DMLN

Technical Note 116

Housing Density and Urban Land Use as Indicators of Stream Quality

A large number of indicators exist to measure the amount of urbanization in a watershed, and in turn, predict stream quality. Impervious cover has traditionally been the primary indicator of watershed urbanization, but two recent studies from Ohio and Illinois focus on housing density, urban land use, and population density as indicators of urbanization. These studies provide some of the first real data on relationships between urbanization and stream quality in the Midwest.

Midwestern streams have many attributes unique to the area. Most Midwestern streams flow across the gently sloping till and outwash plains created after the last great ice sheets receded from North America 10,000 years ago. Typically, these streams are low gradient, shallowly entrenched, alluvial systems with extensive associated wetlands (McNab and Avers, 1994). In terms of aquatic diversity, the Midwest has historically had the highest diversity of freshwater mussels in North America. Prior to settlement, over 80 species of freshwater mussels were present in the state of Illinois alone (INHS, 1996).

Unfortunately, over half of the remaining mussel species existing in the Midwest are now classified as endangered, threatened, or of special state concern (USFWS, 1998). The formerly extensive wetlands of the Midwest have been reduced by over 80% and intensive agricultural and land development practices have led to the straightening, channelization, and impoundment of many streams. These practices have resulted in high rates of sedimentation and nutrient enrichment in the region's streams and rivers.

Land development pressures are increasing in many Midwestern communities, rendering urbanization an even greater threat to the region's aquatic resources. For example, between 1970 and 1990, the northeastern Illinois area population grew by a modest 4%, yet the amount of land in urban/suburban use grew by more than 33% (NIPC, 1998). This pattern of growth appears to be continuing: Census Bureau estimates indicate that the region's population has grown as much since 1990 as it had in the previous two decades (NIPC, 1998).

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Over the past decade, numerous studies have linked increasing urbanization with stream degradation. The research by Chris Yoder and Ed Rankin perhaps best illustrates this relationship. They report, "Few if any, ecologically healthy watersheds exist in the older most extensively urbanized areas of Ohio and no headwater streams (i.e., draining <20 mi^2) sampled by Ohio EPA during the past 18 years in these areas have exhibited full attainment of the Warmwater Habitat (WWH) use designation" (Yoder, 1995; Yoder and Rankin, 1996).

A recent study by Yoder, Dale White, and Bob Miltner (1999) of the Ohio EPA further explored the effects of urbanization on a large number of Ohio streams. This study team utilized bioassessment techniques to link land uses with stream quality in two Ohio ecoregions. Fish, benthic macroinvertebrates, stream habitat and water chemistry were sampled in urban/suburban watersheds in the Cuyahoga River basin in northeastern Ohio and

Table 116.1. Sampling Parameters for the Cuyahoga and Area Streams

Sample Location	Drainage Areas (sq. mi.).	Macro-Invertebrate Samples	Fish Samples	Habitat Assessment	Water Chemistry Samples
Cuyahoga	2 - 700	80	82	82	103
Columbus	<35	0	80	80	0

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smaller subwatersheds in the Columbus metropolitan area of central Ohio. The Cuyahoga watersheds are characterized by extensive development, including a mix of older residential, commercial, and industrial land uses, along with more recent suburban development. The Columbus watersheds are characterized by residential urban land use, much of which has developed within the last two decades. However, a significant difference between the Cuyahoga and Columbus study areas is that many of the sample points in the Cuyahoga drainage were located in larger watersheds that were subjected to significant point source discharges. The smaller subwatersheds of the Columbus study area had far less influence from point source discharges. Table 116.1 summarizes the team's sampling effort.

The researchers chose housing density and urban land use as surrogates of watershed impervious cover. These two indicators were chosen because census data, for calculating housing density, and state land use information, for calculating percent urban land, were readily available. In addition to the effects of urbanization, the study also examined the potential effects of watershed scale and significant other stressors in the urban environment. Table 116.22 lists the predominant stressor types in the Cuyahoga basin.

Results

Data from the Columbus area streams showed a significant decrease in fish assessment scores when watersheds exceeded 33% urban land use, although there was considerable variation above and below this percentage among individual watersheds (Figure 116.1). At this level of urbanization, fish communities displayed a shift in community composition indicated by the loss of intolerant darters and sculpins, a decrease in insectivorous fish, and an increase in the proportion of tolerant species.

Overall, the Cuyahoga basin streams depicted a significant drop in fish index of biotic integrity (IBI) scores at around 8% urban land use (Figure 116.2). This relatively low level of urban land use was related to a significant impact to the biological community primarily because of watershed scale and the presence of other stressors not generally found in the Columbus area streams. The researchers found that when streams with a watershed size of less than 100 mi² were analyzed separately, the level at which fish IBI scores dropped significantly increased to around 15% urban land use (Figure 116.3). Figure 116.4 illustrates this data further broken down by the type of impact. The study showed that sites affected by combined sewer outfalls, significant wastewater treatment plant outfalls, and highly modified habitats (i.e., channelized, impounded) failed to attain their appropriate biocriteria regardless of the degree of urbanization.

Figure 116.1: Index of Biotic Integrity Scores Vs. Urban Land Use (quartiles) for All Columbus Area Samples

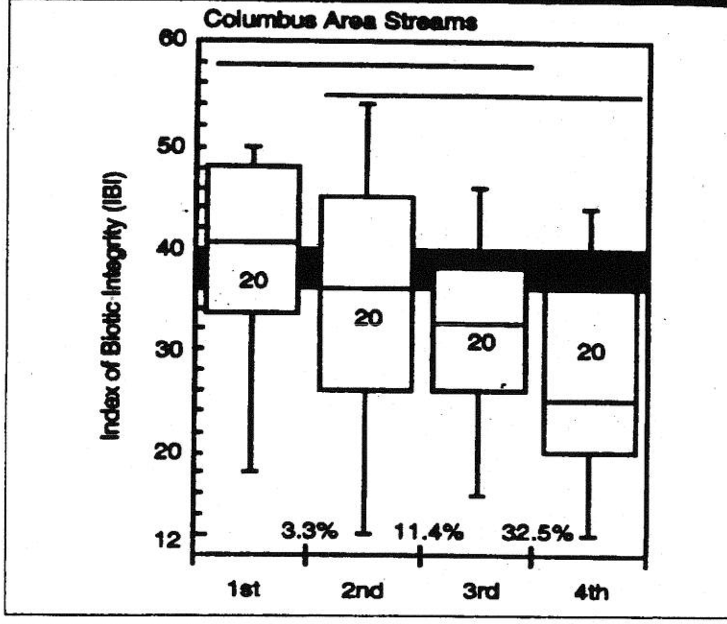

Figure 116.2: Index of Biotic Integrity Scores Vs. Urban Land Use (quartiles) for All Sites in the Cuyahoga Basin

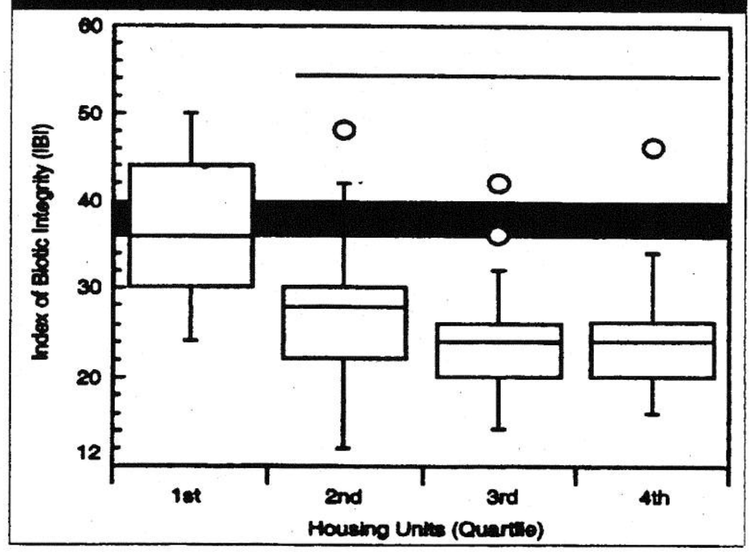

Table 116.2: Predominant Impact Types in the Cuyahoga Basin

Least impacted - large lot residential areas with significant open space
Gross in stream habitat alteration - gross channel modifications and/or impoundments
Combined sewer overflow discharges (CSOs)
Wastewater treatment plant discharges
Wastewater treatment plant discharges w/CSOs
Urbanization

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Housing density was also strongly linked to stream quality, but with somewhat differing results (Figure 116.5). While urban land use depicted a more or less continuous decline in stream quality with increasing urbanization, housing density displayed a threshold response coinciding with approximately one housing unit per acre, above which sites generally failed to attain their appropriate biological criteria.

Similar results were obtained in a study undertaken by Dennis Dreher (1997) of the Northeastern Illinois Planning Commission (NIPC). Dreher's study utilized a similar bioassessment approach with the main difference between the two studies being the choice of urbanization indicator. The Illinois study utilized population density as an indicator of urbanization, rather than housing density or urban land use.

The six-county Northeastern Illinois study area (Cook, DuPage, Kane, Lake, McHenry, and Will counties) includes the extensively urbanized Chicago metropolitan area and its adjacent suburbs, as well as large areas of outlying rural/agricultural land. Even though discharges from point sources and combined sewer overflows in this region have been reduced dramatically over the past 20 years, many of this region's waterways remain seriously impaired.

In this study, population density was chosen as the urbanization indicator for several reasons, the most notable being the difficulty in accurately quantifying the impervious cover in a large number of watersheds on a regional scale. In contrast, digital population data was readily available for the region and could be utilized with existing GIS resources. In addition, the author felt that local land use planners and government officials readily understand population density, perhaps more so than impervious cover.

Dreher found a strong correlation ($r^2 = 0.77$) between population density and fish community assessments for the Northeastern Illinois region (Figure 116.6). The majority of the streams assessed in urban/suburban watersheds with population densities of 1.5 to 8.0+ people per acre had community assessment scores in the fair to poor range, indicative of significant degradation. In contrast, nearly all the rural/agricultural streams (0.05 to 0.5 people/acre) had assessments scoring in the good or better range However, only two of the 13 rural/agricultural streams studied scored in the excellent range. The study also found that most "suburbanizing" watersheds in the range of 0.5 to 1.5 people per acre scored in the fair to good range. With substantial additional development still occurring, these watersheds are at risk of significant further degradation.

Conclusions

Both the Dreher study and the Yoder *et al.* study demonstrate that there is a strong negative relationship between increasing urbanization and stream quality in the Midwest and that bioassessment can play an important role in assessing and managing urban streams. As both studies used similar biological assessment methodologies, the efficiency and utility of the different urbanization indicators can be compared to determine which provides the best predictor of stream quality over a wide range of land use intensities and watershed scales. And indeed, all three indicators appear to pro-

Table 116.3: Comparison of Different Land Use Indicators and Their Applicability to Local Watershed Planning

Land use indicator	Typical value for low density residential use	Level at which significant impact observed	Advantage	Disadvantage	Appropriate scale	Utility for Local Watershed Planning
% Impervious Cover	10%	10-20%	Most accurate	Highest level of effort and cost	Sub-watershed or watershed	High
Housing Density	1 units/acre	>1 unit/acre	Low accuracy in areas of substantial commercial or industrial development, Moderately accurate at larger scales	Less accurate at smaller scales	Watershed or larger	Moderate
Population Density	2.5 people/acre	1.5 to 8+ people/acre	Low accuracy in areas of substantial commercial or industrial development, Moderately accurate at larger scales	Less accurate at smaller scales	Watershed or larger	Moderate
% Urban Land Use	10-100%	33% (variable)	Moderately accurate at larger scales	Does not measure intensity of urbanization	Watershed or larger	Low

vide useful information. Population density and percentage of urban land use were found to depict a continuous negative response to urbanization. Housing density, on the other hand, depicted a threshold response to urbanization. This may indicate that housing density's utility for predicting stream quality at intermediate levels of urbanization is limited. However, additional investigation will be needed in this area.

Both studies appear to have derived similar conclusions regarding the level at which significant stream degradation occurs. In analyzing their results, Yoder and his colleagues identified a threshold at one housing unit per acre, beyond which fish and macroinvertebrate assessments increasingly fail to attain their appropriate biological criteria. Assuming that one unit per acre would represent a suburban medium to low density development (single-family detached homes), then 2.5 people per acre would be a reasonable estimate of population density (ULI, 1997). This would coincide with Dreher's category of 1.5 to 8+ people per acre, at which streams typically scored in the fair to poor range. Based upon the results of these studies, it appears that there is agreement between these two indicators of urbanization, at least in terms of a threshold for use attainment. However, population density may be a more useful tool for predicting stream quality due to its more continuous negative response to increasing urbanization.

Urban land cover was also found to be a good predictor of stream quality, but other factors such as historic development patterns, the level of direct channel alteration, and the array of land uses included as urban land may limit the precision of this indicator.

Figure 116.3: Index of Biotic Integrity Scores Vs. Urban Land Use (quartiles) for All Samples With Drainage Areas <100 mi^2 in the Cuyahoga Basin

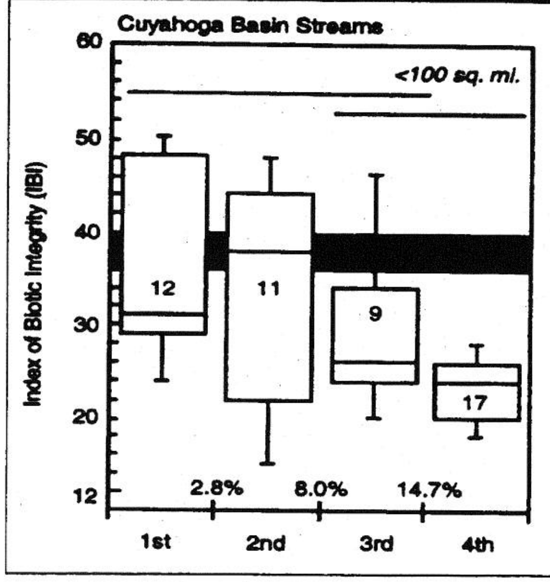


Figure 116.4: Index of Biotic Integrity Scores Vs. Percent Urban Land Use (quartiles) for Cuyahoga Streams With Drainage Areas <100 mi^2 by Stressor Groups

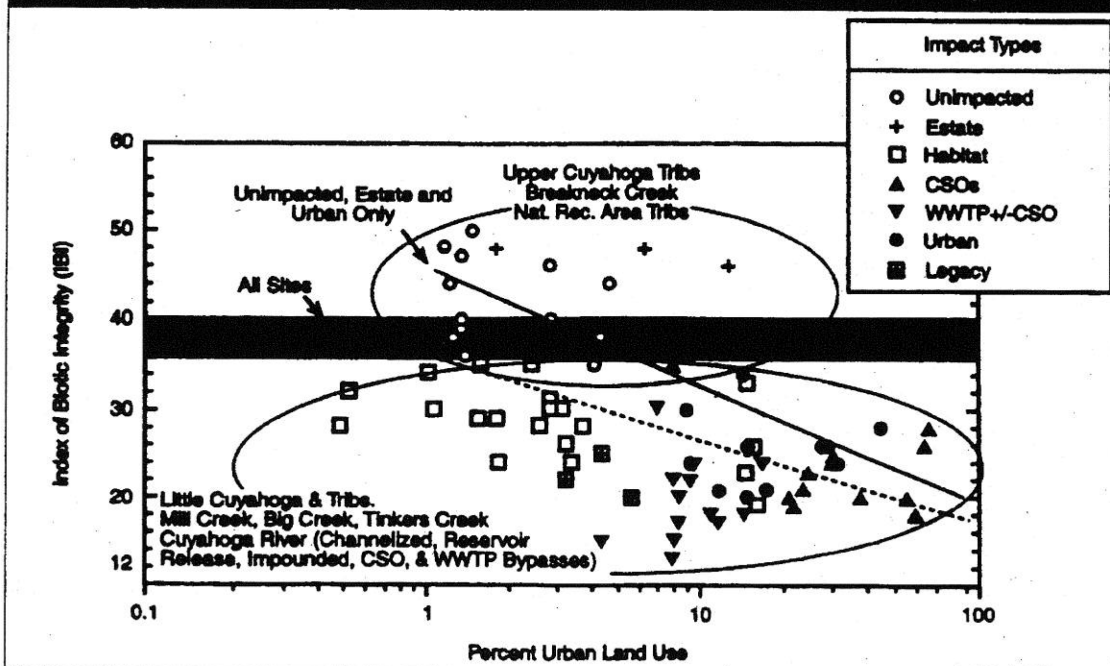
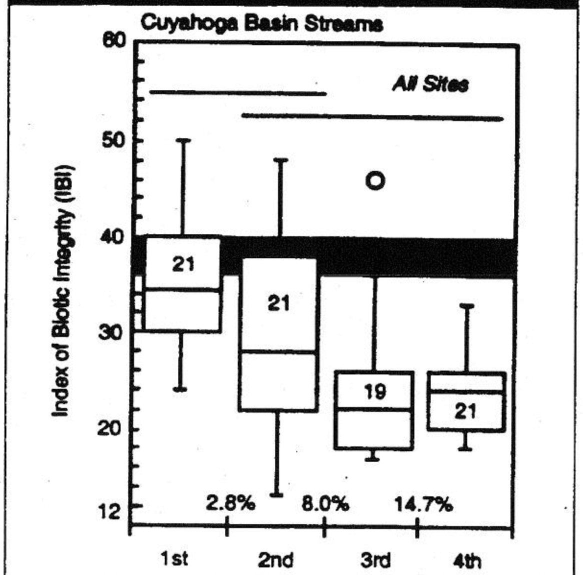


Figure 116.5: Index of Biotic Integrity Scores Vs. Housing Density (quartiles) for All Sites in the Cuyahoga Basin



The Dreher study and the Yoder *et al.* study, as well as others, have demonstrated a clear negative relationship between increasing urbanization and stream quality. However, most assessments of this type to date have been conducted on large regional scales. Robert Steedman of the University of Toronto (1988) found that watershed scale played a significant role in the ability of the urban land use indicator to predict stream degradation. He found that large watersheds, with an average size of 112 mi^2, had poor land use/stream quality correlations (r^2=.11) when compared to small watersheds with an average watershed size of just 6.5 mi^2 (r^2=.78). This would appear to reinforce the idea that watershed scale is an important factor in assessing the utility of indicators of urbanization. As land use decisions are generally made at the local level, land use planners need tools that are applicable to smaller scale local planning areas. More work is still needed in identifying and applying these indicators at smaller scales to determine their practical usefulness in local watershed planning and management. Table 116.3 summarizes some of the advantages and disadvantages of several indicators of urbanization.

Overall, the results of these two Midwestern studies reflect the substantial impacts conventional land use practices have had on the biological integrity of rivers and streams, and may be used to forecast future quality if conventional practices continue. This does not bode well for our streams and rivers, as development pressures continue to grow in many Midwestern communities. However, these relationships may not predict the future quality of our streams and rivers if watershed planning and management practices are implemented to control both point and non-point source pollution. But the authors caution that planning and management decisions should not be based upon a single indicator of urbanization, without considering significant other physical and chemical stressors (i.e., historic alteration, CSO's, failing septic systems, etc.) that may be acting on the system. - ***KBB***

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