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URBANIZATION INFLUENCES ON AQUATIC COMMUNITIES IN NORTHEASTERN ILLINOIS STREAMS[1]

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ABSTRACT: Biotic indices and sediment trace element concentrations for 43 streams in northeastern Illinois (Chicago area) from the 1980s and 1990s were examined along an agricultural to urban land cover gradient to explore the relations among biotic integrity, sediment chemistry, and urbanization. The Illinois fish Alternative Index of Biotic Integrity (AIBI) ranged from poor to excellent in agricultural/rural streams, but streams with more than 10 percent watershed urban land (about 500 people/mi^2) had fair or poor index scores. A macroinvertebrate index (MBI) showed similar trends. A qualitative habitat index (PIBI) did not correlate to either urban indicator. The AIBI and MBI correlated with urban associated sediment trace element concentrations. Elevated copper concentrations in sediment occurred in streams with greater than 40 percent watershed urban land. The number of intolerant fish species and modified index of biotic integrity scores increased in some rural, urbanizing, and urban streams from the 1980s to 1990s, with the largest increases occurring in rural streams with loamy/sandy surficial deposits. However, smaller increases also occurred in urban streams with clayey surficial deposits and over 50 percent watershed urban land. These data illustrate the potentially complex spatial and temporal relations among biotic integrity, sediment chemistry, watershed urban land, population density, and regional and local geologic setting.
(KEY TERMS: aquatic ecology; urbanization; water quality; fish; Illinois)

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INTRODUCTION

Urban development has been a major concern for water resource managers and aquatic ecologists since at least the 1960s (American Society of Civil Engineers, 1969; Spieker, 1970; The H. John Heinz III Center, 2002). Urban development affects the physical and chemical characteristics of streams, thereby altering aquatic habitat and the community of aquatic organisms that depends on it (Garie and McIntosh, 1986; Yoder and Rankin, 1997; Kennen, 1999; Paul and Meyer, 2001, and references within). Urbanization induced increases of flood peaks, duration, and volume are well documented (Hollis, 1975; Booth, 1990; Booth and Jackson, 1997). Locally, flood peaks in northeastern Illinois have increased three-fold due to urbanization (Allen and Bejcek, 1979). Following urbanization, channels may experience erosion, incision, widening, or sedimentation problems (Wolman, 1967; Wolman and Schick, 1967; Guy, 1970; Graf, 1975; Roberts, 1989; Booth, 1990; Gregory *et al.,* 1992; Booth and Jackson, 1997; Trimble, 1997; Colosimo, 2002). Geomorphic conditions of streams in urbanized areas may or may not stabilize after a few decades (Finkenbine *et al.,* 2000; Henshaw and Booth, 2000; Bledsoe and Watson, 2001); and geomorphic processes following urbanization are highly variable both in space and time (Gregory and Madew, 1982).

Contaminants and nutrients from nonpoint sources have been indicated as potential causes for loss of biotic integrity in urban streams (Bannerman *et al.,* 1993; Roesner and Ott, 1995; Crunkilton *et al.,* 1997; Sovern and Washington, 1997). Biotic integrity of urban streams in northeastern Illinois appeared to improve somewhat following improvements to wastewater treatment plants but remains degraded and lower than during preurbanization conditions (Dreher, 1997). This suggests that other factors, such as altered hydrology and possibly contaminants from urban nonpoint sources, are impacting biotic integrity

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(Dreher, 1997). Streambed sediment may be contaminated from historical landuse practices and point sources and may be another source of contaminants to the water column. Sediments from urban streams in the upper Illinois River Basin and in the nation tend to be enriched in antimony, cadmium, chromium, copper, lead, mercury, nickel, phosphorus, silver, and zinc compared to rural streams (Mathis, 1976; Colman and Sanzolone, 1992; Fitzpatrick *et al.,* 1998; Rice, 1999). Rooftops, parking lots, and streets can be nonpoint sources of cadmium, copper, lead, and zinc (Steuer *et al.,* 1997).

An urban gradient approach has been used to examine urbanization effects on aquatic communities and geomorphic conditions (e.g., Booth and Reinelt, 1993; Schueler, 1994; Dreher, 1997; Wang *et al.,* 1997; Wang *et al.,* 2001). Different measures of urbanization are often used (impervious area, amount of urban land, population density, combinations of urban indicators), making it sometimes difficult to distinguish and compare relations among different studies and different aquatic communities (Booth and Jackson, 1997; Gergel *et al.,* 2002). Impervious area is commonly used to quantify the degree of urbanization because of its direct effect on storm runoff (Schueler, 1994; Booth and Jackson, 1997; Wang *et al.,* 2000, 2001); and past studies have shown that biotic integrity and geomorphic conditions start to degrade at about 10 percent effective impervious area (e.g., Booth and Reinelt, 1993; Booth and Jackson, 1997; Maxted and Shaver, 1997; Wang *et al.,* 2000, 2001). Fish index of biotic integrity (IBI) scores in southeastern Wisconsin streams tended to be low in streams with greater than 10 to 20 percent watershed urban land (Wang *et al.,* 1997). In northeastern Illinois, fish IBI scores became impaired in watersheds with greater than 200 people/mi^2 (Dreher, 1997).

The relations among impervious area (effective and total), watershed urban land, and population density are not completely understood and may depend on regional and historical differences in the way urban areas are developed (size of roads, driveways, sidewalks, houses; layout of residential areas and storm sewers) as well as natural factors such as physiography, geologic setting, and soils. In northeastern Illinois, rural densities range from 30 to 300 people/mi^2, whereas urbanizing areas have about 300 to 1,000 people/mi^2 and built-out urban densities are typically about 1,000 to 5,000 people/mi^2 (Dreher, 1997). In northeastern Illinois, 10 percent total impervious area was estimated to be equal to about 1,000 people/mi^2 or 300 houses/mi^2 (Allen and Bejcek, 1979). Similarly in Washington State, 20 percent total impervious area and 640 houses/mi^2 were assumed to be equal to about 10 percent effective impervious area (Dinicola, 1989). However, the national average for residential areas with 320 houses/mi^2 is about 12 percent effective impervious area (U.S. Department of Agriculture, 1986).

In northeastern Illinois and southeastern Wisconsin, urban development is occurring on previously agricultural land. Thus, urbanizing streams are potentially affected by both historical and present-day agricultural practices. The percentage of watershed agricultural land has been shown to be a major factor affecting fish, macroinvertebrate, and habitat integrity in previously forested watersheds (Richards *et al.,* 1996; Roth *et al.,* 1996; Wang *et al.,* 1997; Fitzpatrick *et al.,* 2001; Stewart *et al.,* 2001). However, many agricultural streams in northeastern Illinois and southeastern Wisconsin still support relatively high quality fish assemblages (Dreher, 1997; Wang *et al.*, 1997). Geologic setting may play an important role in moderating the physical response of streams to agriculture and urbanization (Wang *et al.,* 1997).

The major objective of this paper is to compare the responses of fish, invertebrate, and aquatic habitat indices to increases in the percentage of watershed urban land and population density in northeastern Illinois (Chicago area) during the 1980s and 1990s. The response of biotic indices to increases in urban-related contaminants in sediment is examined. The potentially moderating role of watershed geologic setting, specifically texture of surficial deposits, also is explored. This study incorporated historical data from the 1980s and 1990s from 43 streams in the Des Plaines and Fox River Basins, which are part of the upper Illinois River Basin (Figure 1 and Table 1). Streams in the Des Plaines River Basin drain areas of mainly clayey till and lake clay and silt; whereas streams in the Fox River Basin drain areas of mainly loamy or sandy till and outwash sand and gravel (Lineback *et al.,* 1983; Arnold *et al.,* 1999). Land cover in the study area ranges from intensive row-crop agriculture (corn and soybeans) to intensive urban, with limited areas of forest and wetland (Arnold *et al.,* 1999). Two sets of historical fish data were available for 15 of the 43 streams for the time periods 1984 to 1985 and 1995 to 1999. These data were examined to compare changes over time in the number of intolerant species to changes in population density for streams with a range of watershed urban land.

METHODS

This study used two approaches for examining the effects of urbanization on biotic integrity. The first approach used a substitution of space for time and

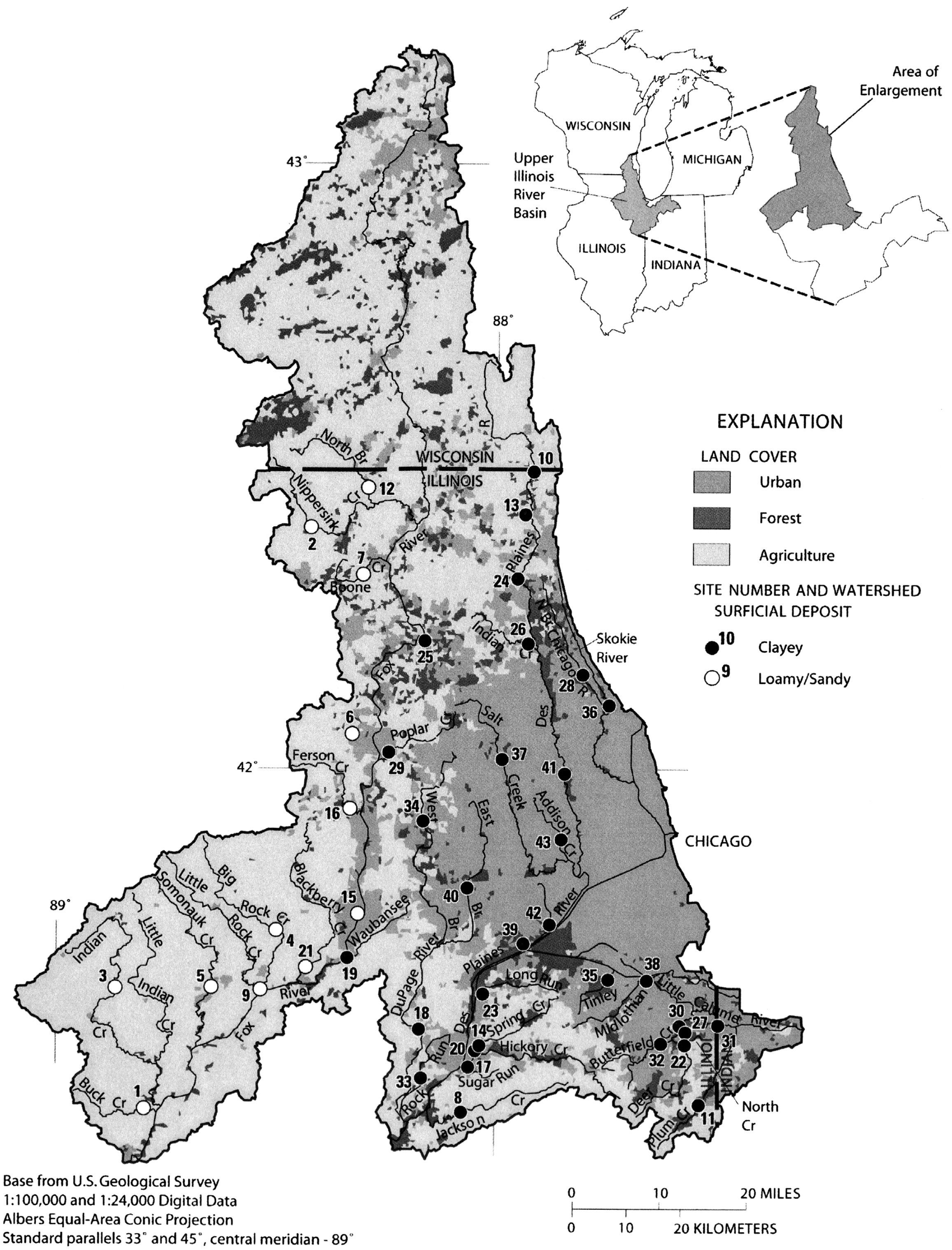

Figure 1. Location of Study Area and 43 Sites Used for Retrospective Analyses of Urbanization Influences on Aquatic Indices in Northeastern Illinois.

TABLE 1. Biotic Integrity, Land Cover, and Geologic Characteristics of 43 Streams in the Chicago Area (IDNR, Illinois Department of Natural Resources; AIBI, alternative index of biotic integrity; MBI, macroinvertebrate biotic index; PIBI, habitat based predicted index of biotic integrity; mi, mile; ppm, parts per million; na, data not available).

									Watershed Characteristics										
Map No.	Stream Name	IDNR Station	Drainage Area (mi^2)	Sampling Date	AIBI	MBI	PIBI	1987 Cu Concentration in Sediment (ppm)	1980 Population Density (people/mi^2)	1990 Population Density (people/mi^2)	2000 Population Density (people/mi^2)	Outwash Sand and Gravel (%)	Sandy and (or) Loamy Till (%)	Clayey Till or Lake Clay and Silt (%)	Bedrock (%)	Alluvium (%)	Water (%)	Surficial Deposits 0-50 ft. Thick (%)	Urban Land (%)
1	Buck Creek	DTZB02	42.7	1986	51	5.7	44	na	16	12	13	0.0	100.0	0.0	0.0	0.0	0.0	8.3	0.0
2	Nippersink Creek	DTK06	25.7	1982	30	5.9	na	na	65	73	38	9.8	77.4	12.8	0.0	0.0	0.0	0.0	0.2
3	Indian Creek	DTA06	42.5	1986	50	5.3	42	na	na	na	32	0.0	74.5	25.5	0.0	0.0	0.0	0.0	0.9
4	Big Rock Creek	DTC07	105.0	1986	50	4.6	na	32	na	na	62	9.5	79.1	11.4	0.0	0.0	0.0	2.5	1.0
5	Somanauk Creek	DTB02	56.4	1986	47	4.7	45	15	na	na	47	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.2
6	Tyler Creek	DTZP04	32.0	1982	38	5.8	44	na	na	na	120	2.6	49.1	48.4	0.0	0.0	0.0	0.0	2.8
7	Boone Creek	DTZT02	15.5	1982	29	6.6	38	na	139	122	146	41.2	40.7	18.1	0.0	0.0	0.0	0.0	3.4
8	Jackson Creek	GC02	43.6	1991	43	4.9	43	na	186	230	345	0.0	0.0	100.0	0.0	0.0	0.0	44.5	3.5
9	Little Rock Creek	DTCA01	75.9	1986	40	4.4	44	na	59	138	155	0.5	99.5	0.0	0.0	0.0	0.0	0.4	3.8
10	Des Plaines River	G08	122.7	1993	44	5.4	38	23	139	156	198	17.8	0.0	82.2	0.0	0.0	0.0	0.0	4.5
11	Plum Creek	HBE02	20.5	1984	36	5.2	35	na	178	187	228	2.4	0.0	97.6	0.0	0.0	0.0	0.0	4.6
12	N. Br. Nippersink Creek	DTKA04	64.6	1986	44	5.4	43	24	120	165	216	49.9	50.0	0.1	0.0	0.0	0.0	0.0	6.0
13	Mill Creek	GW02	65.0	1983	40	5.4	38	26	432	549	808	8.0	0.0	92.0	0.0	0.0	0.0	0.0	9.5
14	Spring Creek	GGA02	18.0	1983	27	5.7	43	na	605	755	528	0.1	0.0	99.9	0.0	0.0	0.0	21.8	11.1
15	Mill Creek	DTZL01	31.0	1986	38	5.8	44	na	535	641	807	28.8	30.8	38.7	1.8	0.0	0.0	7.9	16.4
16	Ferson Creek	DTF02	51.7	1982	34	5.5	44	22	217	369	628	33.2	49.4	17.4	0.0	0.0	0.0	5.3	16.6
17	Sugar Run	GF01	12.2	1983	27	6.6	38	na	626	650	652	0.0	0.0	100.0	0.0	0.0	0.0	78.7	17.8
18	Lily Cache Creek	GBE01	44.1	1983	21	5.8	na	na	1,022	1,193	1,651	31.9	0.0	64.9	3.2	0.0	0.0	66.7	18.9
19	Waubansee Creek	DTE01	29.6	1986	40	5.1	43	na	475	813	1,680	42.6	0.0	56.1	1.4	0.0	0.0	0.1	21.3
20	Hickory Creek	GG02	107.3	1993	28	5.8	46	na	663	777	1,005	1.3	0.0	89.9	0.4	0.0	8.4	18.7	22.0
21	Blackberry Creek	DTD02	70.2	1993	34	5.0	41	13	255	267	402	46.8	41.3	11.9	0.0	0.0	0.0	6.8	22.7
22	Deer Creek	HBDC02	24.2	1984	30	5.9	39	na	883	782	806	3.4	0.0	92.8	2.9	0.0	0.8	37.4	26.1
23	Long Run	GHE01	24.4	1992	na	5.9	43	na	475	888	1,225	0.0	0.0	100.0	0.0	0.0	0.0	12.2	28.5
24	Bull Creek	GV01	12.1	1983	25	5.3	42	27	618	872	1,172	15.6	0.0	84.4	0.0	0.0	0.0	0.0	29.2
25	Flint Creek	DTZS01	36.9	1982	28	7.3	44	na	544	791	883	7.1	0.0	92.9	0.0	0.0	0.0	0.0	30.8
26	Indian Creek	GU02	36.3	1983	32	5.8	42	22	900	1,252	1,832	2.7	0.0	97.4	0.0	0.0	0.0	0.0	33.7
27	North Creek	HBDA01	22.4	1983	28	5.5	30	24	1,566	1,628	1,841	4.0	0.0	96.0	0.0	0.0	0.0	93.9	35.1
28	Middle Fk. N. Br. Chicago R.	HCCC02	19.7	1993	na	7.9	37	55	1,067	1,208	956	0.0	0.0	100.0	0.0	0.0	0.0	0.0	35.9
29	Poplar Creek	DTG02	36.3	1993	36	6.6	42	24	1,404	1,856	2,279	7.9	4.9	87.2	0.0	0.0	0.0	0.0	37.7
30	Thorn Creek	HBD4	103.9	1993	24	5.7	44	na	1,699	1,653	723	1.7	0.0	87.1	1.7	0.0	9.5	46.3	41.6
31	Little Calumet River	HB42	91.6	1993	na	7.4	32	61	1,758	1,654	283	46.8	0.0	52.8	0.4	0.0	0.0	3.0	43.1
32	Butterfield Creek	HBDB03	24.6	1984	23	6.2	43	na	1,705	1,741	2,026	0.0	0.0	78.2	0.0	0.0	21.8	15.3	48.9
33	Rock Run	GBAA01	14.1	1983	27	6.8	na	na	1,551	1,511	2,354	7.1	0.0	66.5	26.4	0.0	0.0	86.6	51.8
34	W. Br. Du Page River	GBK09	28.5	1993	24	6.1	40	36	2,237	2,719	3,527	22.9	0.0	77.2	0.0	0.0	0.0	0.0	52.7
35	Tinley Creek	HF01	11.3	1983	30	6.0	42	na	2,069	2,957	2,876	0.0	0.0	76.8	0.0	0.0	23.2	16.0	56.5
36	Skokie River	HCCD09	29.0	1984	30	5.9	35	58	2,082	2,115	2,013	0.2	0.0	99.8	0.0	0.0	0.0	0.0	61.7
37	Salt Creek	GL10	49.6	1989	23	7.3	43	54	2,666	3,003	3,200	0.0	0.0	100.0	0.0	0.0	0.0	13.1	70.5
38	Midlothian Creek	HBA01	19.9	1984	28	5.9	37	47	2,668	3,134	3,765	0.0	0.0	85.4	0.0	0.0	14.6	25.2	71.7
39	Sawmill Creek	GJ01	12.9	1983	38	6.8	43	na	1,872	2,203	2,333	0.0	0.0	100.0	0.0	0.0	0.0	0.4	73.6
40	E. Br. Du Page River	GBL10	51.5	1993	na	6.2	44	39	2,955	3,165	3,525	33.4	0.0	66.7	0.0	0.0	0.0	9.6	78.9
41	Willow Creek	GO01	20.6	1983	28	6.4	na	na	1,554	1,553	1,401	1.1	0.0	98.9	0.0	0.0	0.0	0.0	85.3
42	Flag Creek	GK03	16.5	1989	23	6.7	42	39	2,880	3,057	3,369	0.0	0.0	71.2	0.0	28.8	0.0	30.8	86.7
43	Addison Creek	GLA 02	18.2	1993	18	6.5	38	na	4,090	4,023	4,374	0.0	0.0	100.0	0.0	0.0	0.0	40.6	92.4

examined biotic integrity data from the 1980s and 1990s collected by the Illinois Environmental Protection Agency (IEPA) from 43 streams with a wide range of urban land and population density. When space is substituted for time, it is assumed that future temporal trends at a site (in this case increases in urban land and population density) will be similar to spatial trends found among sites. The second approach examined temporal trends in fish data collected by the Illinois Department of Natural Resources and compared them to urban growth at a subset of the 43 streams for the time periods 1984 to 1985 and 1995 to 1999.

Fish, invertebrate, and habitat indices were obtained from the IEPA for 43 streams in the Chicago area. Data used to calculate the indices were collected by the IEPA from 1982 to 1993 as part of their intensive basin surveys, with most of the data collected in 1986 (IEPA, 1994). The Illinois alternative fish index of biotic integrity (AIBI) was obtained for 39 streams, the Macroinvertebrate Biotic Index (MBI) for all 43 streams, and the habitat based predicted index of biotic integrity (PIBI) for 38 streams. The State of Illinois has used the IBI and the AIBI since the mid-1980s (Hite and Bertrand, 1989). The IBI or AIBI scores have been used as principal indicators of stream quality in northeastern Illinois (Dreher, 1997).

The IBI is based on 12 fish metrics that fall into three general categories: species richness and composition, trophic composition, and fish abundance and composition (Karr *et al.,* 1986; Hite and Bertrand, 1989). For the more commonly reported AIBI, the disease metric included in the original IBI is set to be equal to the average of the other 11 metrics. This adjustment allows calculation of an index like IBI when disease information is lacking or unreliable. AIBI scores are presented in this paper for the 39 streams. AIBI scores can range from 0 (no fish) to 60 (excellent) (Table 2). For examination of historical changes in fish communities, modified IBI scores and the metrics used to calculate them were obtained for 15 of the 43 streams for two time periods: 1984 to 1985 and 1995 to 1999 (Table 3). The modified IBI is slightly different from AIBI and was calculated in order to compare data from the two different time periods. The modified IBI is based on 10 of the 12 metrics included in the original Illinois IBI. The disease metric was dropped, and because of differences in collection methods, the metric for the number of individuals was dropped. The IBI value, based on the 10 metrics, was then scaled to 60 points. Four of the sites (Hickory Creek, West Branch Du Page River, East Branch Du Page River, and Addison Creek) were at different locations than those used for the comparison of 43 streams. Population density data were calculated for drainage areas that reflect the different locations of these four sites. The historical fish data from the 15 streams were specifically used to document how changes in biotic integrity over time related to changes in population density for streams with a range of urban land cover.

Calculation of MBI and PIBI scores are described in Hite and Bertrand (1989) and Bertrand *et al.* (1996) and are summarized in Table 2. The recommended use of the MBI for biological assessment is generally limited to situations where fisheries data are unavailable and streams have a limited or restricted aquatic resource (Hite and Bertrand, 1989). PIBI scores were generated by the IEPA from multiple regression analysis and are based on water depth, velocity, streambed substrate and instream habitat cover (Bertrand *et al.,* 1996).

A subset of the 43 streams with biotic integrity data also has streambed trace element data collected by the USGS in 1987 (Colman and Sanzolone, 1991). Concentrations of chromium, copper, lead, mercury, nickel, and zinc were selected as examples of urban related trace elements and compared to biotic indices,

TABLE 2. Description of Illinois Alternative Index of Biotic Integrity (AIBI), Macroinvertebrate Biotic Index (MBI), Habitat Based Predicted Index of Biotic Integrity (PIBI), and Associated Stream Classes, Biotic Resource Quality, and Biological Stream Characterization (Hite and Bertrand, 1989; Bertrand *et al.,* 1996).

AIBI Score	Stream Class Based on AIBI	AIBI Biotic Resource Quality	MBI Score	PIBI Score	General Description for MBI and PIBI	Biological Stream Characterization Resource
51 to 60	A	Excellent	< 5.0	51 to 60	Good	Unique
41 to 50	B	Good	5.0 to 5.9	41 to 50	Good	Highly Valued
31 to 40	C	Fair	6.0 to 7.5	31 to 40	Fair	Moderate
21 to 30	D	Poor	7.6 to 8.9	< 31	Fair	Limited
≤ 20	E	Very Poor	> 8.9	–	Poor	Restricted

TABLE 3. Comparison of Modified Fish Index of Biotic Integrity (IBI) Scores, Number of Fish Species, and Number of Intolerant Fish Species for 15 Streams in the Chicago Area for Data from 1984 to 1985 and 1995 to 1999 (USGS, U.S. Geological Survey; IDNR, Illinois Department of Natural Resources; rows in bold text denote streams with loamy surficial deposits; mi, mile).

Map No.	Stream Name	USGS Station No.	IDNR Station No.	Drainage Area (mi^2)	Modified IBI		No. of Fish Species		No. of Intolerant Fish Species		Change in Intolerant Species
					1984-85	1995-99	1984-85	1995-99	1984-85	1995-99	
1	**Buck Creek**	**05552450**	**DTZB02**	**42.7**	**53**	**46**	**21**	**24**	**7**	**10**	**3**
7	**Boone Creek**	**05549000**	**DTZT02**	**15.5**	**29**	**38**	**9**	**15**	**2**	**2**	**0**
9	**Little Rock Creek**	**05551939**	**DTCA01**	**75.9**	**43**	**46**	**16**	**23**	**5**	**8**	**3**
11	Plum Creek	05536176	HBE02	20.5	31	41	13	15	0	0	0
12	**N. Br. Nippersink Creek**	**05548200**	**DTKA04**	**64.6**	**38**	**53**	**15**	**19**	**2**	**6**	**4**
16	**Ferson Creek**	**05551200**	**DTF02**	**51.7**	**36**	**46**	**13**	**21**	**3**	**5**	**2**
20	Hickory Creek	05538270	GG06	49.1	38	41	11	13	2	4	2
21	**Blackberry Creek**	**05551695**	**DTD02**	**70.2**	**36**	**31**	**11**	**16**	**3**	**2**	**-1**
22	Deer Creek	05536236	HBDC02	24.2	29	31	5	13	0	0	0
23	Long Run	05537550	GHE01	24.4	41	26	7	8	0	0	0
24	Bull Creek	05528032	GV01	12.1	26	24	5	9	1	1	0
34	W. Br. Du Page River	05540032	GBK07	60.6	26	38	9	13	0	2	2
37	Salt Creek	05531045	GL10	49.6	34	29	7	9	0	1	1
40	**E Br. Du Page River**	**05540260**	**GBL02**	**79.5**	**13**	**41**	**12**	**18**	**1**	**3**	**2**
43	Addison Creek	0553200	GLA01	18.2	22	29	1	8	0	1	1

land cover, and population density. Copper concentrations for sites with streambed sediment trace element data are shown in Table 1.

Land cover, population, and geologic data were derived from overlays of thematic maps with watershed boundaries by use of a geographic information system (GIS) for the 43 streams. Watershed boundaries for many sites were previously delineated by use of existing USGS digital 1:24,000-scale drainage boundaries. Watershed boundaries were estimated by use of the existing digital boundaries as a base. For land cover information, 30-meter thematic mapper satellite imagery (MRLC) was used (Vogelmann *et al.*, 2001). The urban land cover data are subdivided into low intensity residential, high intensity residential, commercial/industrial/transportation, and urban/recreational grasses. Population data from 1980, 1990, and 2000 also were used to examine changes in population density over the last 20 years for each watershed (U.S. Bureau of the Census, 1985, 1991, 2001). Geologic information generated for each watershed included Quaternary surficial deposits, depth of surficial deposits, and bedrock geology (Arnold *et al.*, 1999).

Streams were grouped into two categories based on the texture of surficial deposits in their watersheds (Figure 1 and Table 1). Streams with greater than 50 percent clayey till, lake clay, and silt were grouped as "clayey streams." Streams with greater than 50 percent loam, sand, or gravel deposits were classified as "loamy/sandy streams." All streams in the Des Plaines River Basin and three eastern tributaries to the Fox River were grouped as having clayey deposits in their watersheds (Figure 1).

For the 43 streams, AIBI scores from 1986 to 1993 were compared as a group to watershed characteristics and sediment trace element data by use of scatter plots. Correlation analysis was used to examine the strength of relations among biotic indices, watershed characteristics, and sediment trace element concentrations. Data distributions for many characteristics were not normally distributed, and thus Spearman rank correlations, which do not require the assumption of normal distributions, were used (Johnson and Wichern, 1992). Significant correlation coefficients (r) were defined as those where the probability of a Type I error is less than 5 percent ($p < 0.05$).

RESULTS

Watershed urban land for the 43 streams ranged from 0 to 92 percent (Table 4). Streams with low

TABLE 4. Summary Statistics for 43 Study Streams in Northeastern Illinois.

	n	Minimum	Maximum	Mean	Median
Alternative Fish Index of Biotic Integrity (AIBI)	39	18	51	33	30
Macroinvertebrate Biotic Index (MBI)	43	4.4	7.9	5.9	5.8
Habitat-Based Predicted Index of Biotic Integrity (PIBI)	38	30	46	41	42
Watershed Urban Land (percent)	43	0	92	32	26
2000 Population Density (people/mi^2)	43	13	4,374	1,315	883
Watershed Agricultural Land (percent)	43	0	99	52	55
Watershed Forest/Wetland (percent)	43	1	42	16	16
Watershed Clayey Deposits (percent)	31	53	100	87	92
Watershed Loamy/Sandy Deposits (percent)	12	52	100	84	87
Drainage Area (mi^2)	43	11	123	41	31
Chromium in Streambed Sediment (parts per million)	19	45	110	67	63
Copper in Streambed Sediment (parts per million)	19	13	61	34	27
Lead in Streambed Sediment (parts per million)	19	21	120	55	41
Mercury in Streambed Sediment (parts per million)	19	.02	.68	.19	.06
Nickel in Streambed Sediment (parts per million)	19	18	46	31	31
Zinc in Streambed Sediment (parts per million)	19	61	410	162	110

percentages of urban land had high percentages of agricultural land. The combined amount of forest and wetland in the watersheds ranged from 1 to 42 percent with an average of 16 percent. Drainage areas ranged from 11 to 123 mi^2 with an average drainage area of 41 mi^2.

Watershed percent urban land and population density were highly correlated ($\rho = 0.96$) (Table 5). By Census Bureau definition, areas with greater than 1,000 people/mi^2 are considered “urban.” In this study, watersheds with a population density of greater than 1,000 people/mi^2 had greater than 30 percent urban land (Table 1). Some outliers were Willow Creek, with a high percentage of urban land but lower than expected population density, and Lily Cache Creek, with high population density and lower than expected urban land (Table 1). Willow Creek is near the O’Hare International Airport and 47 percent of the watershed has industrial/commercial land cover. Lily Cache Creek has high intensity residential land in its headwaters.

Streams with clayey surficial deposits in their watersheds represented a full gradient of urban land and population density (Figure 2). Streams with loamy/sandy surficial deposits represented a partial gradient, with the amount of urban land ranging from 0 to 25 percent. Significant correlations among watershed urban land and other watershed characteristics are shown in Table 5. Urban land and agricultural land were negatively correlated, reflecting the sampling design for an agricultural to urban land cover gradient. The positive correlations among urban land, population density, and clayey deposits are a reflection of the full agricultural to urban land cover gradient for streams in clayey deposits but only a partial gradient for streams in loamy/sandy deposits (streams with high percentages of urban land are found in clayey deposits in and near the city of Chicago). The combined amount of watershed forest and wetland negatively correlated with agricultural land and loamy/sandy deposits, positively correlated with clayey deposits, but did not significantly correlate with urban land.

AIBI and MBI scores significantly correlated with watershed percent urban land (Table 5 and Figures 2 and 3). Both clayey and loamy/sandy streams with less than 10 percent urban land and less than 500 people/mi^2 had a range in AIBI scores from less than 30 to greater than 50 (poor to excellent; Table 1 and Figure 2). Streams with greater than 10 percent urban land or 500 people/mi^2 had AIBI scores consistently at or below 40 (poor to fair). Streams with greater than 40 percent urban land or about 1,600 people/mi^2 generally had AIBI scores at 30 or below (poor). An exception was Sawmill Creek, with 74 percent urban land and an AIBI score of 38 (fair).

Similar to AIBI scores, MBI scores from streams with less than 10 percent urban land covered a range from 4.4 to 6.6 (good-unique to fair), but streams with greater than about 40 to 45 percent urban land had MBI cores of 5.7 to 7.4 (generally fair). Three urban streams had MBI scores below 6.0 and included

TABLE 5. Statistically Significant Spearman Correlation Coefficients for Fish, Macroinvertebrate, and Habitat Indices; and Land Cover, Population Density, and Sediment Trace Element Concentrations (AIBI, Alternative Fish Index of Biotic Integrity; MBI, Macroinvertebrate Biotic Index; PIBI, habitat based predicted Index of Biotic Integrity; URB, watershed urban land; POPD, 1990 population density; AG, watershed agricultural land; FORW, watershed forest and wetland; CLAY, watershed clayey deposits; LOAM, watershed loamy/sandy deposits; DA, drainage area; --, not significant; p-value < 0.05).

	AIBI	**MBI**	**PIBI**	**URB**	**POPD**	**AG**	**FORW**	**CLAY**	**LOAM**	**DA**	**Cr**	**Cu**	**Pb**	**Hg**	**Ni**	**Zn**
AIBI	1.00															
MBI	-.61	1.00														
PIBI	--	--	1.00													
URB	-.68	.65	--	1.00												
POPD	-.74	.64	--	.96	1.00											
AG	.72	-.73	--	-.96	-.93	1.00										
FORW	--	.48	--	--	--	-.54	1.00									
CLAY	-.44	.40	--	.50	.49	-.52	.47	1.00								
LOAM	.58	-.50	--	-.64	-.65	.64	-.43	-.87	1.00							
DA	.45	-.45	--	--	--	.44	--	-.41	.53	1.00						
Cr	-.59	.70	--	.73	.71	-.80	.56	.56	-.67	--	1.00					
Cu	-.55	.69	-.44	.67	.61	-.74	.58	.40	-.52	--	.94	1.00				
Pb	--	--	--	--	--	-.40	--	--	--	--	.61	.65	1.00			
Hg	-.51	.54	--	.47	--	-.52	.69	.48	--	--	.63	.65	.50	1.00		
Ni	-.71	.65	--	.79	.76	-.83	.41	.51	-.67	-.55	.89	.86	.52	.53	1.00	
Zn	--	.54	-.58	.55	.49	-.52	--	--	-.47	--	.71	.73	.90	.65	.64	1.00

Thorn Creek (5.7), Skokie River (5.9), and Midlothian Creek (5.9).

Sawmill Creek had a better AIBI but poorer MBI score compared to other sites with similar percentages of urban land (Table 1). Urban land cover in the Sawmill Creek watershed is a mix of commercial, industrial and high intensity residential, but about 25 percent of the watershed is forested (about 5 mi^2 of the lower part of the watershed is county forest preserve and the Argonne National Laboratory Reservation). In the 1980s there were two dischargers to Sawmill Creek, a sewage treatment plant in the upper part of the watershed and Argonne National Laboratory (treated sewage and laboratory wastewater) near the sampling site. The Creek has a major interstate corridor in the middle of the watershed. Sawmill Creek is a direct tributary to the Des Plaines River (Figure 1) and has a relatively steep slope as the stream cuts through the Des Plaines River valley side. In contrast to Sawmill Creek is Tinley Creek, with similar land cover; however, its AIBI score was poorer, and its MBI score was similar to other streams with similar percentages of watershed urban land cover. Tinley Creek flows into the Calumet Sag Channel and has less local relief than Sawmill Creek.

The PIBI scores for habitat quality ranged from 30 to 46 (fair-moderate to good-highly valued) but did not significantly correlate with percent watershed urban land or population density (Table 5 and Figure 4). PIBI scores did not significantly correlate with either the AIBI or MBI scores.

Chromium, copper, and nickel concentrations in streambed sediment significantly correlated with AIBI and MBI scores, and poor AIBI and MBI scores related to high concentrations of these elements (Table 5). These trace element concentrations also significantly increased with increasing percent urban land and population density. AIBI scores were poor in streams with copper concentrations above about 32 ppm, the consensus based threshold effect concentration below which harmful effects on aquatic ecosystems are unlikely to be observed (MacDonald *et al.,* 2000) (Figure 5). Streams with copper concentrations greater than 32 ppm had greater than about 40 percent urban land. All streams had copper concentrations below the consensus based probable effects concentration of 149 ppm, above which harmful effects are likely to be observed (MacDonald *et al.,* 2000). MBI scores had slightly higher correlation coefficients with chromium and copper concentrations than AIBI scores. For Willow Creek (85 percent urban), AIBI and MBI scores are similar to other urban streams (Table 1), even though the watershed is 47 percent industrial/commercial land and the

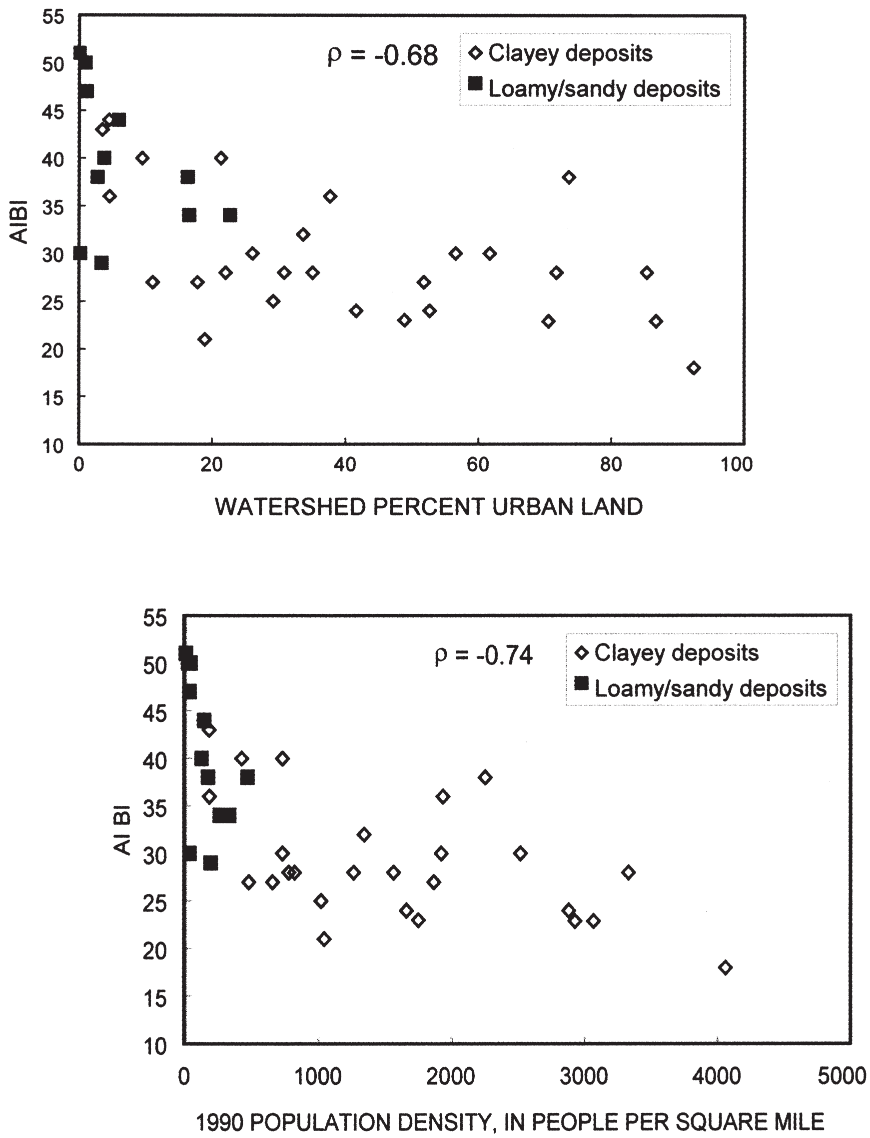

Figure 2. Relations Among Alternative Index of Biotic Integrity (AIBI) Scores and Watershed Percent Urban Land and 1990 Population Density for 43 Urban Gradient Sites in Northeastern Illinois (ρ = Spearman correlation coefficient).

sampling location is 1 mi downstream of one of Chicago's five major waste-water treatment plants, 2 mi downstream of Chicago O'Hare International Airport, and 0.5 mi downstream of a interchange between two major interstates.

The subset of 15 streams with fish community data from 1984 to 1985 and 1995 to 1999 encompass a full range of watershed urban land and population density (Figure 6). The streams were divided into three groups based on their population density and amount of urban land: rural with very little urban development (less than 300 people/mi^2 and less than 10 percent urban land), rural/urbanizing (300 to 1,200 people/mi^2 and 10 to 30 percent urban land), and urban (greater than 1,200 people/mi^2 and greater than 30 percent urban land). The five rural streams experienced little or no population growth from 1980 to 2000. Five of the six rural/urbanizing streams had population growth in their watersheds, only one of the six watersheds decreased in population (Deer Creek). All urban streams continued to grow in population, even those with greater than 70 percent watershed urban land.

Modified IBI scores increased at 10 of the 15 streams from the 1984 to 1985 period to the 1995 to 1999 period within all three groups (Table 3). Modified IBI scores decreased at Buck Creek, Blackberry Creek, Long Run, Bull Creek, and Salt Creek. The number of fish species increased in all streams, most likely because the Illinois DNR updated their fish sampling techniques in the 1990s by incorporating the use of electric seines (Table 3). The number of intolerant fish species in 1995 to 1999 decreased with increasing 1990 population density (Table 3 and Figure 7), with a noticeable decrease in the number of intolerant species at about 500 people/mi^2, similar to what was observed with AIBI scores and population density data for the 43 streams.

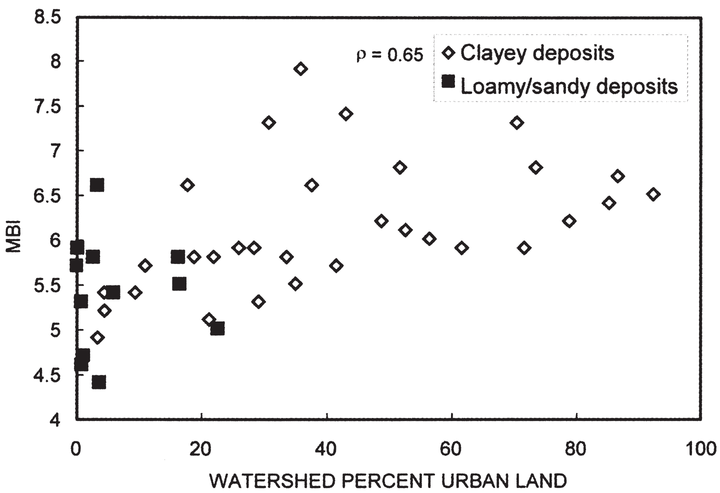

Figure 3. Relation Between Macroinvertebrate Biotic Index (MBI) and Watershed Percent Urban Land for 43 Urban Gradient Sites in Northeastern Illinois. Higher scores indicate a decrease in invertebrate biotic integrity (ρ = Spearman correlation coefficient).

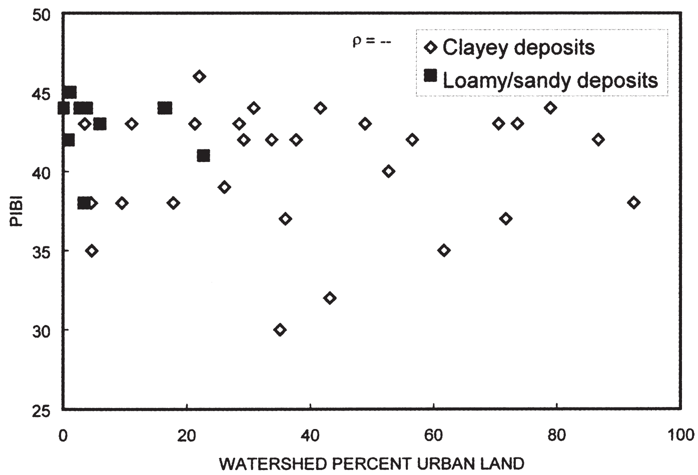

Figure 4. Relation Between Habitat Based Predicted Index of Biotic Integrity (PIBI) Scores and Watershed Percent Urban Land for 43 Urban Gradient Sites in Northeastern Illinois (ρ = Spearman correlation coefficient; -- = not significant, p-value < 0.05).

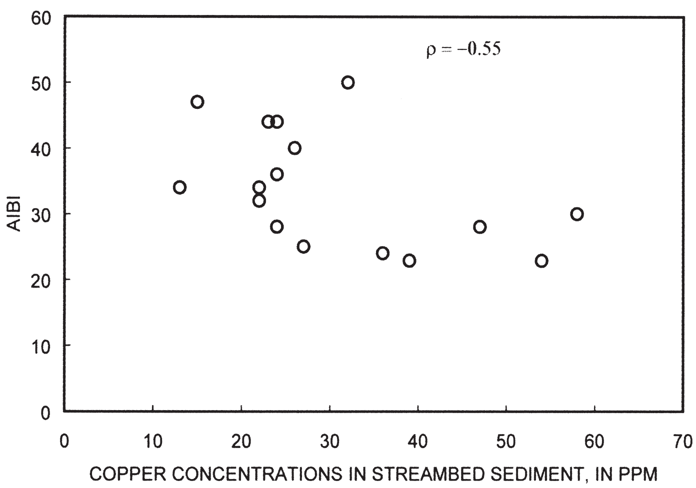

Figure 5. Relation Between Alternative Index of Biotic Integrity (AIBI) Scores and Sediment Copper Concentrations for a Subset of 16 Urban Gradient Sites in Northeastern Illinois (ρ = Spearman correlation coefficient).

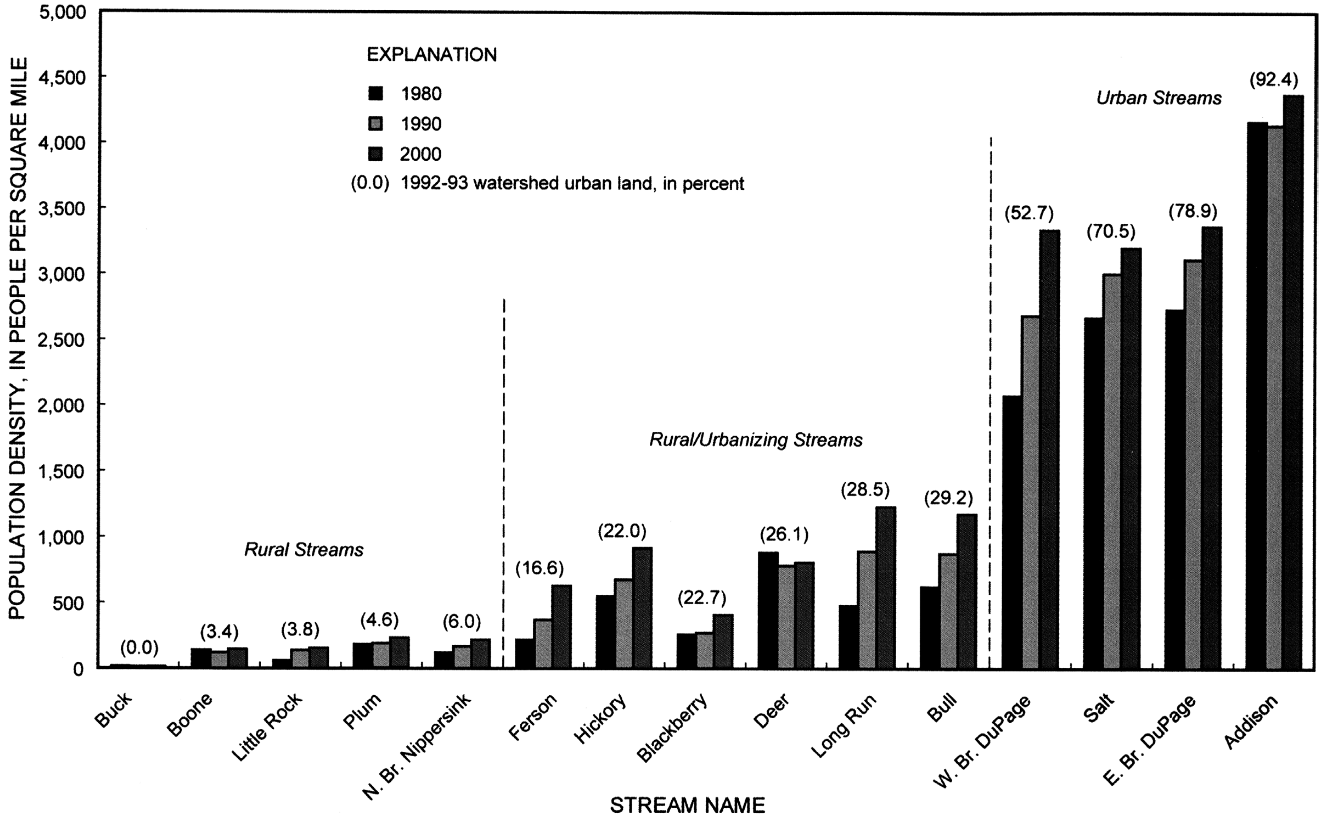

Figure 6. Changes in Population Density from 1980 to 2000 at a Subset of 15 Urban Gradient Sites in Northeastern Illinois.

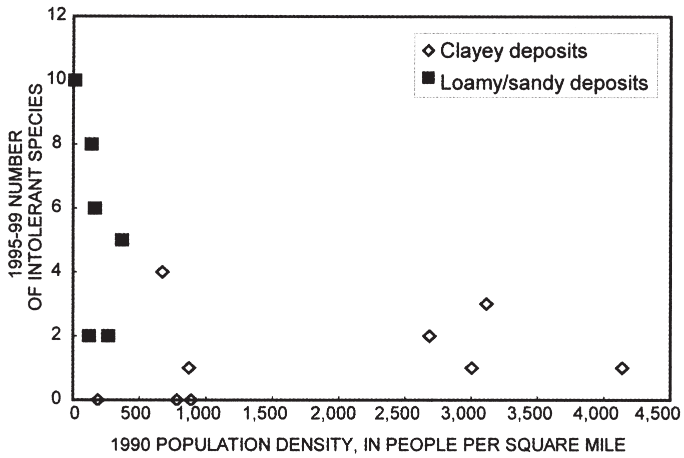

Figure 7. Scatter Plot of Number of Intolerant Fish Species (1995 to 1999) and 1990 Population Density at a Subset of 15 Urban Gradient Sites in Northeastern Illinois.

The number of intolerant fish species also increased at 9 out of 15 of the sites from the 1984 to 1985 period to the 1995 to 1999 period (Figure 8). Sites that gained intolerant species included rural sites with no urbanization (Little Rock Creek), rural sites with urbanization (Ferson Creek), and urbanized sites with continued urbanization (E. Br. Du Page River). There seems to be a general pattern that tributaries to the Fox River with loamy/sandy surficial deposits gained the most intolerant species (up to four), whereas tributaries to the Des Plaines River with clayey surficial deposits did not gain any or only gained one or two intolerant species. In previous examinations of historical data from the Fox River from 1964 to 1982, species richness also was noted to be improving (IEPA, 1987). However, the modified IBI score and the number of intolerant species both decreased at Blackberry Creek (this decrease has not been investigated).

Tributaries to the Des Plaines River in clayey deposits, especially those far removed from the main stem of the Des Plaines River, do not seem to show improving fish populations. This may be caused by a lack of potential recolonizing fish populations (Stephen Pescitelli, Illinois Department of Natural Resources, 2003, personal communication) or poor water quality in the Des Plaines River main stem. The lack of improvement also may be related to the presence of clayey surficial deposits, which may be impacting available habitat. Exceptions to this general trend are Hickory Creek and West Branch Du Page River. Both of these clayey streams had net gains of two intolerant species and had increases in population density (Figure 8).

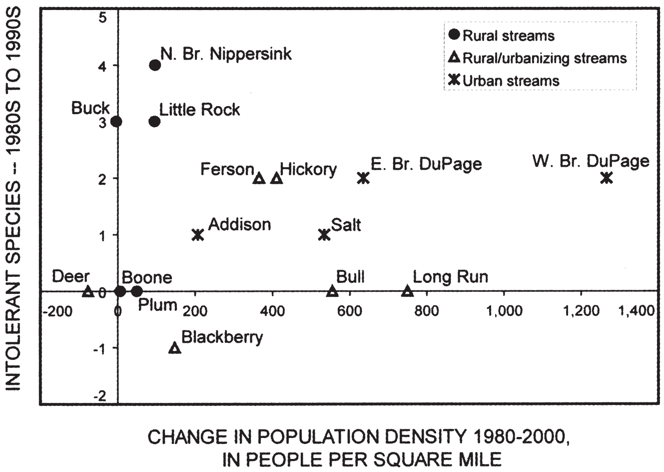

Figure 8. Change in the Number of Intolerant Fish Species (1984 to 1985 and 1995 to 1999) and Population Density (1980 to 2000).

DISCUSSION AND CONCLUSIONS

Results from this study support the findings from other studies in northeastern Illinois and southeastern Wisconsin and indicate that streams with less than 10 percent urban land had a range in AIBI scores from less than 30 to greater than 50 (poor to excellent), but above 10 percent urban land, AIBI scores were consistently at or below 40 (fair or poor). These results are similar to Wang *et al.* (1997, 2000, 2001) results for Wisconsin streams. Relations among AIBI scores and population density also are similar to that from Dreher (1997), in that most streams with greater than 500 people/mi^2 had AIBI scores below 40 (fair or poor). This is not surprising since the streams in this study were a subset of the streams examined by Dreher. However, analysis of both land cover and population density allows a comparison of responses to both types of urban intensity indicators. For this data set, 500 people/mi^2 corresponded to a range of about 10 to 18 percent urban land in northeastern Illinois. For Chicago area streams, 500 people/mi^2 relates to about 7 percent total impervious area (Allen and Bejcek, 1979). MBI scores generally increased to 5.0 or above for streams with greater than 10 percent urban land, which suggests that decreases in macroinvertebrate biotic integrity also may relate to a low amount of urban development.

The significant correlations among AIBI, MBI, and agricultural land show that biotic integrity may further decrease when agricultural land is replaced with urban land. The replacement of forest and wetland with agricultural land previously has been shown to reduce biotic integrity in Wisconsin (Wang *et al.,* 1997; Fitzpatrick *et al.,* 2001; Stewart *et al.,* 2001). In the Fitzpatrick *et al.* (2001) study from southeastern Wisconsin, Wisconsin IBI scores decreased from 70 to 100 in forested watersheds with 0 percent agricultural land to scores of less than 40 in watersheds with 80 percent agricultural land. In the Wang *et al.* (1997) study, Wisconsin IBI scores range from about 10 to 70 in highly agricultural watersheds (greater than 80 percent agricultural land), indicating that some agricultural streams maintain relatively high biotic integrity. Similar to the Wang *et al.* (1997, 2000, 2001) studies, agricultural streams in this study had a range of biotic integrity, but IBI scores dropped further as the percentage of watershed urban land increased.

The moderating role of texture in watershed surficial deposits on biotic integrity of Chicago area streams is unclear. Both clayey and loamy/sandy streams had a range of AIBI and MBI scores at sites with less than 10 percent urban land, although loamy/sandy streams had a wider range in scores for agricultural/rural streams. At greater than 10 percent urban land, the biotic integrity of streams in both types of surficial deposits decreased, but scores were generally lower for some clayey streams. These are some preliminary indications that loamy/sandy streams may maintain higher biotic integrity when urbanized; however, these findings need further substantiation with analysis of data from a larger number of loamy/sandy streams with higher percentages of watershed urban land or population density.

The trace elements chromium, copper, and nickel were correlated with watershed urban land and AIBI and MBI scores. In addition, copper concentrations in sediment were found to exceed sediment guidelines for threshold concentrations above 40 percent watershed urban land. Further decreases in AIBI and MBI scores above 40 percent suggest that aquatic communities, especially invertebrates, may be affected by contaminants as urban areas continue to develop. Benthic invertebrates, which spend more time in contact with streambed sediment, may be more influenced by sediment related contaminants than fish. Streambed sediment in older urban streams, which may have been historically affected by point and nonpoint sources of contaminants, might continue to be a future source for contaminants even if no new sources are added from the watershed. Three of the highest MBI scores (7.3 to 7.9) occurred in streams that had a range of watershed urban land from 31 to 71 percent urban land (Middle Fork North Branch Chicago River, Little Calumet, and Salt Creek). Copper concentrations were similarly elevated at all three streams. There are exceptions to this relation, such as the Skokie River, which had an elevated copper concentration but a MBI score of 5.9.

Habitat indices also would be expected to degrade as channel characteristics are altered from changes in runoff and sediment production during urban development. The lack of relations among watershed percent urban land and the PIBI habitat index may be because: (1) the metrics included in the index are not unique in describing geomorphic processes occurring in urbanizing streams at different temporal and spatial scales and (2) the metrics are not sensitive enough to quantify geomorphic changes. The potential variety of geomorphic responses to urbanization make it difficult to adequately describe and infer the quality of habitat conditions, especially in sampling schemes that substitute space for time. There are a few methodologies specifically designed to assess geomorphic instability (Snodgrass *et al.,* 1997; Thorne, 1998); however, more development and testing of these methodologies are needed to assess their usefulness for a variety of physiographic settings and geomorphic conditions.

These results illustrate the complexities involved with use of multiple years and types of data and also use of a space substituted for time approach. Improvements in fish collection techniques occur more often than not and need to be accounted for when looking at multiple years of data. Fish biotic integrity may improve in some urbanizing and highly urbanized streams, possibly due to stabilization of geomorphic conditions (both natural and human derived), improvements to fish habitat, and historical decreases in point and nonpoint sources of contaminants and nutrients. In addition, in order for fish biotic integrity to improve in small streams, fish need to be able to recolonize the stream after the physical and chemical characteristics improve. There must be both a nearby source of additional fish species and a lack of physical barriers, such as dams or waterfalls that may block recolonization. This may explain the better AIBI score at Sawmill Creek compared to Tinley Creek. Both watersheds are a similar size, have similar percentages of industrial/commercial land, and have forest preserves in the lower part of the watersheds near the sampling sites. The difference may be the proximity of Sawmill Creek to the Des Plaines River as opposed to Tinley Creek, which flows through a short stretch of urban area before reaching the Calumet Sag Channel. Also, Sawmill Creek, where it cuts through the Des Plaines River valley side, has a steeper slope than Tinley Creek. Thus, high AIBI scores in urban streams may result from a combination of proximity to recolonizing species and local forest cover and geologic setting.

The following conclusions can be made about urbanization influences on aquatic communities in streams in northeastern Illinois (Chicago area). In general, fish and macroinvertebrate indices of biotic integrity decrease as agricultural land is replaced by urban land. It is likely that the biotic integrity of many of the agricultural streams was affected by historical agricultural practices, although there were exceptions. This is reflected in the wide range of AIBI scores (poor to excellent) observed at agricultural/rural streams. Initial decreases occur at about 10 percent watershed urban land and 500 people/mi^2. Further decreases occur at about 45 percent watershed urban land and are correlated to concentrations of urban-related trace elements such as chromium, copper, and nickel. The habitat index did not decrease with increasing urban land. The texture surficial deposits within the watershed may play a role in moderating the effects of urbanization but results are inconclusive. The number of intolerant fish species and modified IBI scores increased in some rural, urbanizing, and urban streams from the 1980s to 1990s, with the largest increases occurring in rural streams with loamy/sandy surficial deposits. However, smaller increases also occurred in urban streams with clayey surficial deposits and over 50 percent watershed urban land. These increases may be caused by historical decreases in point and nonpoint sources of contaminants and nutrients, geomorphic stabilization, and fish habitat improvements, as well as local factors such as the proximity to forest cover and recolonizing species and geologic setting. Additional factors (not analyzed in this study) may influence the biological response of streams to urbanization and require further investigation, including historical land cover practices, historical and present-day storm water and sewage treatment practices, presence of fish barriers such as dams, and other human modifications to the channel such as channelization, straightening, restoration/rehabilitation, and detention basins.

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LITERATURE CITED

Allen, H.E., Jr. and R.M. Bejcek, 1979. Effects of Urbanization on the Magnitude and Frequency of Floods in Northeastern Illinois. U.S. Geological Survey Water Resources Investigations 79-36, Urbana, Illinois, 48 pp.

American Society of Civil Engineers, 1969. An Analysis of National Basic Information Needs in Urban Hydrology. American Society of Civil Engineers, Urban Hydrology Research Council, New York, New York, 112 pp.

Arnold, T.L., D.J. Sullivan, M.A. Harris, F.A. Fitzpatrick, B.C. Scudder, P.M. Ruhl, D.W. Hanchar, and J.S. Stewart, 1999. Environmental Setting of the Upper Illinois River Basin and Implications for Water Quality. U.S. Geological Survey Water Resources Investigations Report 98-4268, Urbana, Illinois, 67 pp.

Bannerman, R.T., D.W. Owens, R.B. Dodds, and N.J. Hornewer, 1993. Sources of Pollutants in Wisconsin Stormwater. Wat. Sci. Tech. 28(305):241-259.

Bertrand, W.A., R.L. Hite, and D.M. Day, 1996, Biological Stream Characterization (BSC) – Biological Assessment of Illinois Stream Quality Through 1993. Illinois Environmental Protection Agency Division of Water Pollution Control, IEPA/BOW/96-058, 44 pp.

Bledsoe, B.P. and C.C. Watson, 2001. Effects of Urbanization on Channel Instability. Journal of the American Water Resources Association (JAWRA) 37(2):255-270.

Booth, D.B., 1990. Stream-Channel Incision Following Drainage-Basin Urbanization. Water Resources Research 26(3):407-417.

Booth, D. and C.R. Jackson, 1997. Urbanization of Aquatic Systems: Degradation Thresholds, Stormwater Detection, and the Limits of Mitigation. Journal of American Water Resources Association (JAWRA) 33(5):1077-1090.

Booth, D. and L. Reinelt, 1993, Consequences of Urbanization on Aquatic Systems – Measured Effects, Degradation Thresholds, and Corrective Strategies. Proceedings Watershed '93, A National Conference on Watershed Management, Alexandria, Virginia, pp. 545-550.

Colman, J.A. and R.F. Sanzolone, 1991. Surface-Water-Quality Assessment of the Upper Illinois River Basin in Illinois, Indiana, and Wisconsin – Geochemical Data for Fine-Fraction Streambed Sediment From High- and Low-Order Streams, 1987. U.S. Geological Survey Open-File Report 90-571, Urbana, Illinois, 108 pp.

Colman, J.A. and R.F. Sanzolone, 1992, Geochemical Characterization of Streambed Sediment in the Upper Illinois River Basin. Water Resources Bulletin 28(5):933-950.

Colosimo, M.F., 2002, Physical and Biological Stream Changes in an Urbanizing Watershed: Gwynns Falls, Maryland. Abstract Proceedings, American Water Resources Association 2002 Annual Conference, Philadelphia, Pennsylvania, p. 190.

Crunkilton, R., J. Kleist, J. Ramcheck, W. DeVita, and D. Villeneueve, 1997. Assessment of the Response of Aquatic Organisms to Long-Term Insitu Exposures of Urban Runoff. *In:* Effects of Watershed Development and Management on Aquatic Ecosystems, L.A. Roesner (Editor). American Society of Civil Engineers, New York, New York, pp. 95-111.

Dinicola, R.S., 1989. Characterization and Simulation of Rainfall-Runoff Relations for Headwater Basins in Western King and Snohomish Counties, Washington State. U.S. Geological Survey Water-Resources Investigations Report 89-4052, 52 pp.

Dreher, D.W., 1997. Watershed Urbanization Impacts on Stream Quality Indicators in Northeastern Illinois. Proceedings from the National Symposium on Assessing the Cumulative Impacts of Watershed Development on Aquatic Ecosystems and Water Quality, Chicago, Illinois, pp. 129-135.

Finkenbine, J.K., J.W. Atwater, and D.S. Mavinic, 2000. Stream Health After Urbanization. Journal of American Water Resources Association (JAWRA) 36(5):1149-1160.

Fitzpatrick, F.A., T.L. Arnold, and J.A. Colman, 1998. Surface-Water-Quality Assessment of the Upper Illinois River Basin in Illinois, Indiana, and Wisconsin – Spatial Distribution of Geochemicals in the Fine Fraction of Streambed Sediment, 1987. U.S. Geological Survey Water Resources Investigations Report 98-4109, Urbana, Illinois, 89 pp.

Fitzpatrick, F.A., B.C. Scudder, B.N. Lenz, and D.J. Sullivan, 2001. Effects of Multi-Scale Environmental Characteristics on Agricultural Stream Biota in Eastern Wisconsin. Journal of the American Water Resources Association (JAWRA) 37(6):1489-1507.

Garie, H.L. and A. McIntosh, 1986. Distribution of Benthic Macroinvertebrates in a Stream Exposed to Urban Runoff. Journal of American Water Resources Association (JAWRA) 22(3):447-455.

Gergel, S.E., M.G. Turner, J.R. Miller, J.M. Melack, and E.M. Stanley, 2002. Landscape Indicators of Human Impacts to Riverine Systems. Aquatic Sciences 64:118-128.

Graf, W.L., 1975. The Impact of Suburbanization on Fluvial Geomorphology. Water Resources Research 11(5):690-692.

Gregory, K.J., R.J. Davis, and P.W. Downs, 1992. Identification of River Channel Change Due to Urbanization. Applied Geography 12:299-318.

Gregory, K.J. and J.R. Madew, 1982. Land Use Change, Flood Frequency and Channel Adjustments. *In:* Gravel-Bed Rivers, R.D. Hey, J.C. Bathurst, and C.R. Thorne (Editors). John Wiley and Sons, pp. 757-781.

Guy, H.P., 1970. Sediment Problems in Urban Areas. Water in the Urban Environment. U.S. Geological Survey Circular 601-E, U.S. Government Printing Office, Washington, D.C., 8 pp.

Henshaw, P.C. and D.B. Booth, 2000. Natural Restabilization of Stream Channels in Urban Watersheds. Journal of the American Water Resources Association (JAWRA) 36(5):1219-1236.

Hite, R.L. and B.A. Bertrand, 1989. Biological Stream Characterization (BSC): A Biological Assessment of Illinois Stream Quality. Illinois State Water Plan Task Force Special Report No. 13.

Hollis, G.E., 1975. The Effect of Urbanization on Floods of Different Recurrence Interval. Water Resources Research 11(3):431-435.

IEPA (Illinois Environmental Protection Agency), 1987. An Intensive Survey of the Fox River Basin From the Wisconsin State Line to Ottawa, Illinois, 1982. Illinois Environmental Protection Agency, IEPA/WPC/88-003, p. 3.

IEPA (Illinois Environmental Protection Agency), 1994. Illinois Water Quality Report, 1992-93, Volume II. Illinois Environmental Protection Agency, IEPA/WPC/94-160, pp. 1-26.

Johnson, R.A. and D.W. Wichern, 1992. Applied Multivariate Statistical Analysis (Third Edition). Prentice Hall, New Jersey, 642 pp.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser, 1986. Assessing Biological Integrity in Running Waters: A Method and Its Rationale. Illinois Natural History Survey Special Publication 5, 28 pp.

Kennen, J.G., 1999. Relation of Macroinvertebrate Community Impairment to Catchment Characteristics in New Jersey Streams. Journal of American Water Resources Association (JAWRA) 35(4):939-955.

Lineback, J.A., N.K. Bleuer, D.M. Mickelson, W.R. Farrand, and R.P. Goldthwait, (Compilers), 1983. Quaternary Geologic Map of the Chicago 4°x6° Quadrangle, United States. U.S. Geological Survey Misc. Investigations Series Map I-420 (NK-16), 1: 1,000,000.

MacDonald, D.D., C.G. Ingersoll, and T.A. Berger, 2000. Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems. Arch. Environ. Contam. Toxicol. 39:20-31.

Mathis, B.J., 1976. Heavy Metals in the Illinois River and Some of Its Tributaries. University of Illinois, Champaign-Urbana, Illinois, Water Resources Center Special Report 4, Proceedings of the Illinois River Workshop, pp. 38-45.

Maxted, J. and E. Shaver, 1997. The Use of Retention Basins to Mitigate Stormwater Impacts on Aquatic Life. *In:* Effects of Watershed Development and Management on Aquatic Ecosystems, L.A. Roesner (Editor). American Society of Civil Engineers, New York, New York, pp. 494-512.

Paul, M.J. and J.L. Meyer, 2001. Streams in the Urban Landscape. Annual Review of Ecology and Systematics 32:333-365.

Rice, K.C., 1999, Trace-Element Concentrations in Streambed Sediment Across the Conterminous United States. Environ. Sci. Technol. 33:2499-2504.

Richards, C., L.B. Johnson, and G.E. Host, 1996. Landscape-Scale Influences on Stream Habitats and Biota. Can. J. Fish. Aquat. Sci. (Suppl. 1), pp. 295-311.

Roberts, C.R., 1989. Flood Frequency and Urban-Induced Channel Change: Some British Examples. *In:* Floods: Hydrological, Sedimentological and Geomorphological Implications, K. Beven and P. Carling (Editors). John Wiley and Sons, pp. 57-82.

Roesner, L. and R. Ott, 1995. Common-Sense City, Country Controls. Water Environment and Technology, Sept., pp. 60-64.

Roth, N.E., J.D. Allan, and D.L. Erickson, 1996. Landscape Influences on Stream Biotic Integrity Assessed at Multiple Scales. Landscape Ecology 11(3):141-156.

Schueler, T., 1994. The Importance of Imperviousness. Watershed Protection Techniques 1(3):100-111.

Snodgrass, W.J., B.W. Kilgour, M. Jones, J. Parish, and K. Reid, 1997. Can Environmental Impacts of Watershed Development Be Measured? *In:* Effects of Watershed Development and Management on Aquatic Ecosystems, L.A. Roesner (Editor). American Society of Civil Engineers, New York, New York, pp. 351-385.

Sovern, D.T. and P.M. Washington, 1997. Effects of Urban Growth on Stream Habitat. *In:* Effects of Watershed Development and Management on Aquatic Ecosystems, L.A. Roesner (Editor). American Society of Civil Engineers, New York, New York, pp. 163-177.

Spieker, A.M., 1970, Water in Urban Planning, Salt Creek Basin, Illinois – Water Management as Related to Alternative Land-Use Practices. U.S. Geological Survey Water-Supply Paper 2002, Washington, D.C., 147 pp.

Steuer, J., W. Selbig, N. Hornewer, and J. Prey, 1997. Sources of Contamination in an Urban Basin in Marquette, Michigan, and an Analysis of Concentrations, Loads, and Data Quality. U.S. Geological Survey Water-Resources Investigations Report 97-4242, Middleton, Wisconsin, 25 pp.

Stewart, J.S., L. Wang, J. Lyons, J.A. Horwatich, and R. Bannerman, 2001. Influences of Watershed, Riparian-Corridor, and Reach-Scale Characteristics on Aquatic Biota in Agricultural Watersheds. Journal of the American Water Resources Association (JAWRA) 37(6):1475-1487.

The H. John Heinz II Center (for Science, Economics and the Environment), 2002. The State of the Nation's Ecosystems – Measuring the Lands, Waters, and Living Resources of the United States. Cambridge University Press, Cambridge, 270 pp.

Thorne, C.R., 1998. Stream Reconnaissance Handbook. John Wiley and Sons, Chichester, United Kingdom, 133 pp.

Trimble, S.W., 1997. Contribution of Stream Channel Erosion to Sediment Yield From an Urbanizing Watershed. Science 278:1442-1444.

U.S. Bureau of the Census, 1985, Census of Population (1984) and Per Capita Income (1983) Estimates – Governmental Units. U.S. Bureau of the Census (digital data).

U.S. Bureau of the Census, 1991. Census of Population and Housing, 1990. Public Law 94-171 Data (United States) (machine readable data files on CD-ROM). Prepared by the Bureau of Census, Washington, D.C.

U.S. Bureau of the Census, 2001, Census of Population and Housing, 2000. Public Law 94-171 Data (United States) (machine readable data files on CD-ROM). Prepared by the Bureau of Census, Washington, D.C.

U.S. Department of Agriculture, 1986. Urban Hydrology for Small Watersheds. U.S. Department of Agriculture, Soil Conservation Service, Technical Release 55, U.S. Government Printing Office, Washington, D.C.

Vogelmann, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, and N. Van Driel, 2001, Completion of the 1990s National Land Cover Data Set for the Conterminous United States From Landsat Thematic Mapper Data and Ancillary Data Sources. Photogrammetric Engineering and Remote Sensing 67, p. 650-662.

Wang, L., J. Lyons, P. Kanehl, and R. Bannerman, 2001. Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales. Environmental Management 28(2):255-266.

Wang, L., J. Lyons, P. Kanehl, R. Bannerman, and E. Emmons, 2000. Watershed Urbanization and Changes in Fish Communities in Southeastern Wisconsin Streams. Journal of American Water Resources Association (JAWRA) 36(5):1173-1189.

Wang, L., J. Lyons, P. Kanehl, and R. Gatti, 1997. Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams. Fisheries 22(6):6-12.

Wolman, M.G., 1967, A Cycle of Sedimentation and Erosion in Urban River Channels. Geografiska Annaler 49:385-395.

Wolman, M.G. and A.P. Schick, 1967. Effects of Construction on Fluvial Sediment, Urban and Suburban Areas of Maryland. Water Resources Research 3(2):451-464.

Yoder, C.O. and E.T. Rankin, 1997, Assessing the Condition and Status of Aquatic Life Designated Uses in Urban and Suburban Watersheds. *In:* Effects of Watershed Development and Management on Aquatic Ecosystems, L.A. Roesner (Editor). American Society of Civil Engineers, New York, New York, pp. 201-227.