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Regional Evaluation of Ground-Water and Surface Water Interactions: Preliminary Method Development and Analysis

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Abstract

A methodology has been developed for classifying ground-water and surface water interactions using a combination of small-scale map data (1:250,000) and existing data on stream discharges. Information from statewide maps of soils, geologic materials, and land surface topography was combined and used to define unique hydrogeologic settings, or terranes. A new map was developed that includes 11 different hydrogeologic terranes. Separately, a statewide map of watershed boundaries (developed from 1:24,000 data) was overlaid with a map and database of U.S. Geological Survey stream gaging stations. Low-flow data (area-normalized Q_{90} values) from the gaging station database were used to identify four different Q_{90} groupings. A modified watershed map was developed by reclassifying the statewide watershed map according to these new Q_{90} groups, resulting in a low-flow map with more than 200 watersheds.

The hydrogeologic terrane map was then combined with the modified watershed map, and a preliminary analysis was conducted of the combined data. This analysis indicates that, in general, low-flow rates in the defined watersheds are most closely related to soil hydraulic characteristics and less closely related to the presence of an aquifer within 50 feet of the land surface, the landscape position, or the slope of the land surface.

Although these observations may be considered obvious, to our knowledge such observations have never been made on the basis of statewide data nor with the data sets used for this study. This research suggests that our general approach can be valuable for defining functional relationships between hydrogeologic settings and streamflow characteristics. Moreover, several areas of additional research were identified during the data analysis that could enhance the utility of this approach in future efforts.

Introduction

The U.S. Environmental Protection Agency (USEPA, 1993) identified the interactions between ground water and surface water as a critical component of ground-water resource assessments. In its report, the USEPA noted that more information is needed on these interactions because they can significantly affect human health and ecological systems in areas with ground-water contamination and high rates of ground-water discharge to surface water systems.

The purpose of this study, funded by the USEPA through the Illinois Environmental Protection Agency (IEPA), was to develop and analyze a method for classifying ground-water and surface water interactions using a combination of small-scale map data and existing data on stream discharges. Such information would be very valuable as a screening tool, allowing the targeting of limited monetary and human resources to the most vulnerable areas.

Methodology

Development of Hydrogeologic Terrane Map

A *terrain* is defined as a physiographic or topographic feature, such as a valley or a hill, having a specific position and characteristic that differentiates it from other features of a landscape (Berg et al., 1984). When such a feature is combined with the sequence and character of geologic materials that underlie it, a mapping unit referred to as a *terrane* is formed.

The distribution and characteristics of a terrane should determine to some degree the direction and nature of water flow and any associated chemical transport through its earth materials (Berg et al., 1984). Therefore, a detailed delineation of terranes might suggest the potential of a given area for natural recharge to the shallow ground-water system, as well as the potential for ground water to discharge to surface water bodies. Given the preliminary nature of this study, we limited our data search to relevant hydrogeologic parameters that were included in readily available digital maps and databases.

Data Selection

A statewide map showing the vertical succession of geologic materials to a depth of 15 meters (Berg and Kempton, 1988) was used for this study. This "stack-unit" map was produced by compiling statewide geologic information that included more than 25,000 water-well logs, engineering borings, and test borings. A total of 854 unique sequences of geologic materials were identified in almost 5,200 map areas. The stack-unit map was digitized into the geographic information system (GIS) at the Illinois State Geological Survey (ISGS).

The stack-unit map served as the source of geologic information for this study. In the map, most geologic materials are identified through a combination of generalized textural and stratigraphic classification. For example, diamictons of the Wedron Group are classified under two different map units; one unit identifies silty and clayey diamictons, and the other defines loamy and sandy diamictons. Sorted coarse-grained deposits are classified as sand and gravel and defined according to their depth from the ground surface. Most are also defined in association with a diamicton deposit.

For this study, all materials were reclassified using assumptions on generalized textures. These textural assignments allowed for a further reclassification based on relative water-transport characteristics (Berg et al., 1984; Keefer, 1995a, b). Two categories were identified: aquifer materials and nonaquifer materials. Aquifer materials included any mapped sand and gravel, sandstone, or fractured carbonate deposit. Nonaquifer materials included any other deposits—primarily loess, diamictons, lacustrine sediments, shales, coals, and unfractured carbonates. The thickness and depth information in the stack-unit map, together with this aquifer/nonaquifer classification, allowed for the development of a map showing the depth to the uppermost aquifer within 50 feet of the land surface (Figure 1). This depth-to-aquifer map was selected for use because of its statewide extent, inclusion of the upper 50 feet of geologic materials, and the expected relevance of this information in classifying ground-water and surface water interactions.

Three categories of depth to aquifer were identified for this map: within 20 feet of land surface, 20 to 50 feet from land surface, and not within 50 feet of land surface. These depth ranges were selected for two reasons. First, due to data availability constraints, the ranges correspond to thickness and depth ranges used in the stack-unit map. Second, a recent study of water quality in private rural water-supply wells found these depth categories to be related to differences in water quality (Schock et al., 1992). Results from the study also suggest that these depth ranges are correlated with different ground-water flow characteristics or settings.

In addition to the depth-to-aquifer map, the State Soil Geographic Data Base (STATSGO) (U.S Department of Agriculture, 1991), or soil association map, was identified as potentially useful for this study. The soil associations on the STATSGO map represent groupings of up to 21 individually mapped soil phases. Soil phases are map units used in detailed county-level soil mapping that identify the predominant soil series in an area and include information on the land surface slope and the degree of erosion. The Illinois STATSGO map was developed by joining soil association maps from all of the individual counties. Prior to release, this map was reviewed for boundary errors and for consistency in the soil association definitions. Keefer (1995a) discusses a procedure for interpreting the STATSGO map and database to evaluate water movement through soil profiles.

Nitrate leaching classes for soils in Illinois (Keefer, 1995a, b) were identified as being particularly relevant for this study because they represent a relative measure of the water movement characteristics of the soil profile. To avoid confusion regarding the use of this parameter in this

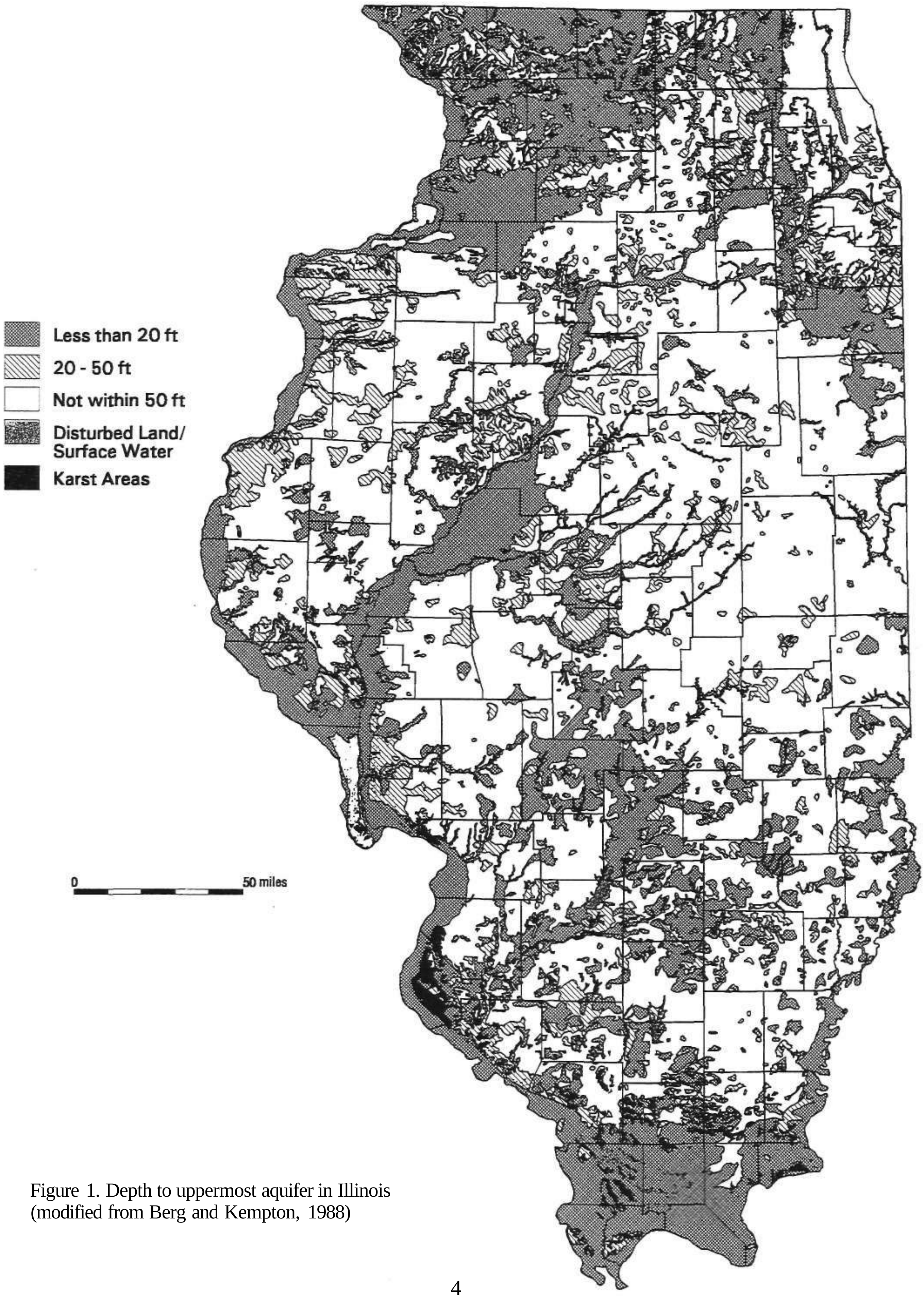

Figure 1. Depth to uppermost aquifer in Illinois
(modified from Berg and Kempton, 1988)

study, the nitrate leaching classes will be referred to as soil percolation categories. (The term "percolation" connotes water movement, whereas "leaching" and "nitrate leaching" connote an evaluation of chemical movement.) Several soil properties were used to define these soil percolation categories, including the hydraulic conductivity of individual soil layers, percolation category of the entire soil profile, presence/absence of a fragic horizon (clay-rich zone restricting water movement), slopes greater than or equal to 15 percent, and soils with thin profiles. A travel-time index was developed to consolidate hydraulic conductivity data into a single value for each profile. This index was used as an indicator of the rate at which water might move through the entire soil profile (Keefer, 1995a).

Figure 2 illustrates the six soil percolation categories of Illinois soils (Keefer, 1995b) used in this study. *Excessive* percolation is most prevalent in western Mason County, southeastern Kankakee County, and in portions of Ogle and Lee Counties, while *High* percolation is common over much of northern Illinois, as well as along the Mississippi, Illinois, and Wabash Rivers. These regions are mostly characterized by sandy geologic materials or jointed/fractured bedrock at or near the surface as well as relatively deep seasonally high water tables. *Moderate* and *Somewhat Excessive* percolation are most prevalent in northeastern Illinois. *Limited* and *Very Limited* percolation are more common in central and southern Illinois where lower hydraulic conductivities commonly occur in combination with shallow seasonally high water tables.

As a third variable, land-surface elevation data, in the form of 1:250,000 USGS digital elevation model (DEM) data, were used to develop a slope map of Illinois. In the DEM, elevation values were assigned to uniformly spaced grid nodes with a grid spacing of approximately 300 feet. A triangulated irregular network (TIN) algorithm was used to convert the gridded DEM data into a slope map. The land surface slope corresponding to each triangle was calculated based on the elevations of the grid points at the apexes of each triangle. The resulting slope values were then classified into six different categories: 0-2 percent, >2-5 percent, >5-7 percent, >7-10 percent, >10—15 percent, and >15 percent.

The vast majority of land area in Illinois has slopes of less than 5 percent; however, the ground-water flow characteristics of these flat to gently sloping areas differ dramatically based on the landscape position (i.e., upland versus lowland). To distinguish flat to gently sloping uplands from lowlands, the newly defined slope map was overlaid with a map of alluvial deposits (from Berg and Kempton, 1988). Areas mapped as containing alluvial deposits and having a slope of less than 5 percent were identified as lowlands. All other areas were assumed to be uplands.

Data Combination and Interpretation

To create the map of hydrogeologic terranes, the maps of depth to uppermost aquifer, soil percolation categories, percent slope, and landscape position were combined. An initial evaluation of these combinations resulted in the definition of 21 different terranes, whereby each terrane was a unique combination of the input variables. In evaluating the areal coverage of these terranes, it was discovered that ten covered less than 1 percent each of the statewide land area.

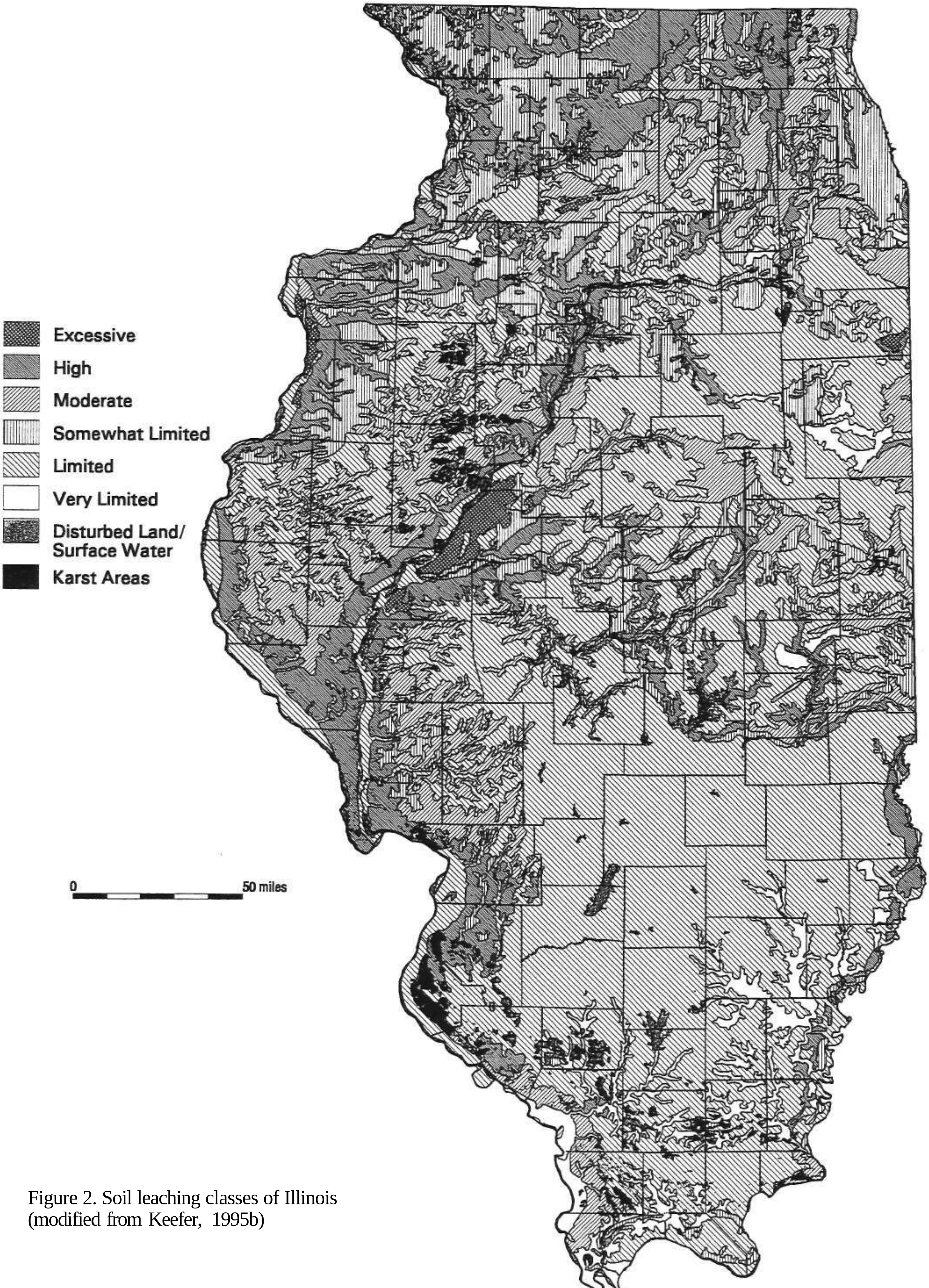

Figure 2. Soil leaching classes of Illinois
(modified from Keefer, 1995b)

Because these terranes were so spatially insignificant, the 21 terranes were regrouped into 11 unique terranes, which are defined in Table 1. Figure 3 illustrates the statewide distribution of the hydrogeologic terranes.

Table 1. Hydrogeologic Terranes

Hydro-geologic terrane	*Land-surface slope**	*Landscape position*	*Soil percolation categories*	*Depth to aquifer material*	*Areal extent in square miles (% state land area)*
1	Flat-gentle	Uplands	High-excessive	<20 feet	3,663 (6.7)
2	Flat-gentle	Uplands	Very poor-moderate	<20 feet	7,431 (13.5)
3	Flat-gentle	Uplands	High-excessive	20-50 feet	2,108 (3.8)
4	Flat-gentle	Uplands	Very poor-moderate	20-50 feet	3,742 (6.8)
5	Flat-gentle	Uplands	High-excessive	Not within 50 feet	8,872(16.1)
6	Flat-gentle	Uplands	Very poor-moderate	Not within 50 feet	20,957(38.1),
7	Moderate-very steep	Uplands	Very poor-excessive	Within 50 feet	1,444 (2.6)
8	Moderate-very steep	Uplands	Very poor-excessive	Not within 50 feet	1,064 (1.9)
9	Flat-gentle	Lowlands	High-excessive	Within 50 feet	804 (1.5)
10	Flat-gentle	Lowlands	Very poor-moderate	Within 50 feet	3,227 (6.0)
11	Flat-gentle	Lowlands	Very poor-excessive	Not within 50 feet	1,654 (3.0)

Note: *The flat-gentle slope category includes slopes of 0 to 5 percent, while the moderate-very steep category includes slopes greater than 5 percent.

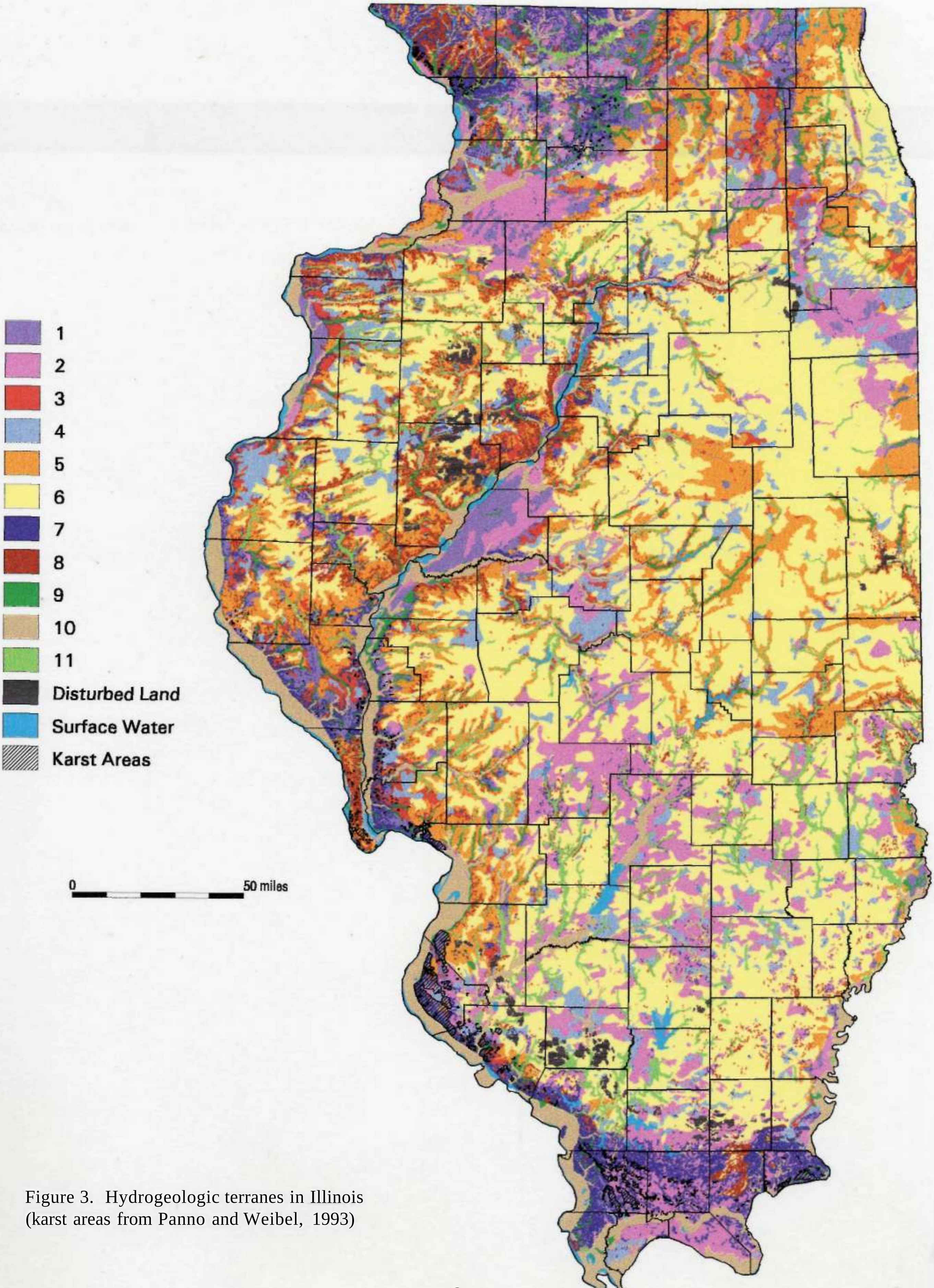

Figure 3. Hydrogeologic terranes in Illinois (karst areas from Panno and Weibel, 1993)

Development of Low-Flow Watershed Map

Streamflow Analysis

The goal of the streamflow analysis component of this project was to classify watersheds throughout the state according to their low-flow characteristics. The streamflow analysis procedures used in a project evaluating the influence of wetlands on streamflow were used to determine low-streamflow characteristics of streams in Illinois (Demissie and Khan, 1993).

Large low-streamflow values generally indicate a significant contribution from ground water or wetlands during periods of low streamflow. Therefore, by delineating regions with large low-streamflow values, it is possible to identify those areas of the state that have a high probability of ground-water discharge into streams.

Long-term (defined as greater than five years) streamflow records were analyzed to generate flow duration curves for 237 gaging stations in Illinois (see Appendix). A flow duration curve gives the flow values that are exceeded 0 to 100 percent of the time. The flow exceeded 0 percent of the time represents the largest flow on record, while the flow exceeded 100 percent of the time represents the smallest flow on record. The 90 to 99 percent flow duration values are used to characterize low-flow conditions. For this study we have selected the Q_{90}, or the flow value exceeded 90 percent of the time, as the low-flow parameter. The same flow duration value was used in a similar study in Ohio by Cross (1949).

The flow duration curves for four streams in Illinois are shown in Figure 4 to demonstrate the usefulness of the flow duration method in characterizing the flow dynamics of streams. The four streams selected were the Kankakee River at Momence (USGS Gage 05520500), the Fox River at Algonquin (USGS Gage 05550000), the Kaskaskia River at Carlyle (USGS Gage 05593000), and the Big Muddy River at Murphysboro (USGS Gage 05599500). Figure 5 shows the stream locations and contributing watershed areas in Illinois. The streamflow values were converted from cubic feet per second into inches per square mile to normalize the effect of drainage-basin size.

The flow with a 99 percent exceedance probability is the smallest streamflow shown in Figure 4. At this exceedance probability, the Big Muddy River has the largest streamflow, 0.007 inches, while the Kaskaskia River has the smallest, 0.00004 inches. Flows for the Kankakee and Fox Rivers fall between these values. Based on a comparison of flow duration curves, it is possible to conclude that streams with larger low flows, such as the Big Muddy and Kankakee, are more likely to have a larger amount of water discharging from ground water or wetlands during periods when flow is minimal.

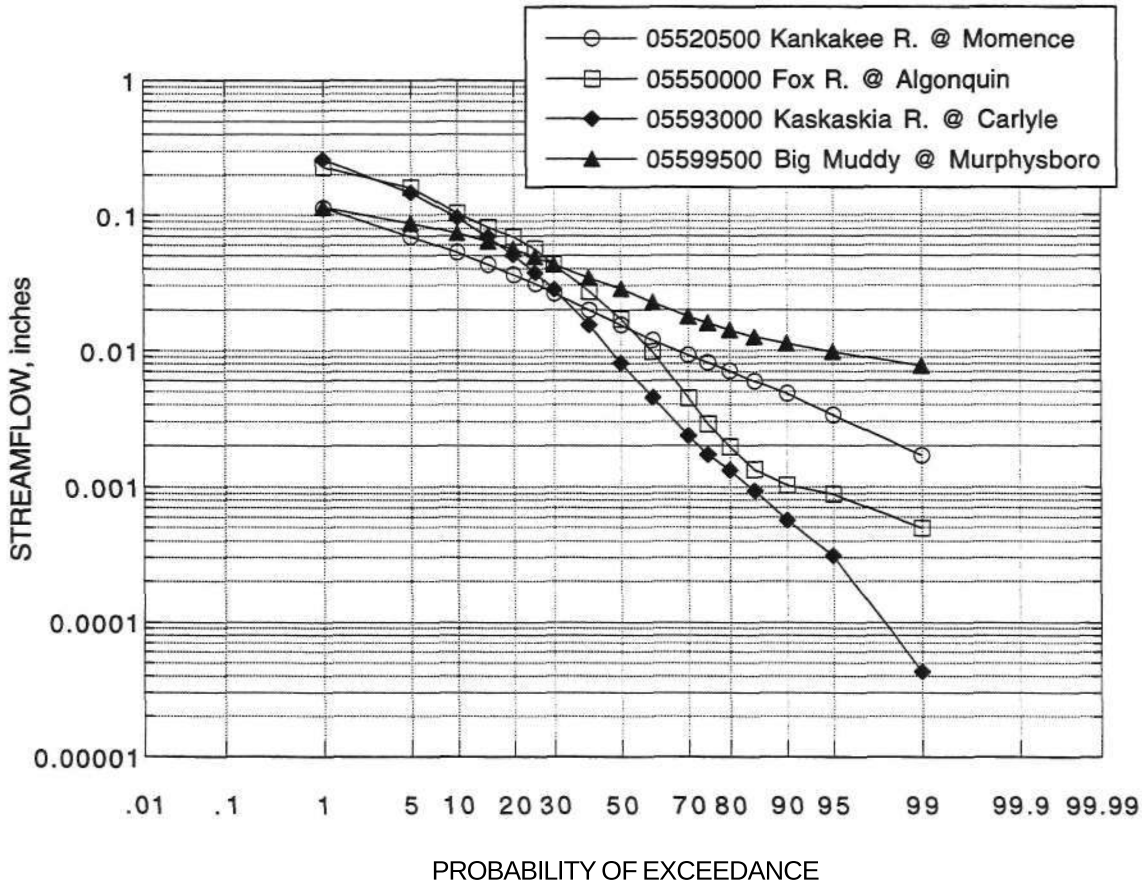

Figure 4. Flow duration curves for four Illinois watersheds

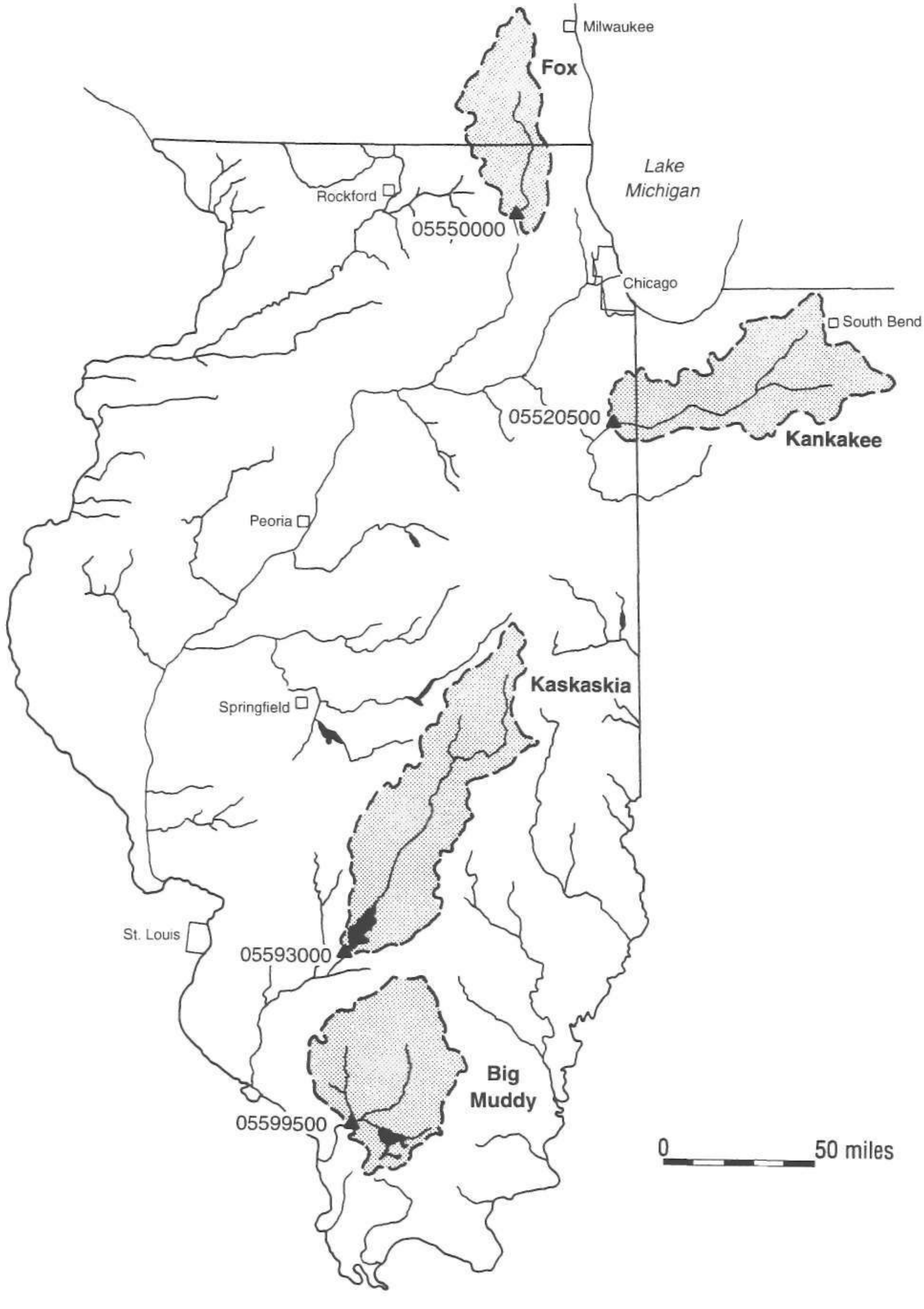

Figure 5. Locations of four Illinois watersheds selected
for comparing flow characteristics using the flow duration method

Low-Flow Watershed Delineation

A coverage containing a unique watershed for each USGS gaging station was constructed from the USGS watershed coverage (Figure 6). This coverage was developed over a number of years and currently contains 2,695 separate watersheds. The USGS gaging station coverage was initially created in 1984 and has been updated to include a total of 1,736 stations (Figure 7). Generally, there are several watershed polygons associated with each gaging station. The REGIONDISSOLVE procedure in ARC/INFO was used to create an overlying layer containing a unique watershed for each gaging station (Environmental Systems Research Institute, Inc., 1995). The unique watersheds were first determined manually by examining plots of the basins, stations, streams, and, where necessary, topography. These watersheds were then entered into a GIS database using the REGIONDISSOLVE command. This ARC/INFO procedure creates unique watersheds for the selected gaging stations by combining several sub-watersheds.

After creating all the unique watersheds for the gaging stations in Illinois, the USGS gage number was added as an attribute to the REGION INFO table to create a direct link between the station gage number and its associated watershed. Approximately 300 gaging stations were not included either because they had no associated sub-basin or because they were located on interstate rivers with portions of their watersheds outside of Illinois.

The accuracy of this watershed coverage was checked by comparing the published value of the drainage area against the value computed by ARC/INFO. Discrepancies of greater than 5 percent were then reevaluated and corrected for any errors. A 'remarks' attribute was also added to the REGION INFO file, giving codes describing errors or reasons for large discrepancies between published and calculated drainage areas. This new watershed coverage, created using the REGION process on the GIS, will hereafter be referred to as the *watershed coverage*.

Low-Flow Map

A low-flow hydrology map, based on Q_{90} values (the flow exceeded 90 percent of the time), was created using the above described watershed coverage (Figure 8). The Q_{90} values, along with several other flow parameters, are contained in the gaging station INFO files. The USGS gage number served as the common attribute linking the watershed and stations INFO files. Each watershed has a unique value for Q_{90}, but smaller watersheds contained within may have different low-flow characteristics. To display this more complex hydrology, the low-flow hydrology map was created by drawing the larger watersheds first, and then overlaying the smaller ones. The final map (Figure 8) uses six color-coded categories to illustrate the distribution of Q_{90} values. Watersheds lacking a gaging station that could be used to compute a value for Q_{90} appear in white on this map.

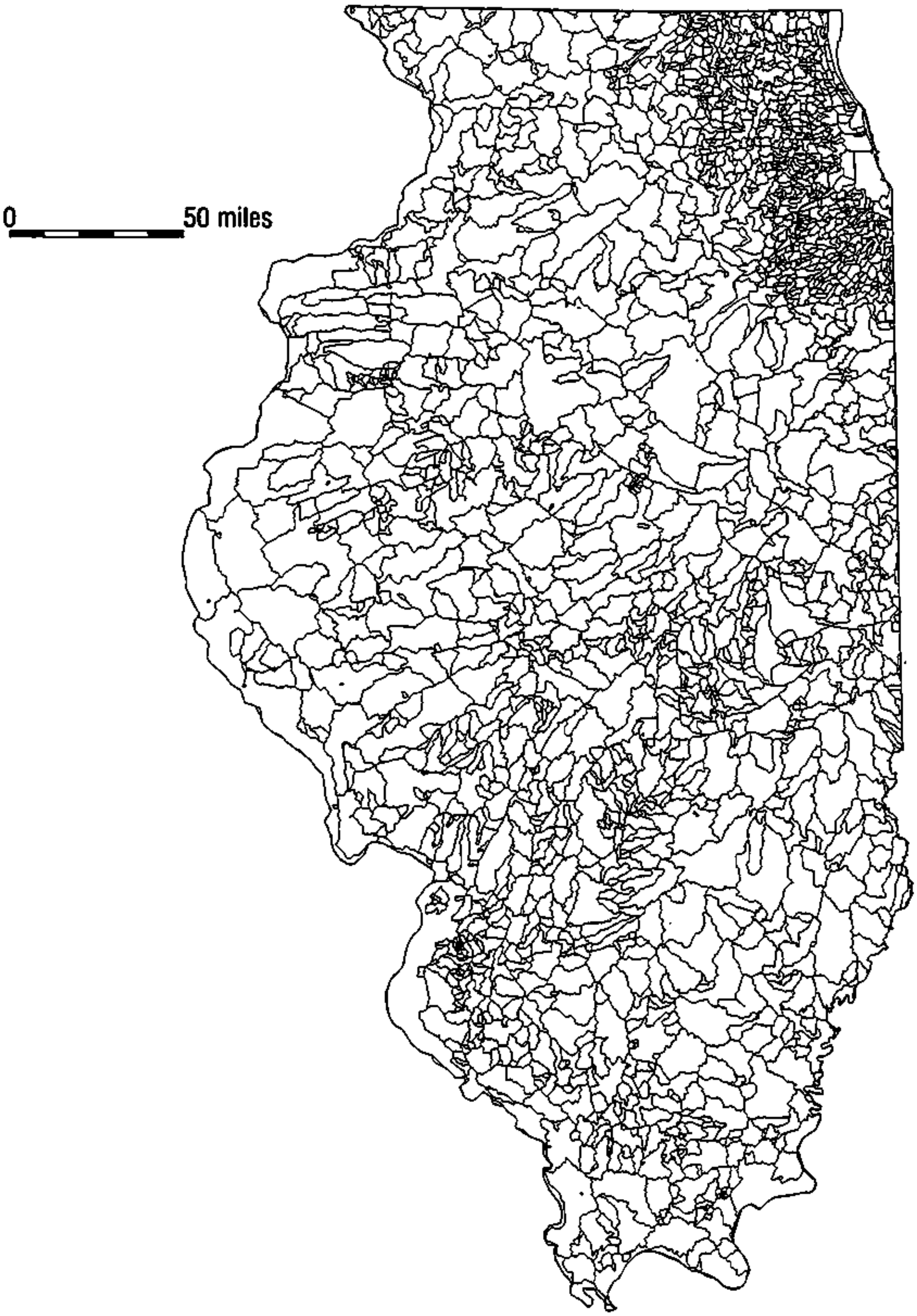

Figure 6. USGS designated watersheds in Illinois

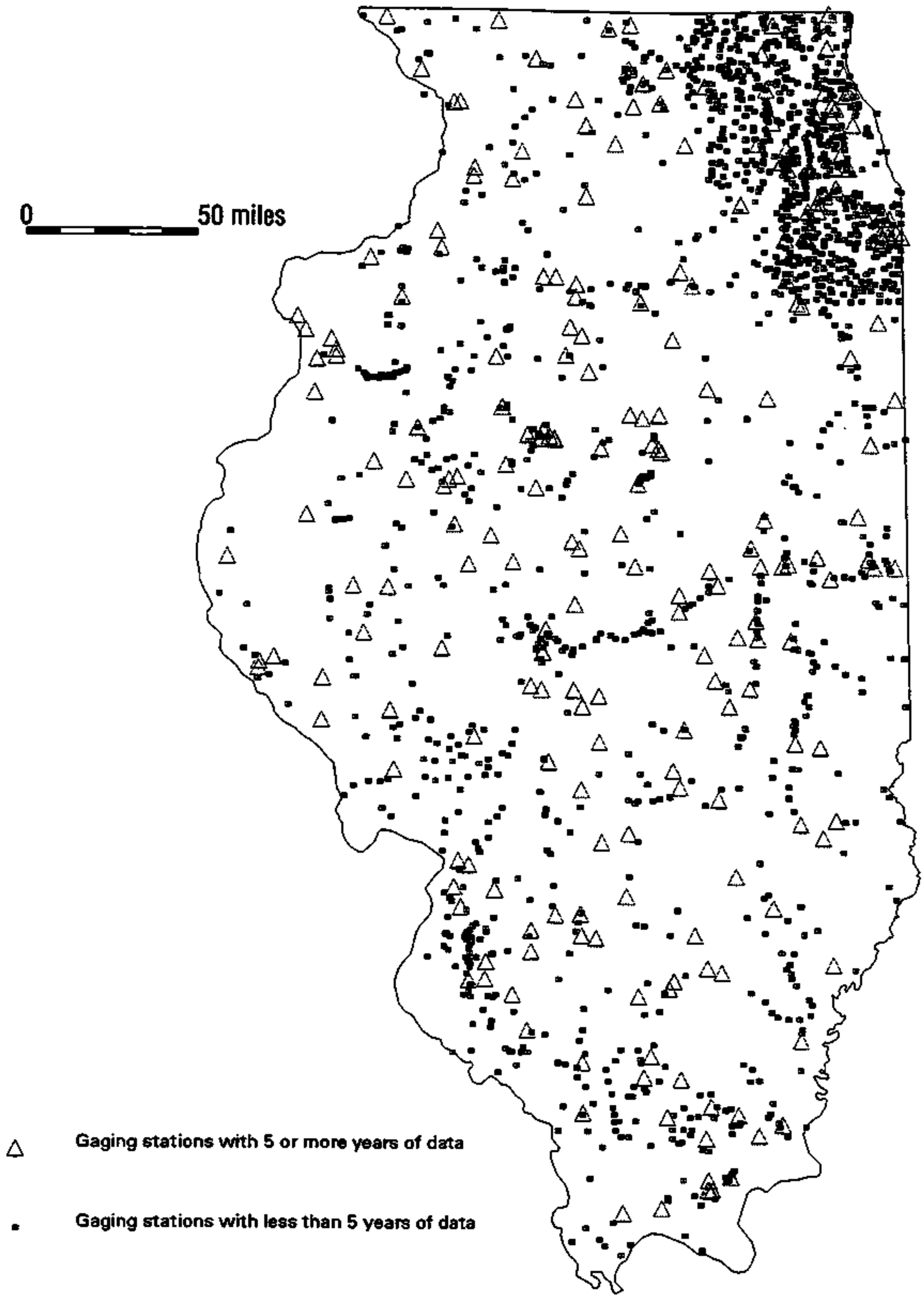

Figure 7. Locations of USGS gaging stations in Illinois

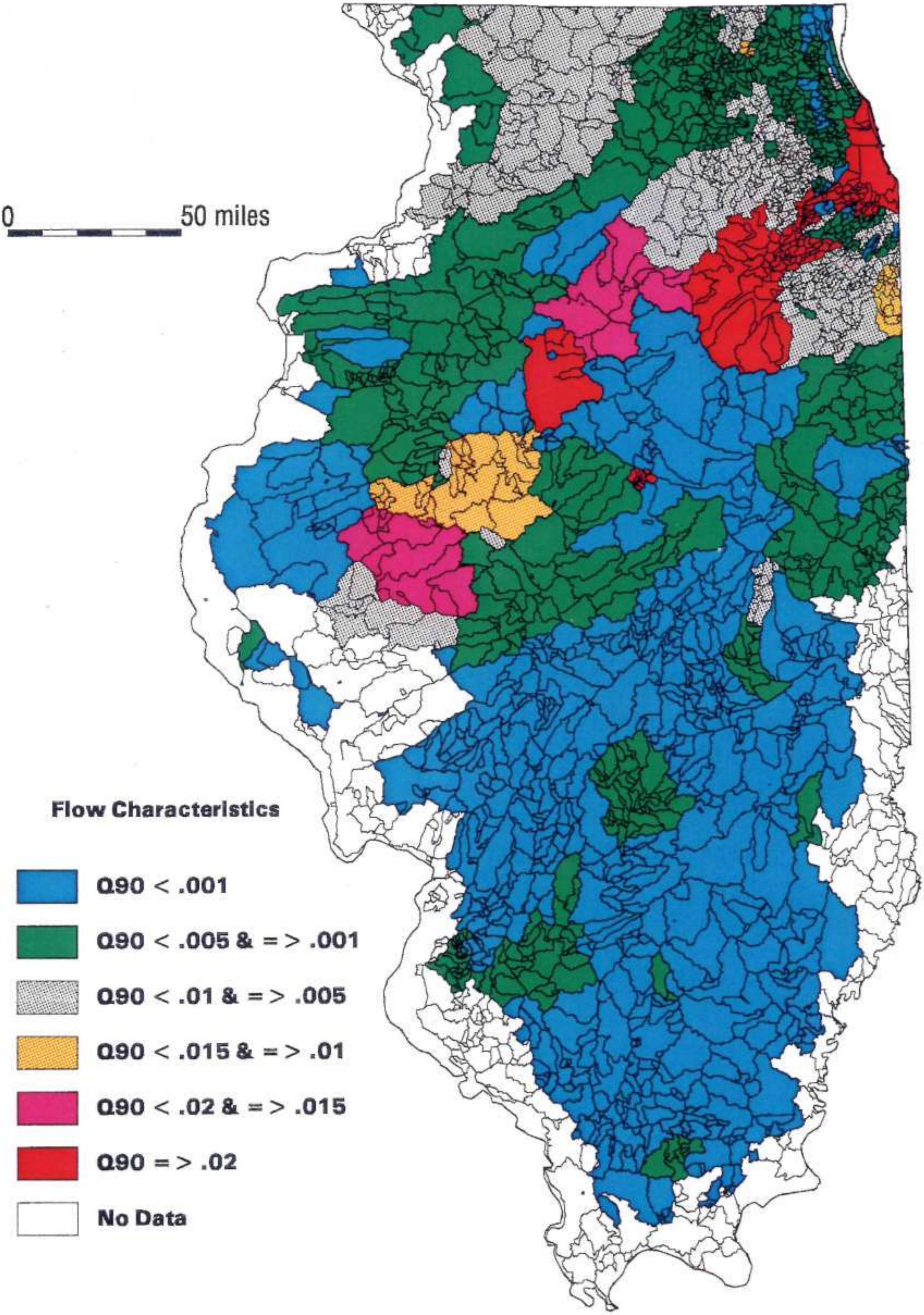

Figure 8. Watershed characterization based on low-streainflow hydrology

The procedures performed to generate the low-flow map for Illinois watersheds are summarized below:

1. A stream gaging point coverage was developed to include all gaging stations in Illinois. The existing ARC/INFO GIS coverage at the Illinois State Water Survey (ISWS) was updated to include additional information from the USGS.

2. Low-flow parameter values were determined at all stream gaging stations in Illinois with five or more years of daily flow record. Data from 270 gaging stations were analyzed, and 237 of these had five or more years of data. The locations of the 237 gages are shown as triangles on Figure 7.

3. The GIS coverage for the existing stream gaging stations was edited to add low-flow attributes: $Q_{90,}$ 90 percent duration flow or the flow value that is exceeded 90 percent of the time; $Q_{95,}$ or 95 percent duration flow; and $Q_{99,}$ or 99 percent duration flow.

4. Low-flow values in cubic feet per second were converted to runoff in inches per square mile. This was done to normalize flow values and to remove the effect of drainage-area size.

5. The USGS watershed coverage was merged with polygon attributes and with the stream gaging station-point coverage to generate a new stream-watershed coverage with polygon attributes.

6. Watershed polygons were grouped according to low-flow values (in inches). Watershed characteristics based on low-flow values are shown in Figure 8. Areas shaded in red, pink, and yellow indicate watersheds with the largest low flows; areas shown in gray indicate moderate low-flow values; and areas in green and blue indicate the small and very small low-flow values, respectively. No data are available for areas shown in white.

The low-flow hydrology of watersheds in Illinois has been classified as follows:

$Q_{90,}$ inches per square mile	*Map color (Figure 8)*
$Q_{90} \geq 0.02$	Red
$0.02 > Q_{90} \geq 0.015$	Pink
$0.015 > Q_{90} \geq 0.010$	Yellow
$0.010 > Q_{90} \geq 0.005$	Gray
$0.005 > Q_{90} \geq 0.001$	Green
$0.001 > Q_{90}$	Blue
Q_{90} undefined	White

Combined Hydrogeologic Terrane and Low-Flow Watershed Data

The use of 30-meter DEM data and the conversion of GIS maps to the REGIONS format dramatically increased the amount of hard drive space needed to accommodate storage and processing of these data. Because the watershed map was developed using REGIONS, the terrane map had to be converted from a polygon format to a REGIONS format before it could be overlaid with the watershed map. These conversion and overlay processes required a large amount of hard disk space and computer processing time. The converted map was so large that it was necessary to split the statewide map into four pieces. The final space requirement for the combined terrane-watershed map exceeded 600 Megabytes. In order to do any processing of these data, an additional 600 to 1,000 Megabytes of space was needed to accommodate output and temporary files. Space limitations on ISGS hard drives also required that the information of source map attributes be deleted, and only the final terrane values were kept on line. These unexpected factors dramatically reduced the amount of analysis that could be conducted on the combined data set.

Data files for the combined terrane and watershed maps included attributes for the hydrogeologic terranes, the low-flow values, and the watershed identifiers. These data were used with a basic frequency analysis to evaluate the relationships between hydrogeologic terranes, as defined for this study, and the low-flow characteristics of more than 200 watersheds.

Results and Discussion

Overlaying the hydrogeologic terrane map with the watershed map allowed for an evaluation of dependence between selected parameters. Our conclusions are preliminary and are based only on a visual comparison and evaluation of the data. We have not performed any statistical analyses of these data. Rather, based on observed patterns in the data, we discuss the importance of individual parameters and the presence or absence of obvious correlation between hydrogeologic terranes and stream low-flow values.

Table 2 shows the statewide percent of each terrane covered by watersheds with various Q_{90} values. For example, 8.9 percent of Terrane 9 occurs within watersheds having Q_{90} values <0.001, while 41.1 percent is within watersheds having Q_{90} values > 0.01.

Due to high interdependence between two pairs of flow categories, the six original Q_{90} categories were consolidated into four: $Q_{90}<0.001$, $0.001 \leq Q_{90} < 0.005$, $0.005 \leq Q_{90} < 0.01$, and $Q_{90} \geq 0.01$. This combination simplified the comparison of hydrogeologic terranes and watershed Q_{90} values. Figure 9 illustrates the percentage of each terrane within these four low-flow watersheds. The two lowest flow categories ($Q_{90}<0.001$ and $0.001 \leq Q_{90} < 0.005$) are referred to as *Very Small* and *Small*, respectively. Q_{90} values ≥ 0.005 and <0.01 are *Moderate*, while values ≥ 0.01 are *Large*.

Table 2. Percent of Terrane Area Covered by Q_{90} Watersheds

Terrane	*$Q_{90} < 0.001$ (Very Small)*	*$0.001 \leq Q_{90} < 0.005$ (Small)*	*$0.005 \leq Q_{90} < 0.01$ (Moderate)*	*$Q_{90} \geq 0.01$ (Large)*
1	6.3	11.9	42.7	39.1
2	27.8	22.0	22.5	27.7
3	10.5	15.6	31.0	42.9
4	19.5	15.4	19.7	45.4
5	17.4	20.5	22.0	40.1
6	25.2	20.5	14.8	39.4
7	14.8	16.7	41.2	27.3
8	12.9	18.3	22.8	46.0
9	8.9	15.5	34.5	41.1
10	11.3	21.2	28.3	39.2
11	30.6	25.6	17.7	26.0

Note: These statistical data were used to produce Figure 9. All rows total 100 percent.

General Observations and Trends: Watershed Q_{90} Values

Trends in watershed Q_{90} values are illustrated in Figure 9.

Very Small Values

The distribution of watersheds with very small Q_{90} values (shaded in blue in Figure 8) ranges from 6.3 to 30.6 percent of the terrane area. The average coverage of these watersheds is 17 percent, and the coefficient of variation is 0.48, making this the least common and most variable Q_{90} category. These watersheds are more common in terranes that have very limited soil percolation characteristics and no aquifer within the upper 50 feet of materials. These watersheds occur in 10 percent or less of terranes characterized by soils that have excessive percolation characteristics and an aquifer within 50 feet of land surface.

Small Values

Watersheds with small Q_{90} values (shaded in green in Figure 8) occur in 11.9 to 25.6 percent of the 11 terranes. The average coverage of these watersheds is 18 percent, with a coefficient of variation of 0.21. Watersheds with these Q_{90} values occur at more equal frequency than those with very small Q_{90} values, and their distribution tends to be less predictable than that of watersheds with very small Q_{90} values.

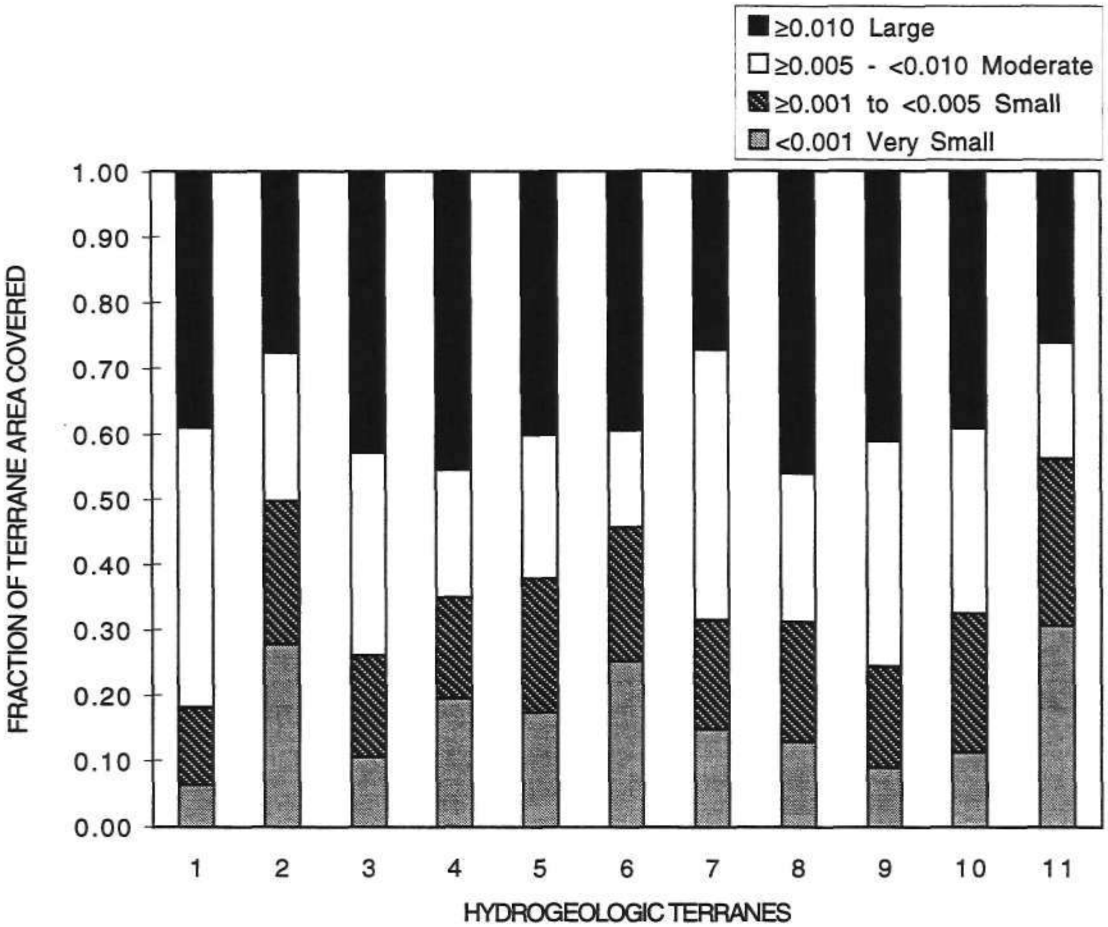

Figure 9. Distribution of watershed low-flow values for Illinois hydrogeologic terranes

Moderate Values

The distribution of moderate Q90 values (shaded in gray in Figure 8) ranges from 15 to 43 percent, with an average occurrence of 27 percent and a coefficient of variation of 0.35. The relationship of terrane characteristics to watershed Q90 values is generally opposite that of very small values. Terranes where moderate Q90 watersheds occur most often are characterized by excessive soil percolation characteristics and an aquifer within 20 feet of land surface. Terranes where these watersheds occur least frequently generally have very limited soil percolation characteristics and no aquifer within 50 feet of land surface. Soil percolation characteristics appear to have a larger impact on the occurrence of these Q90 values than the presence of an aquifer within either 20 feet or 20 to 50 feet of land surface.

Large Values

Watersheds with large Q_{90} values (shaded in yellow, pink, or red in Figure 8) occur in 26 to 46 percent of the 11 terrane types, with an average of 38 percent and a coefficient of variation of 0.19. Large values have the highest average occurrence and lowest variability of all four Q_{90} categories. The relationship of terrane characteristics to large Q_{90} values seems more complicated than any of the other Q_{90} values. Terrane 8, which has moderate to steeply sloping uplands with no aquifer within 50 feet, has the highest occurrence of these watersheds. Conversely, Terranes 11, 7, and 2 have the lowest occurrences of these watersheds, all with about 26 percent. Terrane 11 is characterized by flat to gently sloping lowlands with no aquifer within 50 feet of the land surface, while Terrane 7 has moderate to steep slopes and an aquifer within 50 feet of the surface. Terrane 2 has flat to gently sloping uplands with limited percolation and an aquifer within 20 feet of land surface. The apparent lack of relationship between hydrogeologic parameters and Q_{90} values may be due to several factors, including the arbitrary delineation of terranes and Q_{90} categories and limitations in the number and distribution of characterized watersheds; or, it may be more indicative of a higher degree of variability in flow characteristics in these terranes.

General Observations and Trends: Hydrogeologic Terranes

Trends in hydrogeologic terranes are illustrated in Figure 9.

Terranes 1-3

High soil percolation characteristics appear to be the main factor contributing to high percentages of large and moderate Q_{90} values for Terranes 1 and 3. Although aquifers are present within 20 feet of the surface throughout Terrane 2, very poor to moderate soil percolation rates appear to be contributing to large occurrences of the very small and small Q_{90} values.

The percentage of Terranes 1 and 3 covered by moderate and large Q_{90} values is large compared to Terrane 2. Correspondingly, the percentage of Terranes 1 and 3 covered by the very small and small Q_{90} values is small compared to Terrane 2.

Terranes 1, 2, and 3 are predominant in northern, south-central, western, and southern Illinois where continuous surficial or shallow buried sand and gravel or high permeability bedrock are present (Figure 3). In these areas, drift aquifers consist of either surficial ice-contact and outwash sand and gravel (e.g., in McHenry County southward to Will and Kankakee Counties, Green River Lowland, Mason County), or thin sand and gravel buried by diamicton (e.g., in south-central Illinois), a nonsorted mixture of sand, silt, and clay, which can be interpreted as till.

Terranes 1 and 3 are characterized by high to excessive soil percolation rates and the presence of an aquifer (usually sand and gravel) within 50 feet of the surface. A high rate of water movement through the soil results in relatively rapid and unimpeded flow to the water table. This, along with a highly permeable medium for transporting ground water to streams and rivers, seems to contribute to high percentages of these terranes having large and moderate Q_{90} values. By contrast, Terrane 2 has very poor to moderate soil water movement. Despite the presence of an aquifer within 20 feet of the surface, which theoretically provides a source for large volumes of ground water to streams and rivers, the very poor to moderate soil percolation characteristics may contribute to smaller overall baseflow rates and, therefore, Q_{90} values within this terrane.

The nature of this study prevents direct evaluation of the flow mechanisms responsible for differences in baseflow rates. Our analysis involves only inferences of flow mechanisms based on terrane/Q_{90} flow relationships.

Terranes 4-6

Q_{90} values are different in Terrane 4 than in Terranes 1, 2, and 3, possibly due to differences in the type and size of aquifer material present.

Terrane 4 is characterized by very poor to moderate soil percolation rates and a buried aquifer within 20 to 50 feet of land surface. Its relationship to Terrane 3 was expected to be similar to that between Terranes 1 and 2 and Terranes 9 and 10. While each terrane group has aquifers at similar depths, Terranes 1, 3, and 9 have high to excessive soil percolation, while Terranes 2, 4, and 10 have very poor to moderate soil percolation. For terrane groups 1-2 and 9-10, the percentage of their areas with moderate and large Q_{90} values is great (Terranes 1 and 9) compared to adjacent terranes (Terranes 2 and 10, respectively), and their areal coverage by very small and small Q_{90} values is small (Terranes 2 and 10, respectively) compared to adjacent terranes (Terranes 1 and 9, respectively).

However, this pattern does not exist for Terrane 4, perhaps because this terrane exhibits more variability in the nature of its aquifer materials than do others (e.g., Terranes 1, 2, 3, 9, and 10). Berg and Kempton (1988) mapped those aquifers buried between depths of 20 to 50 feet in Terrane 4 as consisting mainly of (1) sand and gravel less than 20 feet thick (e.g., east of the Illinois River in central Illinois), or (2) fractured bedrock (e.g., along the Mississippi River and in northeastern Illinois).

While a large portion of Terrane 4 is characterized by sand and gravel deposits, these materials were not deposited as massive sheets of outwash or ice-contact deposits, as in much of Terranes 1-3. Rather, they often reside as thin and discontinuous zones within or between diamictons and are restricted to fairly small areas. The portion of Terrane 4 underlain by bedrock may have very inconsistent baseflow characteristics, due to the variable nature of fracture spacings and the limited volume of water that these fractures can hold. This variability in aquifer characteristics, along with poor soil percolation characteristics, may be controlling the less "predictable" distribution of Q_{90} watersheds within Terrane 4.

In the absence of an aquifer, the likely result of greater topographic relief, as expressed in higher soil percolation rates, is a relatively greater occurrence of moderate Q_{90} watersheds in Terrane 5 than in Terrane 6.

Terranes 5 and 6 are the two most common terranes, together covering 54.2 percent of the state land area (see Table 1). The occurrence of moderate Q_{90} values in Terrane 5 is greater than in Terrane 6, while the occurrence of very small Q_{90} values is smaller in Terrane 5 than in Terrane 6. These terranes are both characterized by flat to gently sloping uplands and an absence of aquifers within the upper 50 feet. The absence of an aquifer in these terranes provides some insight to the importance of relief and depth to seasonally high water table for affecting Q_{90} values.

Terrane 5 has high to excessive soil percolation characteristics, while Terrane 6 has very limited to moderate values. Soil percolation characteristics are based in part on soil drainage class, which is often used as a relative indication of seasonally high water tables. More limited percolation categories are dominated by soils with very shallow seasonal water tables. For a given parent material, soil drainage classification is, in turn, generally correlated to a landscape position and land-surface slope.

Both Terranes 5 and 6 reside on flat to gently sloping uplands in loess and diamicton. The presence of excessive to high soil percolation characteristics and an evaluation of the distribution of these two terranes suggest that Terrane 5 has more slopes in the 2 to 5 percent range than Terrane 6. Terrane 5 primarily occurs on moraines (e.g., Valparaiso Moraine, west and northwest of Chicago, and Shelbyville Moraine in northeastern Illinois), or in thick loess areas and bluffs along major rivers (e.g., west-central Illinois). Terrane 6 occurs mainly on flat intermorainal areas (see Figure 3). The very limited to moderate percolation characteristics of the soils in Terrane 6 are probably due to less relief in these areas.

Terranes 7-8

Terranes 7 and 8 are characterized by moderately to steeply sloping areas, where the presence or absence of an aquifer and soil percolation characteristics dramatically affect the occurrence of large and moderate Q_{90} values.

Terranes 7 and 8 cover only 4.5 percent of the state, and include the large-relief regions along major rivers and in driftless areas of southern and northwestern Illinois (Figure 3). Because these regions are so small and high slopes tend to have soils with faster percolation characteristics, we have defined these two terranes based only on the presence or absence of an aquifer. Terrane 7 includes all sloping uplands with an aquifer within 50 feet of land surface, and Terrane 8 includes all sloping uplands with no aquifer in the upper 50 feet.

Very small and small Q_{90} values are basically the same for the two terranes. The presence of an aquifer within 50 feet of land surface in Terrane 7 appears to significantly increase moderate values. The stability of lower Q_{90} values in Terrane 8 suggests that the soil percolation characteristics predominate when no aquifer is present, causing significantly greater occurrences of large Q_{90} watersheds.

Terranes 9-11

Soil percolation characteristics appear to cause slight differences in the occurrence of small Q_{90} values in Terranes 9 and 10. The absence of a shallow aquifer in Terrane 11 appears to significantly reduce the occurrence of watersheds with large and moderate Q_{90} values.

Terranes 9, 10, and 11 are grouped together because they are all characterized by flat to gently sloping lowlands adjacent to a river or stream (see Figure 3). Accordingly, relatively short ground-water flow paths are expected to typify these terranes. The occurrence of moderate and large Q_{90} values in Terranes 9 and 10 is greater than in Terrane 11, while the areal coverage by the very small values is smaller in Terranes 9 and 10 than in Terrane 11. The small difference in watershed Q_{90} values between Terranes 9 and 10 suggests that soil characteristics are not that important in controlling baseflow contributions in lowland areas. The small occurrence of watersheds with moderate and large Q_{90} values in Terrane 11 suggests that the presence of an aquifer within 50 feet of land surface is very important to these larger flow values.

Terrane 9, which occurs in small areas along major river floodplains (e.g., the middle Illinois River valley and Mississippi River-Ohio River valley confluence area), is characterized by high to excessive soil percolation and a sand and gravel aquifer (usually more than 50 feet thick) within 50 feet of the surface. A review of the distribution of Terrane 9 suggests that the sand and gravel aquifers are generally composed of glacial outwash sediments and sandy alluvium, and are frequently at or very near the land surface. Therefore, high and excessive percolation characteristics will likely result in rapid recharge to the water table, and the near-surface occurrence of the aquifer should allow for rapid discharge into the streams as baseflow.

Terrane 10, which occurs extensively on floodplains of the Mississippi, Illinois, Rock, Kaskaskia, Sangamon, Ohio, and Wabash Rivers, has very poor to moderate soil percolation characteristics and a sand and gravel aquifer within 50 feet of the surface. It is likely that these slower percolation characteristics predominate in Terrane 10 because a fine-grained alluvial deposit frequently overlies the sand and gravel outwash sediments. While this finer textured material should slow water percolation rates to the underlying sand and gravel aquifer, thereby limiting the baseflow rates to nearby streams, the Q_{90} values do not show any significant differences between Terranes 9 and 10.

Terrane 11 occurs primarily on tributary floodplains (e.g., Pecatonica River and lower Embarras River), and is characterized by the absence of aquifers in the upper 50 feet of materials.

Summary and Recommendations for Further Study

This study was designed to test the utility of hydrogeologic terranes as a tool for understanding the interaction of shallow ground-water and surface water systems during low-flow regimes. We defined the terranes using several important variables for classifying shallow ground-water flow systems. These variables were limited to previously automated, statewide data sets. The results from this study demonstrate that this approach can be very valuable in identifying functional relationships between hydrogeologic terranes and streamflow characteristics. A few additional steps can be taken to improve the terrane map and to provide more detailed and reliable interpretations of relationships between terranes and variability of streamflow characteristics.

In constructing and analyzing the hydrogeologic terranes map, it became obvious that although slope was likely to be a critical variable in the shallow water cycle, local relief might be a better stratifying variable. For example, where an aquifer is mapped as 20 to 50 feet deep and having soils with high percolation rates at the surface, it might be more useful to subdivide these areas based on local relief (e.g., 0 to 20 feet of relief versus 20 to 60 feet of relief) rather than on slope.

While this study was in progress, a new detailed land-cover map was generated from satellite imagery. Differences in land cover, either natural or human-induced, can significantly affect recharge and the amount of ground water available for discharge to surface water. This information would be very valuable as an additional layer to explain the variability of low flow for designated terranes or portions of terranes. In addition, consideration of land cover would be a meaningful first step to a detailed assessment of the vulnerability of ground water to nonpoint sources originating from agricultural and residential land and municipalities.

In an attempt to perform a statewide analysis of streamflow characteristics, all available data were used. Although we know that human factors can greatly alter streamflow characteristics, our analysis did not attempt to evaluate streams that may have been affected by such factors as dams, wastewater discharges, diversions, and channelization. Future research should analyze the effects of human changes on streamflow and either develop procedures to account for the modifications or remove the streams from further analysis.

Our analysis also included all watersheds without consideration of the effects of drainage-area size. Even though the streamflow values have been normalized, it is possible that the size of the drainage area could have some effect on different streamflow values. Further research should evaluate the influence of drainage area on flow characteristics and identify a classification that could be used to exclude large or small drainage basins from the statewide analysis.

Q_{90} was the low-flow parameter used for this analysis. Additional research is needed to determine whether other low-flow parameters might yield different results. Presently, the classification of low flows as very small, small, moderate, and large is arbitrary. A more systematic classification might produce more consistent relations that could be transferable to other areas.

A logical follow-up study to the present research would be to use multivariate statistical analysis, such as contingency table analysis, principal component analysis, discriminant analysis, or other robust methods to help identify functional relationships between geologic and hydrologic variables. This type of effort would include a reevaluation of the terranes that matches both the observed streamflow characteristics and conceptual ground-water-flow models. This would likely require the identification and inclusion of more representative watersheds in order to reduce the variability caused by inclusion of several very large watersheds.

Finally, additional efforts could include a detailed analysis and discussion of relationships derived from the follow-up research discussed above. Conducting the recommended studies would provide us with an unprecedented understanding of ground-water/surface water relationships in Illinois and help clarify how this information could best be used by water-resource institutions, environmental regulatory agencies, and environmental research agencies. Such information would be very valuable in that it would provide a stratification of surface and ground-water resources based on their sensitivity to contamination. This stratification could easily be prioritized to help allocate financial resources for specific perspectives or interests such as Resource Conservation and Recovery Act (RCRA) site characterizations and Brownfields site evaluations.

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Appendix.

USGS Gaging Stations Used in Low-Flow Analysis

Appendix. USGS Gaging Stations Used in Low-Flow Analysis

USGS gage no.	*Stream and gaging station*	*Start year*	*End year*	*Years of record*	*Drainage area (sq mi)*	Q_{90} *(in/yr)*
05585500	Illinois River at Meredosia	1939	1989	51	26000.00	0.0091
05584000	Illinois River at Beardstown	1921	1938	18	24200.00	0.0170
05570500	Illinois River at Havana	1922	1932	11	18200.00	0.0134
05568500	Illinois River at Kingston Mines	1940	1993	54	15800.00	0.0123
05560000	Illinois River at Peoria	1911	1938	28	14100.00	0.0255
05558300	Illinois River at Henry	1982	1993	12	13500.00	0.0179
05446500	Rock River near Joslin	1940	1993	54	9540.00	0.0075
05443500	Rock River at Como	1915	1977	63	8750.00	0.0064
05543500	Illinois River at Marseilles	1921	1993	73	8250.00	0.0206
05441500	Rock River at Oregon	1940	1949	10	8200.00	0.0069
05437500	Rock River at Rockton	1940	1993	54	6360.00	0.0073
05595000	Kaskaskia River at New Athens	1935	1971	37	5180.00	0.0011
05527500	Kankakee River near Wilmington	1942	1993	52	5150.00	0.0064
05583000	Sangamon River near Oakford	1940	1993	54	5090.00	0.0023
05527000	Kankakee River at Custer Park	1916	1933	18	4810.00	0.0053
05594100	Kaskaskia River near Venedy Station	1970	1993	24	4390.00	0.0012
03381500	Little Wabash River at Carmi	1940	1993	54	3100.00	0.0004
05593000	Kaskaskia River at Carlyle	1940	1993	54	2710.00	0.0007
05552500	Fox River at Dayton	1925	1993	69	2640.00	0.0051
05576500	Sangamon River at Riverton	1915	1962	48	2610.00	0.0007
05437000	Pecatonica River at Shirland	1940	1958	19	2550.00	0.0085
05520500	Kankakee River at Momence	1942	1993	52	2290.00	0.0113
05599500	Big Muddy River at Murphysboro	1931	1993	63	2160.00	0.0006
05526000	Iroquois River near Chebanse	1942	1993	52	2090.00	0.0015
05592500	Kaskaskia River at Vandalia	1942	1993	52	1940.00	0.0010
05582000	Salt Creek near Greenview	1942	1993	52	1800.00	0.0025
05570000	Spoon River at Seville	1915	1993	79	1630.00	0.0014
03345500	Embarras River at Ste. Marie	1942	1993	52	1510.00	0.0011
05538000	Des Plaines River at Joliet	1916	1931	16	1500.00	0.1856
05550000	Fox River at Algonquin	1916	1993	78	1400.00	0.0048
03345000	Embarras River at Newton	1940	1945	6	1390.00	0.0006
05592100	Kaskaskia River near Cowden	1971	1993	23	1330.00	0.0008
05435500	Pecatonica River at Freeport	1942	1993	52	1320.00	0.0089
05585000	La Moine River at Ripley	1922	1993	72	1290.00	0.0007
03339000	Vermilion River near Danville	1929	1993	65	1290.00	0.0016
05555500	Vermilion River at Lowell	1932	1971	40	1270.00	0.0004
03379500	Little Wabash River Below Clay City	1942	1993	52	1130.00	0.0003
05440000	Kishwaukee River near Perryville	1940	1993	54	1090.00	0.0041
05555000	Vermilion River at Streator	1922	1930	9	1080.00	0.0002
05568000	Mackinaw River near Green Valley	1922	1959	38	1070.00	0.0015
05569500	Spoon River at London Mills	1943	1993	51	1070.00	0.0014
05592000	Kaskaskia River at Shelbyville	1941	1993	53	1050.00	0.0004
03382500	Saline River near Junction	1940	1973	34	1050.00	0.0001
05447500	Green River near Geneseo	1937	1993	57	1000.00	0.0034
03338500	Vermilion River near Catlin	1940	1958	19	958.00	0.0012
03344000	Embarras River near Diona	1971	1983	13	919.00	0.0004
05587000	Macoupin Creek near Kane	1941	1993	53	868.00	0.0003
05576000	South Fork Sangamon River near Rochester	1950	1993	44	867.00	0.0002
05597000	Big Muddy River at Plumfield	1942	1993	52	794.00	0.0004
05572500	Sangamon River near Oakley	1952	1967	16	774.00	0.0000

Appendix. Continued

USGS gage no.	*Stream and gaging station*	*Start year*	*End year*	*Years of record*	*Drainage area (sq mi)*	Q_{90} *(in/yr)*
05567500	Mackinaw River near Congerville	1945	1993	49	767.00	0.0006
03378900	Little Wabash River at Louisville	1966	1982	17	745.00	0.0006
05536995	Chicago Sanitary and Ship Canal at Romeoville	1985	1991	7	739.00	0.1179
05594000	Shoal Creek near Breese	1946	1993	48	735.00	0.0006
05525000	Iroquois River at Iroquois	1945	1993	49	686.00	0.0017
05533500	Des Plaines River at Lemont	1916	1944	29	684.00	0.0008
05584500	La Moine River at Colmar	1945	1993	49	655.00	0.0005
05532500	Des Plaines River at Riverside	1944	1993	50	630.00	0.0019
05554500	Vermilion River at Pontiac	1943	1993	51	579.00	0.0004
05575500	South Fork Sangamon River at Kincaid	1946	1961	16	562.00	0.0004
05572000	Sangamon River at Monticello	1915	1993	79	550.00	0.0008
03343550	Embarras River at State Hwy 133 near Oakland	1979	1983	5	542.00	0.0000
05438500	Kishwaukee River at Belvidere	1940	1993	54	538.00	0.0045
05596000	Big Muddy River near Benton	1946	1970	25	502.00	0.0002
05558000	Big Bureau Creek at Bureau	1941	1951	11	485.00	0.0034
05591200	Kaskaskia River at Cooks Mills	1971	1993	23	473.00	0.0017
03380500	Skillet Fork at Wayne City	1942	1993	52	464.00	0.0001
05594800	Silver Creek near Freeburg	1971	1993	23	464.00	0.0007
05525500	Sugar Creek at Milford	1949	1993	45	446.00	0.0008
05466500	Edwards River near New Boston	1935	1993	59	445.00	0.0017
05575000	South Fork Sangamon River near Taylorville	1909	1915	7	434.00	0.0002
05469000	Henderson Creek near Oquawka	1935	1993	59	432.00	0.0015
03336645	Middle Fork Vermilion River above Oakwood	1979	1993	15	432.00	0.0015
05439500	South Branch Kishwaukee River near Fairdale	1940	1993	54	387.00	0.0017
05571000	Sangamon River at Mahomet	1949	1979	31	362.00	0.0004
05529000	Des Plaines River near Des Plaines	1941	1993	53	360.00	0.0010
05495500	Bear Creek near Marcelline	1945	1993	49	349.00	0.0001
05593525	Crooked Creek near Posey	1968	1974	7	344.00	0.0006
03338000	Salt Fork near Homer	1945	1958	14	340.00	0.0020
05578500	Salt Creek near Rowell	1943	1993	51	335.00	0.0012
05581500	Sugar Creek near Hartsburg	1945	1972	28	333.00	0.0015
05540500	Du Page River at Shorewood	1941	1993	53	324.00	0.0051
03346000	North Fork Embarras River near Oblong	1941	1993	53	318.00	0.0003
05580500	Kickapoo Creek near Lincoln	1945	1972	28	306.00	0.0007
05563500	Kickapoo Creek at Peoria	1945	1971	27	297.00	0.0009
05599000	Beaucoup Creek near Matthews	1946	1983	38	292.00	0.0002
05574500	Flat Branch near Taylorville	1950	1983	34	276.00	0.0002
05593520	Crooked Creek near Hoffman	1975	1993	19	254.00	0.0006
05536325	Little Calumet River at Harvey	1917	1933	17	252.00	0.0040
05419000	Apple River near Hanover	1935	1993	59	247.00	0.0047
03612000	Cache River at Forman	1925	1993	69	244.00	0.0003
03378635	Little Wabash River near Effingham	1967	1993	27	240.00	0.0000
05570910	Sangamon River at Fisher	1979	1993	15	240.00	0.0007
05528000	Des Plaines River near Gurnee	1946	1983	38	232.00	0.0006
05420000	Plum River Bl Carroll Creek near Savanna	1941	1977	37	230.00	0.0031
03378000	Bonpas Creek at Browns	1941	1993	53	228.00	0.0000
05580000	Kickapoo Creek at Waynesville	1949	1993	45	227.00	0.0007
03382200	Middle Fork Saline River near Harrisburg	1924	1932	9	225.00	0.0001
05579500	Lake Fork near Cornland	1949	1993	45	214.00	0.0012
05587900	Cahokia Creek at Edwardsville	1970	1993	24	212.00	0.0003

Appendix. Continued

USGS gage no.	*Stream and gaging station*	*Start year*	*End year*	*Years of record*	*Drainage area (sq mi)*	Q_{90} *(in/yr)*
03380350	Skillet Fork near Iuka	1966	1983	18	208.00	0.0000
05536290	Little Calumet River at South Holland	1948	1993	46	208.00	0.0063
05447000	Green River at Amboy	1940	1958	19	201.00	0.0019
05556500	Big Bureau Creek at Princeton	1942	1993	52	196.00	0.0006
05548280	Nippersink Creek near Spring Grove	1967	1993	27	192.00	0.0081
03343400	Embarras River near Camargo	1961	1993	33	186.00	0.0005
05554000	North Fork Vermilion River near Charlotte	1943	1962	20	186.00	0.0001
05467000	Pope Creek near Keithsburg	1935	1992	58	174.00	0.0011
05446000	Rock Creek at Morrison	1941	1951	11	164.00	0.0095
05419500	Plum River near Savanna	1935	1941	7	162.00	0.0016
05445500	Rock Creek near Morrison	1943	1958	16	158.00	0.0047
05466000	Edwards River near Orion	1941	1993	53	155.00	0.0013
05594450	Silver Creek near Troy	1967	1993	27	154.00	0.0001
05592800	Hurricane Creek near Mulberry Grove	1971	1993	23	152.00	0.0005
05467500	Henderson Creek near Litde York	1941	1958	18	151.00	0.0005
05590800	Lake Fork at Atwood	1973	1993	21	149.00	0.0002
05513000	Bay Creek at Nebo	1940	1986	47	148.00	0.0003
03382100	South F Saline River near Carrier Mills	1966	1993	28	147.00	0.0013
05444000	Elkhorn Creek near Penrose	1940	1993	54	146.00	0.0064
03336900	Salt Fork near St. Joseph	1959	1991	33	134.00	0.0027
05468500	Cedar Creek at Little York	1941	1971	31	132.00	0.0026
05595200	Richland Creek near Hecker	1970	1993	24	129.00	0.0026
05594090	Sugar Creek at Albers	1973	1983	11	124.00	0.0001
05527800	Des Plaines River at Russell	1968	1993	26	123.00	0.0009
05563000	Kickapoo Creek near Kickapoo	1945	1962	18	119.00	0.0009
05440500	Killbuck Creek near Monroe Center	1940	1971	32	117.00	0.0018
05442000	Kyte River near Flagg Center	1940	1951	12	116.00	0.0019
05559500	Crow Creek near Washburn	1945	1972	28	115.00	0.0000
05531500	Salt Creek at Western Springs	1946	1993	48	115.00	0.0046
05592900	East Fork Kaskaskia River near Sandoval	1980	1993	14	113.00	0.0000
05591700	West Okaw River near Lovington	1981	1993	13	112.00	0.0000
05572450	Friends Creek at Argenta	1967	1983	17	111.00	0.0000
05590400	Kaskaskia River near Pesotum	1965	1979	15	109.00	0.0068
05539000	Hickory Creek at Joliet	1945	1993	49	107.00	0.0025
05536275	Thorn Creek at Thornton	1949	1993	45	104.00	0.0079
05441000	Leaf River at Leaf River	1940	1958	19	103.00	0.0051
05536000	North Branch Chicago River at Niles	1951	1993	43	100.00	0.0041
05557500	East Bureau Creek near Bureau	1937	1966	30	99.00	0.0000
03380475	Horse Creek near Keenes	1960	1990	31	97.20	0.0000
05567000	Panther Creek near El Paso	1950	1960	11	93.90	0.0003
05540095	West Br Du Page River near Warrenville	1969	1993	25	90.40	0.0099
05595730	Rayse Creek near Waltonville	1980	1993	14	88.00	0.0000
05557000	West Bureau Creek at Wyanet	1937	1966	30	86.70	0.0001
05438250	Coon Creek at Riley	1962	1982	21	85.10	0.0032
05469500	South Henderson Creek at Biggsville	1940	1971	32	82.90	0.0001
05439000	South Branch Kishwaukee River at Dekalb	1980	1993	14	77.70	0.0018
05595820	Casey Fork at Mount Vernon	1986	1993	8	76.90	0.0013
05502080	Hadley Creek near Shinn	1942	1947	6	73.60	0.0012
05502040	Hadley Creek at Kinderhook	1940	1986	47	72.70	0.0004
05594330	Mud Creek near Marissa	1971	1983	13	72.40	0.0000

Appendix. Continued

USGS gage no.	*Stream and gaging station*	*Start year*	*End year*	*Years of record*	*Drainage area (sq mi)*	Q_{90} *(in/yr)*
05551700	Blackberry Creek near Yorkville	1961	1993	33	70.20	0.0051
03337500	Saline Branch at Urbana	1937	1958	22	68.00	0.0022
05468000	North Henderson Creek near Seaton	1941	1951	11	67.10	0.0007
05568800	Indian Creek near Wyoming	1960	1993	34	62.70	0.0014
05448000	Mill Creek at Milan	1942	1992	51	62.40	0.0008
05562000	Farm Creek at East Peoria	1945	1981	37	61.20	0.0007
05586800	Otter Creek near Palmyra	1960	1980	21	61.10	0.0000
05558500	Crow Creek (West) near Henry	1950	1971	22	56.20	0.0002
05593900	East Fork Shoal Creek near Coffeen	1964	1993	30	55.50	0.0000
05564500	Money Creek above Lake Bloomington	1934	1958	25	53.10	0.0000
05575800	Horse Creek at Pawnee	1968	1985	18	52.20	0.0000
05551200	Ferson Creek near St. Charles	1962	1993	32	51.70	0.0027
05564400	Money Creek near Towanda	1959	1983	25	49.00	0.0000
05592300	Wolf Creek near Beecher City	1960	1983	24	47.90	0.0000
05571500	Goose Creek near De Land	1952	1959	8	47.90	0.0000
03384450	Lusk Creek near Eddyville	1968	1993	26	42.90	0.0001
05570370	Big Creek near Bryant	1973	1992	20	41.20	0.0046
05502020	Hadley Creek near Barry	1956	1966	11	40.90	0.0001
05414820	Sinsinawa River near Menominee	1968	1993	26	39.60	0.0085
05512500	Bay Creek at Pittsfield	1940	1993	54	39.40	0.0002
05588000	Indian Creek at Wanda	1941	1993	53	36.70	0.0000
05550500	Poplar Creek at Elgin	1952	1993	42	35.20	0.0012
03336500	Bluegrass Creek at Potomac	1950	1971	22	35.00	0.0001
05591550	Whitley Creek near Allenville	1981	1993	13	34.60	0.0001
05580950	Sugar Creek near Bloomington	1983	1993	11	34.40	0.0204
05575830	Brush Creek near Divernon	1974	1983	10	32.40	0.0000
05600000	Big Creek near Wetaug	1941	1972	32	32.20	0.0007
05531000	Salt Creek near Arlington Heights	1951	1972	22	32.10	0.0005
05597500	Crab Orchard Creek near Marion	1952	1993	42	31.70	0.0000
05566500	East Branch Panther Creek at El Paso	1950	1983	34	30.50	0.0001
05530990	Salt Creek at Rolling Meadows	1974	1993	20	30.50	0.0021
05586000	N Fk Mauvaise Terre Cr near Jacksonville	1951	1975	25	29.10	0.0000
05539900	W Branch Du Page River near West Chicago	1962	1993	32	28.50	0.0084
05570350	Big Creek at St. David	1973	1985	13	28.00	0.0070
05560500	Farm Creek at Farmdale	1949	1988	40	27.40	0.0006
05582500	Crane Creek near Easton	1950	1975	26	26.50	0.0056
05584400	Drowning Fork at Bushnell	1961	1983	23	26.30	0.0000
05536235	Deer Creek near Chicago Heights	1949	1993	45	23.10	0.0014
05589500	Canteen Creek at Caseyville	1940	1982	43	22.60	0.0008
05595800	Sevenmile Creek near Mt. Vernon	1961	1983	23	21.10	0.0000
05535070	Skokie River near Highland Park	1968	1993	26	21.10	0.0044
05537500	Long Run near Lemont	1952	1993	42	20.90	0.0002
05534500	North Branch Chicago River at Deerfield	1953	1993	41	19.70	0.0006
05530500	Willow Creek near Park Ridge	1951	1958	8	19.70	0.0004
05528500	Buffalo Creek near Wheeling	1953	1993	41	19.60	0.0008
05538500	Spring Creek at Joliet	1926	1933	8	19.60	0.0061
03385000	Hayes Creek at Glendale	1950	1976	27	19.10	0.0000
05540060	Kress Creek at West Chicago	1986	1993	8	18.10	0.0027
05532000	Addison Creek at Bellwood	1952	1993	42	17.90	0.0048
05595500	Marys River near Sparta	1950	1971	22	17.80	0.0000

Appendix. Concluded

USGS gage no.	*Stream and gaging station*	*Start year*	*End year*	*Years of record*	*Drainage area (sq mi)*	*Q_{90} (in/yr)*
05593600	Blue Grass Creek near Raymond	1961	1983	23	17.30	0.0000
05536210	Thorn Creek near Chicago Heights	1965	1980	16	17.20	0.0009
05536270	North Creek near Lansing	1949	1980	32	16.80	0.0009
05533000	Flag Creek near Willow Springs	1952	1993	42	16.50	0.0092
05549000	Boone Creek near Mc Henry	1949	1983	35	15.50	0.0125
05437695	Keith Creek at Eighth Street at Rockford	1980	1987	8	13.40	0.0016
03382170	Brushy Creek near Harco	1969	1983	15	13.30	0.0000
05530000	Weller Creek at Des Plaines	1951	1993	43	13.20	0.0006
05535000	Skokie River at Lake Forest	1952	1993	42	13.00	0.0043
05533400	Sawmill Creek near Lemont	1987	1993	7	13.00	0.0013
05536340	Midlothian Creek at Oak Forest	1951	1993	43	12.60	0.0014
05590000	Kaskaskia Ditch at Bondville	1950	1990	41	12.40	0.0007
05526500	Terry Creek near Custer Park	1950	1976	27	12.10	0.0015
05535500	Wf Of N Br Chicago River at Northbrook	1953	1993	41	11.50	0.0052
05561000	Ackerman Creek at Farmdale	1955	1980	26	11.20	0.0000
05536500	Tinley Creek near Palos Park	1952	1993	42	11.20	0.0003
05574000	South Fork Sangamon River near Nokomis	1952	1976	25	11.00	0.0000
03386500	Sugar Creek near Dixon Springs	1951	1972	22	9.93	0.0000
05565000	Hickory Creek above Lake Bloomington	1939	1958	20	9.81	0.0000
05536265	Lansing Ditch near Lansing	1949	1993	45	8.84	0.0025
03382510	Eagle Creek near Equality	1967	1982	16	8.51	0.0003
05591500	Asa Creek at Sullivan	1951	1983	33	8.05	0.0000
05529500	Mc Donald Creek near Mount Prospect	1953	1993	41	7.93	0.0000
03344500	Range Creek near Casey	1951	1983	33	7.61	0.0000
05566000	East Branch Panther Creek near Gridley	1950	1960	11	6.30	0.0000
05570360	Evelyn Branch near Bryant	1973	1992	20	5 78	0.0043
05559000	Gimlet Creek at Sparland	1950	1971	22	5.66	0.0000
05561500	Fondulac Creek near East Peoria	1949	1988	40	5.54	0.0000
03337000	Boneyard Creek at Urbana	1949	1993	45	4.46	0.0083
05596500	Tilley Creek near West Frankfort	1939	1955	17	3.87	0.0000
05586500	Hurricane Creek near Roodhouse	1951	1976	26	2.30	0.0000
03386000	Lake Glendale Outlet near Dixon Springs	1955	1963	9	1 98	0 0000
05435000	Cedar Creek near Winslow	1952	1971	20	1.31	0.0000
03385500	Lake Glendale Inlet near Dixon Springs	1955	1963	9	1.05	0.0000

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