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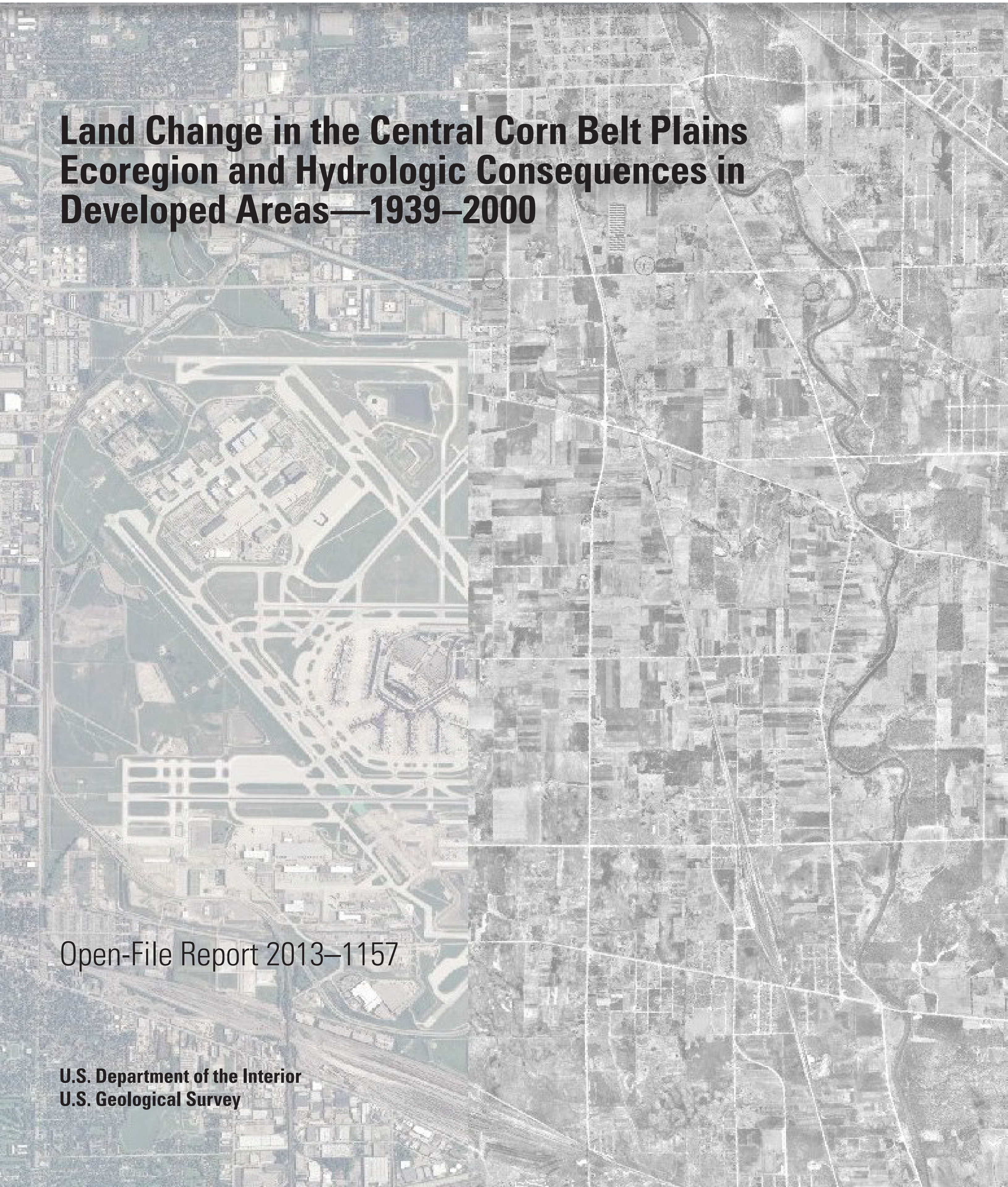

Land Change in the Central Corn Belt Plains Ecoregion and Hydrologic Consequences in Developed Areas—1939–2000

Open-File Report 2013–1157

U.S. Department of the Interior
U.S. Geological Survey

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By Krista Karstensen, David Shaver, Randal Alexander, Thomas Over, and David Soong

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U.S. Department of the Interior
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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
acre	0.4047	square hectometer (hm^2)
	Flow rate	
Cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the equations:

$$°C = 5/9\ (°F - 32)$$

$$°F = 9/5\ (°C) + 32$$

Vertical coordinate information is referenced to, as “North American Vertical Datum of 1988 (NAVD 88).”

Horizontal coordinate information is referenced to as, “North American Datum of 1983 (NAD 83).”

Hydrologic Terms

The hydrologic definitions provided largely are from Langbein and Iseri (1960) and Perry (2005).

A

annual maximum peak streamflow The maximum instantaneous discharge value measured during a given water year at a streamflow-gaging station.

D

discharge Discharge is the volume of water that passes a given location within a given period of time. In its simplest concept, discharge means outflow; therefore, the use of this term is not restricted to course or location, and it can be applied to describe the flow of water from a pipe or a drainage basin.

drainage area The drainage area of a stream at a specified location is the area, measured in a horizontal plane, that is enclosed by a drainage divide.

drainage basin A part of the surface of the Earth where precipitation runs off into the drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

F

flood An overflow of water onto or an inundation of lands that are not normally covered by water, and causes or threatens damage.

P

peak streamflow The maximum instantaneous discharge of a stream or river at a given location, and usually occurs at or near the time of maximum stage.

R

runoff That part of the precipitation, snowmelt, or irrigation water that appears in surface streams, rivers, drains, or sewers.

S

streamflow The water discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than runoff because streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

streamflow-gaging station A site on a stream, lake, reservoir or other body of water where observations and hydrologic data are obtained. The U.S. Geological Survey measures stream discharge at streamflow-gaging stations.

W

water year The continuous 12-month period from October 1 through September 30, and is designated by the year in which it ends. Thus, the year ending September 30, 1994, is called the "1994 water year."

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Abstract

This report emphasizes the importance of a multi-disciplinary understanding of how land use and land cover can affect regional hydrology by collaboratively investigating how increases in developed land area may affect stream discharge by evaluating

- Land-cover change from 1939 to 2000,
- Urban housing density data from 1940 to 2010, and
- Changes in annual peak streamflow from water years 1945 to 2009.

The results and methods crosscut two mission areas of the U.S. Geological Survey (Climate and Land Use, Water) and can be used to better assess developed land change and hydrologic consequences, which can be used to better assess future management and mitigation strategies.

Introduction

The U. S. Geological Survey (USGS) Land Cover Trends Project investigates the rates, trends, causes, and consequences of contemporary U.S. land-use and land-cover change (Loveland and others, 2002). Through comparison of land cover in different time periods, the rates and types of changes can be determined in order to assess possible effects of land use on socioeconomic, biologic, geologic, and hydrologic systems (Loveland and others, 1999).

Historical settlement patterns and contemporary driving forces, such as changes in population and technological advancements, are primary factors that create a complex pattern of land-cover change across the United States. Land-change analyses of the period 1973 to 2000 revealed the geographic and temporal variability of landscape change across a diverse national setting. This 27-year timeframe assessed four temporal periods: 1973 to 1980, 1980 to 1986, 1986 to 1992, and 1992 to 2000. General land-cover classes for these periods include water, developed, mechanically disturbed, mining, barren, forest, grassland/shrubland, agriculture, wetland, non-mechanically disturbed, and ice/snow. Land cover for these periods is interpreted from Landsat Multispectral Scanner, Thematic Mapper, and Enhanced Thematic Mapper Plus imagery to categorize land-cover change and evaluate trends using a modified Anderson Land Use Land Cover Classification System (Anderson and others, 1976) for image interpretation. These land-cover classes were selected because they complemented the objective of looking at land-use change with land cover serving as a surrogate for land use (Loveland and others, 1999).

Mapping for the four temporal periods within the 84 Level III ecoregions was completed in March 2011. Results illustrate a complexity of landscape dynamics and temporally variable processes occurring across the national landscape that vary depending on the environmental setting and interacting change agents. As the project moves forward, teams will be developing an improved analytical framework for understanding human-environment dynamics (such as ecosystem function, biodiversity and habitat, and water quality and quantity) and will work to synthesize biophysical and land-use interactions to better assess the effects of land-use changes on environmental conditions and land management.

Because of the great amount of geographic variability in land-cover change within and among ecoregions, a plan to assess changes with a single ecoregion was developed. The Central Corn Belt Plains was selected as the ecoregion to analyze because (1) the 1973 to 2000 interpretation, analysis, and statistical evaluation were complete; (2) the authors had participated in field analysis of the ecoregion; and (3) aerial photography was readily available to extend the land-cover analysis period back to 1939. This extended period of record provides researchers with more data to help understand the story of land change and associated consequences in the ecoregion.

In addition to these reasons, another motivation for selecting the Central Corn Belt Plains Ecoregion was the presence of the Chicago metropolitan area, which had experienced substantial change during the completed 1973 to 2000 study period. In the Chicago metropolitan area, important

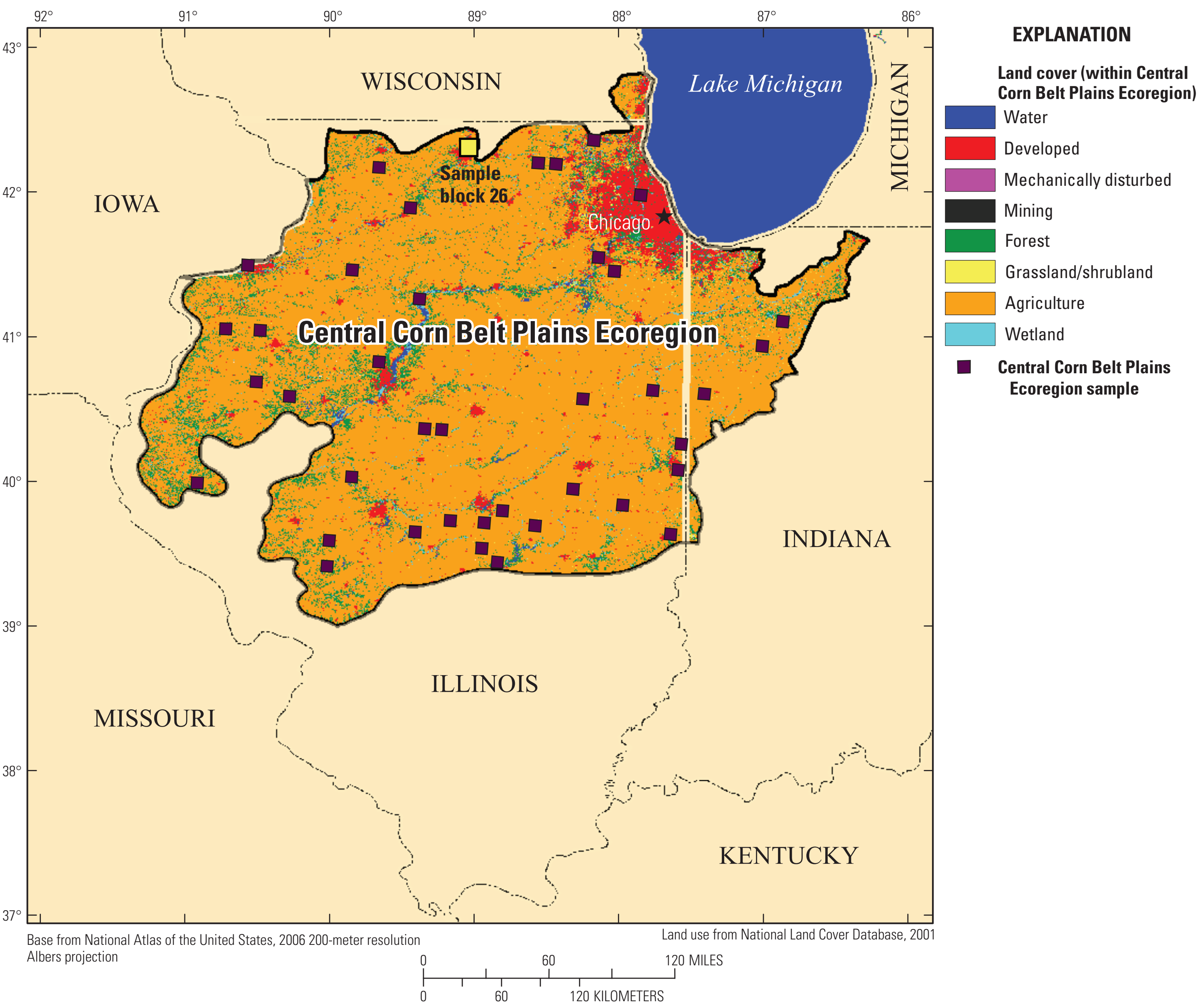


Figure 1. 2001 Land cover in the Central Corn Belt Plains Ecoregion.

drivers of change included changes in population growth rates, socioeconomics, production and manufacturing, and increased development. The spatial growth of developed land in the ecoregion somewhat mirrored the image of the loss of agricultural land. In addition to affecting agricultural land, increases in developed land area also can affect water supply and natural hazards such as urban flooding. The research efforts described herein focus on the potential consequences of land-use changes in the Central Corn Belt Plains Ecoregion and how these consequences may manifest in regional hydrologic trends.

Study Area

The Central Corn Belt Plains Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1999) covers approximately 98,800 square kilometers (km^2) [38,000 square miles (mi^2)] in Illinois and Indiana, extending slightly into Wisconsin (fig. 1). Note that updated ecoregion boundaries are documented by the U.S. Environmental Protection Agency (2007) and were derived from Omernik (1987). These updates took place after the Land Cover Trends Project classification initiative was underway so analysis incorporates the boundaries reflected in Omernik (1987) and the U.S. Environmental Protection Agency (1999).

Elevations in the ecoregion range from approximately 122 meters (400 feet) in the south to about 305 meters (1,000 feet) on a few hills in the north (Omernik and Gallant, 1988). The average length of the frost-free period varies from 160 to about 190 days (Wiken and others, 2011) with most of the annual precipitation falling during the growing season and averaging from 813 millimeters (mm) (32 inches) to 1,117 mm (44 inches) annually (Omernik and Gallant, 1988). The soils in the ecoregion are generally dark and fertile which help support the extensive cropland and livestock farming vital to the ecoregion (Woods and others, 2006).

The native landscape was composed of extensive prairie communities intermixed with oak-hickory forests; however, nearly all of the natural vegetation has been replaced by agriculture (Wiken and others, 2011), and farms are now extensive and primarily produce corn and soybeans. Livestock farming in the Central Corn Belt Plains is not as common as in neighboring ecoregions, but does include hogs, cattle, sheep, and poultry (Woods and others, 2006). Agriculture in the ecoregion has affected stream chemistry, turbidity, and habitat (Woods and others, 2006).

The Central Corn Belt Plains has a relatively high population, especially adjacent to Lake Michigan where nearly all of the natural vegetation has been replaced by urban development (Woods and others, 2006). Chicago is the most populated city in the ecoregion with a 2000 population of 2,896,016. But there are many small- to medium-sized cities scattered throughout the ecoregion including (2000 population) Rockford, Illinois (150,115); the Chicago suburbs of Aurora, Ill. (142,115) and Naperville, Ill. (128,358); Peoria, Ill. (112,892); Springfield, Ill. (111,454); Gary, Indiana (102,746); and Decatur, Ill. (81, 860) (U.S. Census Bureau, 2000).

Chicago Metropolitan Area

Suburban expansion began in the period following World War II (McGrath, 2001). The city of Chicago showed noticeable upward population swings in 1920 and 1950 (Buchanan and Acevedo, 2010) before beginning a slight but consistent decline in the 1960s (fig. 2); however, the decline in population did not slow the urban development: from 1950 to 2000, the urbanized land area of Chicago grew from 1,834 km^2 to 4,330 km^2 (McGrath, 2001).

Historically, the city also underwent substantial infrastructure changes to accommodate emerging modes of transportation during the transition from canals to railroads (1850s), at the turn of the century (electric railroads), and when the automobile began to dominate (1940s) (Buchanan and Acevedo, 2010). As demonstrated in the statistics later in the report, much of the development occurred at the expense of agricultural land (figs. 3 and 4). According to the Northeastern Illinois Planning Commission, the explosion of land consumption continued dramatically between 1970 and 1990 with a 40-percent increase in developed land area in the region, whereas the region's population increased by only 4 percent (Mariner, 2005; Platt, 2004). In a study by Radeloff and others (2005), housing growth varied by ecoregions in the upper Midwest. The study indicates that the highest absolute growth

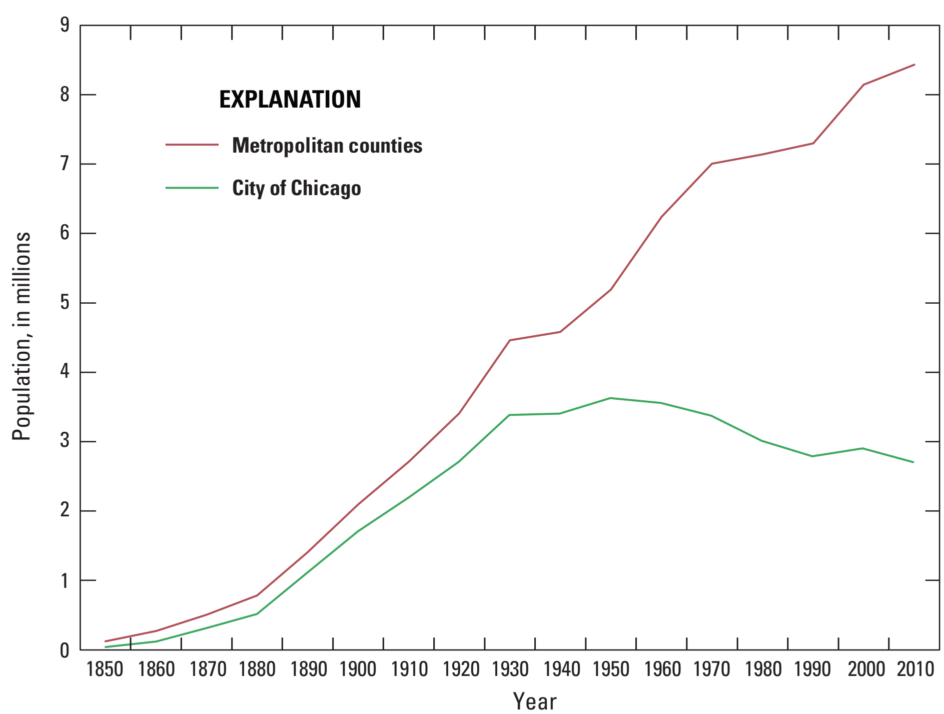


Figure 2. Population trends for the Chicago metropolitan counties and the city of Chicago. Chicago metropolitan counties include Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will (University of Virginia, 2007; McClendon, 2012).

Figure 3. Land-cover change in sample block 26 (fig. 1) throughout the study period *A*, 1939; *B*, 1974; *C*, 1980; *D*, 1986; *E*, 1992; and *F*, 2000.

between 1940 and 2000 occurred in the Chicago, Ill./Gary, Ind./Kenosha, Wisconsin and Milwaukee, Wis./Racine, Wis. areas, and documents that suburban housing growth was especially high post World War II. A historical view of this growth and development pattern in the Chicago area is provided by the Census-based housing density product of Theobald (2005; fig. 5) and further illustrates that the rate of development increased despite minimal population growth. Whether urban population and the corresponding land change is rapid or slow, it can be difficult to measure actual changes in the developed land because it is a collection of areas under various ownerships (Platt, 2004) and surfaces (Xian and others, 2006).

Methods

Land-Cover Change Analysis

The methodology of the Land Cover Trends Project is defined in part by multitemporal analysis of Landsat satellite data and a stratified probability-based sampling of 84 Level III ecoregions (Omernik, 1987) with more than 2,700 sample block locations of 100 km^2 and 400 km^2. The rates of land-cover change are estimated using a stratified, random sampling (Stehman and others, 2005) of 10-kilometer (km) by 10-km blocks allocated within each ecoregion. For each sample block, the satellite images are used to interpret land-cover change for the five time periods. Additionally, historical aerial photographs from similar timeframes and other ancillary data

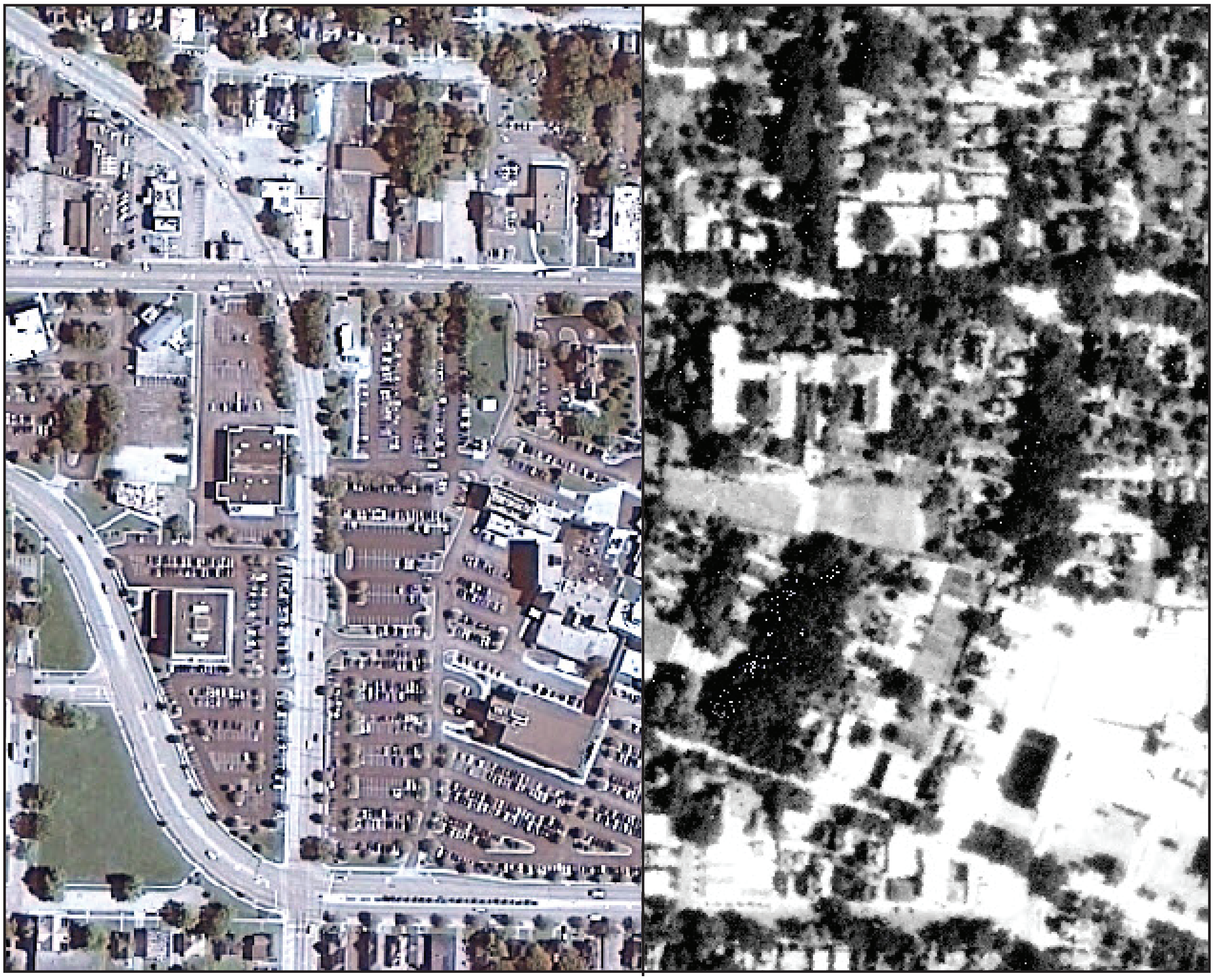


Figure 4. Substantial land change has occurred in sample block 26 near Rockford, Illinois. *A*, 2009 imagery from the National Agriculture Imagery Program; *B*, an aerial photograph of the same location in 1939. These images demonstrate an increase in impervious surface from road width, parking lots, and large buildings.

such as census statistics and published literature are used. The sample block data are then incorporated into statistical analyses to generate an overall land change matrix for the ecoregion. These change statistics are applicable for different levels of scale, including total change for the individual sample blocks and change estimates for the entire ecoregion. At each level of scale, corresponding sets of land-cover change statistics are produced. For example, the scalar statistics indicate the spatial extent and type of change per cover type with time. The sampling was designed to enable a statistically robust estimate of land-cover change within each ecoregion and additional frameworks, such as states and landscape-scale watersheds, although variability of the estimates of other geographic frameworks may change.

Field verification data for the sample blocks included ground surveys for training and validation of image classifications (Loveland and others, 2002). The field measurements and observations made in each ecoregion also allowed additional observations of the character and condition of the landscape for improving interpretation, ground truthing of the Landsat imagery, and to provide evidence for potential driving forces of land change in the ecoregion.

Supporting Data

Aerial Photographs

Historic aerial photographs produced by the U.S. Department of Agriculture (known then as the Agricultural Stabilization and Conservation Service) were used to classify land cover for 1939. The aerial photographs for the sample blocks located in Illinois were downloaded from the Illinois Natural Resources Geospatial Data Clearinghouse at the University of Illinois at Urbana-Champaign (University of Illinois at

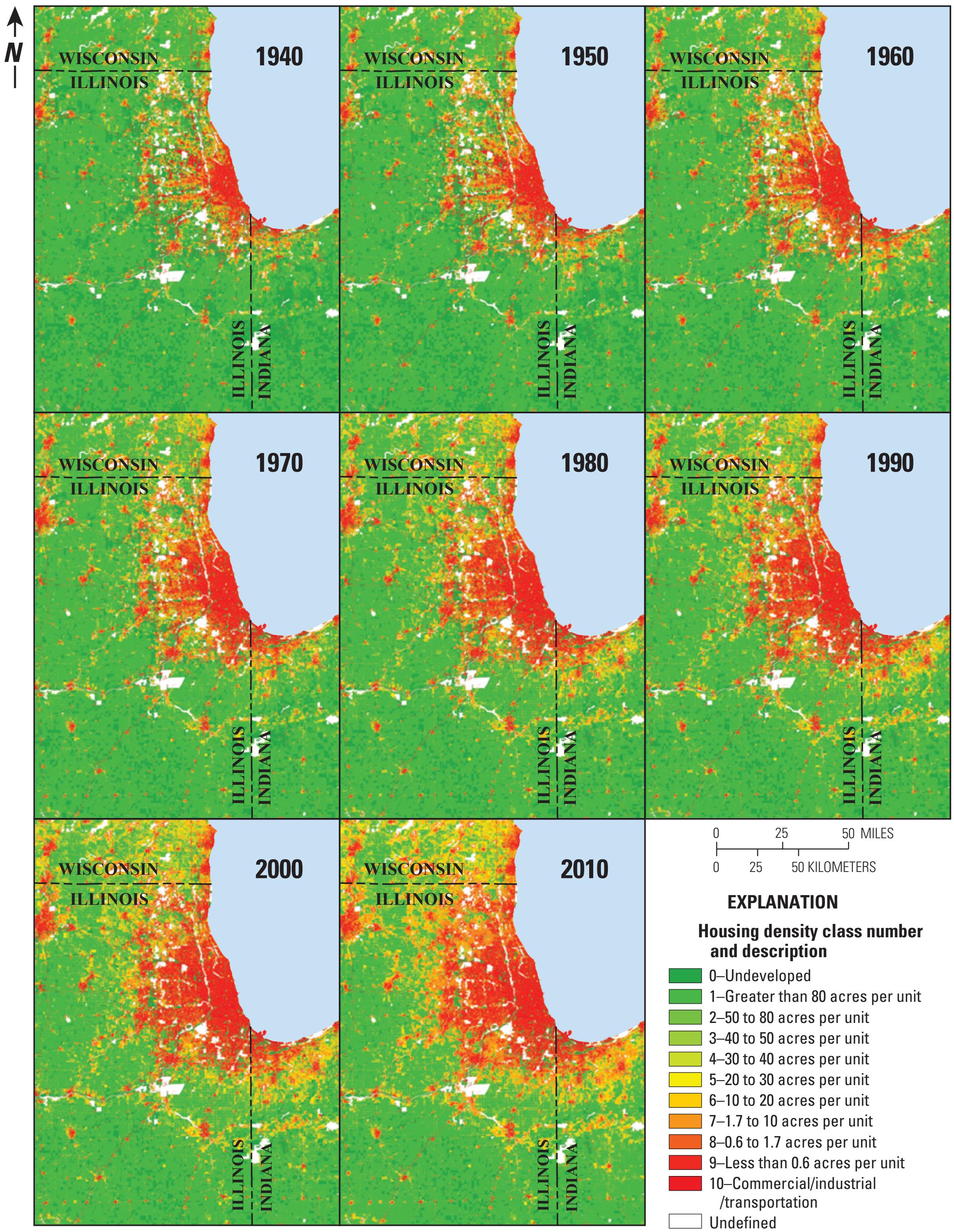


Figure 5. Housing density by decade in northeastern Illinois, 1940 to 2010, based on data from Theobald (2005).

Champaign-Urbana, 2012). The aerial photographs for the sample blocks located in Indiana were acquired from the Indiana Geological Survey (Indiana Geological Survey, 2011). Aerial photographs were not acquired by the research team for sample block 561, in the Indiana part of the ecoregion (fig. 6), so it was not included in the analysis. The land-cover change in the omitted block was minimal enough to not play a significant role in the overall statistical analysis as the overall change in the block from 1973 to 2000 was relatively low. After the data were acquired, the target scenes from the photographs were georeferenced and the rectified image was clipped as close to camera fiducials as possible. The preliminary georeferencing was then further refined through autocorrelation processes and mosaicing techniques.

Satellite Imagery

Land-cover analysis from 1973 to 2000 for the Central Corn Belt Plains was completed by the USGS Land Cover Trends Project in 2010. The land-cover classification data interpreted from Landsat Multispectral Scanner, Thematic Mapper, and Enhanced Thematic Mapper Plus satellite images for each sample block were used in the present study.

Image Process

In order to supplement the contemporary (1973 to 2000) land-cover analysis, land cover also was interpreted from 1939 aerial photographs. The mosaiced photograph image for each sample block was classified for land cover following the same protocol and methods used by the USGS Land Cover Trends Project for the 1973 to 2000 analysis (Griffith and others, 2003; Stehman and others, 2005; and Stehman and others, 2003). A statistical land-cover change product that demonstrates the rates and types of change from 1939 to 2000 was completed following the same standards and equations used in the Land Cover Trends Project (Griffith and others, 2003, Stehman and others 2005, and Stehman and others 2003). Importantly, interpretation dates from 1973 to 2000 generally are 7 years and the interval between 1939 and 1973 is much larger and accounts for 34 years.

Summary of Land Change in the Central Corn Belt Plains—1939–2000

Ecoregional Summary

The percent area of all land-cover types is shown in table 1 for six dates from 1939 to 2000. Again, note that the statistical analysis was calculated with no data reported for one low changing block in the ecoregion. The leading land covers in the ecoregion were agriculture, forest, and developed. Combined, these land-cover classes comprised an estimated 92 percent of the region's land area in 1939 and 96 percent in 2000. By 2000, agriculture had decreased by approximately 5 percent, whereas forest land increased by approximately 2 percent and developed land increased by approximately 7 percent. The principal land change in the ecoregion revolves around loss of farmland resulting from conversions to developed lands.

When normalized to account for varying lengths of time intervals, the overall spatial change for the region—the percentage of land that changed from one land cover to another—was 19.9 percent (table 2). This statistic does not account for the fact that an intermediate date between 1939 and 1973 was not analyzed for image interpretation or land-cover change classification. Approximately 18.3 percent of the land area converted only once, whereas 1.4 percent and 0.1 percent transitioned from one land cover to another two and three times,

Table 1. Percentages of general land cover types for 1939, 1973, 1980, 1986, 1992, and 2000.

[-, minus]

Year or change interval	Water (in percent)	Developed (in percent)	Mechanically disturbed (in percent)	Mining (in percent)	Barren (in percent)	Forest (in percent)	Grassland/shrubland (in percent)	Agriculture (in percent)	Wetland (in percent)	Nonmechanically disturbed (in percent)	Snow/ice (in percent)
1939	1.23	4.54	0	0.03	0.01	7.30	3.44	80.20	0.76	0	0
1973	1.63	9.19	0.02	0.16	0	9.50	0.73	77.42	1.37	0	0
1980	1.56	9.58	0	0.18	0	9.40	0.74	77.09	1.44	0	0
1986	1.53	9.95	0.01	0.21	0	9.34	0.67	76.80	1.48	0	0
1992	1.57	10.47	0.01	0.22	0	9.33	0.62	76.33	1.45	0	0
2000	1.58	11.56	0.02	0.27	0	9.29	0.57	75.27	1.45	0	0
1973–2000 Change	-0.05	2.38	0	0.11	0	-0.21	-0.16	-2.15	0.08	0	0
1939–2000 Change	0.35	7.02	0.02	0.24	-0.01	1.99	-2.87	-4.94	0.69	0	0

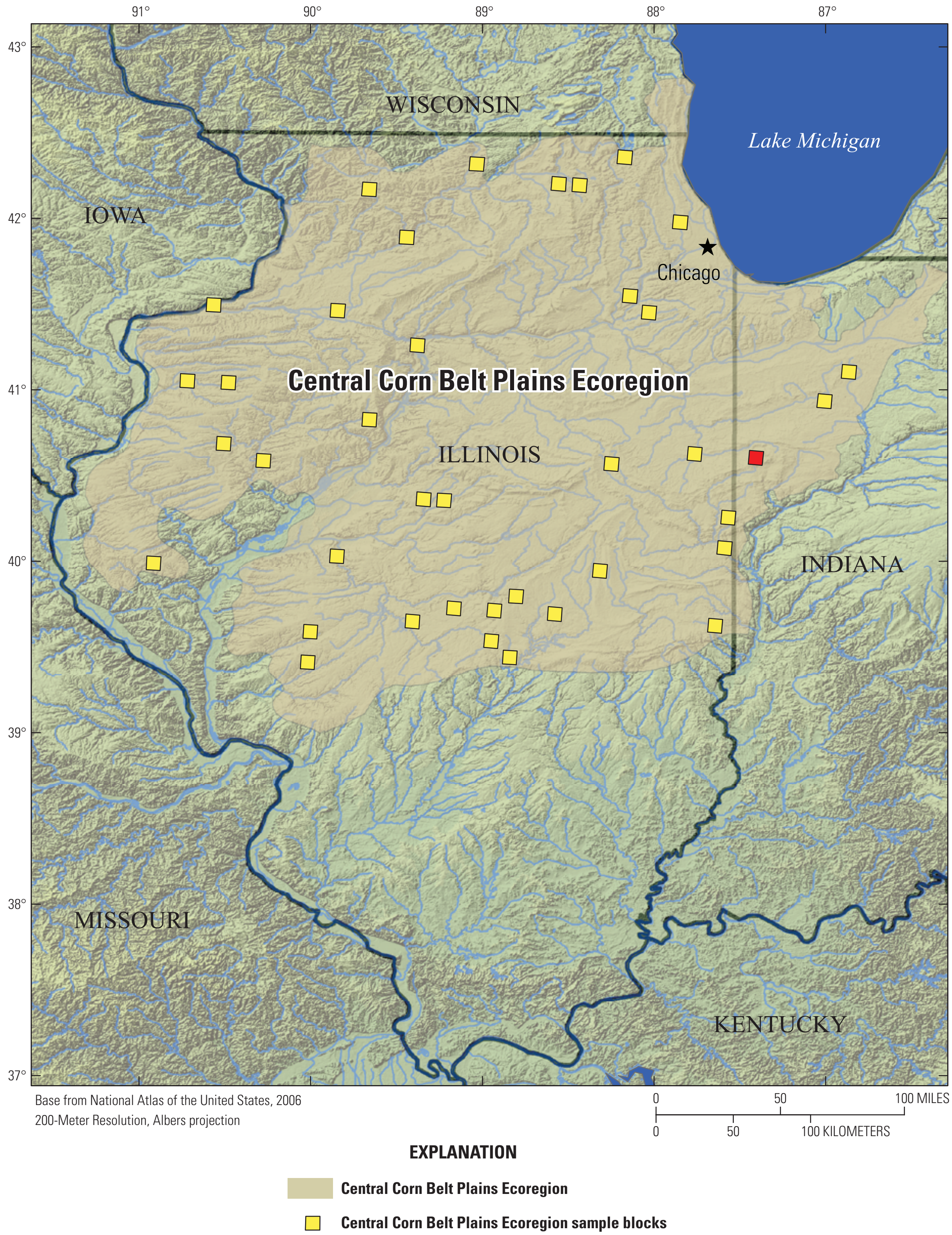


Figure 6. Map showing the one sample block in the Indiana portion of the ecoregion that was not included in the analysis.

Table 2. Percentage of the ecoregion that experienced change and associated error.

[+/-, plus or minus]

Number of changes	Percent of ecoregion (in percent)	85 percent confidence interval +/- (in percent)	Lower bound (in percent)	Upper bound (in percent)	Standard error (in percent)	Relative error (in percent)
All change	19.9	4.8	15.1	24.6	3.2	16.3
1	18.3	4.1	14.2	22.4	2.8	15.4
2	1.4	0.8	0.6	2.2	0.5	37.9
3	0.1	0	0.1	0.1	0	28.7
4	0	0	0	0	0	59.7
5	0	0	0	0	0	0

respectively. No amount of land in the sample blocks underwent more than three changes in land cover. The significant amount of land that underwent change only one time likely is due to the unidirectional changes from agriculture to developed lands.

Land-Cover Sectoral Change

Developed

In 1939, developed lands accounted for approximately 4.5 percent of the region (table 1). By 2000, an estimated 11.6 percent of the region was developed (table 1). A significant percentage increase occurred between 1939 and 1973 as well as between 1992 and 2000, the latter being a noted time of substantial residential expansion (von Hoffmann, 1999). Most of the newly developed lands in each interval were the result of conversions from farmland (fig. 7). Some gains to the developed class resulted from forest clearing, but to a much lesser extent than agricultural land. Developed land change nearly always is a unidirectional change with all of the land remaining in a built-up or developed state, which can have serious implications on hydrologic and ecological systems (U.S. Geological Survey, 2012).

Agriculture

Agriculture was the leading cover class in all of the time intervals; agricultural land use played, and continues to play, a leading role in shaping the Central Corn Belt Plains Ecoregion physical and socioeconomic landscape. When land is converted to agricultural use, the hydrologic processes of the natural landscape are modified toward optimizing agricultural production (U.S. Geological Survey, 2010). Often, these modifications have unintended environmental effects, including changes in water quantity and water quality (U.S. Geological Survey, 2010). In 2000, agricultural land accounted for 75.3 percent of the ecoregion (table 1). The cover class primarily was being lost to developed land from 1939 to 2000, with a small percentage of the region's agricultural land being converted to grassland/shrubland. The primary gain in agricultural land cover in the region occurred during the first three time intervals and came from forests being cleared for agricultural expansion.

Forest

In the early 19th century, scattered areas of forest were documented on level uplands, and river valleys and moraines mostly were forested (Woods and others, 2006). The percentage of forest cover in 1939 (7.3 percent) may reflect the early land use patterns associated with the native vegetation gradually being replaced by agricultural crops (U.S. Environmental Protection Agency, 2010). After a net increase of 2.2 percent between 1939 and 1973 (table 3), the forest land-cover class remained relatively stable in the ecoregion declining from 9.5 percent of the ecoregion in 1973 to 9.29 percent in 2000 (table 1).

Grassland/shrubland

Level uplands in the ecoregion were dominated by tallgrass prairie in the early 19th century, and at the time of settlement no other Illinois Level III ecoregion had as much prairie as the Central Corn Belt Plains (Woods and others, 2006). Grassland/shrubland accounted for approximately 0.57 percent of the land cover of the Central Corn Belt Plains Ecoregion in 2000 and during the time period lost approximately 2.87 percent of land area (table 1). Although the Conservation Reserve Program may have played a more substantial role in grassland/shrubland land-cover conversions in neighboring ecoregions, in the Central Corn Belt Plains, nearly all of the original prairies have been replaced by agriculture (Woods and others, 2006).

Water

The water cover class comprised 1.58 percent of the ecoregion in 2000 (table 1). Overall, this cover class was relatively stable, having only a slight increase (0.35 percent) in regional composition during the study period.

Figure 7. Substantial land change has occurred in the Chicago, Illinois, metropolitan area located in the Central Corn Belt Plains Ecoregion. *A*, 2009 imagery from the National Agriculture Imagery Program of Chicago O'Hare International Airport in 2000; *B*, An aerial photograph of the same location in 1939.

Wetlands

Changes in the wetlands cover class were not prevalent in the ecoregion during the study period, comprising 0.76 percent in 1939 and increasing to 1.45 percent in 2000 (table 1). Fluctuations in wetland principally came from the water cover class and vice versa, and likely are due to interannual weather fluctuations.

Mining

Mining activities accounted for only 0.03 percent of the ecoregion at the beginning of the study period and gradually increased to 0.27 percent in 2000 (table 1). This increase may be most closely related to the increased urbanization the ecoregion experienced.

Barren

Barren land made up the smallest detectable land-cover compositions in the ecoregion during the entire study period, accounting for a mere 0.01 percent of the region in 1939 and was not present in any other time interval.

Mechanically disturbed

Regionally, there was no significant gain or loss of mechanically disturbed land during the study period, ranging from 0.0 percent to 0.02 percent in any time period.

The nonmechanically disturbed and snow/ice classes were not classified in the Central Corn Belt Plains from 1939 to 2000, as these classes were either 1) not present, or 2) below the minimum mapping unit of 60 meters.

Net and Gross Change

To understand land-cover dynamics, it is important to understand gross and net change in the Central Corn Belt Plains. Gross change is the total amount of a given land cover changed, and net change is the aggregate of gains and losses affecting that category. If all land change occurred only once on the same area, then net and gross change would be the same (Roger Auch, Steven Kambly, and Krista Karstensen, U.S. Geological Survey, written commun., 2012); however, the nature of the statistics herein take into account that often, a number of different types of land change tend to change more than once on the same area during the study period. For example, an agricultural field may slowly return to forest or grassland/shrubland depending on changes in land use, management, or both. The differences between gross and net change in a land sector where most of the change is unidirectional, such as the gains in developed land seen in the Central Corn Belt Plains, tend to be small (tables 3 and 4). The differences between gross and net change amounts are large in some sectors where cyclic or multiple changes affect the status of that land cover, such as forest in that particular region (Roger Auch, Steven Kambly, and Krista Karstensen, U.S. Geological Survey, written commun., 2012).

Drivers and Consequences of Land-Cover Change

A variety of land change was observed during georegistration of the 1939 aerial photographs for the Central Corn Belt Ecoregion including historic agricultural practices, urbanization, and transitions in land use. Although the discussion herein focuses on observations, drivers, and consequences of land change from 1939 to 1973, a full discussion of contemporary land change (1973 to 2000) also is available (Daniel Sorenson, U.S. Geological Survey, written commun., 2011).

Historic Agricultural Land Change

The evolution of the agricultural land-use sector has included changes in both farming practices and equipment. This transformation partly was due to the introduction of hybrid seed corn in 1933 (Hart, 1986). The change in corn yields that followed increased after World War II as farmers were able to double and even triple their yields (Hart, 1986). Moreover, from 1939 to 1968, soybean and wheat yields in the State of Illinois noticeably increased(Odell and Oschwald, 1970). While the improved crop varieties boasted increased yields, they also required the use of a variety of agricultural fertilizers (specifically, limestone, nitrogen, phosphorus, and potassium) (Hart, 1986; Odell and Oschwald, 1970), which contributed greatly to the water-quality concerns that continue to be common in the ecoregion (U.S. Geological Survey, 2012; Warner, 1998; Groschen and others, 2000). Although use of fertilizers, adapted varieties of crops, improved tillage practices, timeliness of operations, more efficient management, and technology-improved crop production in the region prompted the size of farms to increase (Hart, 1986), farm numbers (Odell and Oschwald, 1970; U.S. Department of Agriculture, 1964; U.S. Department of Commerce Bureau of the Census, 1942) and total farm area were decreasing (Hart, 1986). This general decline in the number of farms and total farm area also may be exhibited in the statistics of this study as the agricultural land-cover class declined between 1939 and 1973. These changes also may reflect the decline of small family farms and the increase in agribusiness in the rural counties where farm land area did not decline drastically, as well as illustrating agricultural land being developed in the more populated counties where both farm numbers and amount of land in farms declined more noticeably.

Agricultural land change is of special interest to this study because of the measurable amount being lost to other land-cover classes, most notably developed. This conversion of agricultural to developed land has taken place during a time of low population growth, as previously mentioned.

Table 3. Net change by interval in the Central Corn Belt Plains.

[-, minus]

Change interval	Water (in percent)	Developed (in percent)	Mechanically disturbed (in percent)	Mining (in percent)	Barren (in percent)	Forest (in percent)	Grassland/ Shrubland (in percent)	Agriculture (in percent)	Wetland (in percent)	Nonmechanically disturbed (in percent)	Snow/ice (in percent)
1939 to 1973	0.4	4.6	0	0.1	0	2.2	-2.7	-2.8	0.6	0	0
1973 to 1980	-0.1	0.4	0	0	0	-0.1	0	-0.3	0.1	0	0
1980 to 1986	0	0.4	0	0	0	-0.1	-0.1	-0.3	0	0	0
1986 to 1992	0	0.5	0	0	0	0	-0.1	-0.5	0	0	0
1992 to 2000	0	1.1	0	0	0	0	0	-1.1	0	0	0

Table 4. Gross change by interval in the Central Corn Belt Plains.

[, percent; -, minus]

Change interval	Water (in percent)	Developed (in percent)	Mechanically disturbed (in percent)	Mining (in percent)	Barren (in percent)	Forest (in percent)	Grassland/ Shrubland (in percent)	Agriculture (in percent)	Wetland (in percent)	Nonme-chanically disturbed (in percent)	Snow/ice (in percent)
1939 to 1973	0.8	5.5	0	0.2	0	7.8	4.1	12.1	1.5	0	0
1973 to 1980	0.1	0.4	0	0	0	0.2	0.1	0.5	0.1	0	0
1980 to 1986	0.1	0.4	0	0	0	0.2	0.2	0.5	0.1	0	0
1986 to 1992	0.1	0.5	0	0	0	0.1	0.2	0.6	0.1	0	0
1992 to 2000	0.1	1.1	0	0.1	0	0.1	0.1	1.1	0	0	0

For example, between 1970 and 1980, net migration from the State of Illinois amounted to 375,000 people, yet agricultural to developed land conversion accelerated during that time (Dovring and others, 1982.)

Historic Developed Land Change

The principal story of land change in the Central Corn Belt Plains between 1939 and 2000 was the increase of developed land at the expense of agriculture. As previously mentioned, one specific driver of this change was the increase in population during the 61-year study period. The Chicago metropolitan region has grown dramatically since Chicago's incorporation in 1830 (Buchanan and Acevedo, 2010; Auch and others, 2004). Areas in the ecoregion that would be classified as developed in all time periods had an increase in urban density and impervious surface. Structures such as airports, shopping malls, commercial buildings, subdivisions, and schools dramatically increased impervious surface area due to increases in road widths and numbers and sizes of parking lots.

Drivers and Consequences of Developed Land Change

The land change trend of agricultural land declining as the amount of developed land increased is common during all time periods between 1939 and 2000. Often, rates of developed land change have socioeconomic underpinnings; for example, early development was affected by the events such as the Great Depression and World War II. Later in the study period, between 1964 and 1975, general decentralization of Chicago was occurring. A study conducted by Dovring and others (1982) concluded that factors aside from population pressure contributing to land conversion to developed uses in the Chicago area include automobile transportation and the method of financing highways, house financing, tax policies affecting capital gains, and public utility pricing policies.

Chicago

The 1930s were a decade of growth for Chicago. The city's population had grown from approximately 2,700,000 in 1920 to 3,400,000 in 1930 (McClendon, 2012). The population expansion coincided with an increase in development including thousands of new bungalows encircling the city, however, the Great Depression slowed growth and development in the 1940s (McClendon, 2012). A post World War II building boom in the 1950s once again promoted growth and filled in the city and the first ring of suburbs with new houses, and increasing auto ownership increased development away from public transit lines (McClendon, 2012). This postwar era also was when expressways were beginning to be constructed. The increased preference for owner-occupied single-family houses (Mariner, 2004) and the Federal Highway Act of 1956 (Auch and others, 2006) may have helped to drive suburban development. In its Comprehensive General Plan, adopted in 1968, the Northeastern Illinois Planning Commission (NIPC) called for concentrating new development largely along the radial commuter lines focused on the Chicago Loop, and for preserving wedges of open space and low-density development between the radial corridors (Mariner, 2004). The open space and low-density developed areas are two components integral to dissecting the developed land-cover class in order to investigate the amount of historical impervious surface area and its effects on regional hydrology.

Case Study: Urbanization Effects on Flood Flows in the Chicago Area

To address the lack of valuable data on historical imperviousness and other measures of urbanization, USGS researchers are working to characterize the historical process of urbanization in the Central Corn Belt Plains to determine the effect of urbanization on peak streamflows, enabling the adjustment of historic peak flow records to the current level of urban development. These adjusted records can be the basis of more accurate and relevant estimates of the expected frequency of peak flows of given magnitudes.

Developed land change can affect stream discharge by modifying rates and amounts of runoff from precipitation events. In the more agricultural areas in the ecoregion, and areas such as forests and grasslands, rainfall is more likely to be collected and stored on vegetation, in the soil, or in wetlands; however, in developed areas such as the Chicago metropolitan area, much of the land surface is covered by impervious surfaces that limit storage capabilities and capacities, and drainage generally is enhanced with infrastructure such as curb-and-gutter streets and storm sewers. With less storage capacity for water in urban basins and more rapid drainage, urban streams rise more quickly during storms and have higher peak flows than do rural streams, and the total volume of water discharged during a flood tends to be larger in urban streams than rural streams (Konrad, 2003).

Although the impervious surface area of a watershed alone does not determine the hydrologic and other effects of urbanization on streams (Falcone and others, 2007; Sauer and others, 1983), it is the most direct parameter for analyzing and predicting the effects of changes in land cover associated with urbanization on characteristics of streamflow including peak flows (for example, Jacobson, 2011; Lee and Heaney, 2003; Shuster and others, 2005) and water quality and biology (Falcone and others, 2007), particularly when the fraction of the total impervious area that is directly connected[1] to the drainage system can be determined. Although measures of imperviousness at one time or over a limited (usually recent) time span are becoming available [for example, the National Land Cover Database, which includes estimates of imperviousness for 2001 and 2006 (Xian and others, 2011)], these cannot be used in assessing stream effects of urbanization over the multi-decadal time scales usually associated with the urbanization of a given watershed. Because of the difficulty of obtaining historical data for a direct measure of imperviousness, many hydrologic studies have used surrogates, such as population density or housing density, to indirectly account for the effect of impervious area (for example, Moglen and Shivers, 2006), despite the uncertainties in relating land use or other surrogates to impervious areas (Ackerman and Stein, 2008; Alley and Veenhuis, 1983).

To illustrate the effect of increases in urbanization on hydrology in this region, a summary of preliminary results of a longitudinal study of the dependence of annual maximum peak streamflow[2] on changes in urbanization (Thomas Over and David Soong, U.S. Geological Survey, written commun., 2012) is presented. The peak flow data used are from water years 1945 to 2009 and were measured at 143 USGS streamflow-gaging stations in the Chicago metropolitan in the northeastern part of the Central Corn Belt Plains Ecoregion (fig. 8). The streamflow-gaging stations measure watersheds with drainage areas between 0.03 and 200 mi^2 (0.08 km^2 and 518 km^2) (fig. 9) and have record lengths of at least 10 years. A histogram showing the number of streamflow-gaging stations reporting during each water year between 1945 and 2009 is shown in figure 10. The U.S. Census-based housing density product developed by Theobald (2005) (fig. 5) was used to quantify the process of urbanization during the study period because aerial photography/Landsat-based land-use estimates from the Land Cover Trends Project covering these watersheds were not available. Theobald (2005) estimates of urbanization, computed as the sum of the three densest classes of housing (all housing lots 10 acres (4 ha) or smaller in size) plus the commercial-industrial-transportation land-use class (that is, classes 7–10), were validated against the Land Cover Trends Project data by comparing them over the Land Cover Trends sample blocks in the Central Corn Belt Plains Ecoregion (fig. 11). It is evident that on average, the values agree quite well.

By a regression analysis using a panel linear model with fixed station effects (Kleiber and Zeileis, 2008, section 3.6), it was determined that the base-10 logarithms of annual maximum peak flows from the 143 streamflow-gaging stations in the study increase with the urbanized watershed fraction with a coefficient of about 0.51 (fig. 12), after taking into account changes in precipitation by including a precipitation term in the regression model. The mathematical expression of the model is:

$$\log_{10} Q_i(\mathrm{t}) = b_{0i} + b_1 U_i(\mathrm{t}) + b_2 P_i(\mathrm{t}) \tag{1}$$

where

$Q_i(t)$ is annual maximum peak flow in cubic feet per second at station i during year t,

$U_i\,(t)$ is urbanization at station i during year t (nondimensional fraction ranging from 0 to 1),

$P_i(t)$ is the precipitation in inches associated with , $b_{0\mathrm{i}}$ is the intercept (fixed effect) for station i,

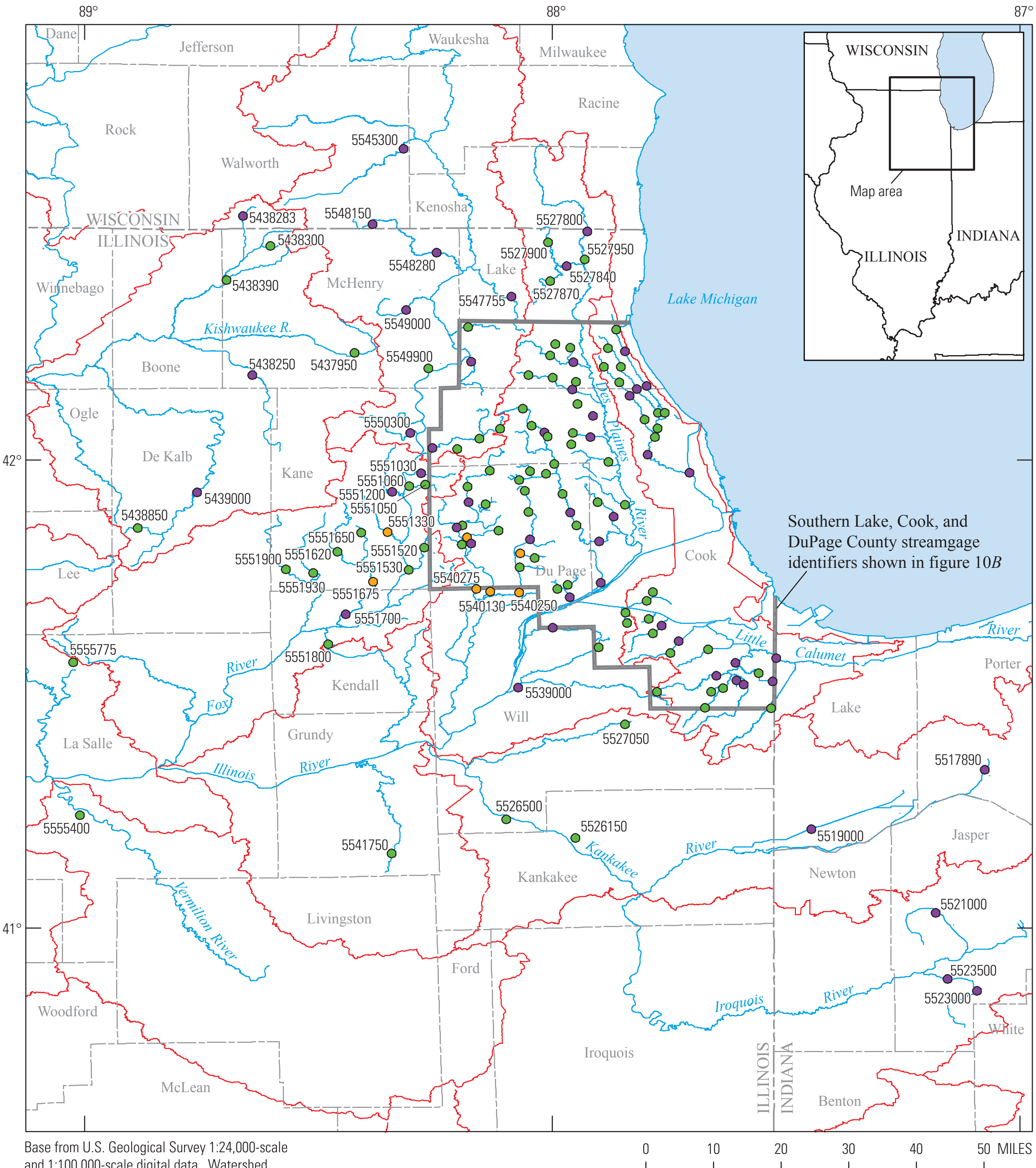
and the regression coefficients are $b_1 = 0.5117 \pm 0.0403$ for urbanization and $b_2 = 0.0846 \pm 0.0035$ for precipitation.

The value of the urbanization coefficient implies, for example, that if a watershed increases from zero urbanization ($U' = 0$) to completely urbanized ($U'' = 1$), one would expect a peak flow increase of $Q(U'')/Q(U') = 10^{b_1(U''-U')} = 3.249$ times (that is, a 225-percent increase), whereas a 10-percent increase in urbanization ($U'' = U' + 0.1$) implies an increase of $Q(U'')/Q(U') = 10^{b_1(U''-U')} = 10^{0.5117(0.1)} = 1.125$ in the peak flows, or a 12.5-percent increase. The complete range of urbanization effects on a watershed that starts out at zero urbanization, according to these results, is shown in figure 13.

[1]The directly connected (or “effective”) impervious area is that part of the impervious area that drains directly to the drainage system of the watershed, such as the storm sewers and street gutters. This includes areas that are graded toward sewer inlets and street gutters such as streets, driveways, and parking lots. Downspouts from roofs may or may not be directly connected; they are not if they drain onto a pervious surface such as a lawn.

[2]The annual maximum peak streamflow data measured by the USGS are available at http://nwis.waterdata.usgs.gov/usa/nwis/peak (U.S. Geological Survey, 2010), and the data used in Thomas Over and David Soong (U.S. Geological Survey, written commun, 2012) were obtained from this Web site.

A



Base from U.S. Geological Survey 1:24,000-scale and 1:100,000-scale digital data. Watershed Boundary Dataset from Natural Resources Conservation Service.

EXPLANATION

Boundary of Level 4 Watershed Dataset subbasin

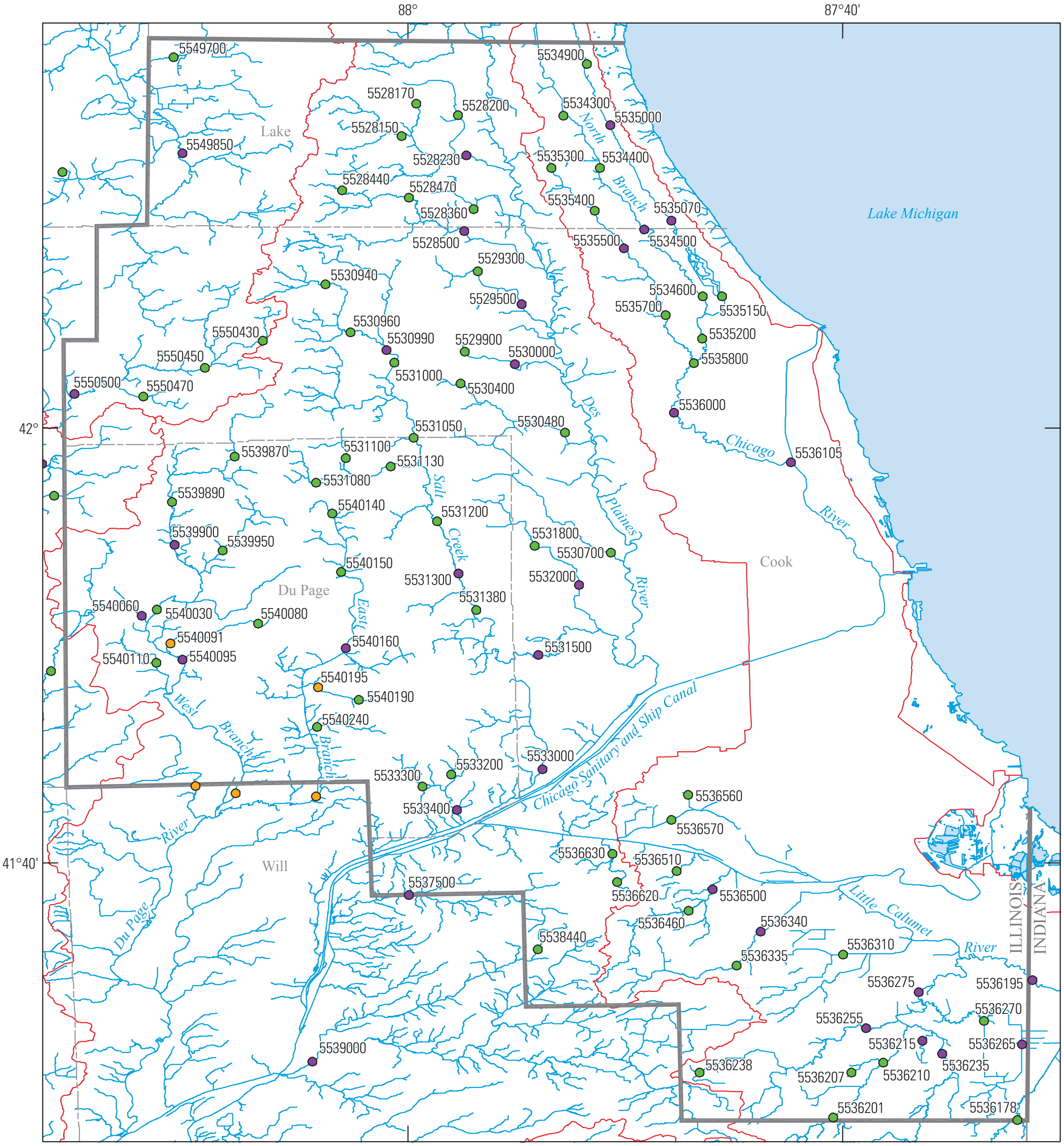
5536310 **USGS streamgage with record ending in 1980 (including 1980) and identifier**

5540195 **USGS streamgage with record starting after 1980 and identifier**

5537500 **USGS streamgage with record through 1980 and identifier**

Figure 8. *A*, Locations of U.S. Geological Survey (USGS) streamgages measuring the 143 watersheds in the Chicago region (Thomas Over and David Soong, U.S. Geological Survey, written commun., 2012); *B*, Locations of U.S. Geological Survey (USGS) streamgages measuring the 143 watersheds in the Chicago region (Thomas Over and David Soong, U.S. Geological Survey, written commun., 2012).

B. Inset area from figure 8*A*



Base from U.S. Geological Survey 1:24,000-scale digital data.
Watershed Boundary Dataset from Natural Resources Conservation Service.

0 2 4 6 8 10 MILES
0 2 4 6 8 10 KILOMETERS

EXPLANATION

Boundary of Level 4 Watershed Dataset subbasin

5536310 **USGS streamgage with record ending in 1980 (including 1980) and identifier**

5540195 **USGS streamgage with record starting after 1980 and identifier**

5537500 **USGS streamgage with record through 1980 and identifier**

Figure 8. *A*, Locations of U.S. Geological Survey (USGS) streamgages measuring the 143 watersheds in the Chicago region (Thomas Over and David Soong, U.S. Geological Survey, written commun., 2012); *B*, Locations of U.S. Geological Survey (USGS) streamgages measuring the 143 watersheds in the Chicago region (Thomas Over and David Soong, U.S. Geological Survey, written commun., 2012).—Continued

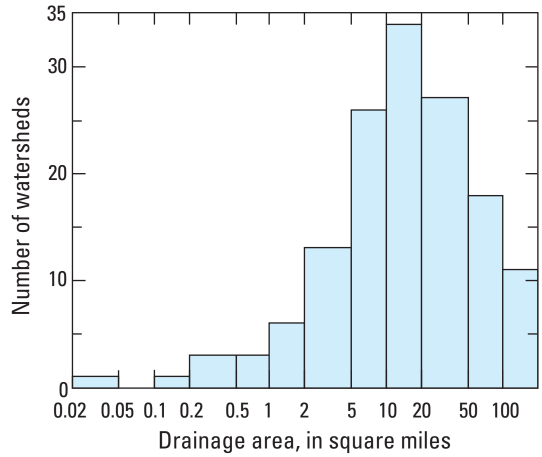


Figure 9. Drainage areas of the 143 watersheds in the Chicago region (Thomas Over and David Soong, U.S. Geological Survey, written commun., 2012).

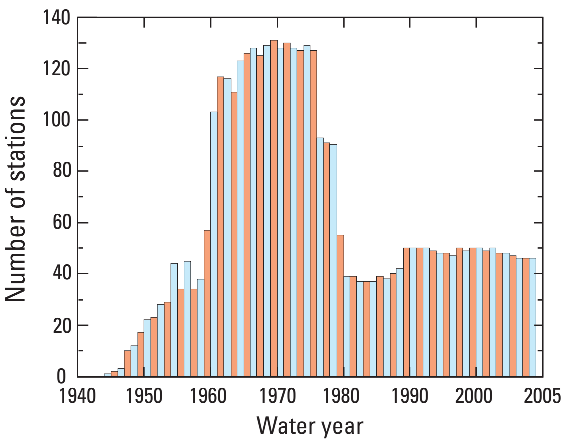


Figure 10. Number of streamflow-gaging stations with peak flow data during each water year in the study of 143 watersheds in the Chicago region (Thomas Over and David Soong, U.S. Geological Survey, written commun., 2012).

Future Steps

The dependence of annual maximum peak streamflow on urbanized area appears to be reasonable and has been used to compute adjusted values of the annual maximum peak flow data for each station record that corresponds to present land-use conditions. Future research could further improve our understanding of the relation between urbanization and discharge. For example, satellite imagery and aerial photograph-based estimates of urbanized areas might improve the coefficient of urbanized fraction. Likewise, how might historical impervious area estimates from aerial photography analyzed over a region of this size affect the estimate of urbanization effects on discharge? As mentioned, impervious area is not the only hydrologically important measure of urbanization. The construction of curb-and-gutter streets, their associated storm drains, and channel straightening and lining also contribute substantially to the effects of urbanization on streamflow. In addition, in the last few decades, the process of urbanization has become associated with measures to mitigate its effects on streamflow, such as stormwater detention. Is it feasible to identify and measure these features of the urban landscape at the regional scale in historical imagery? In recent research (Thomas Over and David Soong, U.S. Geological Survey, written commun., 2012), the effects of these features could not be separately assessed and were assumed to have been subsumed in the housing density-based measure of urbanization. Finally, some studies report that spatial arrangement of impervious area affects response (Falcone and others, 2007; Moglen and Shivers, 2006; Sauer and others, 1983). How then should such information best be used, and how much difference would it make?

Methodological Way Ahead

To begin addressing these questions, further research could develop methods to improve the ability to quantify the amount of impervious surfaces from the aerial photographs. Land-change detection in urbanizing areas is challenging. Although they may shift from one land class to another, agricultural and forested areas in the ecoregion are often more homogenous, whereas urban areas are a heterogeneous mixture of different surfaces with different levels of imperviousness (Platt, 2004; Xian and others, 2006). It is the heterogeneous characteristics of urban areas that contribute to the difficulties of land-change detection in urban and suburban areas using remote sensing techniques. For example, pixels that were classified as developed may vary between 20 percent and 100 percent in their impervious surface and they might vary between 0 and 60 percent in their tree canopy coverage (Xian and others, 2006). To attempt to overcome these challenges, the authors currently are testing a feature extraction method to identify impervious surfaces based on characteristics such as brightness, shape, and texture in the aerial photographs as well as current modeling efforts to determine if backcasted estimates of developed land change based on current land-change rates could be incorporated.

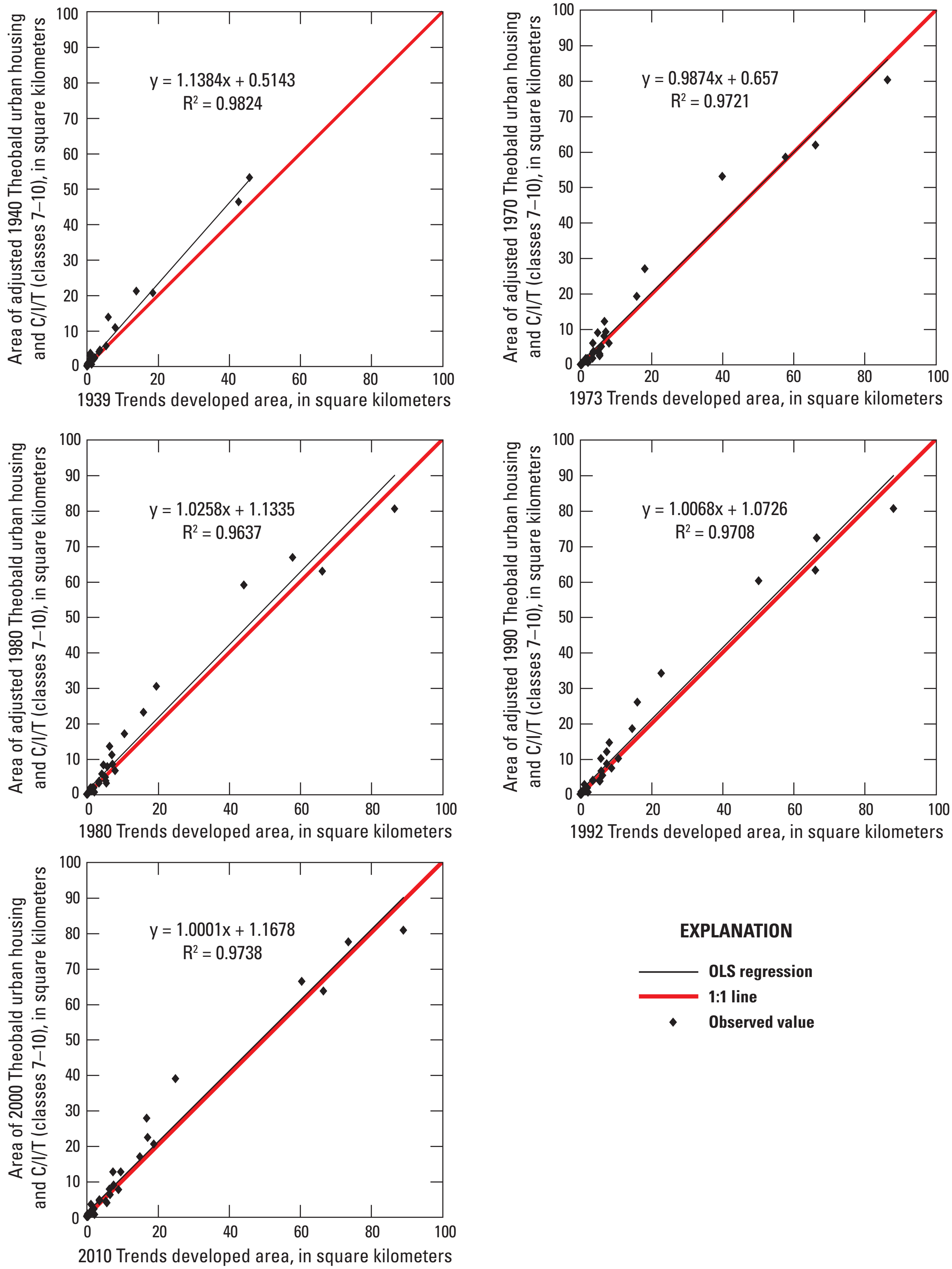


Figure 11. Comparison between Theobald (2005) exurban/urban housing plus commercial-industrial-transportation (C/I/T) land area and U.S. Geological Survey Land Cover Trends Project developed area for the 40 100-km^2 sample blocks in Ecoregion 54 (Central Corn Belt Plains) for 1939/40, 1970/73, 1980, 1990/92, and 2000. The commercial-industrial-transportation land areas in Theobald (2005) are from the year 2000, and so for other years, these values were adjusted proportionally to the changes in housing density (Thomas Over and David Soong, U.S. Geological Survey, written commun., 2012).

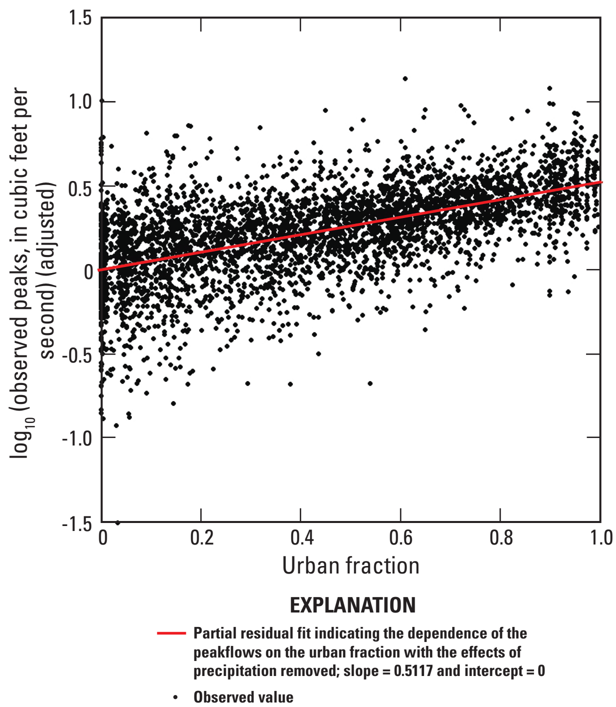


Figure 12. Partial residuals of base-10 logarithms of peak flows adjusted for effects of precipitation as a function of urban fraction (Thomas Over and David Soong, U.S. Geological Survey, written commun., 2012).

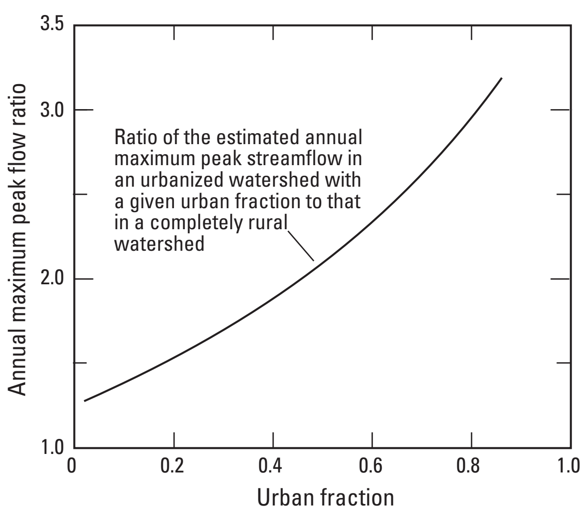


Figure 13. Ratio of the estimated annual maximum peak streamflow in an urbanized watershed to that in a completely rural watershed derived from an analysis of 143 watersheds in the Chicago area (Thomas Over and David Soong, U.S. Geological Survey, written commun., 2012).

Conclusions

This report combines land-cover change analyses with urbanization effects on hydrologic discharge in order to provide input to a multi-disciplinary understanding of the effects of land change on earth systems such as urban watersheds. The Central Corn Belt Plains Level III ecoregion was analyzed for land-change rates, causes, and consequences from 1939 to 2000 with a specific focus on how the increased development may be influencing regional hydrology. The case study presented in this report demonstrates that a generalized quantification of developed ("urban") land needs to be further refined in order to better understand the effects of urbanization on regional hydrology. Further collaboration might begin to assess additional consequences of developed land change such as water quality and stream ecology. Additional avenues of research collaboration would include studying the effect of the patterns of the land change in urban watersheds in response to efforts such as stormwater mitigation structures. Such collaborations provide a more comprehensive approach to determining how changes in land use and land cover contribute to land resources condition, and insight on how the geographic variability of change may affect land management priorities and practices.

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Land-Cover Class Descriptions

water Areas persistently covered with water, such as streams, canals, lakes, reservoirs, bays, or oceans.

developed Areas of intensive use, with much of the land covered with structures or anthropogenic impervious surfaces (for example, high-density residential, commercial, industrial, and roads) or less intensive uses where the land-cover matrix includes both vegetation and structures (for example, low-density residential, recreational facilities, cemeteries, parking lots, and utility corridors), including any land functionally related to urban or built-up environments (for example, parks and golf courses).

mining Areas with extractive mining activities that have a substantial surface expression, which includes (to the extent that these features can be detected) mining buildings, quarry pits, overburden, leach, evaporative, tailings, or other related components.

barren Land composed of soils, sand, or rocks where less than 10 percent of the area is vegetated. Barren lands usually are naturally occurring.

forest Tree-covered land where the tree-cover density is greater than 10 percent. Note that cleared forest land (clear-cuts) is mapped according to current cover (for example, mechanically disturbed or grassland/shrubland).

grassland/shrubland Land predominately covered with grasses, forbs, or shrubs. The vegetated cover must comprise at least 10 percent of the area.

agriculture Land in either a vegetated or an unvegetated state used for the production of food and fiber, which includes cultivated and uncultivated croplands, hay lands, pasture, orchards, vineyards, and confined livestock operations. Note that forest plantations are considered forests regardless of the use of the wood products.

wetland Land where water saturation is the determining factor in soil characteristics, vegetation types, and animal communities. Wetlands usually contain water and vegetated cover.

ice and snow Land where the accumulation of snow and ice does not completely melt in the summer period (for example, alpine glaciers and snowfields).

nonmechanically disturbed Land in an altered and often unvegetated state that, because of disturbances by nonmechanical means, is in transition from one cover type to another. Nonmechanical disturbances are caused by fire, wind, floods, animals, and other similar phenomena.

mechanically disturbed Land in an altered and often unvegetated state that, because of disturbances by mechanical means, is in transition from one cover type to another. Mechanical disturbances include forest clear-cutting, earthmoving, scraping, chaining, reservoir drawdown, and other similar human-induced changes.

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47914 252nd Street, Sioux Falls, South Dakota, 57198
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