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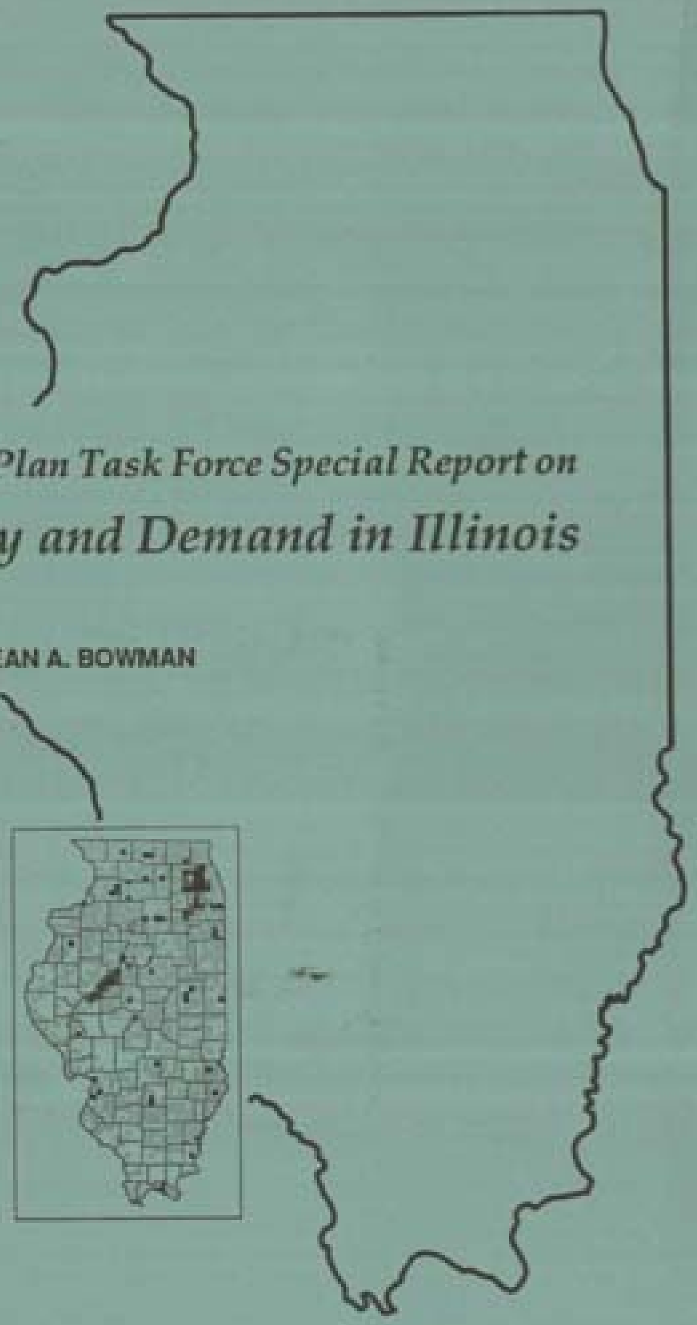
DEPARTMENT OF ENERGY AND NATURAL RESOURCES

State Water Plan Task Force Special Report on

Ground-Water Supply and Demand in Illinois

by JEAN A. BOWMAN



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STATE WATER PLAN TASK FORCE SPECIAL REPORT ON GROUND-WATER SUPPLY AND DEMAND IN ILLINOIS

REPORT OF INVESTIGATION 116

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Title: Stale Water Plan Task Force Special Report on Ground-Water Supply and Demand in Illinois.

Abstract: Present and projected municipal, industrial, and agricultural irrigation ground-water withdrawals are compared to potential ground-water yields on a township scale for the state. The present ground-water supply and demand balance shows long-term deep-sandstone overpumpage in the Chicago metropolitan area and the "Collar Counties" surrounding Chicago due to high demand for ground water for municipal and industrial purposes. There are also indications of possible seasonal overpumpage in certain regions where agricultural irrigation is practiced. Projections indicate a reduction in the overpumpage problem in the Collar County region due to the shift by numerous public water supply systems from ground water to Lake Michigan water. Changes in industrial pumpage are difficult to foresee; in general, they can be expected to fluctuate above and below their average, without having a significant effect on the regional ground-water balance. Large-scale increases in irrigated acreage could significantly affect ground-water resources in Illinois. If increases occur near sandy soils and productive aquifers, where irrigation is already widely practiced, the expanded ground-water pumpage is not expected to cause long-term ground-water resource depletion. Such increases could, however, exaggerate seasonal water-level declines and create increased competition, conflict, and well-interference problems.

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Indexing Terms: Ground water, ground-water resources, Illinois, industrial water, irrigation, municipal water, projections, water balance, water demand, water supply, water use.

State Water Plan Task Force Special Report 12

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Ground-Water Supply and Demand in Illinois

by Jean A. Bowman

ABSTRACT

Ground-water supplies are available to meet most demands in Illinois. However, in some places and under certain conditions, the demand may exceed the supply. Because the demand for ground water for municipal, industrial, and agricultural irrigation uses continues to increase, there has been a growing interest in understanding the regional balance between ground-water supply and demand in Illinois.

This report compares present and projected ground-water uses with ground-water potential yields on a township scale. The potential yield information was gathered for deep sandstone, shallow bedrock, and unconsolidated sand and gravel formations as part of the 1967 Illinois Water Plan issued by the Technical Advisory Committee on Water Resources.

Information on present municipal and industrial ground-water use was obtained from the Illinois Water Inventory Program, which has documented and reported ground-water withdrawals since 1978. Present municipal and industrial ground-water withdrawals are based on averages for 1980-1987.

Present agricultural irrigation estimates are based on a soil- and weather-dependent water-balance model that determines irrigation demand. The demand is then extrapolated into a daily ground-water use value according to the present irrigated acreage in each township.

Projections are also made in this report for municipal, industrial, and agricultural irrigation ground-water withdrawals. Municipal (public water supply) projections are based on a per capita ground-water use for each public water supply system in the state using ground water, according to the population served by each system.

The population served by each system was adjusted by the 1995 projected population change for each county; those projections were made by the Illinois Bureau of the Budget. Adjusted population served by each public water supply system was multiplied by the per capita ground-water use for that system to arrive at projected 1995 municipal ground-water use.

Industrial ground-water use projections were made for industries that supply their own water from a well. Projections were based on adding and subtracting one standard deviation of the 1980-1987 mean ground-water use for each manufacturing category, and adding and subtracting 10 percent of the mean for non-manufacturing uses.

The correct percentage change for each manufacturing or non-manufacturing category was applied to each facility's pumpage in each township of the state for new township totals. The assumption in this method of projection is that given the large uncertainties in industrial ground-water use, the actual ground-water withdrawals will fluctuate above and below the average, as has been the case since 1980, when detailed industrial pumpage record-keeping began statewide.

Agricultural irrigation projections are based on the same water-balance model used for present irrigation estimates. "Irrigable" acreage in Illinois was determined on the basis of soil characteristics and ground-water availability.

The present balance between ground-water supply and demand shows a significant overpumpage problem in the Chicago metropolitan area and in the four surrounding "Collar Counties" (Cook, DuPage, Lake, and Will). This overpumpage is caused by large municipal and industrial demands. In addition, seasonal overpumpage may be experienced in several localized regions where agricultural irrigation is concentrated. This overpumpage is limited to the growing season and is almost entirely balanced by normal recharge over the course of a year. The amount of seasonal overpumpage is largely

determined by weather conditions, since irrigation pumpage is greatly increased in dry years.

The projected balance between ground-water supply and demand shows a reduction in the overpumpage problems in the Chicago/Collar Counties region as a result of shifts from ground water to Lake Michigan water by numerous public water supply systems. Elsewhere in the state, anticipated changes in municipal and industrial pumpage are expected to be small enough or localized enough that they will have only minor effects on the ground-water supply-and-demand balance.

The possibility of large expansions in agricultural irrigation should be considered. This report concludes that expansions are most likely in areas with sandy soils and productive aquifers where irrigation is already being practiced with economic success. In those areas, large expansions in irrigation might exaggerate seasonal water-level declines, but average annual recharge should still provide for full resource recovery.

Extended droughts will continue to be a serious but temporary problem in two ways: 1) irrigation pumpage is greatly increased during droughts; and 2) annual ground-water recharge is reduced during droughts. A long-term climatic change could seriously alter the present balance in which annual recharge compensates for high seasonal irrigation pumpage.

INTRODUCTION

Purpose of Study

The availability and use of ground water in Illinois vary widely, both regionally and seasonally. Ground-water resources are abundant, but they are also finite and are not distributed uniformly. For the most part, ground-water resources are available to meet the demand. However, in some places and under certain conditions, the demand may exceed the supply-

As population, industry, and irrigated agriculture have grown in Illinois, ground water has been relied on increasingly as a dependable source for clean water. Approximately 50 percent of Illinois residents rely on ground water for their drinking water supplies. Between 1980 and 1987, approximately 1 billion gallons of ground water were pumped daily to supply municipal, industrial, rural, irrigation, and other demands. Generally, about 40 percent of that total was used for public water supplies, 20 percent for industries that supply their own water from water wells, and 40 percent for agricultural irrigation and other rural uses, including rural domestic uses.

The reliance on ground water has generally been trouble-free. However, because our ground-water resources have limits, occasional conflicts, competition, and shortages have occurred. Also, periodic droughts disrupt the normal patterns of ground-water recharge and replenishment, causing shortages and supply interruptions for private domestic, municipal, industrial, and irrigation wells. All of these problems have emphasized the need for more comprehensive ground-water planning and management in the state.

The Illinois State Water Plan Task Force has periodically requested statewide water-balance studies to update information about surface and ground-water supplies and demands. These studies have been helpful in describing water resources in the state, and in identifying regions where water demand may exceed the supply or where competition for water has been or could become a problem.

The two previous Water Plan studies that address these issues are *Water for Illinois: A Plan for Action* (Technical Advisory Committee on Water Resources, 1967) and *Illinois State Water Plan* (Illinois State Water Plan Task Force, 1984). Both of these reports contain information on ground-water supply and demand on a statewide scale. Numerous other assessments of ground-water supplies and uses in Illinois have been published over the course of many years. Some of those studies are cited in this report.

This report summarizes the results of recent statewide ground-water supply-and-demand balance studies, and it points out several regions in the state where intensified ground-water management and planning may be necessary to prevent or minimize ground-water supply problems and conflicts. Present and projected ground-water withdrawals for municipal, industrial, and agricultural irrigation uses are compared to potential aquifer yields to determine:

1) Do regions exist in Illinois where ground-water demands exceed ground-water supplies?

2) If so, are those overpumpage problems seasonal or chronic in nature?

3) Can overpumpage problems be expected to spread or worsen with projected changes in ground-water uses?

An effort has been made in this report to present water-use and water-table conditions under average weather conditions as well as under drought conditions. The drought conditions experienced in 1988 in Illinois have been used as a drought "reference" for the purposes of these comparisons. This report presents historical ground-water use records for the period 1980—1987; ground-water use projections are based on data for the same period.

This is the third in a series of three Water Survey Reports of Investigation on specific ground-water management topics in Illinois. The first, Report of Investigation (RI) 109, *Impacts of Irrigation and Drought on Illinois Ground-Water Resources* (Bowman and Collins, 1987), compared ground-water uses with ground-water potential yields on a township scale for the entire state. The present report is an expansion of the work begun in RI 109, and much of the analysis in the present report is based on the methods described in that report.

The second report, RI 114, *Ground-Water Quantity Laws and Management* (Bowman, 1991), reviewed 1) transitions in ground-water quantity laws throughout the United States, with an emphasis on midwestern states; and 2) the use of special ground-water quantity management areas throughout the United States for controlling ground-water withdrawals in regions where ground-water demand exceeds supply. The current report is being issued jointly as Water Survey RI 116 and Illinois State Water Plan Task Force Special Report 14.

Report Structure

The first major section in this report, "Ground-Water Resources," gives a brief description of the hydrogeology, major aquifer systems, ground-water levels, potential aquifer yields, and ambient ground-water quality in Illinois. The next major section, "Ground-Water Uses," reviews historic municipal, industrial, and agricultural irrigation ground-water uses and forecasts changes in those water uses for the near future.

In the third major section, "Balancing Ground-Water Supply and Demand," present and future ground-water uses for municipal, industrial, and irrigation demands are compared with available ground-water supplies. Finally, the conclusions to this report summarize the current and projected ground-water supply and demand balance for Illinois.

The Ground-Water Quantity Committee of the Illinois State Water Plan Task Force has issued a companion report to this report, *Groundwater Quantity Issues* (Illinois State Water Plan Task Force Special Report 12). It contains 23 issue papers compiled during 1988 and 1989, which address numerous topics related to statewide ground-water planning and management and which provide valuable background information on many of the topics touched on in this report. The companion report may be obtained by contacting the Illinois Department of Transportation, Division of Water Resources.

Acknowledgments

This report was prepared under the general supervision of Richard G. Semonin, former Chief, Illinois State Water Survey, and Ellis W. Sanderson, Head of the former Ground-Water Section. This work was sponsored by the Illinois Department of Transportation, Division of Water Resources, under the direction of Donald R. Vonnahme and Gary R. Clark.

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GROUND-WATER RESOURCES

Hydrogeology

The occurrence of ground water is controlled by a combination of climatic and geologic conditions. Unconsolidated rocks (such as loose sands and gravels) and solid rocks (such as sandstone and fractured limestone) form aquifers in which water from precipitation is stored and moves underground. Impermeable materials such as clays and shales form barriers to ground-water movement and thereby maintain differences in water levels and water quality between aquifers. Ground water is obtained through water wells that, in Illinois, are primarily located in unconsolidated sand and gravel deposits composed largely of glacial drift, and in underlying sedimentary bedrock aquifers of sandstone, limestone, and dolomite.

The geologic formations that contain the most productive aquifers in the state can be classified broadly into three systems:

1) The deepest sandstones and dolomites of Pre-Cambrian and Cambrian-Ordovician ages (about 600 million years old).

2) The shallow limestones and dolomites of Devonian and Silurian ages (about 400 million years old).

3) The Pleistocene sands and gravels, both surficial and buried (about 12,000 years old).

The most favorable sites for locating ground-water supplies are the northern third of the state where both bedrock formations and unconsolidated sand and gravel deposits offer dependable supplies; and the Mississippi, Illinois, Wabash, Ohio, Kaskaskia, Embarras, and buried Mahomet bedrock valleys, where sand and gravel deposits have high potential yields. Extensive areas of sand and gravel, as well as bedrock in the northern one-third and extreme southern parts of the state, yield large quantities of water. Elsewhere, yields are generally less, except where preglacial stream valleys are filled with sand and gravel or where bedrock aquifers provide small supplies.

Deep Bedrock Aquifers

The Cambrian-Ordovician aquifer system extends through all of Illinois at depths greater than 300 feet, but potable water is available from this system only in the northern third of the state. This system consists of three primary water-producing units: the Mt. Simon Cambrian sandstone, the St. Peter sandstone of Ordovician age, and the Ironton-Galesville sandstone of Cambrian age. These are generally confined by the Maquoketa shale formation, which inhibits vertical ground-water recharge into the deep bedrock aquifers.

Most Mt. Simon wells penetrate only the upper few hundred feet of that formation because the water is highly mineralized below that level. That formation contains brines in the southern two-thirds of the state and has been used for the containment of injected waste material.

The deep bedrock aquifer system has been used for many years because it offers relatively large supplies of water of predictable quality. It provides ground water for about 250 municipalities and 150 industries in the northern half of Illinois (Visocky et al., 1985) and has been the most developed bedrock water supply in the state (Kirk et al., 1985). However, drilling, pumping, and maintenance costs are appreciably higher for wells in this group than for wells drilled into shallower systems.

Recharge to these aquifers comes mainly from vertical percolation of precipitation in northern and western Illinois where the formations outcrop at the surface or are covered only by glacial till. Some recharge comes from leakage through the confining bed (Maquoketa shale) from the shallow bedrock aquifer.

Shallow Bedrock Aquifers

Shallow bedrock aquifers of importance are distributed in the northern half of Illinois overlying the Maquoketa shale formation. This system is composed of sedimentary limestones, sandstones, and shales of Mississippian and Pennsylvanian age (about 355 million years old) and dolomites of Silurian and Ordovician age (about 500 million years old).

Ground water is present in joints, fissures, and fractures of these formations. The degree of jointing and fracturing in the dolomite formation decreases with depth, and most of the water is obtained from the uppermost 100 feet. The water-yielding fractures and openings in Silurian dolomites are irregularly spaced both vertically and horizontally, so the yields of dolomite wells vary greatly from place to place (Russell, 1963).

Potential yields of the shallow bedrock aquifers range from an estimated 50,000 to 200,000 gallons per day per square mile (gpd/sq mi) (Illinois State Water Plan Task Force, 1984). Figure 1 shows the distribution of potential yields for the deep and shallow bedrock aquifers in Illinois.

The maps in figures 1 through 4 were constructed as part of the 1967 Illinois Water Plan (Technical Advisory Committee on Water Resources, 1967), which equated the potential yield of an aquifer with its estimated recharge. Therefore the average annual hydrologic balance between precipitation, evapotranspiration, runoff, and ground-water recharge is considered in the potential yield estimates. Figure 2 shows expected well yields in the bedrock aquifers.

Most of the high-yielding shallow bedrock wells for public water supply and industrial use in northeastern Illinois are concentrated in Silurian dolomites. The Silurian dolomite aquifer, which may. produce well yields as high as 1,500 gallons per minute (gpm), is usually very productive where it is unconfined and in good hydraulic connection with the overlying glacial drift aquifers which supply recharge water.

In most of central and parts of southern Illinois the dolomite is overlain by sedimentary deposits that are generally less favorable for ground-water supplies. Many of the wells in these formations yield less than 20 gpm and are therefore not a major source for large ground-water supplies. They are relied on for private domestic wells and small municipal and industrial supplies. The Silurian dolomite formation has very high salinity at depths of a few hundred feet, which renders the ground water unsuitable for most purposes.

Unconsolidated Sand and Gravel Aquifers

Discontinuous aquifers of unconsolidated sands and gravels exist throughout much of the state with the exception of extreme southern Illinois. These are primarily glacial and alluvial deposits, both surficial and buried.

Glacial drift covers about 80 percent of Illinois and ranges in thickness from about 1 to 600 feet. The only areas of the state not covered by glacial deposits are the extreme northwestern corner, a small area in the west, and the southern tip. The drift is more than 200 feet thick regionally in northwestern Illinois and as much as 600 feet thick in some of the major bedrock valleys.

These valleys, ancestral stream channels before the last ice age, were filled in with sands and gravels by glacial activity, forming our present-day bedrock valley aquifers; some of these coincide with present stream valleys and lowlands. Because of their thickness and the volume of water that is stored, these bedrock valley deposits are among the most abundant sources of water in the state.

Sand and gravel aquifers are recharged directly from local precipitation percolating through glacial tills. In many cases, the sands and gravels are deeply buried by glacial tills, which are fine-grained and have low vertical permeabilities; this slows recharge to the aquifers.

Estimated potential yields from sand and gravel aquifers range between 50,000 gpd and 5 million gallons per day (mgd) per square mile. The highest yields are found adjacent to the Illinois and Mississippi Rivers. Figure 3 shows the distribution of potential sand and gravel yields. Figure 4 shows expected well yields in sand and gravel aquifers.

Ground-Water Levels

Ground-water levels in Illinois aquifers are governed by the natural influences of the hydrologic balance (precipitation, evapotranspiration, surface runoff, and changes in soil moisture and ground-water storage), and by the human influences of pumping, artificial recharge, and aquifer compression such as from train or barge traffic (Russell, 1963). Water levels fluctuate seasonally in response to natural changes in precipitation and evapotranspiration patterns such that the water table declines in the late spring, summer, and early fall in response to increased evapotranspiration demands.

Water levels then begin to recover in late fall, with most recharge occurring during the wet spring months. In a natural system, precipitation is the only source for water gain to the budget; it is the principal component that ultimately affects ground-water levels and the amount of ground water available for our use. Water leaves the system through evapotranspiration and runoff, as well as through any losses from water stored in the soil and the aquifer.

Normally, the annual changes in soil moisture and ground-water storage will be minimal. However, these quantities can vary significantly on a seasonal basis with changes that are reflected in fluctuating ground-water levels.

In Illinois, more than half the annual precipitation occurs during the growing-season months when evapotranspiration losses are at a maximum. June and July are the months of maximum average precipitation everywhere except the far south, where peaks occur in the early spring and again in midsummer (Bowman and Collins, 1987).

Although precipitation exceeds evapotranspiration on an annual basis, evapotranspiration is nearly always higher than precipitation throughout the state in June, July, and August. This coincides with the time of year when shallow water levels are typically at their lowest.

Figures 5 through 8 illustrate this relationship by showing a) mean monthly precipitation and evapotranspiration as observed at four weather stations, versus b) average month-end water levels at four nearby monitoring well locations. These observation wells are part of a 21-well observation network of shallow wells operated by the Water Survey, which maintains continuous water-level recordings at sites throughout the state. The well locations are remote from pumping centers to minimize the effects of human activities on ground-water levels. Table 1 shows the specifications of well construction and depth for these observation wells.

The wells at Dixon Springs (figure 7) and St. Peter (figure 8) are shallower than those at Galena (figure 5) and Snicarte (figure 6). Water levels in the Dixon Springs and St. Peter wells respond more quickly to precipitation events, and they are more responsive to losses of evapotranspiration. This is evident in the annual water-level cycles at Dixon Springs and St. Peter, which mirror the evapotranspiration cycles with a one- to two-month lag.

Figures 9 through 12 show a) 1988 precipitation and evapotranspiration versus b) 1988 month-end water levels at the same weather stations and monitoring well locations. A comparison of these figures with figures 5 through 8 shows the effect of drought on the annual ground-water recharge cycle as a result of decreased precipitation and increased evapotranspiration.

Figures 13 through 16 show examples of historic water levels for the same four observation wells. Again, these figures show that the Dixon Springs and St. Peter wells are the shallowest of the four wells. Water levels in these wells respond more abruptly to precipitation events and exhibit a stronger annual cycle.

The 1988 summer water levels were the lowest for the period of record for the St. Peter well. The record low water levels could not be determined at Snicarte and Dixon Springs because ground-water levels fell below the bottom of those observation wells. The horizontal lines on the graphs represents the linear trends over time; the long-term changes are negligible at these four observation sites.

Figures 17 through 19 show examples of historic water levels at selected locations where water levels are affected by human activity. The Lake Bluff well (figure 17), a deep sandstone well in the Chicago suburbs, illustrates the well-documented, long-term overpumpage of that supply, a situation that is discussed in greater detail below.

Figure 18 shows the effects of municipal pumpage on shallow dolomite in Addison (DuPage County), which is in a region of recent rapid growth. Figure 19 shows similar effects on a sand and gravel aquifer in the Collinsville area, which has also experienced growth in the last decade. Figure 20 shows the locations of the observation wells and weather stations used in the analyses.

In heavily pumped areas, changes in water levels caused by pumping are superimposed on the natural seasonal variations. In some instances, large developments of ground water have caused pronounced and serious declines in water levels (Russell, 1963). For example, deep sandstone aquifers in the Chicago area were first developed in the mid-1860s, and pumpage started causing noticeable water-level declines as early as the mid-1960s. Visocky et al. (1985) estimated that the average water-level decline in the Chicago region had been about 800 feet since 1984.

Between 1971 and 1980 in other major Cambrian-Ordovician pumping centers, water levels declined 183 feet in the Joliet area, 220 feet in the upper Cook County suburbs, 200 feet in eastern DuPage County, and 190 feet in the Fox Valley (Visocky et al., 1985). These declines are expected to slow significantly (see Burch, 1991) as a result of the increased allocation of Lake Michigan water to Chicago and the expansion in use of shallow sand and gravel deposits for smaller supplies, in lieu of tapping the deep sandstone formation. Detailed discussions of historic Cambrian-Ordovician water-level trends can be found in Suter et al. (1959), Russell (1963), Schicht et al. (1976), Visocky et al. (1985), and Burch (1991).

Water levels in a shallow sand and gravel aquifer in the East St. Louis area declined more than 40 feet in some places between 1900 and 1960 as pumpage increased from 2.1 to 93 mgd, mainly for industrial purposes. However, since the mid-1970s, some industries have left the area and others have shifted from ground water to surface water supplies.

Water levels have recovered to such an extent that the Illinois Department of Transportation has found it necessary to sustain a large aquifer dewatering project to prevent flooding of nearby major highways. Detailed discussions of historic sand and gravel water levels in the East St. Louis area can be found in Bruin and Smith (1953), Schicht and Jones (1962), Schicht (1965), Reitz (1968), Baker (1972), Emmons (1979), Collins and Richards (1986), and Kohlhase (1987).

Extensive development of the Silurian dolomite by irrigation wells in the southeast Kankakee - northern Iroquois County region has caused significant seasonal declines in water levels. Declines in excess of 44 feet were recorded in parts of the region during the summer of 1987, but the potentiometric surface did not decline below the top of the bedrock aquifer (Cravens et al., 1990).

However, during the drought of 1988, substantially greater water-level declines were recorded. In some places these declines were as much as 72 feet. This resulted in the dewatering of the upper few feet of the bedrock aquifer in about 20 square miles during 1988, which led to numerous well-interference and ground-water conflicts (Cravens et al., 1990). It is believed that adequate management of aquifer development and improvements in existing domestic wells can minimize ground-water supply conflicts in that area.

Elsewhere in the state, substantial ground-water development has taken place for agricultural irrigation. The nature of irrigation water use and its impact on ground-water resources in Illinois are discussed in detail later in this report.

Ambient Ground-Water Quality

The ground-water quality in Illinois is generally adequate for most uses, although the water in the deeper aquifers is saline. Ground-water contamination is a threat to the bedrock aquifers in the northwestern corner of the state where the aquifers lie at or near the surface. Contamination is a threat to the unconsolidated aquifers throughout the state.

Gibb and O'Hearn (1980) published a general characterization of ambient ground-water quality throughout the state based on 28,000 water quality analyses and on water quality trend analyses for 21 municipal water supply wells. The statewide ranges in chemical parameters, as described by Gibb and O'Hearn, are summarized in table 2.

GROUND-WATER USES

Ground water is used in -Illinois for municipal, industrial, agricultural, and domestic purposes. The Illinois Water Inventory Program at the Water Survey has monitored ground-water use since 1978. The information presented in this section on ground-water withdrawals for public water supplies and for self-supplied industries has been provided by the Water Inventory Program, which has compiled biannual reports of these ground-water uses since 1980. Rural water uses, including agricultural irrigation, are also estimated as part of the Water Inventory Program; some of those estimates are included here.

In addition, irrigation water-use estimates have been made on the basis of field observations and a detailed water balance model for specific climatic conditions. The methods and results are discussed in detail in the section "Irrigation"; these irrigation water use estimates are clearly differentiated from those made in the Water Inventory Program. All forecasts for irrigation water use are based on water balance model estimates that have been verified through field observations.

Total ground-water use in Illinois fluctuated just under 1 billion gallons per day during the period 1980-1987 (figure 21a). Approximately half of that total, between 400 and 500 million gallons per day, was used by public water supplies (which includes municipalities and some industries) (figure 21b); about 200 to 250 million gallons per day was used by industries that supply their own water from water wells (figure 21c); and an estimated 300 million gallons per day was used for rural purposes including irrigation, rural domestic uses, and livestock watering (figure 21d). Table 3 shows total ground-water withdrawals by crop reporting district from 1980 through 1987.

The following sections discuss each of these ground-water use categories in more detail, examining historic trends and forecasting future trends. The ground-water use statistics are reported by crop reporting districts (figure 22).

Public Water Supplies

Past and Present Ground-Water Use

About 2,000 public water supplies in Illinois use ground water; they serve some 10.4 million people and hundreds of industries. Ground-water withdrawals for those public water supplies from 1980 through 1987 are shown in table 4 by crop reporting district.

Because some industries tap public water supplies, and because some portion of a region's population may rely on surface water instead of ground water, regional population is not always correlated directly with public water supply ground-water use. This is demonstrated in figures 23 through 31; for each crop reporting district, these figures show a) population and b) total and public water supply ground-water uses.

The lines on these graphs that represent public water supply illustrate the information in table 4. They also represent the relative proportion of total ground-water uses for public water supplies in each crop reporting district. Population projections can be used to forecast public water supply ground-water uses if the population change coincides with the fraction of the population that is served by public water supply, and if the water use is altered accordingly as discussed below.

Projected Ground-Water Use

Public water supply ground-water use projections were made according to methods established by Nealon et al. (1989). Those methods are briefly described here.

Information on the number of people served by public water supply in 1986 was assembled for every township in the state having public water supply systems. The 1986 ground-water withdrawal data were used as base data because they were the most closely validated data in the Water Inventory Program during the period 1980-1987.

A "per capita" ground-water use was computed by dividing the public water supply ground-water use per township by the number of people served by public water supply systems in each township (excluding all those public water supplies that use surface water). "Per capita," in this sense, is not strictly a measure of ground water used per person, since it includes industrial water use in many cases. For that reason, some of the per capita rates are substantially higher or lower than the average 150 gallons per person per day that is often used as an estimate of per capita water use.

The population served by public water supply in each township was adjusted by the projected rate of change in population in each county, producing estimates of the number of people that will be served by each public water supply in 1995. That projected population was then multiplied by the per capita value for each township to produce an estimated ground-water use for public water supply for each township in 1995, according to the aquifer group that supplies the township.

The per capita value for each township was computed on the basis of persons served in 1986 and the average ground-water use from 1980 through 1987. That rate was used to project 1995 ground-water use. For that reason, the projections may not reflect the impact of new industries locating in a region and introducing an increase in withdrawals, or, conversely, of industries leaving a region and reducing withdrawals.

Table 5 shows the average ground-water pumpage for public water supplies by county from 1980 through 1987, as well as the 1995 adjusted pumpage by aquifer group in each county. Note that pumpage in Cook, DuPage, Lake, and Will Counties was adjusted for planned Lake Michigan allocations by subtracting the appropriate amount of pumpage in those townships with facilities that will be served by lake water by 1995.

Note also that there are anticipated declines in public water supply ground-water uses of nearly 100 million gallons per day according to this analysis. This is due to 1) expected declines in population in many counties in Illinois; and 2) the planned shift from ground water to Lake Michigan water for numerous large water-using communities in the Chicago metropolitan area.

Nealon et al. (1989) made public water supply projections for the northern 35 counties in the state through the year 2025 using the methods briefly described here. The reader is referred to their publication for a full description of the methods and results. Projections for the present report were made only through 1995 to be consistent with the projections for self-supplied industrial ground-water withdrawals, discussed below.

Self-Supplied Industries

Past and Present Ground-Water Use

Numerous and wide-ranging industries in Illinois supply their own water from water wells. Table 6 shows the average daily ground-water withdrawals for the 11 largest water-using industrial groups. As seen in table 6, average ground-water withdrawals range from 3.3 mgd for the electronics industry to 32.7 mgd for the chemical industry.

A number of other industries using smaller amounts of ground water are not included in this table; they include the lumber, textile, apparel, furniture, printing, and transportation industries. These industries have used less than 1 million gallons of ground water per day on average between 1980 and 1987. The SIC code in table 6 represents the United States Government Standard Industrial Classification code, an industrial classification scheme used nationwide; that code is used as a reference for self-supplied industries throughout this report.

Also note in table 6 that four industries (chemical, food, petroleum, and primary metals) use about three-quarters of all self-supplied industrial ground water used in Illinois. This is also illustrated in figure 32, which is a pie chart of average self-supplied industrial ground-water withdrawals.

Self-supplied industrial ground-water withdrawals vary from year to year in response to changes in the economy, processing methods, product demand, and numerous other factors. This variance is shown in figure 33, which displays high-low bars for minimum, maximum, and average daily ground-water use for each of the large water-using industries.

Total ground-water use for each of the industries from 1980 through 1987 is shown in figure 34 (a through 1). A linear correlation of water use versus time was used to fit a trend line through the eight data points for each industry. In general, water use differs so much from year to year that the correlation over time is low and should not be extrapolated to project future use.

Self-supplied industrial ground-water use also varies regionally. For that reason, total self-supplied industrial ground-water withdrawals from 1980 through 1987 are presented for each of the crop reporting districts in table 7 and figure 35 (a through i). Even greater regional detail in industrial water use patterns can be seen in figure 36 (a through i), which shows total self-supplied industrial ground-water withdrawals from 1980 through 1987 by Standard Metropolitan Statistical Area (SMSA). These are the metropolitan, or industrialized, regions in the state where the majority of industries are clustered. A map of the SMSA locations is shown in figure 37. It should be noted again that no clear patterns of ground-water use are apparent over time, either by single industry or by region.

Projected Ground-Water Use

Three methods were used to forecast self-supplied industrial ground-water use through 1995; however, one of the methods did not produce plausible future industrial water-use trends. All three methods are described here, but only the first two are used in the use/yield analysis presented in the next section, "Balancing Ground-Water Supply and Demand."

These forecasts should be treated with caution, since numerous variables have not been accounted for in the projections; these include such eventualities as labor strikes, plant closings, national or regional economic recessions, and so on. These and other occurrences ultimately play a role in an industry's ground-water use, yet they are difficult to foresee and therefore to factor into water-use forecasts.

The first method of projection (Method A) was to add and subtract one standard deviation of the mean industrial ground-water use from 1980 through 1987. The results of Method A are shown in table 8. The rate of change for each industry (both plus and minus) was applied to all appropriate facilities in the state to determine projected regional changes in industrial ground-water use. Considering the uncertainties involved, it seems reasonable to assume that industrial ground-water use will continue to fluctuate about the mean as it has since 1980.

Method B differed from Method A only in that both ground-water and surface water uses were considered. Many of the industrial groups obtain water from both ground and surface sources. The proportion of ground water to surface water has varied by industry from 1980 through 1987; in other words, individual facilities or industries as a whole made shifts from ground to surface water and vice versa. Therefore mean total water use for each industry was varied by one standard deviation, with the percent change applied to the ground-water proportion of the average total ground-water and surface water use.

The results for Method B are shown in table 9. Again, the appropriate adjustments were made for each facility in the state. A comparison of tables 8 and 9 shows that these two methods do not differ greatly in the ultimate ground-water use adjustments.

Method C was used in an attempt to project industrial water use through use of a simple linear model using three indications of industrial standing (employment, output, and productivity) as independent variables. This analysis did not yield plausible industrial ground-water use projections, but it is described in some detail here because it illustrates the uncertainties involved in making industrial water use projections.

Bivariate correlations were computed for industrial ground-water use from 1980 through 1987 and industrial employment, output, and productivity from 1980 through 1987. The industrial standing data were supplied by the Illinois Department of Energy and Natural Resources; these **data included values** known through 1988 and values projected beyond that. Results of that correlation analysis are shown in table 10.

Table 10 also includes correlations of water use versus time; these are simply the correlations shown graphically in figure 34. As seen in table 10, there are no consistent patterns of relationships between ground-water use and time, employment, output, or productivity individually.

Given that, multivariate correlations were computed between industrial ground-water use from 1980 through 1987 and employment, output, and productivity combined for that time period. Those results are shown in table 11. The probability information indicates the chances of obtaining the given value of R^2 with a completely random set of data; generally, the lower the correlation coefficient, the greater the chance of a coincidental correlation.

The term R^2 used in tables 10 through 12 represents the degree of association between two or more independent variables and one dependent variable. Values of R^2 range from 0 to 1; the closer to a value of 1, the stronger the association. A strong correlation (a value approaching 1) is a valuable predictive tool; if one knew, for example, that industrial productivity and industrial water use were highly correlated, then one could predict future water use on the basis of projections of productivity.

Again, as seen in table 11, there are few strong patterns of correlation for industrial ground-water use. Therefore the analysis was carried a step further to evaluate the relationship between total industrial water use from 1980 through 1987 and the same three industrial variables as independent variables. This was done for the same rationale described above for Method B.

The results, shown in table 12, are correlation patterns that appear reasonably strong for the majority of the large water-using industries. However, the projected 1995 total and ground-water uses derived from these correlation equations (shown in table 13) are unreasonable for most industries. For example, four of the industries were projected to have negative water use by 1995. The most likely explanation for these results is that the projections of industrial employment, output, and productivity displayed strong linear trends, rather than leveling off over time.

Since total water use was highly correlated with these factors from 1980 through 1987, the water use trends were just extrapolated along with the industrial indices, resulting in some very large continual increases and decreases. The results shown in table 13 are not realistic indications of changing water-use patterns and were not used as projections.

Results from Methods A and B were used to project 1995 ground-water withdrawals for each manufacturing self-supplied industrial facility in each township in Illinois according to aquifer system. However, since the differences between Methods A and B were never greater than 10 percent for any single township in the state, only the Method A results are tabulated here.

The non-manufacturing self-supplied industrial pumpage (for example, mining) was assumed to vary at a rate of plus or minus 10 percent of the average pumpage from 1980 through 1987. Manufacturing made up about 72 percent of the total self-supplied industrial pumpage in 1986. Again, 1986 was used as the base year for making projections because of the high degree of verification of that data.

Table 14 shows the 1986 manufacturing and total self-supplied industrial pumpage in Illinois, along with the high and low adjustments. The high adjustment reflects plus 1 standard deviation of the mean on self-supplied manufacturing facility pumpage and plus 10 percent on self-supplied non-manufacturing industrial pumpage. The low adjustment reflects minus 1 standard deviation and minus 10 percent.

Table 15 shows the 1980-1987 average self-supplied industrial pumpage by county, along with the 1986 pumpage and projected pumpages, both high and low.

Irrigation

Past and Present Irrigation Distribution

Agricultural irrigation has been the fastest-growing ground-water use in Illinois in recent years, going from about 15 percent of total ground-water withdrawals in 1978 to approximately 18 percent of the total in 1987, according to estimates made by the Illinois Water Inventory Program. Recent increases in ground-water use conflicts in Illinois have called attention to the large amounts of ground water used for irrigation. This has intensified interest in planning and management of ground-water withdrawals in general, and in optimizing irrigation water use for water conservation.

Irrigation in Illinois has been practiced mainly in places with sandy soils that have low moisture-holding capacities. It has also been used to a lesser extent on soils with heavier textures to offset the effects of drought. Illinois has a sub-humid climate and generally gets enough rain to support crops, particularly where silty loess is present. However, rainfall is not distributed evenly. Even in places where the soil moisture capacity is large, supplemental irrigation is occasionally necessary to maintain crop yields (Bowman and Collins, 1987).

There are presently an estimated 249,000 irrigated acres in Illinois, of which 240,000 are watered from ground-water sources. There are an estimated 2,200 irrigation systems in the state, and 2,100 irrigation wells. Table 16 shows a county breakdown of irrigation systems, wells, irrigated acreage, and acreage irrigated from ground water.

Two hundred thirty-one townships in 75 counties have irrigation systems for farms ranging from one- or two-acre berry patches to 260 acres of corn, soybeans, green beans, wheat, and other vegetable crops grown under center pivot irrigation systems. Figure 38 shows the density and distribution of irrigation wells; most irrigation coincides with the occurrence of sandy soils, as seen by comparing figures 38 and 39.

The most heavily irrigated areas are in 1) Mason and Tazewell Counties, along the Illinois River in the Havana Lowlands; 2) Lee and Whiteside Counties between the Green and Rock Rivers, in the Green River Lowlands; 3) parts of Kankakee County where aeolian sands are present; and 4) a narrow band along the Wabash River in parts of Lawrence, Gallatin, White, Clark, and Crawford Counties.

Irrigation got its start in Illinois in the 1920s in the vegetable and gladioli fields of Kankakee County, where canals are used to transport water from wells to the irrigated fields. By 1950 about 9,000 acres were irrigated. Drought in the 1950s prompted a surge in irrigation in the Mason County area, mainly for potatoes and other vegetable crops.

In the early 1970s, rising crop prices for corn and soybeans accounted for large expansions in irrigation, as the higher crop prices made it possible to recover initial investment costs for expensive irrigation equipment more quickly than had been possible previously. Then, between 1988 and 1989, irrigated acreage is estimated to have increased by as much as 25 percent in response to the drought of 1988. Figure 40 shows the growth in irrigated acreage in Illinois since 1950.

The practice of irrigating field crops like corn and soybeans dominated irrigated agriculture in this state until the late 1980s, when vegetable and specialty crops began to regain their early importance in the irrigation economy. Table 17 shows the types of crops irrigated in Illinois, and the total reported acreage for each.

Note that the acreages listed in table 17 do not add up to the statewide estimate for irrigated acreage. This discrepancy arose because the information was obtained from a statewide survey of irrigation completed by the Water Survey in 1989, and not all irrigation farmers responded to the survey. In general, specialty crops like those listed in table 17 are becoming increasingly dominant in the regional agricultural economies of those areas where irrigation is practiced widely.

Estimating Present Irrigation Water Use

The information on irrigation system location and irrigated acreage was used to update the statewide computerized information system database used for making irrigation water use estimates. Unlike ground-water withdrawals for public water supplies and self-supplied industries, agricultural irrigation water use has not been systematically determined in Illinois. For that reason, irrigation amounts must be estimated. Because of the growing importance and magnitude of irrigation water use, considerable effort has gone into 1) establishing reasonable methods of estimation, and 2) making direct observations of irrigation water use for comparison with and validation of the estimates.

In this study, irrigation water use estimates were made on the basis of water balance analysis methods used by Bowman and Collins (1987). A detailed discussion of water balance analysis is not necessary here, but a brief review of the methods used by Bowman and Collins will help in understanding the results of this project.

In an annual water balance, the amount of water entering the natural system is equal to that leaving. During a given season of the year, this balance may not exist. More water may be leaving the system than is entering, resulting in a moisture deficit for plant growth; or more water may be entering the system than is leaving, resulting in a moisture surplus producing runoff, flooding, or ground-water recharge.

Precipitation is the only natural source of water entering the system; water leaves the system through evaporation, transpiration, ground-water runoff, changes in soil moisture and ground-water storage, and overland flow of water to streams (Dunne and Leopold, 1978).

In this project a seasonal moisture deficit, D, was assumed to be made up by irrigation on fields where irrigation systems already exist. The monthly water deficit, D, for the plant system is given by

$$D = PET - AET \qquad (1)$$

where PET represents potential evapotranspiration and AET is actual evapotranspiration (Thornthwaite and Mather, 1955; Dunne and Leopold, 1978). Evaporation and transpiration, or the combined evapotranspiration, is the process of plant water use and moisture loss from surface evaporation.

Plants use water at the potential, or maximum, rate when soil moisture is not limiting, meaning that under ideal conditions, at least as much water would be available to the plant system as is leaving it through evapotranspiration. However, when plant water demands exceed the amount of water readily available to the root system of the plant, plant stomata close to reduce water vapor transpiration. Under these conditions, evapotranspiration is some fraction of potential evapotranspiration and is usually called actual evapotranspiration.

Actual evapotranspiration, or the amount of water actually available to the plant for use, is a combination of precipitation plus whatever water is available from the soil. The amount of soil moisture varies with the soil texture, permeability, and infiltration capacity. When a soil has a low moisture-holding capacity (such as a coarse sand) or when precipitation is below normal, the actual evapotranspiration rate can be far enough below the potential rate for moisture stress to develop. In the case of irrigated agriculture, that would indicate the need for supplemental irrigation. Equation 1 can be rewritten

$$D = PET - (P + AS) \qquad (2)$$

where P is precipitation and AS is the change in soil moisture storage.

Potential evapotranspiration in centimeters per month was based on the Blaney-Criddle formula:

$$PET = (0.142T + 1.095XT + 17.8)\,kd \qquad (3)$$

where T is the mean monthly temperature in degrees Celsius, k is an empirical crop coefficient, and d is the monthly fraction of annual hours of daylight (Blaney and Criddle, 1950; U.S. Soil Conservation Service, 1967).

Seasonal moisture deficits vary according to the weather and the soil type. Because of this, deficits for a single soil type vary significantly from north to south across the state. For this project, seasonal deficits were computed for five broad soil classes (fine sand, sandy loam, silt loam, clay loam, and clay). These deficits were computed for average weather conditions based on the 30-year mean by crop reporting district, and for drought conditions as seen in 1988 by crop reporting district, as shown in table 18.

Figure 41 (a through i) shows the average annual water budgets for a silt-clay loam soil in each of the nine crop reporting districts, including precipitation, potential evapotranspiration (PET), and actual evapotranspiration (AET). These figures show that summer is the time of maximum evapotranspiration. It is also the time of maximum precipitation everywhere in Illinois except in the far south, where the maximum occurs during late spring and early summer.

These figures also show that seasonal moisture deficits are greater for the same soil type in southern Illinois than in northern Illinois. This is due to two factors. First, potential evapotranspiration rates are higher in southern Illinois because of higher temperatures (see table 18). Second, precipitation rates in southern Illinois are not at their maximum in the summer months when PET rates are highest. Since AET is the sum of precipitation and the change in soil moisture, AET rates are lower, resulting in a larger difference between PET and AET (the moisture deficit) in southern Illinois. The amount of the deficit is indicated on the graphs by shading.

These deficits, shown in table 19, were assumed to be made up by irrigation in those places where irrigation is already used. However, it is recognized that farmers using irrigation must make their irrigation decisions on the basis of limited information about the moisture-holding capacity of their soils and about rates of evapotranspiration.

In addition, soil type is so highly variable that most irrigation systems water an area with more than one soil type. Often, irrigating farmers must overwater their better soils (soils with higher soil-moisture holding capacity) to provide adequate water for their worst soils. Furthermore, the variability in irrigation behaviors of individual farmers also accounts for wide fluctuations in actual irrigation water use.

Given these variabilities, the computed seasonal moisture deficits are taken as general estimates of actual irrigation water use. In general, as shown at the bottom of table 19, they are reasonably accurate estimates, as shown by comparison with average irrigation water use practices observed in field studies in 1988 in the Havana Lowlands, the Green River Lowlands, and Kankakee County, the three most heavily irrigated regions in the state (Bowman et al., 1991; Bowman and Kimpel, 1991).

Table 20 shows computed irrigation ground-water use during average weather years and during drought conditions (1988); the table shows county totals, but computations were actually done on a township basis according to soil type and irrigated acreage. These totals were based on a 92-day irrigation season during June, July, and August. They reflect seasonal irrigation ground-water use, not daily ground-water use for irrigation for 365 days a year.

Projected Irrigation Water Use

The rate of expansion of irrigation in Illinois is uncertain. The most common assumptions about growth in irrigation are: 1) growth will generally be driven by the overall farm economy; and 2) growth will continue in areas with sandy soil, where irrigation has been practiced in the past and where its profitability has already been established.

However, new information and new trends may alter commonly held beliefs, changing the irrigation picture in Illinois. First, the common belief has been that irrigation is not profitable on fine-textured soils. This belief may be changed by evidence that crop yield response to irrigation on soils with light to medium texture and on claypan soils is significant, with yields increasing by 25 to 33 percent even with relatively high levels of precipitation (Stout et al., 1983; Sipp et al., 1984; Walker et al., 1981). Irrigation of finer-grained soils appears to stabilize yields and to maintain higher grain quality, especially during droughts.

A second common belief is that the expansion of irrigation in Illinois will be restricted by the price of field corn and soybeans. While these field crops have dominated irrigated agriculture in Illinois For the last ten to 15 years, changes within the last several years have almost certainly opened the door for more irrigation of higher-valued specialty crops. This shift to growing specialty crops has already prompted Illinois farmers to introduce irrigation on soils that traditionally have not required supplemental irrigation.

Finally, the prevailing assumption has been that the climate in Illinois, which allows for profitable rain-fed agriculture to flourish at least nine years out of ten, will stay the same. There is growing evidence, however, that a global climate change could mean hotter, drier summers for much of the midwestern corn belt, with average summer conditions comparable to those experienced in past droughts. To offset the hotter, drier conditions, agricultural irrigation would likely be introduced in many parts of Illinois that traditionally have not been irrigated.

Given these possibilities and changes, irrigation could expand throughout Illinois onto soils that have typically not been irrigated, allowing for a much larger overall expansion than has previously been thought reasonable. Figure 42 shows the delineation of soils in the state that are considered to be irrigable. The analysis is based on average water availability in the upper meter, subsoil drainage, and subsoil permeability.

The soils that are most irrigable are those having low water availability with well-drained and rapidly permeable subsoils. Soils with low water availability but poorly drained subsoils (such as in "claypan" conditions) may also be suitable for sub-irrigation practices. These conditions are present in large portions of southern Illinois where fresh ground-water supplies are very limited.

Illinois has about 12.2 million acres of irrigable soils, with approximately 1.6 of those being highly suited for irrigation (see figure 42). This estimate is based on soil characteristics and does not account for ground-water availability.

Figure 43 shows irrigable soils in areas where there is also an adequate supply of ground water to support high-capacity irrigation wells. An adequate ground-water supply was defined as having at least 150,000 gallons per day per square mile, which is roughly equivalent to a well producing about 500 gallons per minute. This assumption excludes smaller irrigation operations and those operations using such methods as trickle irrigation and other water-saving alternatives.

About 7.2 million acres of soils could be irrigated from ground water if large-scale center pivot irrigation operations were used. About 1.56 million of these acres are highly suitable, but some of the highly suitable land has been urbanized and is no longer in agricultural production (such as in large parts of Cook County).

Summary of Projections

While it is very difficult to project with any certainty what future water use will be, some general forecasting is possible for planning purposes as long as the assumptions are clearly stated. In this report, ground-water uses have been projected for:

1) Public water supplies, based on the population served by public water supply and on population projections.

2) Self-supplied industries, based on mean annual ground-water use for each industry group from 1980 through 1987.

3) Agricultural irrigation, based on soil type, weather conditions, and the distribution of irrigated acreage.

Table 21 shows the projected 1995 total mean ground-water use for self-supplied industry plus public water supply for both increased and decreased water use scenarios for industries, and it shows expanded agricultural irrigation for those counties with irrigation, totaled by county. In both cases, irrigation is based on average weather conditions and is expressed in annual, not seasonal, terms for consistency with the other daily ground-water uses.

In some cases, the increased and decreased projections are the same for a county's self-supplied industrial and public water supply projected withdrawals. In these cases, projections were based on public water supply withdrawals alone since the county has little or no projected change in industrial water withdrawals.

BALANCING GROUND-WATER SUPPLY AND DEMAND

To evaluate regional relationships between ground-water supply and ground-water demand, a computerized database on ground-water withdrawals and potential aquifer yields has been updated. The database is part of a statewide geographic information system (GIS) used for comparison and analysis of a wide variety of spatial data.

Data on potential aquifer yield were obtained from maps of potential yield for bedrock and sand and gravel aquifers, created as part of the 1967 Illinois Water Plan (Technical Advisory Committee on Water Resources, 1967) (see figures 1 and 3 of this report). The 1967 Water Plan equated potential yield of an aquifer with its estimated recharge; the potential yield estimates do not reflect recharge plus storage. This conservative assessment of potential aquifer yield is appropriate for planning purposes until more precise data are available on aquifer yields throughout the state.

Use/Yield Analysis

Through the use of areally weighted potential yield values for each township, developed by Bowman and Collins (1987), it was possible to compare potential aquifer yield with ground-water use from each aquifer system in each township or any combination of townships. This is expressed by the ratio, r, of ground-water use to ground-water potential yield:

$$r = U/Y \qquad (4)$$

where U is ground-water withdrawal for public water supplies, self-supplied industries, and irrigation in each township in mgd, and Y is potential aquifer yield for each aquifer system in each township in mgd. This "use/yield" ratio represents a qualitative assessment of the percentage of the total resource being used (Bowman and Collins, 1987). Although not meant to be used as the basis for site-specific technical analysis, this use/yield comparison does help identify areas where the aquifer may be overdeveloped. It was assumed that if the use/yield ratio was 1.0 or greater, a potential problem area was identified. If the ratio was between 0.5 and 0.999, overdevelopment is possible but not probable. A ratio less than 0.5 indicates areas where overpumpage probably does not occur.

Results

Use/yield analyses were made for a variety of conditions. The results are categorized into six general groups: 1) all ground-water uses except irrigation; 2) all ground-water uses including irrigation for average weather conditions; 3) all ground-water uses including irrigation for drought conditions (1988); 4) all ground-water uses including average and drought irrigation, with annual rather than seasonal impacts considered; 5) all projected ground-water uses except irrigation; and 6) all projected ground-water uses including irrigation.

In many cases, total ground-water withdrawals are compared with total aquifer potential yield; individual aquifer groups are not distinguished from one another in either the ground-water withdrawals or the ground-water potential yields. In other cases, comparisons are made according to single aquifer groups. In those cases, only potential yield and withdrawals from the aquifer groups being considered are compared with one another. For example, withdrawals from the deep sandstone aquifers in the Chicago area are compared with potential yields from those aquifers in figures 63 and 64.

All Ground-Water Uses *Except Irrigation*

Figure 44a shows the distribution of use/yield ratios for average public water supply and self-supplied industrial ground-water use for all aquifer groups combined. Irrigation use was not considered. The Chicago metropolitan area stands out as a major center of overpumpage, as discussed earlier in this report. Other locations of apparent overpumpage are associated with some of the state's larger municipalities that use ground-water for their public water supplies, such as Peoria, Champaign, and Rockford. In this case, 45 townships have use/yield ratios greater than 1.

Figures 44b through d show the use/yield ratios for each aquifer system individually for all ground-water uses except irrigation. Sand and gravel uses are compared with sand and gravel yields, shallow bedrock uses with shallow bedrock yields, and deep sandstone uses with deep sandstone yields. The ranges of use/yield ratios for the four categories are:

All aquifers combined	0.001- 7.56
Sand and gravel	0.001-50.61
Shallow bedrock	0.001-17.61
Deep sandstone	0.001-15.89

Table 22 shows the number of townships with ratios greater than 1 and the percent of area (with pumpage) that is potentially being overpumped.

All Ground-Water Uses Including Average Irrigation

To evaluate the average impact of irrigation water use on ground-water resources, average irrigation water use (estimated according to the 30-year weather average) was added to municipal and self-supplied industrial ground-water uses, and the new use/yield ratios were computed. The use/yield ratios for all aquifers combined are shown in figure 45a.

Adding irrigation increased the number of townships with ratios greater than 1 from 45 to 60. Most of the change occurs in the heavily irrigated regions in Mason, Tazewell, Lee, Whiteside, and Kankakee Counties. Irrigation water use is represented in figure 45a as a seasonal quantity; the daily ground-water use for irrigation is limited to the 92-day irrigation season during June, July, and August.

Use/yield ratios (including average seasonal irrigation water use) for each separate aquifer system are shown in figures 45b through d. The largest change occurs in the sand and gravel aquifers because approximately 90 percent of all irrigation wells are finished in those aquifers. The number of townships with ratios greater than 1 for these aquifers increases from 28 without irrigation to 50 with irrigation. The ranges of use/yield ratios for the four categories are:

All aquifers combined	0.001- 8.29
Sand and gravel	0.001-50.61
Shallow bedrock	0.001-28.34
Deep sandstone	0.001-15.89

The number of townships with ratios greater than 1 and the percentage of overpumped area are shown in table 23.

All Ground-Water Uses Including Drought Irrigation

As discussed previously in this report, drought conditions have a significant impact on annual irrigation water demands: estimated 1988 (drought) demands were roughly three times the demand in a normal weather year. To evaluate the effect of increased ground-water use in drought years on ground-water resources, 1988 irrigation estimates were added to data on municipal and industrial ground-water withdrawals, and new use/yield ratios were computed.

The ratios for all uses and all types of aquifers combined are shown in figure 46a. The results show that the number of townships with ratios greater than 1 increased from 45 (without irrigation) and 60 (with average irrigation) to 87 with irrigation under drought conditions. Again, the regions most affected are those where irrigation is widely practiced, such as Mason, Tazewell, Lee, Whiteside, and Kankakee Counties.

Figures 46b through d show the use/yield ratios for each aquifer system individually. The ranges of ratios are:

All aquifers combined	0.001-21.36
Sand and gravel	0.001-50.61
Shallow bedrock	0.001-79.75
Deep sandstone	0.001-15.89

Table 24 shows the number of townships with ratios greater than 1 and the percentage of area with potential overpumpage.

Annual Impacts of Average and Drought Irrigation

Unlike most ground-water pumpage for municipal and industrial uses, irrigation water use is strictly seasonal, occurring mainly between June and August. For that reason, the greatest impact from irrigation pumpage is normally during the summer months; this also coincides with a time of naturally low ground-water levels because of maximum evapotranspiration losses.

To get a truer picture of the impact of irrigation water use on ground-water resources, irrigation pumpage was assumed to be spread out over the entire year. This more closely reflects the ability of the ground-water systems to recharge sufficiently during the rest of the year to compensate for the heavy seasonal pumpage.

This analysis was performed for both the average and drought irrigation applications. In both cases, the effects of irrigation on ground-water resources are largely diminished. The annual impacts of average irrigation ground-water use for all aquifers combined are shown in figure 47. In this case, the number of townships with use/yield ratios greater than 1 is 46, only one greater than without any irrigation at all, and 14 less than when the seasonal impacts of average irrigation water use are considered. The ratios range from 0.001 to 7.56. Total average annual irrigation ground-water use (every day for 365 days a year) is estimated at about 80 mgd, compared to 320 mgd during the 92-day irrigation season.

The annual impacts of drought irrigation ground-water use for all aquifers combined are shown in figure 48. In this case, the number of townships with ratios greater than 1 is 51, compared to 87 when the seasonal impacts of irrigation water use under drought conditions are considered. Total annual ground-water use for irrigation under drought conditions is estimated at about 240 mgd (every day for 365 days a year) compared to 950 mgd during the 92-day irrigation season.

On the basis of these results, it appears that irrigation water use in a normal weather year may cause some temporary, localized water supply problems in the most heavily irrigated townships during growing-season months. Under drought conditions, the impact is far greater since irrigation demands are so much larger. However, in both cases, the aquifer systems that are presently being used for irrigation supply appear to have the ability to recover from this amount of pumpage (through normal recharge) without being permanently depleted. Table 25 summarizes information about the annual impact of irrigation on ground-water resources.

All Projected Ground-Water Uses *Except Irrigation*

This section and the following section summarize the results of use/yield analyses that were based on the ground-water use projections (described earlier in this report) for public water supplies, self-supplied industries, and irrigation. The public water supply projections (shown in table 5) are based on 1995 adjustments. The self-supplied industrial projections (shown in table 15) are based on adding 1 standard deviation from the 1980—1987 mean manufacturing ground-water withdrawals (high projection), and on subtracting 1 standard deviation from the mean (low projection).

Figure 49a shows use/yield ratios for all aquifer systems for all projected uses except irrigation, based on the high projections for self-supplied industrial use. A comparison of figures 49a and 44a (which shows present pumpage effects) shows that significantly less overpumpage may occur in the "Collar Counties" around the Chicago metropolitan area with projected pumpage. Thirty-four townships have projected use/yield ratios greater than 1 (figure 49a), compared to the 45 townships with present use/yield ratios greater than 1 (figure 44a).

The major difference in the Collar County region is due to decreased pumpage for public water supplies from deep sandstone aquifers, as communities in that area begin using Lake Michigan water instead. In spite of increases in self-supplied industrial pumpage, the reduced public water supply projections act to reduce the total projected withdrawals.

Table 5 shows that the statewide 1980-1987 average public water supply pumpage totaled about 462 mgd, compared to the 1995 projected 366 mgd. The statewide total self-supplied industrial ground-water pumpage portrayed in figure 49a is estimated at 221 mgd.

As shown in figure 44a, 17 out of the 45 townships with present use/yield ratios greater than 1 (or about 38 percent of the total overpumped area) are in the Collar County region. As seen in figure 49a, 8 of the 34 townships with projected ratios greater than 1 (or about 24 percent of the overpumped area) are in the Collar Counties.

Figure 49b shows the ratios for all aquifer systems for all projected uses except irrigation, based on the low projections for self-supplied industrial use. In this case, 31 townships have projected use/yield ratios greater than 1; again the Collar County region shows a significantly decreased potential for overpumpage, with eight townships having ratios greater than 1.

The effect on the deep sandstone aquifers of the Collar Counties converting to Lake Michigan water is shown more clearly in figures 50a (high projections for self-supplied industrial use) and b (low projections for self-supplied industrial use). When these are compared to figure 44d (which shows the effects of present pumpage), the reduced impact of projected uses is clear. Figure 44d shows 45 townships with ratios greater than 1 in the Collar County region, while figures 50a and b both show only 35 townships in the area with ratios greater than 1. The statewide total self-supplied industrial ground-water pumpage portrayed in figure 49b is estimated at 173 mgd, 48 mgd less than the high projection in figure 61.

All Projected Ground-Water Uses Including Irrigation

Figure 51a shows the impact of all projected uses including irrigation (with a 50 percent projected growth in irrigated acreage), based on the high estimates for self-supplied industrial use. This figure shows the seasonal impact of projected irrigation pumpage in an average weather year.

Table 21 shows that projected irrigation pumpage is estimated to be just under 120 mgd on an annual basis, or about 480 mgd during June, July, and August. The 50 percent expansion increases seasonal irrigation pumpage by about 160 mgd (the difference between total average seasonal pumpage shown in table 20, and expanded seasonal pumpage from table 21), but the expanded total seasonal irrigation pumpage is still far less than during a severe drought such as the drought of 1988.

The use/yield ratios in figure 51a range from 0.001 to 13.39; 61 townships have ratios greater than 1. A comparison of figures 51a and 49a shows that with irrigation, the additional townships with ratios greater than 1 are, not surprisingly, in the heavily irrigated regions in Mason, Tazewell, Lee, Whiteside, and Kankakee Counties.

Figure 51b shows all projected uses including expanded, seasonal irrigation, based on the low projections for self-supplied industrial use. In this case, 59 townships have use/yield ratios greater than 1, two fewer than the number shown in figure 51a. Again, the greatest impact of the projected irrigation pumpage is seen in the three heavily irrigated regions mentioned in the above paragraph. Table 26 summarizes the impacts of projected ground-water uses, including public water supply, high and low projections for self-supplied industry, and seasonal, average irrigation.

Annual impacts of expanded irrigation and adjusted municipal and industrial ground-water uses, based on the high projections for self-supplied industrial use, are shown in figure 52. As with figures 47 and 48, irrigation water use is spread over the entire year, not just the 92-day irrigation season in June, July, and August. Figure 52 shows that even with a 50 percent expansion in irrigated acreage, the effects of the high seasonal pumpage are diminished. This shows, in a very generalized way, that significant irrigation development is still possible in the areas that are already heavily irrigated, without causing permanent water table declines.

On the basis of these analyses, projected changes in ground-water pumpage are expected to:

1) Significantly reduce present regional overpumpage problems for the deep sandstone aquifers in Chicago and the Collar Counties, because of the planned shift to Lake Michigan water for many of the public water supplies in the area.
2) Slightly increase the extent of seasonal overpumpage due to expanded irrigation in the regions of the state that are currently heavily irrigated (the seasonal overpumpage would be worse than during a normal weather year with present irrigated acreage, but not as bad as during a severe drought).

The annual or long-term impacts on regional ground-water resources of the amount of expanded irrigation considered here are negligible. No evidence exists that irrigation in these places will create permanent overpumpage problems. However, well interference and ground-water conflicts during the irrigation season (especially during droughts) are possible and even probable in some places as irrigation is used more widely.

Clearly, there are limits on the amount of ground-water development that any single region may sustain, whether for irrigation or any other intended use. Irrigation is unique in that it represents a very large seasonal water use, which may cause both temporary and long-term problems for neighboring wells. For the most part, ground-water conflicts and problems stemming from irrigation in Illinois are mainly limited to the growing season.

It is difficult to assess the changes resulting from adjusted industrial pumpage. In these analyses, that pumpage was altered to reflect both growth and decline in industrial activity and water use. However, the changes are smaller than those for public water supply adjustments, so regional differences are difficult to detect. Plant openings and closings will almost certainly have some effect on local ground-water use and possibly on regional ground-water levels.

CONCLUSIONS

This report compares present and projected ground-water uses with ground-water potential yields on a township scale. The potential yield information was compiled for deep sandstone, shallow bedrock, and unconsolidated sand and gravel formations as part of the 1967 Illinois Water Plan (Technical Advisory Committee on Water Resources); potential yield is roughly comparable to average annual recharge.

Information on present municipal and industrial ground-water use was obtained from the Illinois Water Inventory Program, based on an average of the period 1980-1987. Present agricultural irrigation estimates are based on a soil- and weather-dependent water balance model that determines irrigation demand.

Projections for municipal, industrial, and agricultural irrigation ground-water uses are also made in this report. Municipal projections are based on per capita demand for each public water supply facility according to the adjusted 1995 population for that facility; adjusted withdrawals were totaled by facility and by township for new township totals.

Industrial ground-water use projections, made for those industries supplying their own water from a well, were based on adding and subtracting 1 standard deviation of the 1980-1987 mean ground-water use for each manufacturing category, and adding and subtracting 10 percent of the mean for the non-manufacturing uses. The correct pumpage change for each manufacturing and non-manufacturing category was applied to each facility's pumpage in each township for new township totals for industrial ground-water use.

Agricultural irrigation projections were based on water balance estimates of irrigation applied to an estimate of "irrigable" acreage. The estimate of irrigable acreage was based on soil characteristics and ground-water availability.

The present balance between ground-water supply and demand shows significant overpumpage in the Chicago metropolitan area and in the Collar Counties surrounding Chicago. This situation primarily affects the deep sandstone aquifers and is the result of many years of high municipal and industrial demand.

In addition to the problems in northeastern Illinois, some seasonal overpumpage is apparent in heavily irrigated regions. Those regions are located 1) adjacent to the Illinois River in Mason and southern Tazewell Counties, 2) between the Green and Rock Rivers in Lee and Whiteside Counties, 3) along the Wabash River in southeastern Illinois, and 4) in parts of Kankakee and Iroquois Counties.

Such irrigation-related overpumpage is limited to the growing season and is almost entirely balanced by normal recharge over the course of a year. The magnitude of this overpumpage is highly variable and is largely determined by weather conditions, since irrigation pumpage is dependent to a great extent on prevailing weather conditions.

The comparison of projected ground-water uses with ground-water potential yields resulted in several major conclusions:

1) The deep sandstone overpumpage problems in the Collar County region can be expected to diminish somewhat according to projections, because of the shift to Lake Michigan water; lower public water supply pumpage is expected to offset any projected increases in pumpage for self-supplied industries in that region.

2) By 1995, public watea supply ground-water withdrawals in Illinois are expected to be about 20 percent less than present withdrawals. In most counties this projected decrease is attributed to anticipated population decline; in the Collar Counties the declines are attributed to the shift by public water supply systems from ground water to Lake Michigan water.

3) In scattered locations throughout the state, increased competition for water may arise among rural users, irrigators, and small, medium-sized, or large public water supply systems. Such competition may be especially likely to occur throughout central Illinois, near growing communities that share a common unconsolidated aquifer.

4) While competition and interference conflicts would be problematic for the communities and parties involved, the likelihood is small of long-term aquifer depletion occurring in the case of the major central Illinois aquifer.

5) Ground-water pumpage by manufacturing facilities is expected to fluctuate above and below the average, as has been the case since 1980 when detailed record-keeping regarding pumpage began statewide.

6) Regional changes in industrial ground-water pumpage are nearly impossible to predict; fluctuations in pumpage in the heavily industrialized counties (primarily the Standard Metropolitan Statistical Areas) can be expected in response to openings and closings of industrial plants, changes in manu-

facturing technology, and changes in the regional and national economies.

7) None of the industrial ground-water pumpage changes projected in this report are expected to have significant or wide-ranging negative impact on regional ground-water resources.

8) Large expansions in agricultural irrigation could have significant impact on regional ground-water resources, depending on the location and magnitude of increases.

9) Analyses in this and previous reports indicate that irrigation expansion is *most* likely to occur in areas with sandy soils and abundant ground-water supplies; generally, areas fitting those conditions are already being irrigated with relative economic success and they are considered to be the most highly "irrigable" regions.

10) Large expansions within the "highly irrigable" regions result in exaggerations in seasonal overpumpage, especially during droughts; however, even with expansion, this overpumpage is expected to be limited to the growing season and to be largely balanced by average annual recharge.

11) The effect of long-term climate variation or change on both ground-water recharge and irrigation demand is not considered in detail in this report, but it warrants further study.

In conclusion, ground-water supplies are available to meet most demands in Illinois at the present time. That situation is not expected to change drastically in the near future, according to the projections for municipal, industrial, and irrigation ground-water use made in this report.

There are only a few regions in the state where, under certain conditions, demand for ground water exceeds the supply. Certainly, there will continue to be a potential for competition and ground-water conflict in localized areas, stemming not from aquifer depletion but from well interference. With adequate planning and oversight by state agencies equipped with information and expertise, these problems should continue to be the exception rather than the norm.

REFERENCES

Baker, W.H., Jr. 1972. *Groundwater Levels and Pumpage in the East St. Louis Area, Illinois, 1967-1971.* Illinois State Water Survey Circular 112.

Blaney, H.F., and W.D. Criddle. 1950. *Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data.* U.S. Department of Agriculture, Soil Conservation Service, Technical Paper 96.

Bowman, J.A. 1991. *Ground-Water Quantity Laws and Management.* Illinois State Water Survey Report of Investigation 114.

Bowman, J.A. and M.A. Collins. 1987. *Impacts of Irrigation and Drought on Illinois Ground-Water Resources.* Illinois State Water Survey Report of Investigation 109.

Bowman, J.A., and B.C. Kimpel. 1991. *Irrigation Practices in Illinois.* Illinois State Water Survey Research Report 118.

Bowman, J.A., F.W. Simmons, and B.C. Kimpel. 1991. *Irrigation in the Midwest: Lessons from Illinois.* Journal of Irrigation and Drainage Engineering, 117(5):700-715.

Bruin, J., and H.F. Smith. 1953. *Preliminary Investigation of the Ground-Water Resources in the American Bottoms in Madison and St. Clair Counties, Illinois.* Illinois State Water Survey Report of Investigation 17.

Burch, S.L. 1991. *The New Chicago Model: A Reassessment of the Impacts of Lake Michigan Allocations on the Cambrian-Ordovician Aquifer System in Northeastern Illinois.* Illinois State Water Survey Research Report 119.

Collins, M.A., and S.S. Richards. 1986. *Ground-Water Levels and Pumpage in the East St. Louis Area, Illinois, 1978-1980.* Illinois State Water Survey Circular 165.

Cravens, S.J., S.D. Wilson, and R.C. Barry. 1990. *Regional Assessment of the Ground-Water Resources in Eastern Kankakee and Northern Iroquois Counties.* Illinois State Water Survey Report of Investigation 111.

Dunne, T., and L. Leopold. 1978. *Water in Environmental Planning.* W.H. Freeman & Co., San Francisco, CA.

Emmons, J.T. 1979. *Groundwater Levels and Pumpage in the East St. Louis Area, Illinois, 1971-1977.* Illinois State Water Survey Circular 134.

Gibb, J.P., and M. O'Hearn. 1980. *Illinois Groundwater Quality Data Summary.* Illinois State Water Survey Contract Report 230.

Ground-Water Quantity Committee, Illinois State Water Plan Task Force. 1989. *Groundwater Quantity Issues.* Illinois State Water Plan Task Force Special Report 12.

Illinois State Water Plan Task Force. 1984. *Illinois State Water Plan.* Illinois Department of Transportation, Division of Water Resources.

Kirk, J., K. Hlinka, R.T. Sasman, and E.W. Sanderson. 1985. *Water Withdrawals in Illinois, 1984.* Illinois State Water Survey Circular 163.

Kohlhase, R.C. 1987. *Ground-Water Levels and Pumpage in the East St. Louis Area, Illinois, 1981-1985.* Illinois State Water Survey Circular 168.

Nealon, J.S., J.R. Kirk, and A.P. Visocky. 1989. *Regional Assessment of Northern Illinois Ground-Water Resources.* Illinois State Water Survey Contract Report 473.

Reitz, G.E., Jr. 1968. *Groundwater Levels and Pumpage in the East St. Louis Area, Illinois, 1962-1966.* Illinois State Water Survey Circular 95.

Russell, R.R. 1963. *Ground-Water Levels in Illinois through 1961.* Illinois State Water Survey Report of Investigation 45.

Schicht, R.J. 1965. *Groundwater Development in the East St. Louis Area, Illinois.* Illinois State Water Survey Report of Investigation 51.

Schicht, R.J., J.R. Adams, and J.B. Stall. 1976. *Water Resources Availability, Quality, and Cost in Northeastern Illinois.* Illinois State Water Survey Report of Investigation 83.

Schicht, R.J., and E.G. Jones. 1962. *Groundwater Levels and Pumpage in the East St. Louis Area, Illinois, 1890-1961.* Illinois State Water Survey Report of Investigation 44.

Sipp, S.K, W.D. Lembke, C.W. Boast, M.D. Thorne, and P.N. Walker. 1984. *Water Management on Claypan Soils in the Midwest.* Water Resources Center, University of Illinois, Research Report 186.

Stout, G.E., P.N. Walker, W.D. Goetsch, M.D. Thorne, E.C. Benham, T.A. Austin, J. Golchin, Z. Shahvar, C.E. Anderson, H.P. Johnson, R.H. Shaw, O. Arjmand, W.L. Miller, R.L. Clouser, P. Erhbor, J. Sobek, V.R. Eidman, P.N. Wilson, and C.C. Shaeffer. 1983. *Efficient Use of Water for Irrigation in the Upper Midwest.* Water Resources Center, University of Illinois, Research Report 176.

Suter, M., R.E. Bergstrom, H.F. Smith, G.H. Emrich, W.C. Walton, and T.E. Larson. 1959. *Ground-Water Resources of the Chicago Region, Illinois.* Illinois State Water Survey and State Geological Survey Cooperative Groundwater Report 1.

Technical Advisory Committee on Water Resources. 1967. *Water for Illinois: A Plan for Action.* Springfield, Illinois.

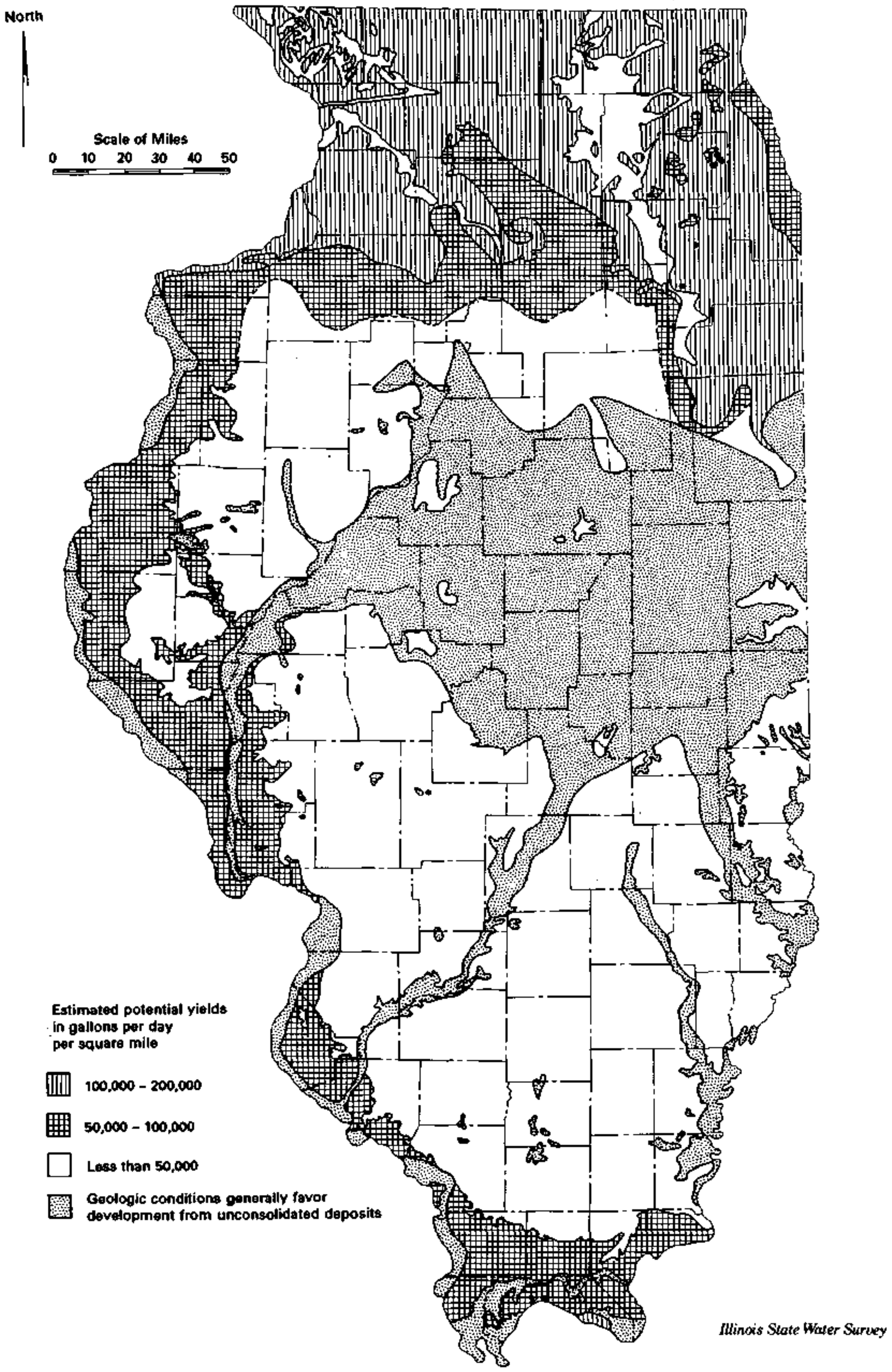
Thornthwaite, C.W., and J.R. Mather. 1955. *The Water Balance.* Laboratory of Climatology. Publication 8, Centerton, NJ.

U.S. Soil Conservation Service. 1967. *Irrigation Water Requirements.* U.S. Department of Agriculture, Technical Release 21.

Visocky, A.P., M.G. Sherrill, and *K* Cartwright. 1985. *Geology, Hydrology, and Water Quality of the Cambrian and Ordovician Systems in Northern Illinois.* Illinois State Water Survey and State Geological Survey Cooperative Groundwater Report 10.

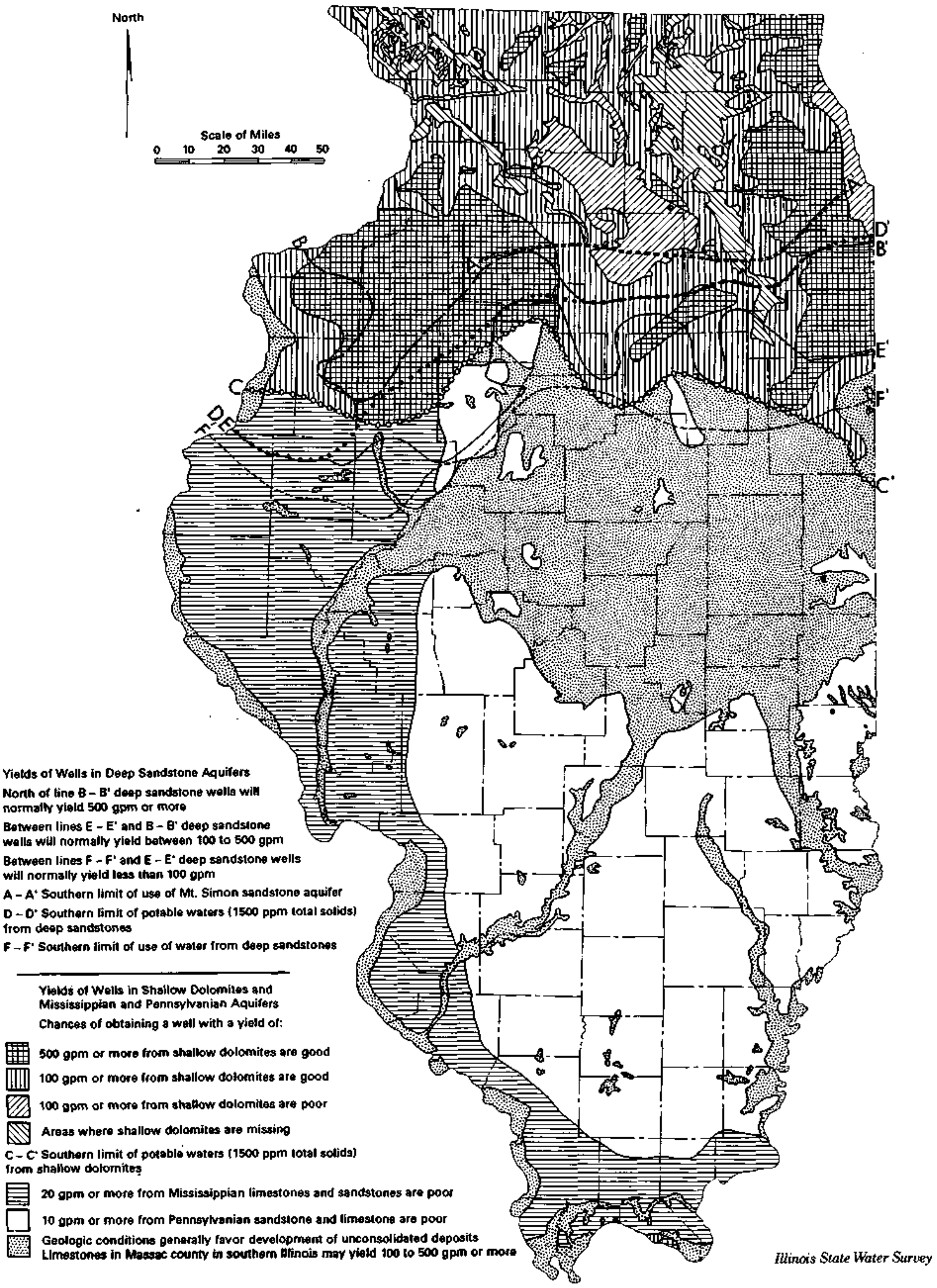
Walker, P.N., M.D. Thorne, E.C. Benham, and W.D. Goetsch. 1981. *Optimization of Water Use for Field Crop Production in the Upper Midwest.* Water Resources Center, University of Illinois, Research Report 159.

FIGURES AND TABLES



Illinois State Water Survey

Figure 1. Distribution of potential yields for deep and shallow bedrock aquifers in Illinois (From Technical Advisory Committee on Water Resources, 1967)



Illinois State Water Survey

Figure 2. Expected well yields in deep and shallow bedrock aquifers
(From Technical Advisory Committee on Water Resources, 1967)

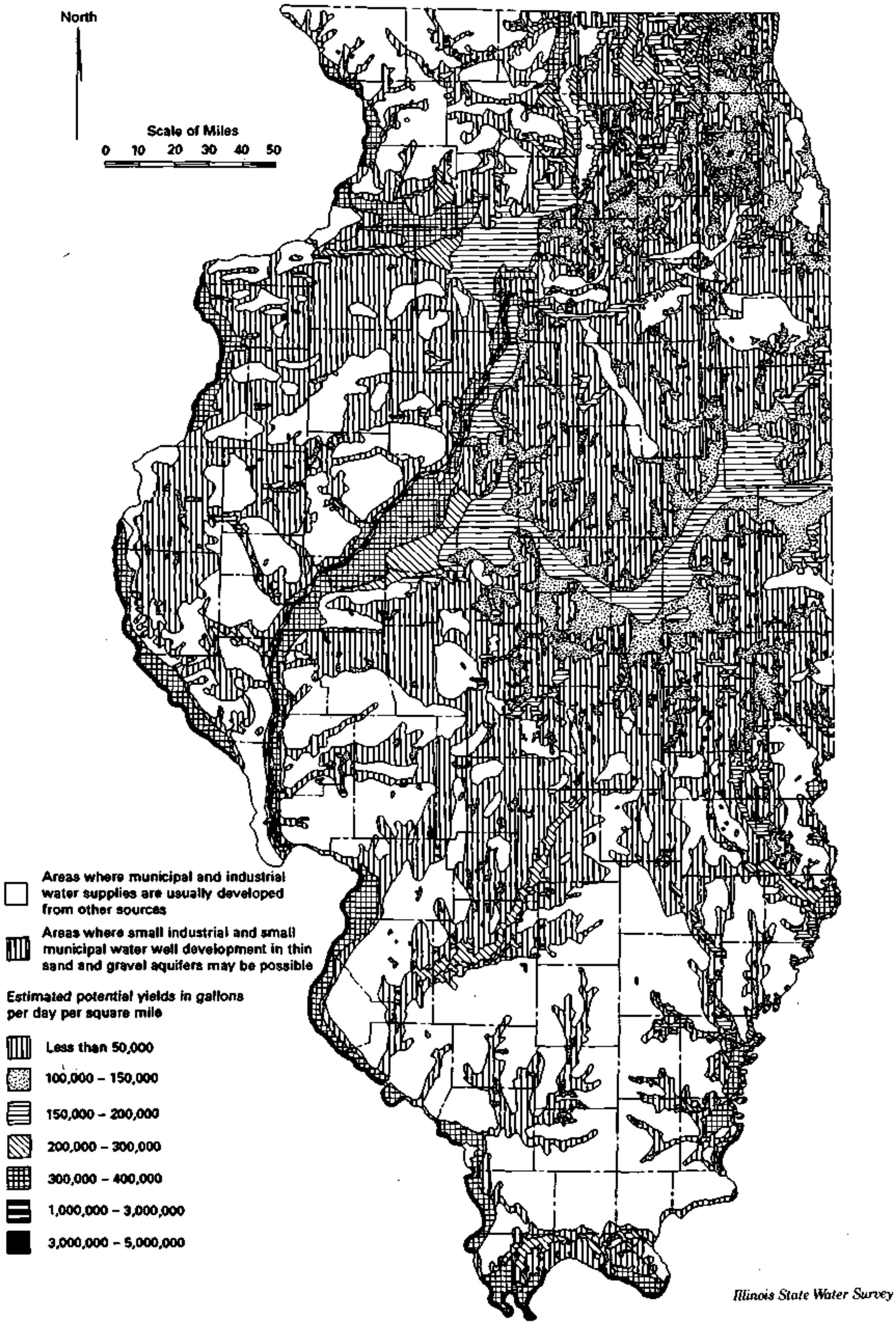
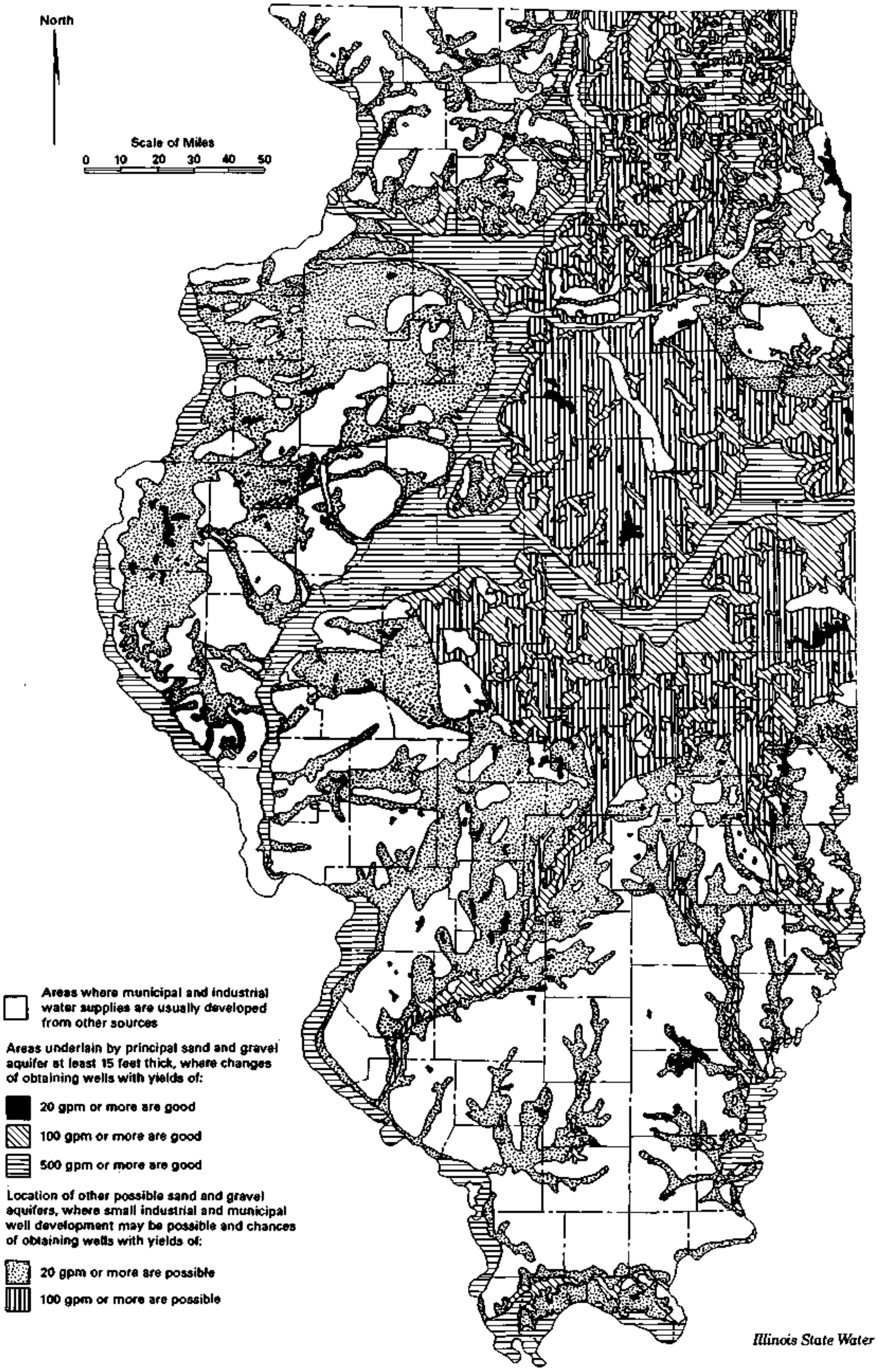


Figure 3. Distribution of potential yields for unconsolidated sand and gravel aquifers in Illinois (From Technical Advisory Committee on Water Resources, 1967)



Illinois State Water Survey

Figure 4. Expected well yields in unconsolidated sand and gravel aquifers (From Technical Advisory Committee on Water Resources, 1967)

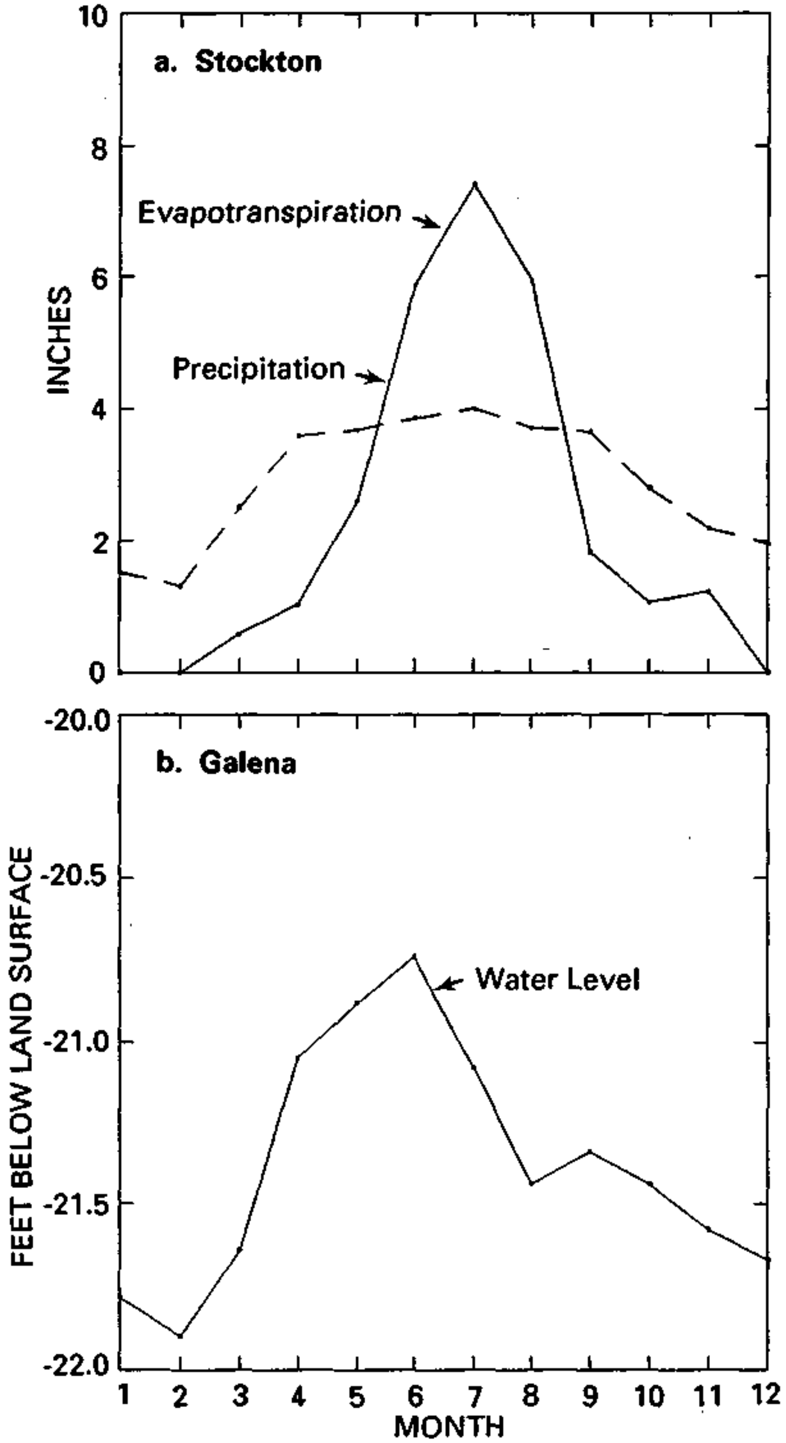


Figure 5. a) 30-year mean monthly precipitation and evapotranspiration at Stockton versus b) 30-year average month-end shallow ground-water levels at Galena

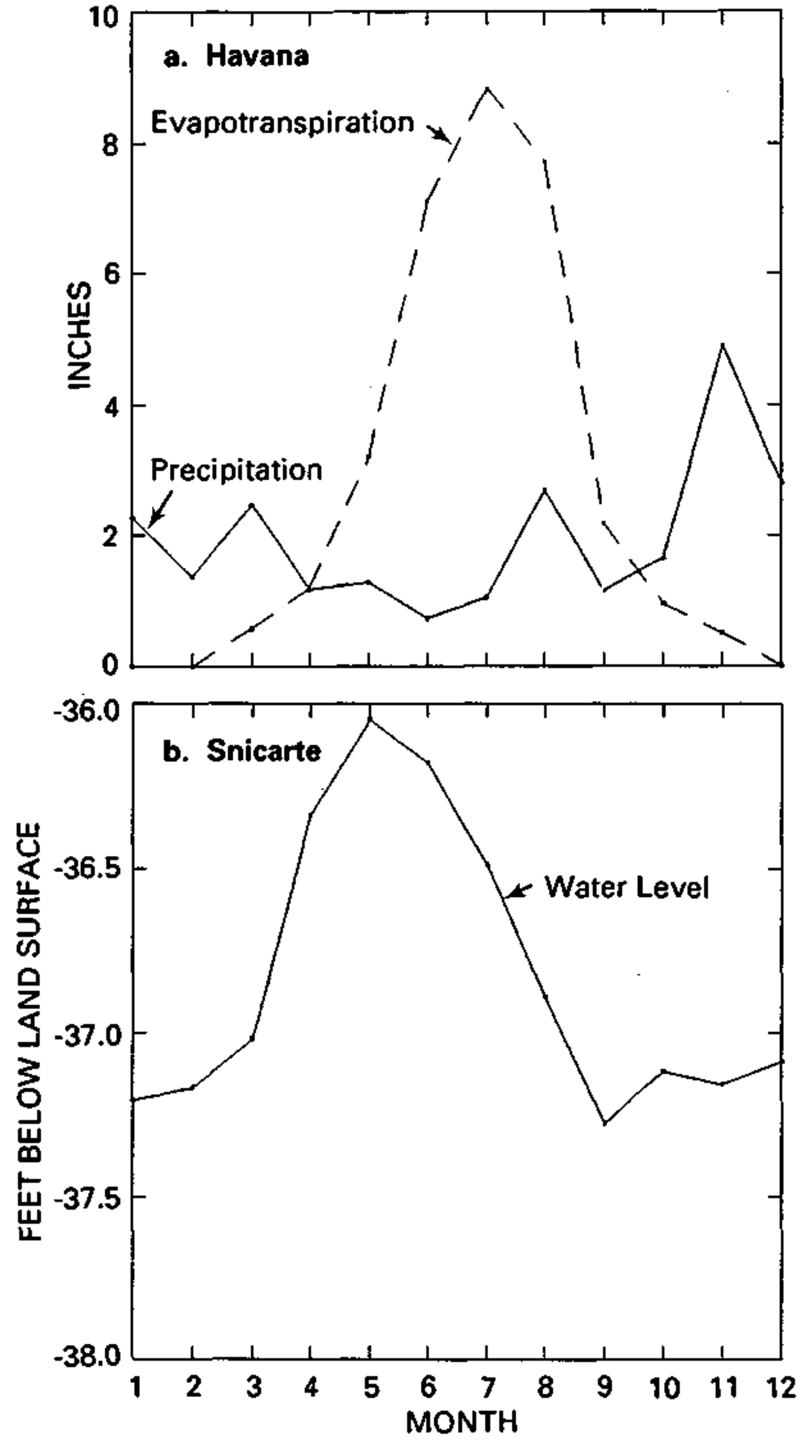


Figure 6. a) 30-year mean monthly precipitation and evapotranspiration at Hayana versus b) 30-year average month-end shallow ground-water levels at Snicarte

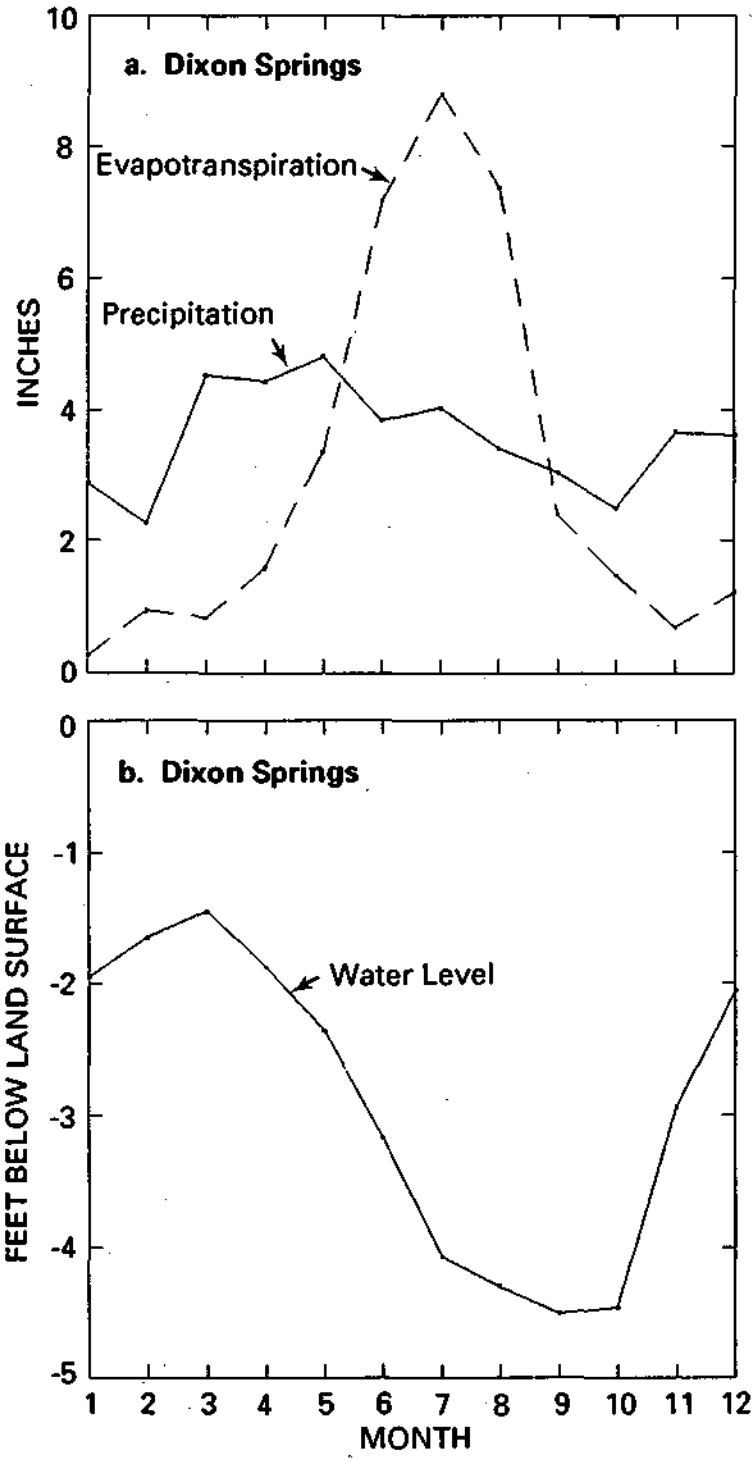


Figure 7. a) 30-year mean monthly precipitation and evapotranspiration at Dixon Springs versus b) 30-year average month-end shallow ground-water levels at Dixon Springs

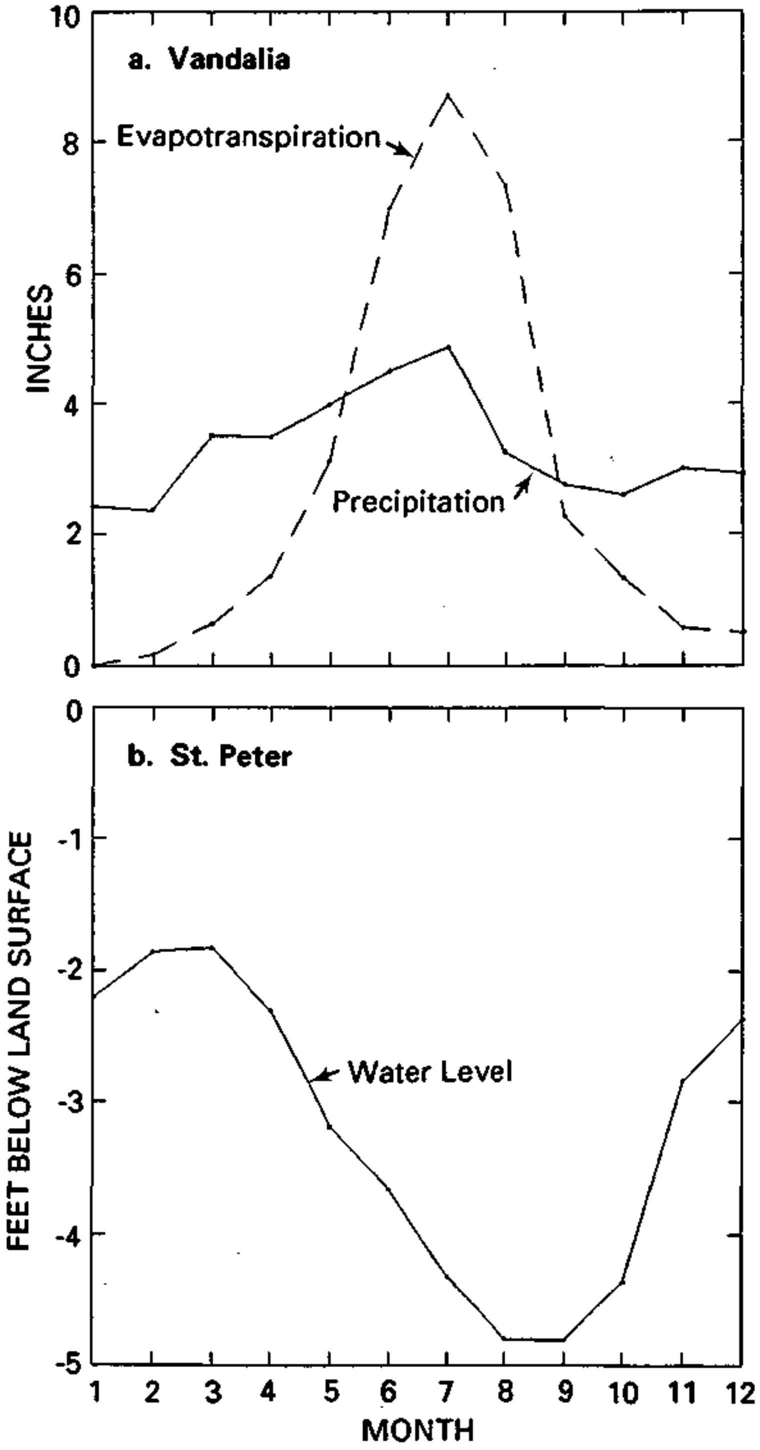


Figure 8. a) 30-year mean monthly precipitation and evapotranspiration at Vandalia versus b) 30-year average month-end shallow ground-water levels at St. Peter

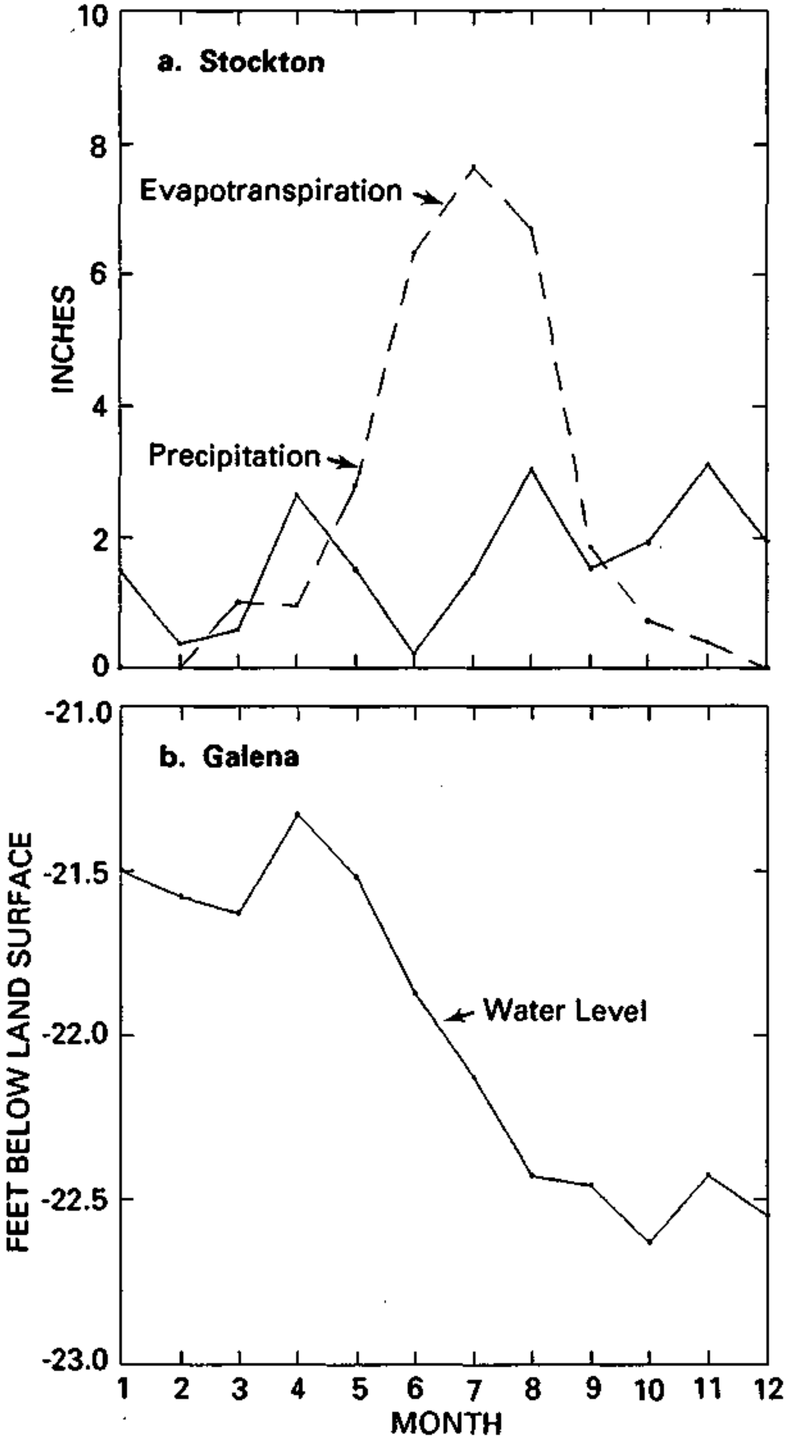


Figure 9. a) 1988 precipitation and evapotranspiration at Stockton versus b) 1988 month-end shallow ground-water levels at Galena

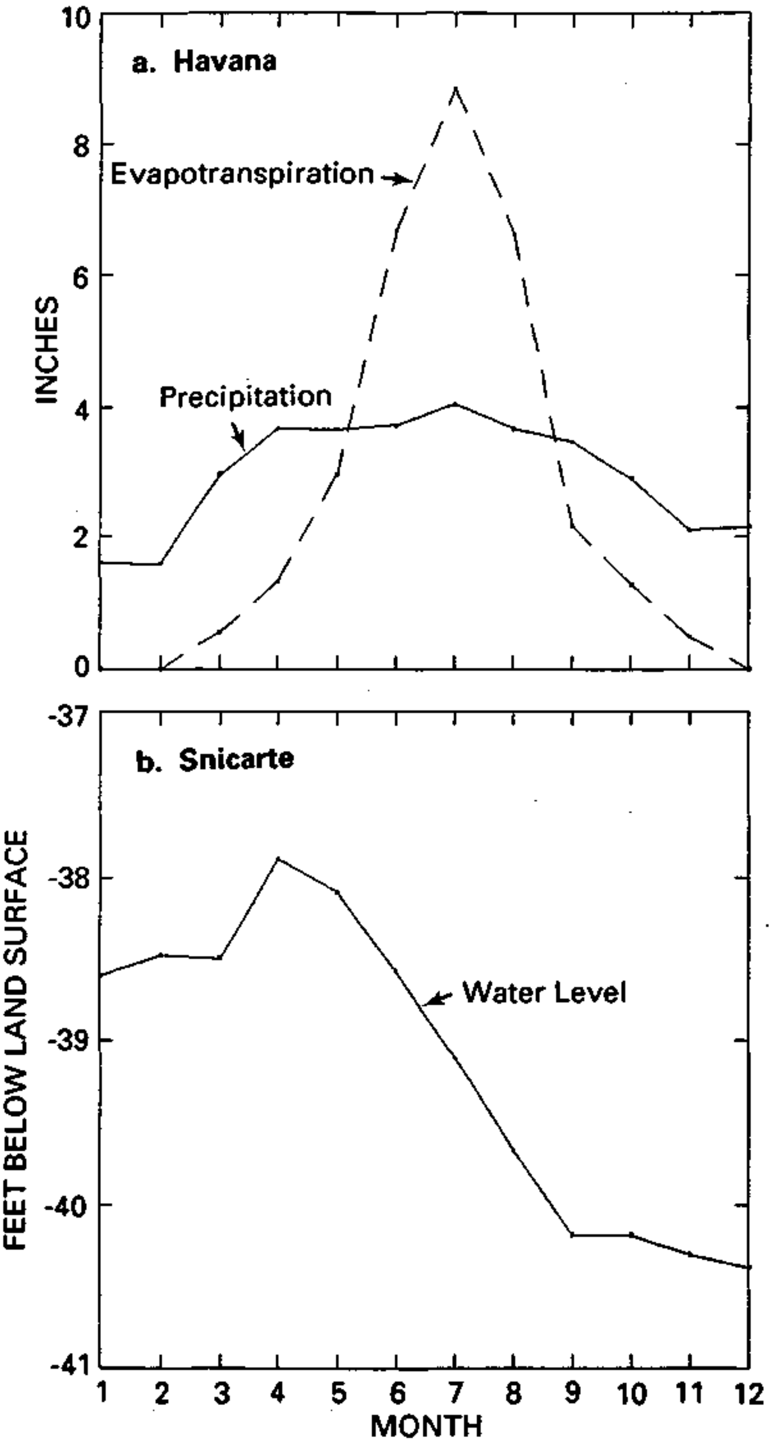


Figure 10. a) 1988 precipitation and evapotranspiration at Havana versus b) 1988 month-end shallow ground-water levels at Snicarte

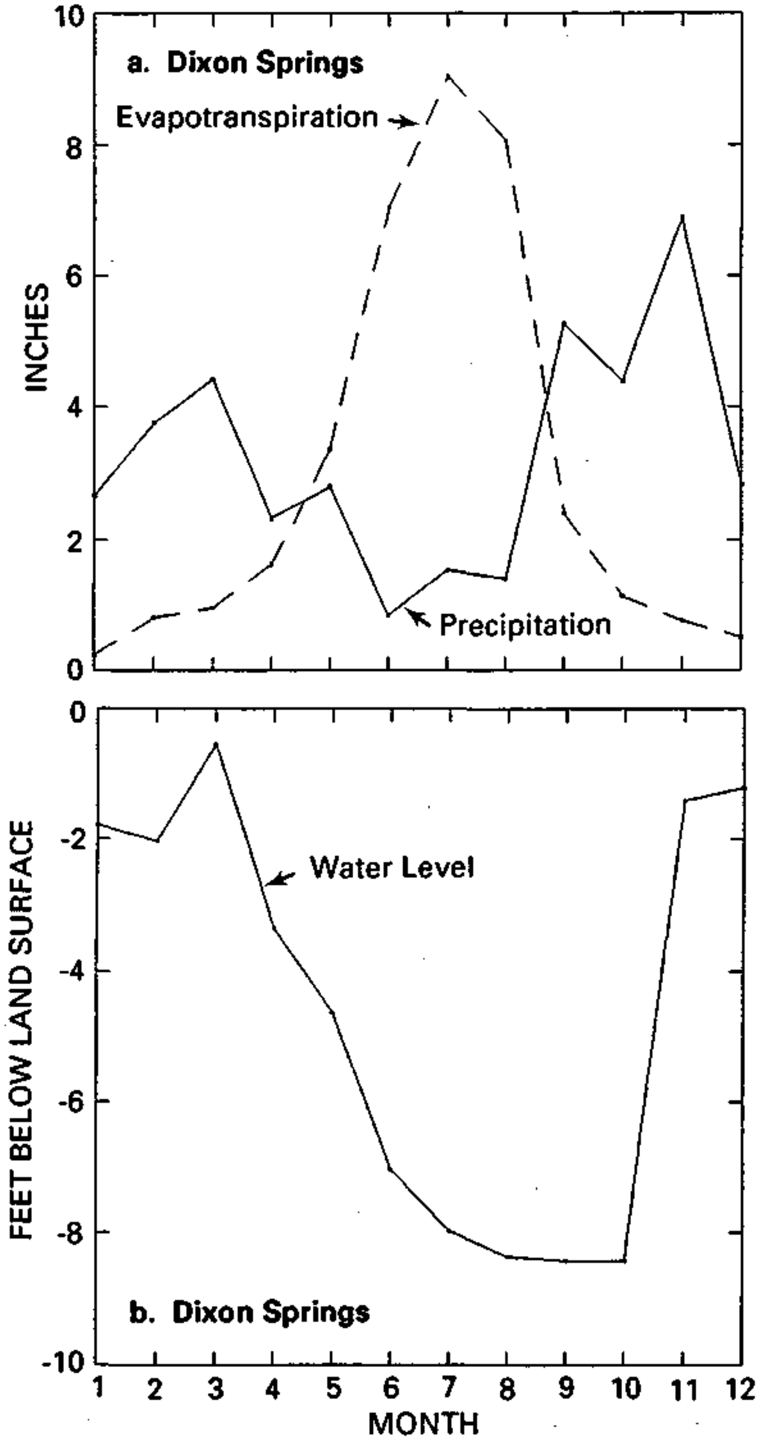


Figure 11. a) 1988 precipitation and evapotranspiration at Dixon Springs versus b) 1988 month-end shallow ground-water levels at Dixon Springs

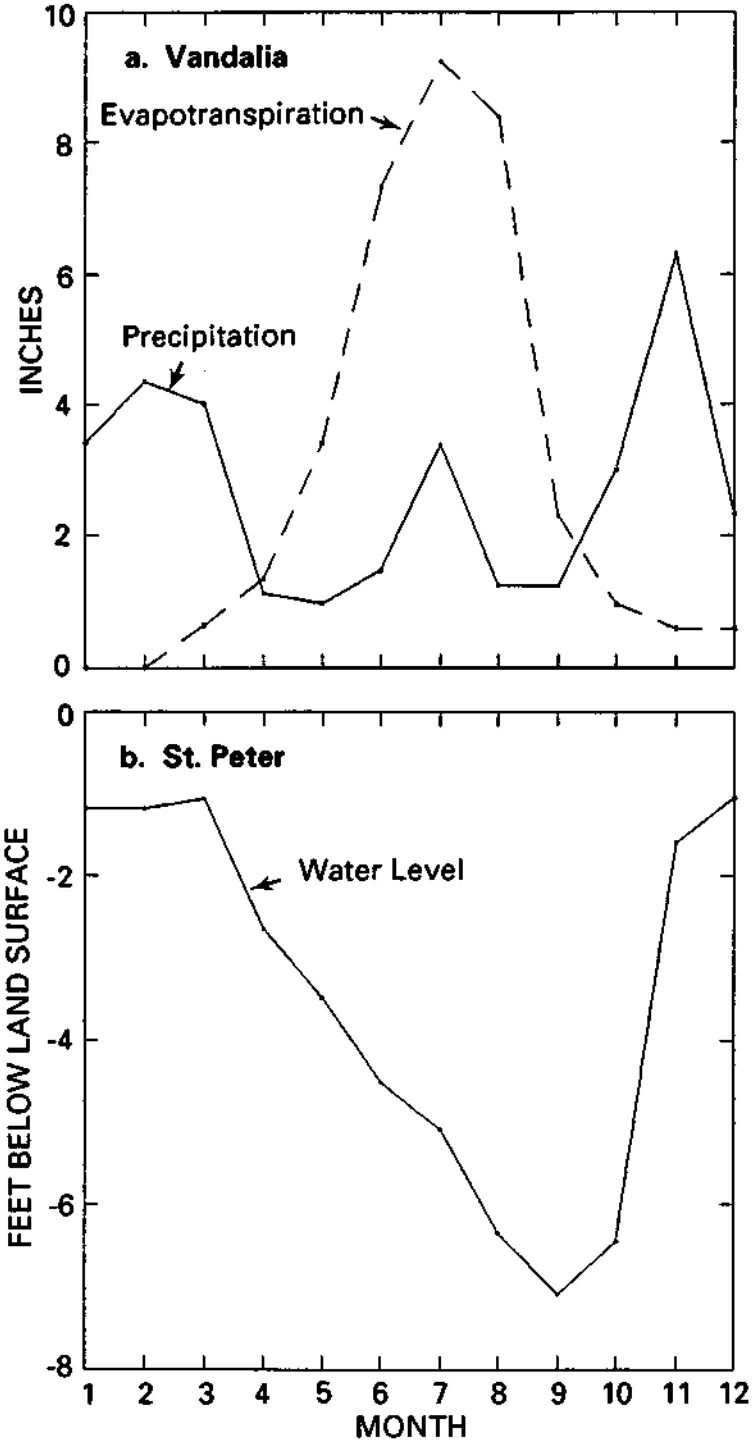


Figure 12. a) 1988 precipitation and evapotranspiration at Vandalia versus b) 1988 month-end shallow ground-water levels at St. Peter

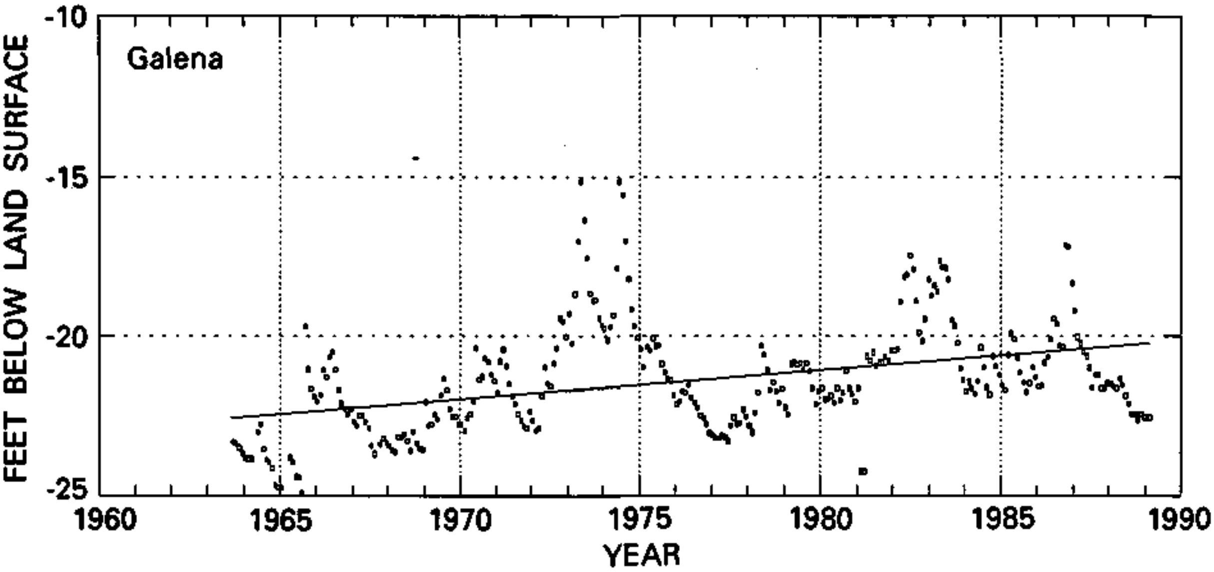


Figure 13. Long-term record of shallow ground-water levels at Galena
(The well is distant from other pumping sites, so the water levels and trend line show natural fluctuations)

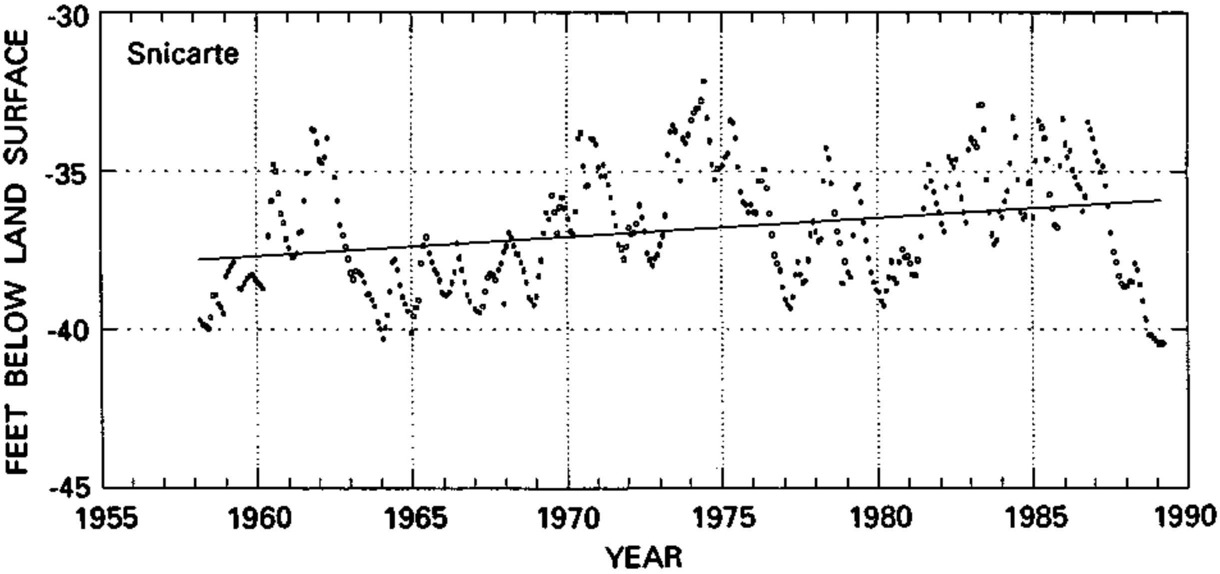


Figure 14. Long-term record of shallow ground-water levels at Snicarte .
(The well is distant from other pumping sites, so the water levels and trend line show natural fluctuations)

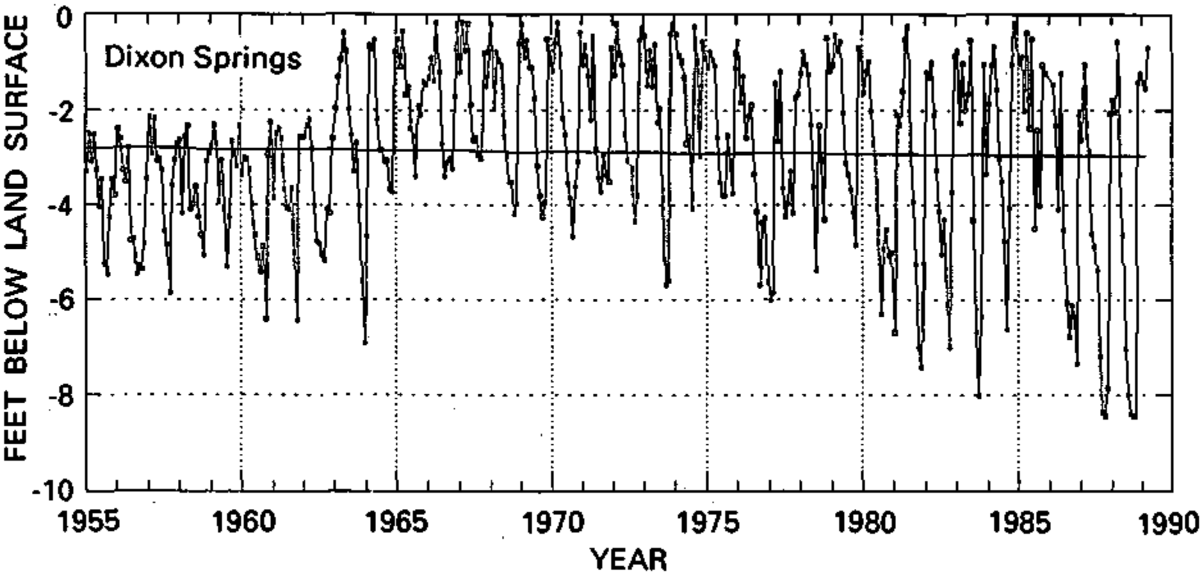


Figure 15. Long-term record of shallow ground-water levels at Dixon Springs
(The well is distant from other pumping sites, so the water levels and trend line show natural fluctuations)

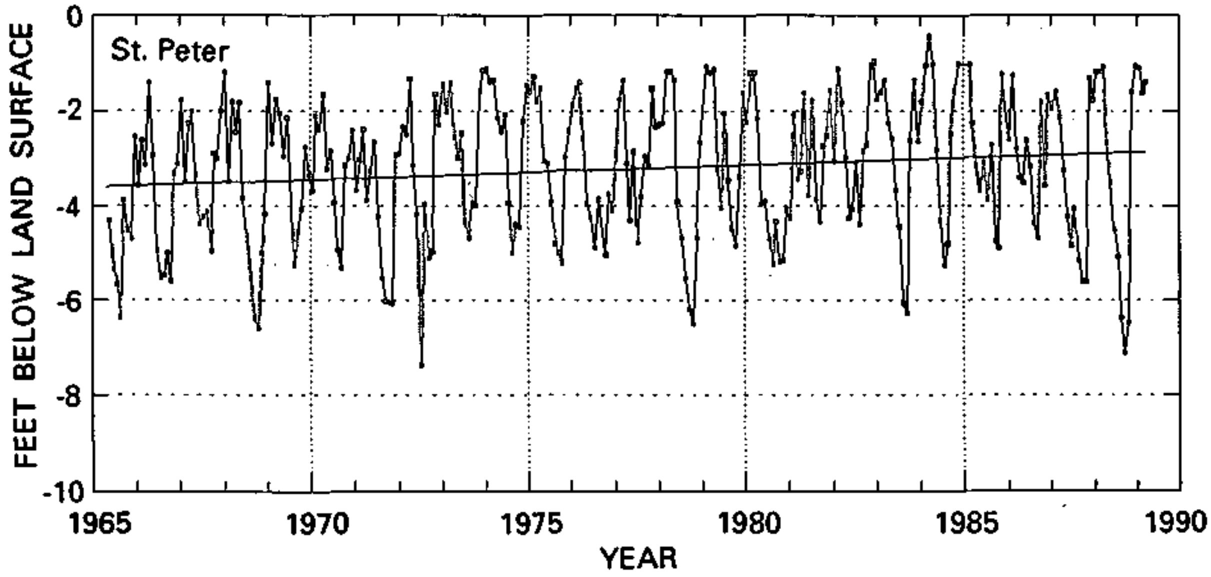


Figure 16. Long-term record of shallow ground-water levels at St. Peter
(The well is distant from other pumping sites, so the water levels and trend line show natural fluctuations)

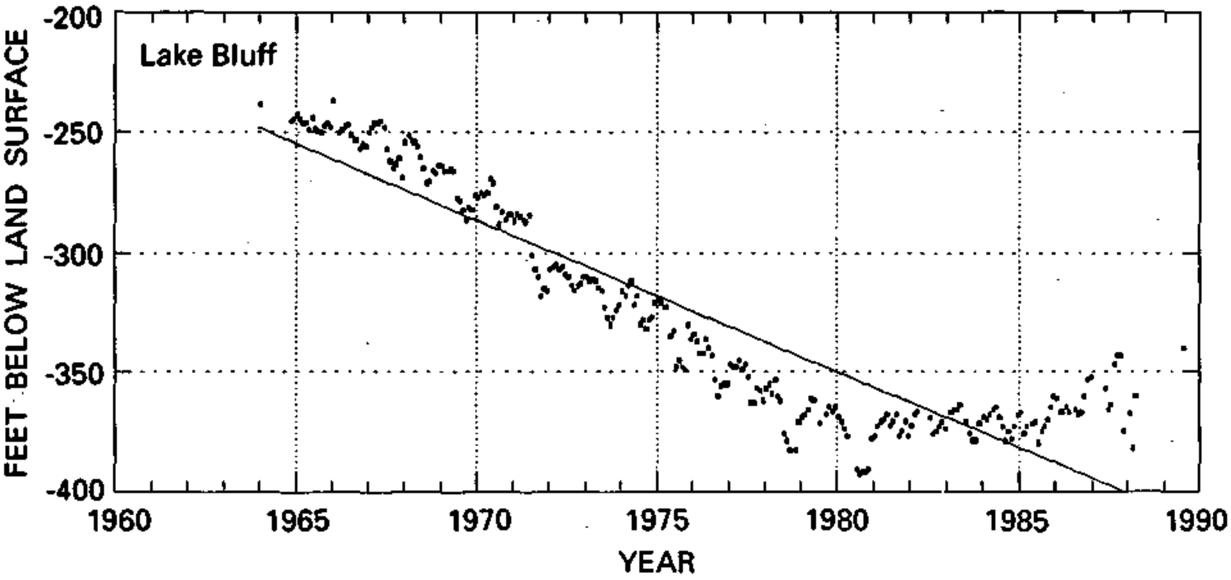


Figure 17. Long-term record of deep sandstone ground-water levels at Lake Bluff

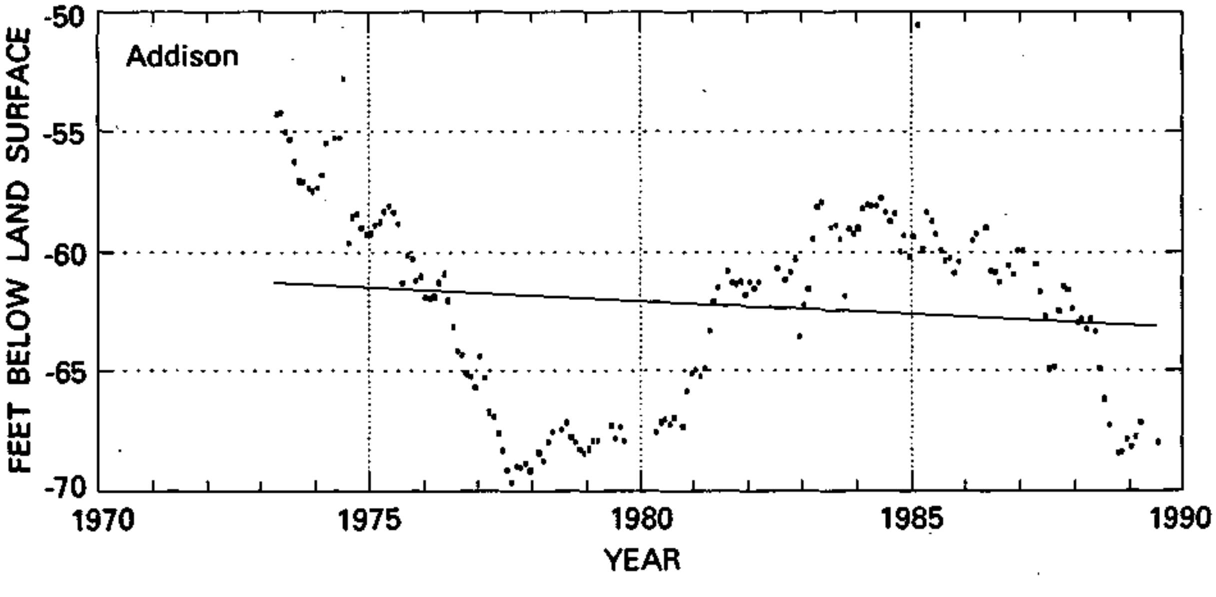


Figure 18. Long-term record of shallow dolomite ground-water levels at Addison

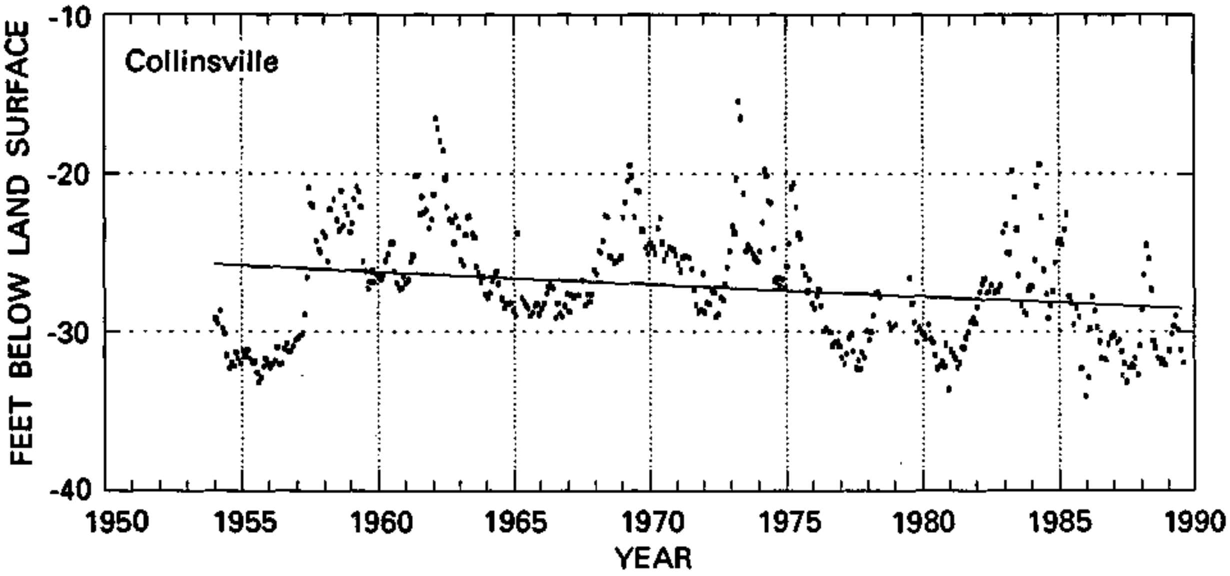


Figure 19. Long-term record of sand and gravel ground-water levels at Collinsville

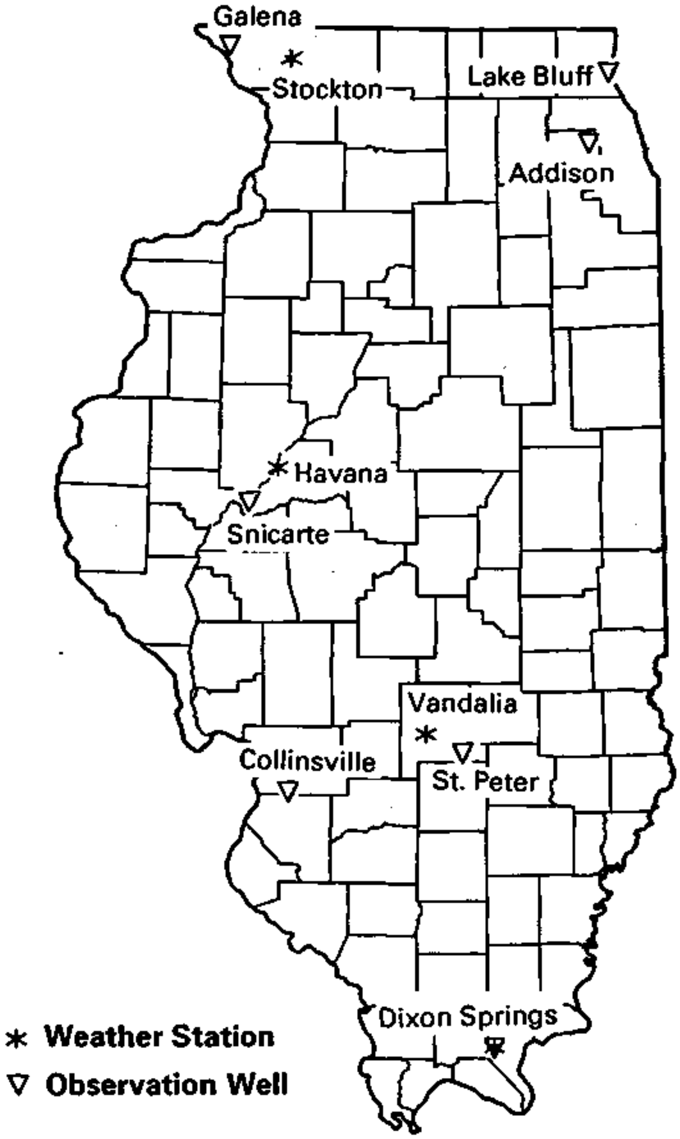


Figure 20. Locations of weather stations and ground-water-level observation wells used in the analyses

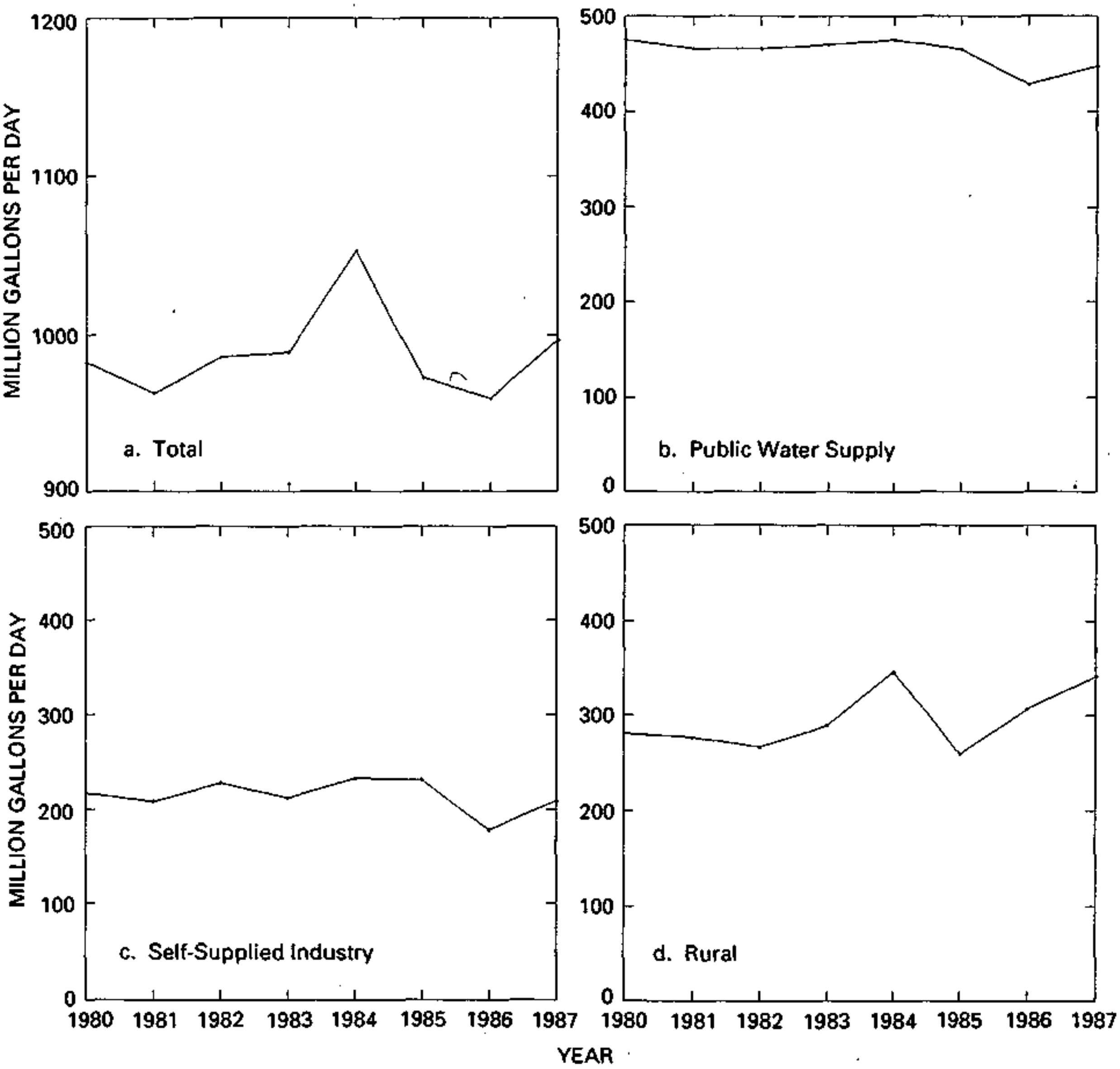


Figure 21. Ground-water withdrawals in Illinois, 1980-1987

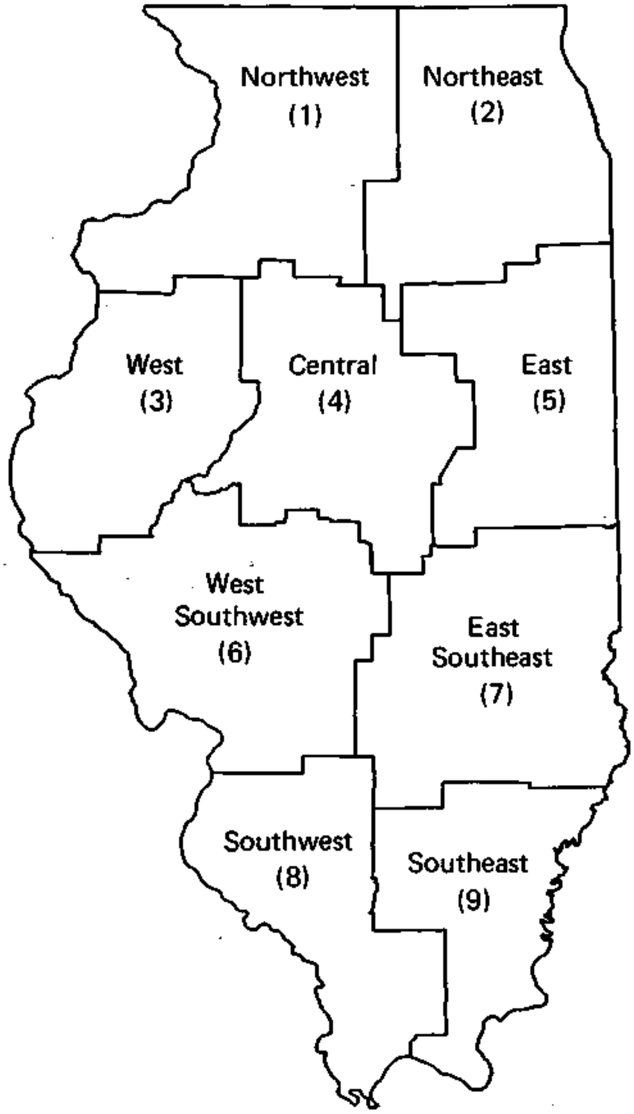


Figure 22. Illinois crop reporting districts

Crop Reporting District 1

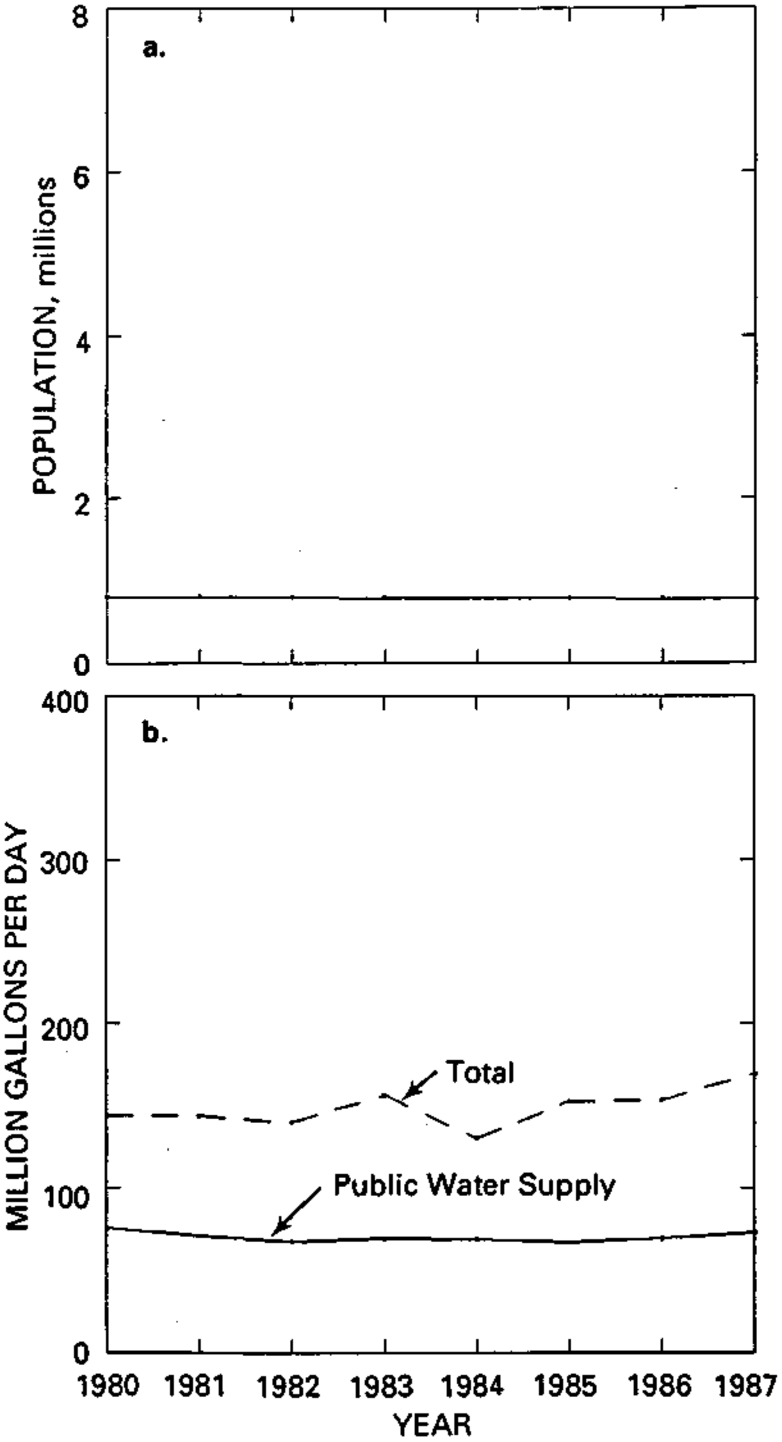


Figure 23. a) Population trends, 1980-1987, and b) total and public water supply ground-water withdrawals, 1980-1987, Crop Reporting District 1

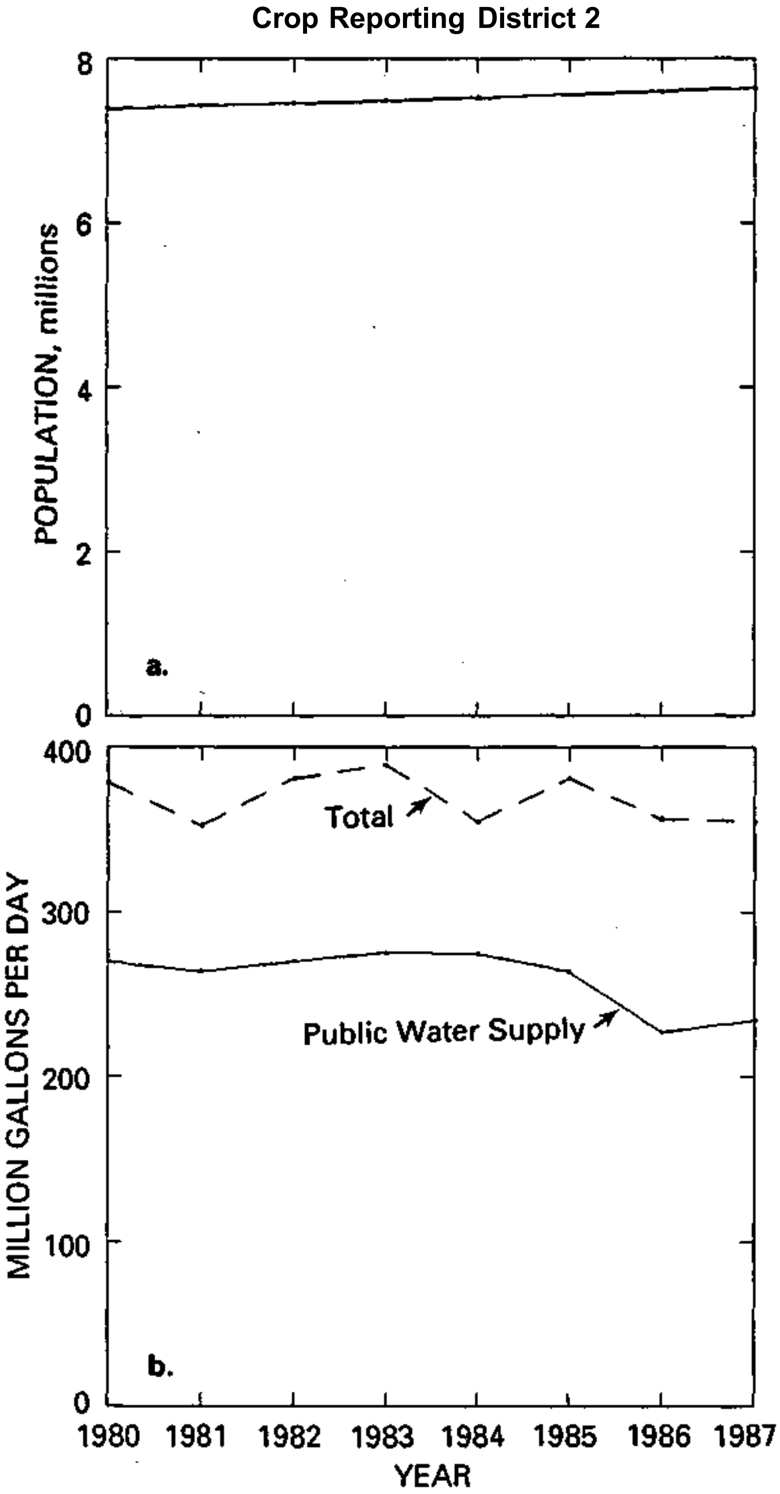


Figure 24. a) Population trends, 1980-1987, and b) total and public water supply ground-water withdrawals, 1980-1987, Crop Reporting District 2

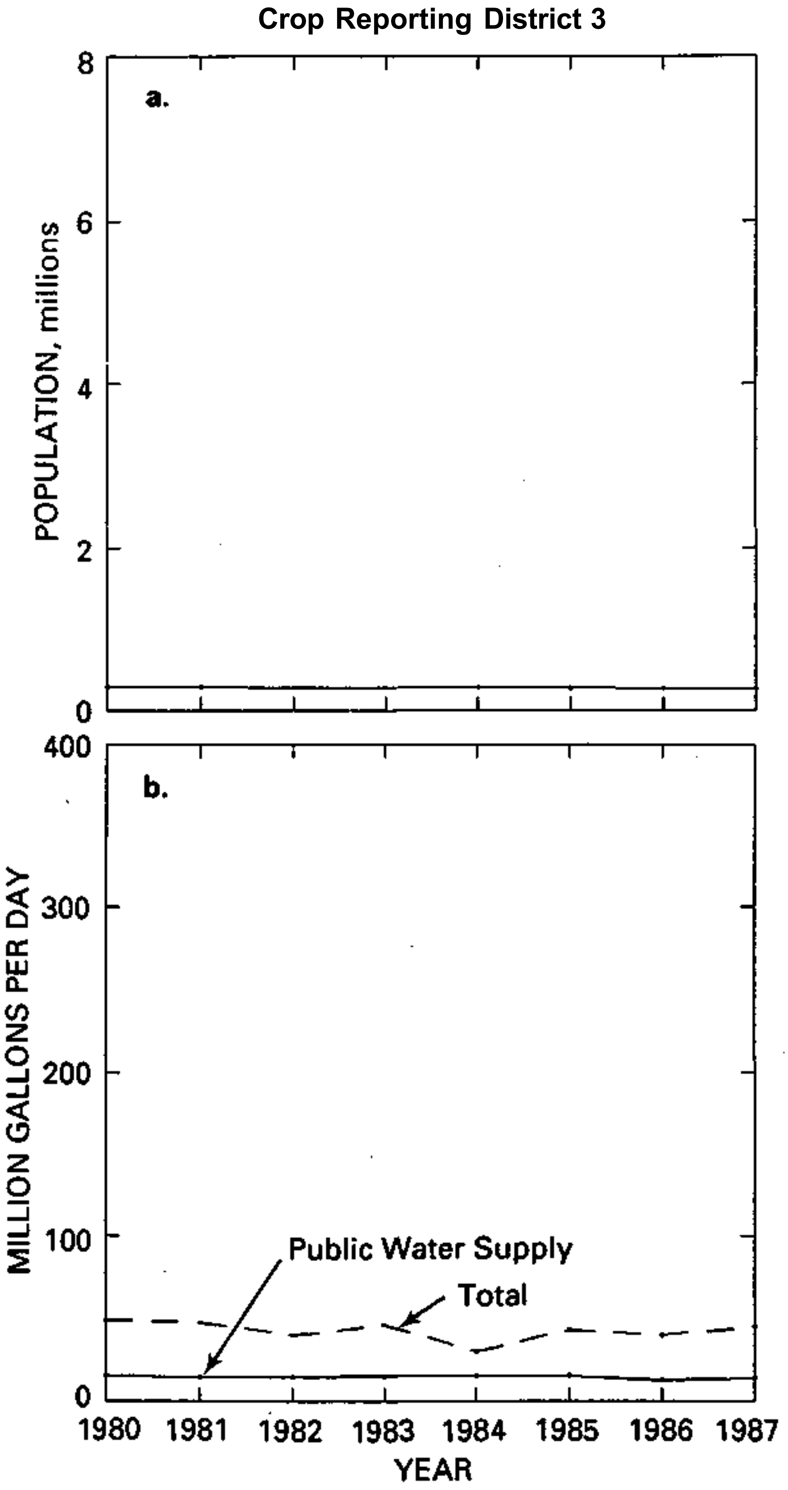


Figure 25. a) Population trends, 1980-1987, and b) total and public water supply ground-water withdrawals, 1980-1987, Crop Reporting District 3

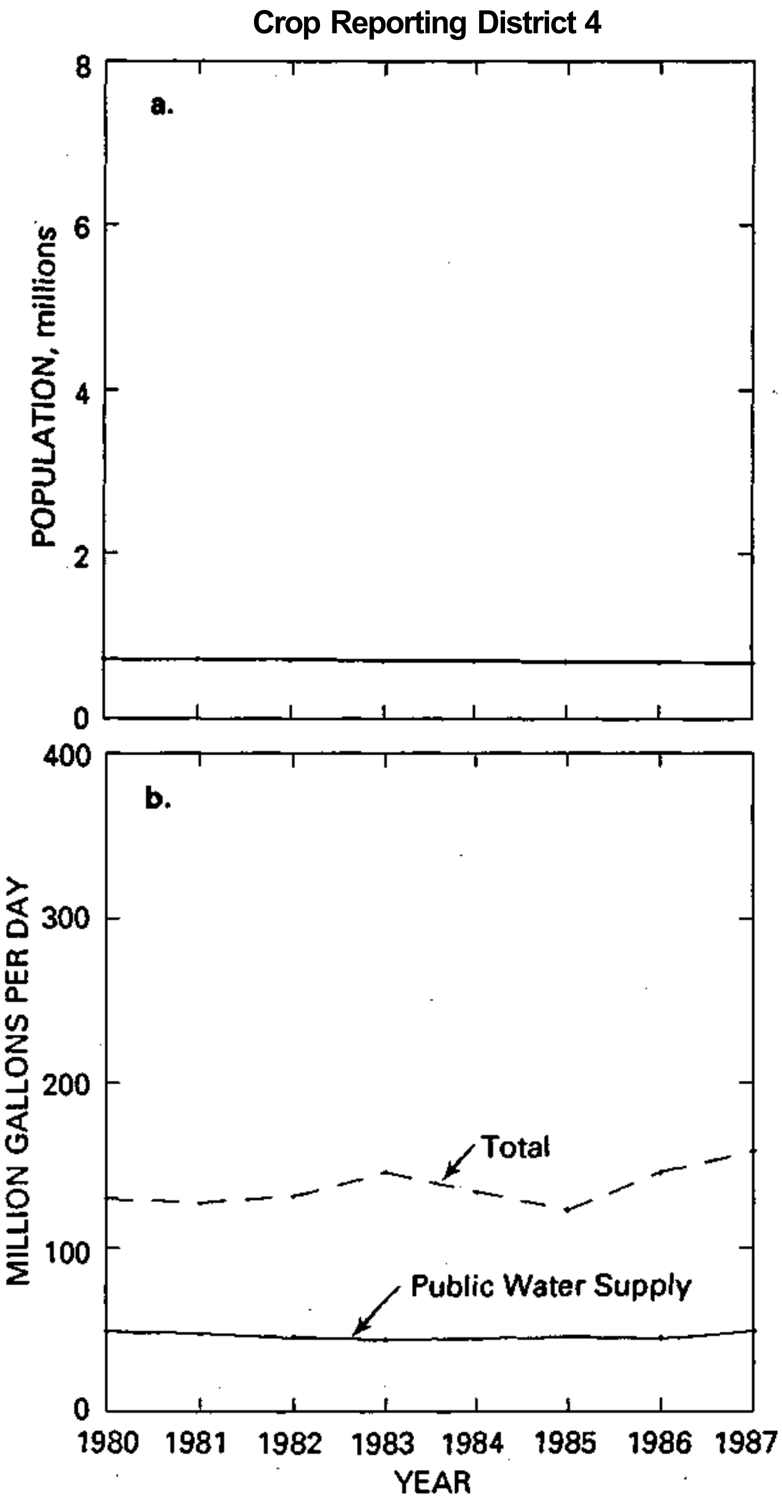


Figure 26. a) Population trends, 1980-1987, and b) total and public water supply ground-water withdrawals, 1980-1987, Crop Reporting District 4

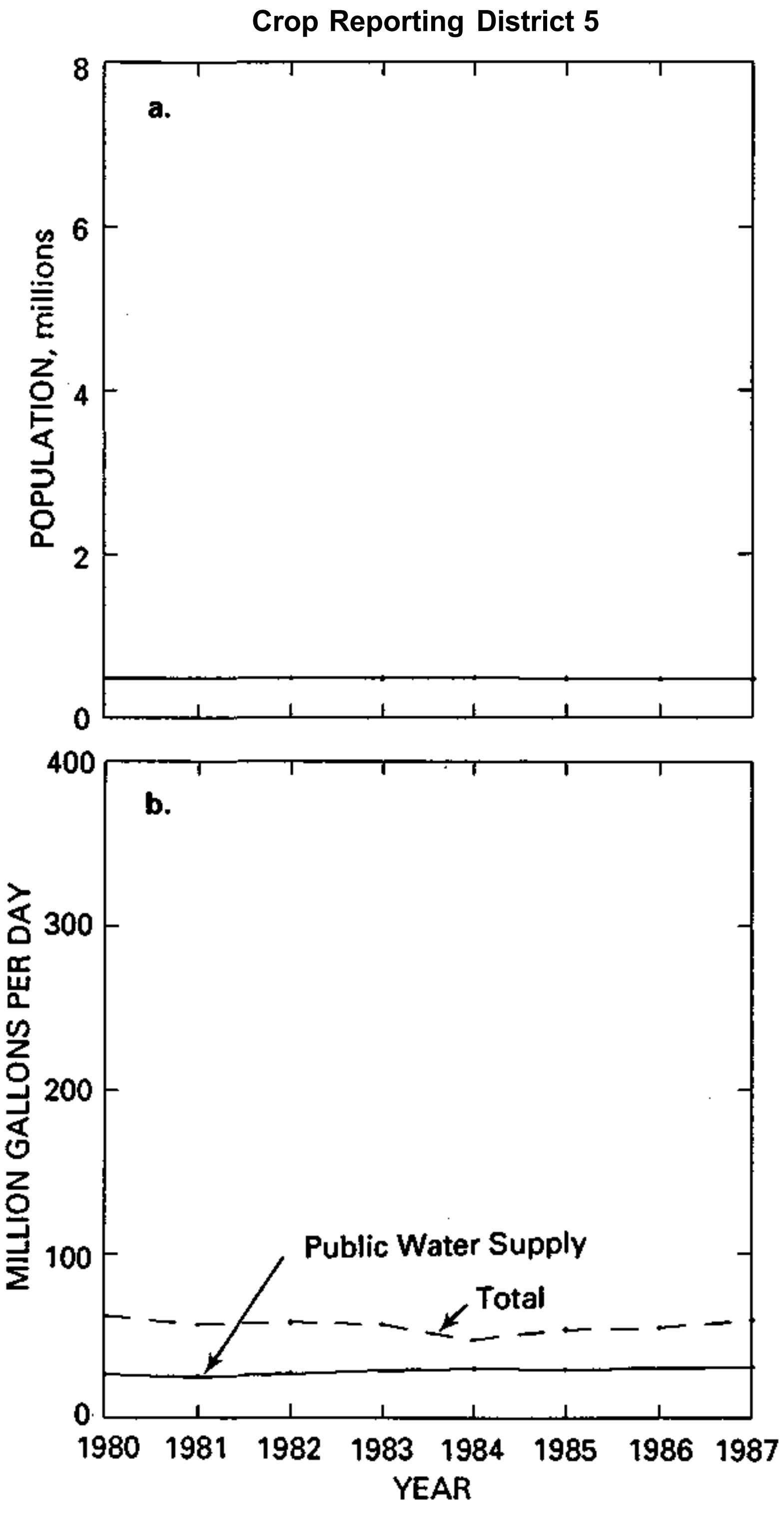


Figure 27. a) Popuiation trends, 1980-1987, and b) total and pubiic water supply ground-water withdrawals, 1980-1987, Crop Reporting District 5

Crop Reporting District 6

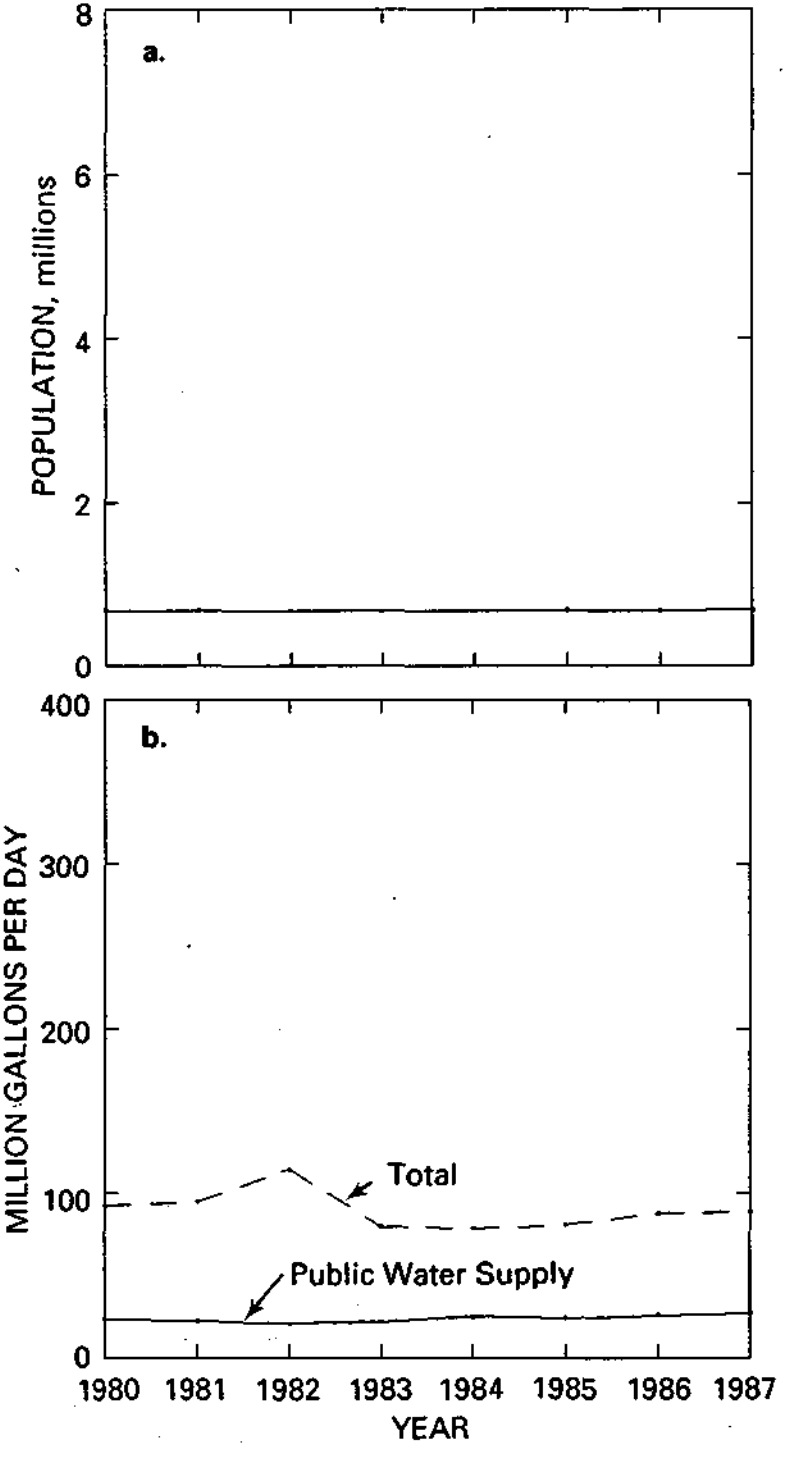


Figure 28. a) Population trends, 1980-1987, and b) total and public water supply ground-water withdrawals, 1980-1987, Crop Reporting District 6

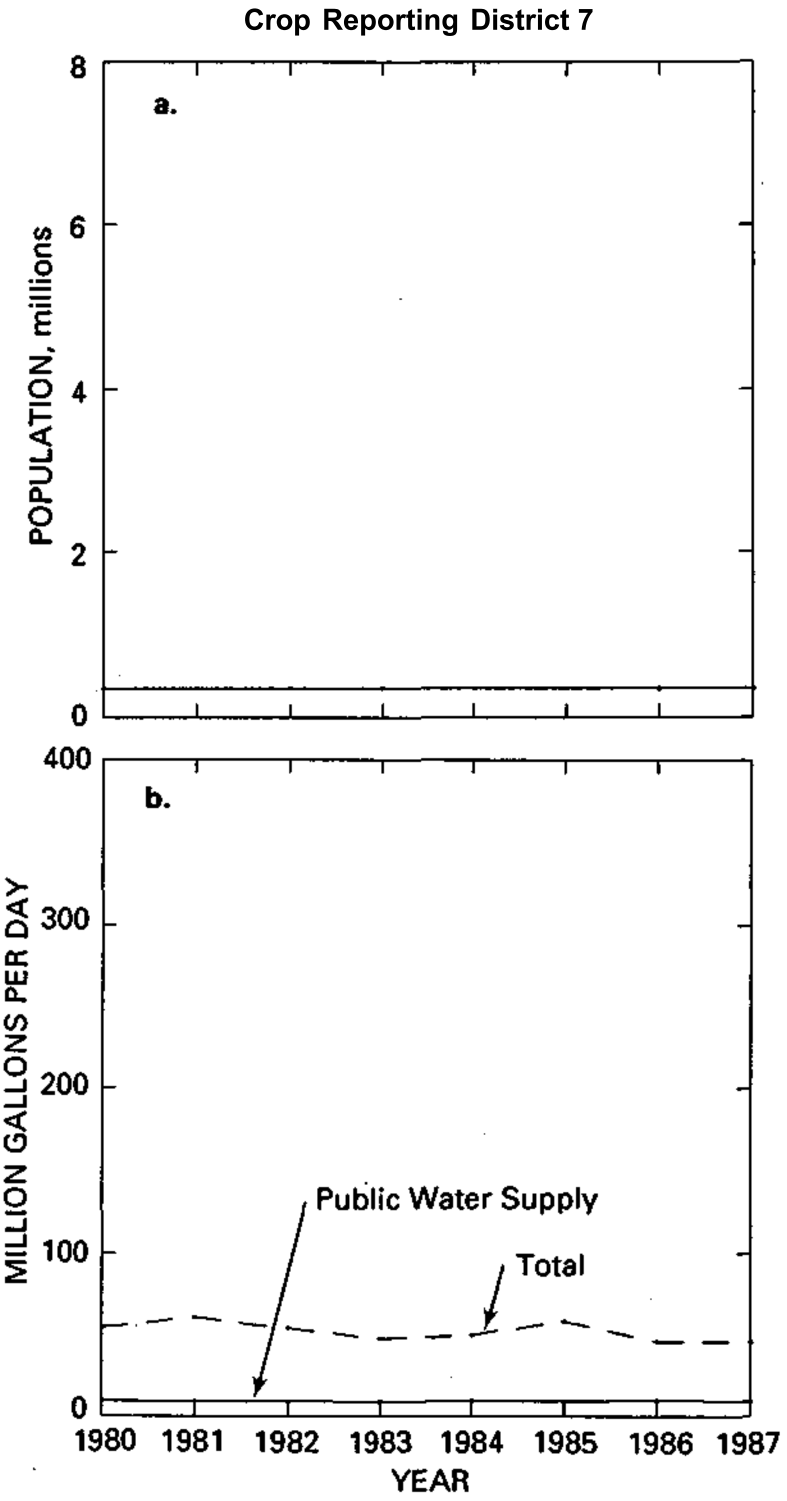


Figure 29. a) population trends, 1980-198/, and b) total and public water supply ground-water withdrawals, 1980-1987, Crop Reporting District 7

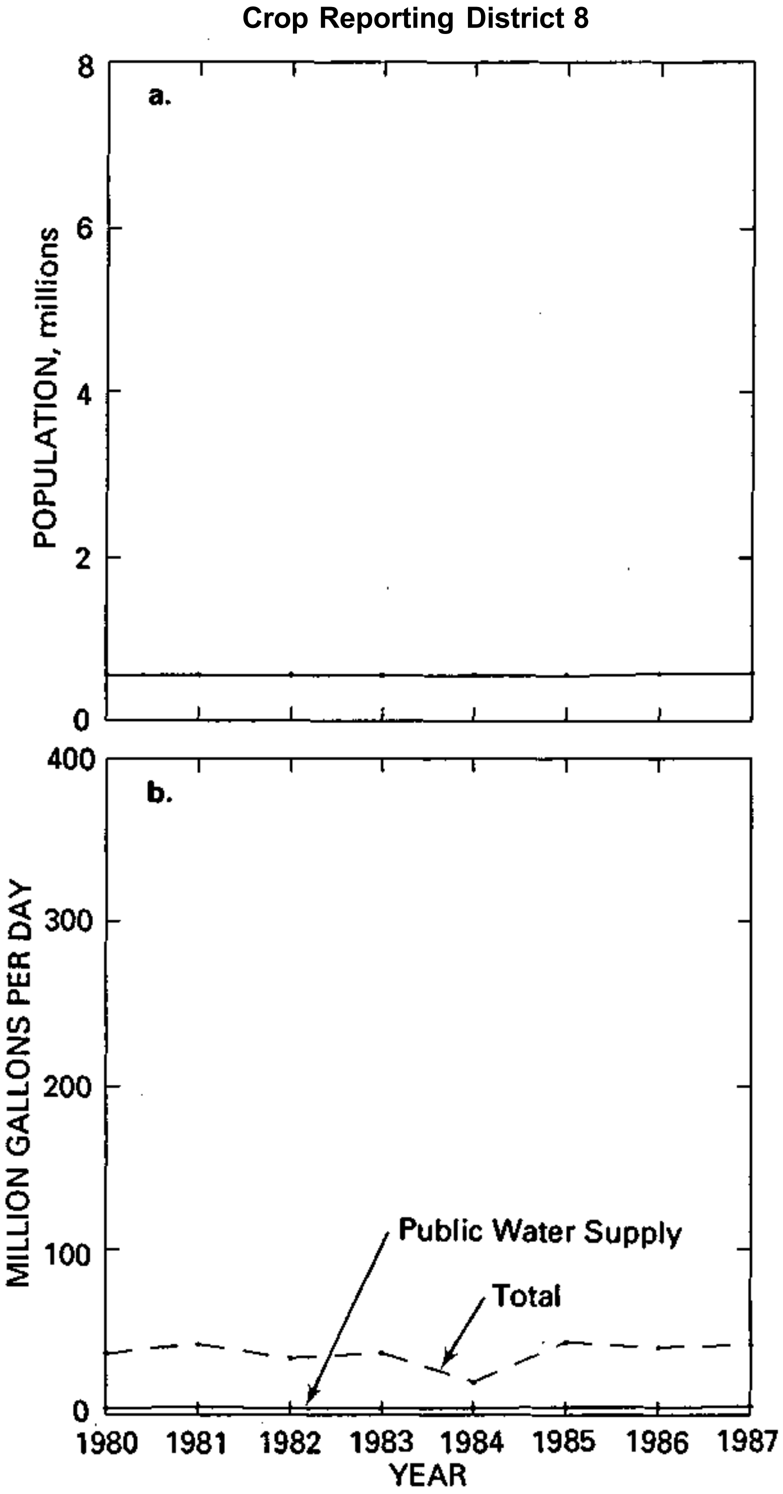


Figure 30. a) Population trends, 1980-1987, and b) total and public water supply ground-water withdrawals, 1980-1987, Crop Reporting District 8

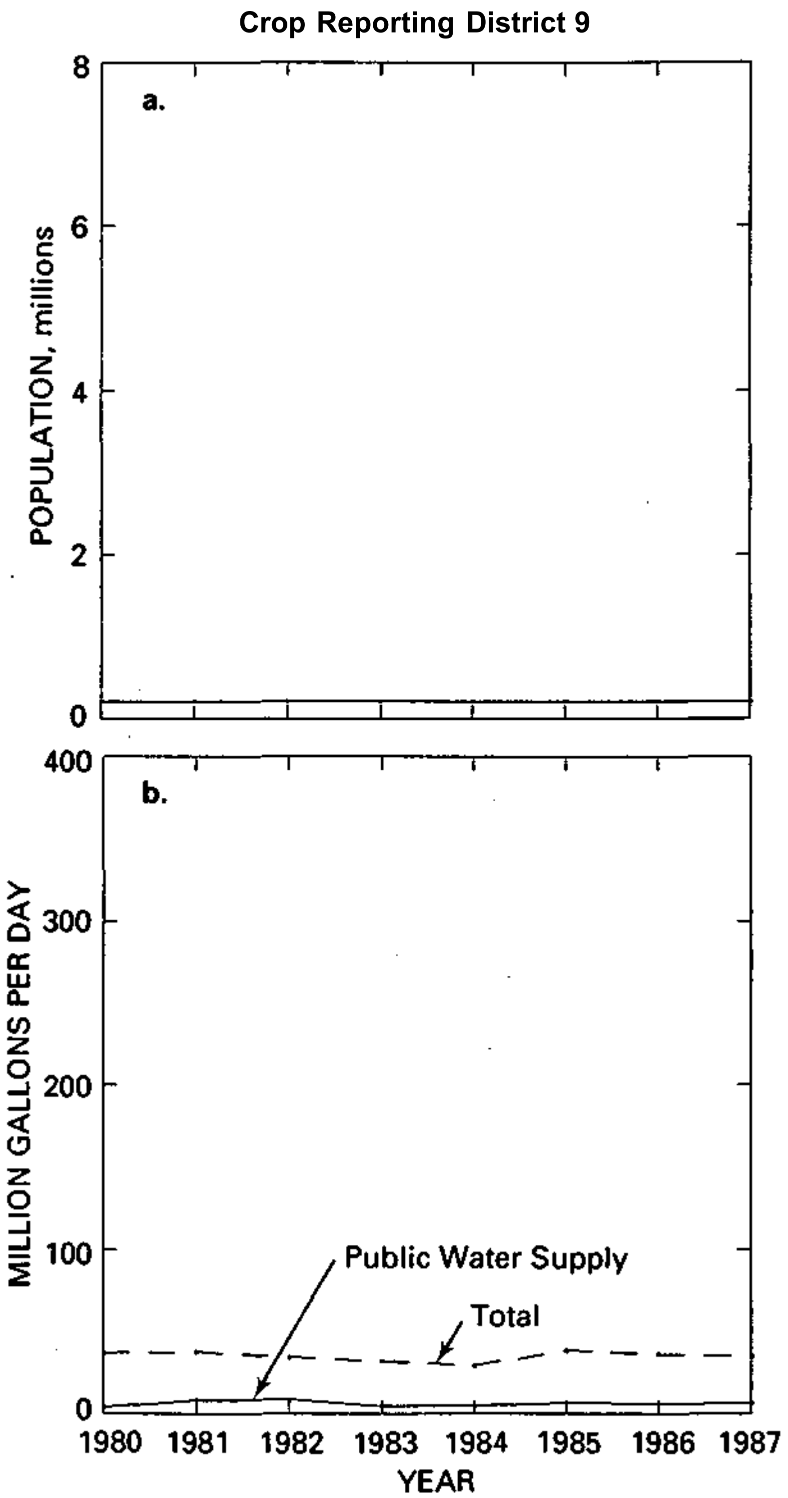


Figure 31. a) Population trends, 1980-1987, and b) total and public water supply ground-water withdrawals, 1980-1987, Crop Reporting District 9

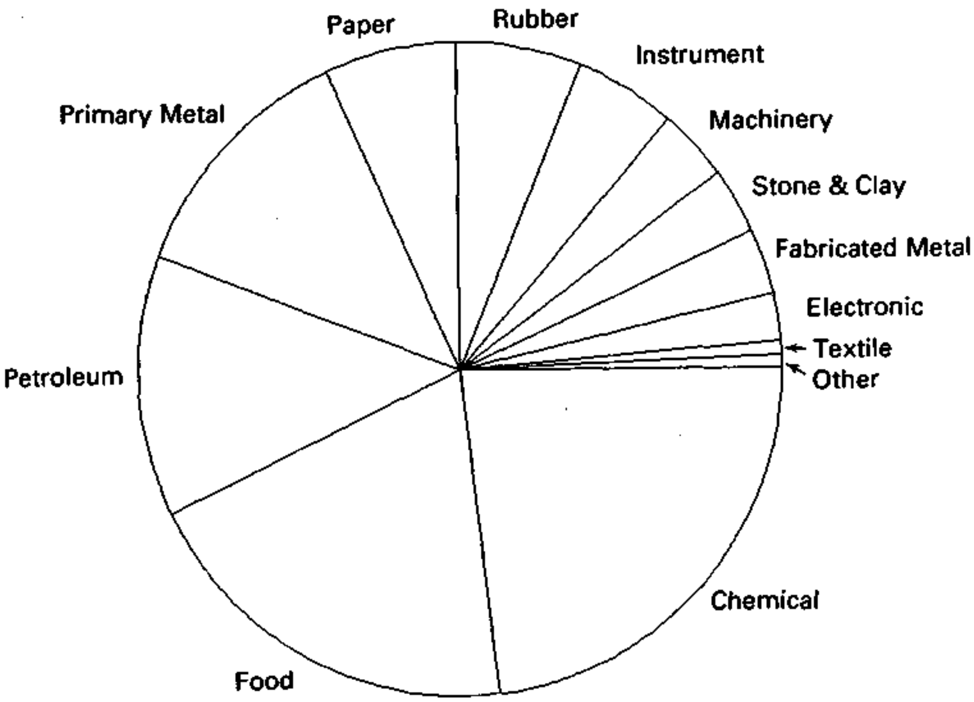
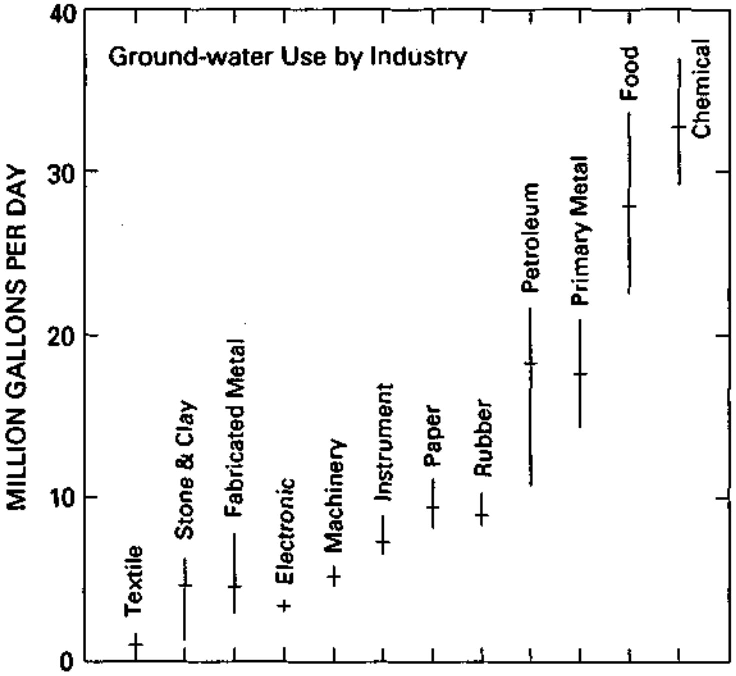


Figure 32. Average self-supplied industrial ground-water withdrawals in Illinois, 1980-1987



Note: The vertical lines represent the range from minimum to maximum annual withdrawals, and the crossbars represent the average from 1980-1987

Figure 33. Variation in self-supplied industrial ground-water withdrawals from 1980 through 1987

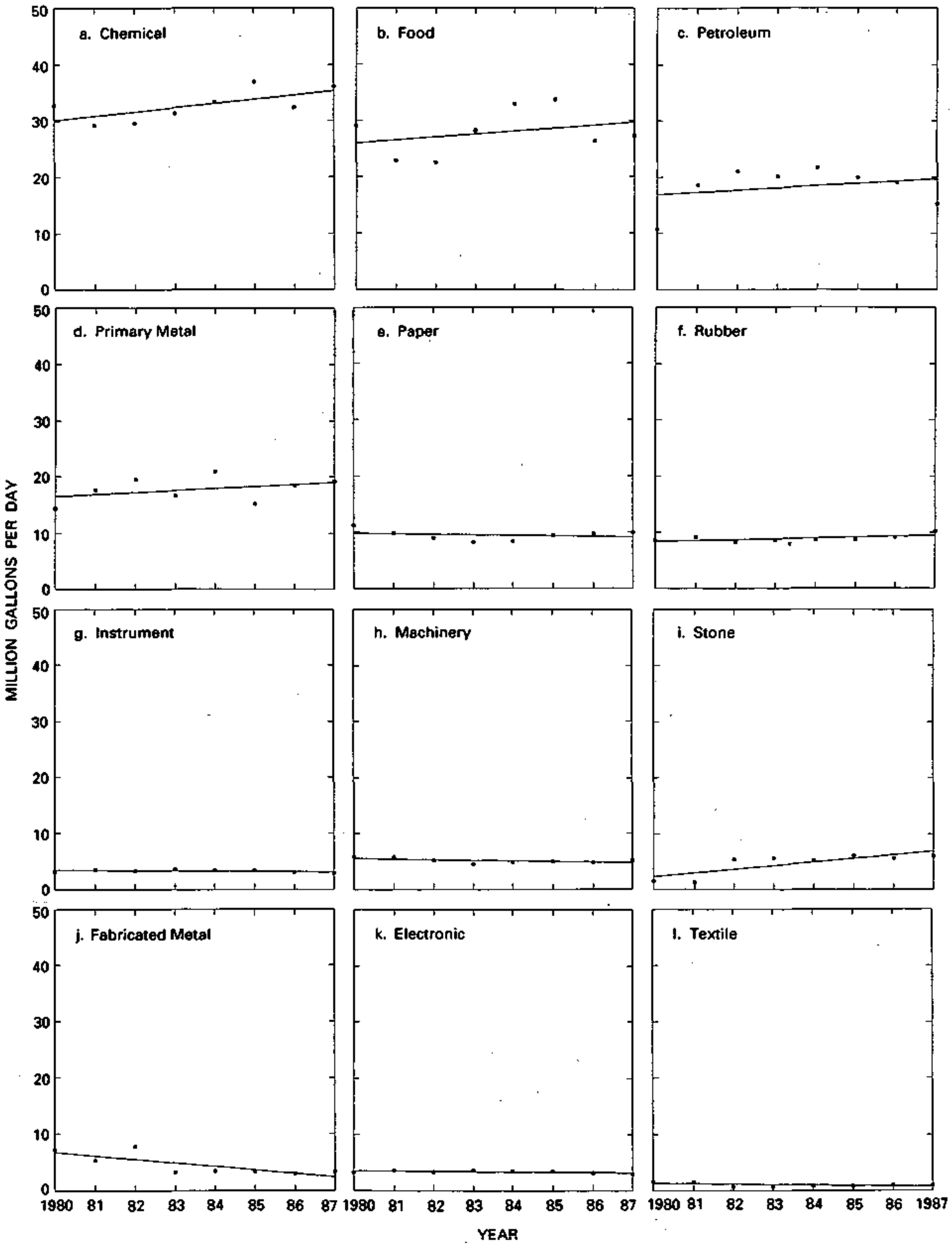


Figure 34. Total self-supplied industrial ground-water withdrawals for each industry from 1980 through 1987 (The straight lines indicate trends in water use over the eight-year period)

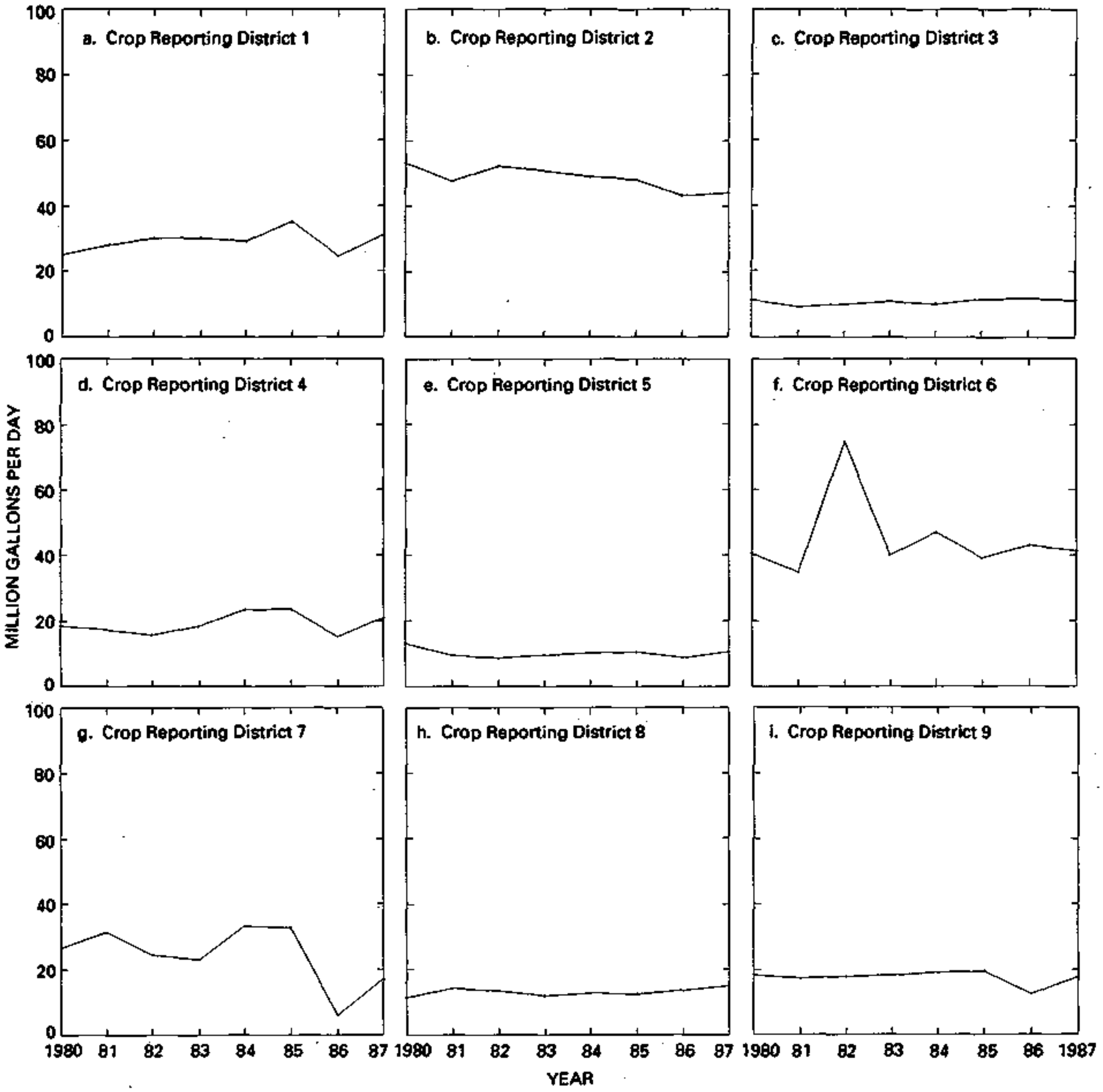


Figure 35. Total self-supplied industrial ground-water withdrawals from 1980 through1987 for each of the nine crop reporting districts

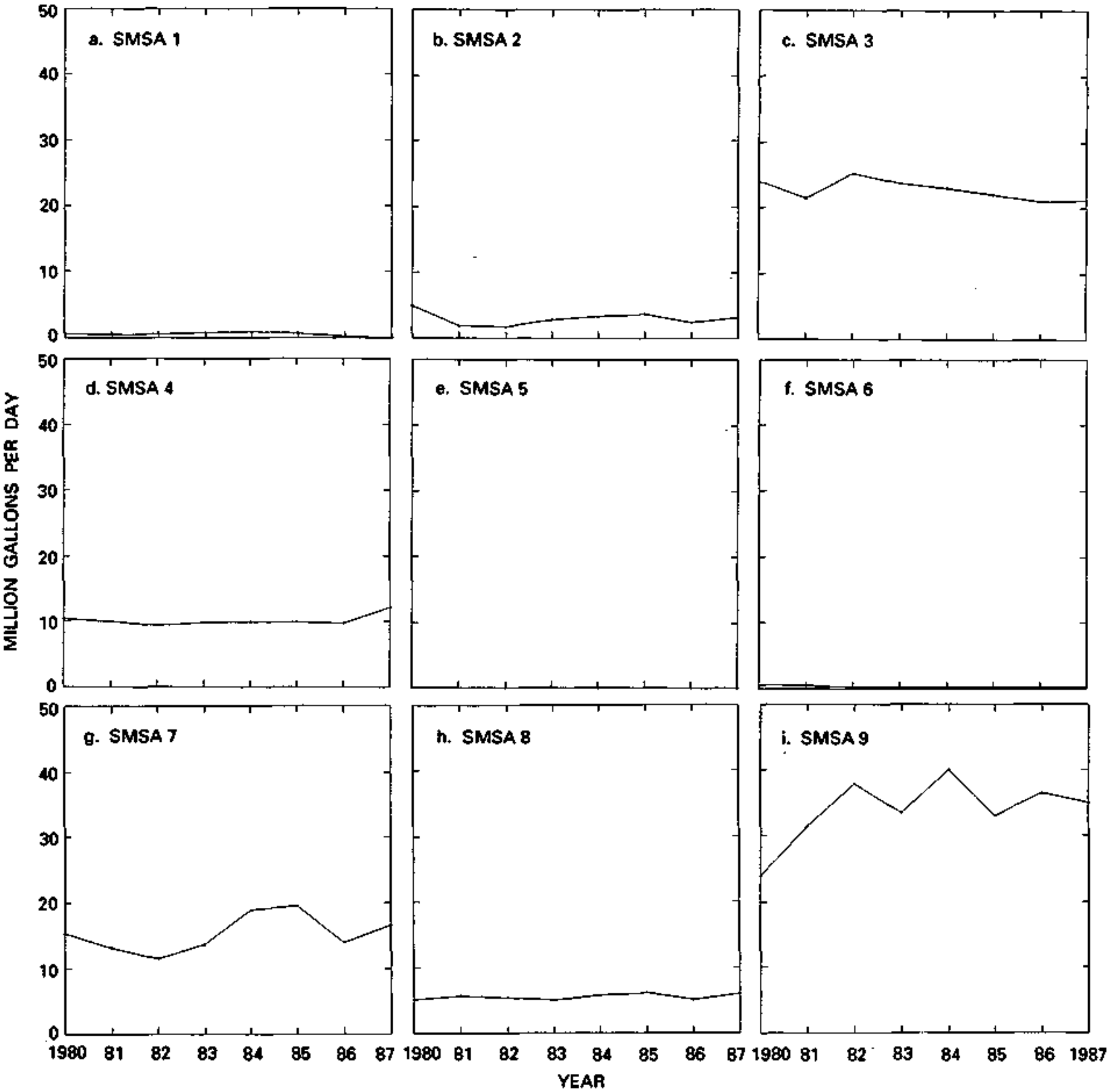


Figure 36. Total self-supplied industrial ground-water withdrawals from 1980 through 1987 for each of the nine Standard Metropolitan Statistical Areas (SMSAs)

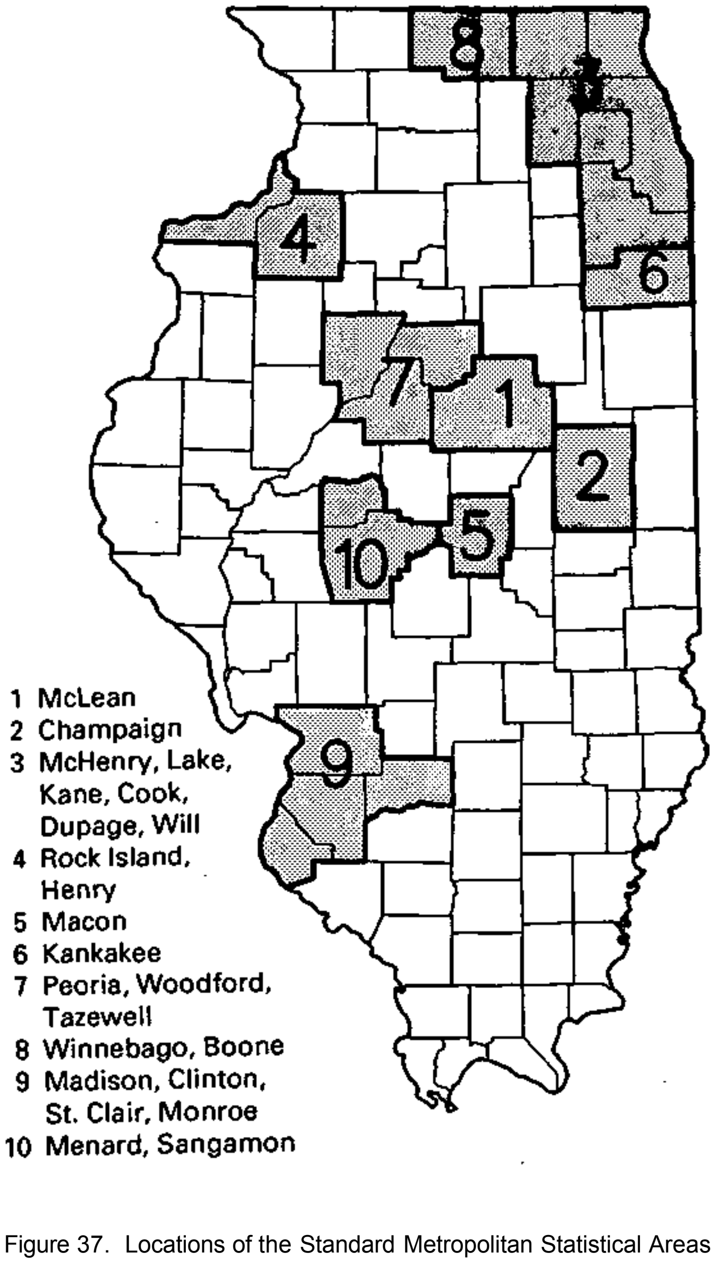


Figure 37. Locations of the Standard Metropolitan Statistical Areas

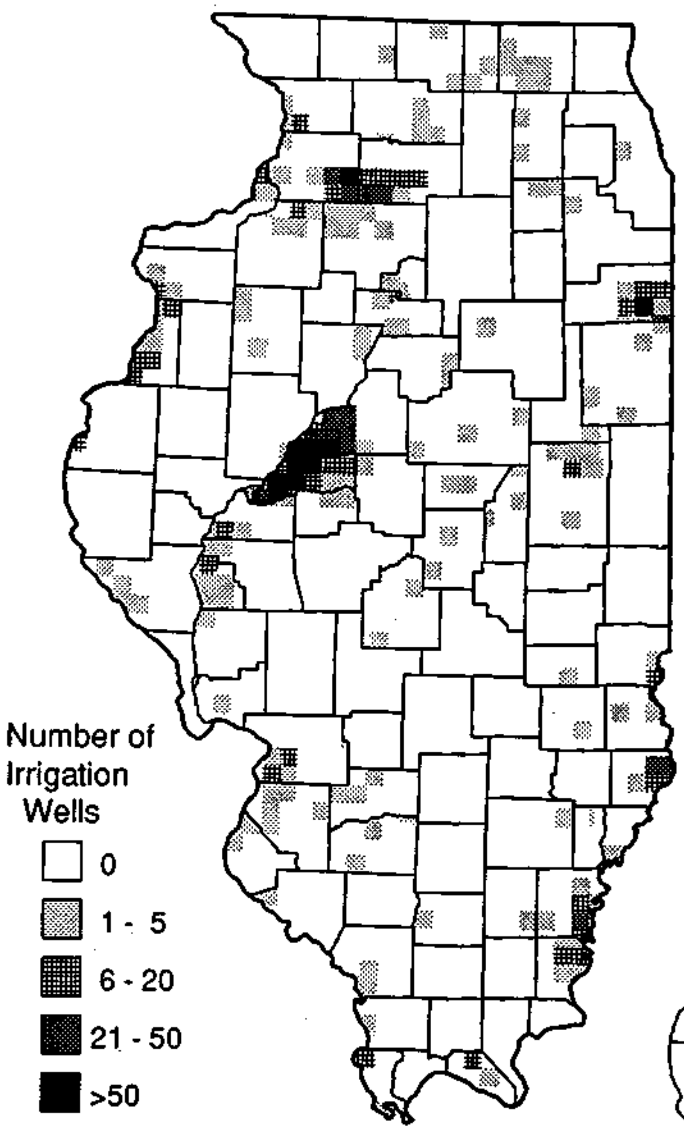


Figure 38. Density and distribution of irrigation wells

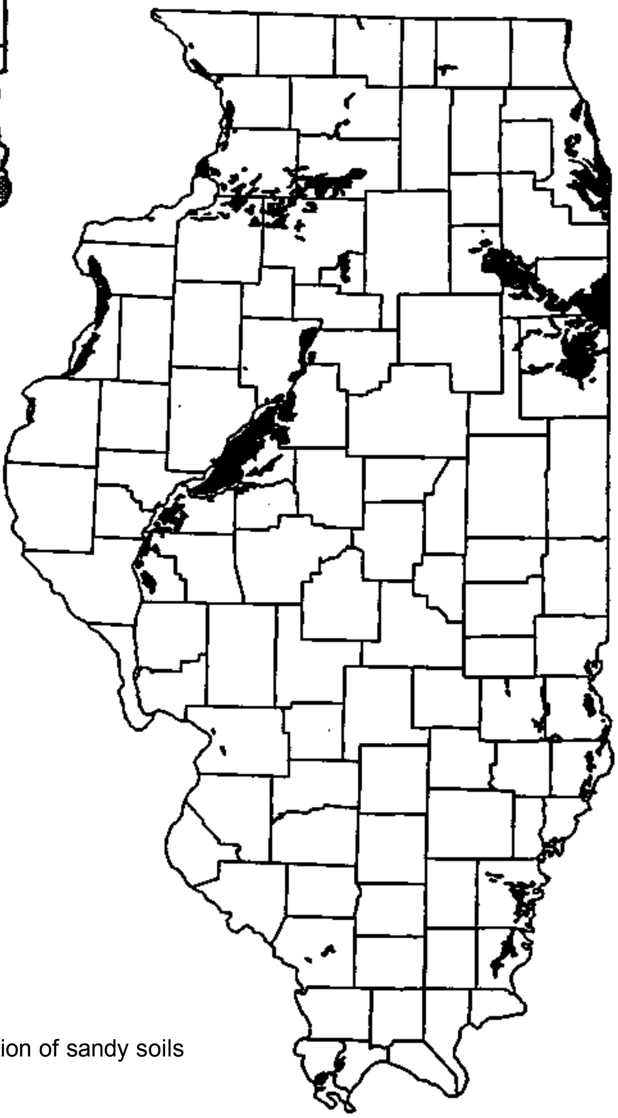


Figure 39. Distribution of sandy soils

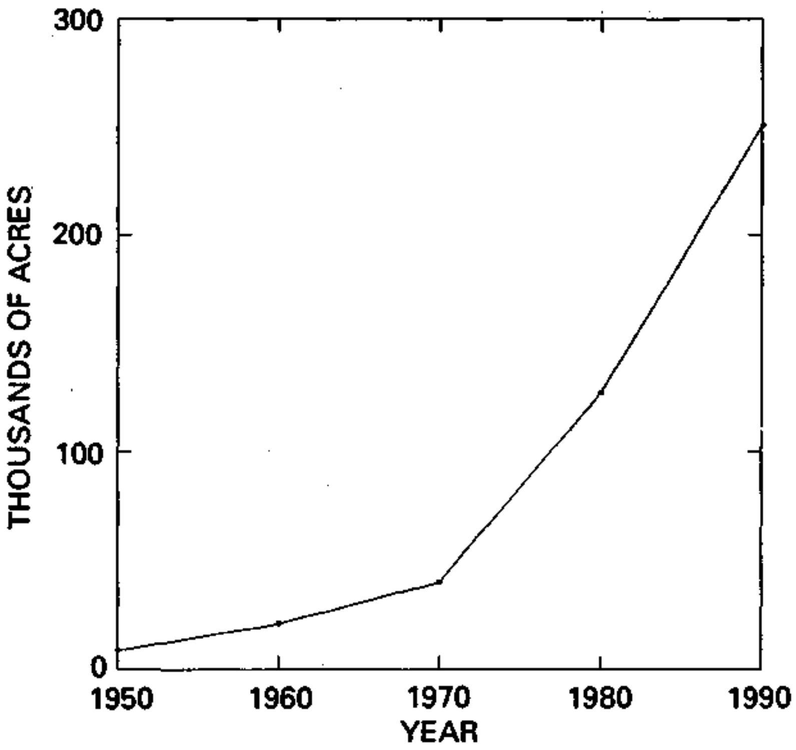


Figure 40. Changes in total irrigated acreage in Illinois, 1950-1990

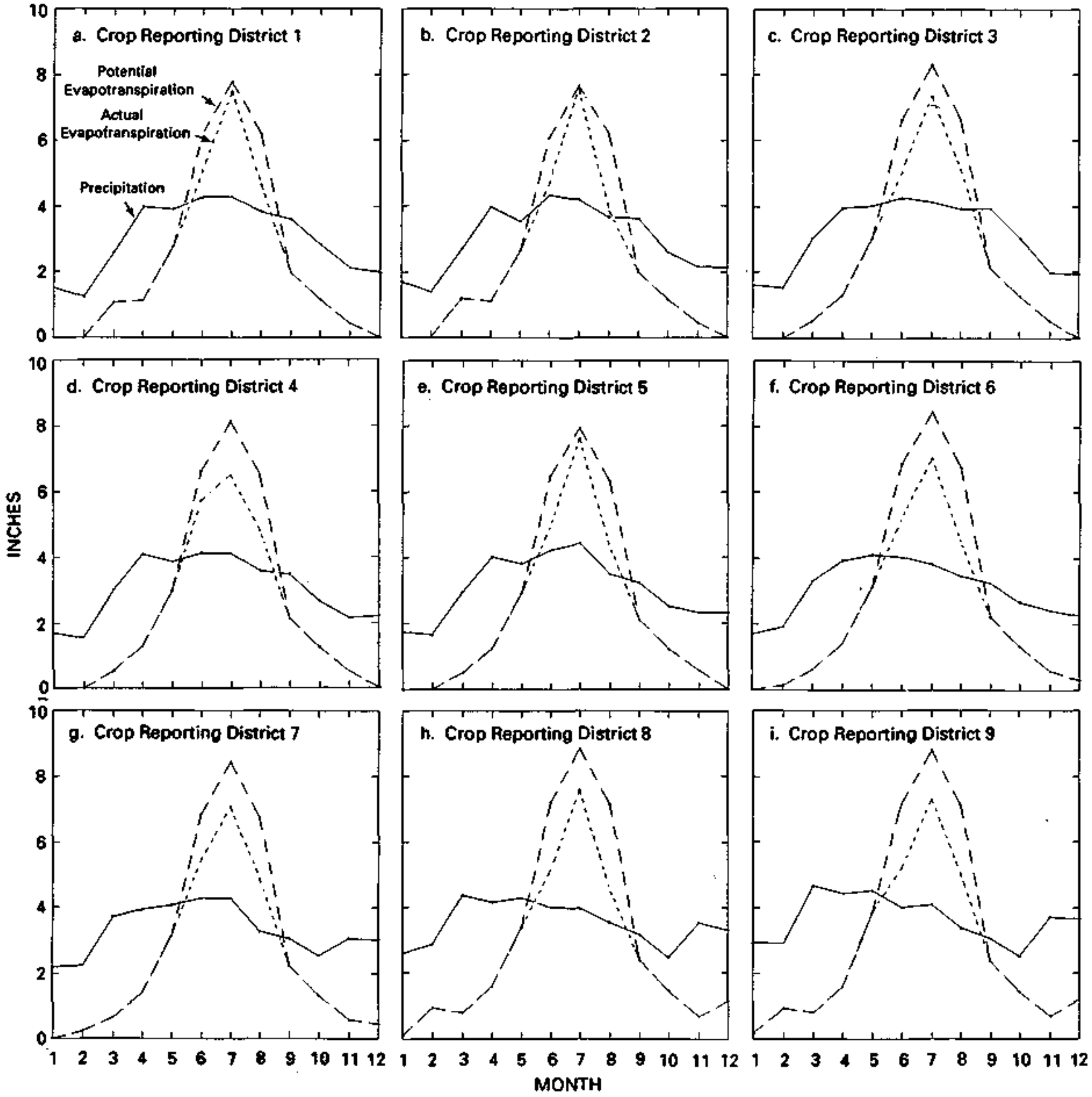


Figure 41. Average annual water budgets for the nine crop reporting districts

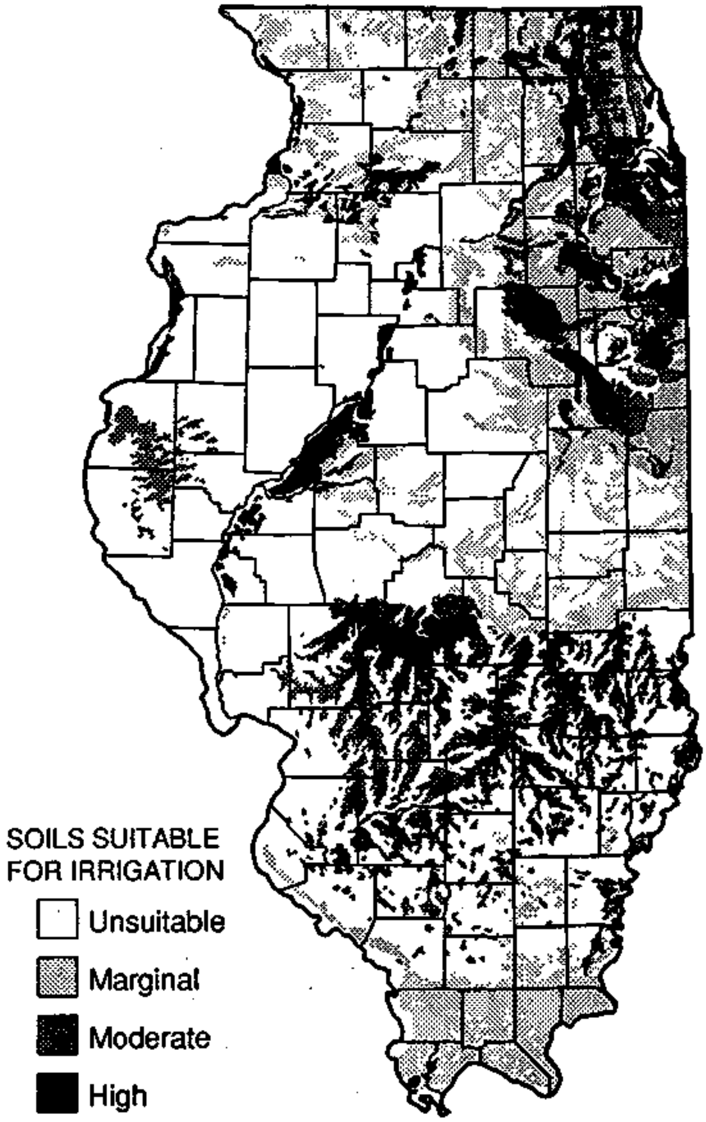


Figure 42. Soils considered unsuitable or marginally, moderately, or highly suitable for irrigation on the basis of average water available in the upper meter, subsoil drainage, and subsoil permeability

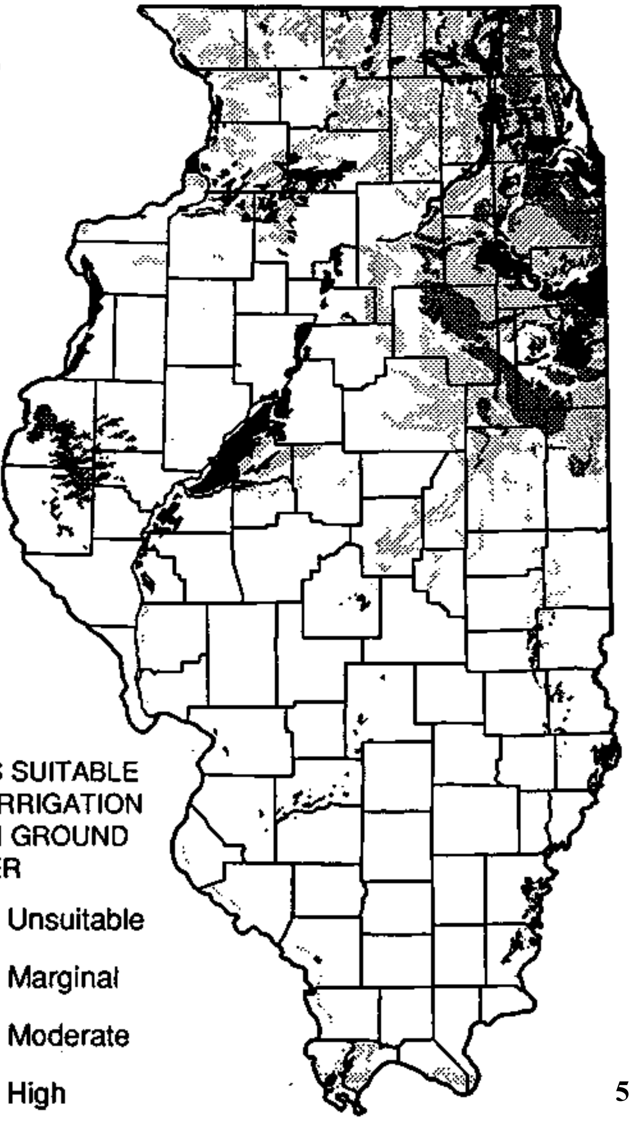
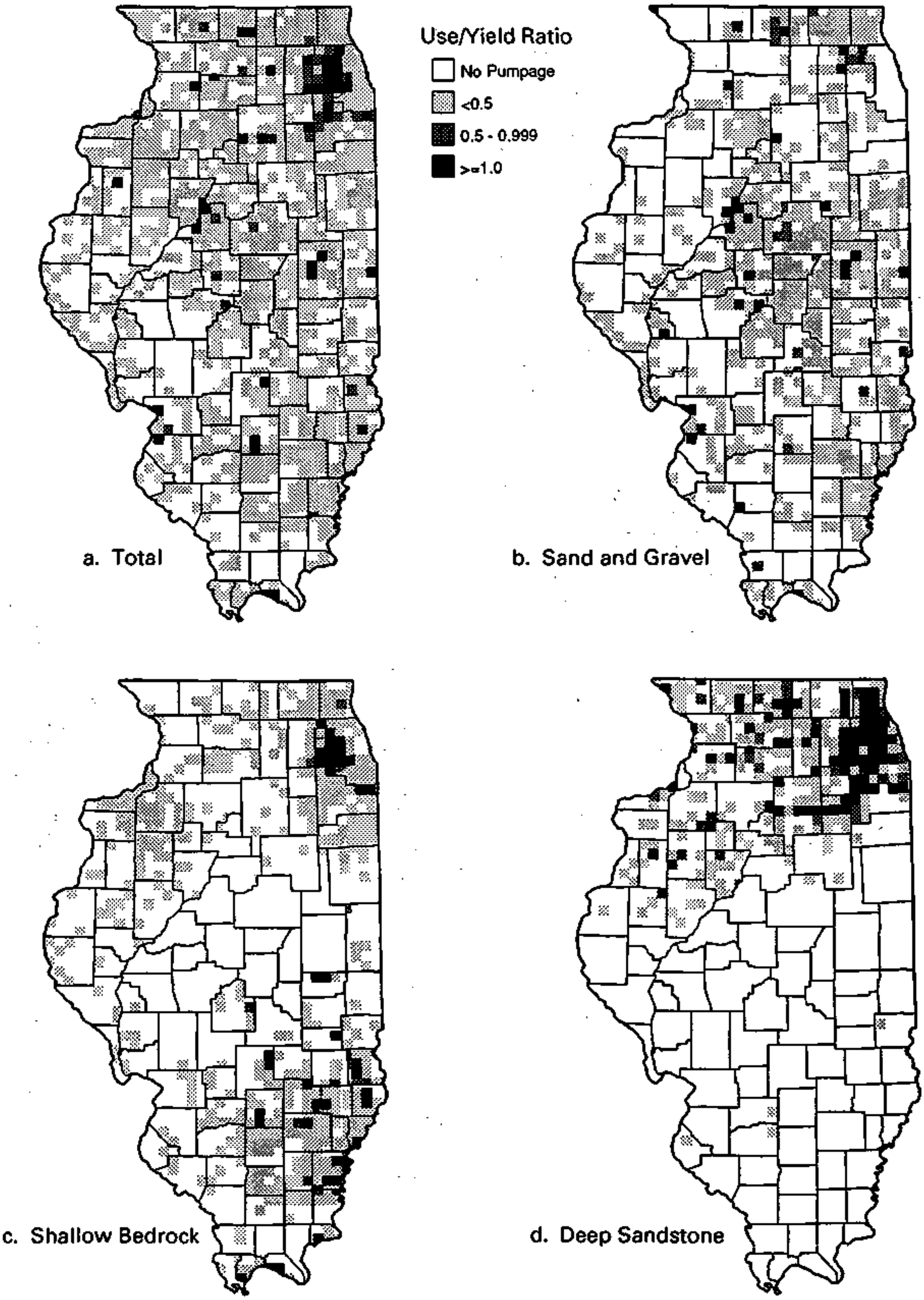


Figure 43. Soils considered unsuitable or marginally, moderately, or highly suitable for irrigation from ground-water resources, on the basis of availability of adequate ground-water resources (defined as 150,000 gallons per day per square mile)



a. Total

b. Sand and Gravel

c. Shallow Bedrock

d. Deep Sandstone

Figure 44. Use/yield ratio distribution for potential aquifer yields and 1980-1987 average of ground-water uses except irrigation

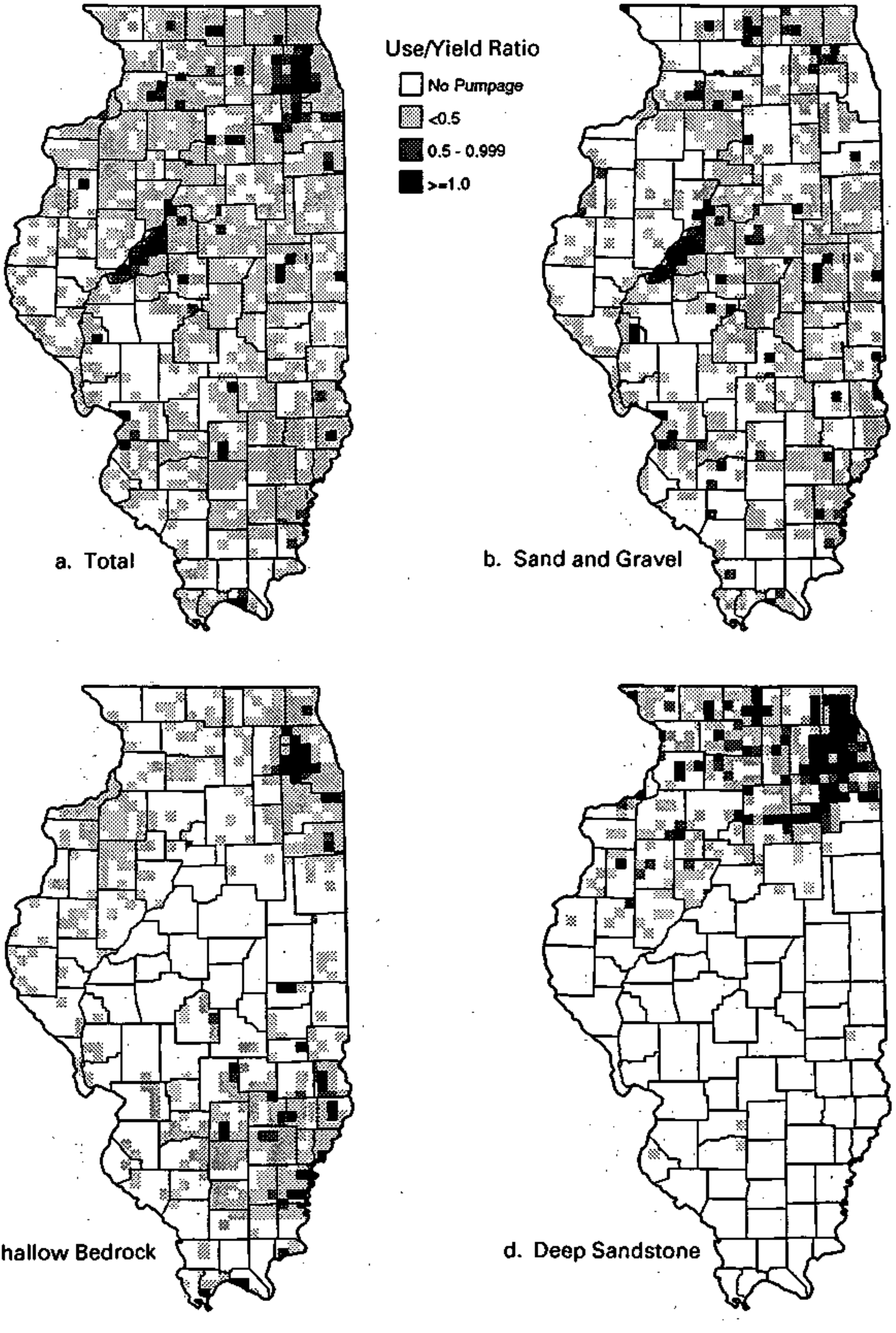


Figure 45. Use/yield ratio distribution for potential aquifer yields and 1980-1987 average of ground-water uses, including estimated irrigation pumpage for 30-year average weather conditions (seasonal impact)

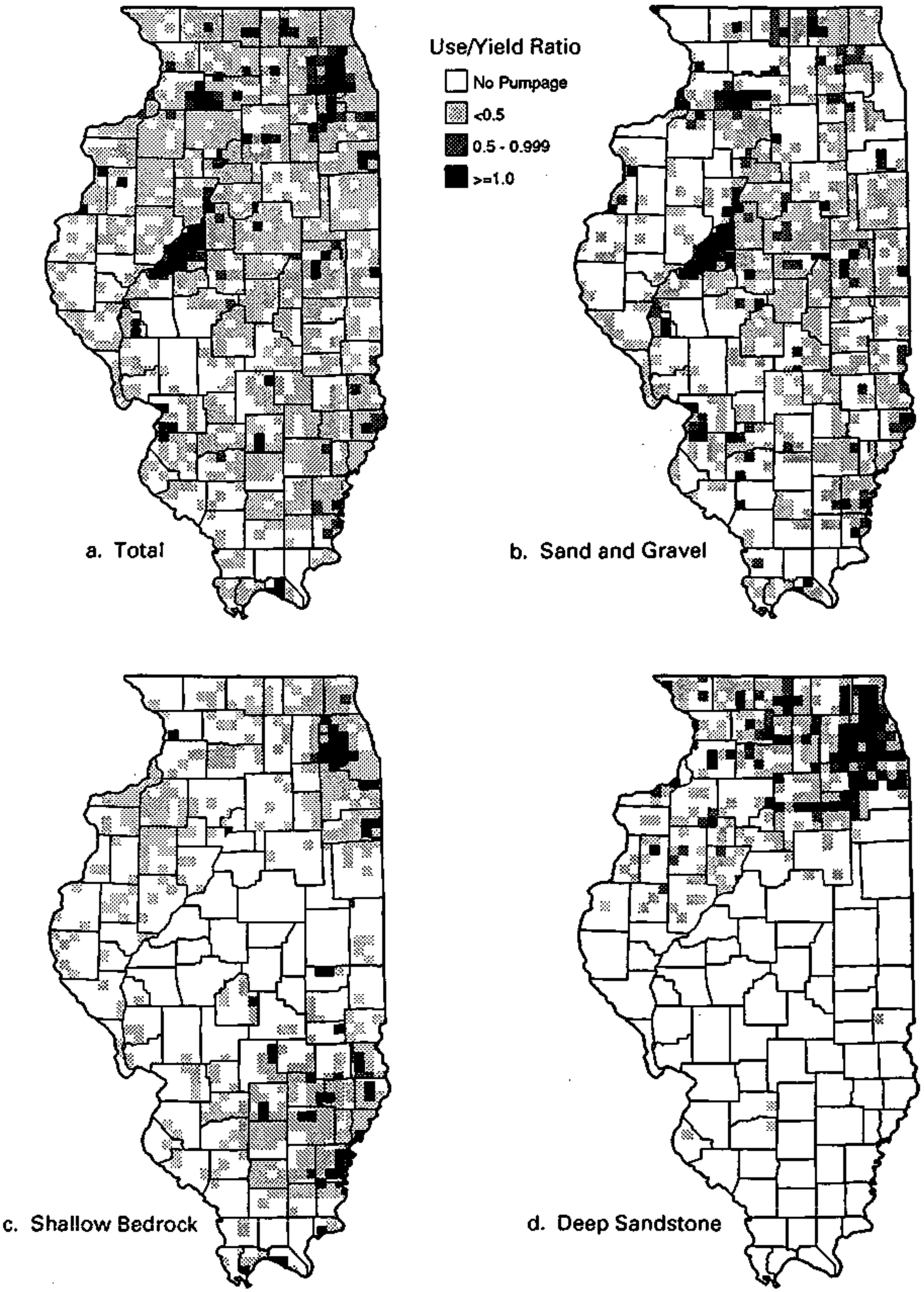


Figure 46. Use/yield ratio distribution for potential aquifer yields and 1980-1987 average of all ground-water uses, including estimated irrigation pumpage for drought (1988) weather conditions (seasonal impact)

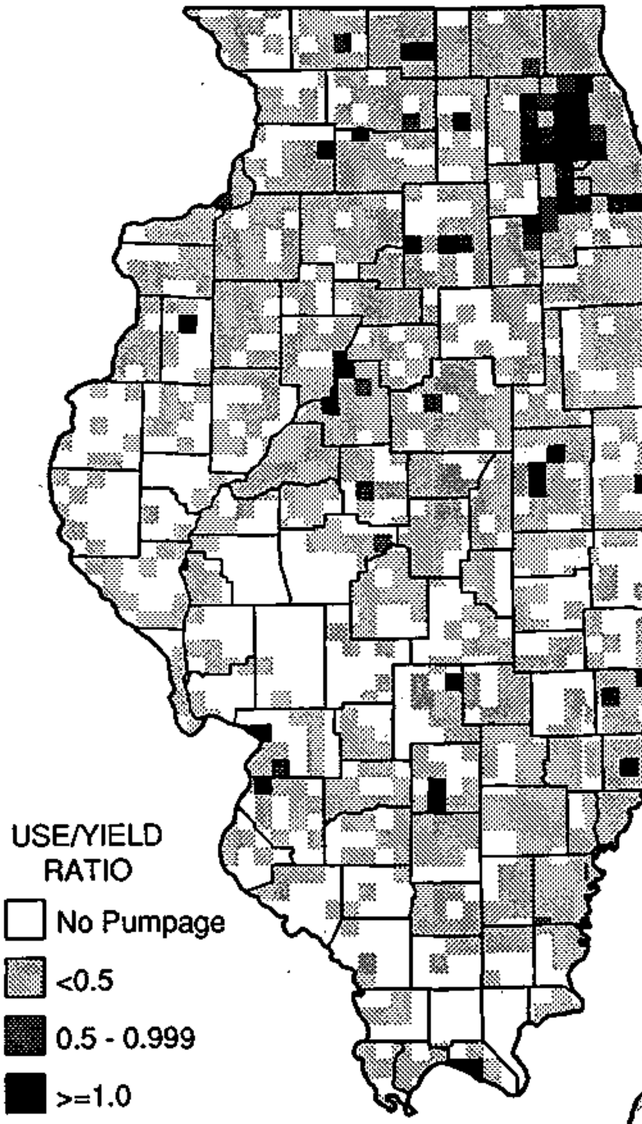


Figure 47. Use/yield ratio distribution for all aquifer potential yields and 1980-1987 average of all ground-water uses, including estimated irrigation pumpage for 30-year average weather conditions (annual impact)

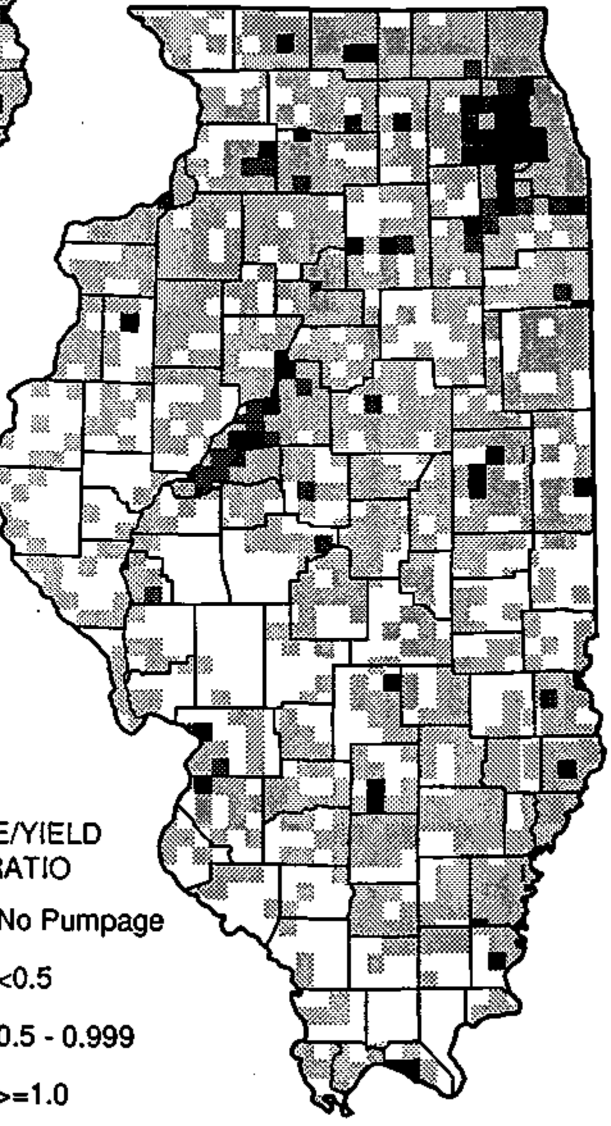


Figure 48. Use/yield ratio distribution for all aquifer potential yields and 1980-1987 average of all ground-water uses, including estimated irrigation pumpage for drought (1988) weather conditions (annual impact)

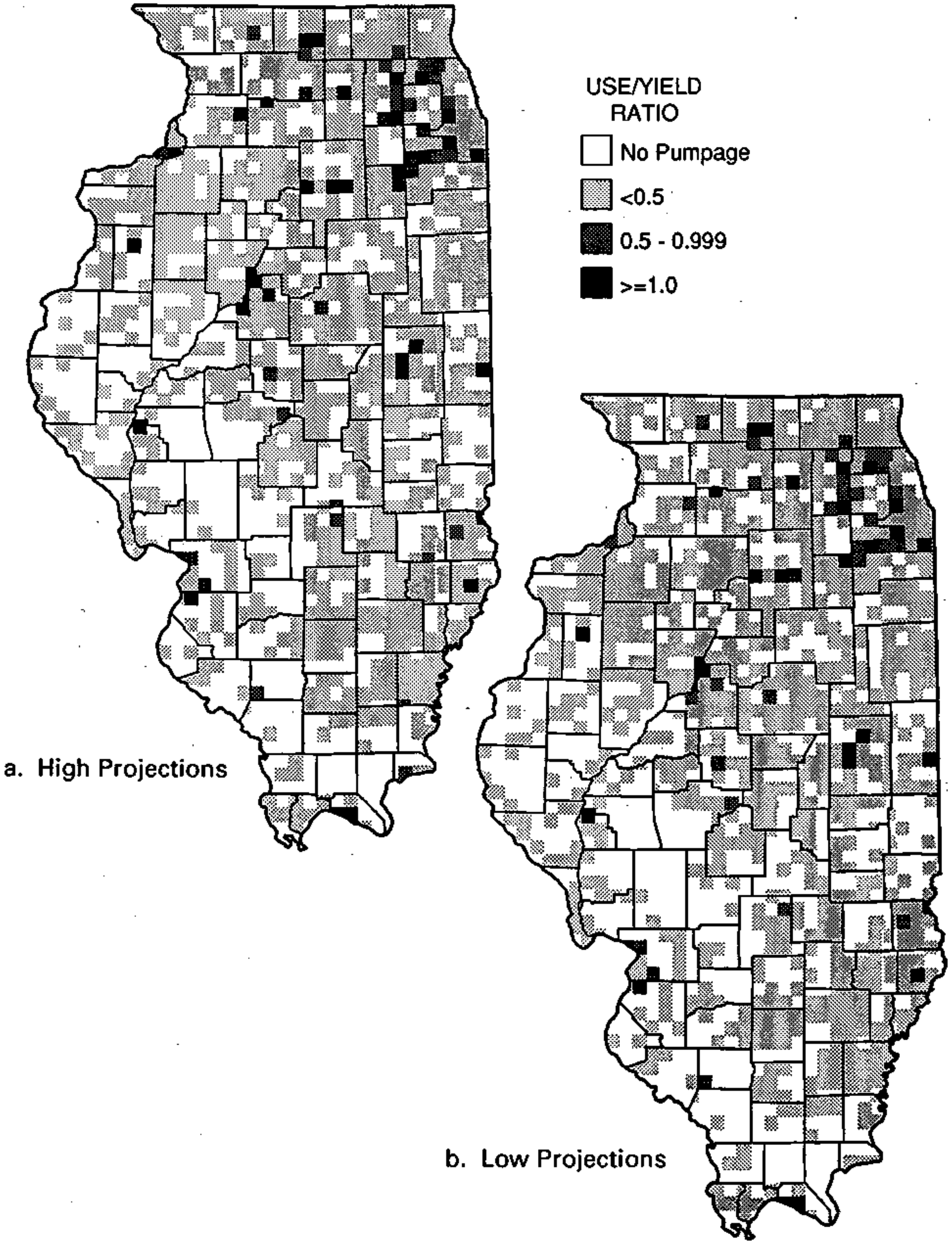


Figure 49. Use/yield ratio distribution for all aquifer potential yields and all projected ground-water uses, except irrigation, based on projections for self-supplied industrial uses

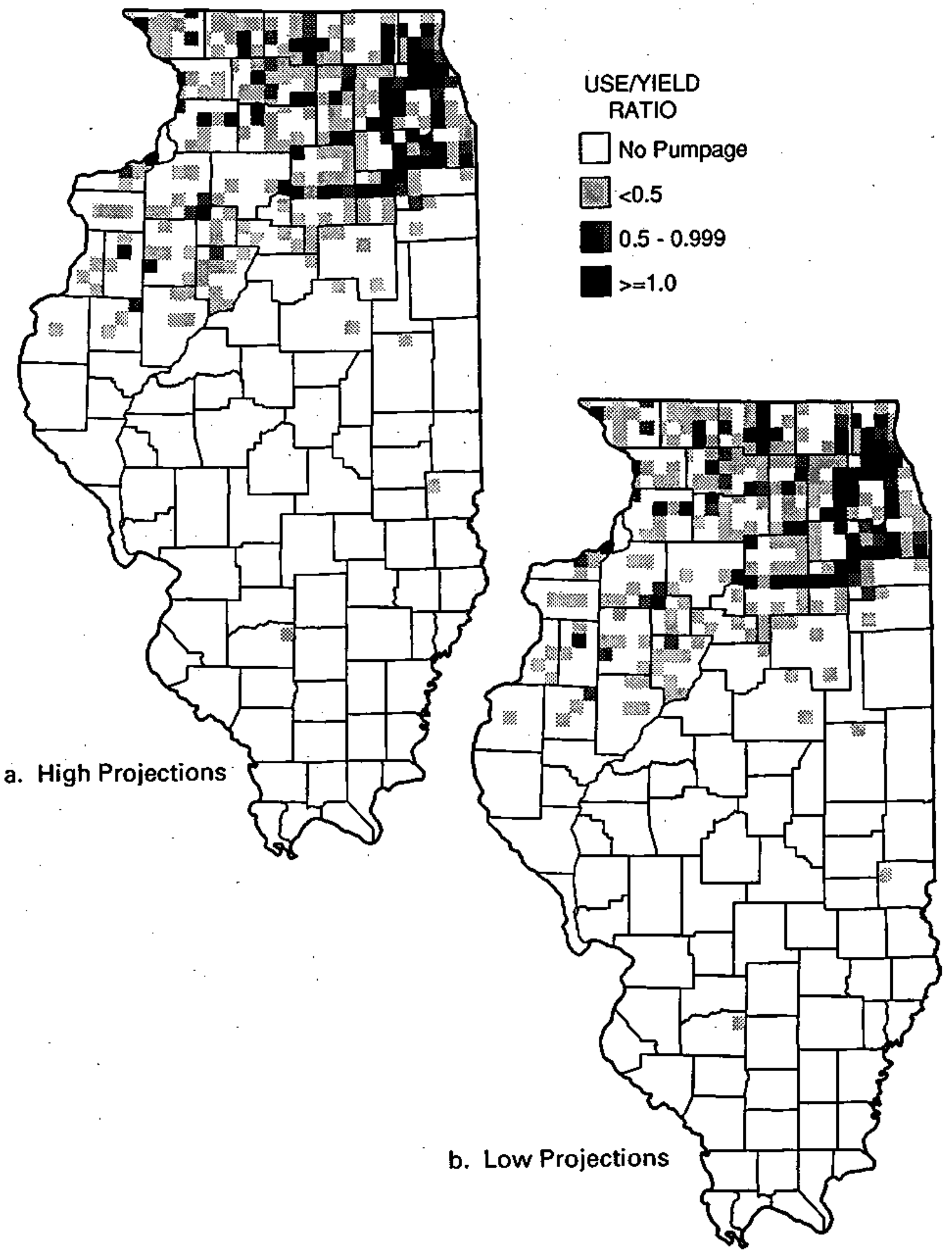
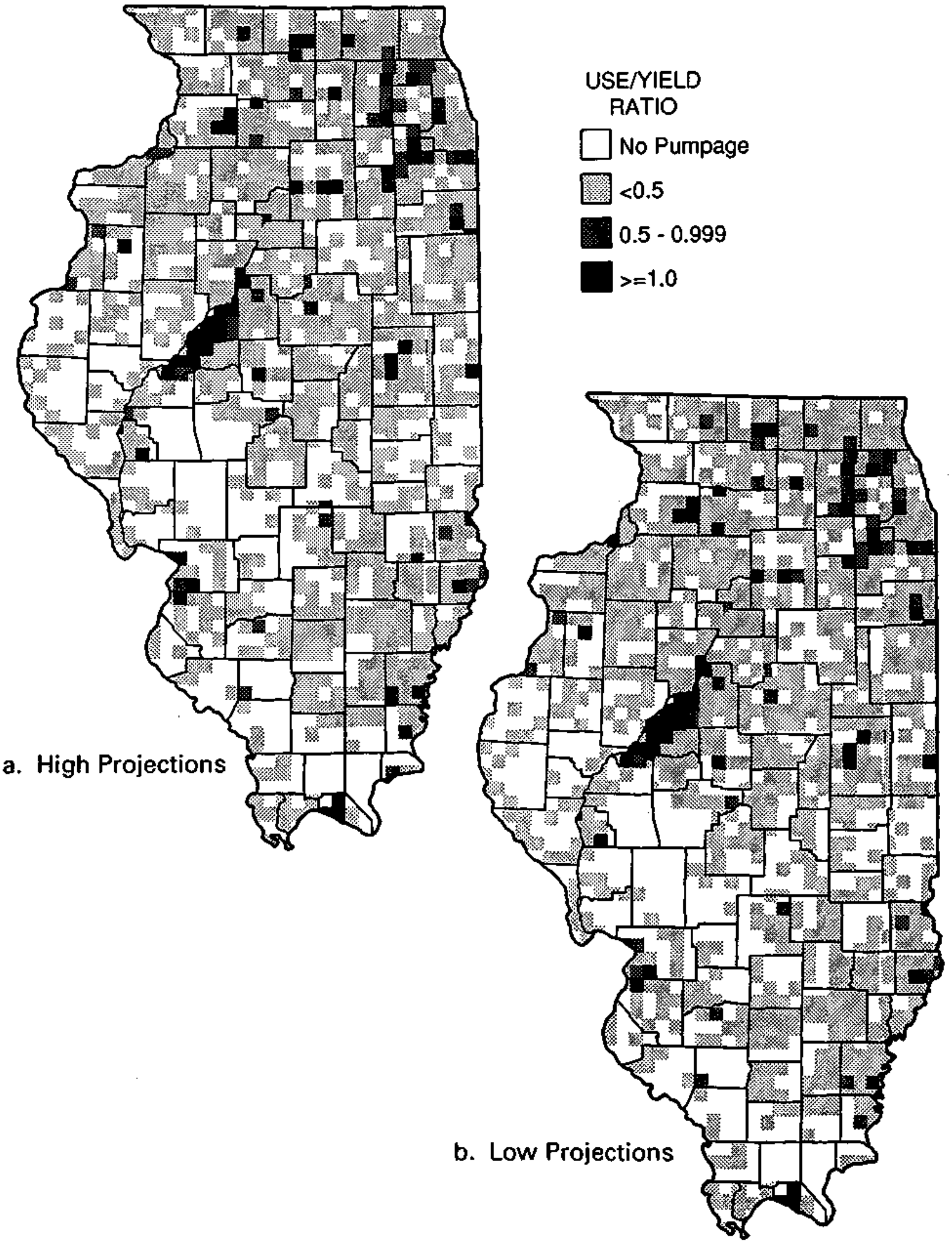


Figure 50. Use/yield ratio distribution for deep sandstone potential yields and all projected deep sandstone ground-water uses except irrigation, based on projections for self-supplied industrial uses



a. High Projections

b. Low Projections

Figure 51. Use/yield ratio distribution for all aquifer potential yields and all projected ground-water uses, including expanded irrigation during average weather conditions, based on projections for self-supplied industrial uses (seasonal impacts)

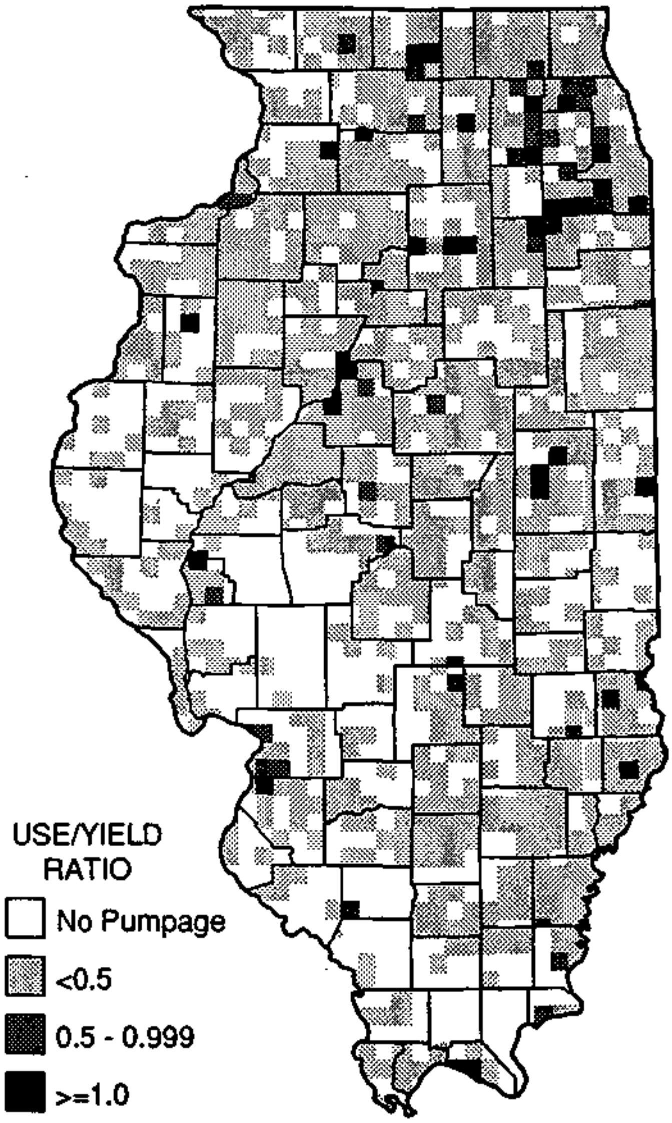


Figure 52. Use/yield ratio distribution for all aquifer potential yields and all projected ground-water uses including expanded irrigation during average weather conditions, based on the high projections for self-supplied industrial uses (annual impacts)

Table 1. Construction Features of Network Wells

Network well name	I.D. number	Date started	Depth (ft)	Diameter (in.)	Type of well construction	Aquifier type*
Northwest						
Cambridge	00011	10/61	42	78	Dug	Unconsolidated
Galena	00021	9/63	25	36	Dug	Sandstone
Mt. Morris	00031	11/60	55	8	Drilled	Unconsolidated
Northeast						
Crystal Lake	00041	9/50	18	6	Drilled	Unconsolidated
Fermi Lab	00052	4/84	19.5	5	Drilled	Unconsolidated
West						
Good Hope	00072	6/80	30	36	Dug	Unconsolidated
Central						
Middletown	00081	11/57	38	36	Bored	Unconsolidated
Snicarte	00091	3/58	41	36	Dug	Sand
East						
Bondville	01120	4/82	21	6	Drilled	Unconsolidated
Swartz	00111	6/54	35	48	Dug	Unconsolidated
Watseka	00122	10/62	19.5	42	Dug	Unconsolidated
West-southwest						
Coffman	00061	3/56	28	36	Dug	Unconsolidated
Greenfield	00132	5/65	22	36	Dug	Unconsolidated
East-southeast						
Janesville	00143	4/69	15	60	Dug	Unconsolidated
St. Peter	00153	5/65	15	60	Dug	Unconsolidated
Southwest						
Elco	00163	3/84	23	36	Dug	Unconsolidated
Sparta	00171	11/60	27	36	Dug	Unconsolidated
SWS No. 2	00181	1/52	81	8	Drilled	Sand
Southeast						
Boyleston	00221	3/84	23	36	Dug	Unconsolidated
Dixon Springs	00191	1/55	9	36	Dug	Unconsolidated
S.E. IL College	00202	8/84	11	10	Drilled	Unconsolidated

**Most dug or bored wells receive water from thin sand lenses with fine-grained unconsolidated glacial materials. Unless specifically known from a driller's log or from units correlated from other wells in the area of similar depth, all network wells are completed in such materials. The principal exceptions are at Galena (the only bedrock well in the shallow network) and at Snicarte and SWS No. 2, which are known to be finished in major sand aquifers.*

Table 2. Ambient Ground-Water Quality in Illinois*

Parameter	*Drift deposits*	*Bedrock aquifers*
Total dissolved solids	400-600 mg/l	350-3,000 mg/l
Hardness	300-500 mg/l	150-1,000 mg/l
Sulfates	50-200 mg/l	25-600 mg/l
Nitrates	0-20 mg/l	0-5 mg/l
Chlorides	0-20 mg/l	0-1,000 mg/l
Iron	0.3-10 mg/l	0.3-5.0 mg/l

**From Gibb and O'Hearn (1980).*

Table 3. Total Ground-Water Withdrawals by Crop Reporting District
(Million gallons per day)

Crop reporting district	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*
1	144.45	144.06	140.23	156.88	130.32	152.92	153.99	169.84
2	377.74	351.91	380.15	388.52	354.52	380.20	355.99	354.51
3	48.41	47.07	39.59	45.64	29.66	42.58	39.48	44.23
4	129.79	126.98	130.93	145.61	133.83	122.64	145.46	158.36
5	62.40	56.94	58.10	56.91	47.61	53.96	54.87	59.50
6	91.53	94.50	114.39	79.28	78.24	80.45	87.47	88.48
7	54.62	61.15	54.46	47.70	49.60	58.47	45.92	45.53
8	36.61	42.45	34.00	36.88	19.71	43.44	40.41	41.72
9	35.99	36.74	33.45	31.01	28.16	37.44	35.26	33.97

Table 4. Public Water Supply Ground-Water Withdrawals by Crop Reporting District
(Million gallons per day)

Crop reporting district	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*
1	74.72	70.52	66.90	68.73	68.25	66.49	68.74	72.59
2	270.19	264.60	270.50	275.64	275.04	264.67	227.01	234.35
3	14.86	14.31	14.66	14.80	14.93	15.28	12.54	13.80
4	48.36	46.96	44.62	43.17	43.74	45.07	44.00	48.39
5	27.11	25.25	27.24	28.94	30.43	29.84	30.22	30.91
6	22.99	22.07	20.43	21.66	24.70	23.90	25.95	26.87
7	8.85	8.91	9.01	8.57	9.13	9.00	9.42	8.85
8	3.75	4.64	3.66	3.79	4.03	4.07	4.06	4.99
9	3.84	8.00	8.11	4.46	4.31	6.35	5.87	6.19

Table 5. Public Water Pumpage by County

(Million gallons per day)

County	*1980-1987 average*	*1995 adjusted pumpage*
Adams	1.301	1.263
Alexander	0.327	0.318
Bond	0.063	0.062
Boone	3.474	3.521
Brown	0.062	0.061
Bureau	3.485	3.402
Calhoun	0.517	0.507
Carroll	1.481	1.449
Cass	1.555	1.501
Champaign	19.023	18.819
Christian	1.393	1.369
Clark	1.283	1.269
Clay	0.219	0.223
Clinton	0.325	0.325
Cook*	72.096	50.518
Crawford	1.893	1.874
Cumberland	0.253	0.247
DeKalb	6.923	6.881
DeWitt	1.568	1.545
Douglas	1.084	1.058
DuPage*	76.020	6.808
Edgar	0.357	0.351
Edwards	0.025	0.026
Effingham	0.296	0.295
Fayette	0.132	0.131
Ford	1.412	1.393
Fulton	0.977	0.911
Gallatin	1.338	1.344
Greene	0.377	0.364
Grundy	2.264	2.288
Hamilton	0.020	0.020
Hancock	0.233	0.231
Hardin	0.125	0.123

Table 5. Continued

County	*1980-1987 average*	*1995 adjusted pumpage*
Henderson	6.564	6.553
Henry	4.054	3.911
Iroquois	2.037	2.009
Jackson	0.103	0.100
Jasper	0.375	0.372
Jersey	0.892	0.888
JoDaviess	2.224	2.217
Johnson	0.022	0.023
Kane	29.978	31.908
Kankakee	1.905	1.863
Kendall	1.771	1.774
Knox	1.316	1.265
Lake*	15.003	9.591
LaSalle	10.502	10.248
Lawrence	1.205	1.218
Lee	3.645	3.491
Livingston	1.640	1.621
Logan	3.593	3.536
McDonough	0.690	0.674
McHenry	11.602	12.229
McLean	4.933	4.934
Macon	1.128	1.115
Macoupin	0.018	0.018
Madison	11.026	11.029
Marion	0.025	0.025
Marshall	1.212	1.170
Mason	1.030	0.984
Massac	2.283	2.303
Menard	0.737	0.733
Mercer	0.936	0.932
Monroe	0.107	0.110
Montgomery	0.530	0.529
Morgan	0.079	0.078
Moultrie	0.438	0.438

Table 5. Concluded

County	*1980-1987 average*	*1995 adjusted pumpage*
Ogle	5.363	5.345
Peoria	16.439	15.879
Perry	0.047	0.048
Piatt	1.358	1.342
Pike	0.781	0.760
Pulaski	0.665	0.655
Putnam	0.426	0.418
Randolph	0.833	0.829
Richland	0.109	0.110
Rock Island	2.730	2.710
St. Clair	0.192	0.163
Saline	0.006	0.006
Sangamon	2.189	2.196
Schuyler	0.577	0.550
Scott	4.161	4.047
Shelby	1.192	1.175
Stark	0.472	0.440
Stephenson	5.503	5.500
Tazewell	13.503	13.131
Union	1.398	1.403
Vermilion	1.372	1.337
Wabash	0.804	0.812
Warren	2.678	2.603
Washington	0.105	0.104
Wayne	0.130	0.131
White	1.224	1.230
Whiteside	4.714	4.597
Will*	30.627	31.605
Winnebago	35.072	34.910
Woodford	1.533	1.521
TOTALS	461.707	365.941

** Adjusted for planned Lake Michigan water allocations.*

Table 6. Average Daily Ground-Water Uses for Largest Water-Using Industries, 1980-1987

Industry	*SIC**	*Average (mgd)*	*Minimum (mgd)*	*Maximum (mgd)*	*Standard deviation*
Food	20	27.836	22.478	33.653	4.091
Paper	26	9.378	8.125	11.644	0.962
Chemical	28	32.717	29.163	36.952	2.798
Petroleum	29	18.303	10.691	21.657	3.633
Rubber	30	8.887	8.229	10.241	0.625
Stone	32	4.595	1.252	6.168	2.014
Primary metal	33	17.665	14.283	20.884	2.250
Fabricated metal	34	4.533	2.932	7.733	1.939
Machinery	35	5.101	4.481	5.797	0.455
Electronic	36	3.315	2.948	3.630	0.231
Instrument	38	7.203	6.421	8.835	0.737

**Standard Industrial Classification*

Table 7. Self-Supplied Industrial Ground-Water Withdrawals by Crop Reporting District

(Million gallons per day)

Crop reporting district	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*
1	24.95	27.71	29.93	29.98	28.87	35.02	24.46	31.09
2	53.02	47.45	52.14	50.60	48.85	48.00	43.01	43.94
3	11.02	8.88	9.69	10.60	9.83	11.23	11.38	11.10
4	18.47	17.22	15.65	18.35	23.38	23.52	15.09	20.96
5	13.00	9.47	8.53	9.38	10.14	10.37	8.79	10.55
6	40.59	34.85	74.77	40.00	46.85	39.06	42.94	41.23
7	26.45	31.30	24.32	22.96	33.12	32.52	6.09	17.01
8	11.28	14.11	13.30	11.84	12.55	12.32	13.45	14.82
9	18.28	17.24	17.75	18.19	19.05	19.48	12.48	17.73

Table 8. Industrial Ground-Water Use Adjustments with Method A

				Ground-water use	
Industry	*SIC**	*1980-1987 average ground-water use (mgd)*	*Percent change for ground water*	*Plus 1 std deviation (mgd)*	*Minus 1 std deviation (mgd)*
Food	20	27.836	15	31.93	23.75
Paper	26	9.378	10	10.34	8.42
Chemical	28	32.717	9	35.52	29.92
Petroleum	29	18.303	18	21.94	14.67
Stone	32	4.595	44	6.61	2.58
Primary metal	33	17.665	13	19.92	15.42
Fabricated metal	34	4.533	43	6.47	2.59
Machinery	35	5.101	9	5.56	4.65
Electronic	36	3.315	7	3.55	3.08
Instrument	38	7.203	10	7.94	6.47

*Standard Industrial Classification

Table 9. Industrial Ground-Water Use Adjustments with Method B

				Ground-water use	
Industry	*SIC**	*1980-1987 average ground-water use (mgd)*	*Percent change for ground water*	*Plus 1 std deviation (mgd)*	*Minus 1 std deviation (mgd)*
Food	20	62.469	16	32.35	23.33
Paper	26	18.235	6	9.90	8.86
Chemical	28	74.307	10	36.03	29.41
Petroleum	29	43.303	21	22.13	14.47
Stone	32	20.031	18	5.42	3.77
Primary metal	33	209.826	30	22.97	12.37
Fabricated metal	34	10.706	19	5.41	3.65
Machinery	35	21.763	28	6.54	3.66
Electronic	36	4.064	1	3.35	3.29

*Standard Industrial Classification

Table 10. Values of R^2 from Bivariate Correlations between Industrial Ground-Water Use and Indices of Industrial Productivity

Industry	*SIC**	*Time*	*Employment*	*Output*	*Productivity*
Food	20	.099	.124	.051	.069
Textile	22	.322	.120	.185	.269
Apparel	23	.196	.136	.229	.090
Lumber	24	.190	.002	.328	.085
Furniture	25	.745	.526	.380	.510
Paper	26	.058	.124	.044	.122
Printing	27	.170	.058	.153	.195
Chemical	28	.441	.122	.518	.441
Petroleum	29	.069	.733	.781	.032
Rubber	30	.383	.320	.247	.166
Stone	32	.650	.831	.270	.417
Primary metal	33	.147	.162	.159	.019
Fabricated metal	34	.607	.360	.110	.680
Machinery	35	.344	.769	.041	.288
Electronic	36	.247	.244	.091	.207
Transportation	37	.880	.542	.282	.655
Instrument	38	.374	.330	.129	.420

**Standard Industrial Classification*

Table 11. Results from Multivariate Correlations between Industrial Ground-Water Use and Indices of Industrial Productivity for Largest Water-Using Industries

Industry	*SIC*	*R^2*	*Probability**	*Standard error*
Food	20	.210	.789	4.808
Paper	26	.912	.014	0.377
Chemical	28	.536	.335	2.522
Petroleum	29	.921	.011	1.348
Rubber	30	.358	.579	0.662
Stone	32	.901	.018	0.837
Primary metal	33	.169	.844	2.713
Fabricated metal	34	.711	.140	1.378
Machinery	35	.943	.006	0.143
Electronic	36	.667	.183	0.177
Instrument	38	.667	.183	0.563

**Probability of obtaining the given value of R^2 with a completely random set of data*

Table 12. Results from Multivariate Correlations between Total Industrial Water Use and Indices of Industrial Productivity for Largest Water-Using Industries

Industry	*SIC*	*R^2*	*Probability**	*Standard error*
Food	20	.929	.004	3.563
Paper	26	.925	.010	0.364
Chemical	28	.639	.213	5.980
Petroleum	29	.972	.001	2.002
Stone	32	.901	.018	1.476
Primary metal	33	.420	.492	63.420
Fabricated metal	34	.815	.060	1.183
Machinery	35	.718	.134	4.324
Instrument	36	.701	.148	0.291

**Probability of obtaining the given value of R^2 with a completely random set of data*

Table 13. Industrial Ground-Water Use Adjustments with Method C

Industry	*SIC*	*1980-1987 average water use (mgd)*	*1995 adjusted water use (mgd)*	*1995 adjusted ground-water use (mgd)*
Food	20	62.469	236.01	106.00
Paper	26	18.235	36.11	18.00
Chemical	28	74.307	-36.87	-16.22
Petroleum	29	43.303	-16.67	-7.00
Stone	32	20.031	-1.50	-0.35
Primary metal	33	209.826	139.92	11.19
Fabricated metal	34	10.706	9.24	3.88
Machinery	35	21.763	18.05	4.15
Electronic	36	4.064	-1.12	-0.92
Instrument	38	7.203	18.49	18.49

Table 14. 1986 Illinois Manufacturing and Total Self-Supplied Industrial Pumpage, with Adjustments
(Million gallons per day)

	Manufacturing	*Total SSI*
1986	138.5	192.910
Adjusted (+)	151.9	221.408
Adjusted (-)	112.3	172.992

Table 15. Present and Projected Self-Supplied Industrial Ground-Water Withdrawals

(Million gallons per day)

County	*1980-1987 average*	*1986*	*Adjusted high*	*Adjusted low*
Adams	10.212	11.284	12.750	9.813
Alexander	0.018	0.027	0.039	0.015
Bond	0.031	0.003	0.003	0.002
Boone	0.652	0.145	0.169	0.118
Bureau	2.018	0.121	0.128	0.104
Calhoun	0.043	0.000	0.000	0.000
Carroll	2.453	2.317	2.526	2.108
Cass	0.914	0.817	0.939	0.694
Champaign	5.191	4.235	4.695	3.750
Christian	0.707	0.509	0.564	0.454
Clark	0.175	0.231	0.255	0.207
Clay	0.982	0.824	0.912	0.736
Clinton	0.566	0.392	0.432	0.353
Coles	0.181	0.119	0.133	0.105
Cook	14.552	12.432	13.737	11.204
Crawford	4.201	4.501	4.870	4.139
Cumberland	0.230	0.196	0.217	0.175
DeKalb	0.500	0.427	0.431	0.321
Douglas	0.063	0.056	0.062	0.051
DuPage	2.058	1.742	1.593	1.298
Edgar	0.047	0.001	0.002	0.000
Edwards	0.530	0.485	0.639	0.431
Effingham	0.284	0.227	0.250	0.000
Fayette	4.150	1.282	1.413	1.151
Ford	0.016	0.000	0.000	0.000
Franklin	0.410	0.278	0.409	0.244
Fulton	0.233	0.082	0.100	0.070
Gallatin	1.255	1.076	1.184	0.968
Grundy	8.444	8.462	8.736	7.260
Hamilton	0.671	1.088	1.198	0.987
Hardin	1.180	1.089	1.198	0.980
Henry	0.031	0.021	0.029	0.012
Iroquois	0.102	0.085	0.096	0.075

Table 15. Continued

County	*1980-1987 average*	*1986*	*Adjusted high*	*Adjusted low*
Jackson	0.060	0.058	0.075	0.045
Jasper	0.660	1.103	1.214	0.992
Jefferson	0.500	0.858	0.953	0.775
Jersey	0.006	0.000	0.000	0.000
JoDaviess	1.757	1.510	1.592	1.303
Kane	2.060	1.856	1.970	1.611
Kankakee	0.461	0.873	1.021	0.832
Kendall	0.662	0.684	0.721	0.616
Knox	0.002	0.000	0.000	0.000
Lake	2.449	1.974	2.730	2.208
LaSalle	5.911	5.397	5.968	4.815
Lawrence	6.209	7.715	8.487	6.944
Lee	0.272	0.072	0.090	0.049
Livingston	0.062	0.053	0.061	0.046
Logan	0.040	0.008	0.010	0.006
McDonough	0.016	0.015	0.021	0.008
McHenry	2.645	2.285	2.496	1.965
McLean	0.518	0.228	0.263	0.193
Macon	0.005	0.001	0.001	0.000
Macoupin	0.001	0.000	0.000	0.000
Madison	38.155	35.846	40.933	30.760
Marion	7.959	0.654	0.729	0.585
Marshall	1.082	1.033	1.126	0.940
Mason	0.796	1.081	1.199	0.979
Massac	5.725	5.672	10.328	6.001
Monroe	0.003	0.001	0.002	0.000
Montgomery	0.027	0.000	0.000	0.000
Morgan	5.117	5.676	6.143	5.128
Ogle	1.579	1.312	1.351	1.075
Peoria	10.257	7.275	9.393	7.308
Perry	0.335	1.276	1.404	1.148
Piatt	1.345	1.267	1.383	1.152
Pike	0.041	0.057	0.063	0.051
Pulaski	0.021	0.000	0.000	0.000

Table 15. Concluded

County	*1980-1987 average*	*1986*	*Adjusted high*	*Adjusted low*
Putnam	0.178	0.187	0.094	0.079
Randolph	0.004	0.001	0.002	0.000
Richland	0.971	0.906	1.000	0.813
Rock Island	10.220	9.817	10.681	8.501
St. Clair	11.532	11.270	12.397	10.143
Saline	0.346	0.351	0.387	0.315
Shelby	0.313	0.288	0.340	0.236
Stephenson	2.030	2.032	2.247	1.688
Tazewell	6.370	5.441	6.407	4.870
Union	0.006	0.003	0.003	0.002
Vermilion	2.849	2.273	3.395	2.510
Wabash	1.439	0.382	0.420	0.344
Washington	0.387	0.345	0.390	0.318
Wayne	2.226	1.733	1.921	1.553
White	3.666	2.784	3.083	2.495
Whiteside	2.323	2.335	2.807	1.864
Will	8.555	7.601	8.242	7.055
Williamson	0.035	0.029	0.035	0.023
Winnebago	6.147	4.732	6.290	4.737
Woodford	0.004	0.004	0.006	0.003
TOTAL	219.439	192.910	221.408	172.992

Table 16. Irrigation Characteristics by County

County	*No. of irrigation systems*	*No. of irrigation wells*	*No. of irrigated acres*	*No. of acres irrigated from ground water*
Adams	1	1	140	140
Alexander	10	10	704	704
Boone	2	2	256	256
Bureau	18	18	2,267	2,267
Carroll	23	18	2,804	2,294
Cass	27	23	3,222	2,822
Champaign	15	15	2,659	2,659
Christian	2	2	192	192
Clark	40	40	5,387	5,387
Clinton	4	4	544	544
Cook	1	1	136	136
Crawford	3	3	322	322
Cumberland	2	1	15	10
DeWitt	5	5	588	588
Edwards	1	1	120	120
Effingham	3	0	200	0
Fayette	3	0	248	0
Ford	2	2	300	300
Franklin	8	1	625	3
Fulton	5	5	680	680
Gallatin	32	32	5,761	5,761
Greene	7	7	1,206	1,206
Hamilton	1	1	136	136
Hancock	10	10	1,162	1,162
Henderson	46	46	5,155	5,155
Henry	22	22	1,844	1,844
Iroquois	6	4	627	355
Jackson	7	2	775	460
Jasper	2	1	30	15
Jersey	1	1	3	3
Kane	4	3	530	360
Kankakee	152	149	12,380	12,210
Kendall	4	4	430	430
Knox	3	3	30	30

Table 16. Continued

County	*No. of irrigation systems*	*No. of irrigation wells*	*No. of irrigated acres*	*No. of acres irrigated from ground water*
Lawrence	74	74	7,154	7,154
Lee	96	96	11,382	11,382
Livingston	4	1	343	15
Logan	2	2	272	272
McHenry	23	13	2,716	1,801
McLean	4	4	247	247
Macon	5	2	74	44
Madison	19	19	2,148	2,148
Marshall	16	15	1,607	1,577
Mason	857	857	90,831	90,831
Massac	12	11	1,533	1,509
Menard	4	4	502	502
Mercer	26	26	2,881	2,881
Monroe	16	11	1,522	1,035
Morgan	3	3	635	635
Ogle	10	10	1,218	1,218
Peoria	10	4	1,005	505
Perry	8	0	1,380	0
Piatt	4	4	421	421
Pike	10	10	1,385	1,385
Putnam	7	7	642	642
Randolph	1	1	136	136
Richland	3	0	15	0
Rock Island	15	15	2,176	2,176
St. Clair	21	9	1,351	598
Sangamon	5	0	183	0
Schuyler	4	0	161	0
Scott	13	13	2,644	2,644
Shelby	1	0	100	0
Stephenson	1	1	10	10
Tazewell	183	183	25,989	25,989
Union	6	2	290	160
Wabash	2	2	390	390
Warren	1	0	2	0

Table 16. Concluded

County	*No. of irrigation systems*	*No. of irrigation wells*	*No. of irrigated acres*	*No. of acres irrigated from ground water*
Washington	**11**	**3**	**1,196**	**401**
Wayne	**3**	**3**	**390**	**390**
White	**57**	**56**	**8,419**	**8,259**
Whiteside	**172**	**172**	**22,154**	**22,154**
Will	**3**	**3**	**408**	**408**
Winnebago	**9**	**7**	**1,015**	**648**
Woodford	**3**	**2**	**467**	**307**
TOTALS	**2,196**	**2,082**	**248,872**	**239,425**

Table 17. Reported Irrigated Crops and Acreages

Irrigated crop	*Acreage*	*Irrigated crop*	*Acreage*	*Irrigated crop*	*Acreage*
Corn	**55,306**	**Cabbage**	**280**	**Other melons**	**43**
Soybeans	**29,589**	**Tomatoes**	**269**	**Cut flowers**	**40**
Seed corn	**9,016**	**Gladiolis**	**250**	**Indian corn**	**40**
Popcorn	**7,558**	**Peppers**	**197**	**Oats**	**32**
Green beans	**2,338**	**Watermelon**	**190**	**Cauliflower**	**25**
Sod	**2,510**	**Apples**	**159**	**Blackberries**	**22**
Sweet corn	**2,027**	**Peaches**	**143**	**Shallots**	**20**
Peas	**1,175**	**Onions**	**140**	**Raspberries**	**15**
Wheat	**1,165**	**Chives**	**140**	**Spinach**	**15**
Alfalfa/hay	**1,044**	**Strawberries**	**121**	**Sweet potatoes**	**5**
Potatoes	**904**	**Muskmelon**	**101**	**Chrysanthemums**	**3**
Pumpkins	**581**	**Herbs**	**90**	**Christmas trees**	**2**
Ornamental nursery crops	**535**	**Seed soybeans**	**80**	**Nut trees**	**2**
Cucumbers/pickles	**453**	**Blueberries**	**65**	**China cabbage**	**1**
Vegetables (misc.)	**371**	**Turnip greens**	**50**	**Asparagus**	**1**
Horseradish	**360**				

Table 18. 30-Year Mean Precipitation (Inches) and Temperature (° F) and 1988 Precipitation and Temperature, by Crop Reporting District

	J	F	M	A	M	J	J	A	S	O	N	D
CRD 1												
Mean precip.	1.49	1.22	2.58	3.97	3.91	4.28	4.28	3.82	3.59	2.82	2.10	1.95
Mean temp.	19.42	24.71	35.29	49.78	60.87	70.07	73.96	71.85	64.27	53.08	38.70	26.00
1988 precip.	1.90	0.76	2.05	2.22	1.97	0.74	1.20	3.48	1.82	2.59	3.81	1.43
1988 temp.	17.06	20.48	37.22	48.92	62.96	72.14	76.64	76.46	65.30	46.04	39.20	26.96
CRD 2												
Mean precip.	1.72	1.39	2.69	3.95	3.52	4.32	4.18	3.65	3.61	2.59	2.16	2.14
Mean temp.	21.22	26.01	35.89	49.78	59.86	69.57	73.56	72.07	64.98	53.78	39.69	27.50
1988 precip.	1.99	1.33	2.28	2.69	1.64	1.14	2.49	3.75	2.10	3.04	5.16	2.05
1988 temp.	17.78	21.74	37.22	48.02	61.52	72.14	76.28	76.82	65.66	46.22	40.82	27.50
CRD 3												
Mean precip.	1.58	1.50	3.03	3.95	4.03	4.27	4.14	3.93	3.94	3.04	1.98	1.92
Mean temp.	23.22	28.71	38.70	52.77	63.07	72.16	76.15	73.96	66.56	55.47	41.29	29.50
1988 precip.	1.85	0.74	1.91	1.52	2.15	2.02	0.70	3.10	1.74	1.42	3.63	1.56
1988 temp.	22.64	23.90	40.10	51.80	65.30	73.94	77.90	78.62	67.82	48.74	41.18	30.20
CRD 4												
Mean precip.	1.69	1.54	3.01	4.08	3.86	4.12	4.10	3.58	3.46	2.66	2.15	2.22
Mean temp.	23.41	28.51	38.79	52.48	62.87	72.07	84.45	73.45	66.76	55.27	41.20	29.50
1988 precip.	1.89	1.02	2.82	1.84	1.51	0.73	0.78	2.69	1.96	1.86	4.53	2.51
1988 temp.	22.64	23.90	39.74	51.44	64.76	73.22	77.54	77.90	67.10	48.02	41.36	29.12
CRD 5												
Mean precip.	1.73	1.64	2.94	4.00	3.80	4.21	4.42	3.48	3.21	2.51	2.32	2.31
Mean temp.	23.81	28.31	38.50	51.78	62.17	71.46	74.66	72.66	66.36	54.77	41.00	29.61
1988 precip.	1.69	1.17	2.96	2.01	1.44	0.39	1.69	2.08	2.73	3.46	5.05	2.94
1988 temp.	21.92	23.90	39.20	50.00	64.40	73.40	77.54	77.72	66.74	47.30	41.54	29.30
CRD 6												
Mean precip.	1.69	1.91	3.32	3.93	4.12	4.04	3.83	3.48	3.26	2.68	2.43	2.26
Mean temp.	26.51	31.41	41.20	54.48	64.17	73.26	76.75	74.66	67.96	56.57	43.09	32.20
1988 precip.	2.22	2.48	4.16	1.24	1.64	1.44	2.96	2.11	1.73	2.02	6.02	3.36
1988 temp.	25.34	26.42	41.54	54.14	65.84	74.48	78.26	79.34	69.26	50.72	43.34	32.79
CRD 7												
Mean precip.	2.20	2.22	3.70	3.92	4.05	4.27	4.28	3.25	3.05	2.53	3.05	3.01
Mean temp.	27.41	32.00	41.79	54.48	64.08	73.17	76.66	74.66	68.16	56.48	43.29	32.90
1988 precip.	2.72	3.35	4.52	1.54	1.54	0.84	4.23	1.56	1.82	2.80	6.41	2.70
1988 temp.	25.88	28.22	42.62	54.14	66.02	74.30	78.62	79.16	68.72	49.82	44.06	33.10

Table 18. Concluded

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
CRD 8												
Mean precip.	2.57	2.84	4.36	4.14	4.28	3.98	3.95	3.52	3.14	2.45	3.28	3.29
Mean temp.	31.21	35.69	45.00	57.27	66.07	74.66	78.26	76.46	69.85	58.46	45.88	36.10
1988 precip.	2.38	3.05	4.87	1.72	2.29	1.15	4.68	2.26	5.16	3.35	6.34	2.65
1988 temp.	29.12	32.11	45.14	56.12	66.20	75.20	78.62	79.70	69.26	51.80	46.04	36.32
CRD 9												
Mean precip.	2.94	2.93	4.65	4.43	4.51	4.00	4.08	3.38	3.06	2.52	3.71	3.66
Mean temp.	31.60	35.69	45.09	57.18	69.96	74.55	78.06	76.35	69.85	58.28	45.99	36.30
1988 precip.	2.78	4.18	4.80	2.30	2.18	1.19	5.47	1.76	3.61	3.72	7.28	2.33
1988 temp.	29.12	32.70	45.68	55.40	65.84	74.48	78.44	79.34	68.90	51.44	45.86	35.96

Table 19. Computed Seasonal Soil Moisture Deficits by Crop Reporting District

(Inches)

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
30-Year Mean									
Fine sand	12.73	12.75	16.05	16.61	14.76	7.81	7.32	9.13	8.66
Sandy loam/clay	3.77	3.62	4.40	5.26	4.25	5.93	5.84	6.61	6.78
Silt/clay loam	2.97	3.82	4.00	4.26	3.85	5.33	4.64	5.89	5.58
1988									
Fine sand	14.98*	12.99	16.13	17.80*	17.52*	16.70	16.78	13.28	13.62
Sandy loam/clay	12.47	11.12	13.37	14.81	14.72	14.94	13.98	11.71	11.48
Silt/clay loam	11.76	9.02	11.73	14.30	13.40	14.50	12.42	10.75	9.82

**Average irrigation water use in 1988 (estimated from field study measurements)*

Crop Reporting District 1 = 11.18 - 14.22 mgd
Crop Reporting District 4 = 18.29 mgd
Crop Reporting District 5 = 10.66 mgd (Cravens et al, 1990)

Table 20. Seasonal Irrigation Ground-Water Use* by County

(Million gallons per day)

County	*Average*	*1988*
Adams	0.180	0.548
Alexander	1.369	2.424
Boone	0.281	0.755
Bureau	2.355	8.153
Carroll	2.096	8.006
Cass	4.467	12.026
Champaign	3.007	10.470
Christian	0.301	0.818
Clark	8.707	21.562
Clinton	0.939	1.714
Cook	0.152	0.360
Crawford	0.439	1.174
Cumberland	0.013	0.034
DeWitt	0.814	2.503
Edwards	0.197	0.346
Ford	0.338	1.178
Franklin	0.004	0.006
Fulton	0.886	2.690
Gallatin	10.274	17.763
Greene	2.055	5.326
Hamilton	0.222	0.391
Hancock	1.499	4.555
Henderson	6.418	19.233
Henry	1.961	6.682
Iroquois	0.399	1.388
Jackson	0.796	1.453
Jasper	0.021	0.055
Jersey	0.004	0.010
Kane	0.406	0.958
Kankakee	16.335	54.624
Kendall	0.457	1.403
Knox	0.033	0.096
Lawrence	10.748	27.405
Lee	10.024	39.373

Table 20. Concluded

County	*Average*	*1988*
Livingston	0.016	0.056
Logan	0.339	1.140
McHenry	1.951	5.458
McLean	0.310	1.040
Macon	0.057	0.190
Madison	3.538	9.276
Marshall	2.396	6.834
Mason	125.606	386.724
Massac	2.465	4.336
Menard	0.723	2.285
Mercer	3.036	10.436
Monroe	1.759	3.114
Morgan	1.084	2.767
Ogle	1.189	4.315
Peoria	0.738	2.178
Piatt	0.475	1.653
Pike	2.240	5.946
Putnam	0.630	2.281
Randolph	0.264	0.468
Rock Island	2.348	7.902
St. Clair	1.030	1.880
Scott	4.280	11.367
Stephenson	0.008	0.032
Tazewell	34.468	109.998
Union	0.311	0.551
Wabash	0.640	1.125
Washington	0.690	1.260
Wayne	0.642	1.129
White	13.546	23.828
Whiteside	22.830	79.533
Will	0.434	1.333
Winnebago	0.717	2.371
Woodford	0.382	1.283
TOTAL	319.336	949.576

Based on a 92-day irrigation season

Table 21. Projected 1995 Ground-Water Pumpage for Public Water Supplies and Self-Supplied Industries Combined and for Expanded Agricultural Irrigation, Totaled by County

(Million gallons per day)

	PWS and SSI** Totals*		
County	***Adjusted up***	***Adjusted down***	***Expanded agricultural irrigation***
Adams	14.013	11.076	0.068
Alexander	0.357	0.333	0.516
Bond	0.065	0.064	--
Boone	3.690	3.639	0.107
Brown	0.061	0.061	--
Bureau	3.531	3.507	0.885
Calhoun	0.507	0.507	--
Carroll	3.976	3.558	0.788
Cass	2.439	2.194	1.675
Champaign	23.517	22.572	1.123
Christian	1.935	1.825	0.115
Clark	1.524	1.476	3.261
Clay	0.912	0.736	--
Clinton	0.656	0.577	0.355
Coles	0.458	0.430	--
Cook	64.255	61.722	0.059
Crawford	6.744	6.013	0.161
Cumberland	0.465	0.423	0.008
DeKalb	7.312	7.202	--
DeWitt	1.546	1.546	0.305
Douglas	1.121	1.110	--
DuPage	8.401	8.106	--
Edgar	0.354	0.352	--
Edwards	0.665	0.457	0.074
Effingham	0.546	0.500	--
Fayette	1.544	1.282	--
Ford	1.394	1.394	0.126
Franklin	0.409	0.244	0.005
Fulton	0.911	0.911	0.331
Gallatin	2.528	2.312	3.850

Table 21. Continued

	PWS and SSI** Totals*		
County	*Adjusted up*	*Adjusted down*	*Expanded agricultural irrigation*
Greene	0.365	0.363	0.770
Grundy	11.023	9.547	--
Hamilton	1.218	1.107	0.085
Hancock	0.235	0.233	0.562
Hardin	1.320	1.102	--
Henderson	6.554	6.554	2.412
Henry	3.940	3.923	0.739
Iroquois	2.107	2.086	0.151
Jackson	0.101	0.101	0.295
Jasper	1.587	1.365	0.007
Jefferson	0.953	0.775	--
Jersey	0.889	0.889	0.005
JoDaviess	3.810	3.521	--
Johnson	0.023	0.023	--
Kane	33.878	33.519	0.154
Kankakee	2.884	2.695	6.125
Kendall	2.496	2.391	0.175
Knox	1.265	1.265	0.014
Lake	12.328	11.800	--
LaSalle	16.218	15.065	--
Lawrence	9.705	8.162	4.029
Lee	3.581	3.540	3.755
Livingston	1.682	1.667	0.007
Logan	3.537	3.537	0.127
McDonough	0.696	0.683	--
McHenry	14.726	14.195	0.733
McLean	5.197	5.127	0.124
Macon	1.117	1.116	0.022
Macoupin	0.018	0.018	--
Madison	51.962	41.789	1.324
Marion	0.754	0.610	--
Marshall	2.297	2.111	0.895
Mason	2.185	1.965	47.105

Table 21. Continued

PWS and SSI** Totals*

County	*Adjusted up*	*Adjusted down*	*Expanded agricultural irrigation*
Massac	12.631	8.304	0.928
Menard	0.735	0.735	0.269
Mercer	0.934	0.934	1.136
Monroe	0.112	0.110	0.655
Montgomery	0.529	0.529	--
Morgan	6.221	5.206	0.403
Moultrie	0.438	0.438	--
Ogle	6.698	6.422	0.445
Peoria	25.271	23.186	0.280
Perry	1.452	1.196	--
Piatt	2.728	2.497	0.175
Pike	0.824	0.812	0.843
Pulaski	0.654	0.654	--
Putnam	0.511	0.496	0.238
Randolph	0.832	0.830	0.098
Richland	1.110	0.923	--
Rock Island	13.391	11.211	0.882
St. Clair	12.561	10.307	0.391
Saline	0.393	0.321	--
Sangamon	2.196	2.196	--
Schuyler	0.550	0.550	--
Scott	4.047	4.047	1.609
Shelby	1.515	1.411	--
Stark	0.441	0.441	--
Stephenson	7.748	7.189	0.005
Tazewell	19.538	18.001	12.926
Union	1.407	1.406	0.115
Vermilion	4.733	3.848	--
Wabash	1.232	1.156	0.243
Warren	2.604	2.604	--
Washington	0.494	0.442	0.260
Wayne	2.052	1.684	0.237
White	4.313	3.725	5.085

Table 21. Concluded

PWS and SSI** Totals*

County	*Adjusted up*	*Adjusted down*	*Expanded agricultural irrigation*
Whiteside	**7.404**	**6.461**	**8.571**
Will	**39.847**	**38.660**	**0.160**
Williamson	**0.035**	**0.023**	**--**
Winnebago	**41.200**	**39.647**	**0.267**
Woodford	**1.529**	**1.526**	**0.145**
TOTAL	**587.397**	**539.101**	**119.793**

* Public Water Supply
** Self-Supplied Industrial

Table 22. Use/Yield Ratios for Municipal and Industrial Pumpage

Category	*Percent area overpumped*	*# Townships with r > 1**	*Total townships with pumpage*
Total	**45**	**994**	**4.5**
Sand and gravel	**28**	**634**	**4.4**
Shallow bedrock	**41**	**518**	**7.9**
Deep sandstone	**72**	**289**	**24.9**

***r = ground-water use / yield ratio**

Table 23. Use/Yield Ratios for Municipal and Industrial Pumpage* under Average Weather Conditions

Category	*Percent area overpumped*	*# Townships with r > 1***	*Total townships with pumpage*
Total	**60**	**1089**	**5.5**
Sand and gravel	**50**	**756**	**6.6**
Shallow bedrock	**44**	**522**	**8.4**
Deep sandstone	**73**	**290**	**25.2**

* *Seasonal pumpage rates*
** r = *ground-water use /yield ratio*

Table 24. Use/Yield Ratios for Municipal, Industrial, and Irrigation Pumpage* under Drought (1988) Conditions

Category	*Percent area overpumped*	*# Townships with r > 1***	*Total townships with pumpage*
Total	**87**	**1089**	**8.0**
Sand and gravel	**89**	**756**	**11.8**
Shallow bedrock	**48**	**522**	**9.2**
Deep sandstone	**75**	**290**	**25.9**

**Seasonal pumpage rates*
**** r *= ground-water use /yield ratio*

Table 25. Annual Impacts of Average and 1988 Irrigation

Irrigation water use		*Ratios*	*# Townships with r* > 1*
Average	**80 mgd**	**0.001 - 7.55**	**46**
1988	**240 mgd**	**0.001 - 7.55**	**51**

*** r = ground-water use / yield ratio**

Table 26. Projected Municipal, Industrial, and Average Seasonal Irrigation Pumpage

	Projected		*Projected with irrigation*	
	High	*Low*	*High*	*Low*
# Townships with r > 1*	**34**	**31**	**61**	**59**
Ratios	**0.001 - 6.79**	**0.001 - 5.94**	**0.001 - 13.39**	**0.001 - 13.39**

***r = ground-water use / yield ratio**