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Effects of Urbanization on the Geomorphology, Habitat, Hydrology, and Fish Index of Biotic Integrity of Streams in

Land-cover gradient and space-for-time approaches have been used to examine urbanization effects on aquatic communities, habitat, geomorphic, and hydrologic conditions (Booth and Reinelt 1993; Dreher 1997; Wang et al. 2001). Various measures have been used to represent urbanization, including imperviousness (total and effective), amount of urban land, population density, and combinations of urban indicators (Schueler 1994; Booth and Jackson 1997; McMahon and Cuffney 2001; Gergel et al. 2002). Past studies of streams showed that biotic integrity degrades at relatively low levels of urbanization (Booth and Reinelt 1993; Booth and Jackson 1997; Maxted and Shaver 1997; Wang et al. 2000, 2001). Near the Chicago area, fish index of biotic integrity (IBI) scores tended to be low in watersheds with greater than 10–20% urban land and about 100–200 people/km^2 (Dreher 1997; Wang et al. 1997; Fitzpatrick et al. 2004). Urbanization in the Chicago area is occurring on previously agricultural land; thus, urbanized streams are potentially affected by historical agricultural practices. The percent watershed agricultural land is 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, some agricultural streams near the Chicago area have high biotic integrity (Dreher 1997; Wang et al. 1997; Fitzpatrick et al. 2004). Agricultural streams with relatively steep slopes and rocky substrates were more likely to have good habitat quality and biotic integrity than streams with relatively flat slopes and sandy substrates (Wang et al. 1997). The steep, rocky streams also were less likely to be channelized than flat, sandy streams.

In urban development, impervious surface area (roads, sidewalks, driveways, parking areas, rooftops) increases, which decreases infiltration and increases the rate and volume of surface runoff. Pervious surfaces are compacted by construction equipment and removal of topsoil. Drainage networks are extended through ditching and construction of storm sewers. These factors result in changes in the frequency, duration, and size of floods (Hollis 1975; Booth 1990; Booth and Jackson 1997; Konrad 2003). Flood peaks in northeastern Illinois potentially have increased threefold due to urbanization (Allen and Bejcek 1979), and relative increases may be greater for small, frequent floods than for large, infrequent floods (Krug and Goddard 1986; Konrad 2003). Decreases in infiltration may result in decreases in the water table and ultimately decreases in base flow (Finkenbine et al. 2000). However, these offsets may be compensated for by contributions from point sources (LaTour 1993). In the Chicago area, point-source discharges may originate from outside the watershed (beyond both surface- or groundwater contributing areas) because the major source for c 0o990;

FIGURE 1. Location of study area, land-cover characteristics, and stream sites sampled in the Chicago, Illinois metropolitan area.

TABLE 1. Map reference number, site name, drainage area, watershed land cover, population density, and potential causes for physical impairments (Illinois Environmental Protection Agency 2002) for sampled sites in the Chicago area. Sites with U.S. Geological Survey (USGS) streamflow gauging stations are **bolded.** Impairment data are not available for Wisconsin streams.

Map reference number (see Figure 1)	Site name	Drainage area (km^2)	Watershed urban land (%)	Watershed agriculture land (%)	Forest/ wetland in 60-m stream network buffer (%)	1980 population density (people/ km^2)	1990 population density (people/ km^2)	2000 population density (people/ km^2)	Potential causes for impairments[a]
1	Brighton Cr.	66	7	62	28	52	80	100	na
2	**Des Plaines R.**	**318**	**5**	**78**	**17**	**50**	**52**	**70**	**None**
3	Mill Cr. (Des Plaines)	169	10	68	21	164	164	311	None
4	Bull Cr.	20	27	52	31	238	337	453	None
5	Willow Cr.	56	86	0	9	555	454	510	1, 5
6	Salt Cr.	128	73	5	17	1,029	1,159	1,236	1, 5, 6, 7, 8, 9
7	**Addison Cr.**	**47**	**92**	**0**	**7**	**1,609**	**1,597**	**1,689**	**1, 4, 5, 6, 7, 8, 10, 11, 12**
8	**Flag Cr.**	**43**	**87**	**0**	**14**	**1,130**	**1,205**	**1,299**	**1, 2, 3, 5, 6, 7, 10, 11**
9	**Sawmill Cr.**	**33**	**74**	**1**	**33**	**706**	**850**	**900**	**None**
10	**N Br Chicago R.**	**48**	**33**	**21**	**49**	**342**	**252**	**334**	**1, 4, 5, 6, 7, 10, 11**
11	**Skokie R.**	**62**	**60**	**11**	**25**	**752**	**678**	**756**	**1, 2, 3, 4, 5, 7, 8, 9, 10, 11**
12	Plum Cr.	85	8	64	35	69	72	88	None
13	**Deer Cr**	**62**	**26**	**51**	**32**	**341**	**302**	**311**	**1, 5, 6, 7**
14	**Butterfield Cr.**	**48**	**38**	**40**	**16**	**537**	**606**	**667**	**2, 3, 5, 6, 7, 10, 11, 12**
15	North Cr.	58	35	44	24	678	679	710	2, 3, 5, 6, 7, 10, 11
16	**Midlothian Cr.**	**51**	**72**	**13**	**16**	**1077**	**1346**	**1451**	**2, 3, 5, 6, 7, 10, 11, 12**
17	**Tinley Cr.**	**29**	**57**	**10**	**35**	**826**	**1005**	**1115**	**2, 3, 5, 6, 7, 10, 11, 12**
18	**Long Run**	**61**	**29**	**45**	**34**	**183**	**343**	**473**	**None**
19	Hickory Cr.	127	21	59	25	211	260	352	1, 2, 3, 4, 5, 6, 9
20	Spring Cr.	47	11	59	36	186	149	204	None
21	Sugar Run	33	17	77	13	192	214	253	2, 3, 5, 14
22	Jackson Cr.	113	4	93	5	75	76	133	None
23	**W Br. Du Page R.**	**157**	**58**	**23**	**18**	**800**	**1,036**	**1,289**	**1, 2, 3, 5, 13**
24	E Br. Du Page R.	206	73	5	22	1,054	1,202	1,300	None
25	Lily Cache Cr.	114	19	69	10	366	377	636	na

TABLE 1. Continued.

Map reference number (see Figure 1)	Site name	Drainage area (km^2)	Watershed urban land (%)	Watershed agriculture land (%)	Forest/ wetland in 60-m stream network buffer (%)	1980 population density (people/ km^2)	1990 population density (people/ km^2)	2000 population density (people/ km^2)	Potential causes for impairments[a]
26	Rock Run	37	52	33	25	594	717	909	1, 2, 3, 5
27	Fox R.	203	30	44	30	244	268	320	na
28	Pewaukee R.	98	19	56	17	188	193	290	na
29	Genesee Cr.	72	7	62	31	66	94	110	na
30	Jericho Cr.	32	3	72	34	69	66	96	na
31[b]	Bassett Cr.	–	–	–	–	–	–	–	–
32	Nippersink Cr.	219	4	87	9	72	81	100	None
33	N Br. Nippersink Cr.	167	6	75	20	46	64	83	None
34	Boone Cr.	40	3	61	26	54	47	56	None
35	Flint Cr.	96	31	32	36	210	303	341	None
36	Tyler Cr.	81	3	87	12	29	39	49	None
37	**Poplar Cr.**	**94**	**38**	**40**	**22**	**541**	**748**	**881**	**None**
38	**Ferson Cr.**	**134**	**17**	**70**	**19**	**84**	**142**	**242**	**None**

for Illinois streams. Average monthly discharges for 2000 were obtained for each watershed (Charles Avery, U.S. Geological Survey, personal communica-
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full stage along each reach and included the top of coarse deposits associated with point bars (minimum elevation); occurrence of a sharp break in slope of the bank above the low-flow water surface where slope changes from vertical to more horizontal; changes in vegetation, such as a change from herbaceous to tree species; and for undercut banks, the top of the undercut (minimum bank-full elevation) (Harrelson et al. 1994; Fitzpatrick et al. 1998).

Channel roughness was estimated in the field using Coon's (1998) adaptation of Cowan's (1956) method. Comparison with photos in Hicks and Mason (1998), Coon (1998), Arcement and Schneider (1987), and Barnes (1967) provided additional guidance.

The U.S. Army Corps of Engineers' HEC-RAS (v. 3.0) computer program (Brunner 2001) was used to estimate average bank-full channel area, width, depth, velocity, shear stress, and unit-channel-area stream power. Inputs to the HEC-RAS model include channel geometry, roughness, and reach water-surface slope. Bank-full area was normalized by drainage area prior to analysis because of its dependence on watershed size.

Stream competence describes the maximum particle size (D) that a stream is capable of transporting under a given flow and was calculated by the formula D =

to the calculation techniques for WIHAB because NAWQA data collection varied from WDNR protocols (archives are available as unpublished files, U.S. Geological Survey, Middleton, Wisconsin, 2002). For example, the riffle:riffle ratio metric for the WIHAB index was not measured; instead, the relative number of geomorphic channel units in a reach (riffle, run, pools) was substituted.

Hydrologic characteristics.—Hydrologic data included discharge measurements at all sites at the time of ecological sampling in July 2000, HEC-RAS modeled bank-full and base flow, and daily streamflow data from 1985 to 2000 for 15 streams with USGS streamgauges (Table 1). Bank-full flows were modeled in HEC-RAS by adjusting discharge to match observed bank-full stage indicators. Bank-full flows were normalized by drainage area.

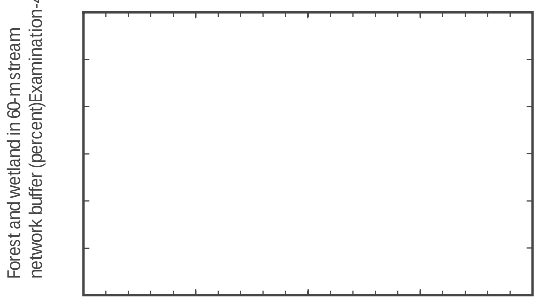
Of the 15 gauged sites, 13 are on clayey streams (12 in the Des Plaines River basin and 1 in the Fox River basin). The time period 1985–2000 was selected for analysis of gauging-station data because it reflects recent urbanization. Flood-frequency analyses of gauging-station data followed guidelines in Interagency Advisory Committee on Water Data (1982) to fit logarithms of annual peak flows to a Pearson Type III distribution. Estimates of flood peaks with a 2-year recurrence interval were used because past studies showed that small, frequent floods were increased more by urbanization than large, infrequent floods (Krug and Goddard 1986). Streamflow data from the gauges were used to estimate base flow in 2001.

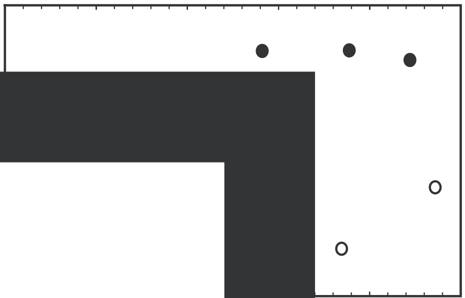
Discharge was measured in streams during ecological sampling; however some streams were sampled during falling stages following summer thunderstorms and thus did not represent base flow. By matching water-surface elevations during base flow conditions obtained from cross-section surveys, HEC-RAS was used to estimate base flow for streams sampled at falling stages. HEC-RAS estimates were compared to discharge measurements collected during ecological sampling and to base flow discharges from the 15 gauging stations. The base flow variable was estimated from comparisons of the three sources. Flow variability was calculated as the ratio of HEC-RAS derived bank-full flow to estimated base flow. Flow data were normalized by drainage area to remove effects of wa-

TABLE 2. Selected urban indicators and landscape characteristics used to determine urbanization effects on the geomorphic, habitat, and hydrologic characteristics and fish index of biotic integrity of 45 Chicago area streams.

Type of variable	Abbreviation	Median	Minimum	Maximum	Correlated variables
Urban indicators					
Watershed urban land (%) (square-root transformed)	URBANLU	19	0	92	Watershed industrial lands; population density, impervious area, road density
Population density change, 1980–2000 (%)	POPDENP	158	–117	1,266	Population density change by area
Mean upstream distance of urban land (km)	URBANDIS	10.2	2.4	25.3	Road area, road length
Landscape characteristics					
Drainage area (km^2) (log-10 transformed)	DRAIN	81.2	20.1	326.1	Stream order, cumulative stream length
Watershed clayey surficial deposits (%)	WATCLAY	71	0	100	Soil permeability
Drainage density (km/km^2)	DRAINDEN	1.34	1.08	1.44	None
Watershed slope (%)	WATSLOP2	1.31	0.20	3.36	None
Transport index *1,000 (km^{-1}) (log-10 transformed)	TRANSIN	4.77	1.23	10.05	Relief ratio
Sinuosity (ratio)	SINUOS	1.3	1.1	2.0	None
Coarse deposits within 60-m stream network buffer (%) (log-10 transformed)	BUFCOARS	2	0	96	Coarse deposits in watershed
Forest and wetland within 60-m stream network buffer (%)	BUFFOWE	19	2	49	None
Disturbed land cover in 30-m buffer (%) (log-10 trans.)	RIPLU	5	0	100	None
Average open canopy angle (°)	CANOPY	48	2	145	None
Geomorphic characteristics					
Reach slope, low-flow water surface (%) (square-root transformed)	SLOPELO	0.20	0.01	0.79	Segment and bank-full slope, velocity, power, stress, bank-full flow/drainage area, competence
Bank-full channel area/drainage area (m^2/km^2) (square-root transformed)	BFAREADA	0.11	0.030	0.43	Channel area, bank-full flow
Stream power (N/(m s))	POWER	12	0.097	149	None
Erosivity potential at bank-full flow (ratio) (inverse square-root transformed)	EROSBF	1.5	0.4	88.7	None
Habitat characteristics					
Fine substrate (%) (log-10 transformed)	FINES	27	3	100	Amount and type of geomorphic units, substrate texture, embeddedness, silt depth, roughness, Wisconsin habitat index
Average bank-full channel	BWDRAT	11	2	31	Shape index, bank-full surface

teristics with nonnormal distributions were transformed prior to the RDA (Table 2). A subset of 11 urban indicators and landscape characteristics; 10 geomorphic, habitat, and hydrologic characteristics; and the revised fish IBI were selected for the RDA based on correlation analysis and the need recognized in the literature for more information about


Forest and wetland in 60-m stream
network buffer (percent)



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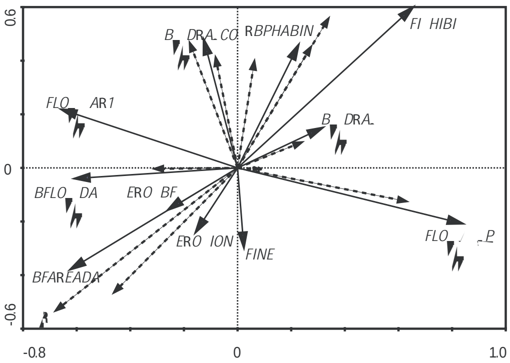

area. This suggests that small streams with high flow variability tended to have low base flow.

Fish IBI scores plotted opposite watershed urban land and clayey surficial deposits, indicating that IBI scores for clayey streams were negatively influenced by the amount of urbanization. Unit-area bank-full channel area plotted directly opposite fish IBI scores as well, indicating that channel enlargement may be the best reflection of physical disturbance to fish habitat associated with urbanization in clayey streams.

Longitudinal Profiles, Local Geologic Setting, and Stream Network Position

Longitudinal profiles and local geologic setting for six tributaries to the Fox River illustrate the complexity of how glacial landforms may influence geomorphic, habitat, hydrologic, and fish characteristics (Figures 2 and 9; Table 6). The six streams are located near each other (within about a 50-km radius) and represent three pairs of streams with similar percentages of watershed urban land (3%, 16–17%, and 31–38%). In general, reaches with steep slopes on the longitudinal profile are prone to incision, whereas reaches with flat slopes are prone to deposition. Reaches in a transition from steep to flat slopes may be erosional or depositional depending on upstream inputs of water and sediment. For Chicago area streams, transitions in slope and shape of longitudinal profiles mainly are caused by spatial distribution of glacial landforms such as end moraines, outwash plains, lake plains, melt-water valleys, or bedrock outcrops.

Some of the variability in geomorphic and habitat characteristics can be explained by location of sampled reach in relation to local glacial and fluvial landforms (Figure 9). Boone and Tyler Creeks are rural streams with similar reach slopes (Table 6). However, the Boone Creek Reach (site 34) is flat and located in a sandy outwash plain, and the Tyler Creek Reach (site 36) is located in a transition zone in slope where the stream is flowing through end moraine and esker deposits. Boone Creek has finer substrate (sand included) and fewer riffles than Tyler Creek, even though overall it has less watershed clay than Tyler Creek. The eskers near Tyler Creek contribute sand and gravel that, along with the locally steep slope, promote development of riffles.

Mill (site 39) and Ferson Creek (site 38) are both rural/urbanizing streams with large changes in population density. Both have similar drainage areas, longitudinal profiles, and local glacial landforms but different reach slopes, bank-full areas, stream power, unit-area bank-full flows, and revised fish IBI scores. The Mill Creek Reach is downstream from a dam and is on the steep slope of the Fox River valley side, which consists of limestone bedrock. This local setting results in a steeper reach slope, higher power, and larger bank-full area for Mill Creek compared to Ferson Creek. The high scour potential at Mill Creek may be affecting the IBI scores. Ferson Creek's IBI scores may be elevated because of channel restoration and habitat improvements in recent years.

Flint and Poplar creeks both are clayey tributaries to the Fox River with similar drainage areas (Table 6).

TABLE

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