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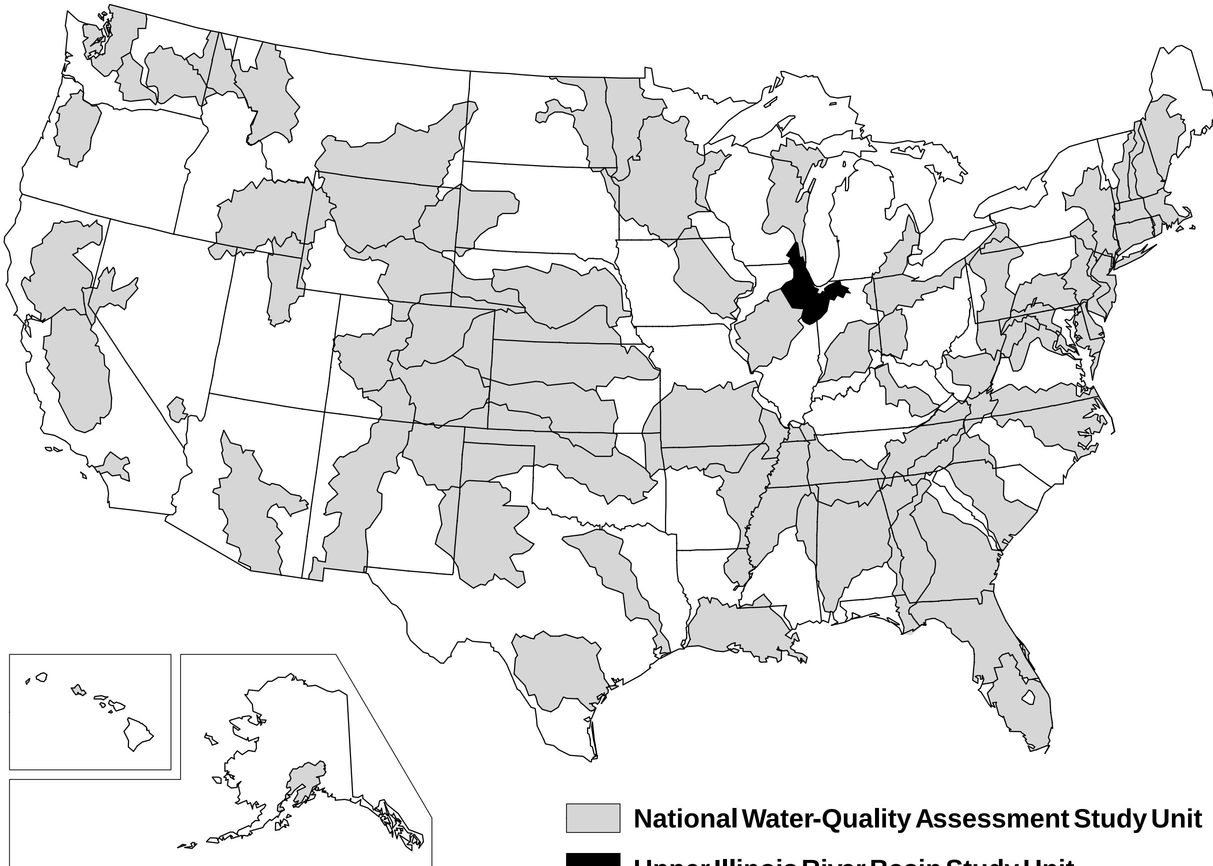
Effects of Land Use on Recharge Potential of Surficial and Shallow Bedrock Aquifers in the Upper Illinois River Basin

Water-Resources Investigations Report 00–4027



National Water-Quality Assessment Program

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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Effects of Land Use on Recharge Potential of Surficial and Shallow Bedrock Aquifers in the Upper Illinois River Basin

By Terri L. Arnold and Michael J. Friedel

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Urbana, Illinois
2000

U.S. DEPARTMENT OF THE INTERIOR
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U.S. GEOLOGICAL SURVEY
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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of more than 50 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
	Area	
acre	0.004047	square kilometer
square mile (mi^2)	2.590	square kilometer
	Flow rate	
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Abbreviations used in this report:.

CDF	Cumulative Distribution Function
GIS	geographic information system
NAWQA	National Water-Quality Assessment
UIRB	upper Illinois River Basin

Effects of Land Use on Recharge Potential of Surficial and Shallow Bedrock Aquifers in the Upper Illinois River Basin

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Abstract

The upper Illinois River Basin (UIRB) is the 10,949-square-mile drainage area upstream from Ottawa, Illinois on the Illinois River and is one of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) program study units. To assist in the interpretation of ground-water data that will be collected during the course of the UIRB study, the study-unit team designed a spatial model to describe recharge potential of surficial and shallow bedrock aquifers. The following factors, identified as having an effect on recharge potential, were incorporated into the model: land use, soil permeability, type and thickness of surficial deposits, and uppermost bedrock geology. Other models designed to simulate recharge potential and the potential for contamination that were examined during the preparation of this model included factors similar to those included in this model, with the exception of land use. Land use and changes in land use over time, however, can affect recharge potential. The UIRB model was used to simulate recharge potential with and without incorporating land use. A comparison of the simulation results showed that recharge potential was overestimated in some areas and underestimated in other areas when land use was not included in the model. Comparisons of simulations that used 1970 and estimated 1990 land use showed changes in recharge potential over time.

INTRODUCTION

The National Water-Quality Assessment (NAWQA) program of the U.S. Geological Survey was designed to provide a national view of the status and trends of the Nation's water resources (Hirsch and others, 1988). This national design facilitates a comparison of water-quality conditions across the country and provides consistent monitoring of water-quality conditions over time. The NAWQA program utilizes an interdisciplinary approach, which integrates ground- and surface-water hydrology and biology, to study basin ecosystems. The NAWQA program is designed around approximately 60 major surface-water drainage basins, called study units. These study units include about one-half the area of the conterminous United States and supply water to approximately 65 percent of the population that relies on public-water supply (Gilliom and others, 1995). The upper Illinois River Basin (UIRB) is one such study unit in the NAWQA program (Friedel, 1998). The UIRB covers 10,949 mi^2 upstream from Ottawa, Illinois, on the Illinois River in parts of northeastern Illinois, northwestern Indiana, and southeastern Wisconsin.

Some of the major water-quality issues in the UIRB are related to urban and agricultural land use: municipal and industrial wastewater releases, urban and agricultural runoff, and atmospheric deposition of pesticides and trace metals (Friedel, 1998). In 1990, most land use in the basin was agricultural (75 percent of the area), followed by urban (17 percent of the area) (Hitt, 1994; Hitt, 1992; Arnold and others, 1999). The human populations and activities within these two principal land-use areas make large demands on the water resources of the basin.

Chicago is the largest urban area in the UIRB. In the northern part of the basin, particularly along the Fox and Des Plaines Rivers, suburban expansion is replacing formerly agricultural land with urban land. In these areas, more ground-water resources are being utilized from surficial and shallow bedrock aquifers because of urban population growth, restricted appropriations of surface water from Lake Michigan, and upwelling of saline water from overpumping in deep bedrock aquifers. In 1995, there were 161 Mgal/d withdrawn for public supply from ground-water sources inside the basin. Excluding withdrawals from Lake Michigan, that 161 Mgal/d of ground water was 82 percent of the public-water supply for the basin (Arnold and others, 1999). Since 1980, some suburbs of Chicago have changed their water-supply source from deep bedrock aquifers to Lake Michigan, shallow bedrock aquifers, and surficial aquifers (Visocky, 1997; Arnold and others, 1999).

Agriculture places its own demands on ground-water resources of the UIRB. Most of the agriculture in the basin is row-crop corn and soybean production. In 1995, crop irrigation used 16 percent of the ground water that was withdrawn from the UIRB (Arnold and others, 1999). Additionally, runoff from fields on which fertilizers and pesticides are used for row-crop agriculture is a source of contaminants that can enter ground water in the agricultural areas of the basin. Because surficial and shallow bedrock aquifers are (and will continue to be) an important resource in the UIRB and the quantity and quality of water in these aquifers is of concern, a model that could be used to estimate relative recharge potential of these aquifers was developed.

Purpose and Scope

The purpose of this report is to describe (1) a spatial model of recharge potential that was developed to facilitate the interpretation of data that will be collected during ground-water surveys of the UIRB, and (2) the effects of land use on the recharge potential of surficial and shallow bedrock aquifers in the UIRB as identified by this model. The study approach involved (1) identifying factors that may affect recharge potential, (2) spatially overlaying the identified factors to create a model that represents recharge potential, (3) deriving histograms and cumulative distribution functions to qualitatively categorize recharge potential, (4) comparing recharge potential with and without considering land use to identify effects of land use on recharge potential, and (5) comparing recharge potential using 1970 and estimated 1990 land use to identify changes in recharge potential over time.

Acknowledgments

The authors thank Donald Keefer of the Illinois State Geological Survey and Daniel Button, Angel Martin, and Chester Zenone of the U.S. Geological Survey for their time and efforts in reviewing this report. Their constructive comments and suggestions were valuable during the report preparation.

METHODOLOGY

Various models designed to simulate infiltration, recharge, or contamination potential were examined, and some of these models (Soller and Berg, 1992; Keefer and Berg, 1991; Wisconsin Department of Natural Resources and the Wisconsin Geological and Natural History Survey, 1987; Berg and Kempton, 1984) were used as templates for the model described in this report. Of the models used as templates, none considered land use except that developed by Berg and Kempton (1984), which targeted contamination by buried municipal wastes. However, land use and changes in land use over time can affect recharge potential. Other than land use, the earlier models incorporated a variety of factors similar to the ones utilized in this model.

Several model simulations were conducted to facilitate comparisons of recharge potential with and without considering land use, and with 1970 and estimated 1990 land-use data. When land use was not considered, the recharge potential of surficial aquifers was evaluated on the basis of soil permeability, and type and thickness of surficial deposits. The recharge potential of shallow bedrock aquifers was evaluated on the basis of soil permeability, type and thickness of surficial deposits, and uppermost bedrock geology. When land use was considered, the recharge potential of surficial aquifers was evaluated using combined data of 1970 land use and soil permeability, type of surficial deposits, and thickness of surficial deposits. The recharge potential of shallow bedrock aquifers, when land use was considered, was evaluated using combined data of 1970 land use and soil permeability, type of surficial deposits, thickness of surficial deposits, and uppermost bedrock geology. Estimated 1990 land-use data were then substituted for 1970 land-use data to identify any changes in recharge potential over time.

Detailed descriptions of land use, soil permeability, type and thickness of surficial deposits, and uppermost bedrock geology is presented in Arnold and others (1999). These descriptions also are being utilized to design certain elements of the ground-water part of the UIRB NAWQA study, such as determining where ground-water data should be collected. Because this model of recharge potential utilizes the same information as the rest of the UIRB NAWQA study, there is a common basis for comparisons between results of the model simulations and results of other UIRB ground-water investigations.

Definition of Terms

An aquifer is a saturated, permeable, geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients (Freeze and Cherry, 1979). In the UIRB, sand or sand and gravel surficial deposits are the major surficial aquifers, and limestone and dolomite are the major shallow bedrock aquifers (Arnold and others, 1999). The extent to which water recharges an aquifer is dependant on various factors. Some of these factors are land use, soil permeability, type of surficial deposits, thickness of surficial deposits, and uppermost bedrock geology. For the purposes of this model, these factors can be thought of as different "layers" between the land surface and the aquifer through which water from the land surface must enter and move. In this report, "infiltration" refers to water entering and moving through a layer. "Recharge potential" refers to the likelihood of water infiltrating all layers, in combination, in order to reach ground water and recharge an aquifer. A "higher recharge potential" means water from the land surface has a higher likelihood of entering ground water and reaching a major aquifer relative to the recharge potential of surrounding areas.

Development of Model Layers

Land use, soil permeability, type and thickness of surficial deposits, and uppermost bedrock geology data were used as layers of the model for recharge potential. The potential for infiltration of each layer except combined land use/soil permeability was ranked 35, 55, 75, or 95, where 35 indicates the highest and 95 indicates the lowest potential for infiltration. The combined land-use/soil-permeability layer was ranked using runoff-potential curve numbers, as described in the "Land Use" section below.

Soil Permeability

Soil permeability, as described below, was included in the model only when land use was not considered. When land use was considered in the model, soil-permeability and land-use data were combined. Hydrologic soil groups, defined by the State Soil Geographic data base of the Natural Resources Conservation Service (formerly known as the Soil Conservation Service), were used as an indicator of soil permeability (U.S. Department of Agriculture, 1994). A hydrologic soil group is a group of soils that have similar runoff potential under similar storm and ground-cover conditions (University of Delaware, 1995). A soil that has a higher runoff potential also has a lower potential for infiltration and, thus, lower soil permeability. Soils of groups A, B, C, and D have high, moderate, low, and very low soil permeability, respectively (fig. 1). The ease with which water can infiltrate the soil layer was ranked into four categories on the basis of soil permeability from rank 35 (highest) to rank 95 (lowest) (fig. 1). Most of the soil in the UIRB, 58 percent of the area, has low permeability (rank 75).

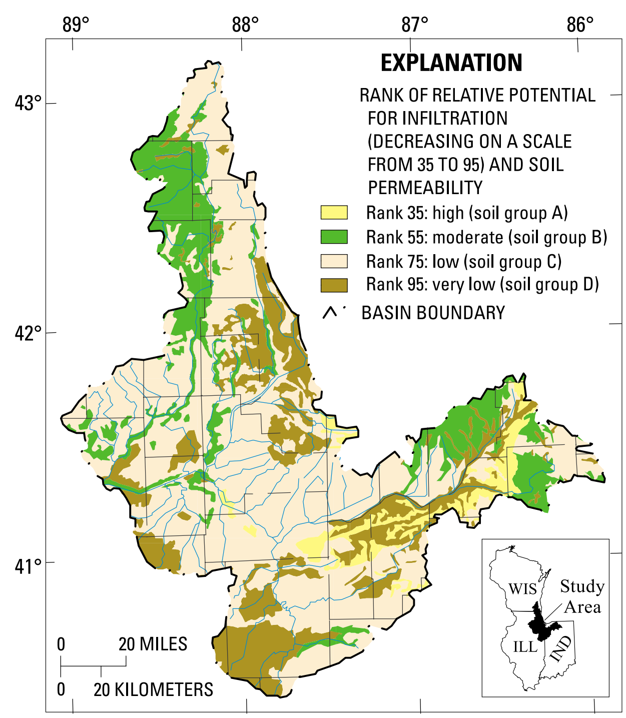


Figure 1. Rank of potential for infiltration and soil permeability of the upper Illinois River Basin.

Land Use

Based on the Anderson classification system (Anderson and others, 1976), the land-use data described 1970 and estimated 1990 land use (Hitt, 1992; Hitt, 1994). The 1990 land-use data provided information only about areas that were classified as new-residential land use, which was based on the 1990 census and population density, but were some other land-use classification in 1970. For this reason, the 1970 land-use data (fig. 2) were used as the basis of model comparisons instead of the estimated 1990 land-use data. At the time this model was created, the 1970/estimated 1990 data set (Hitt, 1992; Hitt, 1994) was the most up-to-date land-use data available for the entire UIRB.

When considering land use in the model, soil-permeability and land-use data were spatially overlaid to combine the effects of land use and soil permeability on recharge potential. Runoff-potential curve numbers (U.S. Department of Agriculture, 1986; Barfield and others, 1987) were assigned to the different land-use/soil permeability combinations that resulted from the spatial overlay (table 1). Runoff-potential curve numbers were based on the Anderson classification system (Anderson and others, 1976), but runoff potential for each land-use classification was separated by soil permeability. A higher runoff potential means a lower potential for infiltration because, in this case, water is more likely to pond on the surface and/or runoff to streams than to move vertically into the subsurface.

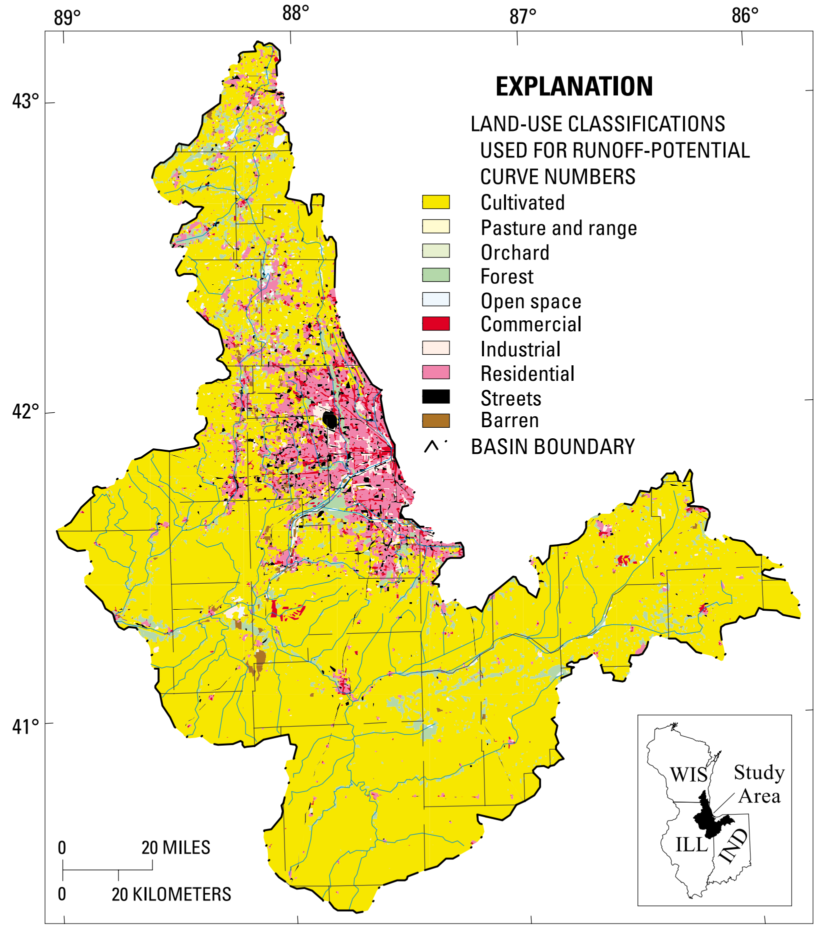


Figure 2. Land-use classifications used for runoff-potential curve numbers of the upper Illinois River Basin.

The runoff-potential curve numbers were used as ranks of potential for infiltration for land use and soil permeability, combined. The highest potential for infiltration corresponds to the lowest runoff-potential curve number (rank 35), and the lowest potential for infiltration corresponds to the highest runoff-potential curve number (rank 95).

Surficial Deposits

To simplify the model, the surficial deposits were assumed to be, on average, similar throughout the thickness of the deposit. The potential for infiltration of surficial deposits was ranked into four categories from rank 35 (highest) to rank 95 (lowest), on the basis of hydraulic conductivity and porosity values presented by Freeze and Cherry (1979)(fig. 3). Where exposed at the surface, bedrock was ranked as having a lower potential for infiltration than the surrounding surficial deposits because it was assumed that consolidated bedrock is likely to be less permeable than unconsolidated surficial deposits. Most of the surficial deposits in the UIRB are sand, and sand and gravel (rank 35) or lake clay and silt, fill, and other (rank 75) (fig. 3). These surficial deposits are 31 and 47 percent of the UIRB area, respectively.

Thickness of Surficial Deposits

The thickness of surficial deposits determines the distance water must travel to reach an aquifer. The thinner a surficial deposit, the more likely the water will infiltrate the surficial deposit and possibly saturate it. When shallow bedrock aquifers are considered, the

Table 1. Runoff-potential curve numbers as a combination of land-use classification and soil permeability in the upper Illinois River Basin (Barfield and others, 1987; U.S. Department of Agriculture, 1986 and 1994; and Anderson and others, 1976)

[A, hydrologic soil group with high soil permeability; B, hydrologic soil group with moderate soil permeability; C, hydrologic soil group with low soil permeability; D, hydrologic soil group with very low soil permeability]

Land-use classification used for defining runoff-potential curve numbers[1] (figure 2)	Anderson land-use classification number and description[2]	Hydrologic soil group[3] (soil permeability) (figure 1)	Runoff-potential curve number (also used as rank of potential infiltration)
Cultivated[4]	21: Cropland and pasture, 23: Confined feeding operations, 24: Other agricultural land	A, B, C, D	67, 76, 83, 86
Pasture and range[5]	31: Herbaceous rangeland	A, B, C, D	54, 70, 80, 85
Orchard[6]	22: Orchards, groves, vineyards, nurseries, and ornamental horticultural areas	A, B, C, D	43, 65, 76, 82
Forest	41: Deciduous forest, 42: Evergreen forest, 43: Mixed forest, 61: Forested wetland	A, B, C, D	35, 61, 74, 80
Open spaces[7]	62: Nonforested wetland	A, B, C, D	44, 65, 77, 82
Commercial	12: Commercial and services, 16: Mixed urban or built-up	A, B, C, D	89, 92, 94, 95
Industrial	13: Industrial, 15: Industrial and commercial complexes	A, B, C, D	81, 88, 91, 93
Residential[8]	11: Residential	A, B, C, D	69, 80, 87, 90
Streets[9]	14: Transportation, communications, and services, 17: Other urban or built-up	A, B, C, D	87, 92, 94, 95
Barren[10]	75: Strip mines, quarries, and gravel pits, 76: Transitional areas	A, B, C, D	72, 81, 88, 91

[1]Barfield and others, 1987, and U.S. Department of Agriculture, 1986.
[2]Anderson and others, 1976.
[3]U.S. Department of Agriculture, 1994.
[4]Average of runoff-potential curve numbers for cultivated land with and without conservation treatment.
[5]Average of runoff-potential curve numbers for pasture and range in good and poor conditions.
[6]Runoff-potential curve number for orchard in fair condition.
[7]Average of runoff-potential curve numbers for open spaces in good and fair conditions.
[8]Average of runoff-potential curve numbers for residential land with less than 1/8 to 1/4 acre lot size.
[9]Average of runoff-potential curve numbers for paved and gravel streets.
[10]Runoff-potential curve number for cultivation with no conservation treatment. Barren land use is less than 2 percent of the study area.

closer the bedrock aquifer is to the land surface (thinner surficial deposits), the greater potential there is for water to enter the bedrock. Thickness of surficial deposits is based on Soller and Packard (1998). In the UIRB, thickness of surficial deposits was ranked into four categories by depth interval with the shallowest range (less than 50 feet) having the greatest potential for infiltration (rank 35) and the deepest range (200 feet or greater) having the least potential for infiltration (rank 95) (fig. 4).

Uppermost Bedrock Geology

The potential for infiltration of water into the uppermost bedrock was ranked into four categories from 35 (highest) to 95 (lowest) on the basis of hydraulic conductivity and porosity values given by Freeze and Cherry (1979) (fig. 5). Most of the uppermost bedrock in the UIRB is limestone and dolomite (rank 35) or shale (rank 95) (fig. 5). Limestone/dolomite and shale are 57 and 35 percent of the UIRB area, respectively. When included in the model, uppermost bedrock geology provided information about the recharge potential of shallow bedrock aquifers, which are an important source of water in the UIRB.

Composite of Model Layers

A geographic information system (GIS) was used to overlay all previously described layers to create the spatial model. The ranks of potential for infiltration of each layer were summed in various combinations to obtain values that described the relative recharge potential of (1) surficial aquifers without considering land use, (2) surficial aquifers when considering 1970 land use, (3) surficial aquifers when considering 1990 land use, (4) shallow bedrock aquifers without considering land use, (5) shallow bedrock aquifers when

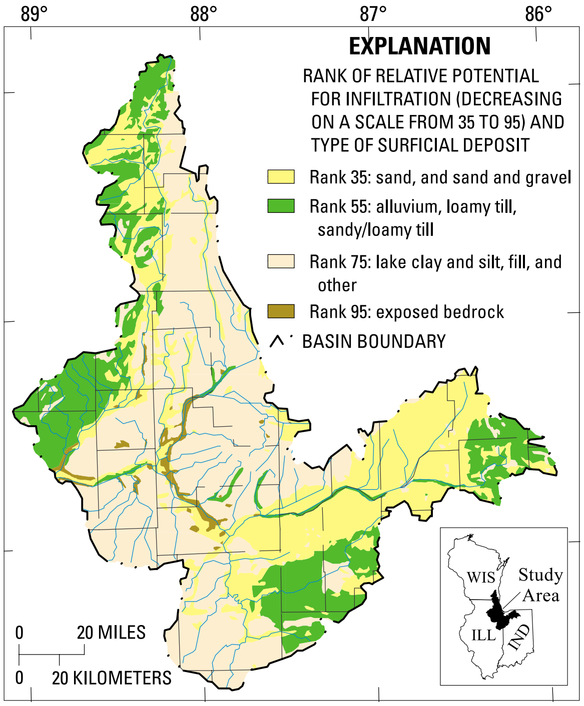


Figure 3. Rank of potential for infiltration and type of surficial deposits of the upper Illinois River Basin.

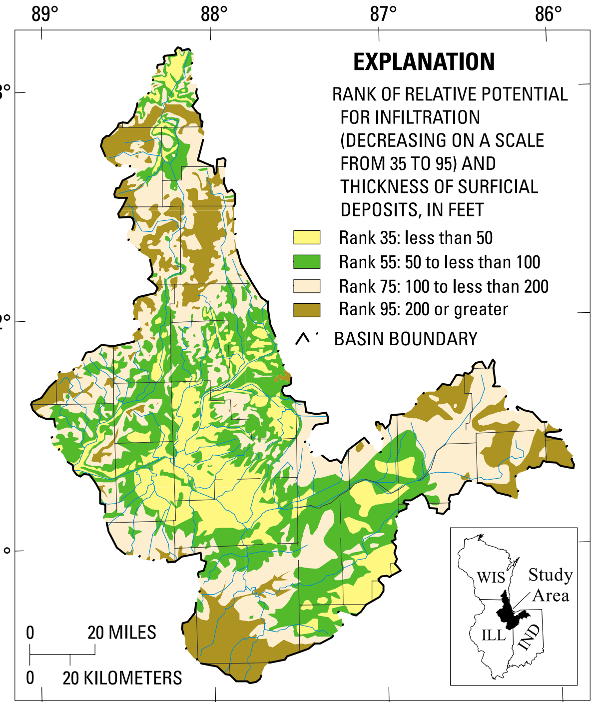


Figure 4. Rank of potential for infiltration and thickness of surficial deposits of the upper Illinois River Basin.

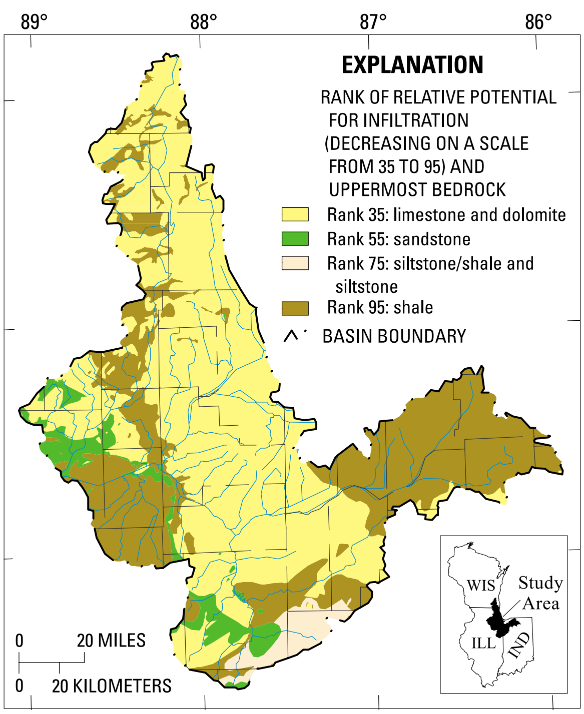


Figure 5. Rank of potential for infiltration and uppermost bedrock geology of the upper Illinois River Basin.

considering 1970 land use, and (6) shallow bedrock aquifers when considering 1990 land use. For both surficial and shallow bedrock aquifers, recharge potential with and without considering 1970 land use (items 1 and 2, and items 4 and 5 above) were compared to determine the effect of land use on recharge potential. Once an effect was identified, recharge potential when considering 1970 land use was compared with recharge potential when considering 1990 land use (items 2 and 3, and items 5 and 6 above) to determine how land-use changes might affect recharge potential over time. The descriptions of recharge potential of surficial and shallow bedrock aquifers with 1970 land use were used as the basis for the comparisons.

Initially, the values describing recharge potential were examined using univariate statistics: minimum, maximum, mean, median, mode, and standard deviation (table 2). In all cases, the distribution of these values mostly conformed to a normal distribution. For both surficial and shallow bedrock aquifers, the mean increased slightly and the standard deviation decreased with the addition of 1970 land use. With an increase of the mean, the distribution of values for both aquifers became more skewed to the left (table 2; figs. 6-7). The decrease in standard deviation indicates that the

Table 2. Univariate statistics for summed ranks representing recharge potential in the upper Illinois River Basin

Statistic	Recharge potential[1]					
	Surficial aquifers			Shallow bedrock aquifers		
	Without land use	With 1970 land use	With 1990 land use	Without land use	With 1970 land use	With 1990 land use
Minimum	105	105	105	140	140	140
Maximum	265	265	265	360	360	360
Mean	195.2	205.7	206.3	246.0	256.5	257.0
Median	205	206	206	240	256	256
Mode	205	224	224	240	259	259
Standard deviation	31.8	28.4	28.3	38.7	36.5	36.4

[1]Lower numbers represent higher potential for recharge, whereas higher numbers represent lower potential for recharge.

variance of the values decreased when land use was considered.

Given that the distribution of values mostly conformed to a normal distribution, a cumulative distribution function (CDF) for values describing recharge potential when considering 1970 land use was derived and divided into five classes. These classes were based on percentiles and represented five general, relative descriptions of recharge potential ranging from very high to very low (figs. 6-7; table 3). The CDF for surficial aquifers ranges from 105 at 0 percent to 265 at 100 percent (fig. 6). The moderate range of recharge potential of surficial aquifers ends around the 60th percentile, indicating that 60 percent of the values are likely to be in the moderate to very high range and 40 percent are likely to be in the moderate to very low range (fig. 6; table 3). For shallow bedrock aquifers, the CDF ranges from 140 at 0 percent to 360 at 100 percent (fig. 7). The moderate range of recharge potential of shallow bedrock aquifers also is around the 60th percentile (fig. 7; table 3).

EFFECTS OF LAND USE ON RECHARGE POTENTIAL

As stated earlier, some model simulations included land use. When results of simulations with and without using land-use data were compared, the effects of land use on recharge potential were identified. When results of simulations with 1970 and 1990 land-use data were compared, the effects of changing land use over time on recharge potential were identified.

Surficial Aquifers

The recharge potential of surficial aquifers was simulated with and without considering 1970 land use. When 1970 land-use data were included in the simulation (fig. 8), 28 percent of the UIRB area displayed a decrease in recharge potential (fig. 9) when compared with the simulation results without land-use data. Recharge potential in the very high to low range when no land-use data were considered decreased to the high to very low range when 1970 land-use data were included. This result indicated that without land use the model overestimated the recharge potential in some areas. For the area in which recharge potential decreased, the most common combination of characteristics (table 4) was low soil permeability (rank 75) (fig. 1); cultivated land use (rank 83) (fig. 2); surficial deposits of lake clay and silt, fill, and other (rank 75) (fig. 3); and surficial deposits between 100 and 200 ft thick (rank 75) (fig. 4). Considering the layers individually for the areas with a decrease in recharge potential, the following were the majority (table 5): 58 percent of the soil-permeability layer was rank 75; 26 percent of the land-use layer was classified as cultivated; 52 percent of the surficial-deposits layer was rank 75; and 46 percent of the thickness of surficial-deposits layer was rank 75.

When 1970 land-use data were included in the simulation, approximately 6 percent of the UIRB area displayed an increase in recharge potential (fig. 9) when compared with the simulation results without land-use data. Recharge potential in the high to very low range when no land-use data were considered increased to the very high to low range when 1970 land-use data were included. This result indicated that without land use the model underestimated the recharge potential for

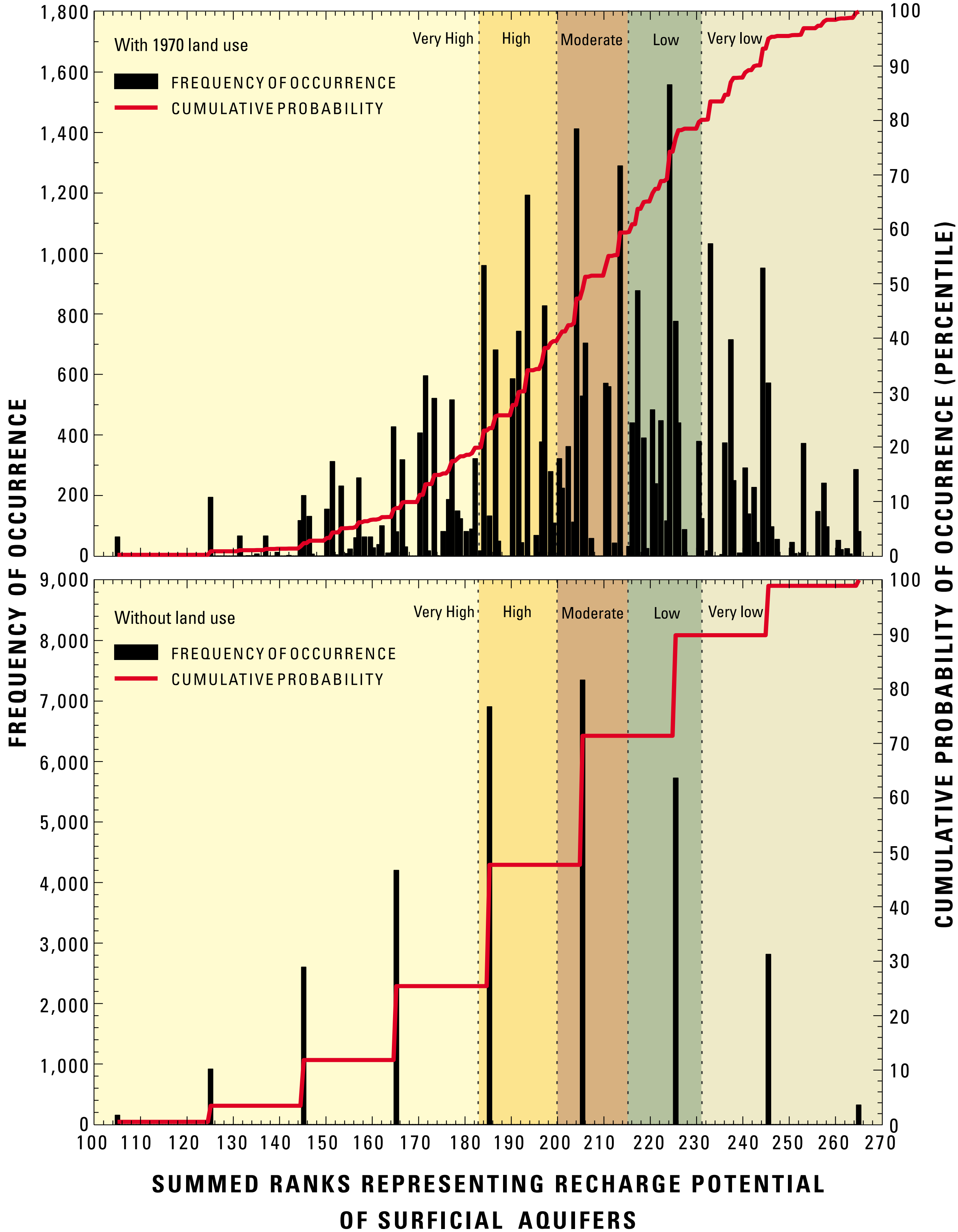


Figure 6. Cumulative distribution functions for surficial aquifers with and without 1970 land use considered.

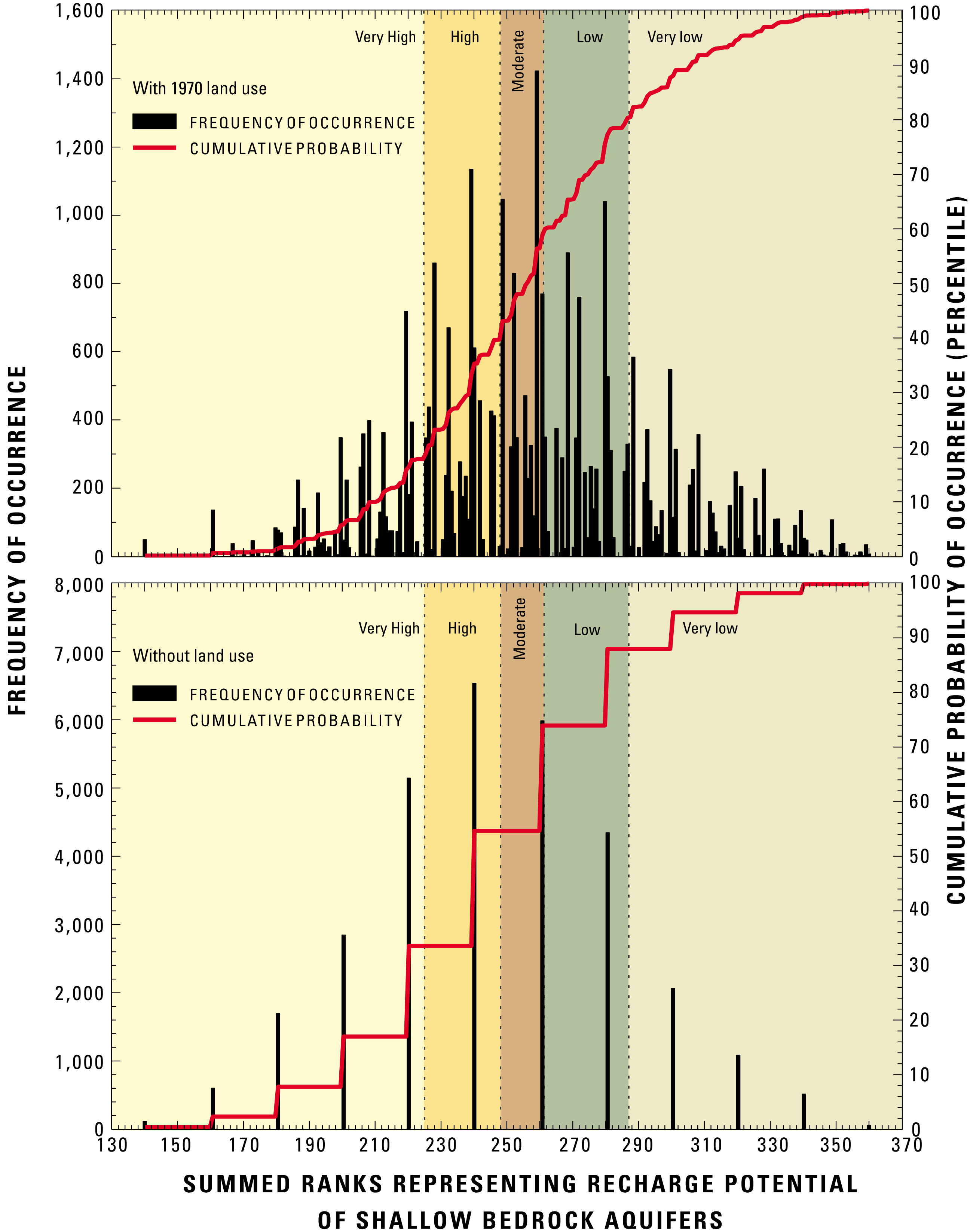


Figure 7. Cumulative distribution functions for shallow bedrock aquifers with and without 1970 land use considered.

Table 3. Classification of recharge potential in the upper Illinois River Basin based on the cumulative distribution function

[≤, less than or equal to; >, greater than]

Potential recharge	Class	Surficial aquifers				Shallow bedrock aquifers			
		Range of values	Percentile for without land use	Percentile for 1970 land use	Percentile for 1990 land use	Range of values	Percentile for without land use	Percentile for 1970 land use	Percentile for 1990 land use
Very high	1	105 – ≤183	25	20	20	140 – ≤225	34	20	17
High	2	>183 – ≤200	48	40	39	>225 – ≤248	55	40	39
Moderate	3	>200 – ≤215	71	60	56	>248 – ≤261	74	60	59
Low	4	>215 – ≤231	90	80	79	>261 – ≤287	88	80	80
Very low	5	>231 – ≤265	100	100	100	>287 – ≤360	100	100	100

some areas. For the area in which recharge potential increased, the most common combination of characteristics (table 4) was very low soil permeability (rank 95) (fig. 1); residential land use (rank 90) (fig. 2); surficial deposits of lake clay and silt, fill, and other (rank 75) (fig. 3); and surficial deposits between 0 and 50 ft thick (rank 35) (fig. 4). Considering the layers individually for the areas with an increase in recharge potential, the following were the majority (table 5): 100 percent of the soil-permeability layer was rank 95; 41 percent of the land-use layer was classified as forest; 49 percent of the surficial-deposits layer was rank 35; and 36 percent of the thickness of surficial-deposits layer was rank 55.

Approximately 66 percent of the UIRB area displayed no change in recharge potential (fig. 9) when simulations with and without 1970 land-use data were compared. For the area in which there was no change in recharge potential, the most common combination of characteristics (table 4) was low soil permeability (rank 75) (fig. 1); cultivated land use (rank 83) (fig. 2); surficial deposits of lake clay and silt, fill, and other (rank 75) (fig. 3); and surficial deposits between 50 and 100 ft thick (rank 55) (fig. 4). Considering the layers individually for the areas with no change in recharge potential, the following were the majority (table 5): 49 percent of the soil-permeability layer was rank 75; 31 percent of the land-use layer was classified as cultivated; 46 percent of the surficial-deposits layer was rank 75; and 35 percent of the thickness of surficial-deposits layer was rank 55.

Between 1970 and 1990, the amount of urban land in the UIRB increased from 14 to 17 percent of the total area of the basin. Although not dramatic, the changes in recharge potential between 1970 and 1990 as shown by the model were predictable. As urban land use, which has a relatively low potential for infiltration, replaced land use with higher potential for infiltration, the overall recharge potential decreased. When recharge potential with 1970 land use was compared with recharge potential with 1990 land use, the model indicated that recharge potential of surficial aquifers decreased when new residential land use replaced cultivated, forest, orchard, or open space (0.63 percent of the UIRB area). The model indicated that recharge potential of surficial aquifers increased when new residential land use replaced land use with a lower potential for infiltration, such as barren land (0.02 percent of the UIRB area). Although the model results did not indicate much change in recharge potential between 1970 and 1990 using the 1970 and estimated 1990 land-use data, more recent and detailed land-use data may indicate more of a change. Because there was a change in recharge potential displayed with change in land use over time, projected future changes in land use could be utilized in this model to estimate projected changes in recharge potential.

Bedrock Aquifers

The recharge potential of shallow bedrock aquifers was simulated with and without considering 1970 land use. When 1970 land-use data were included in the simulation (fig. 10), 42 percent of the UIRB area decreased in recharge potential (fig. 11) when compared with simulation results without land-use data. For the area in which recharge potential decreased, the most common combination of characteristics (table 6) was low soil permeability (rank 75) (fig. 1); cultivated land use (rank 83) (fig. 2); surficial deposits of lake clay and silt, fill, and other (rank 75) (fig. 3); surficial deposits between 100 and 200 ft thick (rank 75) (fig. 4); and limestone and dolomite bedrock (rank 35) (fig. 5). Considering the layers individually for the areas with a decrease in recharge potential, the following were the majority (table 7): 63 percent of the soil-permeability layer was rank 75; 29 percent of the land-use layer was classified as cultivated; 52 percent of the surficial-

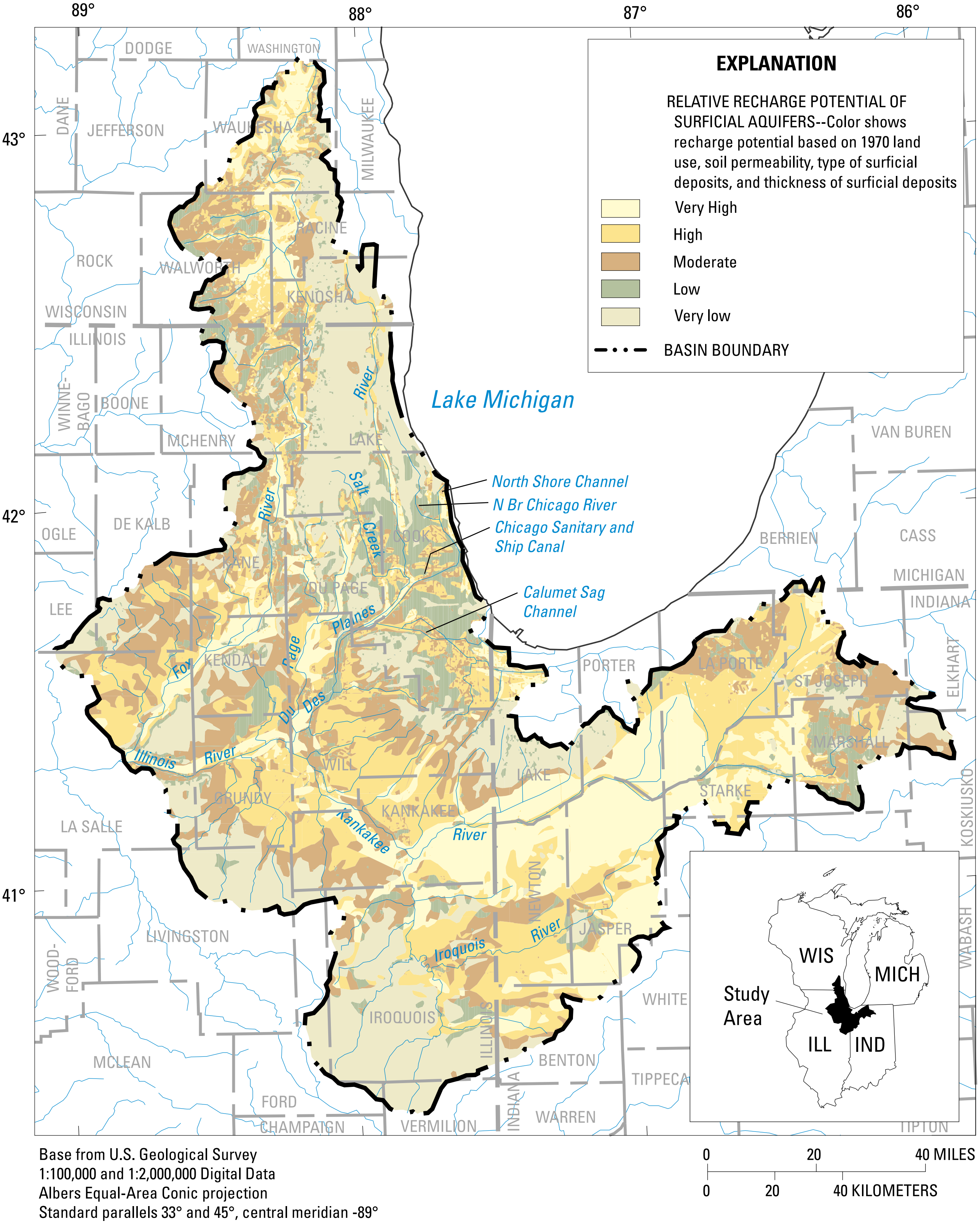


Figure 8. Recharge potential of surficial aquifers when 1970 land use was considered, upper Illinois River Basin.

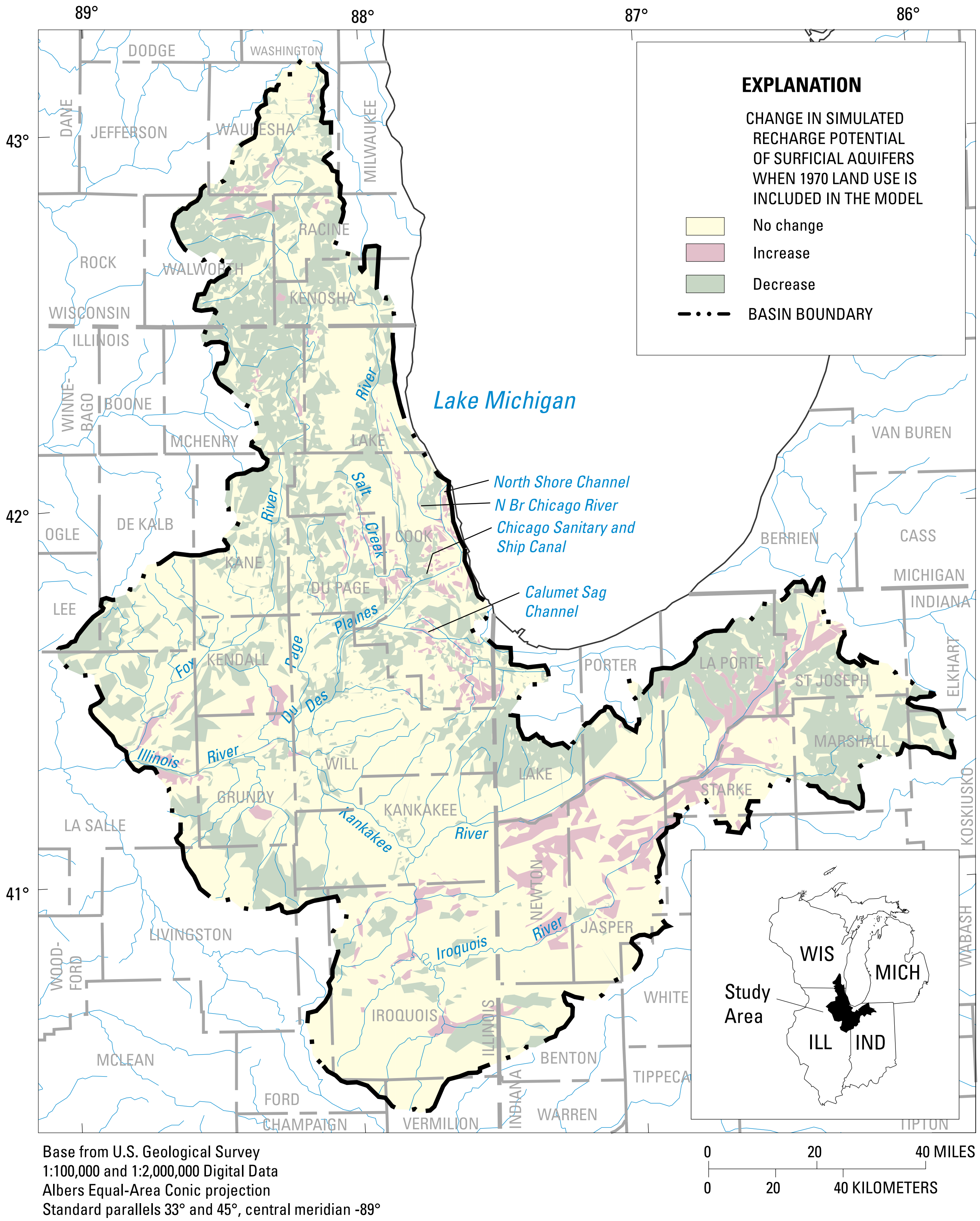


Figure 9. Effects of adding 1970 land use to the model of recharge potential of surficial aquifers, upper Illinois River Basin.

Table 4. The most common combination of characteristics for the areas with a change in recharge potential of surficial aquifers in the upper Illinois River Basin when 1970 land use was included in the model

Change in recharge potential (figure 9)	Frequency of occurrence (percent)	Soil permeability rank (figure 1)	Land use (figure 2)	Surficial deposits rank (figure 3)	Thickness of surficial deposits rank (figure 4)
Decrease	6	75	Cultivated	75	75
Increase	7	95	Residential	75	35
None	3	75	Cultivated	75	55

deposits layer was rank 75; 40 percent of the thickness of surficial-deposits layer was rank 75; and 73 percent of the uppermost bedrock layer was rank 35. Recharge potential in the very high to low range when no land-use data were considered decreased to the high to very low range when 1970 land-use data were included. This result indicated that without land use the model overestimated the recharge potential for some areas.

When 1970 land-use data were included in the simulation, approximately 1 percent of the UIRB area increased in recharge potential (fig. 11) when compared with simulation results without land-use data. For the area in which recharge potential increased, the most common combination of characteristics (table 6) was very low soil permeability (rank 95) (fig. 1); forest land use (rank 80) (fig. 2); surficial deposits of lake clay and silt, fill, and other (rank 75) (fig. 3); surficial deposits between 50 and 100 ft thick (rank 55) (fig. 4); and limestone and dolomite bedrock (rank 35) (fig. 5). Considering the layers individually for the areas with an increase in recharge potential, the following were the majority (table 7): 100 percent of the soil-permeability layer was rank 95; 87 percent of the land-use layer was classified as forest; 45 percent of the surficial-deposits layer was rank 35 and 45 percent was rank 75; 35 percent of the thickness of surficial-deposits layer was rank 75; and 64 percent of the uppermost bedrock layer was rank 35. Recharge potential in the high to very low range when no land-use data were considered increased to the very high to low range when 1970 land-use data were included. This result indicated that without land use the model underestimated the recharge potential for some areas.

Approximately 57 percent of the UIRB area displayed no change in recharge potential when simulations with and without 1970 land-use data were compared (fig. 11). For the area in which no change in recharge potential was displayed, the most common combination of characteristics (table 6) was low soil permeability (rank 75) (fig. 1); cultivated land use (rank 83) (fig. 2); surficial deposits of lake clay and silt, fill, and other (rank 75) (fig. 3); surficial deposits between 50 and 100 ft thick (rank 55) (fig. 4); and limestone or dolomite bedrock (rank 35) (fig. 5). Considering the layers individually for the areas with no change in recharge potential, the following were the majority (table 7): 38 percent of the soil-permeability layer was rank 75; 30 percent of the land-use layer was classified as cultivated; 45 percent of the surficial-deposits layer was rank 75; 37 percent of the thickness of surficial-deposits layer was rank 55; and 71 percent of the uppermost bedrock layer was rank 35.

The change in land use between 1970 and 1990 affected the recharge potential for shallow bedrock aquifers similarly to surficial aquifers. As urban land use replaced land use with higher potential for infiltration, the overall recharge potential decreased. When urban land use replaced land use with a lower potential for infiltration, the overall recharge potential increased. When recharge potential with 1970 land use was compared with recharge potential with 1990 land use, the model indicated that recharge potential of shallow bedrock aquifers decreased where new residential land use replaced cultivated, forest, orchard, open space, or pasture land use (0.68 percent of the UIRB area). The model indicated that recharge potential to shallow bedrock aquifers increased where new residential land use replaced barren land (0.01 percent of the UIRB area).

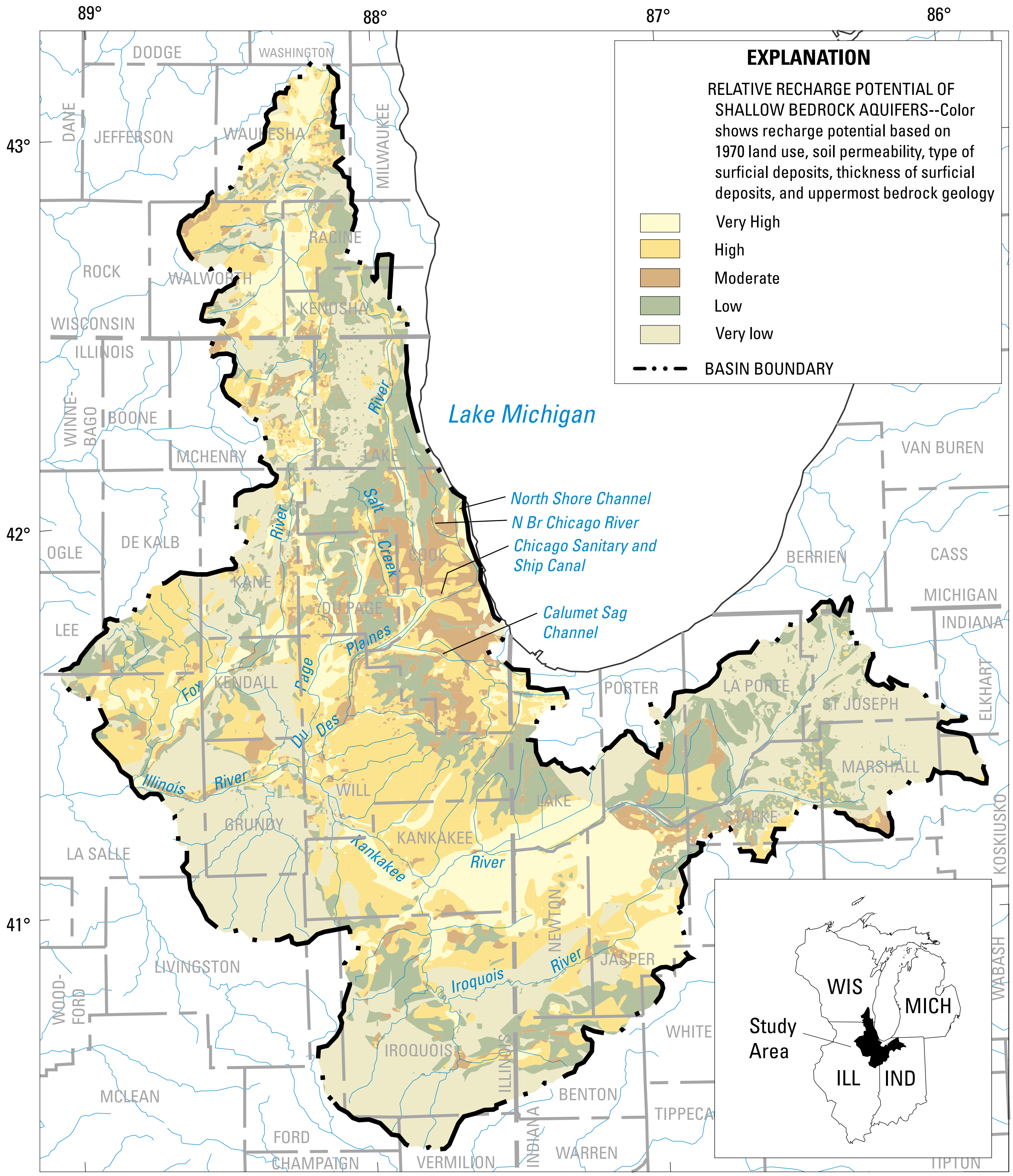
SUMMARY

A model of recharge potential was developed for use by the upper Illinois River Basin (UIRB) study unit of the National Water-Quality Assessment program to facilitate ground-water study design and evaluate recharge potential of the surficial and shallow bedrock

Table 5. Frequency of occurrence of rank or classification for each layer, in percent, for change in recharge potential of surficial aquifers in the upper Illinois River Basin when 1970 land use was included in the model

[--, not applicable; <, less than]

Rank or classification	Decreased recharge potential (frequency of occurrence, in percent)				Increased recharge potential (frequency of occurrence, in percent)				No change in recharge potential (frequency of occurrence, in percent)			
	Permeability (figure 1)	1970 land use (figure 2)	Surficial deposits (figure 3)	Thickness of surficial deposits (figure 4)	Permeability (figure 1)	1970 land use (figure 2)	Surficial deposits (figure 3)	Thickness of surficial deposits (figure 4)	Permeability (figure 1)	1970 land use (figure 2)	Surficial deposits (figure 3)	Thickness of surficial deposits (figure 4)
35	3	--	22	13	0	--	49	30	7	--	38	24
55	39	--	20	25	0	--	11	36	18	--	14	35
75	58	--	52	46	0	--	38	29	49	--	46	26
95	0	--	6	16	100	--	2	5	26	--	2	15
Cultivated	--	26	--	--	--	30	--	--	--	31	--	--
Pasture and range	--	0	--	--	--	0	--	--	--	<1	--	--
Orchard	--	0	--	--	--	0	--	--	--	1	--	--
Forest	--	0	--	--	--	41	--	--	--	26	--	--
Open Spaces	--	0	--	--	--	5	--	--	--	3	--	--
Commercial	--	22	--	--	--	0	--	--	--	10	--	--
Industrial	--	4	--	--	--	1	--	--	--	3	--	--
Residential	--	22	--	--	--	21	--	--	--	15	--	--
Streets	--	15	--	--	--	0	--	--	--	6	--	--
Barren	--	10	--	--	--	1	--	--	--	5	--	--



Base from U.S. Geological Survey
1:100,000 and 1:2,000,000 Digital Data
Albers Equal-Area Conic projection
Standard parallels 33° and 45°, central meridian -89°

Figure 10. Recharge potential of shallow bedrock aquifers when 1970 land use was considered, upper Illinois River Basin.

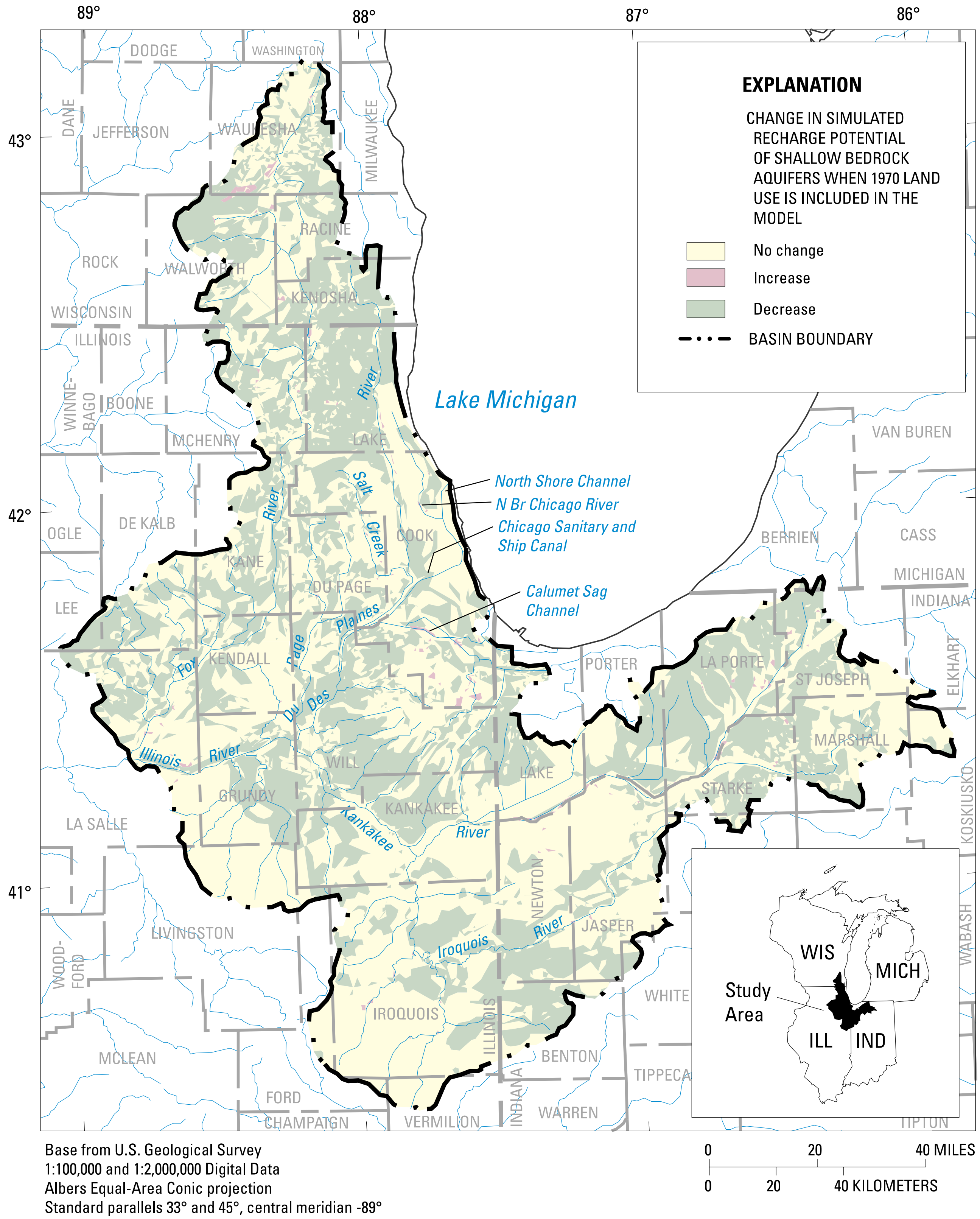


Figure 11. Effects of adding 1970 land use to the model of recharge potential of shallow bedrock aquifers, upper Illinois River Basin.

Table 6. The most common combination of characteristics for the areas with a change in recharge potential of shallow bedrock aquifers in the upper Illinois River Basin when 1970 land use was included in the model

Change in recharge potential (figure 11)	Frequency of occurrence (percent)	Soil permeability rank (figure 1)	Land use (figure 2)	Surficial deposits rank (figure 3)	Thickness of surficial deposits rank (figure 4)	Uppermost bedrock (figure 5)
Decrease	4	75	Cultivated	75	75	35
Increase	15	95	Forest	75	55	35
None	3	75	Cultivated	75	55	35

Table 7. Frequency of occurrence of rank or classification for each layer, in percent, for change in recharge potential of shallow bedrock aquifers in the upper Illinois River Basin when 1970 land use was included in the model

[--, not applicable; <, less than]

Rank or classification	Decreased recharge potential (frequency of occurrence, in percent)					Increased recharge potential (frequency of occurrence, in percent)					No change in recharge potential (frequency of occurrence, in percent)				
	Permeability (figure 1)	1970 land use (figure 2)	Surficial deposits (figure 3)	Thickness of surficial deposits (figure 4)	Uppermost bedrock (figure 5)	Permeability (figure 1)	1970 land use (figure 2)	Surficial deposits (figure 3)	Thickness of surficial deposits (figure 4)	Uppermost bedrock (figure 5)	Permeability (figure 1)	1970 land use (figure 2)	Surficial deposits (figure 3)	Thickness of surficial deposits (figure 4)	Uppermost bedrock (figure 5)
35	4	--	28	19	73	0	--	45	24	64	6	--	37	21	71
55	32	--	16	25	3	0	--	10	27	5	20	--	16	37	3
75	63	--	52	40	1	0	--	45	35	0	38	--	45	28	0
95	0	--	4	16	24	100	--	0	14	30	36	--	3	14	26
Cultivated	--	29	--	--	--	--	0	--	--	--	--	30	--	--	--
Pasture and range	--	0	--	--	--	--	0	--	--	--	--	<1	--	--	--
Orchard	--	0	--	--	--	--	1	--	--	--	--	1	--	--	--
Forest	--	4	--	--	--	--	87	--	--	--	--	27	--	--	--
Open spaces	--	1	--	--	--	--	12	--	--	--	--	2	--	--	--
Commercial	--	18	--	--	--	--	0	--	--	--	--	12	--	--	--
Industrial	--	4	--	--	--	--	0	--	--	--	--	3	--	--	--
Residential	--	23	--	--	--	--	0	--	--	--	--	15	--	--	--
Streets	--	12	--	--	--	--	0	--	--	--	--	7	--	--	--
Barren	--	10	--	--	--	--	0	--	--	--	--	4	--	--	--

aquifers in the UIRB. The model was geographic information system (GIS) based and incorporated layers of land use, soil permeability, surficial deposits, thickness of surficial deposits, and uppermost bedrock geology.

Land use is an important layer in a model that evaluates recharge potential of surficial and shallow bedrock aquifers because a model without land use tends to overestimate the recharge potential for some areas and underestimate the recharge potential for other areas. When 1970 land use was considered in the description of recharge potential of surficial aquifers, recharge potential increased in 6 percent of the UIRB and decreased in 28 percent of the UIRB when compared with recharge potential without land use considered. When 1970 land use was considered in the description of recharge potential of shallow bedrock aquifers, 1 percent of the UIRB increased in recharge potential and 42 percent of the UIRB decreased in recharge potential as compared with recharge potential without land use considered.

A comparison of the simulation results with 1970 and 1990 land-use data shows that as land use changes so does the recharge potential. Areas that became more urbanized generally showed a decrease in recharge potential. As recharge potential decreases, runoff to surface water increases and ground-water recharge decreases. Therefore, the model could be used to estimate how changes in land use might affect recharge potential over time. This estimation would be useful to help planners anticipate changes to ground-water recharge and runoff to surface water as agricultural areas are urbanized or to estimate aquifer susceptibility to contamination.

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Arnold and Friedel—EFFECTS OF LAND USE ON RECHARGE POTENTIAL OF SURFICIAL AND SHALLOW BEDROCK AQUIFERS IN THE UPPER ILLINOIS RIVER BASIN—U.S. Geological Survey Water-Resources Investigations Report 00–4027