in the north-central States decreased from 1950 through 1995. Surface water was the source of 75 to 95 percent of all water withdrawals in the north-central States and consistently accounted for over 90 percent of total withdrawals in Illinois. From 1950 through 1995, the magnitude of increase in withdrawals from surface water was lower in Illinois than in most of the other north-central States, even though surface-water withdrawals in Illinois increased from about 9,000 to 19,000 million gallons per day. Total water withdrawals from ground water in Illinois have decreased by about 150 million gallons per day since 1975. From 1950 through 1995, from 68 to 86 percent of the total water withdrawals in Illinois were for generation of thermoelectric power; this percentage is higher than for the other north-central States and has increased since 1970. Approximately 12 percent of water withdrawals in Illinois are for municipal water supply, which was consistent with the other north-central States. Ten percent or less of the water withdrawn in the north-central States is estimated to have been consumed.

INTRODUCTION

Management of water supplies within an area of concern is aided by knowledge of the total amount of water withdrawn from surface water and ground water and the use of the water. Identification of actual or potential water-supply and water-quality problems can be aided by knowledge of the volume of, and temporal changes in, water withdrawals and water consumption. Because areas of concern often correspond to political boundaries, and because water resources often are shared by multiple areas of concern (cities, counties, States, Nations) management of water supplies in an area of concern also is assisted by knowledge of water use in surrounding areas.

Water withdrawals throughout the United States, including Illinois and the nearby States of Indiana, Iowa, Kentucky, Michigan, Missouri, and Wisconsin have been estimated by the U.S. Geological Survey (USGS) every 5 years from 1950 through 1995 (MacKichan, 1951, 1957; MacKichan and Kammerer, 1961; Murray, 1968; Murray and Reeves, 1972, 1977; Solley and others, 1983, 1988, 1993, 1998). These data were not compiled nationally prior to 1950. Estimates of the amount of water consumed have been compiled every 5 years from 1960 through 1995. These compilations provide a starting point for assessment of potential sources of stress on limited water resources. For the purposes of this report, Illinois, Indiana, Iowa, Kentucky, Michigan, Missouri, and Wisconsin are collectively referred to as the north-central States (fig. 1).

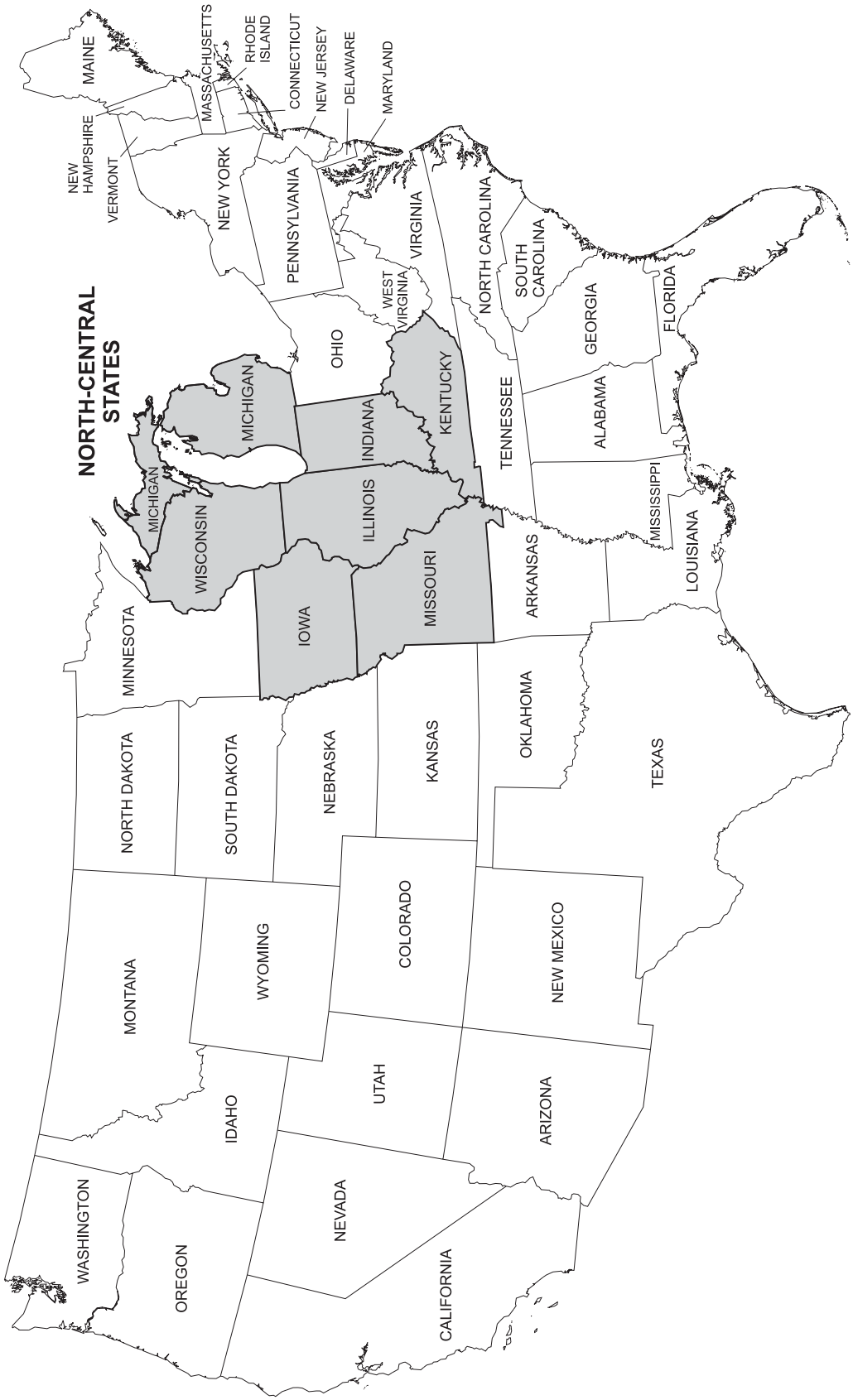

Figure 1. Location of north-central States.

Because one of the goals of the withdrawal estimates is to provide insight into the source of the stresses on water resources, the estimates consist of a breakdown of the volume of water withdrawn from surface- and ground-water sources for use in public-water supplies, domestic water supplies, self-supplied industrial operations, self-supplied commercial operations, mining operations, thermoelectric power generation, irrigation, and livestock operations as well as the volume of water consumed. Public-water supplies, domestic water supplies, self-supplied industrial operations, self-supplied commercial operations, mining operations, thermoelectric power generation, irrigation, and livestock operations account for all offstream (water is diverted from its source and conveyed to its place of use) water use. Instream (water is used at its source) water use, such as boat navigation or hydroelectric power generation, is not discussed in this report. Definitions of these and other terms used in the report are presented in the glossary.

The estimated data are presented in the reports cited in the reference section (MacKichan, 1951, 1957; MacKichan and Kammerer, 1961; Murray, 1968; Murray and Reeves, 1972, 1977; Solley and others, 1983, 1988, 1993, 1998). The sources of the data and the methods of data analysis also are discussed (to varying degrees) in these reports. Estimation of withdrawals and consumption for the various water-use categories is based on a variety of techniques with varying degrees of accuracy. For example, suppliers typically measure, monitor, and report the amount of withdrawals for public-water supplies and these estimates are comparatively accurate. Withdrawals from rural-domestic supplies and withdrawals for livestock use are based on census estimates of the human or animal population served and assumptions about per capita water use for humans and various types of livestock. The accuracy of these and other estimates of water use are less certain. The volume of water consumed was estimated by multiplying the total water withdrawals for a particular water-use category by the percentage assumed to have been consumed. Consumption values may contain a high percentage of error.

The components of the withdrawal and consumption estimates for many of the categories have changed from 1950 through 1995, affecting the estimated amount of withdrawals. Some of the apparent trends in water withdrawals from 1950 through 1995 are a reflection of changes in the definition of the water-use categories and do not necessarily reflect actual changes in water withdrawals or water use. For example, dewatering was removed from the estimation of water withdrawals for mining use in the 1995 data. Where possible, changes in evaluation of the components of a water-use category will be noted and the effects, if any, will be discussed.

Public-water supply withdrawals are made by a utility for use by the general public, commercial, industrial, and civic concerns (MacKichan, 1951). The amount of water delivered from a public supply for domestic use; public use and conveyance loss; industrial and commercial supply; and thermoelectric power generation were differentiated at various times since 1955.

Rural domestic water supply withdrawals are withdrawals for domestic use (drinking, bathing, washing clothes, watering lawns) by individual or small groups of homeowners not served by a public system (MacKichan, 1957). Estimates of per capita withdrawals for rural domestic use have increased through time, as the percentage of the rural population with running water increased (households with running water use more water than households without running water). Prior to 1960, rural water withdrawals for domestic use were combined with withdrawals for use by livestock.

Livestock water use includes drinking water for livestock, dairy sanitation, evaporation from stock-watering ponds, and cleaning and waste disposal (Solley and others, 1998). These withdrawals typically are self-supplied. Withdrawals for aquaculture were considered industrial withdrawals prior to 1980, but have been included in livestock withdrawals since 1980. This change is likely to have had minimal effect on water-use estimates in the north-central States.

Self-supplied industrial water withdrawal is water not obtained from public-water supplies that is used for such purposes as processing, washing, and cooling in facilities that manufacture products (MacKichan and Kammerer, 1961). Industries that use substantial quantities of water in their daily operations such as mining, and the manufacture of steel, chemical, and paper products, are present in varying amounts in the north-central States.

Withdrawals for thermoelectric power generation include self-supplied water used for the generation of electrical power with fossil-fuel, nuclear, or geothermal energy (Solley and others, 1988). Most of the water withdrawn by thermoelectric power plants is used for condenser and reactor cooling. Withdrawals for thermoelectric power generation were included in the self-supplied industrial category in 1950 and 1955, but have been tabulated separately since 1955 (MacKichan and Kammerer, 1961).

Self-supplied commercial water withdrawal is water not obtained from public-water supplies that is used for hotels, restaurants, office buildings, and other commercial facilities including military bases. Self-supplied withdrawals for commercial uses were included in the self-supplied industrial category prior to 1985, but were tabulated separately in 1985, 1990 and 1995.

Mining water use includes both fresh and saline water used for the extraction of naturally occurring rock, liquids, and gasses such as stone, coal, petroleum, and natural gas (Solley and others, 1988). This category includes quarrying, milling, and other operations done as part of the mining activity. All mining water is assumed to be self-supplied for purposes of estimation. Withdrawals for mining uses were included in the self-supplied industrial category prior to 1985, but were tabulated separately in 1985, 1990, and 1995.

Irrigation water use includes all water artificially applied to farm and horticultural crops, as well as water for golf courses (Solley and others, 1998). All water used for irrigation is considered to be self-supplied for the purposes of estimation.

This report describes the results of a compilation of estimates of water withdrawals, water deliveries, water use, and water consumption for a variety of water-use categories in the north-central States at 5-year intervals from 1950 through 1995. Estimates of total withdrawals and breakdowns of withdrawals from surface-water and ground-water sources for each of the major water-use categories are presented. Differences in the estimated water withdrawals and water consumption between the north-central States are discussed for each water-use category, and temporal trends are presented.

ESTIMATED WATER WITHDRAWALS

Much of the water withdrawn for offstream use is returned to the water environment as discharge to a stream, where it is available to be withdrawn again. For this compilation, each time that water was taken from a natural source it was added to the accumulated totals of water withdrawn; therefore, some of the water has been counted more than once. Most of the water withdrawn from the ground water is returned to surface water. Diversion of ground water to surface water increases the availability of surface water, but depletes the ground-water resource. As a result, water-supply problems in the north-central States are more common with ground water than surface water.

Total Withdrawals for Offstream Water Use

Illinois typically has the largest total water withdrawals among the north-central States (19,953 million gallons per day (Mgal/d) in 1995), followed by Michigan (12,062 Mgal/d), Indiana (9,139 Mgal/d), Wisconsin (7,249 Mgal/d), Missouri (7,030 Mgal/d), Kentucky (4,416 Mgal/d), and Iowa (3,038 Mgal/d) (fig. 2). Quantities of water withdrawn show a general correlation with the population of each of the north-central States (fig. 3). Total withdrawals showed an overall increase in all of the north-central States from 1950 to 1995. Comparison of the total water withdrawals in 1950 and 1995 showed an increase ranging from slightly less than a factor of two in Iowa (1,625 to 3,038 Mgal/d) to about a factor of seven in Missouri (995 to 7,030 Mgal/d). Water withdrawals in Illinois essentially doubled from 9,910 Mgal/d in 1950 to 19,953 Mgal/d in 1995 and showed an overall increase during this period. Water withdrawals in Indiana, Iowa, Kentucky, and Michigan were largest in 1980, decreased from 1980 to 1985 (as did total water withdrawals in Illinois and Missouri) and increased gradually from 1985 through 1995.

Total Withdrawals from Surface Water and Ground Water

More than 75 percent of the total water withdrawals in the north-central States are supplied from surface water, with ground water making up the

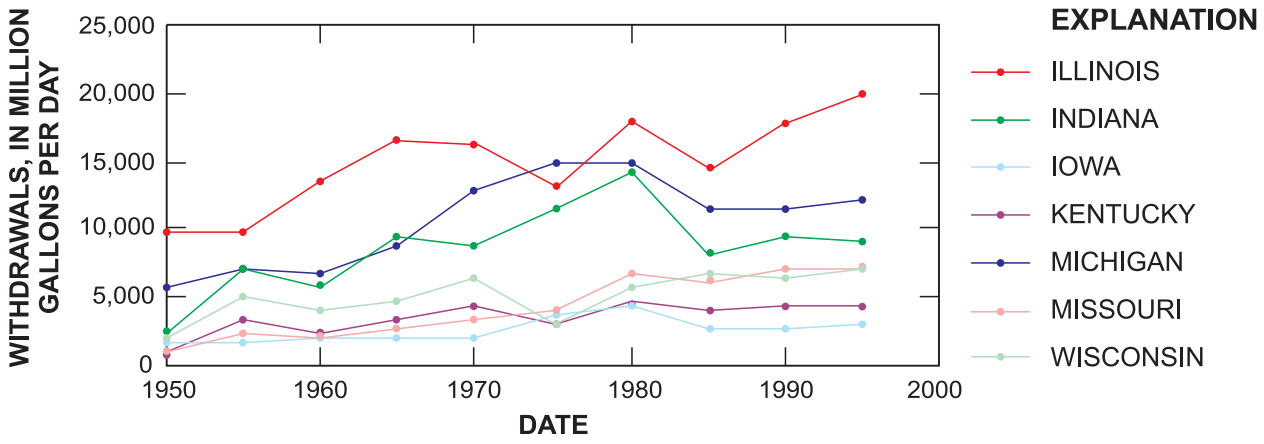

Figure 2. Total water withdrawals in the north-central States, 1950-95.

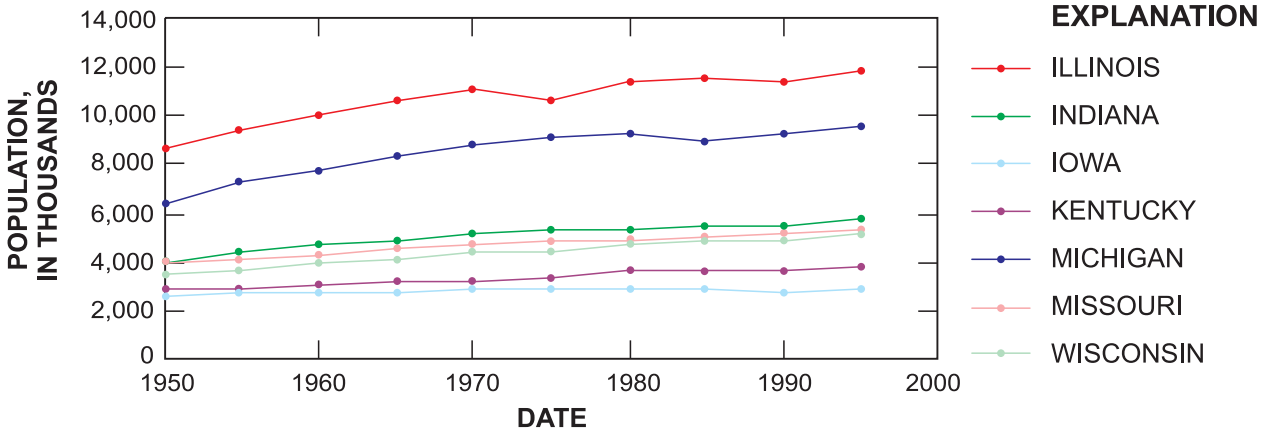

Figure 3. Population of the north-central States, 1950-95.

difference (figs. 4, 5, 6). Surface water typically has accounted for more than 90 percent of the total withdrawals in Illinois, Indiana, Kentucky, and Michigan from 1950 through 1995 (fig. 4). The percentage of the total water withdrawals derived from surface water in the north-central States historically has been smallest in Iowa (from about 66 to 84 percent), and intermediate in Missouri and Wisconsin (from 86 to 93 percent). The percentage of the total amount of water withdrawals derived from surface water or ground water has remained fairly constant in each of the north-central States from 1950 through 1995.

The total volume of surface water withdrawn increased overall in all of the north-central States from 1950 through 1995, mirroring the increase in total water withdrawals (fig. 5). The magnitude of the increase was about a factor of two in Illinois (9,390 to 19,000 Mgal/d), Iowa (1,300 to 2,510 Mgal/d), and Michigan (5,300 to 11,200 Mgal/d); more than a factor of three in Wisconsin (1,780 to 6,490 Mgal/d), and Kentucky (1,106 to 4,190 Mgal/d); about a factor of four in Indiana (1,990 to 8,430 Mgal/d); and about a factor of seven in Missouri (880 to 6,140 Mgal/d). Total surface-water withdrawals were largest in Indiana (13,000 Mgal/d), Iowa (3,500 Mgal/d), Kentucky (4,600 Mgal/d), Michigan (14,000 Mgal/d), and Missouri (6,400 Mgal/d) in 1980.

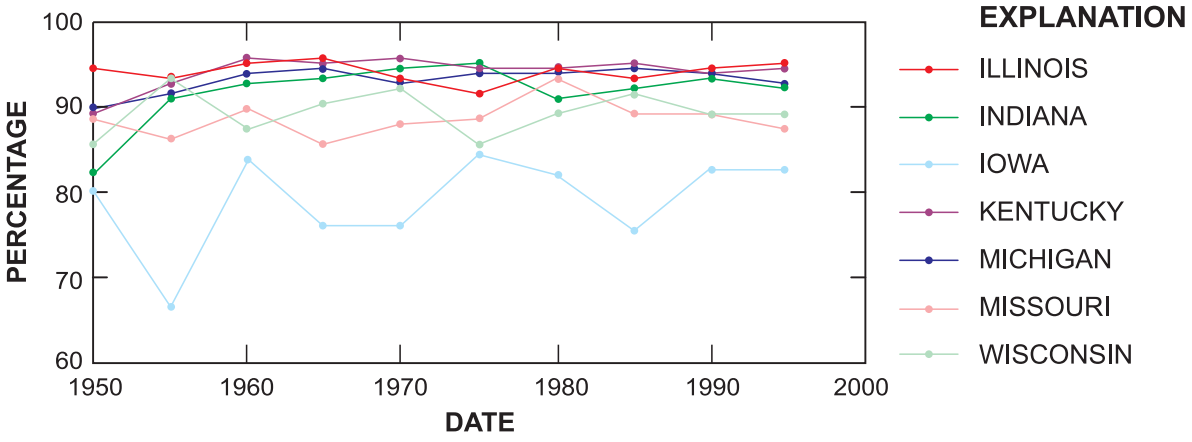

Figure 4. Percentage of total withdrawals in the north-central States from surface water, 1950-95.

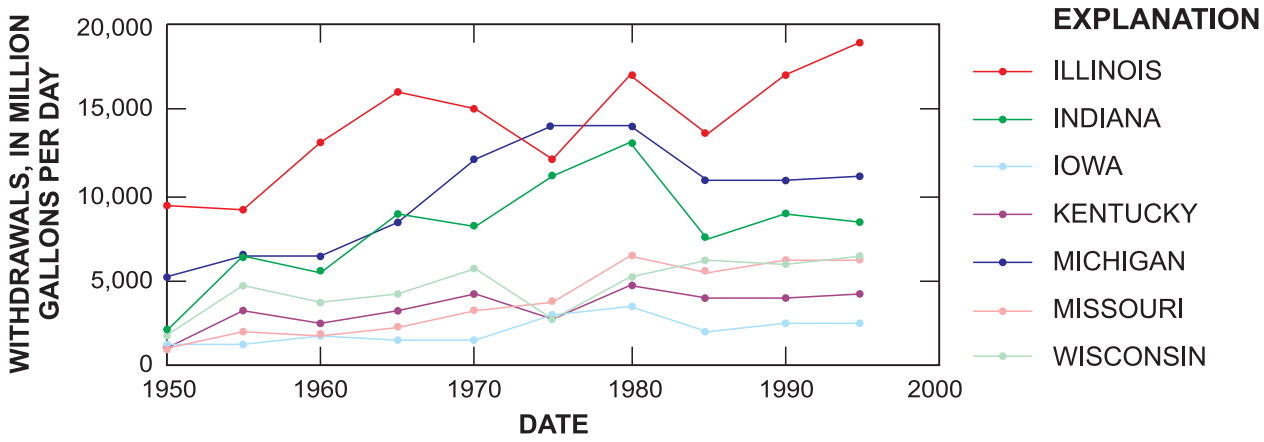

Figure 5. Total withdrawals from surface water in the north-central States, 1950-95.

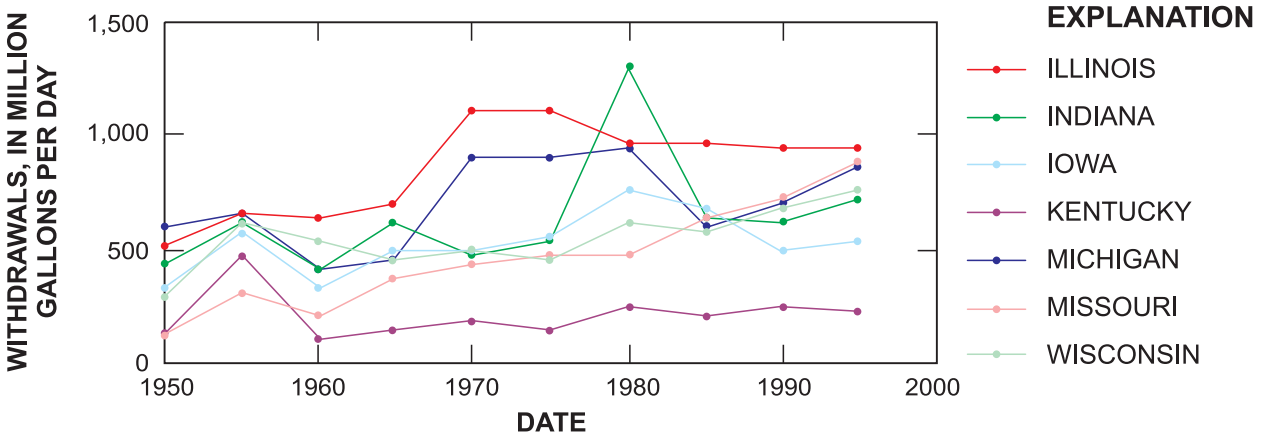

Figure 6. Total water withdrawals from ground water in the north-central States, 1950-95.

The total volume of ground water withdrawn from 1950 through 1995 typically has been largest in Illinois and smallest in Kentucky (fig. 6). Comparison of the total volume of ground water withdrawn in 1950 and 1995 showed an increase in all of the north-central States. The magnitude of the increase was less than a factor of two in Illinois (520 to 953 Mgal/d), Indiana (440 to 709 Mgal/d), Iowa (325 to 528 Mgal/d), Kentucky (120 to 226 Mgal/d), and Michigan (600 to 862 Mgal/d); more than a factor of two in Wisconsin (295 to 759 Mgal/d); and nearly a factor of eight in Missouri (115 to 891 Mgal/d). Total ground-water withdrawals were largest in Illinois (1,100 Mgal/d) in 1975 and in Indiana (1,300 Mgal/d), Iowa (760 Mgal/d), Kentucky (250 Mgal/d), and Michigan (950 Mgal/d) in 1980.

Per Capita Water Withdrawals

Total per capita water withdrawals, the total amount of water withdrawn divided by the population of a State, increased overall for each of the north-central States from 1950 through 1995 (fig. 7). Per capita water withdrawals exceeded 1,000 gallons per day (gal/d) in the north-central States from 1980 through 1995. The magnitude of the increase in the per capita total water withdrawals from 1950 through 1995 ranged from less than a factor of two in Michigan (926 to 1,260 gal/d) and Illinois (1,138 to 1,680 gal/d), the States with the largest overall withdrawals, to more than factor of five in Missouri (252 to 1,320 gal/d). Per capita total water withdrawals for all of the north-central States increased overall from 1950 to 1980. Per capita total water withdrawals for all of the north-central States except Wisconsin decreased by at least 170 gal/d from 1980 to 1985, then increased between 10 and 430 gal/d from 1985 to 1995. Only Illinois and Wisconsin had higher total per capita water withdrawals in 1995 than in 1980. Per capita total water withdrawals in 1950 were largest in Illinois, followed by Michigan. For most of the period from 1955 through 1990, Indiana had the largest per capita water withdrawals (geometric mean value of 1,563 gal/d from 1955 through 1990), followed by Illinois (mean value of 1,362 gal/d) or Michigan (mean value of 1,200 gal/d). Illinois regained the largest per capita water withdrawals in 1995. The disparity between the States with the largest and smallest per capita water withdrawals has decreased dramatically since 1950. In 1950, per capita water withdrawals in Illinois were about 880 gal/d greater than in Missouri and exceeded per capita withdrawals in Missouri by more than a factor of four. In 1995, per capita water withdrawals in Illinois were about 600 gal/d greater than in Iowa and exceeded per capita withdrawals in Iowa by less than a factor of two.

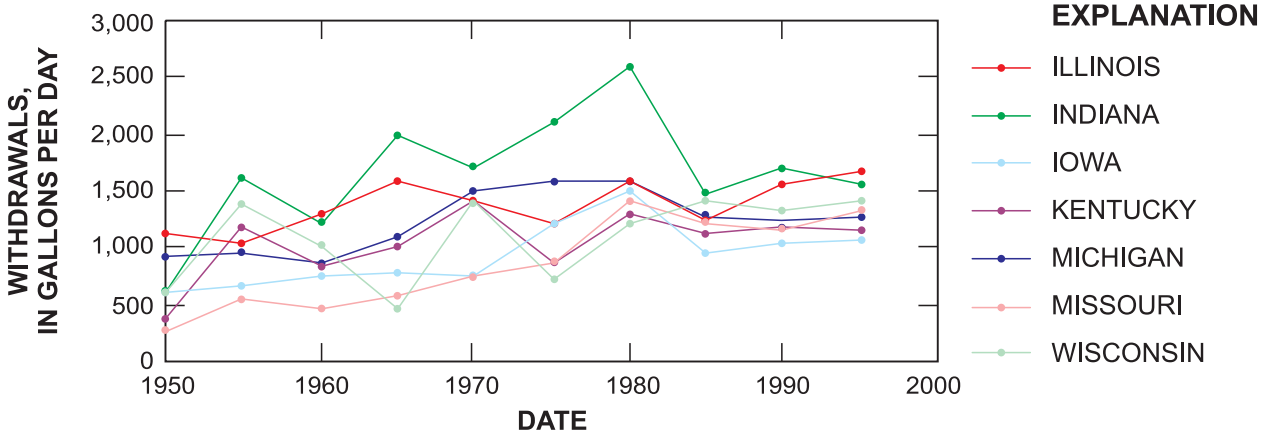

Figure 7. Per capita water withdrawals in the north-central States, 1950-95.

Withdrawals for Public-Water Supply

Total volumes of water withdrawn for public-water supplies were a general reflection of population and industrial activity, being largest in Illinois, second largest in Michigan, intermediate in Indiana, Wisconsin, and Missouri, and smallest in Kentucky and Iowa (fig. 8). Volumes of water withdrawn for public-water supply increased overall from 1950 to 1995 in each of the north-central States, although the maximum withdrawals in Illinois occurred in 1970. The largest total increases, from 1950 to 1995, were measured in Illinois (611 Mgal/d) and Michigan (550 Mgal/d) with smaller increases in Missouri (414 Mgal/d), Kentucky (376 Mgal/d), Indiana (369 Mgal/d), Wisconsin (310 Mgal/d), and Iowa (218 Mgal/d). The amount of water withdrawn for public-water supply in 1950 and 1995 increased by more than a factor of four in Kentucky (120 to 496 Mgal/d); more than a factor of two in Indiana (300 to 669 Mgal/d), Missouri (285 to 699 Mgal/d), Wisconsin (290 to 600 Mgal/d), and Iowa (155 to 373 Mgal/d); and less than a factor of two in Michigan (750 to 1,300 Mgal/d) and Illinois (1,210 and 1,821 Mgal/d). Water withdrawals for public-water supply typically were between 5 and 15 percent of the total withdrawals for each State and typically were from 9 to 12 percent of the total withdrawals in Illinois. Withdrawals for public-water supply in Indiana typically were the smallest percentage of the total water use, from 4 to 7 percent, whereas withdrawals for public-water supply from Missouri, prior to 1980, were 15 percent or more of the total water use.

Volumes of both surface water and ground water extracted for public-water supply showed an overall increase in most of the north-central States from 1950 through 1995 (figs. 9, 10). However, withdrawals of ground water for public-water supply in Illinois peaked in 1970, declined slightly in 1975, and have dropped substantially since 1975 (fig. 10). This decline in withdrawals from ground water is at least partially the result of a shift in water supply from ground water to water from Lake Michigan in suburban Chicago. With the exception of Iowa, surface water typically was the primary source of water for public-water supply in the north-central States from 1950 through 1995 (fig. 11). Surface water typically accounted for less than one-third of the water withdrawn for public-water supply in Iowa; between 48 and 64 percent of the water withdrawn for public-water supply in Indiana; about 80 percent of the water withdrawn for public-water supply in Michigan; and about 85 percent of the water withdrawn for public-water supply in Kentucky. From 1950 through 1995, surface water has decreased from 91 to 68 percent of the water withdrawn for public-water supply in Missouri. In Illinois, surface water accounted for 84 to 88 percent of the water withdrawn for public-water supply from 1950 through 1965, decreased to about 68 percent in 1970 and 1975, and has consistently increased to 80 percent in 1995. In Wisconsin, surface water accounted from 55 to 60 percent of the water withdrawn for public-water supply from 1950 through 1975, and decreased to about 50 percent in 1980 through 1995.

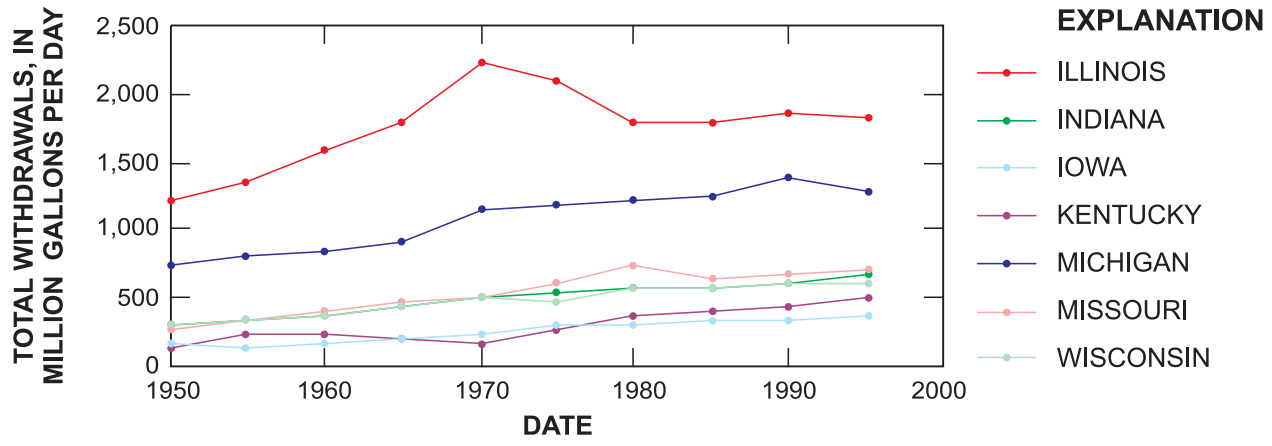

Figure 8. Total withdrawals for public-water supply in the north-central States, 1950-95.

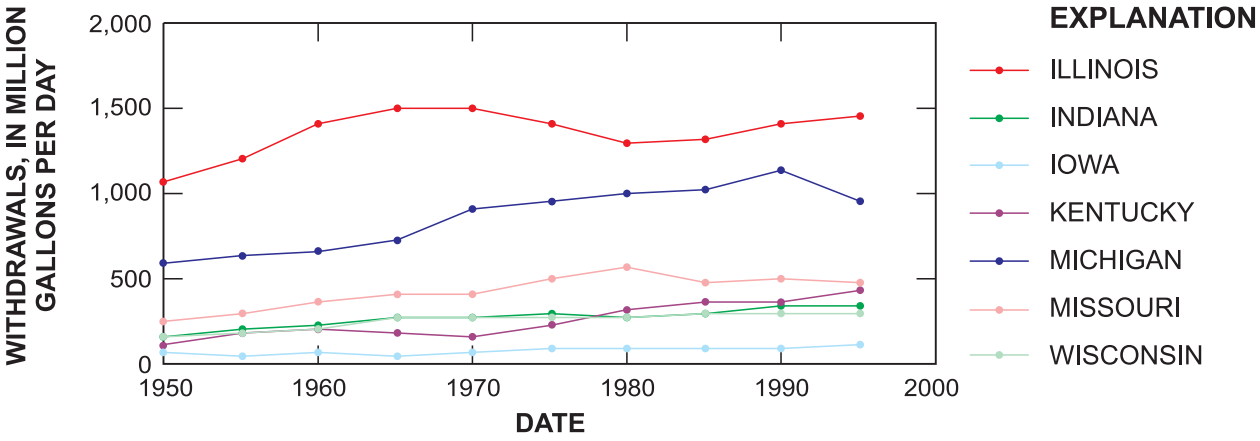

Figure 9. Total withdrawals of surface water for public-water supply in the north-central States, 1950-95.

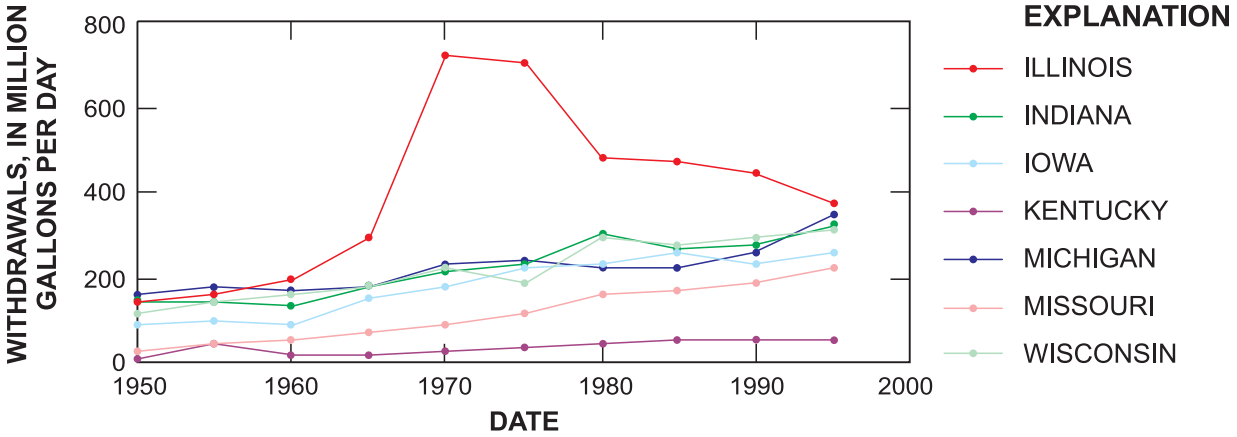

Figure 10. Total withdrawals from ground water for public-water supply in the north-central States, 1950-95.

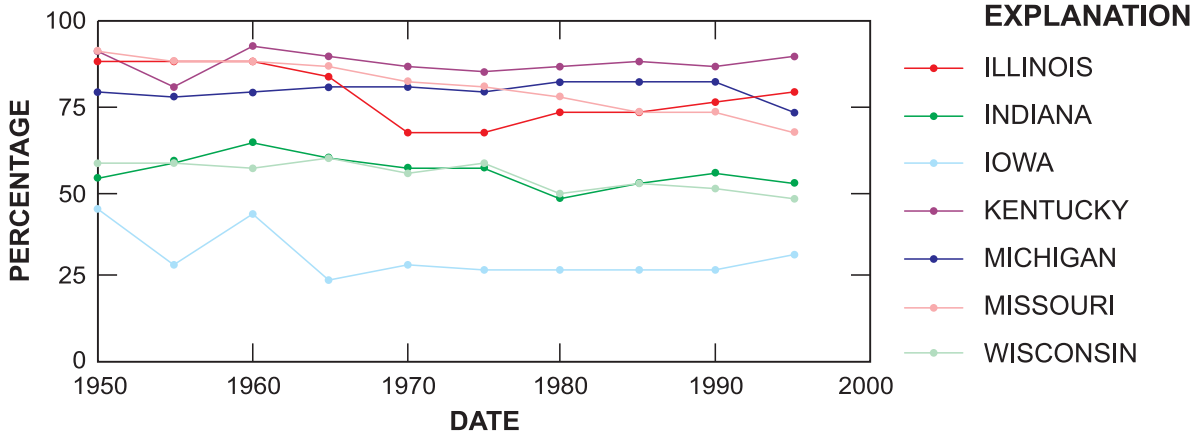

Figure 11. Percentage of withdrawals for public-water supply in the north-central States from surface water, 1950-95.

Withdrawals from ground water for public-water supply increased from about 25 to 65 percent of the total withdrawals from ground water in Illinois from 1950 to 1975, then decreased to 39 percent of the total withdrawals from ground water in Illinois in 1995 (figs. 6, 10). Withdrawals from ground water for public-water supply typically have accounted for about 40 and 25 percent of the total ground-water withdrawals for Wisconsin and Missouri, respectively, from 1950 through 1995. Withdrawals from ground water for public-water supply generally are an increasing percentage of the total withdrawals from ground water in Indiana (from 32 to 45 percent), Iowa (from 26 to 49 percent), Kentucky (from 8 to 24 percent), and Michigan (from 27 to 40 percent) from 1950 through 1995.

Withdrawals from surface water for public-water supply decreased from about 30 to 8 percent of the total withdrawals from surface water in Missouri from 1950 to 1995 (figs. 5, 9). From 1950 through 1995, withdrawals from surface water for public-water supply typically have accounted for about 10 percent of the total surface-water withdrawals in Illinois, Kentucky, and Michigan; and about 4 percent of the total surface-water withdrawals in Indiana, Iowa, and Wisconsin.

Deliveries from Public-Water Supply Systems

In addition to withdrawals by public-supply systems, deliveries from public-supply systems have been estimated. Deliveries from public-supply systems are to industrial, domestic, and public users. In addition, some of the water withdrawn by public-supply systems is lost during conveyance from the point of withdrawal to the point of delivery.

The volume of water delivered from public-supply systems to industrial users included estimates of delivery to commercial users and thermoelectric power generators from 1955 through 1980. The volume of water delivered from public-supply systems to commercial users and thermoelectric power generators was differentiated from the volume delivered to industrial users in 1985, 1990, and 1995. For consistency, the volumes of water delivered to industrial users, commercial users, and thermoelectric power generators are grouped in all estimates of deliveries to industrial users in this report.

The volume of water delivered from public-supply systems to domestic and public users and lost during conveyance was estimated from 1960 through 1995. The volume of water delivered to domestic users was differentiated from the conveyance loss and public use (conveyance loss and public use were not differentiated from each other) in 1985, 1990, and 1995. For consistency, the volumes of water delivered for domestic use as well as public use and conveyance losses are combined in the discussion of total deliveries from the public-water supply systems, but are differentiated for the discussion of volumes of water delivered for domestic use, and for public use and conveyance loss. The volume of water lost in conveyance and used for public use is estimated by subtracting the volume delivered to domestic, industrial and commercial users, thermoelectric power generators, and any other users from the total volume of water withdrawn by the public-water supplies.

From 1960 through 1995, the period for which these records are available, total deliveries from public-water supply systems for domestic use, and public use and conveyance losses typically accounted for more than 1,000 Mgal/d in Illinois, about 400 to 800 Mgal/d in Michigan, about 200 to 500 Mgal/d in Indiana, Missouri, and Wisconsin, and about 100 to 300 Mgal/d in Iowa and Kentucky (fig. 12). Total deliveries from public-water supply systems for domestic use, public use, and conveyance loss showed a generally consistent increase from 1960 through 1995 in each of the north-central States, typically increasing by about a factor of two. The exception to this trend was Illinois, with maximum deliveries from 1960 through 1975.

Deliveries for domestic use exceeded conveyance loss and deliveries for public use in each of the north-central States from 1985 through 1995. Deliveries for domestic use exceeded deliveries for public use and conveyance loss by less than a factor of two in Iowa (typically about 139 and 88 Mgal/d, respectively) and Wisconsin (geometric mean of 179 and 157 Mgal/d, respectively); by about a factor of three in Indiana (typically about 300 and 100 Mgal/d, respectively) and Missouri (geometric mean of 359 and 118 Mgal/d, respectively); about a factor of four in Illinois (geometric mean of 896 and 234 Mgal/d, respectively); by about a factor of five in Kentucky (geometric mean of 196 and 35 Mgal/d, respectively); and by nearly a factor of nine in Michigan (geometric mean of 612 and 71 Mgal/d, respectively).

From 1960 through 1995, withdrawals from public-water supply systems for delivery to commercial, industrial, and thermoelectric power generating facilities typically accounted for about 500 to 800 Mgal/d in Illinois and Michigan, 100 to 300 Mgal/d in Indiana, Missouri, and Wisconsin, 70 to 225 Mgal/d in Kentucky, and 50 to 100 Mgal/d in Iowa (fig. 13). From 1960 through 1995, deliveries from public-water supply systems for industrial, commercial, and thermoelectric power uses increased by less than a factor of two in Illinois, Indiana, Michigan, Missouri, and Wisconsin; increased by a factor of two in Iowa, and increased by about a factor of three in Kentucky. From 1985 through 1995, withdrawals from public-water supplies for delivery to thermoelectric power generating facilities were negligible in the north-central States. From 1985 through 1995, withdrawals from public-water supplies for delivery to commercial facilities exceed deliveries to industrial facilities in Illinois (typically by less than a factor of two), whereas deliveries to industrial facilities tended to exceed deliveries to commercial facilities in Kentucky, Missouri, and Wisconsin. From 1985 through 1995, public-supply deliveries to industrial and commercial facilities were similar in Indiana. No clear patterns were observed for Iowa and Michigan.

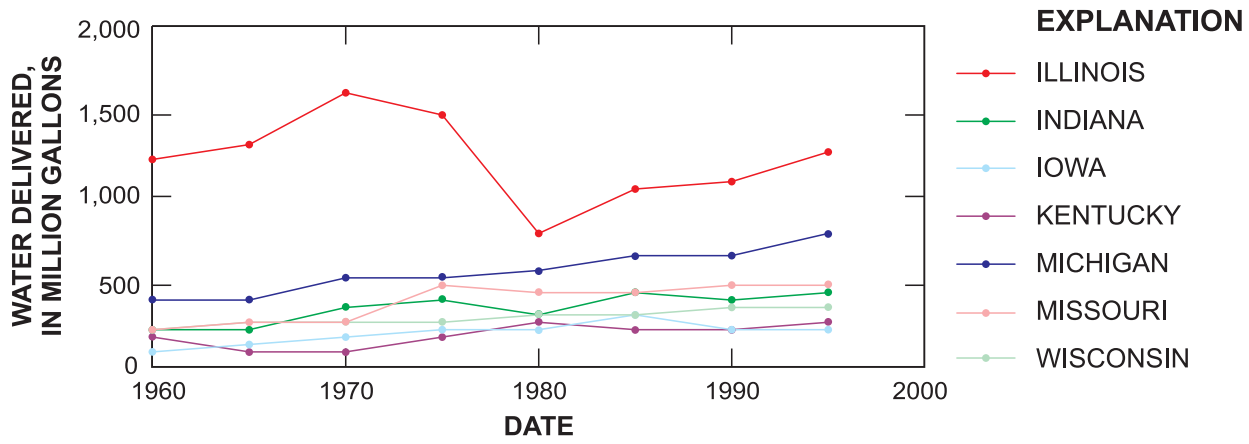

Figure 12. Volume of water delivered from public suppliers to domestic users, public users, and lost to conveyance in the north-central States, 1960-95.

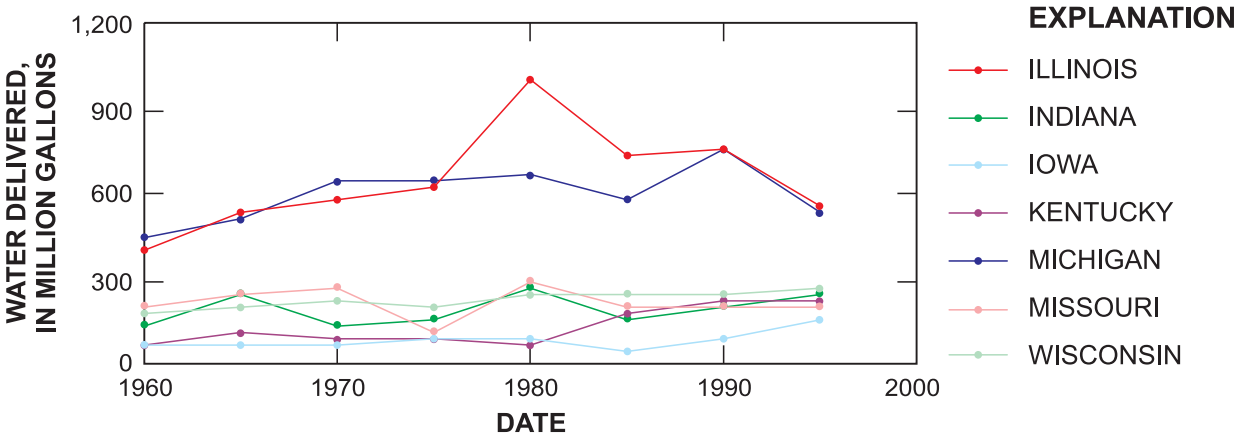

Figure 13. Volume of water delivered from public suppliers to industrial and commercial users and thermoelectric power generators in the north-central States, 1960-95.

Most of the water withdrawn for public-water supply in the north-central States since 1955 has been used for domestic and public use or is lost in conveyance, with the exception of Michigan. Deliveries to domestic users, public users, and conveyance losses typically accounted for 59 to 75 percent of the total water withdrawn by public-water supply systems in Illinois, Indiana, and Iowa, 50 to 75 percent in Missouri, 45 to 70 percent in Kentucky, about 55 percent in Wisconsin, and 43 to 48 percent in Michigan.

Withdrawals for Rural Domestic Supply

Volumes of water withdrawn for rural domestic supply from 1960 through 1995 (withdrawals for rural domestic and livestock use were not differentiated in 1950 and 1955) ranged from 100 to 194 Mgal/d in Michigan, 87 to 139 Mgal/d in Indiana, 70 to 92 Mgal/d in Wisconsin, 39 to 92 Mgal/d in Missouri, 41 to 65 Mgal/d in Iowa, and 24 to 65 Mgal/d in Kentucky (fig. 14). The volume of water withdrawn for rural domestic supply in Illinois increased from 73 to 92 Mgal/d from 1960 to 1965, decreased to about 17 Mgal/d in 1970 and 1975, and increased to 115 and 130 Mgal/d in 1985 and 1995, respectively. With the exception of the trends described in Illinois and an approximately twofold increase in Michigan, the total volume of water withdrawn for rural domestic water supply in the north-central States did not change appreciably from 1960 through 1995. A small decrease was calculated in Iowa. Water withdrawals for rural domestic supply typically were less than 2 percent of the total withdrawals for each State. Withdrawals for rural domestic supply in Illinois always were the smallest percentage of the total water withdrawals in the north-central States and always were less than 1 percent of the total withdrawals in Illinois. Withdrawals for rural domestic supply in Iowa typically were the largest percentage of the total water withdrawals in the north-central States, ranging from 2.7 to 15 percent of the total water withdrawals in Iowa.

With the exception of small quantities from Kentucky (less than 6 Mgal/d) and Michigan (0.1 Mgal/d), surface water was not used extensively for rural domestic water supply in any of the north-central States since 1980. Essentially, all water withdrawn for rural domestic supply in the north-central States since 1980 has been withdrawn from ground water. Although variable, withdrawals for rural domestic supply constitute about 20 percent of the total ground-water withdrawals in Kentucky and Michigan, about 15 percent of the total ground-water withdrawals in Indiana and Wisconsin, and about 10 percent in Illinois, Iowa, and Missouri.

Withdrawals for Use by Livestock

The volume of water withdrawn for use by livestock from 1960 through 1995 exceeded 105 Mgal/d in Iowa, ranged from 71 to 90 Mgal/d in Wisconsin, ranged from 42 to 78 Mgal/d in Illinois,

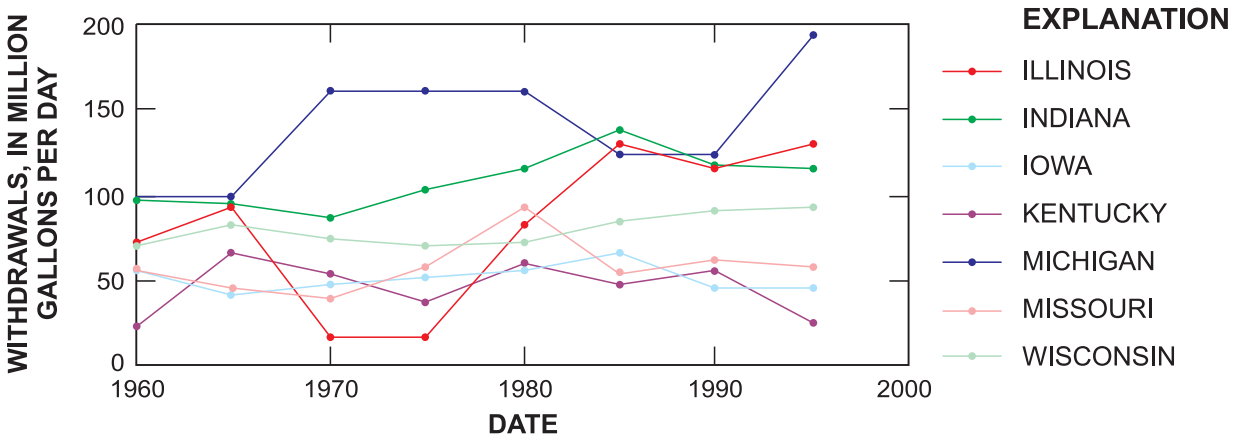

Figure 14. Total withdrawals for rural domestic supply in the north-central States, 1960-95.

typically was between 40 and 50 Mgal/d in Indiana, ranged from 31 to 50 Mgal/d in Kentucky, and 13 to 31 Mgal/d in Michigan (fig. 15). The volume of water withdrawn for livestock supply in Missouri increased from 72 to 159 Mgal/d from 1960 through 1975, decreased to about 40 Mgal/d by 1985, and increased to 76 Mgal/d in 1995. Water withdrawals for livestock supply decreased overall from 1960 through 1995 in Illinois, Iowa, Michigan, and Wisconsin, remained essentially unchanged in Indiana and Missouri, and increased by less than a factor of two in Kentucky. Withdrawals in Missouri increased by about a factor of two from 1960 through 1975 then decreased to approximately 1960 levels from 1980 through 1995. Water withdrawals for livestock supply were less than 1 percent of the total withdrawals in Illinois, Indiana, and Michigan; were often between 1 and 2 percent of total withdrawals in Kentucky and Wisconsin; and ranged from about 3 to 7 percent of the total withdrawals in Iowa. Livestock water supply accounted for more than 3 percent of all water withdrawals in Missouri from 1960 through 1975,
and has been approximately 1 percent of withdrawals since 1975.

It is estimated that ground water supplies most of the water withdrawn for livestock supply in all of the north-central States, except Kentucky and Missouri (fig. 16). The percentage of water withdrawals for livestock derived from ground water in Illinois increased from about 75 percent from 1960 through 1980, to more than 95 percent since 1980. Surface water is estimated to account for nearly all of the water withdrawn for livestock supply in Kentucky, and for about 75 percent of withdrawals in Missouri.

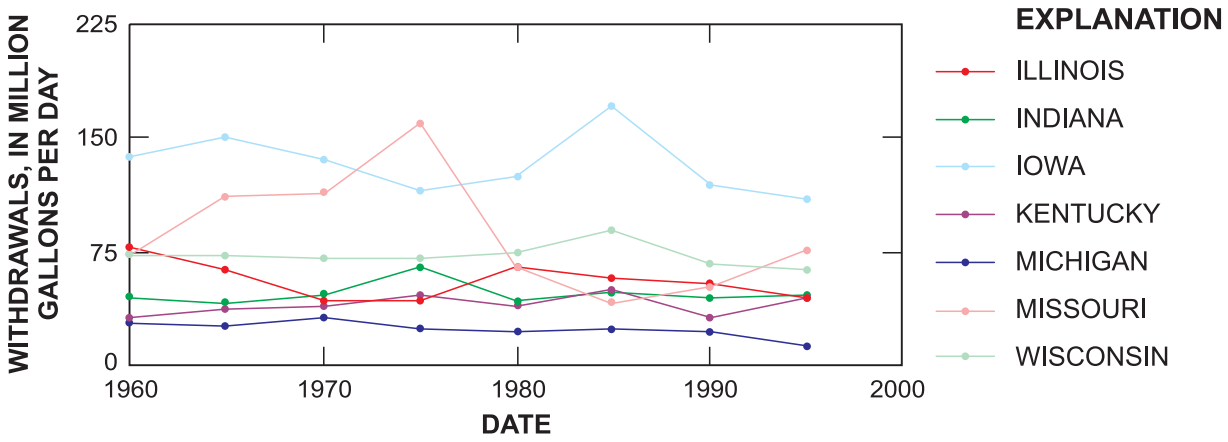

Figure 15. Total withdrawals for livestock supply in the north-central States, 1960-95.

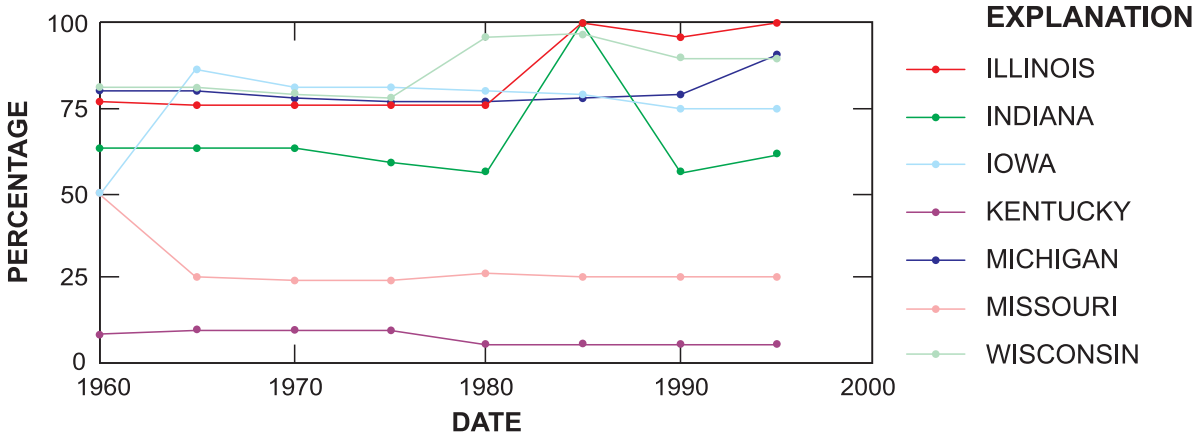

Figure 16. Percentage of water withdrawals for livestock use from ground water in the north-central States, 1960-95.

Withdrawals for livestock use typically constitute less than 8 percent of the total withdrawals from ground water in Illinois, Indiana, Kentucky, Michigan, and Missouri; constitute about 10 to 15 percent of the total withdrawals from ground water in Wisconsin; and typically are 15 to 25 percent of the total ground-water withdrawals in Iowa. Withdrawals for livestock use typically constitute less than 0.5 percent of the total withdrawals from surface water in Illinois, Indiana, Michigan, and Wisconsin; and are typically about 1 percent of the total withdrawals from surface water in Iowa, Kentucky, and Missouri.

Estimated withdrawals for animal-specialty use in 1990 and 1995 typically were less than 1 Mgal/d in Indiana, Iowa, Kentucky, Michigan, and Missouri; about 10 Mgal/d in Illinois; and about 30 Mgal/d in Wisconsin. The volume of water withdrawn for animal-specialty is less than 6 percent of the volume of water withdrawn for livestock use in Indiana, Iowa, Kentucky, and Missouri; from 5 to 27 percent of the volume withdrawn for livestock supply in Michigan; about 20 percent in Illinois; and about 45 percent in Wisconsin.

Withdrawals for Irrigation

The estimated volume of water withdrawn for irrigation has increased substantially since 1950 in each of the north-central States (fig. 17). Irrigation data were not available for Kentucky in 1995. Because water use for irrigation in the north-central States typically was negligible in 1950, the States with the largest increases from 1950 to 1995 also are the States with the largest total water use. Estimated water withdrawals for irrigation in the north-central States since 1980 typically were greatest in Missouri (306 to 567 Mgal/d); intermediate in Michigan (210 to 228 Mgal/d), Illinois (71 to 180 Mgal/d), Wisconsin (84 to 169 Mgal/d), and Indiana (47 to 116 Mgal/d); and least in Iowa (22 to 68 Mgal/d) and Kentucky (8 to 12 Mgal/d in 1990). The volume of water estimated to have been withdrawn for irrigation use increased overall from 1950 through 1995 in each of the north-central States, except Indiana and Iowa, which had their largest withdrawals in 1980 and 1985, respectively. Water withdrawals for irrigation always were less than 1 percent of the total withdrawals in Illinois and Kentucky; and typically were less than 1 percent in Indiana. Water withdrawals for irrigation supply typically were less than 3 percent if the total withdrawals in Iowa, Michigan, and Wisconsin, and have accounted for as much as 8.1 percent of the total withdrawals in Missouri.

Ground water has supplied an increasingly large percentage of the water withdrawn for irrigation in Illinois, Iowa, Missouri, and Wisconsin, accounting for more than 90 percent of irrigation water in 1995 in these States (fig. 18). Surface water accounts for nearly all of the water withdrawn for irrigation in Kentucky, and for slightly over half of irrigation withdrawals in

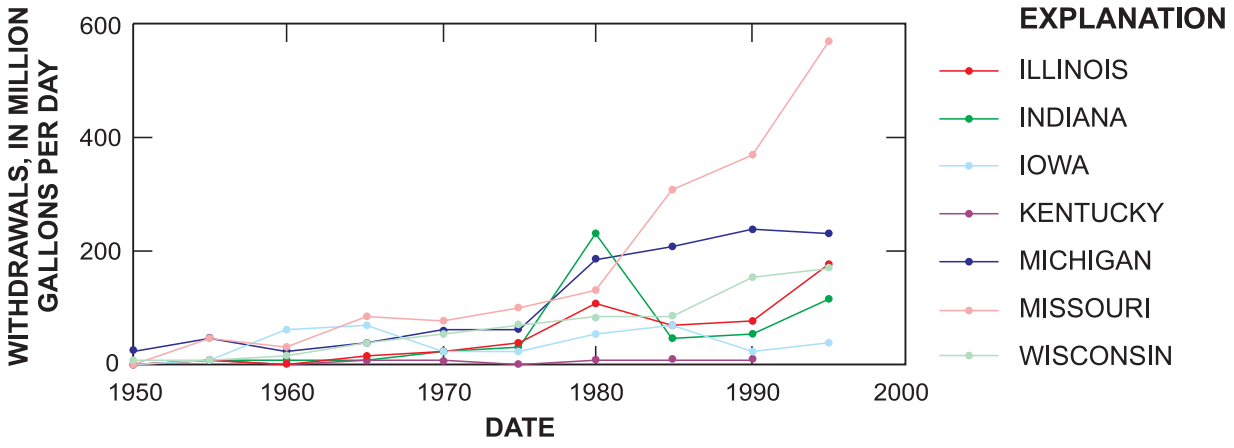

Figure 17. Total withdrawals for irrigation in the north-central States, 1950-95.

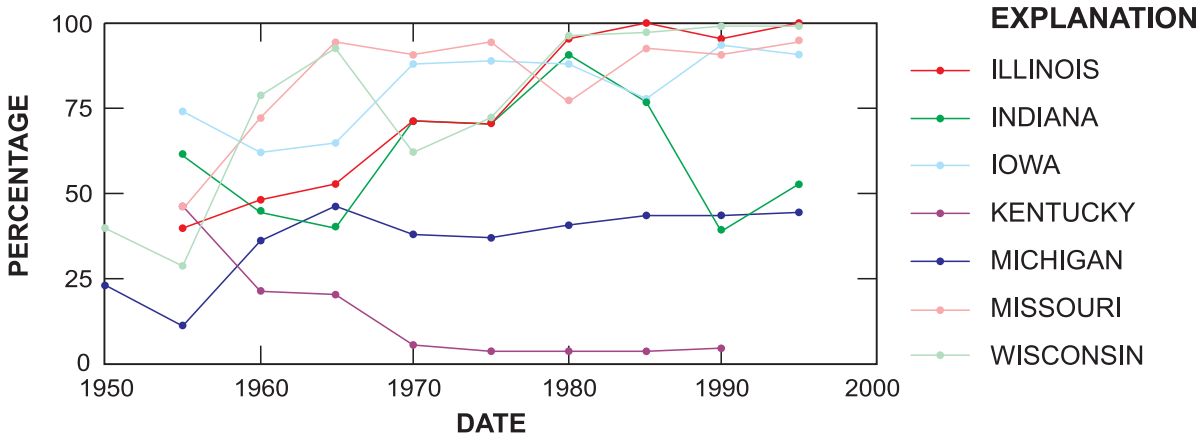

Figure 18. Percentage of water withdrawals for irrigation use from ground water in the north-central States, 1950-95.

Michigan. Ground water has supplied a highly variable percentage of the water withdrawn from irrigation in Indiana, decreasing from 61 percent in 1955 to 40 percent in 1965, increasing to 91 percent in 1980, decreasing to 39 percent in 1990, and increasing to 53 percent in 1995. The percentage of the total amount of water withdrawn for irrigation that is supplied by surface water and ground water in the north-central States, except Indiana, typically has varied by less than 6 percent since 1975.

Withdrawals for irrigation constitute an increasingly large percentage of the total withdrawals from ground water, increasing from essentially nothing in 1950 to 60 percent in Missouri, 22 percent in Wisconsin, 19 percent in Illinois, 12 percent in Michigan, and about 8 percent in Indiana and Iowa by 1995. Irrigation accounts for less than 1 percent of the ground-water withdrawals in Kentucky. Withdrawals for irrigation typically constitute less than 0.5 percent of the total withdrawals from surface water in all of the north-central States, except Michigan, where about 1 percent of all surface water withdrawn from 1980 through 1995 has been for irrigation.

Withdrawals for Self-Supplied Industrial Use

Estimated withdrawals for mining and self-supplied commercial use were included in the national estimates of withdrawals for self-supplied industrial use from 1950 through 1980, but were tabulated separately from 1985 through 1995. For consistency, water withdrawals for mining and self-supplied commercial use are included in the estimates of withdrawals for self-supplied industrial use in 1985, 1990, and 1995 presented in this report. Because industrial withdrawals were combined with withdrawals for thermoelectric power generation in 1950 and 1955, these years are omitted from the following discussion.

The volume of self-supplied water withdrawn for industrial use from 1960 through 1995 was largest in Indiana, Michigan, and Illinois. Self-supplied withdrawals for industrial use in Indiana and Michigan, and to a lesser extent Illinois, typically exceeded withdrawals from Iowa, Kentucky, Missouri, and Wisconsin by more than 1,000 Mgal/d (fig. 19). The volume of self-supplied industrial water withdrawn decreased between 12 and 60 percent in each of the north-central States, except Wisconsin, between 1980 and 1985 and continued to decrease through 1995 in Illinois (from 747 Mgal/d in 1985 to 630 Mgal/d in 1995), Indiana (from 2,751 to 2,508 Mgal/d), and Missouri (from 133 to 77 Mgal/d). The volume of self-supplied industrial water has increased above 1985 levels in Kentucky (from 283 Mgal/d in 1990 to 397 Mgal/d in 1995), Michigan (1,416 to 1,951 Mgal/d), and Wisconsin (from 466 to 470 Mgal/d). From 1960 through 1995, self-supplied industrial water withdrawals consistently have been from about 25 to 35 percent of the total water withdrawals in Indiana, typically were between 12 and 22 percent of the total

withdrawals in Michigan, were about 10 percent of total withdrawals in Iowa, and between 5 and 10 percent of total withdrawals in Kentucky and Wisconsin. Self-supplied withdrawals for industrial use decreased from more than 15 percent of total water withdrawals in 1960 to about 3 percent in 1995 in Illinois, and decreased from about 11 percent in 1965 to about 1 percent in 1995 in Missouri.

With the exception of Missouri and Iowa prior to 1990, most self-supplied water withdrawn for industrial use in the north-central States was taken from surface water. Surface water accounted for more than 80 percent of self-supplied water withdrawn for industrial use in Illinois between 1950 and 1980, but has been less than 70 percent since 1980. Surface water has consistently accounted for between 75 and 90 percent of the self-supplied water withdrawn for industrial use in Indiana and Michigan, about 70 percent in Kentucky, and has increased from about 30 to 73 percent of the self-supplied water withdrawn for industrial use in Iowa from 1950 to 1995.

Self-supplied withdrawals for industrial use constituted 50 percent or more of the total ground-water withdrawals in Illinois, Indiana, Kentucky, and Michigan at least once from 1960 through 1995, but have been a decreasing percentage of the total ground-water withdrawals in the north-central States during this period. From 1970 through 1995, self-supplied withdrawals for industrial use have accounted for about 25 percent of total ground-water withdrawals in Illinois, Indiana and Iowa, and Michigan; about 45 percent of total ground-water withdrawals in Kentucky; and about 15 percent of all ground-water withdrawals in Missouri and Wisconsin. From 1960 through 1995, self-supplied withdrawals for industrial use generally have accounted for an increasingly smaller percentage of the total surface-water withdrawals in Illinois (from more than 10 to less than 4 percent), and Missouri (from more than 6 to less than 1 percent); showed no clear variation through time in Indiana, Michigan, and Wisconsin; consistently accounted for about 6 percent of the total surface-water withdrawals in Kentucky; and accounted for a consistently larger percentage of total surface-water withdrawals in Iowa (from about 2 to 10 percent).

Mining

Although included in the discussion of self-supplied water withdrawals for industrial use for the entire 1950 to 1995 period, volumes of self-supplied water withdrawn for use in mining were broken out from self-supplied industrial use after 1980 (Solley and others, 1988, 1993, 1998), permitting detailed discussion of water withdrawals for use in mining operations from 1985 through 1995. Total water withdrawals for mining use from 1985 through 1995 were from 90 to 136 Mgal/d in Indiana; 75 to 105 Mgal/d in Illinois; 56 to 61 Mgal/d in Michigan; 34 to 62 Mgal/d in Iowa; about 25 Mgal/d in Missouri;

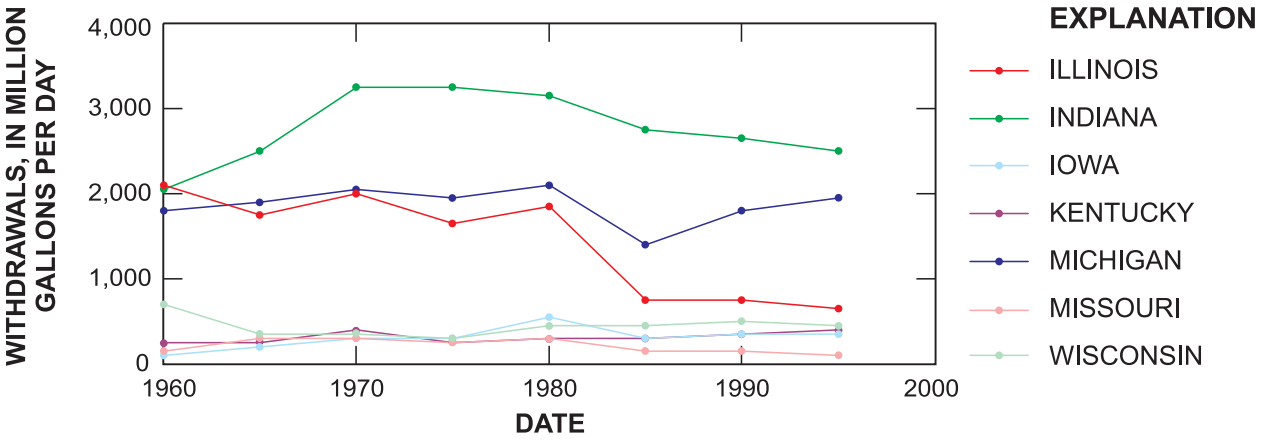

Figure 19. Total withdrawals for self-supplied industrial use in the north-central States, 1960-95.

and from 0 to 12 Mgal/d in Wisconsin. The volume of water withdrawn for use in mining operations decreased from 1985 through 1995 in Illinois and Iowa, increased in Indiana and Wisconsin, and essentially remained unchanged in Kentucky, Michigan, and Missouri. Saline water constitutes from 60 to 80 percent of the water withdrawals for mining in Illinois, but is not used to any appreciable extent for mining purposes in the other north-central States. Mining water withdrawals consistently have been less than 1 percent of the total water withdrawals in Illinois, Kentucky, Michigan, Missouri, and Wisconsin, and are about 1 percent of the total withdrawals in Indiana and Iowa.

Surface water consistently has accounted for about 91 percent of mining withdrawals in Indiana and about 85 percent of withdrawals in Michigan. Surface water has accounted for 50 to 65 percent of mining withdrawals in Illinois, and 71 to 87 percent of mining withdrawals in Kentucky. Surface water and ground water have accounted for highly variable percentages of mining withdrawals in Iowa and Wisconsin.

From 1985 through 1995, mining withdrawals constituted less than 2 percent of the total ground-water withdrawals in Indiana, Michigan, and Wisconsin; between 1 and 4 percent of the withdrawals from ground water in Kentucky and Missouri; and from 3 to 6 percent of the ground-water withdrawals in Illinois. Mining withdrawals were more than 7 percent of ground-water withdrawals in Iowa in 1985, but less than 0.5 percent in 1990 and 1995. Mining withdrawals accounted for about 13 percent of the self-supplied industrial water withdrawals in Illinois from 1985 through 1995, about 4 percent of the self-supplied withdrawals for industrial use in Indiana, about 7 percent in Kentucky, about 3 percent in Michigan, and less than 3 percent in Wisconsin. The percentage of self-supplied industrial water derived from mining withdrawals in 1985 through 1995 ranged from 10 to 21 percent in Iowa, and 19 to 31 percent in Missouri.

Commercial

Volumes of self-supplied water withdrawn for commercial use were reported separately from self-supplied industrial use after 1980 (Solley and others, 1988, 1993, 1998). These withdrawals, however, are primarily estimates with a high level of uncertainty. Total self-supplied water withdrawals for commercial use from 1985 through 1995 were substantially higher in Illinois (104 to 173 Mgal/d) than in any of the other north-central States, though by 1995 self-supplied withdrawals for commercial use from Indiana were 93 Mgal/d, only 11 Mgal/d below Illinois at that time. From 1985 through 1995, the estimated volume of self-supplied water for commercial use increased by a factor of about 90 in Indiana (1.1 to 93 Mgal/d), increased by about a factor of four in Wisconsin (4 to 17 Mgal/d), and did not vary substantially in the remaining north-central States (27 to 43 Mgal/d in Iowa, 34 to 41 Mgal/d in Michigan, and 13 to 22 Mgal/d in Kentucky and Missouri). Self-supplied water withdrawals for commercial use consistently have been less than 0.5 percent of the total water withdrawals in Kentucky, Michigan, Missouri, and Wisconsin, and consistently have been less than 1.5 percent of the total withdrawals in Illinois, Indiana, and Iowa.

Surface water accounts for an increasing percentage of the self-supplied water withdrawals for commercial use in Indiana, Iowa, and perhaps Illinois from 1985 through 1995 and was the source of more than half of the self-supplied water withdrawn for commercial use in these States by 1995. Surface water consistently has accounted for about 65 percent of the self-supplied water withdrawals for commercial use in Kentucky, and 60 to 75 percent of self-supplied water withdrawals for commercial use in Michigan. Ground water and has accounted for essentially all of the self-supplied water withdrawals for commercial use in Missouri and Wisconsin from 1985 through 1995.

From 1985 through 1995, self-supplied water withdrawals for commercial use constituted less than 5 percent of the total withdrawals from ground water and less than 1 percent of the total withdrawals from surface water in the north-central States. Commercial withdrawals accounted for less than 5 percent of the self-supplied withdrawals for industrial use in Indiana, Michigan, and Wisconsin from 1985 through 1995, about 6 percent of the self-supplied withdrawals for industrial use from Kentucky, and from 13 to 24 percent in Illinois and Missouri.

Withdrawals for Thermoelectric Power Generation

The volume of self-supplied water withdrawn for use in the generation of thermoelectric power from 1960 through 1995 (1995 data are not available for Kentucky) was largest in Illinois and Michigan, intermediate in Indiana, Wisconsin, and Missouri, and smallest in Kentucky and Iowa (fig. 20). The volume of self-supplied water withdrawn for use in the generation of thermoelectric power increased from 1960 to 1995 by more than a factor of 4 in Missouri (1,301 to 5,550 Mgal/d), increased by about a factor of two in Illinois (9,708 to 17,111 Mgal/d), Indiana (3,200 to 5,691 Mgal/d), Kentucky (2,000 to 3,448 Mgal/d), Michigan (3,900 to 8,373 Mgal/d), and Wisconsin, and increased by a factor of about one-half in Iowa (1,500 to 2,125 Mgal/d). Self-supplied water withdrawals for use in thermoelectric power generation have accounted for more than 65 percent of the total water withdrawals in Illinois from 1965 through 1995, and have accounted for more than 80 percent of the total water withdrawals in Illinois since 1980. Self-supplied water withdrawals for use in thermoelectric power generation typically have accounted for about 80 percent of the total withdrawals in Kentucky, from 70 to 85 percent of total withdrawals in Wisconsin, 60 to 80 percent in Michigan and Missouri, 65 to 75 percent in Iowa, and 55 to 68 percent of total withdrawals in Indiana. Essentially all of the water withdrawn for thermoelectric power generation in the north-central States is surface water.

Thermoelectric power generation typically has accounted for less than 2 percent of total withdrawals from ground water in Illinois, Indiana, Michigan and Wisconsin; has accounted for as much as 6.9 percent of ground-water withdrawals in Missouri; and has exceeded 15 percent of the total withdrawals from ground water in Kentucky since 1980. Withdrawals for thermoelectric power generation have accounted for an increasing percentage of the total withdrawals of surface water in Illinois (from about 75 to about 90 percent) and Missouri (from about 70 to about 90 percent); consistently have been between 85 to 95 percent in Iowa; 80 to 90 percent in Kentucky and Wisconsin; and about 60 to 75 percent in Indiana (fig. 21). Thermoelectric power generation accounted for an increasing percentage of the total surface-water withdrawals in Michigan from 1960 (about 61 percent) through 1980 (about 85 percent), and has declined since 1980.

ESTIMATED WATER USE

The total volume of water delivered from public-water suppliers to industrial and commercial users was estimated from 1955 through 1995. The total volume of water delivered from public-water suppliers for domestic use was estimated in 1985, 1990, and 1995. Estimates of deliveries from public-water supplies to domestic and industrial and commercial suppliers can be added to estimates of self-supplied domestic and

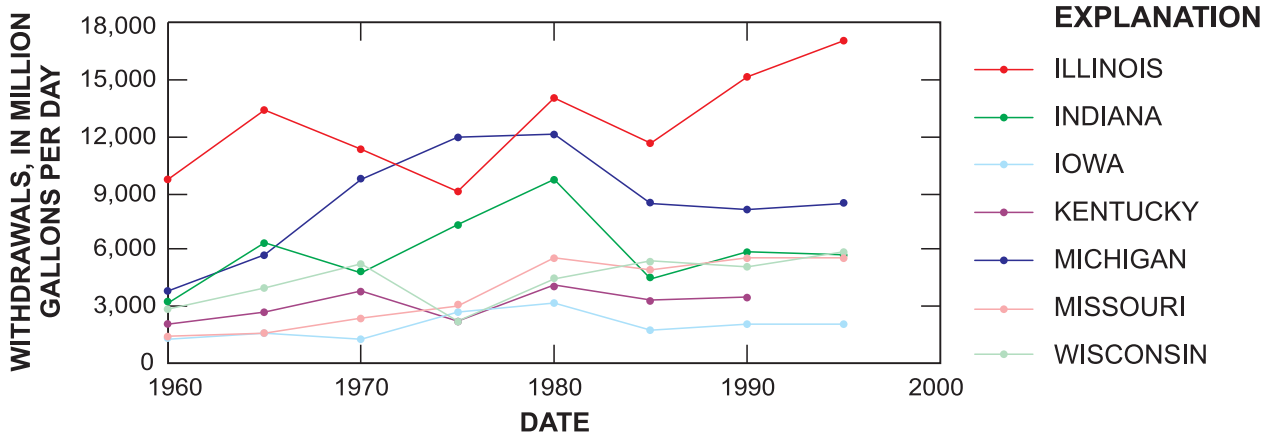

Figure 20. Total self-supplied withdrawals for thermoelectric power generation in the north-central States, 1960-95.

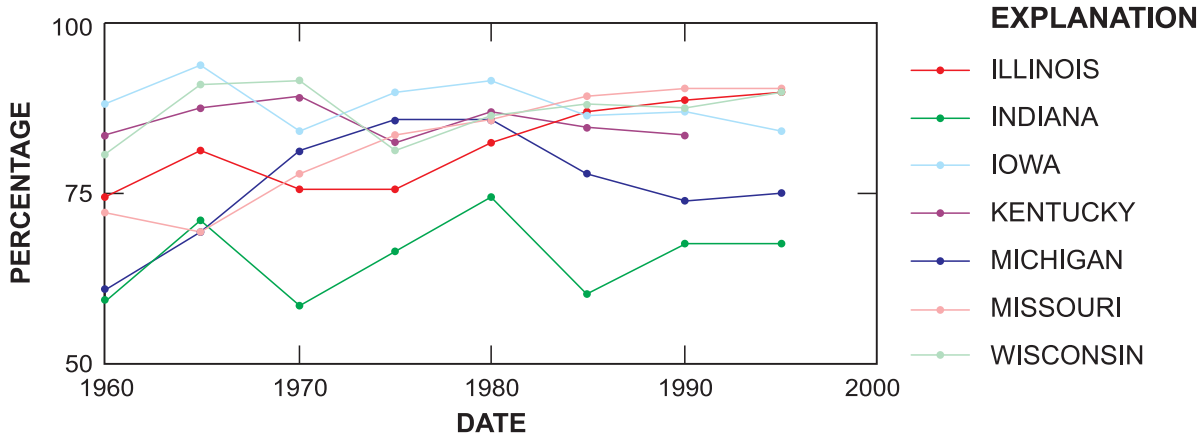

Figure 21. Percentage of total surface-water withdrawals in the north-central States used for thermoelectric power generation, 1960-95.

industrial and commercial withdrawals to determine the total amount of water used for domestic and industrial and commercial purposes in the north-central States. Withdrawals for livestock, irrigation, mining operations, and thermoelectric power generation are assumed to be self supplied; therefore, these uses already have been discussed.

Domestic

From 1985 through 1995, the volume of water used for domestic purposes from both municipal and self-supplied (rural domestic) systems totaled more than 975 Mgal/d in Illinois, between 700 and 820 Mgal/d in Michigan, 421 to 562 Mgal/d in Indiana, about 415 Mgal/d in Missouri, from 225 to 281 Mgal/d in Kentucky and Wisconsin, and typically about 180 Mgal/d in Iowa. Public-water supply deliveries constitute approximately 88 percent of all water used for domestic supply in Illinois and Missouri, 75 to 90 percent of the domestic supply from Kentucky, 75 to 80 percent of the domestic supply from Michigan, approximately 75 percent of domestic use in Indiana and Iowa, and 67 percent of domestic use in Wisconsin. Water used for domestic purposes accounted for about 4 to 7 percent of the total water withdrawals in each of the north-central States.

Industrial and Commercial

From 1985 through 1995, the volume of water used for industrial and commercial purposes from both municipal and self-supplied systems decreased from about 2,800 to 2,600 Mgal/d in Indiana, 1,350 to 1,100 Mgal/d in Illinois, and from about 300 to 250 Mgal/d in Missouri. From 1985 through 1995, the volume of water used for industrial and commercial purposes from both municipal and self-supplied systems increased from about 1,900 to 2,400 Mgal/d in Michigan; 330 to 720 Mgal/d in Wisconsin, 440 to 590 Mgal/d in Kentucky; and 280 to 450 Mgal/d in Iowa. Approximately 90 percent of the water for industrial and commercial supply in Indiana, 65 to 85 percent in Iowa and Michigan, 60 percent in Kentucky and Wisconsin, 50 percent in Illinois, and less than 40 percent in Missouri is self supplied. Industrial and commercial use accounted for about 30 percent of the total water use in Indiana, about 20 percent in Michigan, about 12 percent in Iowa, Kentucky, and Wisconsin, about 8 percent in Illinois, and about 4 percent in Missouri.

ESTIMATED WATER CONSUMPTION

Some portion of the water withdrawn for each water-use category is removed from the immediate water environment by evaporation; uptake by crops and animals; or incorporation into products. This water is consumed, or unavailable for reuse, until it returns as precipitation.

Reporting of water consumption by customers of public-water supplies, rural domestic households, and self-supplied industrial operations in the north-central States varied from 1960 through 1995, necessitating some manipulation of the data for this report. From 1960 through 1995, consumption of water by thermoelectric power plants, livestock and during irrigation was reported in a consistent manner and did not require manipulation. Again, values of consumptive use are highly estimated and may contain appreciable errors.

From 1960 through 1980, the water-use reports presented estimates of the volume of water consumed by domestic, industrial, and commercial customers of public-water suppliers; self-supplied (rural domestic) households; and self-supplied industrial systems. The total volume of water consumed by customers of public-water suppliers was reported during this period, but the volume of water consumed by the domestic, industrial, and commercial users was not differentiated.

From 1985 through 1995, the reports also presented estimates of the total volume of water consumed for domestic and industrial use. Consumption of water during industrial use from 1985 through 1995 was further divided into consumption during commercial and mining operations. The volume of water consumed by self-supplied and public-supplied methods of delivery for domestic and industrial use was not differentiated during this period.

To provide a consistent reporting of the estimates of water consumption, the percentage of the total estimated domestic and industrial (including commercial) water use delivered by public-supply systems from 1985 through 1995 was multiplied by the total volume of water estimated to have been consumed for each of these water-use categories. These values then were totaled to estimate the consumptive use associated with deliveries from public-supply systems. The percentage of the self-supplied withdrawals for domestic and industrial (including commercial and mining) use also was multiplied by the total volume of water consumed for each of these categories to estimate the volume of water consumed by self-supplied industrial and rural domestic water use during this period. All, or virtually all withdrawals for livestock use, irrigation, and thermoelectric power generation are self-supplied; therefore, the consumption estimates for these water uses did not require manipulation to estimate a public-supply component.

Total Consumption

Water consumption in each of the north-central States showed an overall increase from 1960 through 1995. Illinois typically had the largest water consumption of the north-central States (884 Mgal/d in 1995) (fig. 22). Michigan (668 Mgal/d), Missouri (690 Mgal/d), and Indiana (505 Mgal/d) had large to intermediate consumption from 1960 through 1995, whereas Wisconsin (442 Mgal/d), Kentucky (318 Mgal/d), and Iowa (290 Mgal/d) typically consumed the smallest amounts of water. Comparison of the total water consumption in 1960 and 1995 showed an increase of less than a factor of two in Iowa (234 to 290 Mgal/d) and Indiana (295 to 505 Mgal/d), an increase by a factor of about 2.5 in Illinois (337 to 884 Mgal/d), and about a factor of three in Missouri (244 to 691 Mgal/d), Wisconsin (150 to 442 Mgal/d), Michigan (212 to 668 Mgal/d), and Kentucky (96 to 318 Mgal/d).

Less than 8 percent of all of the water withdrawn in Illinois, Indiana, Kentucky, Michigan, and Wisconsin; and about 10 percent of all of the water withdrawn in Iowa and Missouri, from 1960 through 1995 was consumed. These percentages varied by 5 percent or less in each of the north-central States from 1960 through 1995.

Public-Water Supplies

From 1960 through 1995, the volume of water delivered from public-water supply systems that was consumed decreased slightly in Illinois and Indiana, increased by less than a factor of two in Michigan, Missouri, and Kentucky, increased by more than a factor of two in Wisconsin, and increased by more than a factor of four in Iowa (fig. 23). Water consumption from public-supply systems typically was largest in Illinois, but decreased by about a factor of ten in 1975 and 1980, before increasing again in 1985. The large decline in the estimate of the volume of water consumed is related to a change in how consumption was calculated in Illinois at that time. Domestic uses, including lawn watering, typically have accounted for more than half of the water consumed from public supply systems since 1980 in the north-central States.

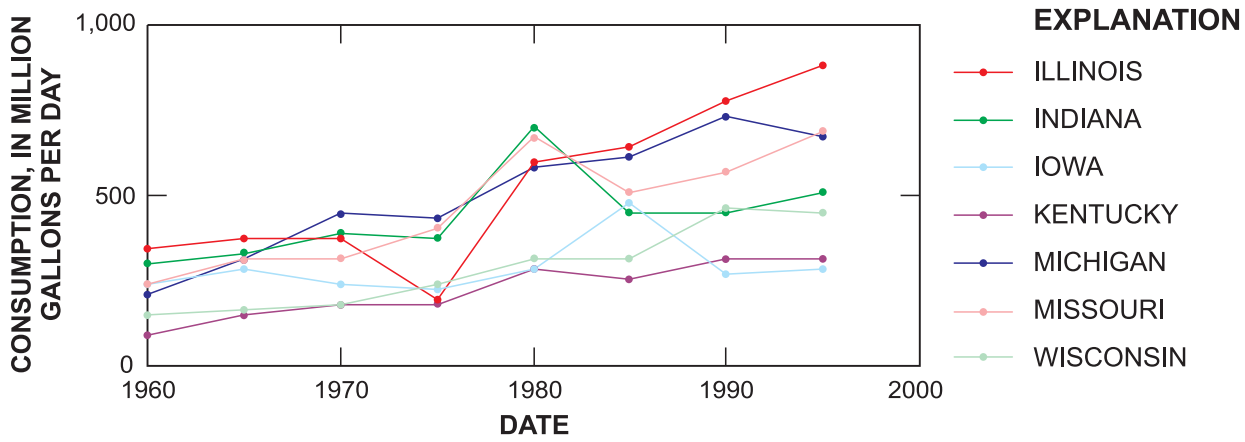

Figure 22. Total water consumption in the north-central States, 1960-95.

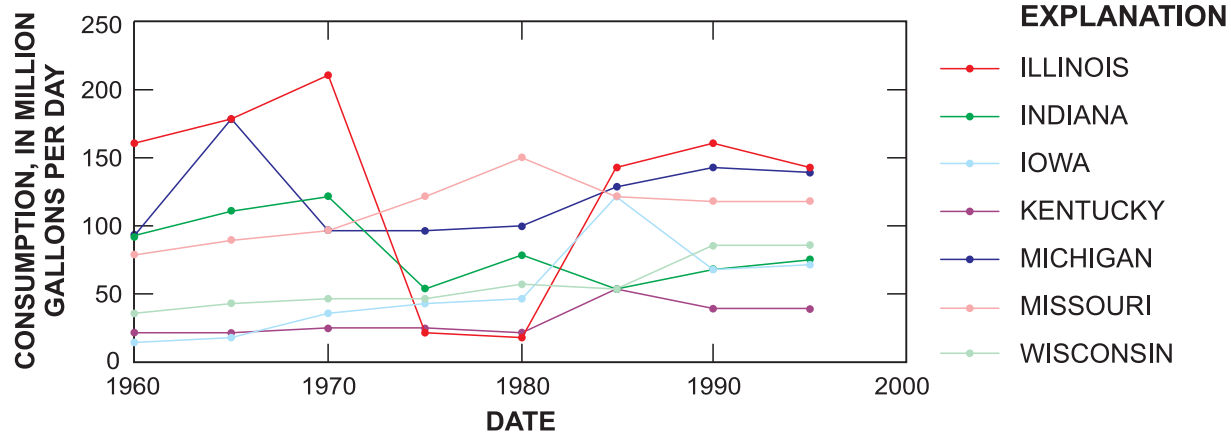

Figure 23. Water consumption by customers of public supplies in the north-central States, 1960-95.

Estimates indicate that from 3 to 57 percent of the water consumed from 1960 through 1995 was obtained from public-supply systems in the north-central States (fig. 24). With the exception of Iowa, these percentages have decreased through time, particularly in Illinois, Indiana, and Michigan. Since 1980, consumption of water from public-supply systems has accounted for about 25 percent of the water consumed in Iowa; about 20 percent of the water consumed in Illinois, Michigan, Missouri, and Wisconsin; and about 15 percent of the water consumed in Indiana and Kentucky.

Estimates are that about 10 percent of the water from public-water supply systems was consumed in Illinois, Kentucky, and Michigan, and about 20 percent was consumed in Missouri. Prior to 1975, about 25 percent of public supply water in Indiana was consumed, decreasing to less than 15 percent since 1970. In Iowa, about 10 percent of the water from public-water supplies was estimated to have been consumed, increasing to 20 percent or more after 1980.

Rural Domestic

From 1960 through 1995, the volume of water withdrawn for rural domestic use that was consumed decreased substantially in Illinois, Indiana, Kentucky, and Missouri, remained essentially unchanged in Iowa and Michigan, and increased by about a factor of two in Wisconsin (fig. 25). Water consumption for rural domestic use in the north-central States varied by more than 50 Mgal/d from 1960 through 1970, but has varied by less than 20 Mgal/d from 1985 through 1995.

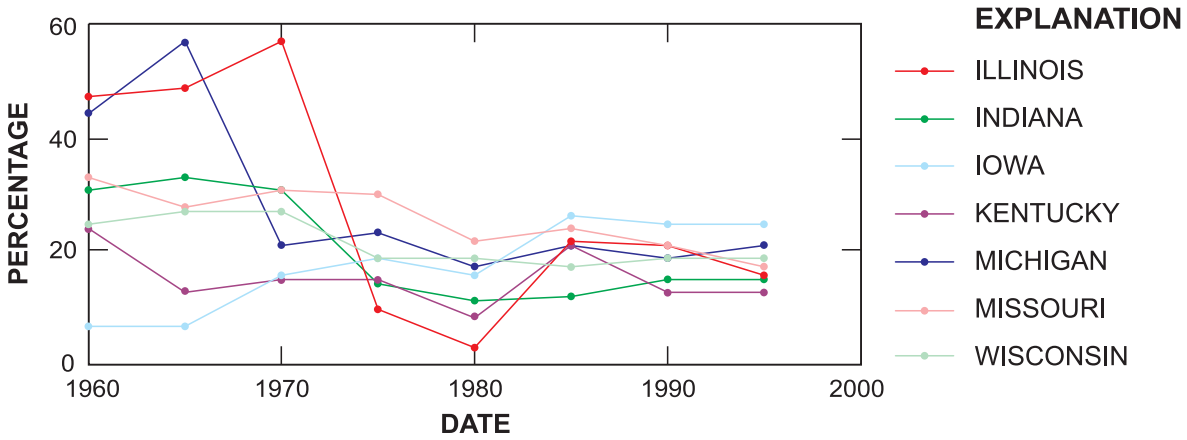

Figure 24. Percentage of total water consumption in the north-central States by customers of public supplies, 1960-95.

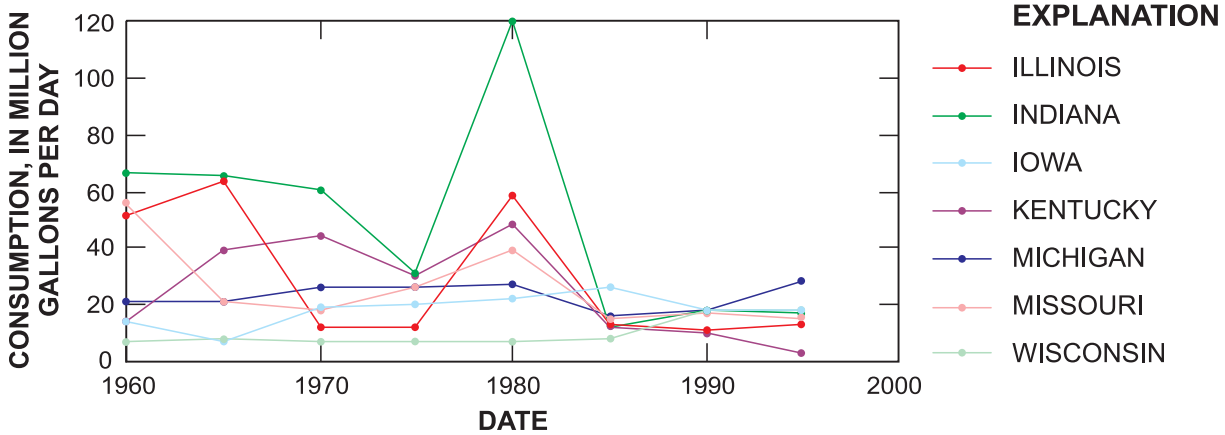

Figure 25. Rural domestic water consumption in the north-central States, 1960-95.

Estimates indicate that from 1 to 25 percent of all of the water consumed from 1960 through 1995 was consumed in rural domestic use (fig. 26). With the exception of Iowa and Wisconsin, these percentages have decreased through time, particularly in Illinois, Indiana, and Kentucky. Since 1980, water consumption from rural domestic systems has accounted for about 6 percent of the total water consumed in Iowa and 5 percent or less of the water consumed in the remaining north-central States.

Estimates indicate that from 10 to 100 percent of the water withdrawn for rural domestic use was consumed in the north-central States from 1960 through 1995 (fig. 27). These values tend to vary between States and through time, indicating that the variations in the estimates are affected by changes in the underlying assumptions for the calculations. From 1985 through 1995, the mean percentages of water withdrawals for domestic use that have been consumed varied from 10 percent in Illinois to 40 percent in Iowa.

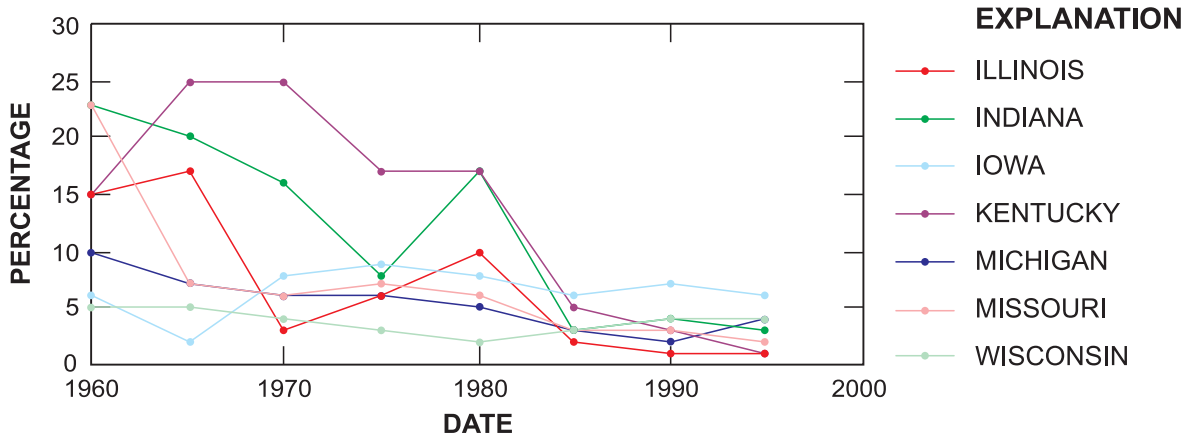

Figure 26. Percentage of total water consumption in the north-central States from rural-domestic systems, 1960-95.

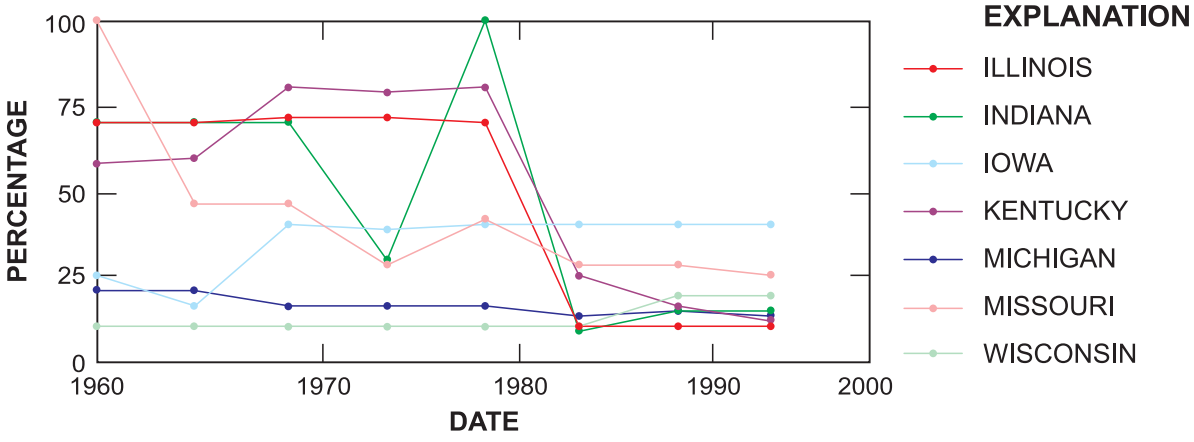

Figure 27. Percentage of water withdrawals for rural-domestic use in the north-central States that is consumed, 1960-95.

Livestock

From 1960 through 1995, the volume of water consumed by livestock in the north-central States decreased by less than a factor of two in Illinois, Indiana, Iowa, Michigan and Wisconsin, essentially remained unchanged in Missouri, and increased by less than a factor of two in Kentucky. Because water consumed by livestock (including water held in stock-water ponds) is evaporated or discharged as wastewater to the ground, essentially all water withdrawn for use by livestock is consumed; therefore, trends in livestock consumption mirror trends in water withdrawals for livestock use (fig. 15).

Estimates indicate that from 2 to 56 percent of all of the water consumed in the north-central States from 1960 through 1995 was consumed by livestock (fig. 28). These percentages have decreased through time in each of the north-central States.

Irrigation

Incorporation into crops, evaporation, or seeping into shallow ground water typically consumed more than 90 percent of all water withdrawn for irrigation in the north-central States except Missouri, where about 75 percent of all water withdrawn for irrigation is estimated to have been consumed. Because water withdrawals for irrigation in each of the north-central States (except Iowa) increased substantially from 1960 through 1995 (fig. 17), consumption of water withdrawn for irrigation also increased substantially. Consumption of water withdrawn for irrigation in Iowa decreased by less than a factor of two from 1960 through 1995.

Estimates indicate that from 1 to 64 percent of all of the water consumed in the north-central States from 1960 through 1995 was irrigation water (fig. 29). In Iowa, irrigation water declined from about 25 percent of the water consumed in 1960 and 1965 to about 10 percent of the water consumed in 1980 and 1985. From 1960 through 1995, irrigation water has been an increasing percentage of the water consumed in Illinois (from 1 percent in 1960 to 20 percent in 1995), Indiana (2 to 21 percent), Michigan (10 to 32 percent), Missouri (11 to 61 percent), and Wisconsin (11 to 34 percent); and was consistently about 3 percent of the total amount of water consumed in Kentucky.

Self-Supplied Industrial Water

Between 1960 and 1995, the volume of water obtained from self-supplied industrial systems that was consumed decreased by less than a factor of two in Kentucky, remained essentially unchanged in Missouri, increased by about a factor of two in Illinois and Indiana, increased by about a factor of three in Iowa and Michigan, and increased by more than a factor of four in Wisconsin (fig. 30). Consumption of water from self-supplied industrial systems typically was largest in Indiana or Michigan, and was smallest in Iowa, Kentucky, or Missouri.

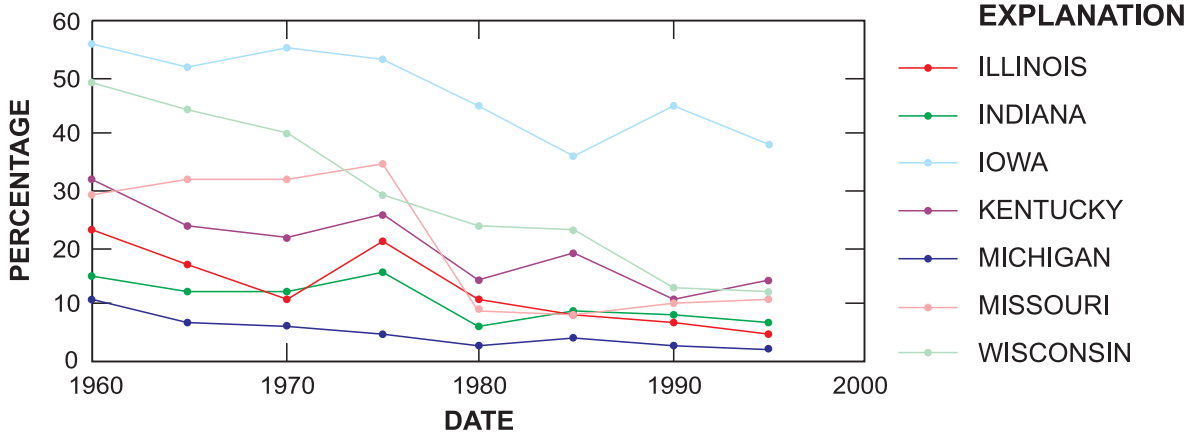

Figure 28. Percentage of total water consumption in the north-central States by livestock, 1960-95.

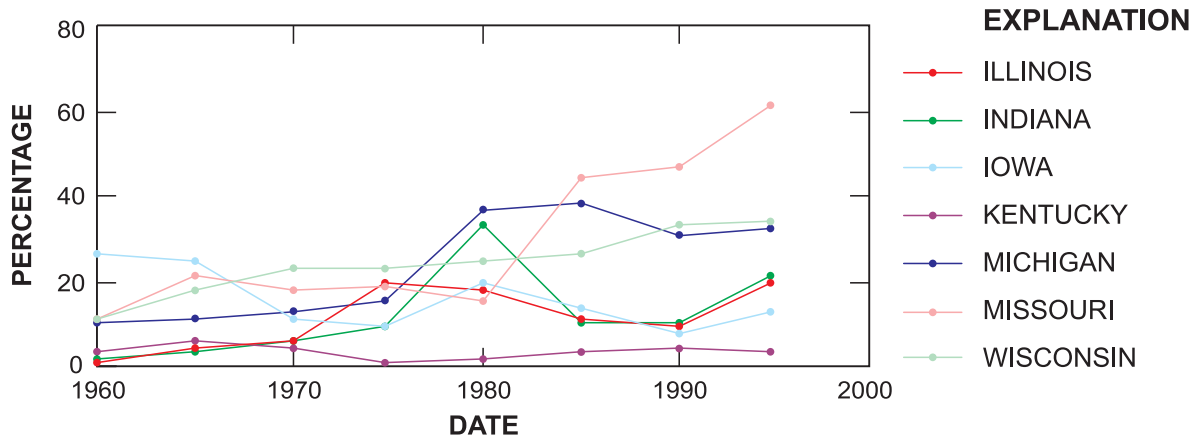

Figure 29. Percentage of total water consumption in the north-central States from irrigation, 1960-95.

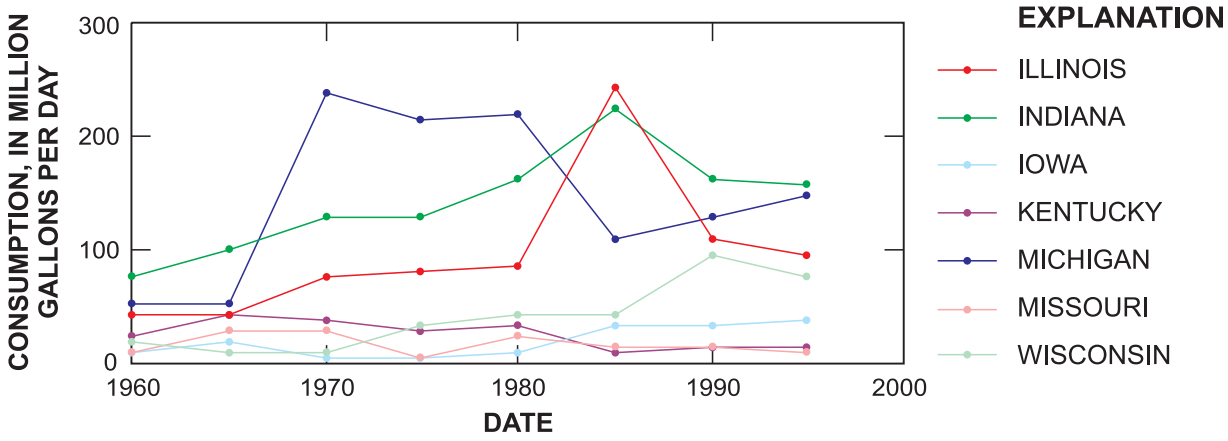

Figure 30. Water consumption by self-supplied industrial systems in the north-central States, 1960-95.

Estimates indicate that from 1 to 54 percent of all of the water consumed in the north-central States from 1960 through 1995 was consumed from self-supplied industrial systems (fig. 31). These percentages have varied substantially through time, and have shown no consistent trends. Since 1985, water consumption from self-supplied industrial systems has accounted for less than 5 percent of the total water consumed in Kentucky and Missouri; about 12 percent of the water consumed in Illinois and Iowa; about 20 percent of the total water consumed in Michigan and Wisconsin; and about 33 percent of the total water consumed in Indiana.

Estimates indicate that since 1980 about 4 percent of the water withdrawn from self-supplied industrial systems in Kentucky was consumed. About 7 percent of the water withdrawn from self-supplied industrial systems in Indiana and Michigan; about 10 percent of the water in Iowa and Missouri; and about 15 percent of the water withdrawn from self-supplied industrial systems in Illinois and Wisconsin was consumed.

Thermoelectric Power Generation

From 1960 through 1995, the volume of water consumed during the generation of thermoelectric power increased by a factor of five in Iowa, and increased by more than a factor of ten in the remaining north-central States (fig. 32). Most of this increase has occurred since 1975. Since 1975, water consumption during the generation of thermoelectric power typically was largest in Illinois, followed by Kentucky, Michigan, Indiana, Missouri, Wisconsin, and Iowa.

Estimates indicate that from less than 1 to as much as 66 percent of all of the water consumed in the north-central States from 1960 through 1995 was consumed during the generation of thermoelectric power (fig. 33). Thermoelectric power generation consistently has accounted for an average of about 6 percent of all of the water consumed in Iowa from 1960 through 1995. These percentages have varied substantially through time in the other north-central States, but have tended to increase substantially since 1970 or 1975. In 1990 and 1995, thermoelectric power generation accounted for about 12 percent of the total

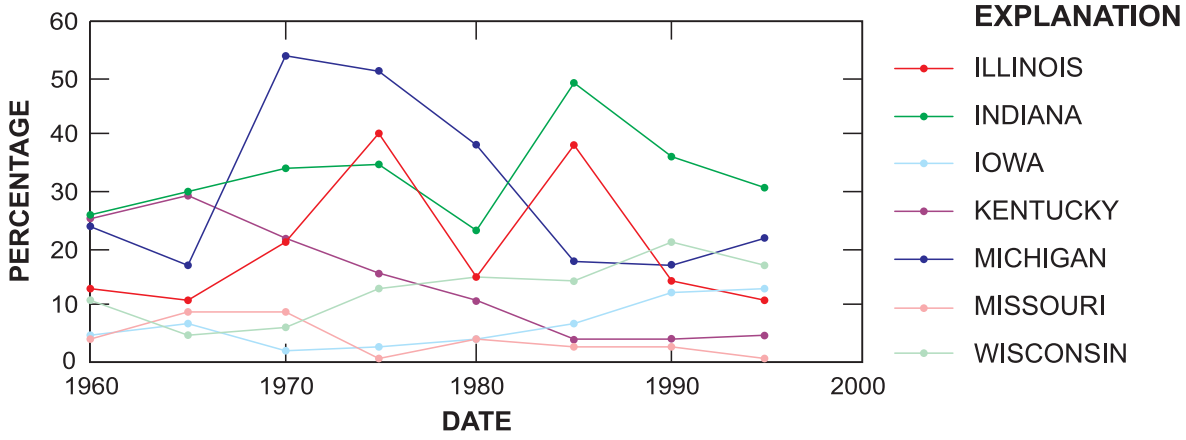

Figure 31. Percentage of total water consumption in the north-central States by self-supplied industrial systems, 1960-95.

water consumed in Missouri and Wisconsin; about 25 percent of the total water consumed in Indiana and Michigan; about 45 percent of the water consumed in Illinois; and about 65 percent of the water consumed in Kentucky.

Less than 4 percent of the water withdrawn for generation of thermoelectric power in the north-central States from 1960 through 1995 was consumed. The large percentage of the total water consumed attributed to the generation of thermoelectric power is affected by the large amount of the water withdrawn for the generation of thermoelectric power.

SUMMARY

Management of water supplies within an area of concern is aided by knowledge of the total amount of water withdrawn from surface water and ground water, the disposition of the water, temporal trends in the disposition of the water, and water use in hydraulically adjacent areas. Estimation of water withdrawals in Illinois and the nearby States of Indiana, Iowa, Kentucky, Missouri, Michigan, and Wisconsin (referred to as the north-central States in this report) by the U.S. Geological Survey (USGS) from 1950

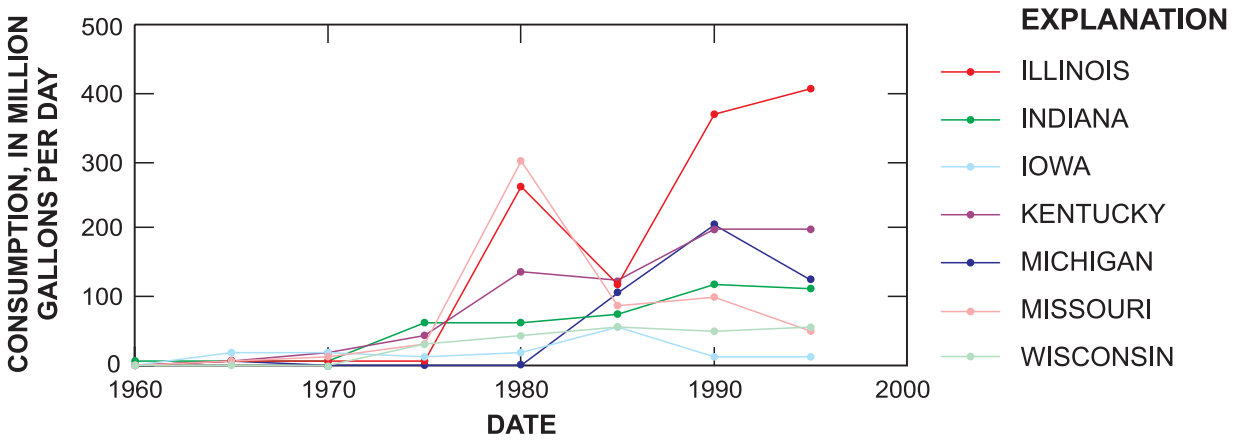

Figure 32. Water consumption by generation of thermoelectric power in the north-central States, 1960-95.

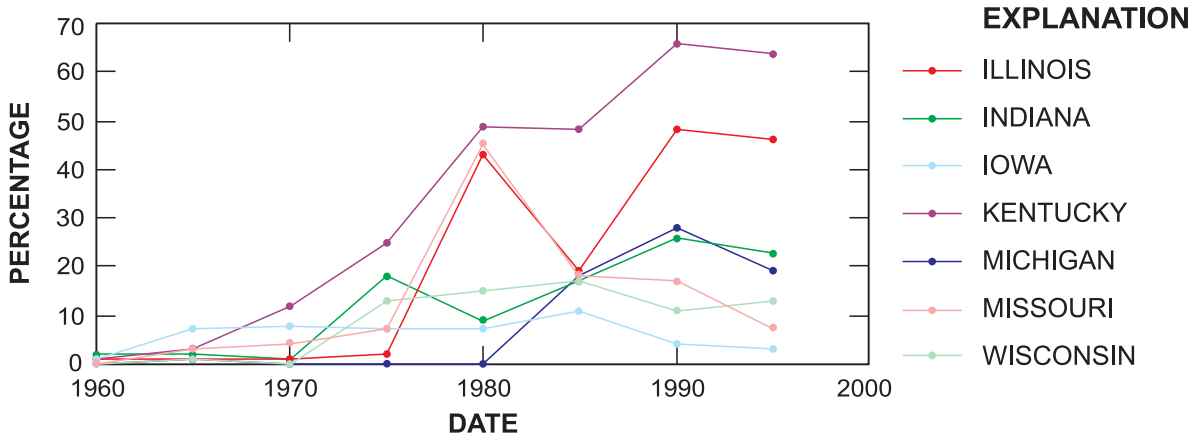

Figure 33. Percentage of total water consumption in the north-central States from thermoelectric power generation, 1960-95.

through 1995 allows for a general assessment of regional and temporal changes in water withdrawals and water use in the north-central States.

Total water withdrawals in Illinois doubled from 1950 through 1995 and have exceeded total water withdrawals in Indiana, Iowa, Kentucky, Michigan, Missouri and Wisconsin during this period by as much as a factor of eight. Per capita withdrawals in Illinois during this period were either the largest or second largest of the north-central States, but the disparity in per capita water use decreased from 1950 through 1995. Approximately 95 percent of all water withdrawals in Illinois are from surface water, which is similar to or slightly higher than the percentage of the total water withdrawals in most of the north-central States. Surface-water withdrawals are higher in Illinois than in the other north-central States, and total water withdrawals from surface water doubled from 1950 to 1995, a magnitude of increase that tended to be similar to or lower than most of the other north-central States. Total water withdrawals from ground water in Illinois typically exceeded those of the other north-central States, but have decreased since 1975.

Self-supplied water withdrawals for generation of thermoelectric power constitute about 75 to 90 percent of surface-water withdrawals in Illinois, a percentage that tends to be somewhat higher than the other north-central States. Withdrawals of water for public-water supply constitute about 10 percent of surface-water withdrawals in Illinois, the percentage decreasing somewhat since 1950. Withdrawals of water for public-water supply were as much as 64 percent of the total ground-water withdrawals in Illinois from 1950 through 1995, but have been less than 50 percent of the total withdrawals from ground water since 1975. Self-supplied ground water for industrial use has constituted a decreasing percentage of the total ground-water withdrawals, from 50 percent of total ground-water withdrawals in 1960 to about 25 percent of withdrawals since 1965. Irrigation is the fastest growing category of withdrawals from ground water from 1950 through 1995 in the north-central States.

The volume of water estimated to have been consumed in the north-central States from 1960 through 1995 increased, typically by more than a factor of two. Total water consumption typically was 10 percent or less of the total withdrawals. The percentages of the total water consumption attributed to each of the water-use categories varied through time in each of the north-central States. Rural-domestic supply, livestock use, and deliveries from public-water supply systems, typically accounted for a decreasing percentage of the total water consumption in the north-central States from 1960 through 1995, whereas irrigation and thermoelectric power generation accounted for an increasing percentage of the total water consumption. Consumptive use is highly estimated and values may contain appreciable errors.

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GLOSSARY

Animal specialties—Water use associated with the production of fish in captivity, except fish hatcheries, fur-bearing animals in captivity, horses, rabbits, and pets.

Aquaculture—Farming of organisms that live in water, such as fish, shellfish, and algae.

Commercial water use—Water for motels, hotels, restaurants, office buildings, other commercial facilities, and institutions. The water may be obtained from a public supply or may be self supplied.

Consumptive use—That part of the water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment. Also referred to as water consumed.

Conveyance loss—Water that is lost in transit from a pipe, canal, conduit, or ditch by leakage or evaporation.

Domestic water use—Water for household purposes, such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and watering lawns and gardens. The water may be obtained from a public supply or may be self supplied.

Evaporation—Process by which water is changed from a liquid into a vapor.

Ground water—Generally all subsurface water as distinct from surface water; specifically that part of the subsurface water in the saturated zone (a zone in which all voids are filled with water) where the water is under pressure greater than atmospheric.

Industrial water use—Water that is used for industrial purposes, such as fabrication, processing, washing, and cooling, and includes such industries as steel, chemical, and allied products, paper and allied products, mining, and petroleum refining. The water may be obtained from a public supply or may be self supplied.

Irrigation water use—Artificial application of water on lands to assist growing of crops and pastures or to maintain vegetative growth in recreational lands, such as parks and golf courses.

Livestock water use—Water for livestock watering, feed lots, dairy operations, fish farming, and other on-farm needs. Livestock as used here includes cattle, sheep, goats, hogs, and poultry. Also included are animal specialties.

Million gallons per day (Mgal/d)—A rate of flow of water.

Mining water use—Water use for the extraction of minerals occurring naturally including solids, such as coal and ores; liquids, such as crude petroleum; and gases, such as natural gas. Also includes uses associated with quarrying, well operations (dewatering) (prior to 1995), milling (crushing, screening, washing, flotations, and so forth), and other preparations. Use of water in mining operations customarily is done at the mine site or as part of a mining activity. Does not include water used in processing, such as smelting, refining petroleum, or slurry pipeline operations, which are included in industrial water use.

Offstream use—Water withdrawn or diverted from a ground- or surface-water source for public-water supply, industry, irrigation, livestock, thermoelectric power generation, and other uses.

Per capita water use—The average amount of water used per person during a standard time period.

Public supply—Water withdrawn by public and private water suppliers and delivered to users. Public suppliers provide water for a variety of uses, such as domestic, commercial, thermoelectric power, industrial, and public-water use.

Rural domestic water use—Self-supplied water for domestic water use.

Saline water—Water that contains more than 1,000 milligrams per liter of dissolved solids.

Self-supplied water—Water withdrawn from a surface- or ground-water source by a user rather than being obtained from a public supply.

Surface water—An open body of water, such as a stream or a lake.

Thermoelectric power water use—Water used in the process of generation of thermoelectric power. The water may be obtained from a public supply or may be self supplied.

Transpiration—Process by which water that is absorbed by plants is evaporated into the atmosphere.

Water use—In a restrictive sense, the term refers to water that actually is used for a specific purpose, such as for domestic use, irrigation, or industrial processing. In this report, the quantity of water use for a specific category is the combination of self-supplied withdrawals and public-supply deliveries.

Withdrawal—Water removed from the ground or diverted from a surface-water source for use.

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