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***Grant Title*: Exurban Land Use Change, Watershed Management, and Surface Water Quality in Ohio's Lake Erie Watershed**

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ABSTRACT

Impervious cover resulting from urbanization is a significant nonpoint pollution source impairing surface water quality. This study employed an ordinary least squares regression analysis to measure the impact of remotely-sensed impervious cover upon the Index of Biotic Integrity (IBI), an Ohio EPA numerical bioassessment of fish species diversity and extent. 23 USGS HUC 14 subwatersheds within the Cuyahoga River HUC 8 watershed served as spatial units/observations. Unexpectedly, while impervious cover was not statistically significant, US EPA NPDES point source pollutant total flow (summed within each HUC 14) was found to explain 17% of the variation in IBI. The low number of observations and spatial coarseness of the regression model likely contributed to these results. Nevertheless, the findings suggest that, while measurement and regulation of nonpoint pollution sources should continue apace, point sources of pollution remain significant causes of water quality impairment despite great strides in their management and deserve continued research and management attention.

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1. INTRODUCTION

Land use and land cover change is widely recognized as contributing to the impairment of surface water quality, with urbanization recognized as a particularly environmentally deleterious land use. Impervious surfaces (often called impervious cover) are man-made, water impermeable surfaces such as roofs, roads, and parking lots. These surfaces increase runoff temperature and flow as well as concentrate runoff-borne pollutants such as motor vehicle oils and emissions. Impervious cover is a predominant land cover type within urban areas, with increasing levels of impervious cover widely recognized as being related to increasingly impaired water quality. However, uncertainty exists concerning the degree to which low levels of impervious cover (especially below 10%) affect water quality.

In order to further examine the effect of impervious cover upon surface water quality, an ordinary least squares regression model was employed. The dependent, or response, variable was the Index of Biotic Integrity (IBI), an Ohio EPA numerical bioassessment of fish species diversity and extent. Independent, or stressor, variables included: 1) impervious cover derived from Landsat satellite images; 2) US EPA National Pollution Discharge Elimination System (NPDES) data for point source total flow; 3) low season total flow; 4) biological oxygen demand (BOD); 5) low season BOD demand; and 6) other spatial measures (explained further in section 4).

We found, unexpectedly, that point sources of pollution were statistically significant in relation to fish biocriteria scores while impervious cover was not. Point sources were included as a control variable for land cover, but ended up being the only statistically significant stream quality stressor variable. This result is, in part, an artifact of this particular research design.

Nevertheless, the findings remind us of the complexity of watershed analysis within the Lake Erie watershed and elsewhere and caution against simplistic water management policies.

2. BACKGROUND

Urbanization worldwide, including within the United States, is a significant driver of land use and land cover change, an important constituent of global anthropogenic environmental change (Vitousek et al. 1997; Landis 1998). The human behaviors that drive urbanization and alter landscapes are constrained by social institutions, resulting in complex interactions between human and biophysical processes.

Urban sprawl is a low density form of urbanization currently prominent in the United States. Much is known concerning the *social* causes, nature, and consequences of urban sprawl, yet our understanding of its specific *environmental* impacts is limited (Johnson 2001). Spatially, sprawl begins in the rural-urban (exurban) fringe, often replacing agricultural land uses, which are generally less detrimental to surface water quality than urban uses (Lenat and Crawford 1994; Schueler 1994; Wang et al. 2000). However, it remains unclear the degree to which the mixed-use, low density development of the exurban fringe impairs surface water quality.

The extent of impervious surface correlates well with polluted runoff and is a widely studied indicator of water quality (Schueler 1994; Arnold and Gibbons 1996; Lerberg, Holland and Sanger 2000). Impervious cover is thus a water quality stressor in its own right, as well as a proxy for urban development generally. Impervious cover occurs as a continuum, decreasing as one travels from highly urbanized areas to semi-rural exurban areas.

Point sources of water pollution are easily identifiable, discrete sites such as waste water treatment plants and industrial facilities. Nonpoint sources are non-discrete, manifest at the landscape-level, and therefore require a watershed-based approach, since watersheds are the drainage areas of streams and rivers. Watershed-based analyses are inherently difficult due to the complexity of biophysical interactions occurring over time and space.

Aquatic numerical bioassessments involve the systematic recording of organisms present in a water body as well as ancillary data concerning water chemistry, nutrient and toxin load, dissolved oxygen, and changes in stream morphology. These bioassessments best represent aquatic ecological integrity as well as water safety and usability for humans (Karr 1981). Ohio EPA has been a national leader in the theory and practice of surface water bioassessment, and in 1990 Ohio became the first state to adopt numerical biological criteria for evaluation of aquatic biodiversity (Sanders 2000).

This study therefore investigates the degree to which water quality, as measured by numerical bioassessments, is affected by urbanization, as measured by impervious cover. Particular attention was paid to low levels of impervious cover, about which our knowledge is limited.

3. STUDY AREA

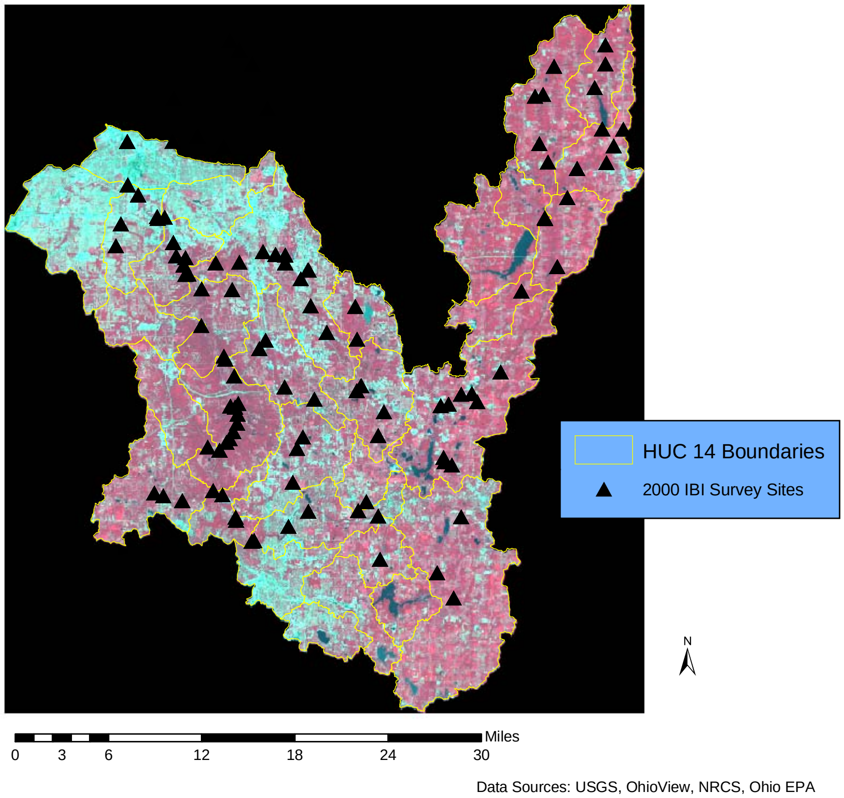
In order to evaluate the influence of land cover type upon aquatic biodiversity a study area was required with extensive exurban growth and detailed aquatic bioassessment data over time. These attributes are found within Cleveland, Ohio and its eastern suburbs and exurban fringe. Greater Cleveland typifies many Rust Belt metropolitan areas, based around large central cities often suffering economically and with declining populations and with similarly declining inner suburbs, surrounded by low density outer suburbs often growing rapidly economically and in population.

Additional factors make this area a desirable study site, including both high relief and precipitation for Ohio, likely intensifying runoff-related problems; the western half of the metro area is notable flatter and drier (Sanders 2000). Certain land management practices found here may simulate theoretical best management practices (BMPs); for example, some suburbs have enacted riparian buffer legislation while other areas are covered by extensive parkland.

Three United States Geological Survey (USGS) eight-digit Hydrologic Unit Code (HUC 8) watersheds comprise the eastern half of the Cleveland metropolitan area (Cuyahoga, Ashtabula-Chagrin, Grand, total area 2144 mi^2). These three watersheds are composed of 82 HUC 14 watersheds (median area 22.32 mi^2). While HUC 11 watersheds remain the spatial unit of concern for most watershed organizations and government agencies, increasing attention is being paid to the smaller HUC 14 watersheds (Rogers 2003).

The Cuyahoga River HUC 8 watershed (809 mi^2), with 32 HUC 14s, was selected as the study site for the regression analysis. The 32 watersheds of the study site comprise a continuum of impervious cover ranging from highly urbanized downtown Cleveland to lightly developed exurban land, providing an adequate sample from which to statistically analyze the relationship of land use to water quality as well as enabling basic relationships between water quality and the built environment to be assessed as a check upon regression results. The watershed contains numerous and varied point sources of pollution and is also on the more geographically complex eastern side of the metro area. Appendix A lists the 32 HUC 14s comprising the Cuyahoga River watershed as well as the 23 HUC 14s used for the regression analysis. Figure 1 depicts a Landsat false color image of the Cuyahoga River watershed and its HUC 14 subwatersheds (along with year 2000 IBI sample points, explained further in section 4). Built up urban areas appear as shades of blue within the image and vegetation as shades of red.

Figure 1.
Cuyahoga HUC 8 False Color Image



4. DATA

4.1 Bioassessment Data

Three numerical biocriteria measures and one nominal-data habitat evaluation assessment method are employed by Ohio EPA. Only one biocriteria measure was employed in this study, the Index of Biotic Integrity (IBI), which measures fish species diversity and extent. The IBI is calibrated on an ecoregional basis according to relatively "natural" reference sites and stream/river size (OEPA 1987). The IBI comprises 12 metrics describing presence and proportions of species and individuals. Appendix B, organized from Ohio EPA data (OEPA 1987), lists IBI constituent metrics for different sample site type.

Metrics are calibrated for stream size and type of sample site (OEPA 1987). Surface waters are generally analyzed every five years on a schedule now integrated with Total Maximum Daily Load (TMDL) assessments. Sampling generally occurs during low flow summer months to best represent year-round water resource integrity. Sample sites are chosen within a geometric sampling framework to best capture the variation between stream size as well as to use limited administrative resources most efficiently. Each metric is scored 5, 3, or 1 according to whether it, respectively, meets, somewhat deviates from, or strongly deviates from, numbers and types of species and individuals found at reference sites. A maximum score of 60 is thus possible, with scoring calibrated according to the size of the drainage area upstream of sample site locations. Only the total IBI score was used in this study.

Year 2000 IBI data for the Cuyahoga River HUC 8 watershed was obtained from the Ohio EPA Division of Surface Water. Lacustrine (Lake Erie) influenced sites (measured with different biocriteria) were removed, leaving 109 sample sites. Sites surveyed twice during the 2000 sampling season and one site sampled in October were also removed. Sites surveyed twice would not be independent observations, violating an assumption of the regression equation. The one site sampled in October was considered to be temporally distinct from sites sampled during the summer months. This left 92 sites sampled in July and August, including a few sampled in early September.

All IBI scores in each HUC 14 were averaged to create one IBI score per HUC 14. This method permits one biocriteria score to be assigned for the entire spatial area in question, enabling generalizations to be made about relatively large areas. Over-generalizing is a possibility, of which more will be said later. Nevertheless, since no other recognized method currently exists for calculating IBI scores for USGS HUC 14 watersheds, IBI scores from sample sites within each HUC 14 were averaged across that HUC 14. Nine HUC 14s with no IBI data were removed, leaving 23 HUC 14s for the regression analysis.

4.2 Point Source Pollution Data

Although the biophysical focus of this research was the influence of nonpoint source pollution associated with land cover change upon aquatic biodiversity, point sources of pollution were considered significant and their inclusion viewed as essential for a thorough analysis. The US EPA National Pollution Discharge Elimination System (NPDES) regulates and monitors industrial and municipal effluent dischargers, with Ohio EPA monitoring dischargers within Ohio. Four independent/stressor point source variables were analyzed: total conduit flow, biological oxygen demand, low season (June through September) total conduit flow, and low season biological oxygen demand. Aquatic life in streams is more sensitive to pollution during the summer months because of the lower water levels.

Total conduit flow, a good broad measure of human impacts from point sources, was measured as an average daily flow in millions of gallons per day and summed for each HUC 14. That is, conduit flow from every outfall (pipe) for each permitted discharger was added together for each HUC 14. Geospatial data was unavailable for facilities accounting for roughly 20% of conduit flow; these were not included in the analysis.

Biological Oxygen Demand (BOD) (also referred to as Biochemical Oxygen Demand) refers to the amount of oxygen necessary to stabilize organic material by aerobic activity, as well as the concentration of decomposable material present in organic waste. The amount of oxygen, in milligrams per liter, consumed in five days is a common measure and the one employed here. Point source concentrations of BOD were summed for each HUC 14 and converted to a total

HUC load measured in kilograms/day. Geospatial data was unavailable for facilities responsible for roughly 40% of BOD; these were not included in the study.

All permitted NPDES dischargers in the Cuyahoga HUC 8 for 1998, 1999, and 2000 were examined, entailing 267 distinct outfalls (pipes) from 134 facilities. The raw data included over 970,000 entries. Three years of discharge were analyzed in order to capture the long term effects of effluent upon biological integrity. Since aquatic organisms live and breed in streams, data with a limited temporal scope is less likely to uncover the effects of long-term low-level pollutant exposure. Using a three year time span helps to reveal the impacts of this type of pollution. Illegal, non-permitted dischargers were not considered in this study due to the difficulty in their measurement. However, these illegal dischargers, along with legal residential septic systems, are deserving of further study, since they both contribute to surface water quality impairment.

4.3 Remotely Sensed Impervious Cover

Impervious cover is widely recognized as contributing to water quality decline. However, the measurement of impervious cover from air photos or county auditor maps can be costly and time consuming. Deriving impervious cover from satellite imagery has certain advantages: images are relatively inexpensive, are acquired on a regular basis, and time series as long as a few decades can be constructed. However, impervious surface estimation from multispectral satellite imagery is difficult, and varied techniques have been utilized (Deguchi and Sugio 1994; Ridd 1995; Ji and Jensen 1999; Ward, Phinn and Murray 2000; Madhavan et al. 2001; Small 2001; Phinn et al. 2002).

Categorical classifications such as “low density residential” are widely used proxies for impervious cover, but usually entail estimating impervious cover from calibrated references (NOAA CSC 2003; Prisloe, Giannotti and Sleavin 2000). Data are lost and error more likely introduced. This research therefore utilizes a technique deriving impervious, vegetation, and soil covers directly from satellite data using a linear spectral mixture model to calculate fractions of four endmembers: vegetation, soil, low albedo, and high albedo, as described by Wu and Murray (2003). Impervious cover is derived by combining the low and high albedo image fractions to capture the variation present in man-made materials, for example light-absorbing blacktop roads vs. highly reflective metal roofs. This method shows promise as a low cost method of calculating impervious cover.

Two multispectral Landsat 7 Enhanced Thematic Mapper Plus (ETM+) satellite images (30 meter spatial resolution) acquired on August 20, 2000 and containing the study area were obtained and mosaicked together. We assumed homogeneous atmospheric conditions within the image; no atmosphere corrections were performed. Figure 2 shows the calculated impervious cover for the watershed. The three highest and lowest IBI HUC 14s are also indicated, along with their respective percent impervious cover. Additional representative HUC 14 impervious cover percentages are also listed.

4.4 Additional Independent Variables

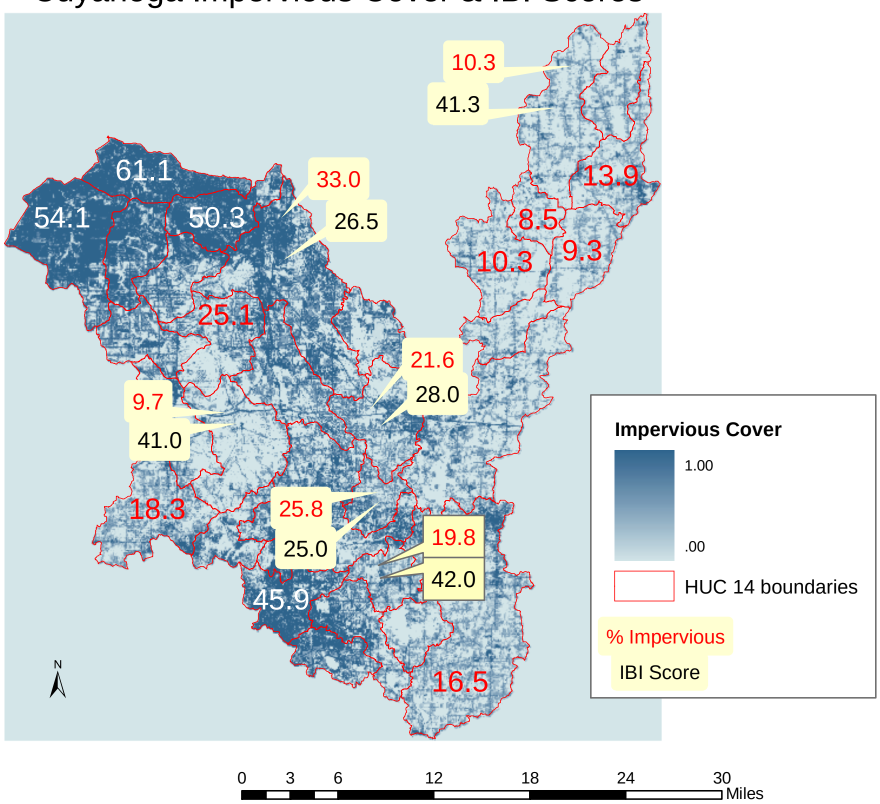
In addition to HUC 14 impervious cover area and the four NPDES point source pollution independent/stressor variables discussed above, a number of other independent variables were included for their potential effect upon the dependent/response variable of IBI score per HUC 14. These are listed in Table 3.

Table 3. Additional Independent Variables.

Area of HUC 14 in square miles
Area of HUC 8 upstream of HUC 14
Area of HUC 8 upstream of HUC 14 that is impervious cover
Area of HUC 8 upstream of HUC 14 in percent impervious cover

The area of each HUC 14 was considered to examine the effect, if any, of HUC 14 size. The area upstream of each HUC 14 in question was also examined in order to try and determine the significance, if any, of the spatial location of the HUC 14 within the larger HUC 8. Similarly, absolute upstream area in impervious cover from each HUC 14, and that upstream area as percent impervious cover, were included to try and determine their impact upon the HUC 14 IBI score.

Figure 2.
Cuyahoga Impervious Cover & IBI Scores



5. RESULTS AND DISCUSSION

Table 4 relates descriptive summary statistics for the 23 HUC 14s used in the analysis. For clarity only the most important variables are listed here. The independent variables involving upstream total area and upstream impervious cover area were not found to be statistically significant, although they doubtless have some impact which further research may reveal. Appendix C lists values for each variable for all 23 HUC 14s.

Notable is the huge range of values for total flow and BOD (and their low season values as well). Also notable is the watershed impervious cover, averaging about 23% per HUC 14, indicating a fairly urbanized watershed. Impervious cover per HUC 14 ranges from lightly developed areas with a low of 8.5% to quite urbanized areas with 50% impervious cover.

Table 4. Independent Variable Descriptive Statistics by HUC 14

HUC 14 value	IBI	AREA* (mi^2)	IC_PCT	FLOW (mgd)	BOD (kg/dy)	FLOW_LO (mgd)	BOD_LO (kg/dy)
mean	35	27.2	22.9%	45.8	696.6	37.6	691.6
median	35	22.9	21.0%	2.0	10.5	1.5	4.2
minimum	25	10.6	8.5%	0	0	0	0
maximum	42	78.8	50.3%	558.0	9029.8	312.8	8840.0

*n.b. Independent variables are as follows:
AREA = Size of HUC 14
IC_PCT = Percent impervious cover
FLOW = Total conduit flow (millions of gal/day)
BOD = Biological Oxygen Demand load (kg/day)
FLOW_LO = Low season total conduit flow (millions of gal/day)
BOD_LO = Biological Oxygen Demand low season load (kg/dy)

A bivariate Pearson's R correlation was performed upon all of the independent variables, as well as various linear bivariate multivariate regression analyses. IBI score per HUC 14 was the dependent variable in all cases. Pearson's R bivariate correlations between each the independent variable of IBI score per HUC 14 and the independent variables from Table 4 (except Area) are shown below in Table 5. For the other independent variables, the correlations were of the wrong sign or not statistically significant; these variables are not shown. An incorrect sign indicates a counterintuitive, or even counterfactual relationship. The spatial resolution of the data, that is, summing data for HUC 14 watersheds, likely obfuscated many biophysical relationships, of which more will be said later.

Table 5. Pearson's R Correlation between IBI and Independent Variables

HUC 14 Independent Variable	correlation with IBI	Significance (2-tailed)
IC_PCT (Percent impervious cover)	-.309	.152
FLOW (Total conduit flow [millions of gal/day])	-.457	.028
BOD (Biological Oxygen Demand load [kg/day])	-.416	.048
FLOW_LO (Low season total conduit flow [millions of gal/day])	-.409	.053
BOD_LO (Low season BOD load [kg/dy])	-.427	.042

A moderately strong correlation exists between IBI score and impervious cover and is of the correct (negative) sign; that is, a higher IBI score indicating greater fish biodiversity is associated with lower percent impervious cover. However, the statistical significance of this relationship is rather weak, with the low N of 23 observations likely affecting this relationship. More observations are of course desirable, with 30 to 35 preferred with this number of independent variables. Regression analyses can be performed with fewer cases, but statistically significant results are more difficult to obtain. Moderately strong and statistically significant relationships of the correct sign exist between total conduit flow and biological oxygen demand as well as their low season subsets.

The HUC 14s with the three highest and three lowest IBI scores, mapped in Figure 2, are listed in Table 6, along with values for their respective independent variables and area. Surprisingly, the HUC 14 with the best IBI score (42.0) possesses a relatively high 19.8% impervious cover. More typically, watersheds with less impervious cover exhibit higher IBI scores, as illustrated by the second highest IBI score of 41.3 with 10.3% impervious cover, and the third highest score of 41 with 9.7% impervious cover. (This HUC 14 is dominated by the extensive wooded areas of the Cuyahoga Valley National Recreation Area.) As expected, HUC

14s with greater total conduit flow and BOD generally have lower IBI scores. HUC 14s with very high point source pollution discharges were generally the lowest in IBI score, that is, with the least numbers and biodiversity of fish, while HUC 14s with little point source pollution exhibited more robust fish populations.

Table 6. Three Highest and Lowest HUC 14 Averaged IBI Scores

HUC 14 IBI Rank	USGS HUC 14 Number	IBI Score	AREA (mi^2)	IC_PCT	FLOW (mgd)	BOD (kg/dy)	FLOW_LO (mgd)	BOD_LO (kg/dy)
#1 IBI	04110002030020	42.0	13.1	19.8%	0.3	0.0	68.4	15.8
#2 IBI	04110002010030	41.3	35.7	10.3%	0.3	1.4	0.4	3.5
#3 IBI	04110002040040	41.0	33.3	9.7%	4.5	55.2	0.2	45.5
#21 IBI	04110002050030	28.0	24.9	21.6%	124.5	1657.5	162.3	2550.7
#22 IBI	04110002050050	26.5	55.3	33.0%	558.0	9029.8	312.8	8840.0
#23 IBI	04110002030030	25.0	11.5	25.8%	27.1	185.0	22.7	155.5

Numerous bivariate and multivariate regression models were run in an attempt to better explain the processes at work. All of these save one yielded results with incorrect signs for independent variables or which were statistically insignificant. The low number of observations played a role here, as did the aforementioned incompleteness of total conduit flow and BOD data. The complexity of these watershed interactions also makes analysis difficult.

A bivariate model utilizing IBI score and total conduit flow was both of the correct sign and statistically significant, as depicted in Table 7. That is, the most statistically significant results were obtained using only total conduit flow as the independent variable. Roughly 17% of the variation in HUC 14 IBI scores can be explained by total conduit flow.

Table 7. Bivariate Regression Model

R Square	Adjusted R Square	Std. Error of the Estimate			
0.209	0.172	4.255			
Independent Variable	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	35.499	0.952		37.308	0.000
FLOW	-0.018	0.008	-0.457	-2.357	0.028
Dependent Variable: IBI					

Aggregating smaller spatial units (sample site drainage areas) into larger ones (HUC 14s), as we did here, avoids the ecological fallacy (making claims about a smaller spatial unit based upon data disaggregated from a larger spatial unit). However, certain data problems do exist with the methods employed.

Averaging IBI scores from a variety of sample sites for an entire HUC 14 watershed eliminates important sample site information. The many constituent metrics of the IBI (listed in Appendix B), describing types of species present and numbers of individuals, are based upon the specific drainage area of the IBI sample site. One cannot legitimately make claims about species presence for larger spatial areas. Site-specific features of stream morphology and riparian habitat, which have a great impact upon aquatic biodiversity, are measured with the Qualitative Habitat Evaluation Index (QHEI). The QHEI also cannot legitimately be extrapolated for larger spatial areas. Additionally, while averaging IBI scores over an entire HUC 14 provides a general flavor for the watershed’s water quality, such averaging does little to help explain the *causes* of water resource impairment, especially how varying land uses interact with point sources of pollution and other biophysical and social processes.

IBI sample points are not arbitrarily chosen; in fact, they are carefully selected to represent variation within the larger watershed. Nevertheless, the resulting ad hoc drainage areas do not correspond to any conventionally recognized hydrologic units, such as HUC 14s. The customary approach to using IBI data employs the drainage area upstream of the sample site as the spatial unit. The benefits of using a standardized hydrological spatial unit, HUC 14s in this case, must be weighed against the significant loss of data specificity accompanying the use of such standardized spatial units.

Sample sites representing USGS drainage areas would be preferable. These drainage areas are widely used, easily understood, and familiar to many policy makers and members of the general public. However, Chris Yoder, a pioneer in the development of aquatic bioassessments for Ohio EPA, believes bioassessment sample site drainage areas are more scientifically useful than standardized drainage areas such as HUC 14s (Yoder 2004). A great deal more data are available with drainage areas, especially details concerning riparian habitat integrity.

Drainage areas could be selected to capture the full variation in HUC 14 area (roughly 3 mi^2 to 70 mi^2) present within the Cleveland metro area. Appendix D lists drainage areas of this size range sampled for IBI in years 2000 to 2002, and also sampled for riparian habitat quality (the Qualitative Habitat Evaluation Index, QHEI, mentioned earlier) as well as aquatic insects (the Invertebrate Community Index (ICI)). These drainage areas in Appendix D have also been selected to avoid spatial autocorrelation: the tendency for data values to resemble data values nearby spatially. Using drainage areas with data concerning all three biocriteria (IBI, QHEI, and ICI) would enable much more detailed analyses, thus increasing a model’s explanatory power. Using Ohio EPA sample site drainage areas instead of standardized watersheds such as HUC 14s would also permit more observations (watersheds/drainage areas) thus increasing statistical rigor. That said, however, there remains a certain utility in employing familiar, standardized drainage areas such as HUC 14 watersheds.

6. CONCLUSION

This study, like much current research, reminds us that impervious cover alone cannot adequately explain variation in surface water quality. Relationships between impervious cover, point sources of pollution, and water resource integrity are complex—relevant policies should reflect that complexity. For example, certain individuals might, for regulatory reasons, desire impervious cover totaled or averaged over a relatively large spatial unit, such as a HUC 14 or a County; however, smaller subwatersheds are likely the more significant area of concern. Or, additional development in an area, many would argue, should not reasonably be disallowed simply because it would raise the impervious cover from, say, 12% to 15%, since many other factors affect water quality besides impervious cover.

The regulatory and public focus on water quality has shifted in recent years to nonpoint pollution sources, generally runoff, both agricultural and urban. However, in spite of great progress in their management, industrial and municipal point source dischargers continue to significantly impair surface water quality. Continued research and regulatory vigilance in this arena is important for continued water quality improvement.

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Appendix A. Cuyahoga River HUC 14s.

HUC 11	HUC 14	ACRES	MI SQ	NARRATIVE
04110002010	***04110002010010***	11837.2	18.50	East Branch Cuyahoga River Reservoir
	04110002010020	14637.5	22.87	Cuyahoga River below E. Br. Reservoir to above W. Branch
	04110002010030	22847.7	35.70	West Branch Cuyahoga River
	04110002010040	13167.0	20.57	Cuyahoga River below W. Branch to above Black Brook [except Bridge Cr.]
	04110002010050	17907.0	27.98	Ladue Reservoir near Burton
	04110002010060	6799.4	10.62	Bridge Creek below Ladue Reservoir to Cuyahoga R.
	04110002010070	8077.2	12.62	Black Brook
04110002020	***04110002020010***	39129.2	61.14	Cuyahoga River below Black Brook to above Breakneck Cr.
	04110002020020	50408.0	78.76	Breakneck Creek
04110002030	***04110002030010***	16066.6	25.10	Cuyahoga River below Breakneck Cr. to above L. Cuyahoga R. [except Plum Cr. and Fish Cr.]
	04110002030020	8357.1	13.06	Plum Creek
	04110002030030	7362.9	11.50	Fish Creek
	04110002030040	8437.7	13.18	Mogadore Reservoir
	04110002030050	11787.4	18.42	Little Cuyahoga River below Mogadore Reservoir to above Springfield Lake outlet
	04110002030060	8026.7	12.54	Springfield Lake Outlet
	04110002030070	11769.9	18.39	Little Cuyahoga River below Springfield Lake Outlet to Cuyahoga R.
04110002040	***04110002040010***	8175.2	12.77	Cuyahoga River below L. Cuyahoga R. to above Yellow Cr. [except Mud Brook]
	04110002040020	18759.3	29.31	Mud Brook
	04110002040030	19829.0	30.98	Yellow Creek
	04110002040040	21287.5	33.26	Cuyahoga River below Yellow Cr. to above Brandywine Cr. [except Furnace Run]
	04110002040050	13079.2	20.44	Furnace Run
	04110002040060	17354.0	27.12	Brandywine Creek
04110002050	***04110002050010***	15536.0	24.28	Cuyahoga River below Brandywine Cr. to above Tinkers Cr. [except Chippewa Cr.]
	04110002050020	11385.1	17.79	Chippewa Creek
	04110002050030	15922.6	24.88	Tinkers Creek headwaters to above Pond Brook
	04110002050040	10170.8	15.89	Pond Brook
	04110002050050	35374.6	55.27	Tinkers Creek below Pond Brook to Cuyahoga R.
04110002060	***04110002060010***	10795.4	16.87	Cuyahoga River below Tinkers Creek to above Mill Cr.
	04110002060020	12429.0	19.42	Mill Creek
	04110002060030	12198.6	19.06	Cuyahoga River below Mill Cr. to above Big Cr.
	04110002060040	24049.4	37.58	Big Creek
	04110002060050	14495.5	22.65	Cuyahoga River below Big Cr. to Lake Erie

n.b. Bold italics indicates HUC 14s used in study

Appendix B. IBI Metrics and Site Types.

Metric	Metric Description	Site type
1	Total number indigenous fish species	all
1	Score number species	all
2	Number darter species	wading
2	Score number darter species score	wading
2	Number darter and sculpin species	headwaters
2	Score number darter and sculpin species	headwaters
2	Percent round-bodied suckers	boat
2	Score percent round-bodied suckers	boat
3	Number sunfish species	wading & boat
3	Score number sunfish species	wading & boat
3	Percent nine headwater sunfish species present	headwaters
3	Score nine headwater sunfish species present	headwaters
3	Percent pioneering species present	headwaters
3	Score percent pioneering species present	headwaters
4	Number sucker species	wading & boat
4	Score number sucker species	wading & boat
4	Number minnow species	headwaters
4	Score number minnow species	headwaters
5	Number intolerant species	wading & boat
5	Score intolerant species	wading & boat
5	Number sensitive species	headwaters
5	Score sensitive species	headwaters
6	Percent tolerant species	all
6	Score percent tolerant species	all
7	Percent omnivores	all
7	Score percent omnivores	all
8	Percent insectivores	all
8	Score percent insectivores	all
9	Percent top carnivores	all
9	Score top carnivores	all
9	Percent pioneering species	headwaters
9	Score pioneering species	headwaters
10	Number individuals	all
10	Score number individuals	all
11	Percent simple lithophils	all
11	Score percent simple lithophils	wading & boat
11	Number species simple lithophils	headwaters
11	Score number species simple lithophils	headwaters
12	Percent Deformaties, Eroded fins, Lesions, Tumors (DELTs)	all
12	Score DELTs	all

Appendix C. Description of Regression Variables by HUC 14.

HUC 14	IBI	Area (mi^2)	Percent Impervious Cover	Area of Impervious Cover (mi^2)	Upstream Area (mi^2)	Upstream Area of Impervious Cover (mi^2)	Upstream Area % Impervious Cover	Total Flow (milllion gal/day)	BOD (kg/day)	Total Flow Low Season (milllion gal/day)	BOD Low Season (kg/day)
04110002010010	36	18.50	10.9%	2.02	0.00	0.00	0.0%	0.0000	0	0.0000	0
04110002010020	33	22.87	13.9%	3.18	18.50	2.02	10.9%	11.1133	48	4.7443	42
04110002010030	41	35.70	10.3%	3.69	0.00	0.00	0.0%	0.2895	1	0.3816	3
04110002010040	35	20.57	9.3%	1.92	77.07	8.89	11.5%	0.0000	0	0.0000	0
04110002010060	30	10.62	8.5%	0.90	27.98	2.88	10.3%	16.8043	0	0.3130	0
04110002020010	39	61.14	13.8%	8.46	148.86	15.92	10.7%	1.4052	11	1.4948	4
04110002020020	33	78.76	16.5%	12.99	0.00	0.00	0.0%	2.1673	10	1.8055	0
04110002030010	33	25.10	32.1%	8.05	288.77	37.37	12.9%	0.0213	0	0.0250	0
04110002030020	42	13.06	19.8%	2.59	0.00	0.00	0.0%	0.3353	0	68.3505	16
04110002030030	25	11.50	25.8%	2.97	0.00	0.00	0.0%	27.1199	185	22.7313	155
04110002030070	38	18.39	45.9%	8.44	44.14	11.52	26.1%	2.0270	78	1.6646	122
04110002040010	37	12.77	21.0%	2.68	430.28	79.23	18.4%	2.3290	23	2.1498	23
04110002040020	32	29.31	28.3%	8.29	0.00	0.00	0.0%	111.6138	1441	96.6914	577
04110002040030	38	30.98	18.3%	5.68	0.00	0.00	0.0%	21.9026	946	11.2817	572
04110002040040	41	33.26	9.7%	3.23	474.03	87.59	18.5%	4.5425	55	0.1586	45
04110002040060	33	27.12	25.1%	6.81	0.00	0.00	0.0%	0.0662	0	0.0587	0
04110002050010	39	24.28	18.0%	4.36	554.85	101.14	18.2%	0.0234	0	0.0219	0
04110002050030	28	24.88	21.6%	5.37	0.00	0.00	0.0%	124.4552	1657	162.3471	2551
04110002050040	36	15.89	21.1%	3.35	0.00	0.00	0.0%	169.1497	2534	177.9981	2956
04110002050050	27	55.27	33.0%	18.22	40.77	8.72	21.4%	557.9850	9030	312.7563	8840
04110002060010	38	16.87	29.6%	5.00	692.96	136.66	19.7%	0.0198	0	0.0202	0
04110002060020	32	19.42	50.3%	9.76	0.00	0.00	0.0%	0.0000	0	0.0000	0
04110002060030	31	19.06	44.8%	8.54	729.24	151.42	20.8%	0.0346	0	0.0203	0

Appendix D. Metro Cleveland HUC 14-Sized Drainage Areas with Complete Bioassessment Data circa 2000.

Ohio EPA River Basin	Ohio EPA Stream Number	River/Stream Name	River Miles from Mouth	Survey Year	Drainage Area of Site	QHEI	ICI	IBI
Grand	010	Coffee Creek	0.2	2000	12.0	76	54	36
Ashtabula	010	Fields Brook	0.9	2000	5.3	69	0	20
Huron	200	West Branch Huron River	35.3	2002	64.0	67	40	40
Huron	200	West Branch Huron River	38.4	2002	27.8	65	16	28
Rocky	100	East Branch Rocky River	3.0	2001	75.0	56	42	36
Rocky	100	East Branch Rocky River	22.0	2001	24.0	82	54	52
Rocky	101	Baldwin Creek	1.1	2001	11.4	67	32	20
Rocky	205	North Branch Rocky River	5.6	2001	28.0	68	52	40
Cuyahoga	001	Cuyahoga River	87.3	2000	38.4	42	38	38
Cuyahoga	001	Cuyahoga River	90.9	2000	18.6	54	28	22
Cuyahoga	007	Tinkers Creek	0.1	2000	96.0	78	36	32
Cuyahoga	007	Tinkers Creek	25.0	2000	17.0	35	46	22
Cuyahoga	010	Brandywine Creek	0.6	2000	26.0	58	46	42
Cuyahoga	021	Yellow Creek	3.0	2000	24.4	84	50	42
Cuyahoga	024	Mud Brook	8.3	2000	16.3	49	32	26
Cuyahoga	027	Plum Creek	0.2	2000	11.6	69	36	42
Cuyahoga	028	Breakneck Creek	7.0	2000	56.2	66	40	44
Cuyahoga	028	Breakneck Creek	14.6	2000	42.3	34	46	24
Cuyahoga	030	Little Cuyahoga River	0.3	2000	68.0	72	24	38
Cuyahoga	036	West Branch Cuyahoga River	5.6	2000	25.5	66	38	48
Cuyahoga	036	West Branch Cuyahoga River	10.2	2000	13.0	58	8	34
Cuyahoga	038	Tare Creek	1.6	2000	5.6	60	4	34
Cuyahoga	041	Euclid Creek	0.7	2000	23.0	68	32	24
Black	002	French Creek	3.2	2001	27.0	70	40	24
Black	015	West Fork East Branch Black River	1.2	2001	36.5	68	34	38
Black	020	West Branch Black River	28.5	2001	39.0	70	38	30
Black	021	Plum Creek	0.9	2001	10.7	83	42	34
Black	024	Charlemont Creek	0.7	2001	22.7	77	32	36
Vermilion	001	Vermilion River	45.7	2002	76.0	79	36	52
Vermilion	001	Vermilion River	50.7	2002	69.0	68	28	36