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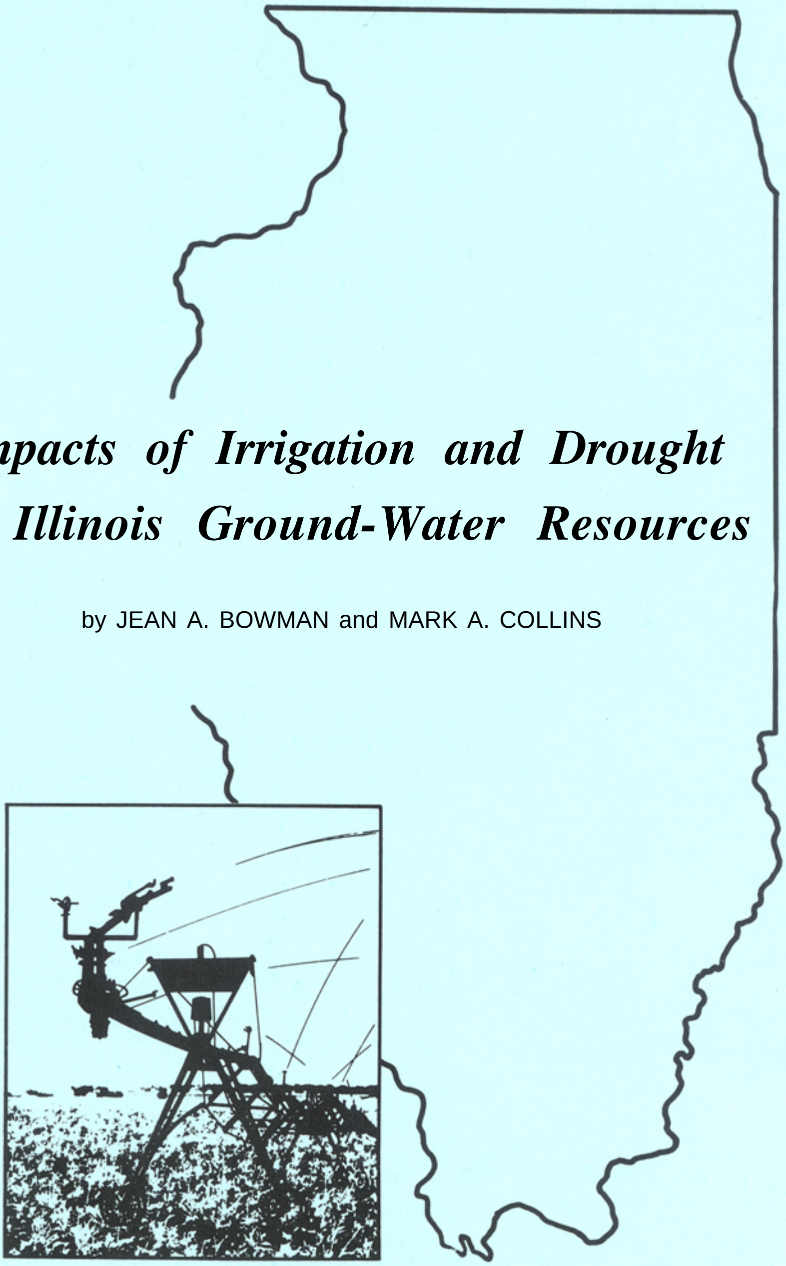

Impacts of Irrigation and Drought on Illinois Ground-Water Resources

by JEAN A. BOWMAN and MARK A. COLLINS

ILLINOIS STATE WATER SURVEY
CHAMPAIGN
1987

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Abstract: Effects of irrigation and drought on Illinois ground-water resources are examined. Irrigation water use for five soil types is estimated from a monthly water budget model on the basis of precipitation and temperature data. Irrigation water use from each township with irrigated acreage is added to municipal and industrial ground-water use data and then compared to aquifer potential yields. A statewide geographic information system is used for the spatial analysis. The model is tested for sensitivity to climate variation; seasonal water deficits are calculated by using data from extreme growing seasons and extended droughts. The effect of increasing the amount of irrigated land is also considered. The effects of variable irrigation demand on ground-water resources are expressed as use/yield ratios, to highlight regions most susceptible to ground-water stress because of drought or increased irrigation. Results show that irrigation is a substantial seasonal consumptive ground-water use in Illinois. but effects are localized and highly dependent on climate variability. Some potential for seasonal or temporary overpumpage may exist in the most heavily irrigated areas during years with below-normal precipitation or during extended droughts. However, theaquifers being used for irrigation appear to be able to recover from high seasonal demands for irrigation water without suffering significant depletion. Exceptions to this may occur during extended drought periods, especially if widespread expansion of irrigation practices occurs.

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Indexing Terms: Drought, geographic information system, ground-water management, Illinois, irrigation, water budget modeling.

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HON. JAMES R. THOMPSON, Governor

DEPARTMENT OF ENERGY AND NATURAL RESOURCES
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ABSTRACT

This investigation is the first of three phases of a ground-water management study. In this report, effects of irrigation and drought on the ground-water resources of Illinois are examined. Irrigation water use for five soil types is estimated from a monthly water budget model on the basis of precipitation and temperature data from the last 30 years at selected weather stations across Illinois. Moisture deficits are computed for each soil type on the basis of the water requirements of a corn crop. It is assumed that irrigation is used to make up the moisture deficit in those places where irrigation systems already exist. Irrigation water use from each township with irrigated acreage is added to municipal and industrial ground-water use data and then compared to aquifer potential yields. The spatial analysis is accomplished with a statewide geographic information system. An important distinction is made between the seasonal effects of irrigation water use and the annual or long-term effects. The model is tested for its sensitivity to weather variation; seasonal water deficits are calculated by using data from extreme growing seasons and extended drought periods. The effect of increasing the amount of irrigated land by 50 percent is also considered for normal weather conditions and droughts. The effect of variable irrigation demand on ground-water resources is expressed as the ratio of ground-water use to ground-water potential yield for each township. This is done to highlight regions most susceptible to ground-water stress because of drought or increased irrigation by showing where use could exceed yield. The sensitivity of the results is not tested for variations in spatial aggregation. This will be one of the primary tasks in subsequent study phases.

Results show that irrigation is a substantial seasonal consumptive ground-water use in Illinois, with the potential for growth. However, present effects appear to be localized and highly dependent on weather conditions. Some potential for seasonal or temporary overpumpage may exist in the heavily irrigated areas during years with below-normal precipitation or during extended droughts. The aquifers being used for irrigation appear to have the ability to recover from present irrigation demands without suffering significant depletion, implying that the annual effect of irrigation is currently relatively minimal. The exception to this may be during extended drought periods, especially if widespread expansion of irrigation practices also occurs in the state. A 50 percent expansion of irrigation would appear to have surprisingly little additional impact on ground-water resources under most climatic conditions. That degree of growth around currently irrigated land would result in expanded irrigation areas still within reach of the productive, high-yielding aquifers already being pumped for irrigation. A much larger degree of irrigation expansion into areas with heavier-textured soils is possible in Illinois. The availability of ground-water would be a major limiting factor in the speed and direction of that expansion. That kind of massive irrigation expansion is not considered in this report; however, its effects on the state's ground water are assumed to be considerable and will be addressed in subsequent study phases.

The Chicago metropolitan area stands out as a major region of overpumpage, but not because of irrigation. Variable irrigation pumpage does appear to consistently

affect several other regions, most notably parts of Mason, Kankakee, Tazewell, Lee and Whiteside Counties. The degree to which these counties are affected by irrigation depends largely on weather conditions. For all these counties, with the possible exception of Kankakee, surficial sand and gravel aquifers are the most susceptible to stress from drought and irrigation water use. Shallow bedrock aquifers may also be impacted by irrigation in parts of Kankakee County. The impact of an extended drought is likely to be more widespread and inconsistent because of the multiple effects of increased water use for irrigation and other demands, and reduced ground-water storage.

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. As population, industry, and agriculture have grown in Illinois, ground water has been increasingly relied on as a ready source for water. But because ground-water resources are limited, conflicts, competition, and shortages of ground water have occurred on occasion. This has given rise to the recent focus on the need for ground-water management in Illinois, especially as it relates to drought planning.

Illinois has a sub-humid climate with ample mean annual precipitation ranging from 34 inches in the north to 46 inches in the south. However, precipitation distribution can be very uneven, and prolonged droughts do occur. Droughts of shorter duration during the growing season are also not uncommon. These events are unpredictable and can have wide-ranging economic and hydrologic effects, making them particularly important to ground-water planning in Illinois.

Of particular interest also is the increase in irrigated agriculture and the effect that may have on the ground-water resources of the state. Although a very small portion of Illinois farmland is currently irrigated, that fraction is growing and seasonal consumptive water use by irrigation appears to be substantial. This can cause ground-water competition, although incidents of conflict in Illinois are infrequent and localized. The Illinois State Water Plan Task Force (1984) identified irrigation growth as a potential cause of ground-water competition. Irrigation could be expanded greatly in Illinois, bringing with it the potential for a considerably more substantial impact on ground water. Given the importance of both ground water and the agricultural economy in Illinois, it will be very important to know if there will continue to be enough ground water to sustain a growing irrigation demand without placing a burden on other users, particularly during droughts. There is a clear need to measure, or accurately estimate, the amount of ground water used for irrigation during years with good, bad, and normal weather, and to better understand the implications of a growing irrigation water demand on ground-water resources and future ground-water management objectives.

It is important to protect Illinois ground-water resources from depletion, plan for the effects of drought, and help minimize potential conflicts among ground-water users. Increasing irrigation and climate variability need to be considered in future ground-water planning of the state. A three-phase ground-water management study is planned to consider the need for designating ground-water management areas (GWMA's) to address problems of drought and water competition.

The three phases of this ground-water management study are:

1) To gain a better understanding of the stresses on ground-water supplies from drought and increased irrigation

2) To delineate potential ground-water management areas

3) To design an administrative and technical structure for operating ground-water management areas.

The first phase, which is discussed in this report, has been completed. Specifically, irrigation water use was estimated for variable climatic and land use conditions. Estimated irrigation water use was compared to existing municipal and industrial ground-water withdrawals and to potential aquifer yields. The methods used were designed to identify ground-water problems on a regional scale. The study does not attempt to identify more specific problems such as locations of well interference or supply interruption, which may be localized and temporary. This report summarizes the results of the analysis.

Report Structure

The following section in this report, "Climatic and Hydrogeologic Conditions in Illinois," is a brief description of Illinois' climate, aquifer systems, and ground-water use for municipal and industrial purposes. The next section contains a brief comparison of ground-water withdrawals and aquifer yields in Illinois, including the development of the initial ground-water-use and potential-aquifer-yield database. The next section, "Irrigation Trends in Illinois," discusses the history and distribution of irrigation in the state. "Estimating Irrigation Water Use in Illinois" presents the methodology used to determine average annual irrigation water use in the state. Results are compared to potential aquifer yields and to municipal and industrial uses in the state. The following section is a series of sensitivity analyses of the effects of climate variability on irrigation water use and on potential aquifer yield; the results show, in a broad way, what the effects of short and longer-duration droughts would be on the ground-water resources of Illinois. The last major section discusses the effects of expanded irrigation. Finally, the report offers conclusions and recommendations concerning the effects of drought and increased irrigation on the state's ground water.

Acknowledgements

This report was prepared under the general supervision of Richard G. Semonin, Chief of the Illinois State Water Survey, and Ellis W. Sanderson, Head of the Ground-Water Section. This work was underwritten by the Illinois Department of Transportation, Division of Water Resources, under the direction of Donald R. Vonnahme and Gary R. Clark. John W. Brother, Jr., and Linda Riggin provided graphic assistance. Gail Taylor provided editorial assistance. Many individuals at the State Water Survey provided valuable technical advice, criticism, and input which aided greatly in the preparation of this report.

CLIMATIC AND HYDROGEOLOGIC CONDITIONS IN ILLINOIS

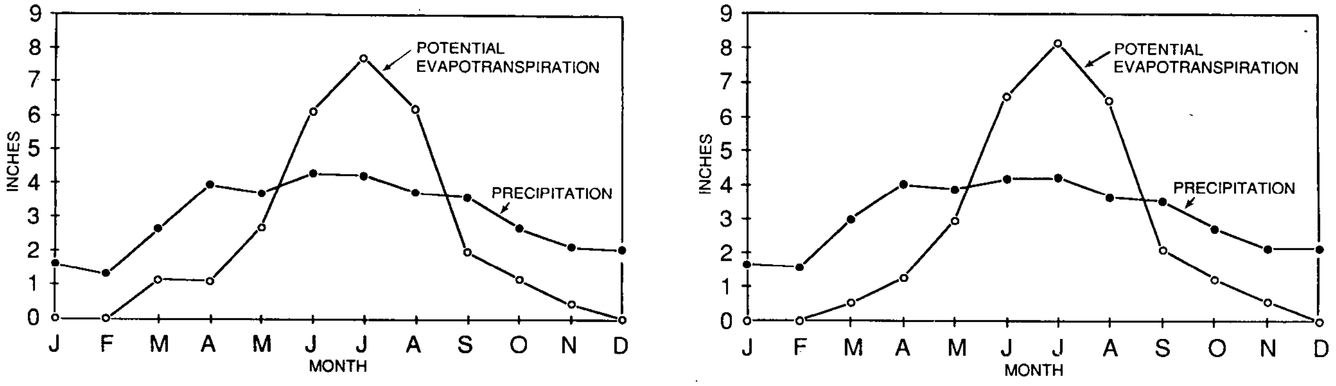
Climate

Illinois climate is extremely variable. A certain amount of natural climatic fluctuation occurs on time scales ranging from years to decades to centuries (Changnon, 1983). Spatial variability in the weather of Illinois also occurs primarily because of the state's long north-south axis.

Northern Illinois is both cooler and drier than the southern part of the state, and has a later peak seasonal rainfall and shorter growing season on the average. Figure 1 shows mean annual rainfall distributions and potential evapotranspiration for four east-west bands across the state. Figure 1a presents data on the northwest and northeast crop reporting districts (see figure 2). Figure 1b represents the west, central, and east districts. Figure 1c covers the west southwest and east southeast, and figure 1d covers the southwest and southeast districts. Average rainfall is based on the 30-year period between 1955 and 1985. Potential evapotranspiration trends are based on the Blaney-Criddle formula (Blaney and Criddle, 1950), with temperature averages for the same 30-year period.

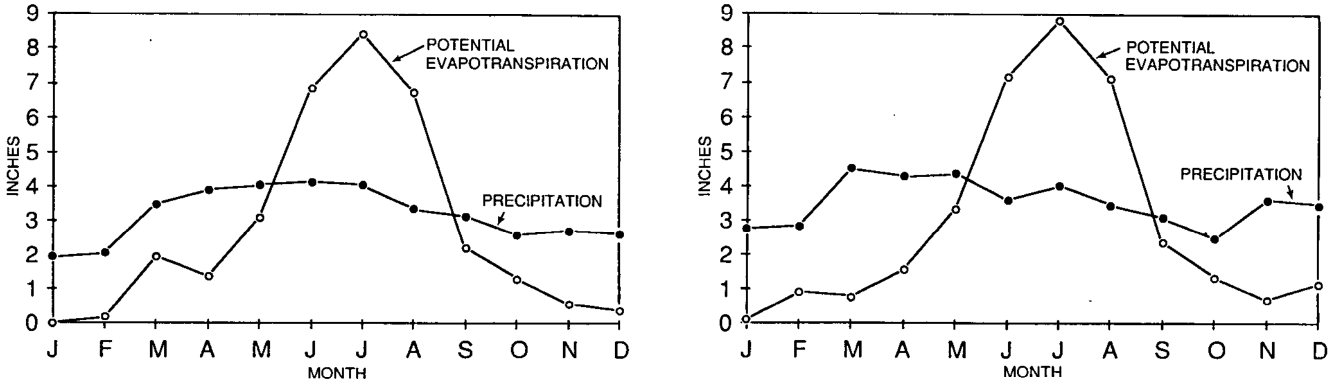
More than half of the annual precipitation occurs during the growing season when evapotranspiration losses are at a maximum. June and July are the months of maximum average precipitation everywhere except the far south (figure 1d), where there are peaks in the early spring and then again in mid-summer. Although precipitation exceeds evapotranspiration on an annual basis, evapotranspiration is nearly always higher than precipitation throughout the state in June, July, and August, the heart of the growing season. This is particularly important with regard to corn and soybean yields, since adequate moisture during the critical flowering stage (usually the last half of July) is one main limiting factor on yields. Crops will grow unstressed only if stored soil moisture is sufficient to make up the difference between precipitation and potential evapotranspiration, or if supplemental irrigation is used (Scott et al., 1986). For this reason, irrigation is viewed as one means of reducing yield fluctuations caused by reduced soil moisture and rainfall variations.

Ground-water levels respond in varying degrees to these natural climatic forces. The water table in Illinois is affected by precipitation, evapotranspiration, discharge of ground water to streams, and withdrawals from wells (Russell, 1963). Seasonal weather fluctuations typically cause the water table to decline in the late spring, summer, and early fall, primarily in response to evapotranspiration. Recovery of water levels begins late in the fall and is most pronounced in wet spring months before the growing season begins. This natural cycle can be, and often is, disrupted by variable climate events like droughts.



a. North

b. North-central



c. South-central

d. South

Figure 1. Annual precipitation and potential evapotranspiration distribution for four east-west hands across Illinois

Aquifers

The most productive aquifers of Illinois can be broadly categorized into three systems: 1) the deepest sandstones and dolomites of Pre-Cambrian and Cambrian-Ordovician ages; 2) the shallow limestones and dolomites of Devonian and Silurian ages; and 3) the Pleistocene sands and gravels, both surficial and buried. Numerous assessments of these aquifers have been conducted over the course of many years. Some of those studies are cited here.

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. The Cambrian-Ordovician system provides ground water for about 250 municipalities and 150 industries in the northern half of Illinois (Visocky et al., 1985). It has been the most developed bedrock water supply in the state (Kirk et al., 1985). Recharge occurs principally through vertical percolation of precipitation from overlying glacial deposits, but some leakage can occur through the generally confining Maquoketa shale formation (Visocky et al., 1985). Walton (1965) estimated recharge at 1,300 gallons per day per square mile (gpd/sq mi) in the Chicago area where the Maquoketa shale is present. That is thought to be about the lowest recharge rate in the state (Walton, 1965). Visocky et al. (1985) estimated recharge at between 3,000 and 42,000 gpd/sq mi for other parts of the Cambrian-Ordovician system, on the basis of a flow-net analysis of potentiometric surface data.

Suter et al. (1959), Walton (1965), and Schicht and Moench (1971) have all made estimates of the potential yield of the Cambrian-Ordovician system. Potential yield is defined as the maximum amount of ground water that

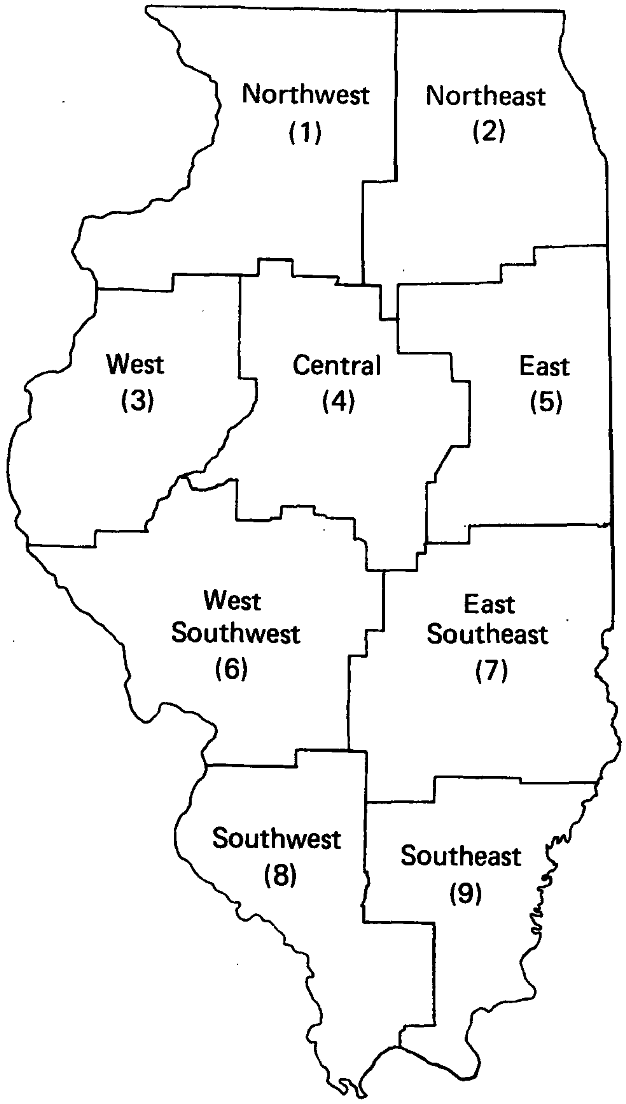


Figure 2. Illinois crop reporting districts

can be developed from a reasonable number of wells and well fields without exceeding recharge. The most recent estimate, 65 million gpd, was made by Visocky et al. (1985), who noted that pumpage has exceeded that amount since about 1958. In fact, regionalized pumpage started causing noticeable water level declines as early as 1864 in the Chicago area. Visocky et al. (1985) estimated that the average Chicago region water-level decline has been about 800 feet since 1864. Water-level declines between 1971 and 1980 in other major Cambrian-Ordovician pumping centers are 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). Discussions of historic Cambrian-Ordovician water-level trends can be found in Suter et al. (1959), Russell (1963), Schicht et al. (1976), and Visocky et al. (1985).

Shallow Bedrock Aquifers

Shallow bedrock aquifers of appreciable importance are distributed in the northern half of Illinois above the confining Maquoketa shale formation. Most of the high-yielding shallow bedrock wells for public water supply and industrial use in northeastern Illinois are concentrated in Silurian dolomites. The water-yielding fractures and openings in the Silurian dolomite are irregularly distributed both vertically and horizontally, so the yields of dolomite wells vary greatly from place to place (Russell, 1963). The shallow dolomites are used for public water supply primarily in the northeastern part of the state, and localized overpumpage has been common in those regions.

In most of central and parts of southern Illinois the dolomite is overlain by Pennsylvanian shales that are relatively unfavorable for ground-water supplies (Russell, 1963). In these areas ground-water development from unconsolidated deposits is preferred. Although bedrock aquifers in central and southern Illinois are not high-yielding, some shallow water-yielding dolomites of Mississippian age are unevenly distributed to the west of the Illinois River and in southern Illinois along the Mississippi River. The Illinois State Water Plan Task Force (1984) estimated that potential yields for the shallow bedrock aquifers range from an estimated 50,000 to a maximum of 200,000 gpd/sq mi. These figures are based on data compiled for the 1967 Illinois Water Plan (Technical Advisory Committee on Water Resources, 1967). Recharge to these aquifers is from overlying glacial deposits.

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. Continuous sand and gravel deposits of significant thickness are more common within bedrock valleys than on bedrock uplands (Russell, 1963). They are particularly thick in the buried preglacial valleys, some of which coincide with present valleys and lowlands. Sand and gravel aquifers are recharged directly from precipitation and from vertical leakage through the glacial tills present throughout most of the state. 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 only in limited areas adjacent to the Illinois and Mississippi Rivers where well fields in proximity to the rivers enhance recharge by induced infiltration.

Major pumping centers for sand and gravel aquifers are spread throughout the state, particularly in central Illinois to the east of the Illinois River. Most of the state's irrigation pumpage is from sand and gravel aquifers. Water levels in these unconsolidated aquifers (particularly those under water-table conditions) are quickly affected by climatological variability and seasonal evapotranspiration fluctuations (Russell, 1963; Kohlhase et al., State Water Survey open file report).

GROUND-WATER WITHDRAWALS AND AQUIFER YIELDS IN ILLINOIS

Each of the three aquifer classes provides potable water for domestic, municipal, industrial, and agricultural needs across the state. Table 1 shows 1984 ground-water use statistics broken down by crop reporting district and aquifer system.

Sand and gravel aquifers provide the most fresh water throughout the state, except in the northeast where the Chicago metropolitan area also draws very heavily on both shallow and deep bedrock aquifers. In parts of southeastern Illinois, brine pumpage accounts for part of the high shallow bedrock pumpage. Ground-water consumption in the northeastern region of the state is highly correlated with population and industry (Schicht et al., 1976).

Data Base Development

To evaluate regional relationships between ground-water use and ground-water availability, a computerized data base of ground-water-withdrawal and potential-aquifer-yield data for each legal township in the state has been developed. The data base is part of a statewide geographic information system (GIS) used for comparison and analysis of a wide variety of spatial data.

The source of the tabular ground-water withdrawal data was the Illinois Water Inventory Program. Specific township data were obtained from a preliminary version of the 1982 Water Inventory Program report (Kirk et al.,

Table 1. 1984 Illinois Ground-Water Withdrawal in mgd
(Excluding Rural Domestic and Livestock Uses)*

District	*Sand / gravel*	*Shallow bedrock*	*Deep bedrock*
Northwest (1)	68.1	8.2	56.9
Northeast (2)	40.6	125.7	195.3
West (3)	23.8	1.2	4.6
Central (4)	171.2	0.2	2.3
East (5)	39.1	8.1	0.2
W. Southwest (6)	75.0	1.2	0.0
E. Southeast (7)	21.1	29.8**	0.0
Southwest (8)	23.1	2.8	0.0
Southeast (9)	13.3	15.9**	0.0
TOTAL	**475.3**	**193.1**	**259.3**

* After Kirk et al., 1985
** Includes brine pumpage

1984). Withdrawals were calculated as the total of annual pumpage for public water supply (not including rural domestic withdrawals) and self-supplied industrial uses by aquifer system for each legal township in the state. The GIS ground-water-withdrawal data base did not originally include estimates of irrigation water use.

Data on potential aquifer yield came from maps of the potential yield for sand and gravel and bedrock aquifers created 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. These potential yield maps depict a range of yields, expressed as gallons per day per square mile of surface area (gpd/sq mi). Potential yield values equal to the lower limits of the ranges designated in the Water Plan were assigned to the digital potential yield maps. A map of the townships was merged with the potential yield maps through use of the GIS. With a value assigned to each area of potential yield, it was possible to compute an areally-weighted potential yield for each township.

Use/Yield Analysis

Having an estimated potential yield for each aquifer system in each township allowed for comparison to ground-water withdrawal from each aquifer system in each township or any combination of townships. This comparison was accomplished by calculating the ratio r of ground-water use to ground-water potential yield:

$$r=U/Y \tag{1}$$

where U is ground-water withdrawal for municipal and self- supplied industrial uses 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. 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.

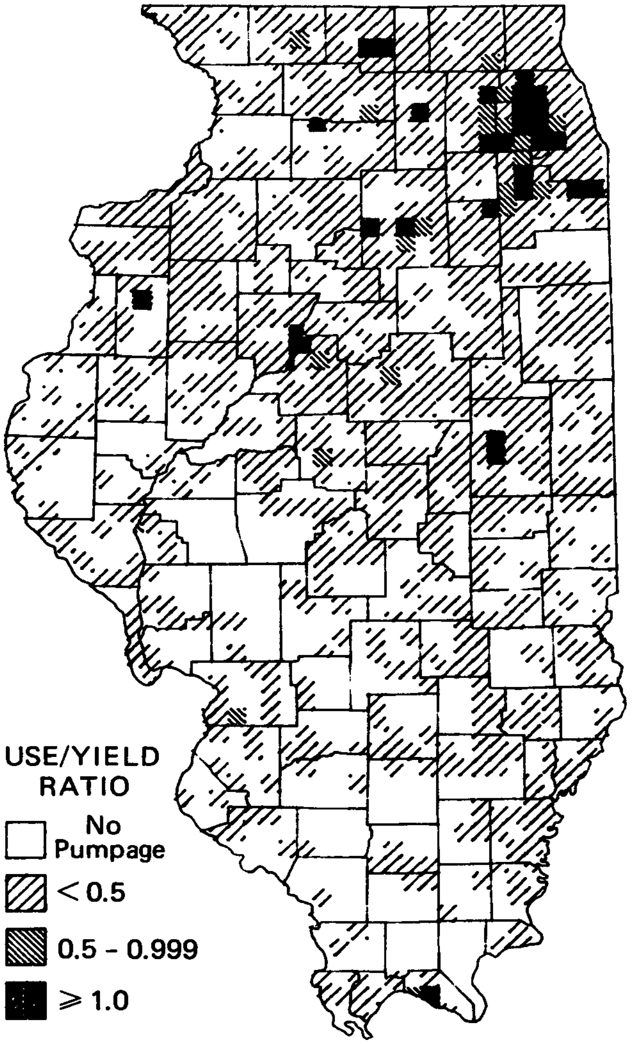


Figure 3. Use/yield ratio distribution for all aquifer potential yields and all ground-water uses except irrigation

The distribution of the use/yield ratios (excluding irrigation and other rural pumpage) for all aquifer systems combined is shown in figure 3. Figure 4 shows the number of townships in Illinois with pumpage in each aquifer system and the use/yield breakdown within each aquifer system.

This use/yield method of analysis is repeated in later sections of this report when estimates of irrigation water use are added to municipal and industrial withdrawals. This analysis allows for evaluation of the seasonal and annual effects of irrigation water use.

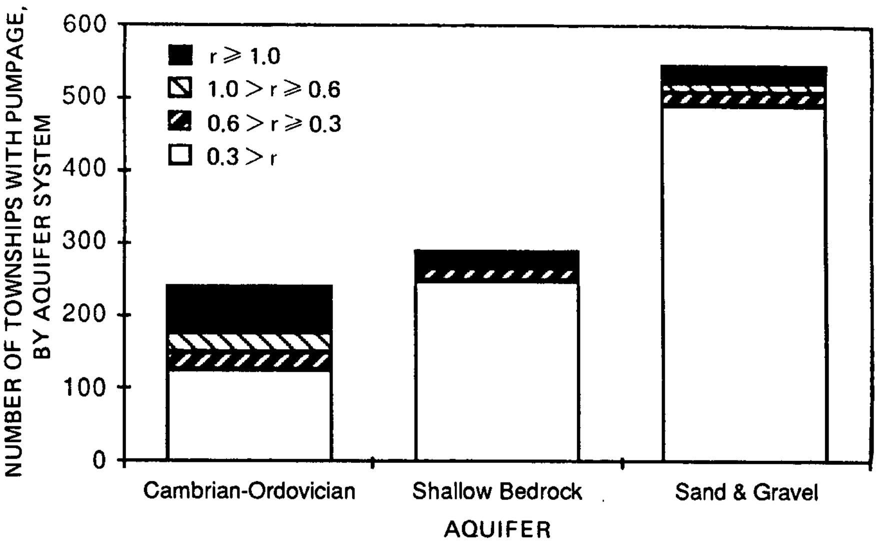


Figure 4. Number of townships with pumpage in each aquifer system and distribution of use/yield ratios (r) for each aquifer system (excluding estimated irrigation demand)

IRRIGATION TRENDS IN ILLINOIS

Historical Trends

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 covers the soil. However, rainfall is not distributed evenly. Even in places where the soil moisture capacity is large, supplemental irrigation is occasionally necessary to maintain yields.

There are presently an estimated 1,400 irrigation wells and 200,000 irrigated acres in Illinois. While that is only about 1 percent of the total cropland in the state, it is more than 20 times the area irrigated in 1950 in Illinois. Irrigation increased rather unevenly in the years between 1950 and 1986. Roberts (1951) reported that by 1950 irrigation had been practiced in isolated pockets of Illinois for about 25 years. In 1950, 164 irrigation systems watered about 9,000 acres of truck crops, flowers, pasture, and corn (Roberts, 1951). More than 80 percent of all irrigation activity at that time was concentrated in the vegetable and gladioli fields of Kankakee County. This trend began to shift when a prolonged drought in the 1950s apparently prompted an abrupt increase in irrigation in 1959 and 1960 in Mason County in the Illinois River floodplain (Walker et al., 1965). By 1966 a University of Illinois irrigation survey estimated a total of 28,000 irrigated acres in Illinois (Lah et al., 1978). Between 1966 and 1973 the increase was gradual. Crop prices soared in 1973, prompting farmers to expand irrigated acres to increase crop yields. Irrigation increased to about 110,000 acres by 1977 (Lah et al., 1978).

Since 1977, several factors appear to have caused a slow but steady increase in irrigation. First, tax depreciation laws now provide advantages for large farming operations or for farms where capital investments are desired, making the installation of irrigation systems more cost-effective. Second, irrigation development is beginning to occur on the silt and clay loam and claypan soils of the state. Crop yield response to irrigation on soils with light to medium texture and on claypan soils appears to be significant, with increases ranging from 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 soils appears to stabilize yields and maintain higher grain quality, especially during droughts. Third, irrigation on any soil appears to offer the farmer insurance against drought with greater assurance of stable crop yields.

Present Irrigation Distribution

Most of the current irrigation in Illinois is still in localized areas generally corresponding to alluvial and glacial outwash sands. More than 90 percent of all irrigation water used in Illinois comes from ground-water supplies, and of that, about 92 percent comes from unconsolidated sand and gravel aquifers. Figure 5 shows the density and distribution of suspected irrigation wells in the state (few have been field-verified) and figure 6 shows the distribution of fine sandy soils in the state. Table 2 lists counties where irrigation is used, their respective irrigated acreages, and number of suspected irrigation wells, and provides a breakdown of the aquifer systems tapped by the wells. Kankakee County remains one of the major centers of irrigation, but the most heavily irrigated area is now the Havana Lowlands in Mason and Tazewell Counties, immediately east of the Illinois River. The Green River floodplain in Lee and Whiteside Counties is a third major center of irrigation. Truck and flower crops are still irrigated, but now large grain operations growing corn and soybeans dominate irrigation in Illinois. The statewide average number of acres per irrigation system is about 140.

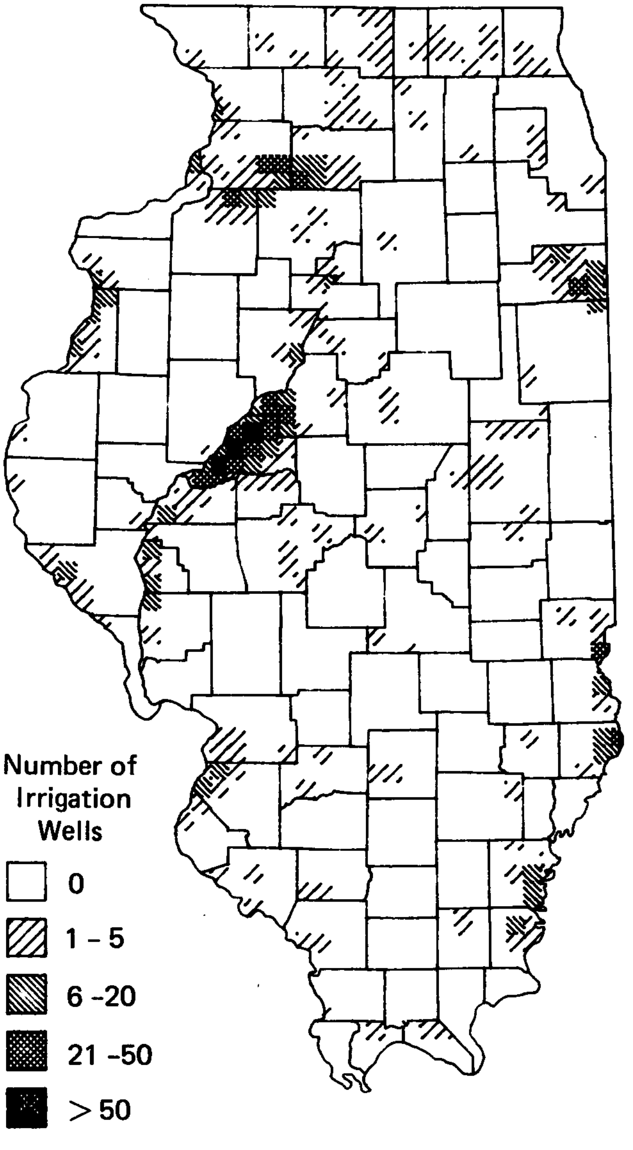


Figure 5. Density and distribution of suspected irrigation wells

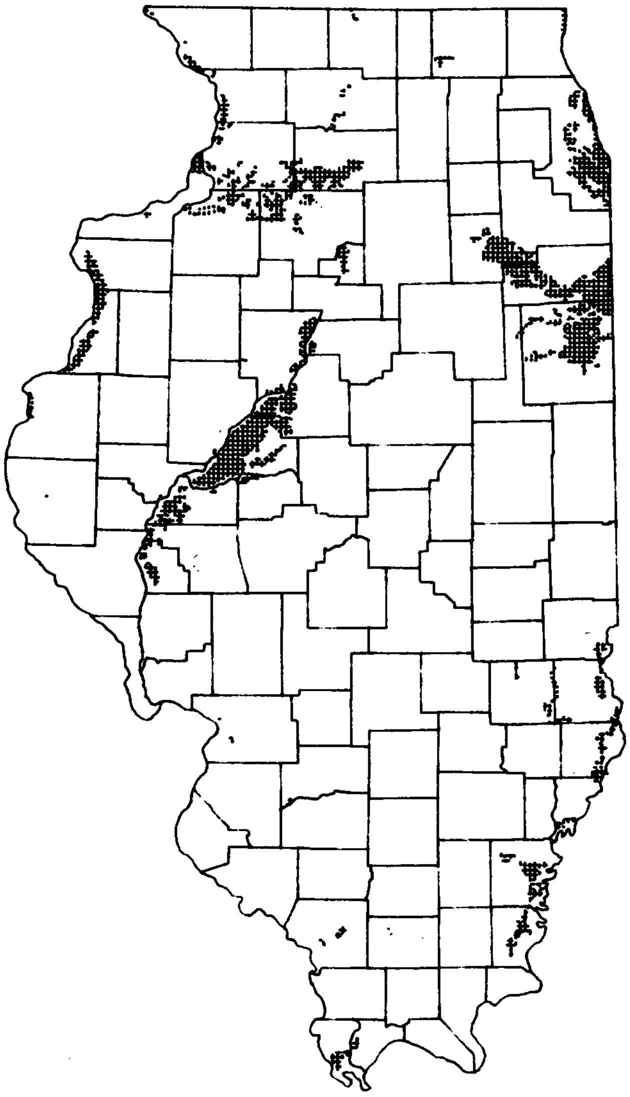


Figure 6. Distribution of sandy soils

Table 2. Distribution of Suspected Irrigation Wells in Illinois

County	*Estimated # of irrigation wells*	*Sand/ gravel*	*Shallow bedrock*	*Deep bedrock*	*Total estimated acres*
Adams	1	1	0	0	150
Boone	1	1	0	0	192
Bureau	13	13	0	0	1,170
Carroll	17	16	1	0	5,000
Cass	13	13	0	0	1,500
Champaign	7	7	0	0	400
Clark	26	26	0	0	3,000
Clinton	2	2	0	0	105
Cook	2	0	2	0	277
Crawford	13	13	0	0	335
DeKalb	2	1	0	1	650
DuPage	2	0	2	0	66
Fulton	2	2	0	0	100
Gallatin	22	22	0	0	3,500
Greene	11	11	0	0	1,200
Hancock	5	5	0	0	800
Henderson	57	57	0	0	6,226
Henry	46	46	0	0	3,341
Iroquois	7	1	6	0	2,000
Jackson	2	2	0	0	100
JoDaviess	2	2	0	0	300
Kane	2	1	0	1	500
Kankakee	70	2	68	0	8,000
Lake	2	1	1	0	240
LaSalle	1	0	0	1	130
Lawrence	49	49	0	0	4,000
Lee	67	66	1	0	12,000
McHenry	12	12	0	0	2,892
McLean	4	4	0	0	100
Madison	16	16	0	0	1,500
Marshall	16	16	0	0	1,748
Mason	471	471	0	0	80,000
Massac	12	12	0	0	1,563
Mercer	16	16	0	0	1,158
Monroe	9	9	0	0	700
Ogle	15	0	6	9	1,950
Peoria	9	8	1	0	5,115
Perry	2	0	2	0	500
Piatt	1	1	0	0	35
Pike	17	17	0	0	1,000
Putnam	4	4	0	0	450
Randolph	7	6	1	0	500
Rock Island	14	14	0	0	2,081
St. Clair	17	17	0	0	904
Scott	14	14	0	0	1,350
Shelby	3	3	0	0	300
Stephenson	2	2	0	0	356
Tazewell	103	103	0	0	18,000
Union	3	3	0	0	100
White	41	39	2	0	1,600
Whiteside	118	118	0	0	15,000
Winnebago	13	13	0	0	1,055
TOTAL	**1,383**	**1,278**	**93**	**12**	**195,100**

ESTIMATING IRRIGATION WATER USE IN ILLINOIS

Background and Previous Studies

Although irrigation pumpage has not been monitored consistently in Illinois, a number of studies have estimated the demand for irrigation water and have evaluated the impact of irrigation pumpage on regional water resources. Changnon (1969) developed a climatological model using pre-growing season and growing season weather data to determine how frequently supplemental irrigation water would be needed to maximize crop yields. Scott et al. (1986) determined the potential for irrigation from surface water in the tight soil or claypan soil regions of southern Illinois, south of the Wisconsinan glaciation. They found that approximately 1.2 million acres of cropland in claypan soils could benefit economically from supplemental irrigation. Similarly, Eheart and Libby (1981) made a regional assessment of potential irrigation impacts in the Little Wabash Basin of Illinois, using an economic profit maximization model to predict the adoption of irrigation.

A similar analysis was made for the entire state by the Illinois State Water Plan Task Force (1984), which determined that irrigation expansion is most likely on sandy and claypan soils. Crop reporting districts that have the potential for substantial irrigation water use include all but the western district, with the extent of growth depending on soils, ground-water availability and the agricultural economy. The Task Force determined that several districts (northeast, central, and east) could experience ground-water conflicts if substantial irrigation development occurs.

Data Expansion

Some basic expansions of the original ground-water-withdrawal and potential-aquifer-yield data base were needed in order to quantify irrigation water use and evaluate its effects on ground-water resources. Two additions were made to the data base: 1) the estimated number of irrigation wells per township, broken down by aquifer system; and 2) the total area under irrigation in each township, broken down by aquifer system.

Data on the number of suspected irrigation wells in each township were obtained from a combination of well files maintained by the Ground-Water Section of the Illinois State Water Survey, and the 1982 Census of Agriculture, U.S. Department of Commerce, Bureau of the Census. The census contained data on the number of wells per county in Illinois. This information was cross-checked with data from the well files, which include a township and range location for each well, well depth, and aquifer tapped. This resulted in a list of suspected irrigation wells per township per aquifer system in each county of the state. They are suspected irrigation wells because they have not been field-verified. Although the data base is updated regularly, some new irrigation wells may exist for which information has not been filed. Other irrigation wells may have been abandoned.

Data on the total area under irrigation in each township came from the 1982 census and, in some cases, from county agricultural agents. The census included data on the total acres per county under irrigation. It was assumed that each well in the county irrigated the same number of acres, so the total number of irrigated acres was divided by the total number of irrigation wells per county and that number of acres was assigned to each well in each of the irrigated townships.

Methodology

Modeling

While information exists about irrigation practices and distribution in Illinois, still very little is known about how much ground water is actually used for irrigation in any given growing season. Therefore, some means of estimating that water use was necessary in order to evaluate the effects of irrigation on the state's ground-water resources. For this study a modified monthly water balance model was used to calculate growing season moisture deficits for corn grown in five soil classes under varying weather conditions. The moisture deficits were assumed to be made up by irrigation in those places where irrigation systems already exist.

A detailed description of water balance modeling techniques would be inappropriate here, but a brief discussion of the concepts is relevant to understanding the results of this project. Water balance methodology has been developed and improved over the last 40 years. The techniques have proven to be understandable and flexible and have been applied to a tremendous diversity of hydrologic problems. Water balance methods can be used to obtain a better understanding of the vulnerability of water resources systems to changes in climatic and land use conditions (Gleick, 1986, 1987). A "water balance" implies equilibrium. The amount of water entering a system is equal to that leaving the system; otherwise, a deficit or surplus results. Precipitation and irrigation are the sources of water entering the system, although irrigation is an artificial source that depends on precipitation in the long run. Water can leave the system through evaporation and transpiration, ground-water runoff, changes in soil moisture storage and ground-water storage, and overland flow of water to streams (Dunne and Leopold, 1978). The water balance model used in this study was based on early work by Thornthwaite and Mather (1955), also detailed in Dunne and Leopold (1978). The monthly water deficit, D, for the plant system is given by

$$\mathbf{D = PET - AET} \qquad (2)$$

where PET is potential evapotranspiration and AET is actual evapotranspiration. This model does not account for surface and ground-water runoff, or changes in ground-water storage. For that reason, it is technically a water budget model, not a water balance model, since an equilibrium is not present as a water balance model would imply.

Evaporation and transpiration, or the combined evapotranspiration, is a process with a potential, or maximum, rate and an actual rate, which reflects the amount of water actually used by the plant when precipitation is less than plant water needs (Thornthwaite and Mather, 1955). Plants use water at the potential 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. Often during the growing season, this is not the case. When the water demand exceeds the amount of water readily available to the root system of the plant, plant stomata close to reduce water vapor transpiration. Evapotranspiration, under these conditions, is some fraction of potential evapotranspiration and is usually called actual evapotranspiration (Thornthwaite and Mather, 1955).

The rate of actual evapotranspiration depends on the amount of moisture held in the soil profile that is available to the root systems of plants. That available soil moisture is never 100 percent of the water in the soil. The amount that is available depends on rooting depth, soil type (texture, permeability, and infiltration capacity), and precipitation. When the soil has a low moisture-holding capacity (such as a fine sand), or when precipitation is below normal, actual evapotranspiration, or plant water use based on the quantity of water actually available to the plant, can be far enough below the potential rate for moisture stress to develop, indicating the need for supplemental irrigation in the case of crop farming (Dunne and Leopold, 1978). The difference between potential and actual evapotranspiration is the moisture deficit, which is equal to the amount of irrigation water needed to avoid crop stress and reduced yield (Dunne and Leopold, 1978). Equation 2 can be rewritten as

$$\mathbf{D = PET - (P + \Delta S)} \qquad (3)$$

where P is precipitation and ΔS is the change in soil moisture storage, which reflects the seasonal contribution of moisture from the soil profile.

Potential evapotranspiration calculations were made on the basis of temperature data from each of the nine crop reporting districts in the state. Because of its wide agricultural application and fairly limited weather data requirements, the U.S. Soil Conservation Service version of the modified Blaney-Criddle formula was used to calculate potential evapotranspiration for this study (Blaney and Criddle, 1950; U.S. Soil Conservation Service, 1967; Allen et al., 1986; Doorenbos and Pruitt, 1977). The potential evapotranspiration PET in centimeters per month is

$$\mathbf{PET = (0.142T+1.095)(T+17.8)\ kd} \qquad (4)$$

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. Values for k and d were obtained from the U.S. Soil Conservation Service (SCS) (1967) and Dunne and Leopold (1978), respectively. Although the SCS empirical crop coefficients were first developed for western crop water demands, the values of k are very similar to Illinois corn crop coefficients evaluated by Engel (1984). Values for k and d are shown in Table 3.

Actual evapotranspiration, again, is equivalent to the sum of precipitation and the change in soil moisture. The change in soil moisture was estimated with empirical data from Thrnthwaite and Mather (1957) on the amount of water retained in various soil types whenever PET is greater than precipitation, creating a potential water loss. Data for available water capacity within the root zone of a moderately deeply rooted corn crop were obtained from Thornthwaite and Mather (1957) for five broad soil classes: fine sand, sandy loam, silt loam, clay loam, and clay. The water-holding capacities are merely representative of average conditions. Soil water-holding capacity may vary greatly within each of those classes, as will rooting depth of a corn crop, depth to the water table, and other factors important in determining the actual amount of water available to a plant in any given soil.

Table 3. Average k Values for Grain, Silage, and Sweet Corn
and d Values for 40° North Latitude

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
k	0.45	0.45	0.45	0.45	0.61	0.97	1.06	0.97	0.45	0.45	0.45	0.45
d	0.067	0.066	0.082	0.089	0.099	0.100	0.101	0.094	0.083	0.077	0.067	0.075

Note: k is an empirical crop coefficient; d is the monthly fraction of annual hours of daylight (see equation 4)

Given these broad assumptions regarding water-holding capacity, water budget computations were made for each of the five soil classes since seasonal water deficits can be different for the same crop growing in different soils. Data on the distribution of soils in Illinois were already part of the statewide computerized data base. It is important to note that the estimates of soil moisture-holding capacity and seasonal changes in soil moisture made in this study are generalized and regional.

GIS Applications

Once the growing season water deficits were calculated, they were converted to a ground-water withdrawal expressed in mgd/sq mi. This was done in two ways. First, irrigation was expressed as a seasonal demand spread over the actual irrigation season, approximately 92 days during June, July, and August. Second, irrigation water demand was spread over the entire year to reflect the ability of the aquifer to recover naturally from periods of high demand without suffering permanent depletion. Seasonal and annual values for irrigation water use, differing according to soil type and location in the state, were associated with the proper soil type and crop reporting district and added to the data base by using GIS software. A map of townships, along with corresponding tabular ground-water withdrawal, aquifer yield, and irrigation distribution data, was merged with a soils map (with tabular growing season water deficit data). This allowed for the computation of an areally-weighted sum of the irrigation water use values for all soil types within each township, based on the fraction of each township under irrigation.

Results

Water Budget Modeling

Results based on 30-year mean climate conditions show that soils of all textures in Illinois usually begin the growing season at field capacity. Evapotranspiration demands generally begin to exceed precipitation in the first month of the growing season, but the moisture retained in the soil can make up for the initial difference. This is especially true for the silt and clay loams in northern Illinois, which can even have a moisture surplus going into the second month of the growing season. However, the water budget calculations indicate that by July and August, all soil types have at least small moisture deficits.

Figure 7 shows the water budget modeling results for corn for each crop reporting district. Average growing season deficits range from 2.5 to 9.5 inches for a corn crop. There is wide spatial variability in these potential deficits because of differences in soil type and the large climatic differences between northern and southern Illinois. Southern Illinois, in spite of receiving more rain in the growing season than northern Illinois, has consistently higher potential water deficits for all soil types. Temperatures are higher in southern Illinois, creating higher potential evapotranspiration rates which account for higher seasonal water deficits. The overall average water deficit in southern districts is estimated to be 6.5 inches per growing season. For the fine, sandy soils, that average is estimated to be 8.3 inches. The average for the northern districts, by comparison, is estimated to be 4.4 inches overall and 5.8 inches for fine sand.

Only three soil categories are plotted in figure 7 because the estimated deficits are similar for sandy loam and clay and for silt loam and clay loam. These soils can have similar amounts of water available to the root system of an average corn plant (Dunne and Leopold, 1978). While a sandy loam may not hold as much water as clay per unit depth, the plant roots may extend deeper in sand, thereby gaining access to more soil moisture. Likewise, water availability can be similar for silt and clay loams, as might be expected. The fact that soils with heavier textures experience a climatological water deficit but are not generally irrigated may be explained in two ways. First, average rainfall distribution may be such that small

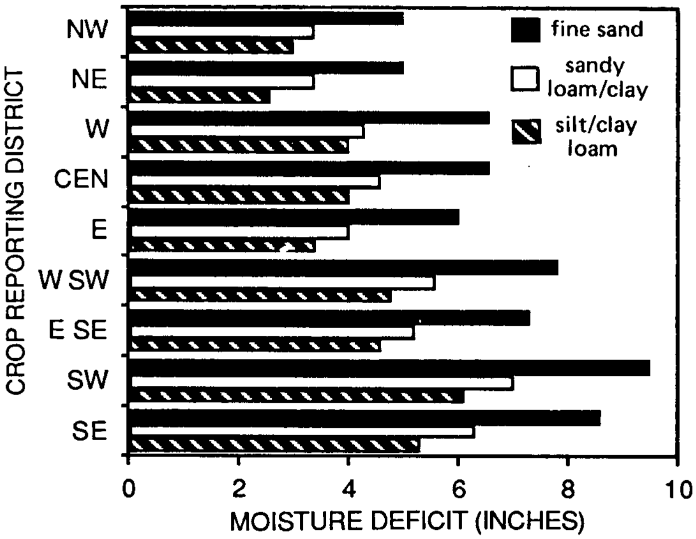


Figure 7. Water budget modeling moisture deficit results for corn by soil type and crop reporting district for 30-year mean climate conditions

deficits spread over the course of the growing season do not overly stress the crops. Second, the nutrient balance in soils with heavier textures aids greatly in maintaining strong plant growth and adequate yields.

It should be noted that the data in figure 7 are not necessarily indicative of actual irrigation practices in Illinois. Information from Illinois farmers indicates that annual irrigation water applied may be as high as 12 inches in places in a year with "normal" weather.

Use/Yield Analysis

By totaling the expected irrigation water use for each township with irrigated acreage, irrigation water use in Illinois was calculated to be about 310 mgd during the 92-day irrigation season. This is considered to be the average seasonal irrigation water use, since it reflects an irrigation demand over 92 days during a climatologically average growing season. Seasonal irrigation water use was added to the total ground-water withdrawals for other uses, and new use/yield ratios were computed. The distribution of these ratios is shown in figure 8b. A comparison of figure 8b with figure 8a shows the use/yield relationships with and without irrigation. As seen in figure 8a, the Chicago metropolitan area stands out as an area of major overpumpage, but not because of irrigation. When irrigation is added in figure 8b, a new center of heavy pumpage emerges along the Illinois River in Mason County, coinciding with heavy irrigation. Elsewhere, areas of both new and expanded pumpage appear as a result of estimated irrigation water use. Figure 8b shows that in 10 additional townships the possibility of use exceeding yield during the growing season months emerges because of irrigation.

Since most irrigation water use is supplied by sand and gravel aquifers, the use/yield ratio distribution for those aquifers alone was calculated and is shown in figure 9. A comparison of sand and gravel aquifer use with and without irrigation shows that of the 225 townships with irrigated agriculture, only 89 townships have any substantial pumpage out of sand and gravel wells for uses other than irrigation. In the irrigated townships, sand and gravel pumpage without irrigation demand is about 67 mgd on an annual average. With irrigation water use included, that pumpage increases to about 300 mgd during the growing season.

Effects of irrigation on ground-water resources are largely diminished when irrigation pumpage is assumed to be spread out over the entire year. This annual irrigation water use is estimated at about 78 mgd. New use/yield ratios were computed to reflect the ability of the hydrologic systems to absorb irrigation pumpage over the long run; the results are shown in figure 10. A comparison of figures 10 and 8a shows that on an annual

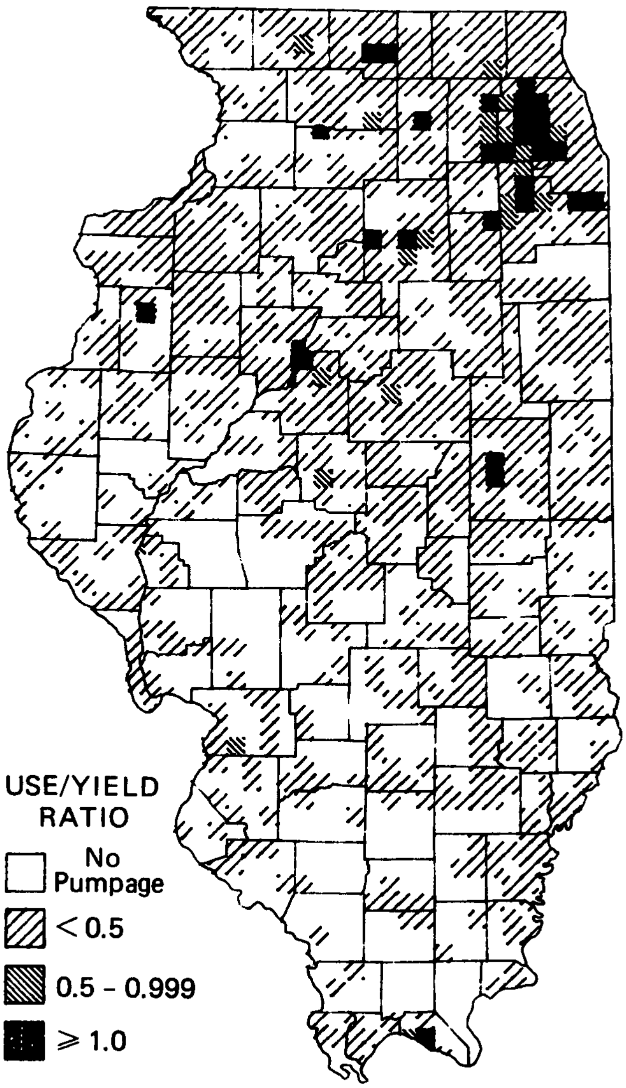


Figure 8a. Use/yield ratio distribution for all aquifer potential yields and all ground-water uses except irrigation *(see figure 3)*

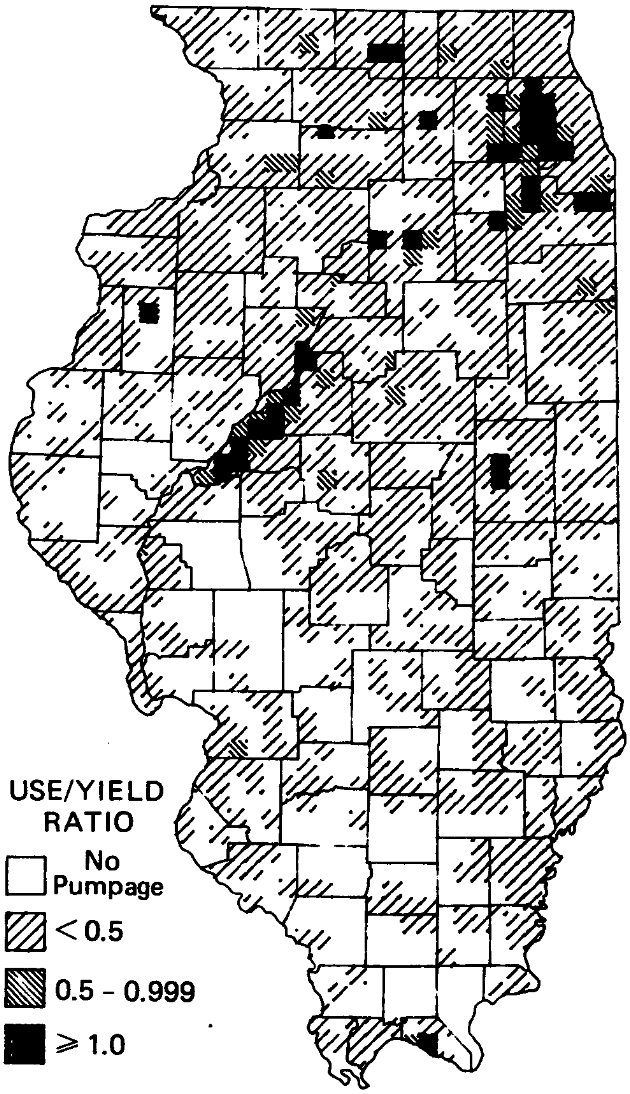


Figure 8b. Use/yield ratio distribution for all aquifer potential yields and all ground-water uses including estimated irrigation pumpage for 30-year mean weather conditions (*seasonal impact*)

basis, irrigation water use in a year with normal or near-normal precipitation has almost identical effects to those of a non-irrigated situation. 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 the growing season months. However, the aquifers appear to have the long-term ability to withstand this amount of irrigation water use without being permanently depleted.

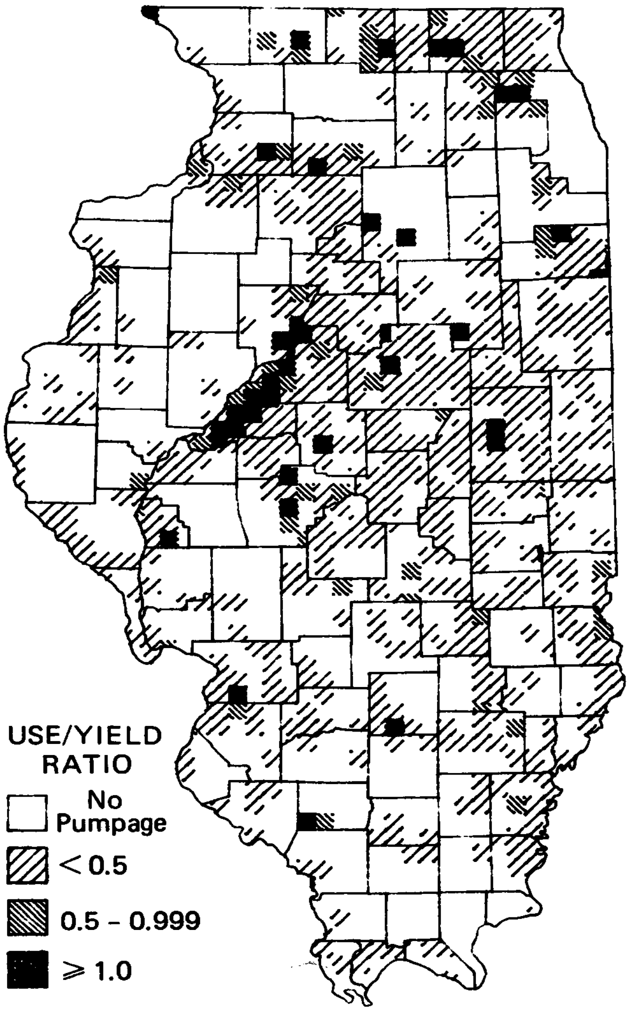


Figure 9. Use/yield ratio distribution for sand and gravel aquifers and 30-year mean irrigation
(*seasonal impact*)

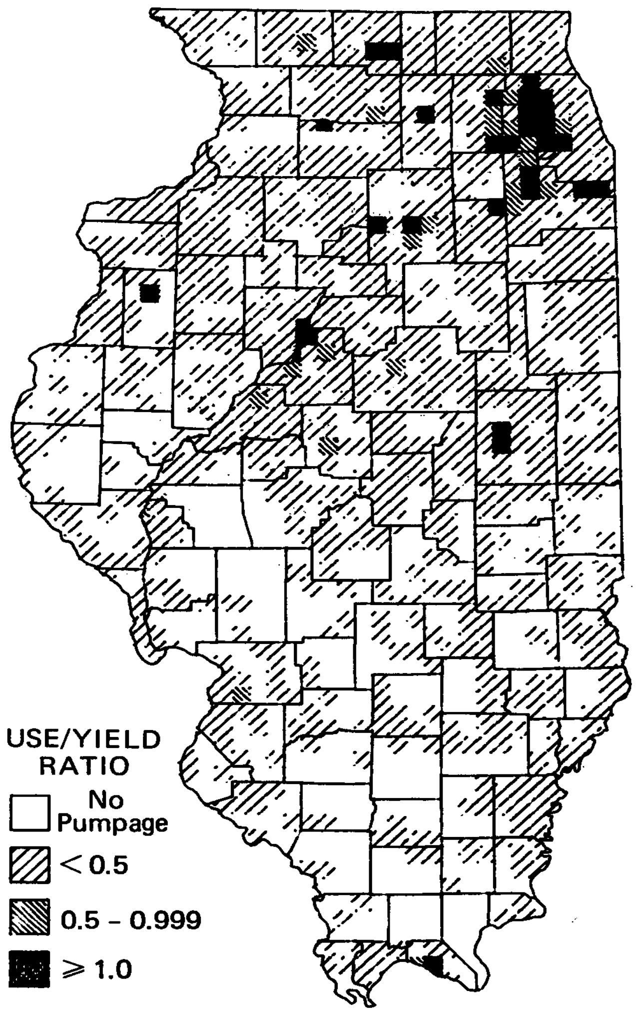


Figure 10. Use/yield ratio distribution for all aquifer potential yields and all ground-water uses including estimated irrigation pumpage for 30-year mean weather conditions
(*annual impact*)

WATER BUDGET MODELING SENSITIVITY ANALYSES

Because of the great variability, in annual precipitation from year to year in Illinois, the annual averages are not representative of the conditions that can be expected in any particular year (Changnon, 1983). Therefore, it is necessary to study the effects of climate variability on the water budget modeling results. In the following sections, the effects of short-term and extended droughts are evaluated. For a comprehensive study of drought in Illinois, the reader is directed to Changnon et al. (1982) and Changnon (1987).

Single Growing Season (Agricultural) Drought Impacts

Precipitation deficiency in Illinois varies in persistence, magnitude, duration, and areal coverage (Easterling and Changnon, 1987). A drought can affect all or part of Illinois, and it can last from several weeks to several years. The amount of July and August precipitation is considered one of the most important climatic factors in determining corn and soybean yields (Thompson, 1985), and growing season, or agricultural, droughts can significantly reduce agricultural profitability. Numerous agricultural droughts have occurred in various places over the last 30 years in Illinois, but few of them have caused statewide problems. In the summer of 1983 practically all of Illinois had significantly drier, hotter weather than normal. The expected corn yield for 1983, according to the Illinois Agricultural Statistics Service, was about 115 bushels per acre. Actual average yields ranged from less than 50 to about 90 bushels per acre.

Table 4 shows 1983 July and August rainfall totals and mean temperatures, and the departures from the 30-year means, for selected weather stations in each crop reporting district. The severity of the 1983 drought was comparable to that of other agricultural droughts in most of the state in the last 30 years. Growing season conditions were considered to be representative of short-duration, statewide droughts in Illinois, and were used in calculating a seasonal water budget for comparison to the mean conditions.

Water budget calculations based on 1983 growing season weather conditions were made for each of the nine crop reporting districts in the state. Seasonal water deficits ranged from about 5.5 to about 15.5 inches, depending on soil type and location in the state. Seasonal irrigation water use was calculated to be about 630 mgd, more than twice the estimated pumpage for a normal (30-year mean) weather year. The seasonal use/yield ratio distributions for all aquifer systems combined and for sand and gravel aquifers alone are shown in figures 11 and 12, respectively. Large portions of the heavily irrigated regions appear to have some possibility of overpumpage during the growing season months. Figure 8a (which excludes irrigation water use) shows that 32 townships have a use/yield ratio greater than 1. Most of those townships are in the Chicago metropolitan area and are unaffected by irrigation pumpage. When irrigation water use for a normal weather year is added in figure 8b, 10 additional townships have a ratio greater than 1. In figure 11, when irrigation water use for a year with below-normal precipitation is added, 59 townships have a use/yield ratio greater than 1. That is 17 more than occurred in the normal weather year, and 27 more than with no irrigation. The areas most heavily impacted are parts of Mason, Kankakee, Lee, Whiteside, and Tazewell Counties (figures 11 and 12).

Again, however, the annual effects of irrigation water use are far less dramatic than the apparent seasonal impacts, even in a year with below-normal precipitation, such as 1983. Annual use/yield ratios for 1983 for all aquifers combined and for sand and gravel aquifers only are shown in figures 13 and 14.

Illinois also has years with favorable weather and good crop yields, such as 1985. The 1985 spring was not excessively wet and crops were planted early. Precipitation came steadily and evenly during the growing season throughout the state except in the two northern crop reporting districts, where July and August

Table 4. Precipitation, Temperature, and Deviations from the Mean in Summer 1983

*Station**	*July/August precipitation (inches)*	*Deviation from mean (inches)*	*July/August temperature (degrees F)*	*Deviation from mean (degrees F)*
Moline (1)	3.75	-4.89	79.5	+5.6
Chicago (2)	6.33	-0.83	78.4	+4.9
Quincy (3)	2.24	-5.76	81.6	+6.1
Peoria (4)	3.08	-4.30	80.5	+6.5
Urbana (5)	6.03	-1.98	78.8	+4.6
Springfield (6)	2.44	-4.29	80.2	+4.8
Effingham (7)	1.17	-5.66	79.3	+3.4
Carbondale (8)	3.63	-4.09	79.5	+2.3
Fairfield (9)	4.90	-2.95	79.7	+3.5

*Numbers in parentheses indicate crop reporting districts (*see figure 2*)

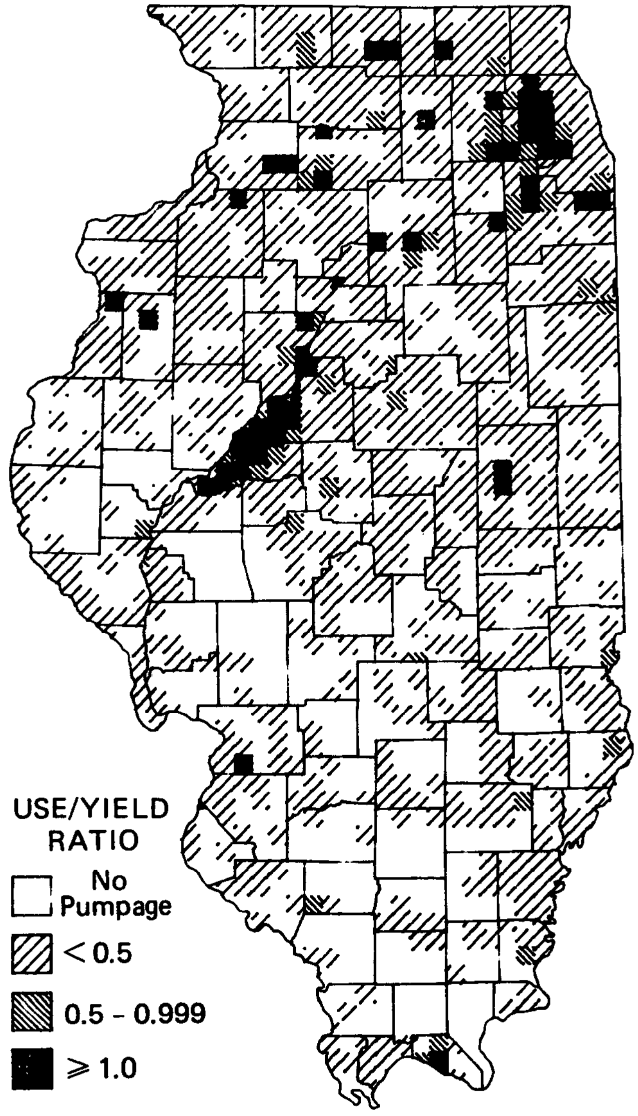


Figure 11. Use/yield ratio distribution for all aquifer potential yields and 1983 irrigation pumpage *(seasonal impact)*

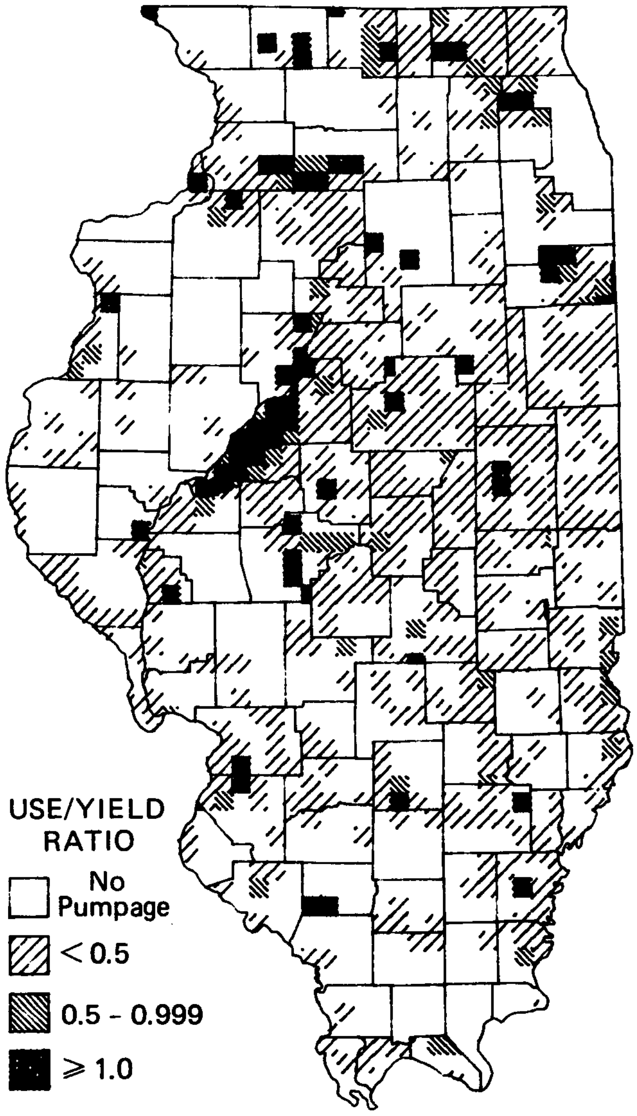


Figure 12. Use/yield ratio distribution for sand and gravel aquifers and 1983 irrigation pumpage *(seasonal impact)*

precipitation was slightly below normal. Corn yields ranged higher than 150 bushels per acre. So for purposes of comparison with normal and bad-weather years, water budget calculations were made for a good-weather year, in this case 1985. Water deficits ranged from 0.6 to 6 inches, depending on soil type and location in the state. Seasonal irrigation water use was estimated at 230 mgd, about two-thirds the expected irrigation amount under normal weather conditions. The 1985 seasonal use/yield ratio distributions for all aquifer systems combined and for sand and gravel aquifers alone are shown in figures 15 and 16. Areas where use exceeds yield because of irrigation pumpage appear to be significantly reduced during good-weather years. Thirty-six townships have a use/yield ratio exceeding 1, compared with 32 townships when irrigation water use is not included, 42 townships with mean irrigation, and 59 townships with 1983 irrigation.

Statewide average growing season precipitation and potential evapotranspiration for good (1985), bad (1983), and normal (30-year mean) weather years, shown in figures 17 and 18, account for variability in the water budget modeling results. A comparison of modeled moisture deficits for sandy soils for good, bad, and normal weather

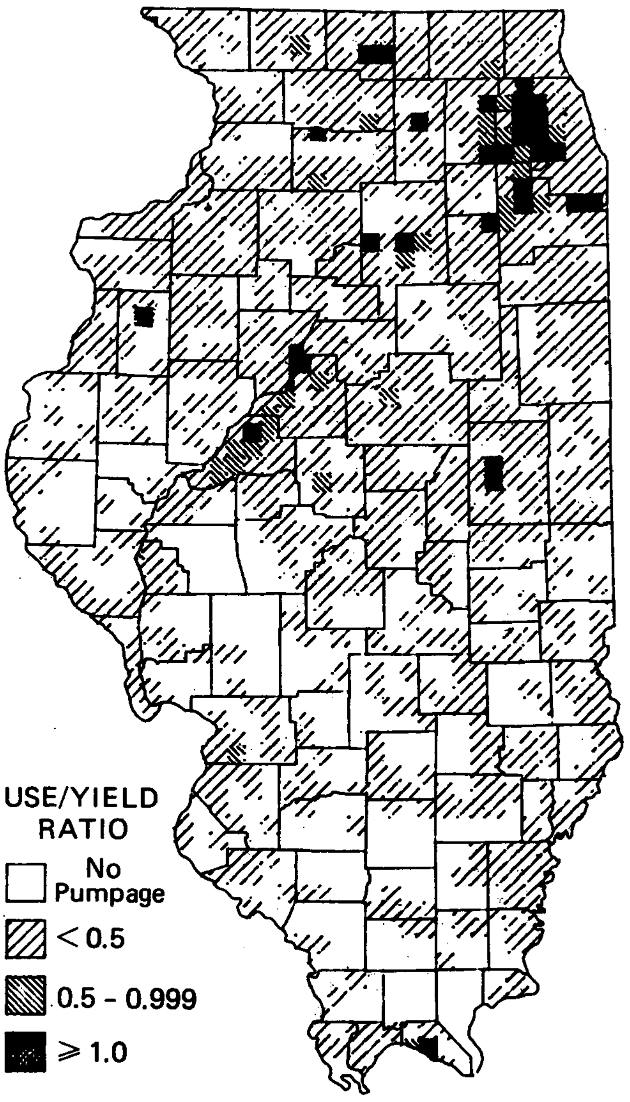


Figure 13. Use/yield ratio distribution for all aquifer potential yields and 1983 irrigation pumpage
(annual impact)

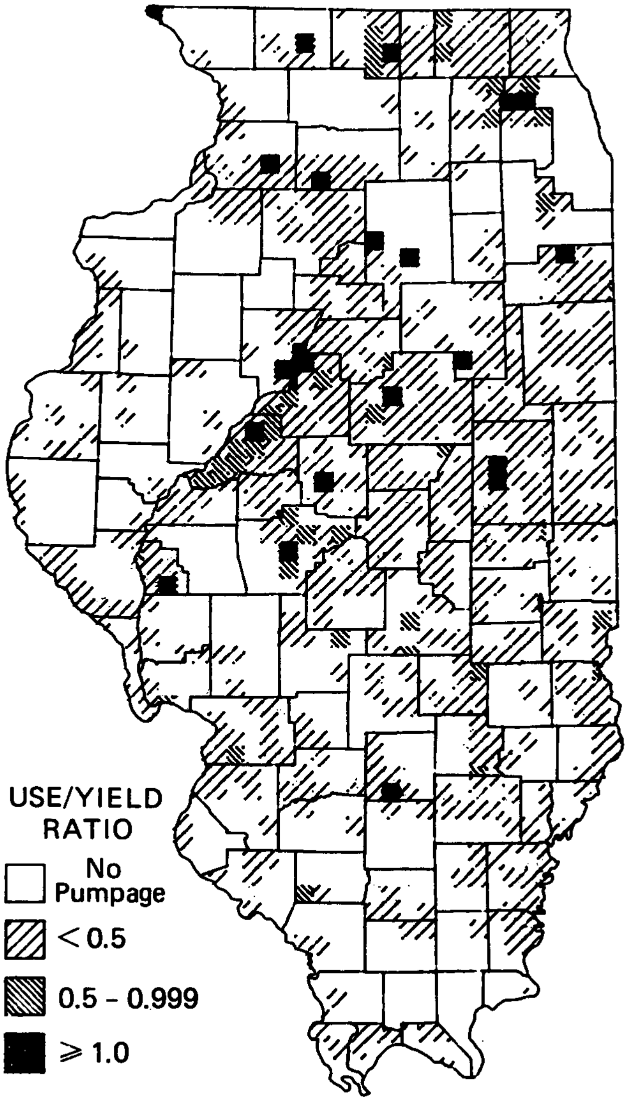


Figure 14. Use/yield ratio distribution for sand and gravel aquifers and 1983 irrigation pumpage
(annual impact)

conditions is shown in figure 19 for each crop reporting district. The fluctuations in seasonal water deficits represent the relative effects of short-term climate variability on the need for irrigation. The seasonal effects of climate variability on the state's ground-water resources are further illustrated in table 5, which compares the total area of overpumpage (where r, or the ratio of ground-water use to ground-water potential yield, is greater than 1) in each of the case studies. Table 6 shows the annual effects of irrigation water use in normal (30-year mean) and bad (1983) weather years.

Extended Drought Impacts

The effects of drought on ground-water resources are more complicated when the precipitation deficiency persists beyond a single growing season. Under normal conditions ground-water storage is recharged whenever precipitation exceeds evapotranspiration and soil moisture requirements (Olson, 1982). The annual evapotranspiration cycle (high in the growing season, low in the winter) imparts a pattern to the ground-water storage cycle such that shallow water levels peak in spring and are lowest in

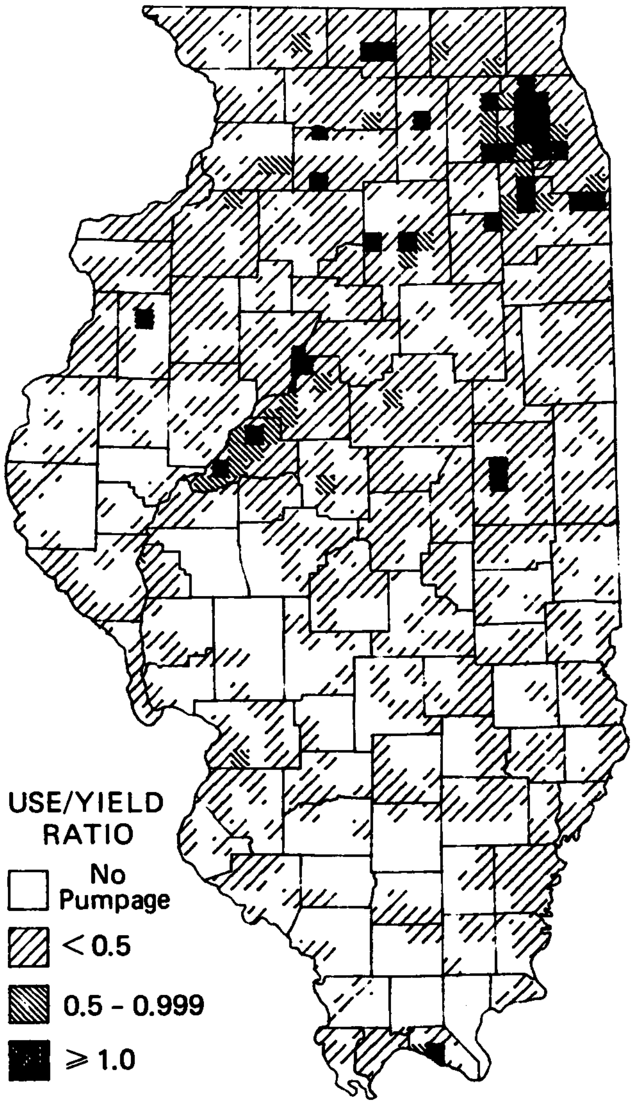


Figure 15. Use/yield ratio distribution for all aquifer potential yields and 1985 irrigation pumpage
(seasonal impact)

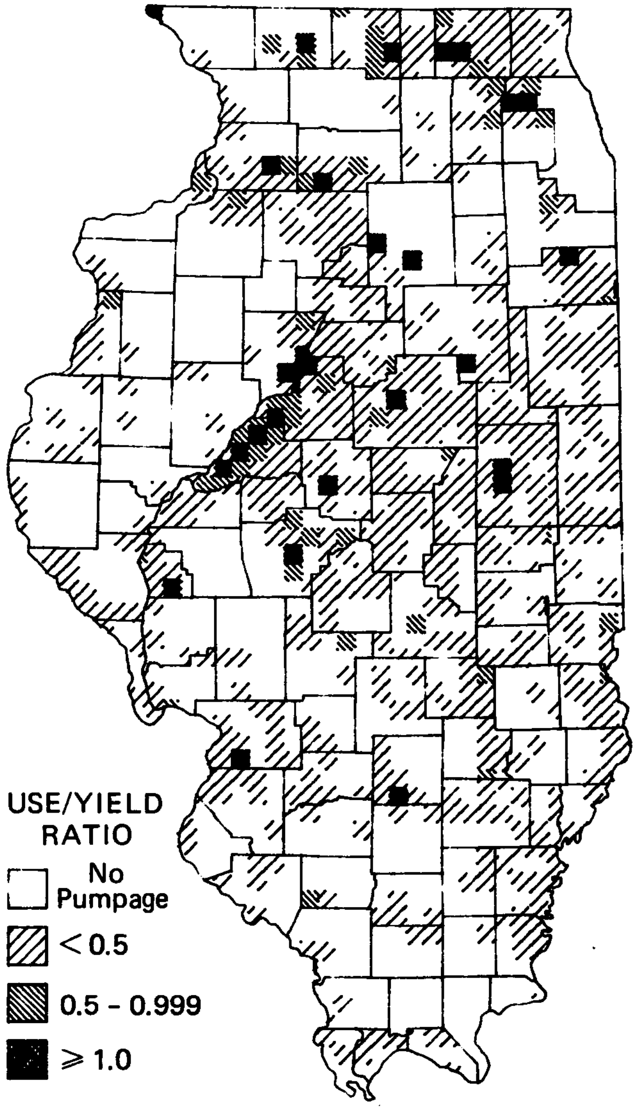


Figure 16. Use/yield ratio distribution for sand and gravel aquifers and 1985 irrigation pumpage
(seasonal impact)

fall, reflecting a lag in recharge response to precipitation and evapotranspiration (Changnon, 1987).

The effects of agricultural droughts on ground-water resources are temporary and difficult to discern because beyond causing an increased demand for irrigation water, these events are hidden in the natural cycle of high evapotranspiration and lowering water levels. Ground-water storage begins to recover at the end of the growing season, when evapotranspiration falls below precipitation. Olson (1982) emphasized the importance of the evapotranspiration cycle on ground-water levels on the basis of data showing that moderate amounts of rainfall cause ground-water levels to recover in the fall and winter months, but that during late spring and summer, water levels typically decline despite the same or larger amounts of rainfall.

When precipitation is below normal during the usual period of peak ground-water recharge, ground-water storage and soil moisture can both be reduced, perhaps to the point of beginning the next growing season without having

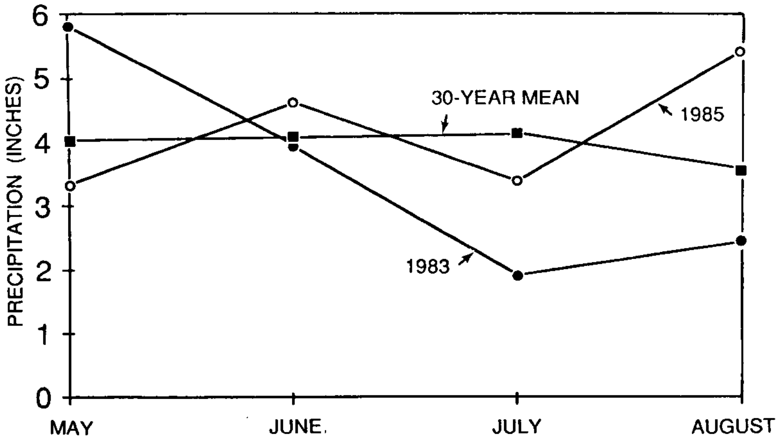


Figure 17. Precipitation variations for 1983, 1985, and 30-year-mean growing seasons

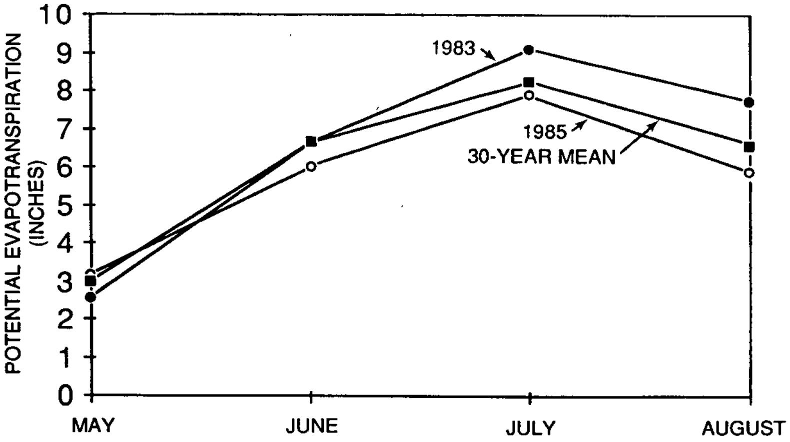


Figure 18. Potential evapotranspiration variations for 1983, 1985, and 30-year-mean growing seasons

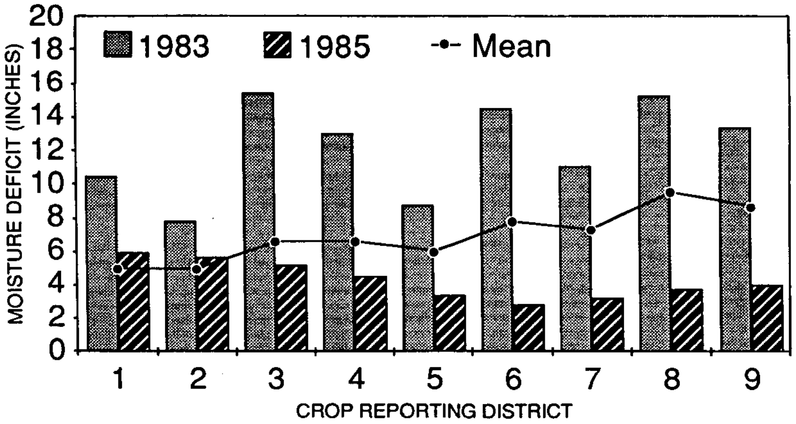


Figure 19. Water budget model moisture deficit results for sandy soils for 1983, 1985, and 30-year-mean growing season weather conditions

Table 5. Extent of Seasonal Impact from Varying Irrigation Demands

	Without irrigation	*With mean irrigation*	*With 1985 irrigation*	*With 1983 irrigation*
Area with r > 1 (sq mi)	1,011	1,275	1,117	1,757
Percent of state with r > 1	1.8%	2.3%	2.0%	3.2%
No. of townships with r > 1	32	42	36	59

Note: **r** = ratio of ground-water use to ground-water potential yield

Table 6. Extent of Annual Impact from Varying Irrigation Demands

	Without irrigation	*With mean irrigation*	*With 1983 irrigation*
Area with r > 1 (sq mi)	1,011	1,013	1,049
Percent of state with r > 1	1.8%	1.8%	1.9%
No. of townships with r > 1	32	33	34

Note: **r** = ratio of ground-water use to ground-water potential yield

fully recovered from the last. The degree to which regions are susceptible to this kind of extended drought depends largely on various soil conditions and aquifer characteristics. Recharge to surface deposits can occur relatively rapidly when substantial amounts of sand and gravel are present. In the parts of Illinois covered by glacial drift, however, recharge to deep aquifers is hampered by the low vertical permeability of the till, which buffers the effects of short-term precipitation irregularities and creates a lag in reaction to drought (Olson, 1982).

In order to approximate, in a general way, the impact of a statewide extended drought on ground-water resources, the water budget model used in this study was run concurrently for each station with data from the last 30 years. Soil moisture amounts were allowed to carry over from year to year to help identify periods when agricultural droughts were preceded by winters with below-normal precipitation and reduced ground-water storage. Such conditions occurred in much of Illinois beginning in 1962 and lasting into 1963, varying in severity and extent (Easterling and Changnon, 1987). Growing season water deficits were of comparable magnitude to those in the 1983 agricultural drought, but the extended drought conditions were exaggerated by reduced ground-water storage.

The degree to which ground-water storage is actually reduced during an extended drought was estimated from Walton (1965), who found that annual ground-water runoff can drop 50 percent on a statewide average in years of below-normal precipitation. So potential yields for all sand and gravel aquifers in the GIS data base were reduced by 50 percent, although some unconsolidated aquifers are not surficial and are thereby somewhat buffered against the effects of drought. New use/yield ratios were computed for these conditions for all aquifer systems combined and for sand and gravel aquifer systems alone, as shown in figures 20 and 21. A comparison of the extended drought maps with the 1983 agricultural drought seasonal maps (figures 11 and 12) shows the seasonal effect of ground-water storage reduction brought on by extended drought conditions. The extended drought impact appears to spread beyond heavily irrigated areas, and extensive effects are more widely distributed throughout the state. In addition to an increased impact from irrigation, other isolated locations of stress emerge. These areas correspond to municipalities which rely on sand and gravel aquifers for their public water supply.

It is difficult to assess the annual effects of irrigation water use during an extended drought since the drought itself may span more than one growing season. In addition, it is difficult to separate the effects of heavy

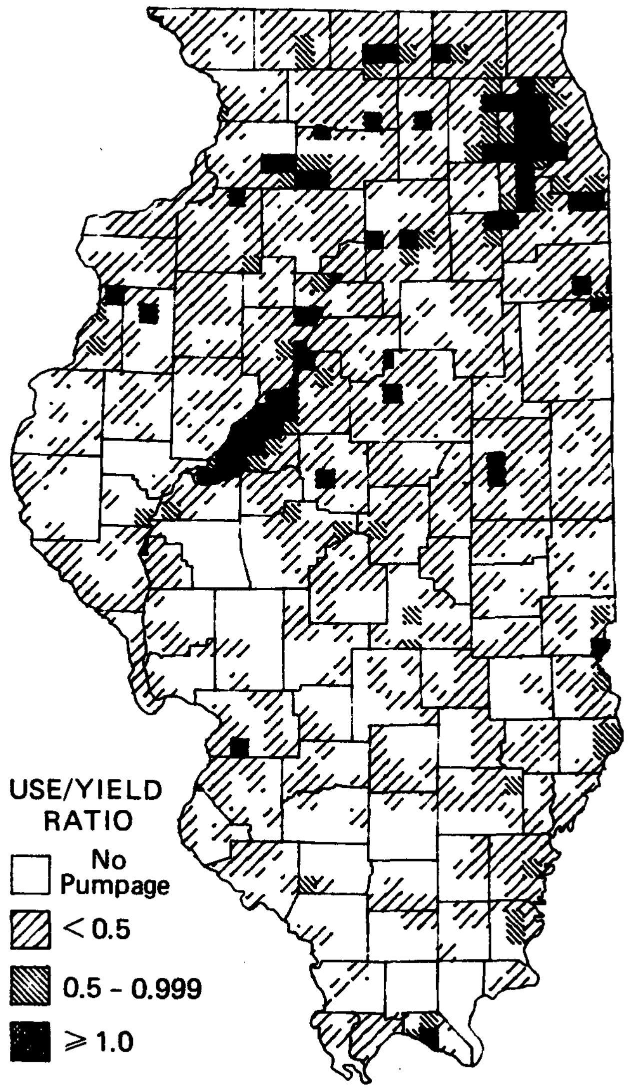


Figure 20. Use/yield ratio distribution for all aquifer potential yields and extended drought irrigation pumpage (*seasonal impact*)

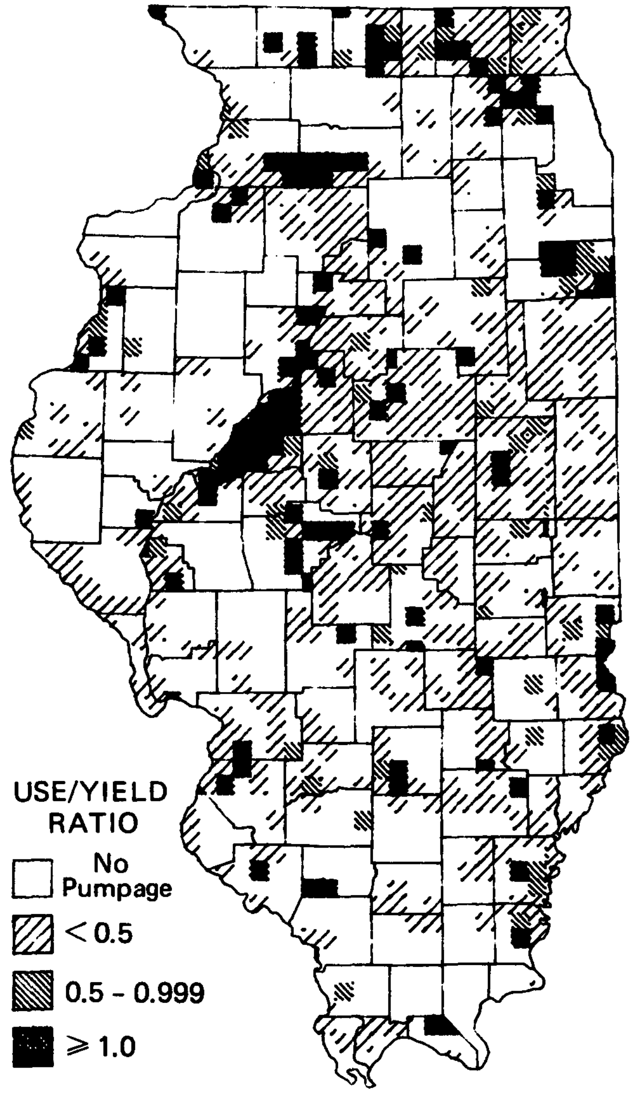


Figure 21. Use/yield ratio distribution for sand and gravel aquifers and extended drought irrigation pumpage (*seasonal impact*)

irrigation pumpage because of below-normal precipitation and the effects of the drought in reducing ground-water storage. However, the annual use/yield analysis shows that additional portions of the state (50 townships) could experience ground-water depletion problems at least temporarily during an extended drought, as shown for all aquifers combined in figure 22 and for sand and gravel aquifers only in figure 23. Part of that impact would be from an increased demand for irrigation water, and part would be from the loss of ground-water storage because of the drought. In general, some municipal, industrial, and irrigation ground-water uses depending solely on surficial unconsolidated aquifers could be stressed by extended drought events on both a seasonal and an annual basis.

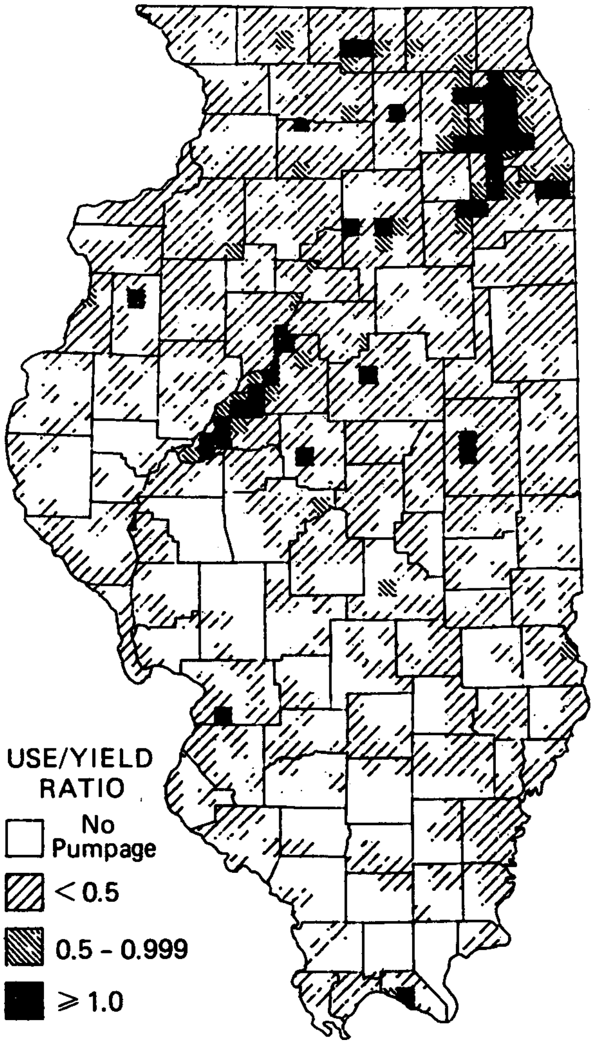


Figure 22. Use/yield ratio distribution for all aquifer potential yields and extended drought irrigation pumpage (*annual impact*)

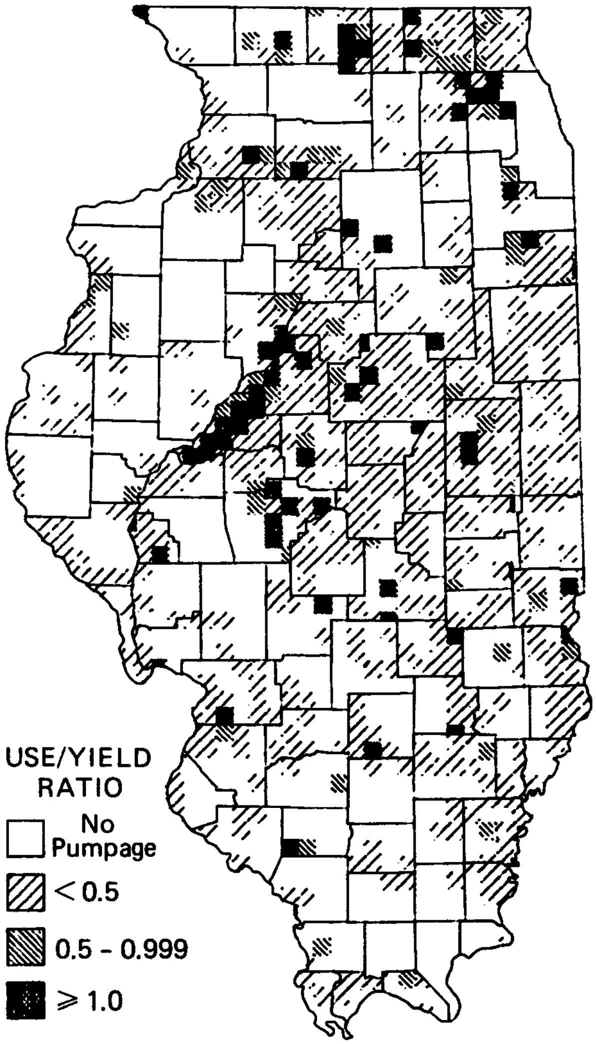


Figure 23. Use/yield ratio distribution for sand and gravel aquifers and extended drought irrigation pumpage (*annual impact*)

IRRIGATED ACREAGE EXPANSION IN ILLINOIS

Potential for Expanded Irrigation

It is unclear where and to what extent the use of irrigation in Illinois will expand. A common assumption is that given an adequate upswing in the farm economy, irrigation will continue to spread out in areas with sandy soils, where irrigation is already practiced and where its profitability has been established. Historically, this has been the case. In most of these areas, ground-water supplies are relatively abundant, so ground-water availability would not necessarily be the limiting factor in the expansion.

However, the vast majority of Illinois cropland is not on marginal, sandy soil. Some of that cropland could still be irrigable under the right economic and climatic circumstances. For that reason, the potential for expansion of irrigation in Illinois may be much larger than the present picture would indicate. In that case, ground-water availability could be the major limiting factor in the introduction of irrigated agriculture, as indicated by the Illinois State Water Plan Task Force (1984). Ground-water supplies themselves are susceptible to climatic variations and regional pumping. So the extent to which a major transition from rainfed agriculture to irrigated agriculture is possible in Illinois will largely be controlled by: 1) aquifer response to large-scale increases in irrigation pumpage; and 2) fluctuations in ground-water storage because of varying climate and pumping conditions.

Effects of Expansion

To estimate the effects of expanding current irrigation, several analyses were made in which the irrigated area in Illinois was assumed to have increased by 50 percent. This level of expansion is possible in currently irrigated areas because even the most heavily irrigated township in Mason County is presently only about half irrigated. These analyses do not reflect the much larger potential for expansion of irrigation on the silt and clay loam and clay and claypan soils of the state. Both seasonal and annual effects of expanded irrigation were considered under 30-year mean weather conditions, single season drought conditions, and extended drought conditions.

Normal Weather Conditions

Under normal (30-year mean) weather conditions, expanding irrigation by 50 percent has little seasonal or annual effect. During a normal-weather year, expanded irrigation water use is estimated at 466 mgd seasonally or about 117 mgd annually, and during the growing season 10 additional townships in the heavily irrigated regions have the possibility of overpumpage (r greater than 1). These seasonal and annual use/yield distributions are shown in figures 24 and 25, respectively.

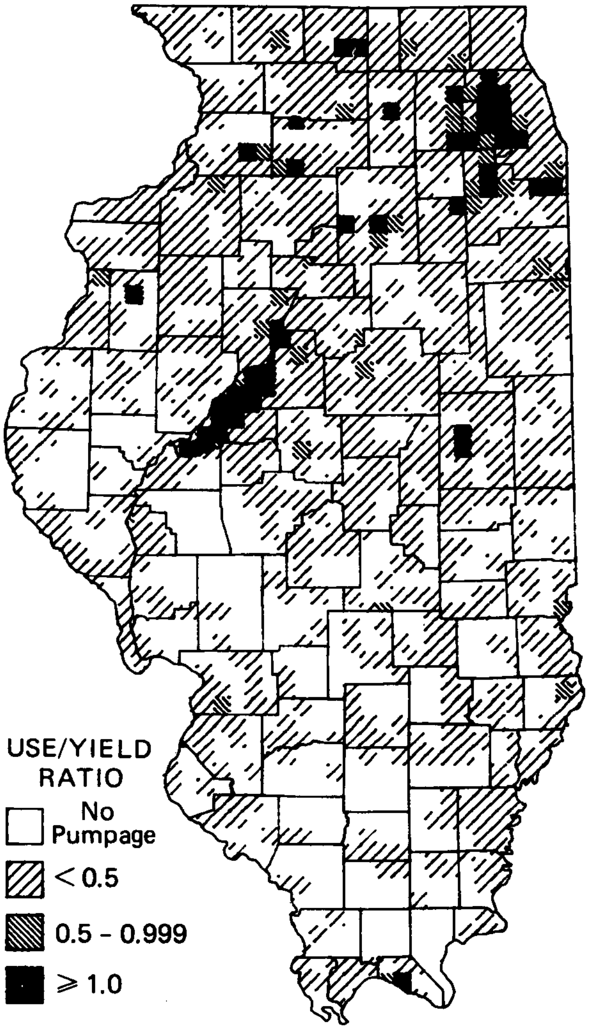


Figure 24. Use/yield ratio distribution for all aquifer potential yields and 30-year mean irrigation pumpage with 50 percent expansion of irrigated acreage *(seasonal impact)*

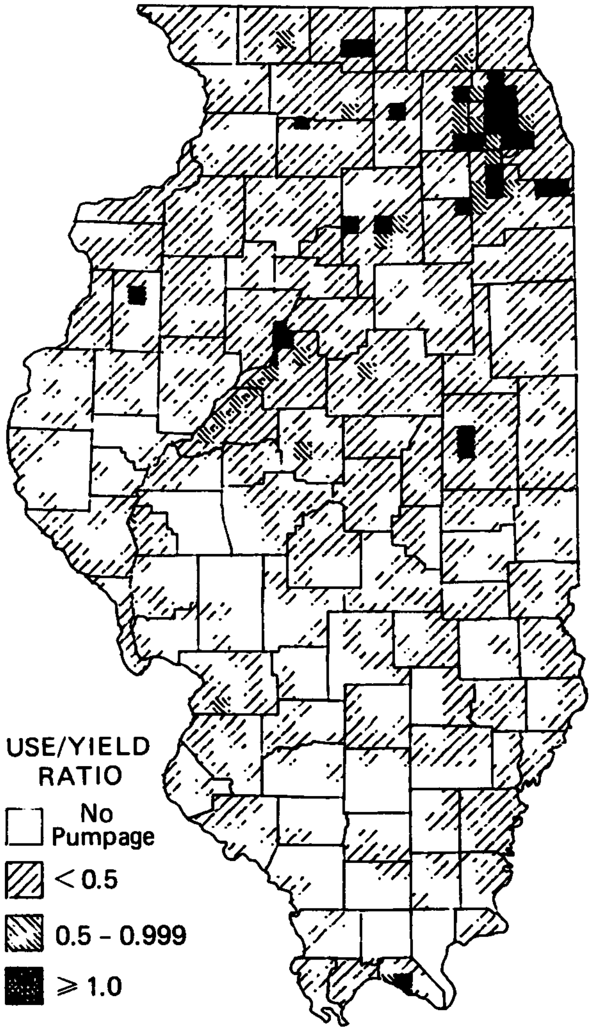


Figure 25. Use/yield ratio distribution for all aquifer potential yields and 30-year mean irrigation pumpage with 50 percent expansion of irrigated acreage *(annual impact)*

Single Growing Season Drought Conditions

In a year with below-normal precipitation, however, expanded seasonal irrigation water use is estimated at about 950 mgd. As might be expected, the seasonal effects of expanded irrigation in a year like 1983 are heaviest in parts of Mason, Kankakee, Lee, Whiteside, and Tazewell Counties. Eleven additional townships appear to be susceptible to seasonal overpumpage because of the expansion of irrigation. The distribution of use/yield ratios for the 1983 growing season conditions with expanded irrigation is shown in figure 26.

On an annual basis, again, the effects of increased irrigation because of short-term drought are mitigated. The distribution of use/yield ratios for 1983 conditions is shown in figure 27. These conditions are similar to the seasonal effects of irrigation in a normal weather year (as shown in. figure 8b). It can be concluded from this that expanded irrigation in a year with below-normal precipitation may cause fairly widespread seasonal problems, and that there may be some potential for annual aquifer depletion in the most heavily irrigated parts of Mason County.

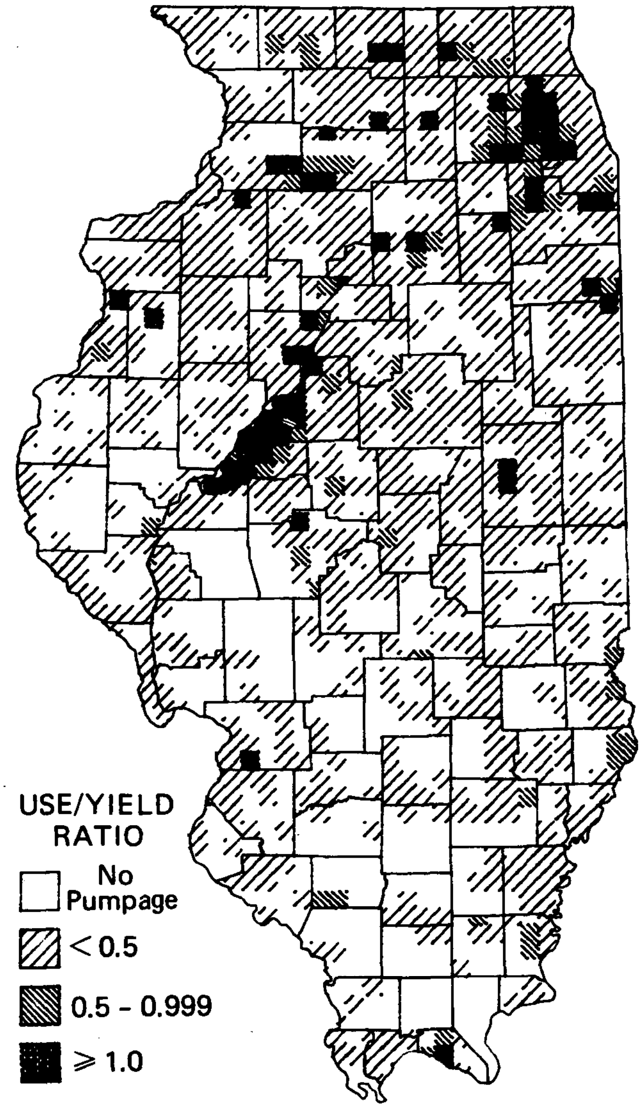


Figure 26. Use/yield ratio distribution for all aquifer potential yields and 1983 irrigation pumpage with 50 percent expansion of irrigated acreage
(seasonal impact)

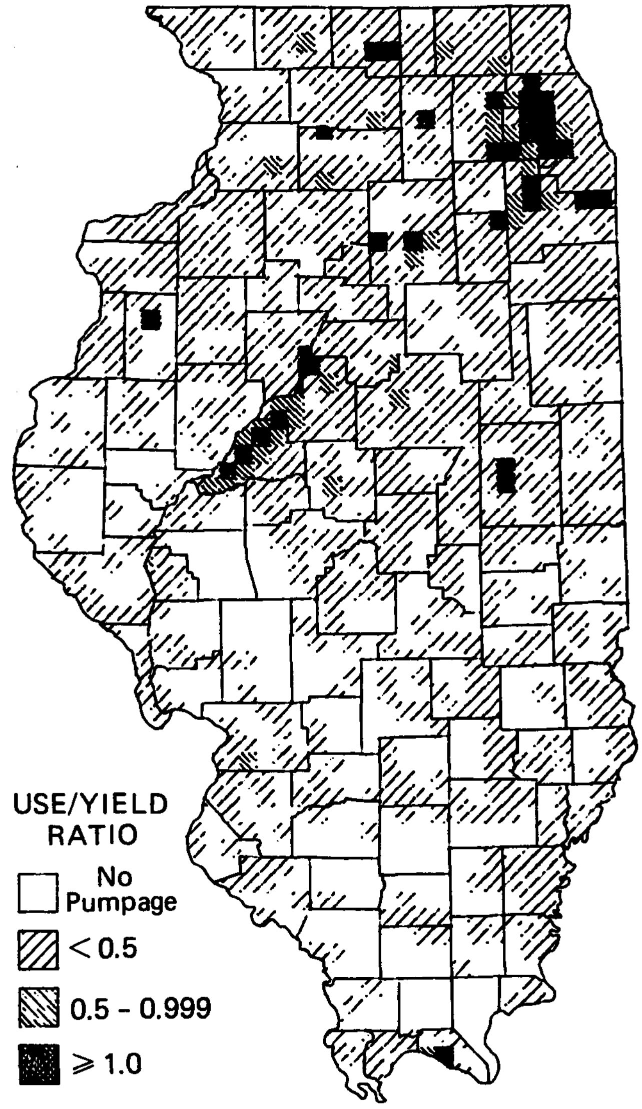


Figure 27. Use/yield ratio distribution for all aquifer potential yields and 1983 irrigation pumpage with 50 percent expansion of irrigated acreage
(annual impact)

Extended Drought Conditions

Finally, the seasonal and annual effects of an extended drought were considered for a 50 percent expansion in irrigated area. Both the seasonal and the annual effects are more widespread than for any other conditions considered in this study. Seasonal use/yield ratios are shown in figure 28 and annual ratios in figure 29. Tables 7 and 8 help clarify the varying extent to which expanded irrigation water use would impact the state's ground-water resources, depending on weather conditions.

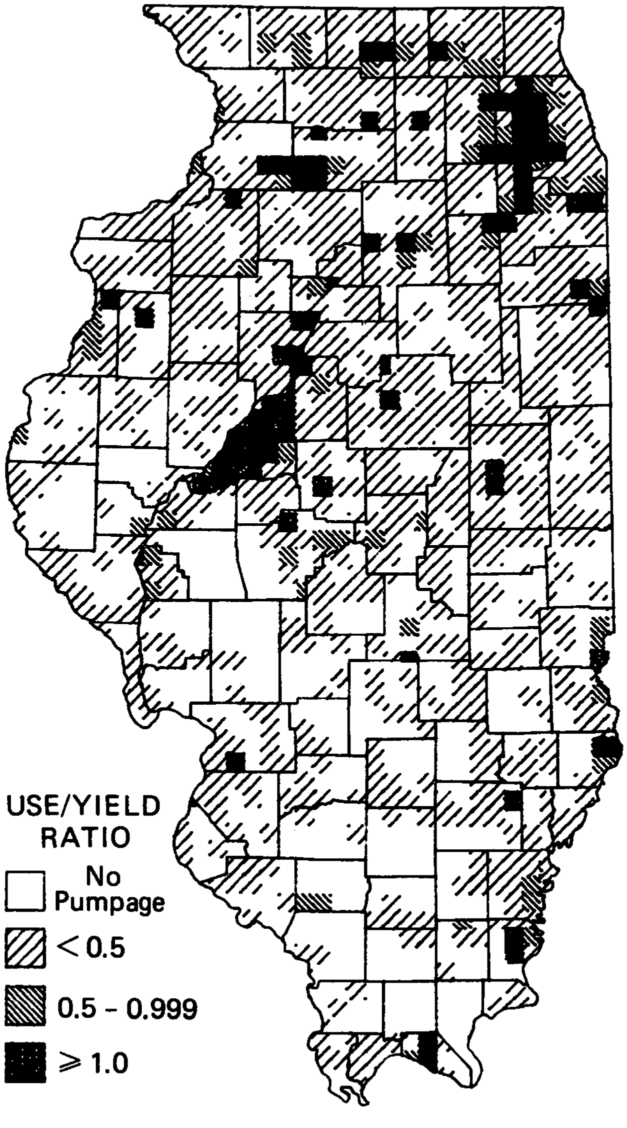


Figure 28. Use/yield ratio distribution for all aquifer potential yields and extended drought irrigation pumpage with 50 percent expansion of irrigated acreage *(seasonal impact)*

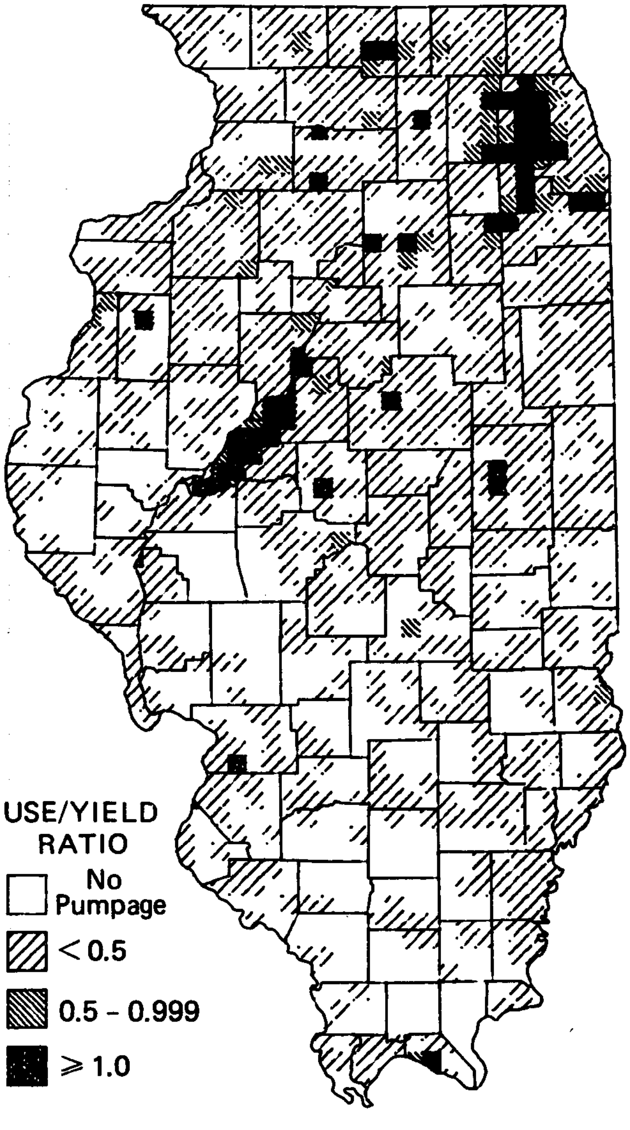


Figure 29. Use/yield ratio distribution for all aquifer potential yields and extended drought irrigation pumpage with 50 percent expansion of irrigated acreage *(annual impact)*

Table 7. Extent of Seasonal Impact from Expanded Irrigation

	No expansion / mean irrigation	*50% expansion / mean irrigation*	*50% expansion / 1983 irrigation*	*50% expansion / extended drought irrigation*
Irrigation water use	310 mgd	466 mgd	950 mgd	950 mgd
Area with r > 1 (sq mi)	1,275	1,531	1,989	2,681
Percent of state with r > 1	2.3%	2.7%	3.6%	4.8%
No. of townships with r > 1	42	52	68	91

Note: **r** = ratio of ground-water use to ground-water potential yield

Table 8. Extent of Annual Impact from Expanded Irrigation

	No expansion / mean irrigation	*50% expansion / mean irrigation*	*50% expansion / 1983 irrigation*	*50% expansion / extended drought irrigation*
Irrigation water use	78 mgd	117 mgd	237 mgd	237 mgd
Area with r > 1 (sq mi)	1,013	1,013	1,151	1,733
Percent of state with r > 1	1.8%	1.8%	2.1%	3.1%
No. of townships with r > 1	33	33	38	57

Note: **r** = ratio of ground-water use to ground-water potential yield

CONCLUSIONS

The purpose of this project was to evaluate the effects of drought and increased irrigation on the ground-water resources of Illinois. This evaluation was generalized and intended for statewide planning purposes. The results are not suitable for localized interpretation. Given these limitations, the results of seasonal water balance modeling and spatial analyses of soils, land use, and aquifer potential yield lead to several general conclusions. It appears that irrigation can be a substantial consumptive ground-water use in Illinois during the growing season, but its effects are very localized and depend heavily on weather conditions. Some potential for seasonal aquifer overpumpage may exist because of irrigation in some of the heavily irrigated regions during seasons with below-normal precipitation, implying the possibility for temporary ground-water use conflicts. For the most part, however, these ground-water supply problems appear to be limited to the growing season. Natural aquifer recovery compensates for heavy summer irrigation water use over the course of a year so that on an annual basis, Illinois' aquifers appear able to withstand irrigation pumpage without suffering significant, long-term depletion. The exception to this may be in the event of an extended drought when potential aquifer overpumpage appears possible over larger areas of the state. This condition would presumably be temporary, reversing when the drought ends. The other, potentially much more far-reaching exception would be the wholesale expansion of irrigation out of the traditionally irrigated sandy soils and into the much larger portion of the state which has soils of heavier texture. Specific points are as follows:

1. The Chicago metropolitan area is a major center of ground-water overpumpage, but not because of irrigation.
2. Sand and gravel irrigation water use and droughts do not appear to significantly affect bedrock aquifers during the short time frames considered in this study. The shallow bedrock regions of Kankakee County may be an exception.
3. Present irrigation water use in a year with normal or near-normal precipitation will have little effect on ground-water resources, seasonally or annually.

This could change if irrigation spreads on a statewide scale.

4. The seasonal impact of irrigation water use is more apparent in years of below-normal precipitation. In these cases, there is some potential for seasonal overpumpage during June, July, and August in the most heavily irrigated areas. The main impact falls on parts of Mason, Kankakee, Lee, Whiteside, and Tazewell Counties.

5. On an annual basis increased irrigation water use due to below-normal precipitation appears to be possible without significant depletion of aquifer resources over a long period.

6. Periods of extended drought have the coupled effect of creating elevated demand for ground water (for irrigation and municipal uses) and reducing ground-water storage. The seasonal effects of these conditions are widespread throughout the state, but may be limited primarily to sand and gravel aquifers. Annual effects are somewhat mitigated, but some potential for long-term aquifer overpumpage still appears to exist in some of the most heavily irrigated townships.

7. Expanding the currently irrigated area by 50 percent impacts a surprisingly small number of additional townships. This is true for irrigation in normal-weather years and single-season droughts, during which the effect of adding more irrigated acres is simply the proportional areal increase of presently heavily irrigated regions.

8. An extended drought appears to create more widespread potential for overpumpage when irrigation is expanded, with seasonal effects similar to the non-expanded, extended drought case. Again, annual effects are somewhat mitigated, but some potential for aquifer depletion appears possible during an extended drought.

9. Even the worst case, seasonal impacts of expanded irrigation during an extended drought, appears to create the possibility of aquifer overpumpage only for relatively small portions of the state, not counting any potential effects from a very large-scale, statewide expansion of irrigation activity.

Two central lessons emerge with regard to ground-water management needs in Illinois, on the basis of these conclusions. First, there appears to be a distinction between urban and rural ground-water use patterns and problems in Illinois. Water management needs, therefore, are different in urban and rural areas. The Chicago metropolitan area is the largest urban center in the state, and one which has a long history of bedrock aquifer overpumpage to supply its industrial and municipal water requirements. In an effort to reverse this trend of aquifer depletion and to maintain a stable water supply, Chicago has shifted to alternative water sources, including becoming part of the Lake Michigan Water Allocation Plan. This management approach is specifically suited to a large urban area, but it would not have bearing on the large number of rural water users in Illinois.

Many rural domestic, municipal, and industrial wells and most irrigation wells in Illinois obtain water from surficial sand and gravel aquifers. These aquifers are more susceptible to the natural stresses of seasonal evapotranspiration and periodic drought, and to the induced seasonal stresses of irrigation pumpage. Not only are ground-water supply stresses seasonal, they are also localized, temporary in most cases, and highly variable depending on weather conditions. Also, rural water supply problems are not restricted to a central urban entity. Rather, they occur in various areas depending on soil type, aquifer characteristics, and climatic conditions. For all of these reasons, rural ground-water management areas would be difficult to define and administer effectively.

The second and most fundamental lesson to emerge is that in spite of the relatively minimal impact of present irrigation activity in the state, the potential for irrigation expansion into the traditionally non-irrigated parts of Illinois (mainly the areas that have soils with heavier textures) could lead to substantial water use from marginal and low-yield aquifers. Unlike the present irrigation picture in Illinois, this type of expansion could have a much more significant impact on the ground-water resources of the state. It is difficult to speculate with any certainty about the economic and climatic conditions necessary to spur a shift to irrigated agriculture in this state. Even so, it will be important to identify areas where substantial increases in irrigation are possible within the limitations of ground-water supplies and existing ground-water uses.

Continuing work is needed to better assess the effects of irrigation and drought on Illinois ground-water resources. Specifically, there is a need for better information on the exact number and location of active irrigation wells and irrigated acreage in this state. Also, more detailed data on irrigation well pumpage, crop rooting depths, crop water uses, evapotranspiration, seasonal soil moisture storage changes, and precipitation variations will be necessary to improve and verify the preliminary water budget model used in this study.

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