Riparian forests in NW Ohio watersheds: relations between landscape structure, land use, and water quality in regional rivers

Final Report to the Ohio Lake Erie Commission

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Abstract

We investigated how landscape structure links to water quality in agricultural watersheds draining into Lake Erie and if such structure may serve as an effective water quality indicator. Specifically, we used correlation and regression analyses to assess if water quality correlates with metrics of riparian forests landscape structure and with proportions of land cover types in non-riparian areas. We also quantified the relative contribution of these spatial parameters to water-quality benefits within selected watersheds. We used historical data to compute yields for suspended sediments (SS), total phosphorus (TP), nitrate+nitrite (NO_{23}), and total dissolved solids (TDS, estimated from conductivity) and computed landscape metrics in GIS using land cover and other spatial data. In the riparian corridor, there were no significant ($p \leq 0.05$) correlations between water quality parameter yields and landscape metrics computed for forests cover or combined natural land cover types. Within non-riparian portions of watersheds, %row crops was positively correlated with SS ($p=0.01$) and TP ($p=0.05$) and showed weak but not significant correlations with NO_{23} ($p=0.07$). Conversely, SS was negatively correlated with cover of forests, wetlands, woody vegetation, and all natural vegetation combined. Except for wetlands cover, this was also the case for TP, while all NO_{23} correlations were non-significant. TDS showed weak negative correlations with the amount of pasture/hay and wetlands and positive correlations with developed cover. According to multiple regression results, proportions of land cover in non-riparian areas and other landscape factors within entire watersheds were generally better indicators of water quality, while the %row crops and %pasture/hay were the only riparian metrics that contributed to explaining water quality variability. These results suggest that the reduction of pollutants in streams and rivers depends primarily on improving land management practices in non-riparian portions of watersheds. On the other hand, results also suggest that an increase in vegetation cover (natural or planted herbaceous buffer strips) in the riparian areas may contribute to further mitigate pollutant loading into streams. Although not significantly correlated, pollutant yields generally showed a negative trend with the amount of natural vegetation cover types in the riparian corridor. Furthermore, model results indicated that pasture/hay cover in riparian areas reduces NO_{23} and TDS loading.

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1- Introduction

Riparian zones are complex transitional zones between aquatic and terrestrial systems. These areas are functionally diverse and have long been recognized for their importance in the landscape (Naiman *et al.* 1993, Naiman and Décamps 1997). Riparian forests provide buffering functions important for water quality in rivers. They serve as filters and/or transformer for sediments, nutrients, and pesticides coming laterally into rivers from the adjacent land (Lowrance *et al.* 1984, Peterjohn and Correl 1984, Décamps 1993) or modify flows and sediment transport moving longitudinally along the rivers (National Research Council 2002).

It is also recognized that proportions of land use/cover types in non-riparian areas may affect water quality by modifying the loading of pollutants into aquatic systems (Hunsaker and Levine 1995). These aspects are particularly important in the Western and Central Lake Erie basins, which are affected by intense agricultural and urban land use. Yet, an assessment of how riparian buffer structure and land use/cover adjacent to that buffer are related to water quality is lacking in the agricultural watersheds that drain into these Lake Erie basins.

Research has linked the structure of riparian buffers to their ecological function and has demonstrated that width of buffers (Lowrance *et al.* 1984, Peterjohn and Correl 1984, Décamps 1993) and the presence of continuous buffers along streams (Wenger, 1999) are important for effective riparian buffering function. In addition, research efforts have suggested that simple metrics characterizing such structure (such as width and connectivity) may complement the traditional intensive chemical and biological monitoring for water quality or substitute these approaches to optimize management resources (Gergel *et al.* 2002). Such landscape-level indicators can be derived from recurrent remote sensing data with a geographic information system (GIS). With this technique, large tracts of land can be covered so that the monitoring of trends becomes convenient.

To determine the effectiveness of riparian forests metrics as indicators of water quality, we specifically investigated (1) if metrics of riparian forest structure are correlated with water quality, (2) if the proportion of land use/cover types in non-riparian areas is correlated with water quality, and (3) what the relative contribution of these spatial parameters is to water-quality benefits. The latter provided information about which landscape parameters are the most effective predictors for water quality benefits. In this case, we defined "most effective" predictors as those that have higher statistical explanatory power, are ecologically meaningful relative to the process being investigated, and can be measured in a GIS using landscape-level digital data. In this investigation, we also compared the effectiveness of landscape structure metrics computed for forest cover alone and forest cover combined with other natural vegetation covers, grouped as 'natural vegetation'.

2- Methods

The general approach used in this landscape-level study (Benedict, undated) was to obtain historical chemical water quality data from sampling stations in watersheds in the NW Ohio region. These water quality datasets needed to be extensive enough to compute annual loads for selected water quality parameters. As this restricted the availability of complete datasets, we included watersheds that extended into SE Michigan in order to increase our sample size. Spatial data manipulation and analysis were performed in ArcView 3.3© (Environmental Systems Research Institute, Inc.) geographical information system (GIS). Water quality sampling stations were plotted in the GIS and watersheds delineated upstream from such stations; in the remainder of this text the term "watershed" refers to this upstream drainage area. A riparian corridor of fixed-width was delineated along both sides of streams. Publicly-available digital datasets were then used to derive watershed characteristics and compute landscape structure metrics for the riparian and non-riparian watershed areas. The water quality data were used to compute daily, seasonal, and annual parameter loads, followed by computation of seasonal and annual yields. And finally, relationships between water quality parameter yields and the landscape structure metrics were performed with statistical analyses (detailed below). Besides using such metrics as explanatory variables, we also included additional independent variables that may affect water quality. These parameters are described later in the text.

2.1. Study area

The nine watersheds investigated are located in Northwest Ohio and Southeast Michigan and either drain into, or are tributaries in basins that drain into Lake Erie (Fig. 1). Their areas range from 11 to 3240 km^2 (Table 1). Agriculture is the predominant land cover type in all watersheds, which contain few small to mid-sized urban areas. The remaining natural vegetation is comprised mainly of forests and wetlands. The region's glaciated geology is comprised mainly of glacial tills (ground moraines, recessional moraines) and lake deposits. Soils range from well-drained sands and gravels to moderately coarse to fine textured soils, with a predominance of fine textured clays with low drainage.

2.2. Data

Water quality data were obtained from the USGS National Water Information System (NWIS), the Ohio Tributary Monitoring Program at the Water Quality Laboratory at Heidelberg College, Ohio EPA's Northwest Ohio District Office, and the City of Toledo Division of Environmental Services. The spatial datasets included: soils, from the State Soil Geographic (STATSGO) Database; elevation, from the National Elevation Dataset (NED), produced by the U.S. Geological Survey (USGS 1999); hydrography, from U.S. Environmental Protection Agency Reach File V.3 Hydrography Dataset; surficial geology data, from the Michigan Center for Geographic Information and the Ohio Department of Natural Resources, Division of Geological Survey; and land use and land cover, from the USGS's National Land Cover Characterization Project (NLCD). These land use and land cover data were chosen because they are used by national and regional agencies for studies and management efforts. As such, our results on land use patterns will be comparable with such other studies.

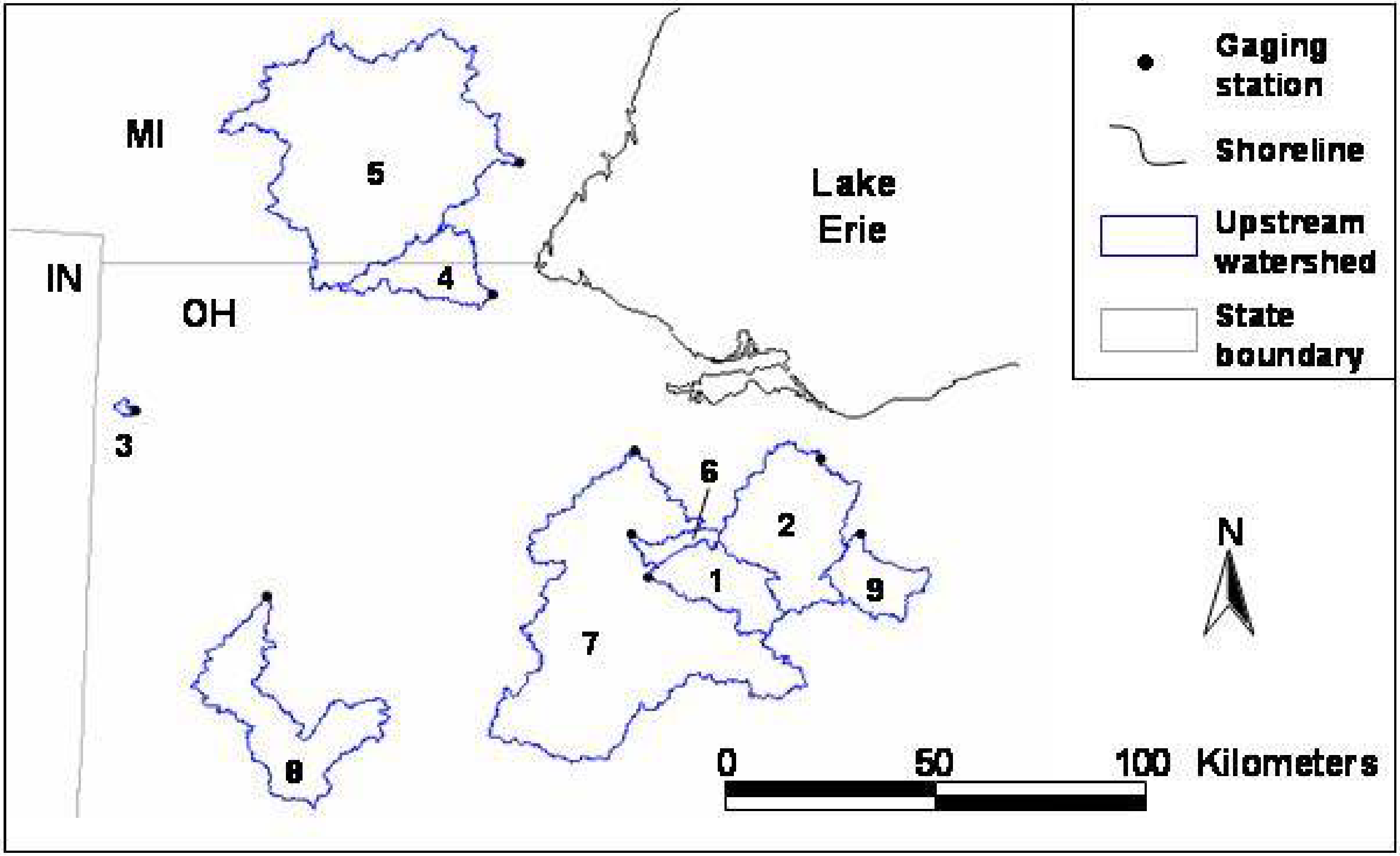

Figure 1. Upstream watersheds extending over NW Ohio and SE Michigan: 1- Honey Creek, 2-Huron River, 3- Lost Creek Tributary, 4- Ottawa River, 5-River Raisin, 6- Rock Creek, 7- Sandusky River, 8- Upper-Auglaize River, 9- Vermillion River

Table 1. Watersheds upstream from gaging stations and contributing drainage areas.

	USGS station number	Area (km^2)
Honey Creek	04197100	385.9
Huron River	04199000	960.9
Lost Creek Tributary	04185440	11.0
Ottawa River	04177000	388.5
River Raisin	04176500	2698.8
Rock Creek	04197170	89.6
Sandusky River	04198000	3240.1
Upper-Auglaize River	04186500	859.9
Vermilion River	04199287	290.1

The NLCD land use data were produced from Landsat satellite imagery for circa 1992 including leaves-off and leaves-on images and ancillary datasets (USGS undated). This 1992 dataset represented the most recent time period for which land use data was consistently available for the entire area of study. It includes nine types subdivided into 21 classes (NLCD undated, Table 2). Not all land cover classes were present in the watersheds studied. From here on throughout the text, land use/cover will be referred to as land cover.

All spatial data were projected into the same coordinate system as the land cover data, namely Universal Transverse Mercator (UTM) - Zone 17, North American Datum of 1983, and the Geodetic Reference System 1980 spheroid.

Table 2. National Land Cover Data Classification System Key.

Land use/land cover types	Classes
Water	Open Water Perennial Ice/Snow
Developed	Low-Intensity Residential High-Intensity Residential Commercial/Industrial/Transportation
Barren	Bare Rock/Sand/Clay Quarries/Strip Mines/Gravel Pits Transitional
Vegetated; Natural Forested Upland	Deciduous Forest Evergreen Forest Mixed Forest
Vegetated; Natural Shrub land	Shrub land
Vegetated; Non-natural Woody	Orchards/Vineyards/Other
Herbaceous Upland Natural/Semi-natural Vegetation	Grasslands/Herbaceous
Herbaceous Planted/Cultivated	Pasture/Hay Row Crops Small Grains Fallow Urban/Recreational Grasses
Wetlands	Woody Wetlands Emergent Herbaceous Wetlands

2.3. Water quality

The water quality parameters investigated in this study included suspended sediments (SS), total phosphorus (TP), nitrate+nitrite (NO_{23}), and total dissolved solids (TDS). As sampling frequencies and total number of samples collected varied among basins, we manipulated the water quality data to account for any inconsistencies among watersheds. Whenever available, we used continuous daily data records in the analyses. If such continuous data were not available for the time period of interest (i.e., encompassing the period of land cover data), we estimated daily parameter concentrations from sampled concentration and water discharge data using the rating-curve method (Gordon *et al.* 1992, Clark *et al.* 2000). There were only a few TDS data records for one watershed (Ottawa River), but there was conductivity data for every watershed. Thus, we estimated TDS concentrations from conductivity for all watersheds (APHA/AWWA/WEF 1992, Brooks *et al.* 1997).

Simple linear regressions for log of parameter concentrations (mg/L) against log of water discharge (m^3/s) were used to develop the rating curves. The log-log rating curves produced estimated log of parameter concentrations. These log-values were transformed back to original units in order to calculate parameter loads and yields. As this procedure introduces a bias that may lead to large underestimations (Cohn *et al.* 1989, Helsel and Hirsh 2002), we corrected this bias with the non-parametric Smearing Estimator (Duan 1983) procedure.

The existing data records and the estimated concentrations from the rating-curve approach were used to calculate daily (kg/day) parameter loads, which were used to compute seasonal and annual (metric tons/time) parameter loads. Seasonal or annual loads were calculated as the sum of daily loads for the period of interest. As the watersheds investigated varied in size, we normalized the parameter loads per unit area (km^2) by computing yields (metric tons/km^2/time) (Baker 1993, Clark *et al.* 2000). We did not account for point-source contributions to pollutant loadings. Although point-source pollution represents a comparatively low proportion of pollutant yields such as for phosphorus in these regional basins (Baker and Richards 2002), this may be a source of error in our yield computations.

A lag-time effect may occur in the transport of contaminants from the watershed into the streams, resulting in a process of intrabasinal storage. Such intrabasinal storage processes can mask the effects of different land covers on pollutant loadings into streams (Evans *et al.* 2000). We accounted for such processes by computing the water quality parameter yields for a period of time that included 1992 and additional years prior. The annual yields in this multi-year time period were then averaged to produce a final annual yield. We determined how many years before 1992 to include in this average by identifying the annual peak runoff events prior to 1992 that were equal to or larger than bankful discharge. These events were considered sufficiently strong to "flush" the system. It was decided that 1992, 1991 and 1990 should be included in the procedure. Although other years could also be included based on the magnitude of peak discharge events for certain basins, going further back in time would increase the probability of having different land cover patterns than those present in 1992.

For the investigation of seasonal relationships between water quality and landscape parameters, we analyzed spring and summer combined. These two seasons represent the growth period and include higher runoff events, considered relevant for the assessment of the relationships being investigated. In the remainder of the text, the "integrated total annual yield" and the "integrated total seasonal yield" will be termed simply as "total annual yield" and "total seasonal yield", respectively. Additional details about the rating curve, bias correction, and intrabasinal storage procedures can be found in (Benedict, undated).

2.4. Riparian corridor delineation and watershed delineation

We delineated a 120-meter wide fixed-width riparian corridor on both sides of the streams using ArcView's "buffer" function. This 120-meter distance was used because it was consistent with an appropriate minimum distance for riparian buffers for water quality function (Castelle *et al.* 1994, Wenger 1999). Moreover, it generally encompassed most of the forest and woody wetlands covers occurring along streams in the watersheds studied. In addition, such width was consistent with the 30-meter resolution of the land cover data used in the study.

The delineation of watershed boundaries upstream from water quality gaging stations was accomplished with digital elevation data in the GIS using the Basin1 Extension for ArcView GIS (Petras 2003). For this, the large NED elevation datasets were subset to an area encompassing and extending well beyond each watershed boundary to avoid loss of elevation data at the edge of such boundaries during spatial analyses. The subset digital elevation data were manipulated to obtain hydrologically correct elevation data. This was accomplished by correcting for the presence of sinks before computing the flow direction and flow accumulation grids needed to define the area draining to a sampling station (Petras 2003). In addition, we burned the hydrography data for each watershed into the digital elevation and also burned the hydrography data for surrounding watersheds. This allowed us to obtain the most possibly accurate boundary for any given watershed, as the water dividers were captured and used when delineating the boundaries.

2.5. Landscape structure and watershed characteristics

The landscape structure metrics computed for this study are presented below. We computed the metrics for both forest cover and natural vegetation groupings (detailed later in text). Many of the landscape structure metrics are based on patches of different land covers. As such, we defined a *patch* as a block of one or more contiguous grid cells belonging to a distinct land cover class. Patch boundaries occurred where grid-cell contiguity was interrupted by the occurrence of a grid cell belonging to a different land cover class. This definition accounted for the smallest patch size discernible in the land cover dataset, i.e., 30-meter grid cells. It also accounted for the ecological function targeted in this investigation, i.e., the buffering capability. The 30-meter grid cell size represented a spatial scale sufficiently large for buffering function to take place within certain land cover types (e.g., forest). In addition to patch-based metrics, we included the mean width of riparian vegetation as a relevant metric as the width of riparian vegetation buffers affects their effectiveness in improving the quality of waters flowing from the upland areas into streams.

- Landscape structure metrics for the riparian corridor:

- *Percentage of landscape for a particular land cover type:* This represented the proportional abundance of a land cover type within the area of interest (e.g., riparian corridor). For this study, certain land cover classes were combined to produce an aggregate land cover type. These groupings are listed and detailed in Table 3.
- *Mean width of riparian vegetation:* This metric was computed using the proportional area approach by Schuft *et al.* (1999), which provided an estimate of mean riparian vegetation width.

The next four patch metrics were computed using the Patch Analyst version 3.1 (Rempel and Carr 2003) extension for ArcView and provide information about connectivity and fragmentation patterns:
- *Number of patches:* An increased number of patches of a particular land cover (e.g., forests) suggested breaks in connectivity.
- *Patch density:* This represented a measure of the number of patches per unit area. Together with the previous metric it provided additional information about fragmentation.
- *Mean patch size:* This metric described fragmentation patterns such as increase or decrease in area when coupled with the number of patches or patch density metrics.

- *Standard deviation of mean patch size*: Such measure of variability provided an assessment of landscape heterogeneity that is not captured by the mean patch size alone (McGarigal and Marks 1995).

- Landscape structure metrics for the non-riparian zone:

For the purposes of this study, only the *percentage of landscape for a particular land cover type*, was computed in non-riparian portions of the watershed.

- Watersheds characteristics as additional explanatory variables:

Because other landscape features may also influence the transport and loading of water quality parameters into aquatic systems, we quantified selected landscape features within watersheds and applied these as potential explanatory variables in the multiple regression models used to assess relationships with the water quality parameters. These features were computed within the GIS and are presented below.

- *Mean watershed slope* and *mean riparian corridor slope (as a percentage)*. These were computed from the original elevation data.

- *Standard deviation of elevation*. This value was used to represent topographic heterogeneity within entire watersheds (Richards *et al.* 1996, Johnson *et al.* 1997) and was computed from original elevation data.

- *Percent of hydrologic soil group*. The Hydrologic Soil Group Classification indicated the runoff potential of soils. This included groups A, B, C, and D, ranging from low to high runoff potential, respectively (USDA 1972, USDA 2002). Hydrologic soil group descriptions (USDA 2002) are presented below. In such descriptions, "infiltration rate is the rate at which water enters the soil at the surface and is controlled by the surface conditions. Transmission rate is the rate at which water moves in the soil and is controlled by soil properties" (USDA 2002). Some wet soils with a D classification under natural conditions can receive a dual classification (A/D, B/D, and C/D) if they can be adequately drained. The first letter in the dual classification represents drained conditions and the second letter undrained conditions (USDA 2002). We considered soils with dual hydrologic groups as belonging to group D because it was not possible to determine from the dataset if the soils are drained or not.

> A. (Low runoff potential). The soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmission.
>
> B. The soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well drained to well drained soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission.
>
> C. The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission.
>
> D. (High runoff potential). The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have a high swelling potential, soils that have a permanent high water table, soils that have a claypan or clay layer at or near the

surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission.

- *Percent total impervious area*. The amount of total impervious area was estimated from the NLCD land cover data based on Caraco *et al.* (1998), USEPA (2001) and USEPA (2004).
- *Percent surficial geology*. This parameter was classified into five broad categories: Glacial till, Glacial outwash sand and gravel and postglacial alluvium, Glacio-lacustrine silt and clay, Glacio-lacustrine sand and gravel, and Peat. Due to differences in data resolution between the Ohio and Michigan original datasets, we reclassified them into these broad categories in order to quantify surficial geology consistently across all watersheds. This was done through the inspection and cross-referencing of surficial deposits and materials included in the GIS datasets against published printed maps (Farrand, W.R. 1982, Pavey *et al.* 1999, Fullerton *et al*. 2003) and consultation with regional geologists (Dr. J. Evans, Bowling Green State University and Dr. T. Fisher, University of Toledo).
- *Mean stream sinuosity*. Sinuosity was defined as the ratio of channel length to river valley length (Gordon *et al.* 1992, Rosgen 1996). It was calculated for the stream segments within watersheds, and subsequently averaged.

The landscape metrics and land cover groupings used in analyses of relationships with water quality are summarized in Table 3 below. In some cases, abbreviations are presented for these metrics and used later in the Results and Discussion section.

Table 3. List of landscape metrics analyzed for relationships with water quality and their abbreviations used in tables and figures. Percent area per land cover type preceded by "R", "B", or "NR" refer to riparian, whole basin, or non-riparian areas of watersheds, respectively.

Landscape metrics	Abbreviated names
% area of pasture and hay	% R_Past/Hay, B_Past/Hay, NR_Past/Hay
% area of row crops	% R_RowCrops, B_RowCrops, NR_RowCrops
% area of developed [1]	% R_Developed, B_Developed, NR_Developed
% area of forests [2]	% R_Forests, B_Forests, NR_Forests
% area of wetlands [3]	% R_Wetlands, B_Wetlands, NR_Wetlands
% area of woody vegetation [4]	% R_WoodyVeg, B_WoodyVeg, NR_WoodyVeg
% area of natural vegetation [5]	% R_NatVeg, B_NatVeg, NR_NatVeg
Patch density (# patches km^{-2}) of riparian forests, woody vegetation	PD_R_Forests, PD_R_ WoodyVeg
Mean width (m) of riparian forests, wetlands, woody vegetation, natural veget.	MW_For, MW_Wetl, MW_WoodyVeg, MW_NatVeg
Mean slope (%), in watershed	Bas.Mean_Slope%
Mean slope (%), in riparian corridor	Rip.Mean_SLope%
Standard deviation of elevation (m) in watershed [6]	SD_Elevation
% of hydrologic soil groups A, B, C, D	Soil_A, Soil_B, Soil_C, Soil_D
% total impervious area	%TIA
% of surficial geology categories: Glacial till, Glacial outwash sand and gravel and postglacial alluvium, Glacio-lacustrine silt and clay, Glacio-lacustrine sand and gravel, Peat	Till, Outw. sand/gravel & alluv., lac_silt/clay, lac_sand/gravel, Peat
Mean stream sinuosity	Sinuosity

[1] Aggregates Low and High-Intensity Residential, and Commercial/Industrial/Transportation classes

[2] Aggregates Deciduous, Evergreen, and Mixed Forest classes

[3] Aggregates Woody and Emergent Herbaceous Wetland classes

[4] Aggregates Forests and Woody Wetland classes

[5] Aggregates Forests and Woody and Emergent Herbaceous Wetland classes

[6] Provides a measure of topographic heterogeneity

2.6. Statistical Analyses

Relationships between water quality parameter yields and the landscape structure metrics were assessed with correlations and multiple regressions analyses. As many variables showed non-normal distributions, we used the non-parametric Spearman Rank Correlation Coefficient to test for correlations between yields for selected water quality parameters and riparian forests landscape metrics and proportions of land covers in the non-riparian area of watersheds. We also used this non-parametric test to select potential predictor variables to use in the multiple regressions. This was done by identifying any landscape metric related to an individual water quality parameter with a p-value of ≤ 0.1.

The different land cover classes or groupings of land cover classes suggested potential intercorrelations among these data. Thus, we assessed for, and removed redundancy in the landscape data (i.e., multicollinearity) before using multiple regressions to identify which metrics were most important predictors of water quality. This allowed us to obtain the most parsimonious regression model. Multicollinearity was assessed using two complementary approaches. First we produced a total correlation matrix for the predictor variables. For any two intercorrelated variables, we calculated partial correlations against the water quality parameter and kept the variable with the highest partial correlation. Second, we applied the variance inflation factor (VIF) diagnostic, a more rigorous approach to improve the multicollinearity assessment because the correlation matrix sometimes does not capture collinearity entirely (Ott and Longnecker 2001).

Selection of the multiple regression model was accomplished using three goodness-of-fit measures (Mallow's Cp statistic, the coefficient of determination (R^2), and the adjusted coefficient of determination (adjusted-R^2) as well as scree-diagrams of adjusted-R^2. Once the potentially best models were identified, we assessed if the predictor variables in the models were ecologically meaningful relative to their potential effect on the response variable. And lastly, multiple regressions were performed to assess each model. Here, we assessed the model's overall statistical explanatory power with an F-test and the explanatory power of the individual predictor variables using partial t-tests.

Because the multiple regression model assumes a linear relationship between the response and predictor variables, we assessed the linearity of individual predictor variables against a water quality parameter using bi-variate plots and simple linear regressions. When needed, we applied transformations on the predictor variables to linearize the relationship. The linearized models were used to obtain the models' coefficients. For models with more than one explanatory variable, however, the magnitude of each predictor variable can affect its contribution to the response variable. Thus, we computed the standardized partial regression coefficients (i.e., beta weights) for each predictor variable to remove this magnitude effect and determine the variable's relative contribution. This approach allowed for the determination of which variables among the landscape parameters analyzed were the best predictors of a given water quality parameter in the streams investigated.

After the best general model was identified for each water quality parameter, we reviewed the model selection and identified the model that had the best applied management value. That is, the model that explained the highest amount of variability using only landscape variables that can be manipulated or controlled by managers. Although such model might not account for all the variability explained by the best general model, it potentially identifies the important landscape variables that need to be managed to improve the water quality, while excluding landscape watershed features that can not be controlled through management efforts. Additional details about the statistical analyses may be found in Benedict (undated).

3- Results and Discussion

3.1. Watersheds Characterizations

Land cover

All watersheds were heavily impacted by agriculture (Table 4). Row crops were the predominant land cover in all watersheds, ranging from 50.6 % in the Vermillion River to 76.3% in the Upper-Auglaize River. Pasture/Hay was generally the second most abundant land cover in the watersheds, varying from 8.8 to 23.1%. Forest cover ranged from 8.1% in the Upper-Auglaize River watershed to 24.5% in the Vermillion River, suggesting that this watershed was the least impacted by intensive agricultural practices. Developed land cover type generally represented ≤ 2% among watersheds, except for the Ottawa River with 10.2%. This was due to the presence of a large urban concentration with the City of Toledo and surrounding communities.

Similarly, land cover in riparian corridors (Table 5) was generally dominated by row crops, which ranged from 30.4% in Vermillion River to 70.8% in the Upper-Auglaize River. Riparian forest cover represented from 10.5 to 38.3% of riparian area in the Lost Creek Tributary and Vermillion River, respectively. Noteworthy is the fact that the extent of forest cover was the same as row crops cover in Vermillion River's riparian corridors. Pasture/Hay cover was generally comparable to forest cover in the riparian corridors of six watersheds, while the Developed cover extent, again, reflected the urbanization in the Ottawa River watershed.

A visual inspection of the watersheds' 1992 land cover maps provided insights into distribution patterns among the land cover classes' (Figures 2-A to 10-A). The majority of wetlands areas within watersheds were located along streams. And although there were forest patches of variable size scattered throughout the watersheds, forest cover was generally located along streams or in close proximity to them. There were, however, some distinct patterns in forest cover concentration among the watersheds. In Honey Creek, Lost Creek Trib., Rock Creek, Sandusky River, and Upper-Auglaize River (Fig. 2-A, 4-A, 7-A, 8-A, 9-A, respectively) forest cover was somewhat equally distributed in the watersheds with a few larger areas associated with natural preserves. In the River Raisin watershed (Fig. 6-A), forest cover was concentrated in the upper reaches in the North-Northwestern portions. In the Ottawa River watershed (Fig. 5-A), forest cover was concentrated in lower Eastern area and was associated with the extensive park system located within the City of Toledo and surrounding areas. In the Huron and Vermillion Rivers (Fig. 3-A and 10-A, respectively), forest land cover was concentrated along large main channels, with the Vermillion River possessing the highest amount of forests among all watersheds. This concentration of forest cover along streams in the Huron and Vermillion Rivers may be due to underlying factors that limit land use in these areas. For example, for the Huron and Vermillion Rivers, respectively, 80% and 96% of forest cover in the riparian corridor was located over ground moraines, recessional moraines, or alluvium and alluvial terraces deposited in present and former floodplains. Future studies investigating linkages between forest cover remnants and landscape edaphic, geologic, and topographic factors may be warranted, as such factors may act as disincentives to deforestation along rivers.

Topography and surficial geology
The topography was generally flat among the watersheds as evidenced by their low mean slope values (Table 6). Some watersheds, however, showed areas of higher relief due to the presence of moraines. This was verified by the topographic heterogeneity, quantified as the standard deviation of elevation, in watersheds such as the Huron River, River Raisin, and Sandusky River.

The surficial geology reflected the glacial history of Western and Central Lake Erie basin. Glacial tills were the predominant feature within most of the watersheds (Table 6), comprising from 30.4% to 95.0% of their extent. Glacio-lacustrine silts and clays, and sands and gravels, were generally the next most dominant features in watersheds such as the Ottawa River and River Raisin, characterizing the depositional environment that occurred in these areas.

Imperviousness (%TIA) and hydrologic soil groups
The estimated percent total impervious area (%TIA, Table 7) within the watersheds was low. It ranged from 2.2 (Lost Creek Tributary) to 8.6% in the Ottawa River, due to its higher amount of developed areas. Although total amount of impervious surfaces was low, the watersheds generally had high runoff potential because of the high occurrence of hydrologic soil groups C and D (Table 7). These soils have low to very low water infiltration and transmission rates and were the predominant groups in eight out of the nine watersheds. The widespread use of tile drainage to improve lands for agriculture, however, may have altered the high runoff potential of these soils. Soils types A and B (with high to moderately high infiltration and transmission rates, respectively) had a generally low occurrence in most watersheds, but were increasingly present in the Ottawa River and comprised over a third of the River Raisin watershed.

Table 4. Percent area for land cover classes within watersheds upstream from gaging stations. Values were calculated for the terrestrial portions only, which represent the relevant areas contributing materials into water bodies. Open water areas covered ≤1.5% in all watersheds.

	Land cover						
Watershed	Barren[1]	Developed[2]	Forests[3]	Pasture/ Hay	Row crops	Urban/ Recreational grasses	Wetlands[4]
Honey Creek	<1	<1	10.1	19.5	68.7	<1	<1
Huron River	<1	2.1	15.4	18.6	63.1	<1	<1
Lost Creek Trib.	0	0	8.3	20.9	69.6	0	1.1
Ottawa River	<1	10.2	11.0	8.8	66.4	1.3	2.0
River Raisin	<1	1.9	14.3	18.5	61.6	<1	3.2
Rock Creek	0	2.0	12.9	18.1	66.6	0	<1
Sandusky River	<1	1.3	9.3	17.1	71.4	<1	<1
Upper-Auglaize River	<1	2.0	8.1	12.8	76.3	<1	<1
Vermilion River	0	<1	24.5	23.1	50.6	0	1.0

[1] Aggregates Quarries/Strip Mines/Gravel Pits and Transitional classes

[2] Aggregates Low and High-Intensity Residential, and Commercial/Industrial/Transportation classes

[3] Aggregates Deciduous, Evergreen, and Mixed Forest classes

[4] Aggregates Woody and Emergent Herbaceous Wetlands

Table 5. Percent area for land cover classes within a buffer distance delineated 120-meters on each side of streams. Values were calculated for the terrestrial portions only, which represent the relevant areas contributing materials into water bodies. Open water areas covered ≤1.5% in all watersheds.

Watershed	Land cover						
	Barren[1]	Developed[2]	Forests[3]	Pasture/ Hay	Row crops	Urban/ Recreational grasses	Wetlands[4]
Honey Creek	<1	<1	16.1	19.0	62.4	<1	1.5
Huron River	0	<1	27.8	19.0	50.8	<1	1.2
Lost Creek Trib.	0	0	10.5	20.6	66.6	0	2.3
Ottawa River	<1	8.0	11.8	10.3	65.3	1.8	2.7
River Raisin	<1	1.0	18.3	16.4	56.5	<1	7.1
Rock Creek	0	1.4	21.0	21.1	56.2	0	<1
Sandusky River	<1	<1	17.0	18.2	62.5	<1	1.2
Upper-Auglaize River	0	1.6	12.9	13.5	70.8	<1	<1
Vermilion River	0	<1	38.3	21.9	38.4	0	<1

[1] Aggregates Quarries/Strip Mines/Gravel Pits and Transitional classes

[2] Aggregates Low and High-Intensity Residential, and Commercial/Industrial/Transportation classes

[3] Aggregates Deciduous, Evergreen, and Mixed Forest classes

[4] Aggregates Woody and Emergent Herbaceous Wetlands

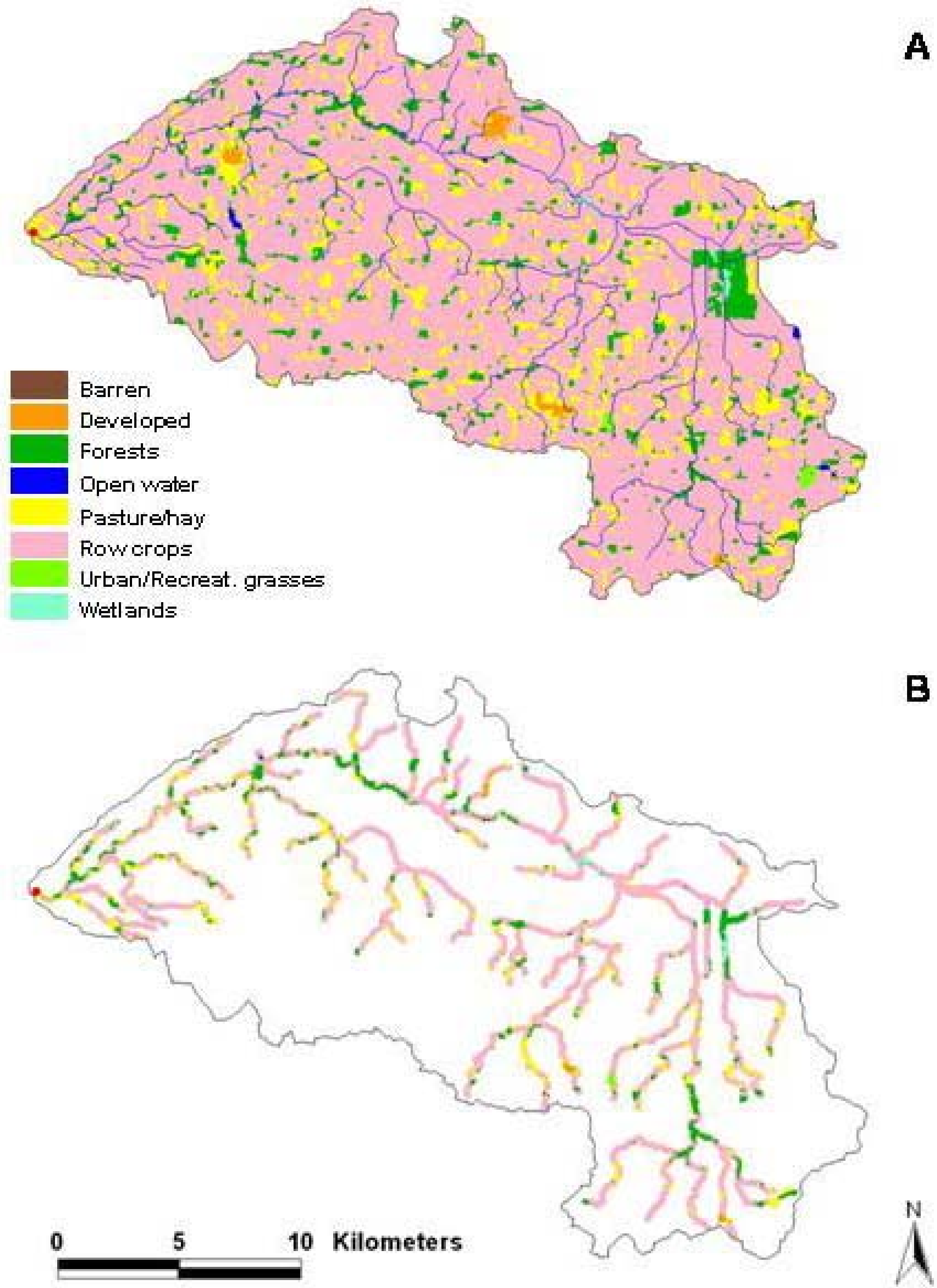

Figure 2. Land cover in Honey Creek watershed (A) and riparian corridor (B).

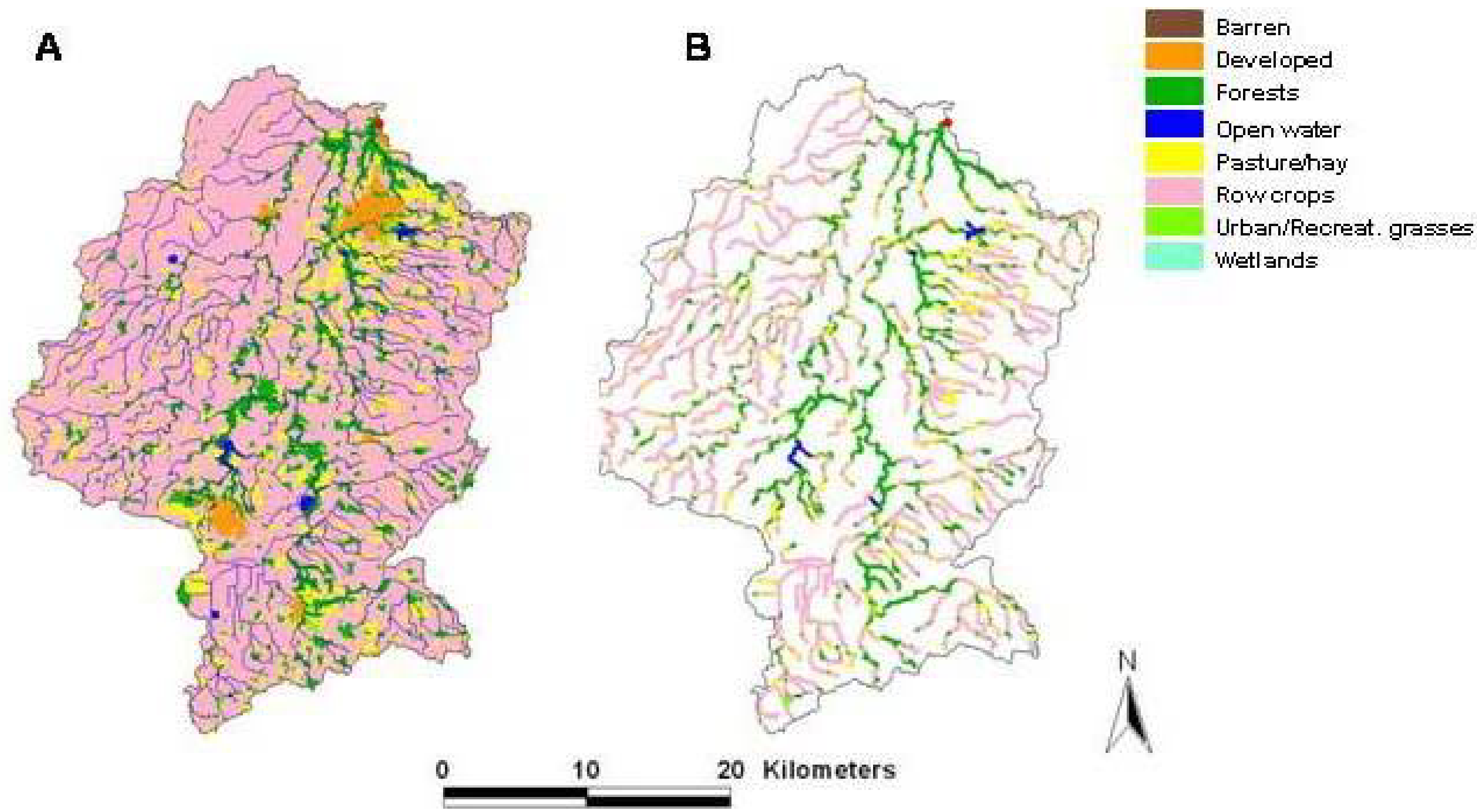

Figure 3. Land cover in Huron River watershed (A) and riparian corridor (B).

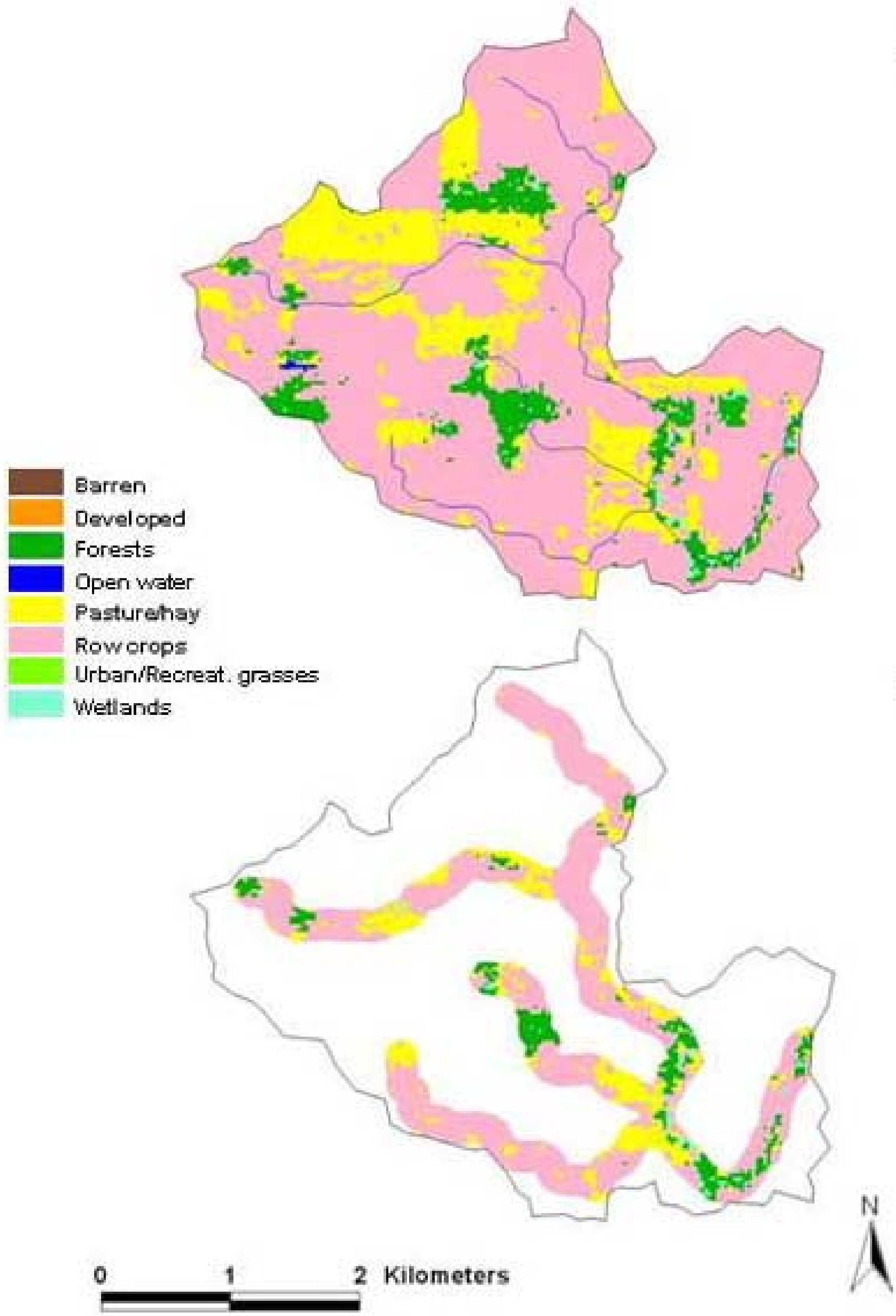

Figure 4. Land cover in Lost Creek tributary watershed (A) and riparian corridor (B).

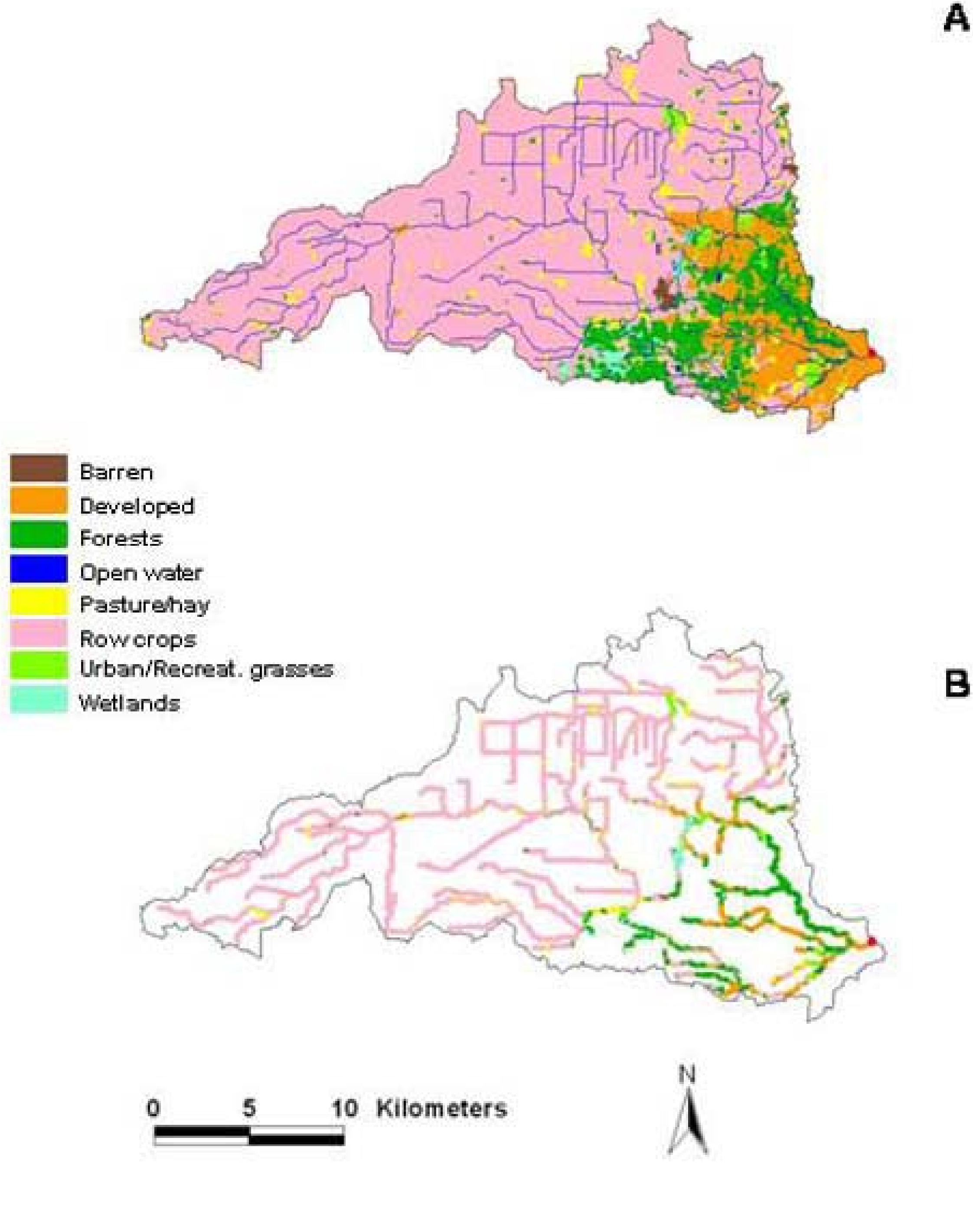

Figure 5. Land cover in Ottawa River watershed (A) and riparian corridor (B).

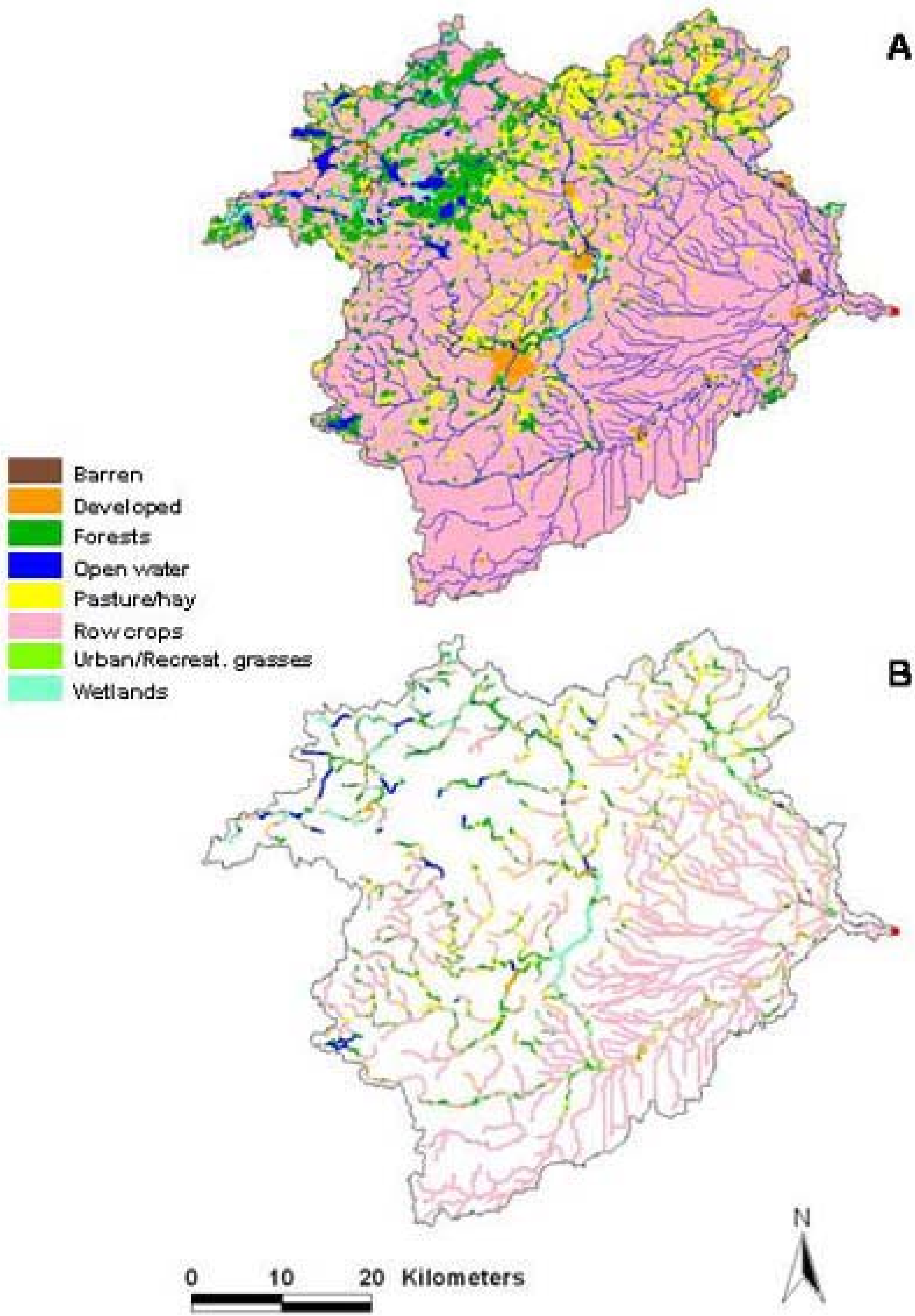

Figure 6. Land cover in River Raisin watershed (A) and riparian corridor (B).

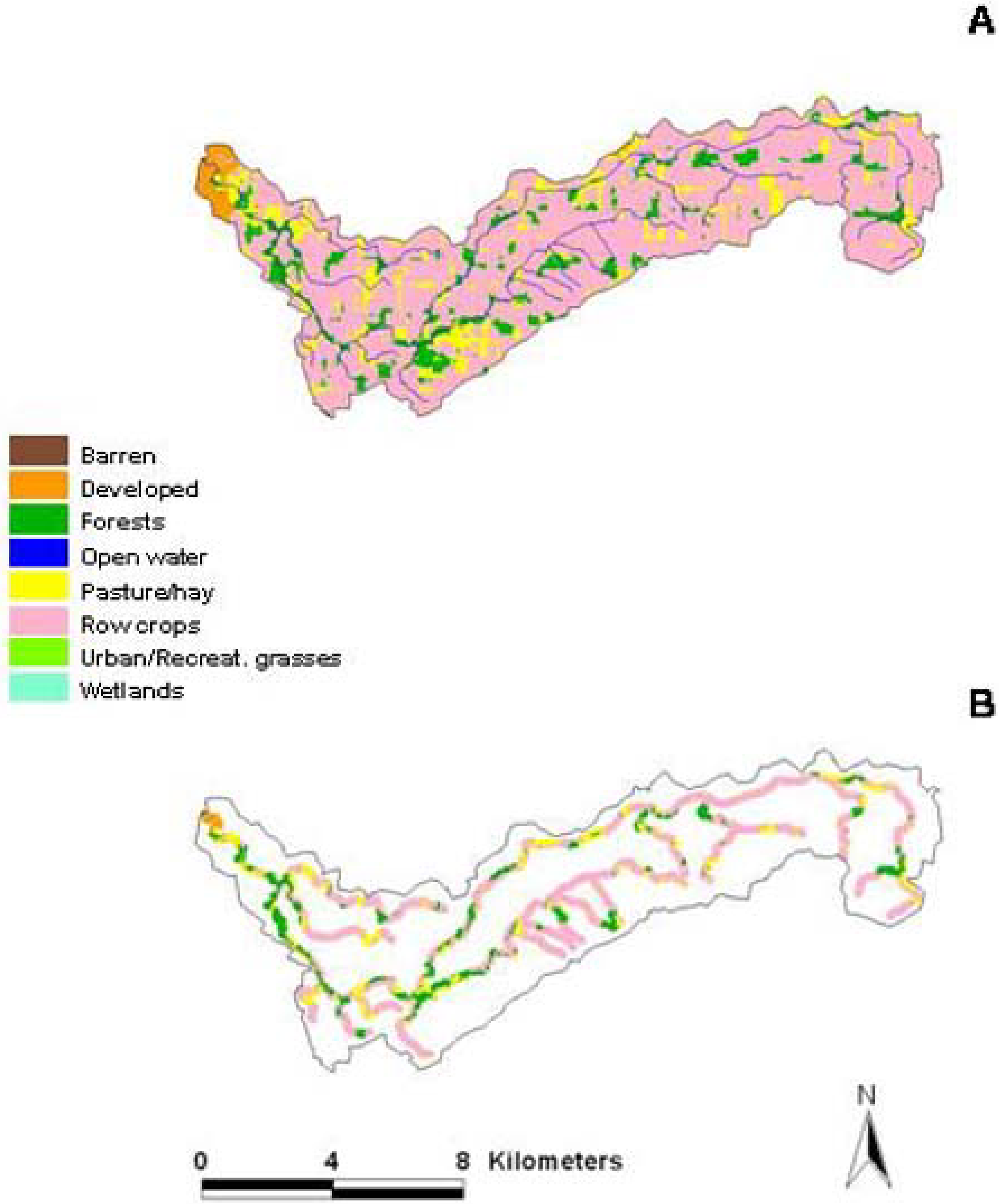

Figure 7. Land cover in Rock Creek watershed (A) and riparian corridor (B).

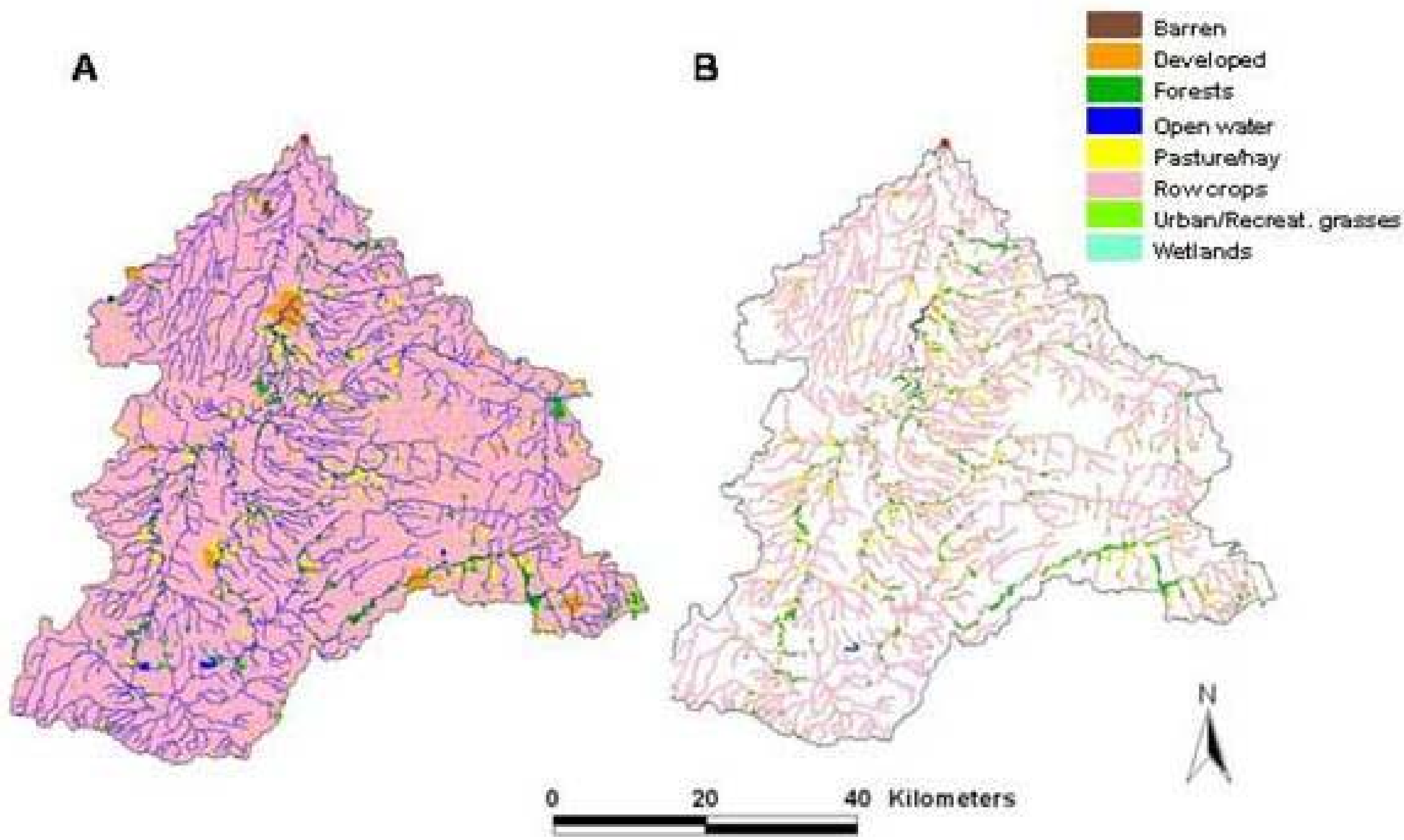

Figure 8. Land cover in Sandusky River watershed (A) and riparian corridor (B).

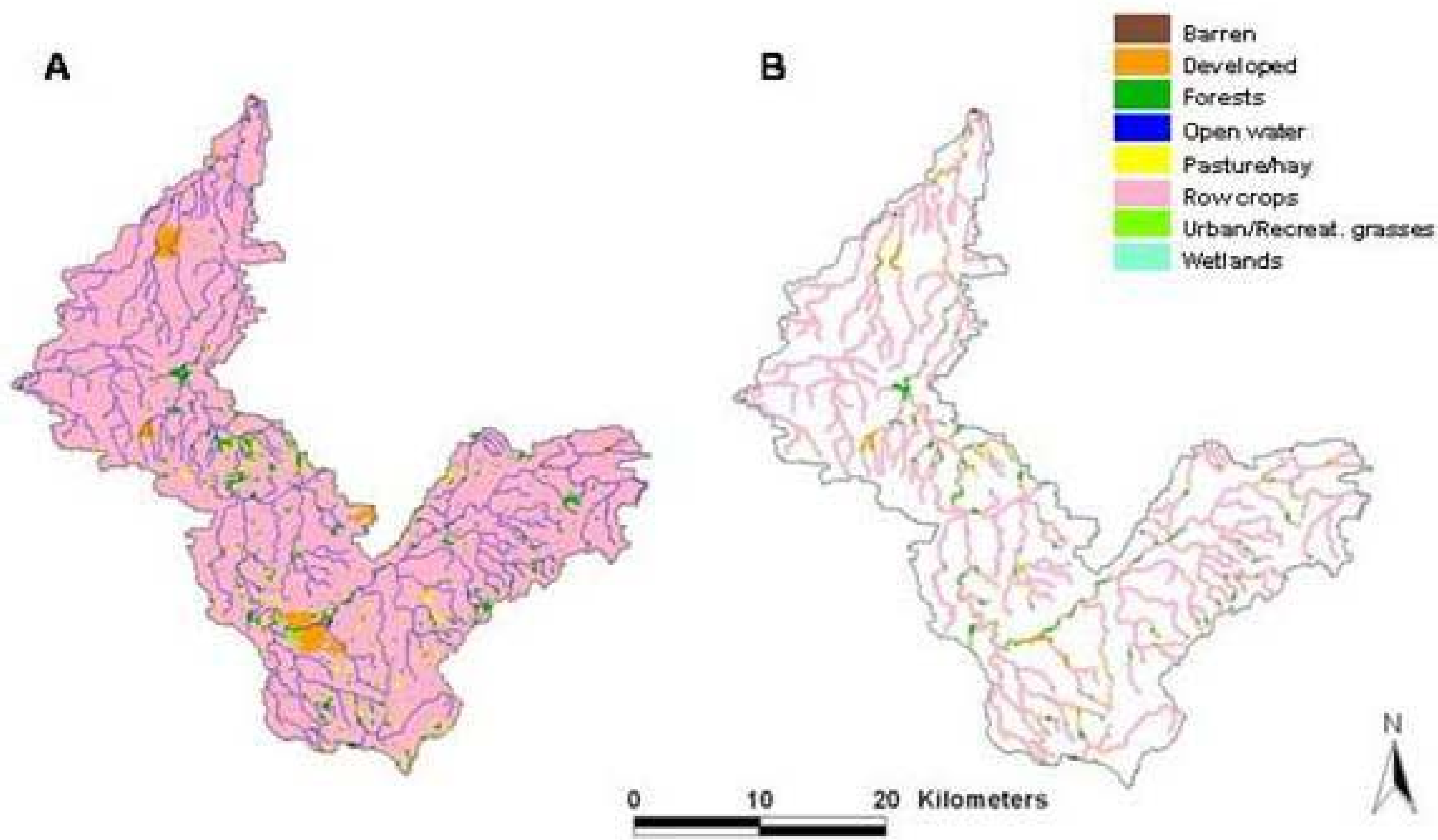

Figure 9. Land cover in Upper-Auglaize River watershed (A) and riparian corridor (B).

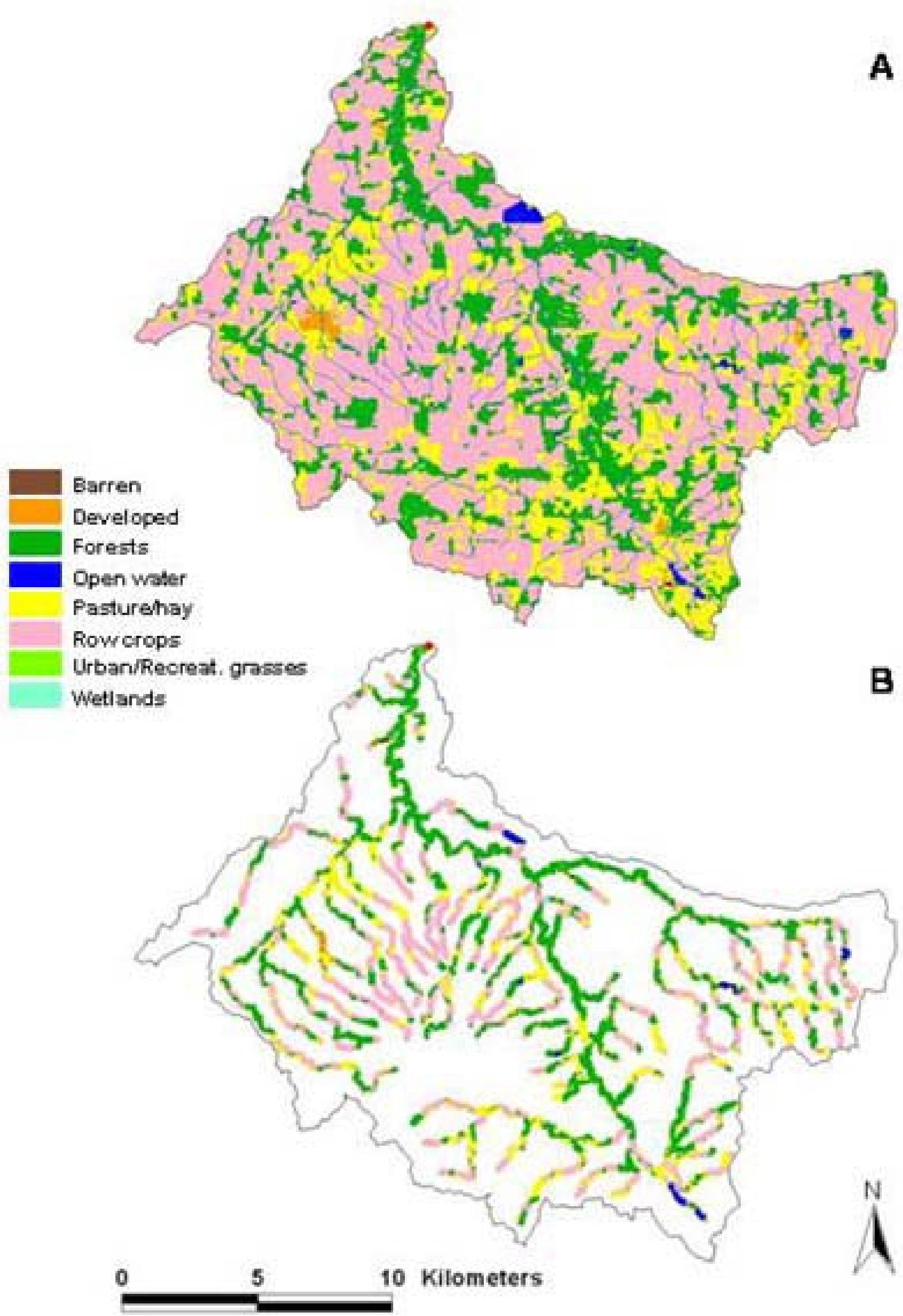

Figure 10. Land cover in Vermillion River watershed (A) and riparian corridor (B).

Sinuosity
Mean stream sinuosity values were significantly ($p<0.0001$) different among watersheds and ranged from 1.18 (Ottawa River) to 1.26 (Lost Creek Trib., River Raisin and Sandusky River) (Table 8). These values suggested that, when taken as a whole, the hydrographic network in the watersheds had low to moderate sinuosity. Straight streams have a 1.0 sinuosity value, while values of ≥ 1.5 represent meandering streams. These results are indicative of the extensive channelization found in regional streams. It should be noted, however, that highly meandering portions do occur in these streams and rivers. This is evidenced in the range of sinuosity values found in some of the watersheds, such as Huron River (3.32), Ottawa River (3.68), Sandusky River (4.07), and River Raisin (5.04).

3.2. Landscape structure of the riparian corridor

Forests landscape structure within the riparian corridor (Table 9) suggested extensive forest fragmentation in most watersheds. Patch densities ranged from about 16 (Lost Creek Trib.) to 33 (River Raisin) patches km^{-2}, although most watersheds had patch densities around 20 patches km^{-2}. Mean patch size varied from 0.5 to 1.6 hectares. Watersheds with smaller mean patch sizes generally had lower patch size standard deviations, while increasingly larger patch size standard deviation values were found in watersheds with progressively larger mean patch sizes. This suggests two things. Watersheds with smaller riparian forest patches may have several similar-sized patches (i.e., more fragmented riparian corridor) (McGarigal and Marks 1995). And, although watersheds with larger riparian forest patches have a generally less fragmented riparian corridor, the broad range of patch sizes (including the presence of small patches) indicates some fragmentation is occurring in portions of such watersheds.

Visual inspections of maps of land cover within riparian corridors (figures 2-B to 10-B) generally supported these interpretations. It seemed that larger riparian forest patches were located in riparian corridors of main channels (i.e., higher order streams) and that lower order tributaries had small or no forest patches. The larger mean riparian forest patches (Table 9) were found within the Huron and Vermillion Rivers and reflected the forest cover concentration adjacent to streams. As seen above, this concentration pattern may result from the underlying geological features that impede the predominantly agricultural land use from encroaching closer to the rivers.

The mean width of riparian forest cover ranged from 12.6 to 45.9 meters in the Lost Creek Trib. and Vermillion River, respectively (Table 9). This indicated a predominance of narrow forest strips relative to the 120-meter wide riparian corridor on each side of streams. Inspection of land cover within riparian corridor maps (Fig. 2-B to 10-B) indicated that this is the case for most watersheds, but that the less impacted watersheds (such as Vermillion River, Fig. 10-B) had wider forest strips in certain segments of larger main channels. This was reflected in the mean forest patch sizes.

Table 6. Topographic characteristics and estimated percent surficial geology for watersheds upstream from gaging stations.

	Topography			Estimated % surficial geology				
Watersheds	SD of Elevation (m)	Mean watershed slope (%)	Mean riparian slope (%)	Glacial till	Glacial outwash sand/ gravel, & postglacial alluvium	Glacio-lacustrine silt/clay	Glacio-lacustrine sand/gravel	Peat
Honey Creek	12.2	1.1	1.6	81.5	3.3	11.5	1.3	2.4
Huron River	33.4	1.8	2.8	83.2	3.2	1.4	10.8	1.1
Lost Creek Trib.	6.9	1.9	2.4	88.2	0	0	11.8	<1
Ottawa River	10.4	0.7	1.2	30.4	0	31.6	38.0	0
River Raisin	36.2	2.5	2.7	44.7	16.3	24.7	14.0	<1
Rock Creek	15.5	1.7	2.2	87.2	0	0	12.8	0
Sandusky River	31.8	1.3	2.0	74.3	3.7	14.1	7.1	<1
Upper-Auglaize Rv.	26.0	1.6	2.0	95.0	4.0	0	0.9	<1
Vermilion River	20.4	2.1	2.9	93.1	5.0	1.4	0	<1

Table 7. Estimated percent total impervious area (%TIA) and percent hydrologic soil groups for watersheds upstream from gaging stations.

		% hydrologic soil group			
Watersheds	%TIA	A	B	C	D
Honey Creek	2.3	0.4	2.5	72.1	24.2
Huron River	2.9	0.2	7.7	70.7	20.8
Lost Creek Trib.	2.2	0.2	3.5	67.4	28.9
Ottawa River	8.6	9.7	11.0	9.3	68.4
River Raisin	5.3	6.8	27.8	29.3	25.8
Rock Creek	2.5	1.9	7.1	60.6	30.4
Sandusky River	2.5	0.6	5.7	59.1	34.3
Upper-Auglaize Rv.	2.6	0.3	2.1	59.3	38.3
Vermilion River	2.6	0	3.1	84.6	11.8

Table 8. Mean stream sinuosity for hydrographic network upstream from gaging stations.

Watershed	Number of segments	Range of segment lengths (m)	Range of sinuosity ratios	Mean sinuosity
Honey Creek	111	149 - 6823	1.00 - 2.22	1.20
Huron River	328	22 - 11334	1.00 - 3.32	1.23
Lost Creek Trib.	7	193 - 2883	1.01 - 1.55	1.26
Ottawa River	156	29 - 8533	1.00 - 3.68	1.18
River Raisin	561	32 - 19984	1.00 - 5.04	1.26
Rock Creek	35	209 - 10832	1.02 - 1.73	1.25
Sandusky River	1009	42 - 15575	1.00 - 4.07	1.26
Upper-Auglaize Rv.	257	55 - 16130	1.00 - 2.04	1.21
Vermilion River	144	77 - 12948	1.00 - 1.90	1.22

Table 9. Landscape structure metrics of forest patches in the riparian corridor.

Watersheds	Mean width (m)	Patch density (#/km^2)	Mean patch size (ha)	Patch size standard deviation
Honey Creek	19.3	20.1	0.8	3.1
Huron River	33.3	19.9	1.4	7.0
Lost Creek Trib.	12.6	15.9	0.7	1.2
Ottawa River	14.1	22.4	0.5	3.2
River Raisin	21.9	33.2	0.5	2.0
Rock Creek	25.2	22.1	0.9	3.5
Sandusky River	20.4	21.0	0.8	3.3
Upper-Auglaize Rv.	15.5	22.2	0.6	2.0
Vermilion River	45.9	23.8	1.6	9.1

Metrics of the riparian landscape structure indicated that the full potential buffering function provided by riparian forests is not being obtained entirely. In addition, the extensive fragmentation or complete deforestation found in headwater reaches is particularly troublesome for water quality in these rivers. Vegetation corridors around headwater and other low-order streams minimize flooding in downstream reaches, can prevent pollution by dissolved constituents through protection of water sources such as springs and seepages, and can minimize erosion (Forman 1995).

3.3. Water Quality

The loads of SS, TP, NO_{23} and TDS were positively correlated with watershed area, and larger watersheds generally had higher loads (Fig. 11). When comparing loads (metric tons/year) to yields (metric tons/km$^{2/}$year), however, certain watersheds with smaller areas had some of the highest yields, suggesting that other landscape characteristics than watershed area were influencing the amount of pollutants being exported from those watersheds. For example, while the largest (Sandusky River) and smallest (Lost Creek Trib.) watersheds had the largest and smallest SS loads, respectively, Lost Creek Trib.'s SS yield was larger than Sandusky River's.

The integrated total annual yields found for SS, TDS, TP, and NO_{23} were comparable to other regional studies (Baker 1993, Myers *et al.* 2000, Baker and Richards 2002) and were generally considered high for most watersheds, reflecting the predominance of row crops cover within these watersheds. The SS total annual yields varied from 18.1 (Vermillion River) to 114.9 (Upper-Auglaize River) metric tons km^{-2} year^{-1} (Fig. 11-A). Total dissolved solids total annual yields ranged from 94.6 (Honey Creek) to 137.5 (Huron River) metric tons km^{-2} year^{-1}, (Figure 11-B). The total annual yields for TP ranged from 0.05 (River Raisin) to 0.21 (Lost Creek Trib.) metric tons km^{-2} year^{-1} (Figure 11-C). And the NO_{23} total annual yields varied from 1.4 (Rock Creek) to 8.6 (Upper-Auglaize River) metric tons km^{-2} year^{-1} (Figure 11-D).

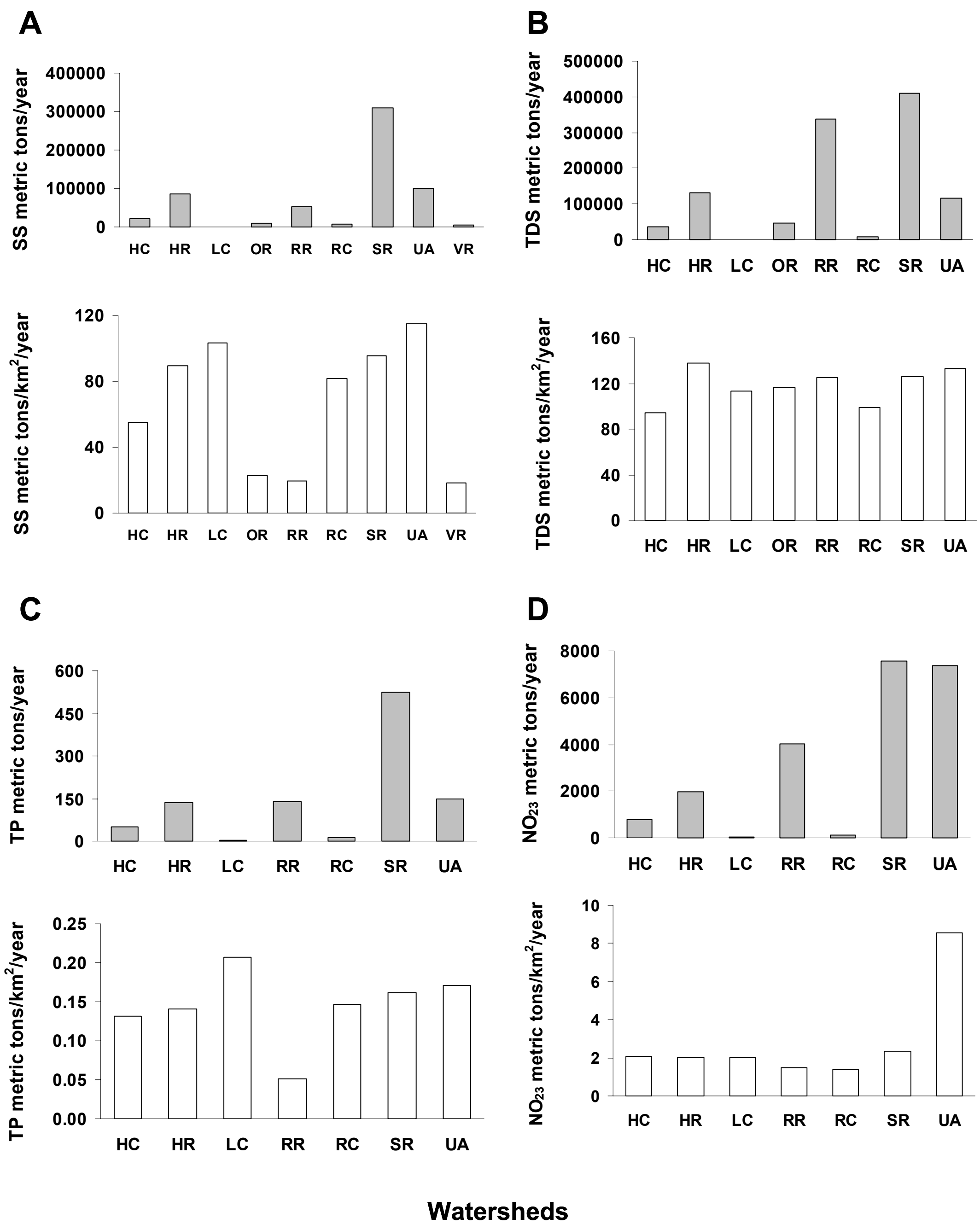

Figure 11. Comparison of loads and yields for SS (A), TDS (B), TP (C), and NO23 (D). Number of watersheds vary per parameter. Watershed names are abbreviated: Honey Creek (HC), Huron River (HR), Lost Creek Trib. (LC), Ottawa River (OR), River Raisin (RR), Rock Creek (RC), Sandusky River (SR), Upper-Auglaize River (UA), and Vermillion River (VR).

3.4. Landscape structure and water quality relationships

Water quality correlations with proportions of non-riparian land cover

Proportions of selected land cover types in the non-riparian portions of watersheds were correlated with SS and TP total annual yields. Non-parametric Spearman Rank correlations show that SS and TP annual yields were significantly positively correlated with % RowCrops within the non-riparian portions of watersheds (Table 10.A), while NO_{23} annual yield showed a weak positive correlation with this land cover class. Conversely, SS, TP, and NO_{23} annual yields were negatively correlated with all different natural vegetation cover classes within the non-riparian areas. There was a significant negative correlation between SS and forests, wetlands, woody vegetation, and all natural vegetation combined. With the exception of wetlands, this was also the case for TP yields, while NO_{23} yields showed weaker non-significant correlations. Interestingly, these three water quality parameters were negatively correlated with the amount of pasture/hay. Although this is an agricultural land cover, such finding indicates that pasture/hay is retaining NO_{23} within the landscape.

Total annual yields of total dissolve solids (Table 10.A) were weakly negatively correlated with the amount of pasture/hay and wetlands, and positively correlated with developed land cover in the non-riparian areas of watersheds. This suggests developed areas are a source and wetlands are a sink of dissolved solids. And interestingly, pasture/hay cover is also functioning as a sink for such dissolved solids.

Similar trends were found between SS, TP, NO_{23}, and TDS seasonal (spring+summer) yields and non-riparian % land cover (Table 10.B). The Spearman Rank correlation values calculated for this seasonal time period were generally slightly higher than those computed using total annual yields. Noteworthy were the stronger negative correlations between wetlands cover and TP and NO_{23} seasonal yields. This suggests that during this growth season wetlands have a higher retention of these nutrients.

Water quality correlations with riparian landscape metrics

Significant Spearman Rank correlations between total annual (Table 11), and total seasonal (Table 12) yields for the water quality parameters analyzed and landscape metrics in the riparian corridor were only encountered at the $p \leq 0.1$ level. Among the total annual yields computed (Table 11), SS was negatively correlated with the proportion of woody vegetation, the proportion of all natural vegetation types combined, the mean width of these two cover classes, and the density of forest patches. Conversely, SS was positively correlated with the amount of row crops. Total phosphorus was negatively correlated with the proportions of forests, woody vegetation, all natural vegetation combined, as well as with the mean width of these three cover classes. Positive correlations for TP were found with the proportion of row crops. While nitrate+nitrite was also positively correlated with the amount of row crops, it was negatively correlated with the percentage of pasture and hay in the riparian corridor. Here, the latter agricultural land cover may function as planted riparian buffer strip and, as such, may limit the export of NO_{23} from the land into streams.

Among the total seasonal yields (Table 12), significant ($p \leq 0.1$) relationships were found between SS and the same landscape metrics as for the annual yields. This was also generally the case for TP, except for the correlations with proportion of forests and the forest mean width. For nitrate+nitrite, there were no significant ($p \leq 0.1$) correlations with any landscape structure metric. Total dissolve solids, on the other hand, showed a negative correlation with the amount of pasture and hay.

Table 10. Spearman rank correlations between proportions of land uses in the non-riparian (NR) area of watersheds and water quality parameter total annual (A) and total seasonal (spring+summer) (B) yields (metric tons km^{-2} year^{-1}).

A	Total annual yields							
	Suspended Sediments		Total phosphorus		Nitrate+nitrite		Total dissolved solids	
Landscape metric	Correlation	p-value	Correlation	p-value	Correlation	p-value	Correlation	p-value
% NR_Past/Hay	- 0.33	0.345	- 0.21	0.599	- 0.46	0.255	- 0.40	0.284
% NR_RowCrops	0.87	0.014**	0.79	0.054**	0.75	0.066*	0.00	1.000
% NR_Developed	- 0.07	0.850	- 0.25	0.540	- 0.14	0.726	0.38	0.313
% NR_Forests	- 0.88	0.013**	- 0.86	0.035**	- 0.64	0.115*	0.07	0.850
% NR_Wetlands	- 0.80	0.028**	- 0.50	0.220	- 0.39	0.335	- 0.48	0.207
% NR_WoodyVeg	- 0.92	0.010***	- 0.79	0.054**	- 0.75	0.066*	- 0.10	0.801
% NR_NatVeg	- 0.92	0.010***	- 0.79	0.054**	- 0.75	0.066*	- 0.10	0.801
B	**Total seasonal (spring+summer) yields**							
% NR_Past/Hay	- 0.35	0.322	- 0.39	0.336	- 0.68	0.097*	- 0.60	0.115*
% NR_RowCrops	0.90	0.011***	0.82	0.044**	0.75	0.066*	0.07	0.850
% NR_Developed	- 0.08	0.814	- 0.07	0.861	0.11	0.793	0.48	0.207
% NR_Forests	- 0.92	0.010***	- 0.86	0.036**	- 0.61	0.137*	0.05	0.899
% NR_Wetlands	- 0.78	0.027**	- 0.68	0.097*	- 0.61	0.137*	- 0.52	0.166
% NR_WoodyVeg	- 0.93	0.008***	- 0.82	0.044**	- 0.75	0.066*	- 0.14	0.705
% NR_NatVeg	- 0.93	0.008***	- 0.82	0.044**	- 0.75	0.066*	- 0.14	0.705

(*) significant at p=0.10, (**) significant at p=0.05, (***) significant at p=0.01

Table 11. Spearman rank correlations between selected riparian (R) landscape metrics (e.g., % landcover, mean width or MW, and patch density or PD) and water quality parameter total annual yields (metric tons km^{-2} year^{-1}).

	Suspended Sediments		Total phosphorus		Nitrate+nitrite		Total dissolved solids	
Landscape metric	Correlation	p-value	Correlation	p-value	Correlation	p-value	Correlation	p-value
% R_Past/Hay	- 0.18	0.604	0.11	0.793	- 0.61	0.137*	- 0.52	0.166
% R_RowCrops	0.65	0.066*	0.68	0.096*	0.61	0.137*	0.00	1.000
% R_Developed	0.02	0.962	- 0.11	0.793	0.00	1.000	0.26	0.488
% R_Forests	- 0.48	0.171	- 0.61	0.137*	- 0.43	0.293	0.29	0.449
% R_Wetlands	- 0.30	0.396	- 0.29	0.484	- 0.14	0.726	- 0.17	0.659
% R_WoodyVeg	- 0.63	0.073*	- 0.71	0.080*	- 0.39	0.335	0.29	0.449
% R_NatVeg	- 0.63	0.073*	- 0.71	0.080*	- 0.39	0.335	0.29	0.449
MW_For	- 0.48	0.171	- 0.61	0.137*	- 0.43	0.293	0.29	0.449
MW_Wetl	- 0.30	0.396	- 0.29	0.484	- 0.14	0.726	- 0.17	0.659
MW_WoodyVeg	- 0.63	0.073*	- 0.71	0.080*	- 0.39	0.335	0.29	0.449
MW_NatVeg	- 0.63	0.073*	- 0.71	0.080*	- 0.39	0.335	0.29	0.449
PD_R_Forests	- 0.65	0.066*	- 0.36	0.381	- 0.04	0.930	0.10	0.801
PD_R_ WoodyVeg	- 0.43	0.220	- 0.39	0.336	- 0.29	0.484	0.31	0.412

(*) significant at p=0.10

Table 12. Spearman rank correlations between selected riparian zone corridor landscape metrics and water quality parameter total seasonal (spring+summer) yields (metric tons km^{-2} year^{-1}).

Riparian landscape metric	Suspended Sediments		Total phosphorus		Nitrate+nitrite		Total dissolved solids	
	Correlation	p-value	Correlation	p-value	Correlation	p-value	Correlation	p-value
% R_Past/Hay	- 0.13	0.706	- 0.18	0.662	- 0.39	0.335	- 0.60	0.115*
% R_RowCrops	0.67	0.059*	0.68	0.096*	0.43	0.293	- 0.02	0.949
% R_Developed	0.05	0.887	0.04	0.930	0.21	0.599	0.48	0.207
% R_Forests	- 0.50	0.157	- 0.54	0.189	- 0.21	0.599	0.38	0.314
% R_Wetlands	- 0.35	0.322	- 0.36	0.381	- 0.54	0.189	- 0.33	0.378
% R_WoodyVeg	- 0.67	0.059*	- 0.61	0.137*	- 0.29	0.484	0.33	0.378
% R_NatVeg	- 0.67	0.059*	- 0.61	0.137*	- 0.29	0.484	0.33	0.378
MW_For	- 0.50	0.157	- 0.54	0.189	- 0.21	0.599	0.38	0.314
MW_Wetl	- 0.35	0.322	- 0.36	0.381	- 0.54	0.189	- 0.33	0.378
MW_WoodyVeg	- 0.67	0.059*	- 0.61	0.137*	- 0.29	0.484	0.33	0.378
MW_NatVeg	- 0.67	0.059*	- 0.61	0.137*	- 0.29	0.484	0.33	0.378
PD_R_Forests	- 0.60	0.089*	- 0.29	0.484	0.04	0.930	0.33	0.378
PD_R_ WoodyVeg	- 0.38	0.278	- 0.36	0.381	- 0.14	0.726	0.52	0.166

(*) significant at p=0.10

Comparison between water quality correlations with combined natural cover types and forest cover alone

Landscape metrics computed for combined natural cover types generally had stronger correlations with water quality than forest cover alone. Although Spearman Rank correlations with riparian metrics were not significant at the $p<0.05$ level, when compared to forest metrics the combined natural cover metrics for the riparian corridor (i.e., R_WoodyVeg and R_NatVeg) had stronger correlations with SS and TP total annual yields (Table 11) and with the SS, TP, and NO_{23} total seasonal yields (Table 12) than individual metrics alone. This was not the case for NO_{23} total annual yields (Table 11), however, which showed a stronger correlation with riparian forest cover. Within the non-riparian portions of watersheds, combined natural cover metrics had stronger correlations with SS and NO_{23} annual (Table 11.A) and seasonal yields (Table 11.B) than did forest cover alone. For TP, however, forest cover had a stronger correlation than the combined natural cover metrics.

The most effective predictors for water quality benefits

Multiple regression models generally explained a large portion of the variability in the water quality parameter yields. And in most cases, this variability was explained by landscape metrics computed for the non-riparian portions of watersheds or within the entire watersheds. When all types of landscape factors (i.e., the overall best model) were considered, 89% of SS annual yields (Table 13) were explained by the non-riparian natural vegetation cover and the percentage of glacio-lacustrine silts and clays in the watersheds. The standardized partial regression coefficients (i.e., β-weights) indicated that the natural vegetation cover accounted for almost double the variability than the silts and clays. When only landscape factors subject to management (i.e., landscape variables that can be manipulated or controlled by managers) were considered in the best applied-model, 86% in annual SS was explained by the amounts of non-riparian wetland cover and of riparian row crops cover. Here, the non-riparian wetland cover explained about twice the variability than did riparian row crops.

Eighty eight percent of variation in seasonal SS yields (Table 13) was explained by the amount of row crops in non-riparian areas and the percentage of total impervious area, with the non-riparian row crops explaining a larger portion of the variability. Among the variables with management application, only non-riparian row crops accounted for 72% of such seasonal variability.

The natural vegetation cover in non-riparian areas accounted for about 80% and 88% of annual and seasonal TP yields, respectively. TP was negatively correlated with natural vegetation cover and assessment of the best-applied annual and seasonal models resulted in the same results (Table 13). This suggests the natural vegetation located in non-riparian areas is the overriding factor affecting TP loading into streams. This may be because the higher amount of natural areas (forests and wetlands) may restrict erosion, resulting in less phosphorus in the particulate form being transported into streams while adsorbed to sediment particles (Horne and Goldman 1994). In addition, phosphorus in the dissolved phase may also be retained/transformed by forest vegetation and wetlands (Mitsch and Gosselink 2000).

For NO_{23} annual yields (Table 14), the amount of pasture/hay cover in the riparian corridor and the percentage of hydrologic soil group B within watersheds accounted for about 91% of the variability, with riparian pasture/hay having a higher explanatory power. When only landscape factors with management application were considered, riparian pasture/hay cover and the amount of row crops in the entire watershed (riparian + non-riparian areas) explained 88% of NO_{23} annual yields; both variables explained a similar proportion of this variability. For seasonal NO_{23} yields, the amount of pasture/hay in non-riparian areas was the only variable selected for both the overall and applied models, accounting for 75% of the variability for this water quality parameter.

Estimated TDS total annual yields (Table 14) were positively correlated with and best explained by topographic heterogeneity within watersheds (measured as the standard deviation of elevation in meters). This landscape parameter, however, only accounted for about 52% of the variability, suggesting other factors may also be affecting the dissolved constituents throughout the year.

About 94% of the variability in seasonal estimated TDS yields (Table 14) was accounted for by riparian pasture/hay cover and the % total impervious area and topographic heterogeneity within watersheds. TDS was positively correlated with topographic heterogeneity and negatively correlated with riparian pasture/hay cover and the percentage of total impervious area. While an increase in pasture/hay cover in the riparian corridor during the growth season intuitively would cause a decrease in the amount of dissolved solids, such inverse relationship was not expected with the percentage of total impervious area. Based on the positive correlations between TDS and percentage of developed area (Tables 10, 11, 12), one would expect an increase in impervious area to result in an increase in TDS yield. These results suggest several possible explanations. Other unknown factors associated with land cover types may be influencing this relationship. The procedure for estimating total impervious area from land cover types may be introducing some error. Or the %TIA is so small in these watersheds that any positive or negative relationships found between this variable and TDS yield is spurious.

Different explanatory variables were selected for the annual and seasonal multiple regression models for SS, NO_{23}, and TDS, suggesting seasonal variations in these water quality parameters are influenced by different landscape factors at different times of the year. When all landscape factors were considered in the overall model, SS and NO_{23} annual yields were determined by land cover and watershed edaphic or geologic factors, but their seasonal yields were better explained by land cover variables or percent total impervious area (which is derived from land cover data). On the other hand, TDS annual yields were better explained by watershed topography (i.e., standard deviation of elevation), while its seasonal yields were better explained by topography and land cover factors. For TP, however, both annual and seasonal yields were better explained by the same land cover factor (percentage of non-riparian natural vegetation), indicating that the amount of non-riparian natural vegetation is an important factor influencing TP loading both on an annual basis and during the growth season (spring + summer). Seasonal differences in the influences of landscape variables on water quality were also reported in other studies (e.g., Johnson *et al.* 1997, Tufford *et al.* 1998, Sliva and Williams 2001), and reflect processes such as climatic events and vegetation cover changes (natural or anthropogenic) occurring in terrestrial portions of watersheds (Brooks *et al.*1997, Moldan and Cerny 1994 *in* Sliva and Williams 2001).

Table 13. Multiple regression models of landscape metrics that best predict total annual and seasonal (spring + summer) suspended sediments (SS) and total phosphorus (TP) yields (metric tons km^{-2} $year^{-1}$). Both the overall best model and the model with best applied management value (see Methods for explanation) are presented. The standardized partial regression coefficients (i.e., β-weights) are presented for each predictor variable in models with more than one term.

	Regression model	R^2	β-weights
SS, annual			
Overall model	SS_{annual} = -5.601 - 918.672 (-1/NR_NatVeg) - 6.880 SQRT(lac_silt/clay)	89.1	-1/NR_NatVeg: 0.73 SQRT(lac_silt/clay): 0.40
Applied model	SS_{annual} = 14.298 + 1.525 R_RowCrops - 40.998 NR_Wetlands	85.9	R_RowCrops: 0.39 NR_Wetlands: 0.79
SS, seasonal			
Overall model	SS_{Sp+Su} = -146.188 + 2.219 NR_RowCrops - 72.707 (-1/pctTIA)	88.3	NR_RowCrops: 0.72 -1/pctTIA: 0.42
Applied model	SS_{Sp+Su} = -149.190 + 2.634 NR_RowCrops	72.8	--
TP, annual			
Overall model	TP_{annual} = 0.289 - 0.014 NR_NatVeg	80.5	--
Applied model	Same as overall model above		--
TP, seasonal			
Overall model	SS_{Sp+Su} = 0.134 - 0.007 NR_NatVeg	87.8	--
Applied model	Same as overall model above		--

Table 14. Multiple regression models of landscape metrics that best predict total annual and seasonal (spring + summer) nitrate+nitrite (NO_{23}) and total dissolved solids (TDS) yields (metric tons km^{-2} $year^{-1}$). Both the overall best model and the model with best applied management value (see Methods for explanation) are presented. The standardized partial regression coefficients (i.e., β-weights) are presented for each predictor variable in models with more than one term.

	Regression model	R^2	β-weights	
NO_{23}, annual				
Overall model	$NO_{23annual}$ = 20.051 - 0.877 R_Past/Hay - 0.151 Soil_B	91.4	R_Past/Hay: Soil_B:	0.90 0.53
Applied model	$NO_{23annual}$ = -5.269 + 0.272 B_RowCrops - 0.571 R_Past/Hay	88.0	B_RowCrops: R_Past/Hay:	0.53 0.59
NO_{23}, seasonal				
Overall model	$NO_{23Sp+Su}$ = 9.904 - 0.477 NR_Past_Hay	75.0	--	
Applied model	Same as overall model above		--	
TDS, annual				
Overall model	TDS_{annual} = 97.596 + 0.958 SD_Elevation	51.5	--	
Applied model	No significant model was found using only metrics that can be managed.		--	
TDS, seasonal				
Overall model	TDS_{Sp+Su} = 97.936 - 2.693 R_Past/Hay - 3.260 PctTIA + 0.459 SD_elevation	93.8	R_Past/Hay: PctTIA: SD_elevation:	1.10 0.81 0.59
Applied model	No significant model was found using only metrics that can be managed.			

Although water quality was generally better explained by landscape factors in the non-riparian portions of watersheds or within the entire watersheds, this study showed some mixed results regarding the spatial scale at which landscape factors are better predictors of water quality in streams. Such findings correspond with some conflicting results found in other studies. Hunsacker and Levine (1995) found that landscape metrics computed for entire watersheds were better predictors of water quality that metrics computed within 200 or 400-meter riparian corridors. In addition, Sliva and Williams (2001) found slightly better correlations between water quality and watershed-scale landscape than with riparian buffer landscape. Conversely, Tufford *et al.* (1998) reported stronger relationships between water quality and proportions of land cover closer to streams. And Johnson *et al.* (1997) found that landscape factors quantified within a 100-m riparian corridor better predicted most water quality parameters when compared to those for whole watersheds.

The development of the best overall and best applied models in this region served two basic and complementary management purposes. The best overall model took into consideration landscape structure metrics derived both from land cover and other watershed characteristics. It provided information about land cover factors that can be managed but which influence is combined with other watershed landscape features such as soils and topography. Data pertaining to such landscape parameters may be used in a GIS to identify other areas or watersheds with similar landscape settings and that may be similarly degraded in terms of water quality. This would allow managers to prioritize field assessments or monitoring efforts. The best applied model, on the other hand, only included landscape metrics derived from land cover, which are the main parameters that can be changed by managers. This identified potential landscape structure factors to be targeted with management for water quality improvement.

This study's results suggested that riparian buffering function is not fully benefiting water quality in the watersheds investigated. The results of the analysis of riparian forest landscape structure and the visual examination of land cover maps demonstrated extensive fragmentation or complete lack of natural vegetation cover along portions of streams and rivers, particularly in upper-reaches of the watersheds. Such interpretation is also consistent with the ineffectiveness of the amount of forest cover and combined natural cover types in the riparian corridor in predicting water quality yields, as demonstrated by the correlation and multiple regression results. This unrealized buffering potential is further suggested by the NO_{23} general and best-applied multiple regression models (Table 14). Here, the amount of pasture/hay, which is essentially acting as a planted buffer strip, contributed significantly to explaining the variability of this water quality parameter. Osborne and Wiley (1988) found a similar situation for an agricultural watershed. Using ratios of different land covers as explanatory variables in multiple regression models, they considered a lack of importance of the ratio of forest to agriculture towards explaining soluble reactive phosphorus (SRP) and Nitrate-N to be surprising, as most of the forest cover was located next to streams in lower portions of a watershed. These authors attributed this result to two possible factors – the restriction of forest cover to the lower portion of the watershed, and urbanization as an overriding influence on SRP concentrations. Another factor, however, may be contributing to the low riparian buffering. There is an extensive system of tile drainage pipes in these watersheds used to drain the predominantly-hydric soils for agricultural purposes. Although not well-quantified, such drainage transports waters laden with pollutants directly into the streams, largely bypassing the riparian vegetation.

The percentage in the variability in water quality yields explained by the multiple regression models varied from about 52% to 94% among the selected water quality parameters. Several factors may account for the unexplained variability found among the models. For example, this may be due to error introduced with the methods used to compute water quality parameter yields or used to estimate some landscape parameters. It may be due to the potential influence of drainage tiles used in the region or due to the contributions of point-source pollution. In addition, there may be impacts on water quality from other landscape factors that were not analyzed. Finally, the resolution of the land cover data may be too coarse to capture some variation in land cover that is relevant for water quality.

4- Conclusions

Landscape structure metrics for forests or combined natural cover types in the riparian corridor are not effective indicators of water quality in the streams and rivers in our nine watershed study area. The only riparian corridor metrics that contribute to explaining water quality variability are proportions of agricultural land cover types. Conversely, proportions of land cover in non-riparian areas and other landscape factors within entire watersheds (e.g., soils, topography, impervious surfaces) are generally better indicators of water quality than metrics of riparian landscape structure.

These findings do not imply that conservation buffer programs are ineffective. Our correlation results do indicate that increased natural vegetation cover in the riparian corridors reduces the loading of pollutants into streams. The amount of pollutants generated by the land use practices in the upland areas, however, seems to overwhelm the buffering capacity of existing natural riparian vegetation. This is further aggravated by the fact that land around several low-order streams is devoid of natural riparian vegetation cover, where such headwaters areas are crucial for water quality in watersheds. On the other hand, the multiple regression results indicate that increased cover of managed vegetation such as pasture and hay reduces the loading of NO_{23}.

This study's results suggest that, given the lack of riparian natural vegetation and intensive agricultural use in the watersheds investigated, the reduction of the amount of pollutants in streams and rivers will initially depend primarily on improving land management practices in non-riparian portions of those watersheds. The results also indicate, however, that an increase of vegetation cover in the riparian areas may contribute to further mitigate the pollutant loading into streams. This vegetation includes both natural or non-row crop managed types such as pasture and hay.

While the buffering function of vegetation has been determined through *in situ* studies, when the riparian area is considered as a whole along the entire drainage network contributing to a specific point (i.e., water quality sampling station), the potential influence of the non-vegetated riparian areas becomes apparent. Future investigations focusing on the influences from these non-vegetated riparian areas would be relevant for our understanding of the landscape-level factors affecting water quality and for management efforts aiming at improving conditions in streams. For example, how much increase in riparian vegetation cover (natural or artificially planted) would be necessary to increase the riparian corridor's buffering efficiency to significant levels? In addition, at which stream order would such an increase of riparian vegetation be most relevant? We suggest initially testing the influence of changes in riparian vegetation cover along low-order streams, considering the importance of headwaters for water quality in downstream reaches.

Although landscape structure metrics computed for forests or combined natural cover types in the riparian corridor are inadequate indicators of water quality, the results of this study suggest that some selected landscape metrics may serve as substitutes to traditional chemical and biological monitoring techniques for water quality. For our predominantly agricultural watersheds, such metrics include the proportion of natural vegetation cover or the proportion of row crop agriculture in the non-riparian areas of watersheds for suspended sediments. The proportion of natural vegetation cover is a relevant landscape metric for total phosphorus and the proportion of row crops within the entire watershed or the proportion of pasture/hay within the non-riparian areas serves that purpose for nitrate+nitrite. Our results also demonstrate that agricultural land cover classes within riparian corridors may serve as indicators of water quality (e.g., pasture/hay for nitrate+nitrite). The presence of such land cover classes in riparian areas, however, reflects their prevalence throughout those watersheds. As such, their use as indicators may only be appropriate for those watersheds with extensive agricultural areas. On the other hand, our multiple regression models indicate that relationships between water quality and some landscape structure metrics may be mediated by other watershed characteristics such as soil types and their hydrological functions or topographic factors. Further studies are necessary to assess if the relevant landscape metrics identified above also serve as indicators in other watersheds or if our findings are an artifact of site-specific characteristics.

5- References

APHA (American Public Health Association), AWWA (American Water Works Association), WEF (Water Environment Federation) 1992. Standard Methods or the Examination of Water and Wastewater. 18Th Edition. pp: 2-43 - 2-45

Baker, D.B. 1993. The Lake Erie Agroecosystem Program: water quality assessments. Agriculture, Ecosystems and Environment 46: 197-215

Baker, D.B., Richards, R.P. 2002. Phosphorus Budgets and Riverine Phosphorus Export in Northwestern Ohio Watersheds. J. Environ. Qual. 31:96-108

Benedict, M. Undated. Riparian forests in NW Ohio watersheds: relations between landscape structure, land use/land cover, and water quality in streams. Ongoing dissertation. University of Toledo, Toledo, Ohio.

Brooks, K.N., Ffolliott, P.F., Gregersen, H.M., DeBano, L.F. 1997. Hydrology and the Management of Watersheds. Second edition. Iowa State University Press, Ames, Iowa, 502 pp.

Caraco, D., Claytor, R. Hinkel, P., Kwon, H.Y., Schueler, T. Swann, C. Vysotsky, S. Zielinske, J. 1998. Rapid Watershed Planning Handbook. Center for Watershed Protection. Ellicott City Maryland.

Castelle, A.J., Johnson, A.W., Conolly, C. 1994. Wetland and stream buffer requirements - A review. Journal of Environmental Quality 23:878-882.

Clark, G.M., Mueller, D.K., Mast, M.A. 2000. Nutrient concentrations and yields in undeveloped stream basins of the United States. Journal of the American Water Resources Association 36(4): 849-860.

Cohn, T.A., DeLong, L.L., Gilroy, E.J., Hirsh, R.M., Wells, D.K. 1989. Estimating constituent loads. Water Resources Research 25(5): 937-942

Décamps, H. 1993. River margins and environmental change. Ecological Applications 3(3): 441-445.

Duan, N. 1983. Smearing estimate – a nonparametric retransformation method. Journal of the American Statistical Association, 78(383), p:605-610.

Evans, J.K., Gottgens, J.F., Gill, W.M., Mackey, S.D. 2000. Sediment Yields Controlled by Intrabasinal Storage and Sediment Conveyance over the Interval 1842-1994: Chagrin River, Northeast Ohio, USA. Journal of Soil and Water Conservation 55(3): 264-270.

Farrand, W.R. 1982. Quaternary Geology of Southern Michigan. Michigan Department of Natural Resources, Geological Publication QG-01, 1:500,000-scale map.

Forman, R. T. T. 1995. Land Mosaics. The ecology of landscapes and regions. Cambridge University Press, Cambridge, UK. 632 pp.

Fullerton, D.S., Bush, C.A., and Pennell, J.N. 2003. Map of Surficial Deposits & Materials in the Eastern & Central US (East of 102˚ West Longitude), United States Geological Survey-USGS

Gergel, S.E., Turner, M.G., Miller, J.R., Melack, J.M., Stanley,. E.H. 2002. Landscape indicators of human impacts to riverine systems. Aquatic Sciences 64:18-128.

Gordon, N.D., McMahon, T.A., Finlayson, B.L. 1992. Stream Hydrology: An Introduction for Ecologists. John Wiley and Sons. New York, NY. 526 pp.

Helsel, D.R., Hirsh, R.M. 2002. Statistical Methods in Water Resources. U.S. Geological Survey. 510 pp.

Horne, A.J., Goldman, C.R. 1994. Limnology. Second edition McGraw-Hill, Inc. New York, USA, 276 pp.

Hunsaker, C. T., Levine, D.A. 1995. Hierarchical Approaches to the Study of Water Quality in Rivers. Bioscience 45(3): 193-203

Johnson, L.B., Richards, C., Host, G.E., Arthur, J.W. 1997. Landscape influences on water chemistry in Midwestern stream ecosystems. Freshwater Biology 37:193-208

Lowrance, R., Todd, R. Fail, Jr., Hendrickson, O., Jr., Leonard, R., Asmussen, L. 1984. Riparian Forests as Nutrient Filters in Agricultural Watersheds. BioScience 34(6): 374-377.

McGarigal, Kevin; Marks, Barbara J. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Rep. PNW-GTR-351. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 122 p.

Mitsch, W.J., Gosselink, J.G., 2000. Wetlands. 3rd edition. Van Nostrand Reinhold, New York: 920 pp.

Moldan, B., Cerny, K. 1994. Biogeochemistry of Small Catchments: A Tool for Environmental Research. Wiley, Chichister, England. 419 pp.

Myers, D. N., Metzger, K. D., Davis, S. 2000. Status and Trends in Suspended-sediment Discharges, Soil Erosion, and Conservation Tillage in the Maumee River Basin – Ohio, Michigan, and Indiana. USGS Water-Resources Investigations Report 00-4091. 35 pp.

Naiman, R.J., Décamps, H. 1997. The Ecology of Interfaces: Riparian Zones. Annu. Rev. Ecol. Syst. 28: 621-58.

Naiman, R.J., Décamps, H., Pollock, M. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3(2): 209-212.

NLCD Manual, undated

National Research Council. 2002. Riparian Areas: Functions and Strategies for Management. National Academy Press. Washington, D.C. 428 pp.

Osborne, L.L, Wiley, M.J. 1988. Empirical Relationships Between Land Use/Cover and Stream Water Quality in an Agricultural Watershed. Journal of Environmental Management 26:9-27.

Ott, R.L., Longnecker, M. 2001. An Introduction to Statistical Methods and Data Analysis. Fifth edition. Duxbury – Thomson Learning, Pacific Grove, CA, USA 1152 pp

Pavey, R. R., Goldthwait, R. P., Brockman, C. S., Hull, D. N., Swinford, E. M., and Van Horn, R. G., 1999, Quaternary geology of Ohio: Ohio Division of Geological Survey Map M-2, 1:500,000-scale map.

Peterjohn, W.T., Correl, D.L. 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. Ecology 65: 1466-1475

Petras, I. 2003. ArcView GIS Basin1 Extension. Department of Water Affairs and Forestry, South Africa. Available at http://arcscripts.esri.com/details.asp?dbid=10668

Rempel, R.S. Carr, A.P. 2003. Patch Analyst extension for ArcView: version 3.1. http://flash.lakeheadu.ca/~rrempel/patch/index.html

Richards, C., Johnson, L.B., Host, G.E., 1996. Landscape scale influences on stream habitats and biota. Canadian Journal of Fisheries an Aquatic Sciences 53 (Suppl. 1): 295-311.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology. Pagosa Springs, Colorado.

Schuft, M.J., Moser, T.J., Wigington, Jr., P.J., Stevens, Jr., D.L., McAllister, L.S., Chapman, S.S., and Ernst, T.L. 1999. Developing of Landscape Metrics for Characterizing Riparian-Stream Networks. Photogrammetric Engineering and Remote Sensing 65(10):1157-1167.

Sliva L and D.D. Williams 2001. Buffer Zone versus Whole Catchment Approaches To Studying Land Use Impact on River Water Quality. Water Resources, 35: 3462-3472.

Tufford, D.L., McKellar, Jr., H.N., Hussey, J.R. 1998. In-Stream Nonpoint Source Nutrient Predicition with Land-Use Proximity and Seasonality. J. Environ. Qual. 27:100-111.

U.S. Department of Agriculture-USDA. 1972. National engineering handbook. Section 4, Hydrology.

U.S. Department of Agriculture. 2002. National Soil Survey Handbook, title 430-VI. [Online] Available: http://soils.usda.gov/procedures/handbook/main.htm.

United States Environmental Protection Agency-USEPA. 2001. ATtILA- Analytical Tools Interface for Landscape Assessments. Landscape Ecology Branch Fact Sheet 011, United States Environmental Protection Agency, Las Vegas, Nevada, USA.

United States Environmental Protection Agency-USEPA. 2004. Analytical Tools Interface for Landscape Assessments (ATtILA). User Manual Version 2004. EPA/600/R–04/083, United States Environmental Protection Agency, Las Vegas, Nevada, USA.

United States Geological Survey-USGS. Undated. The National Land Cover Dataset (NLCD) Manual.

United States Geological Survey-USGS. 1999. National Elevation Dataset. USGS Fact Sheet 148-99.

Wenger, S. 1999. A review of the scientific literature on riparian buffer width, extent and vegetation. Office of Public Service and Outreach. Institute of Ecology, University of Georgia. Athens, Georgia.