Second Quarterly Report

Longitudinal Assessment of Development Composition and Spatial Patterns of Green Infrastructure for Effective Flood Control in Growing and Shrinking US Metropolitan Areas

Submitted to the Council of Educators in Landscape Architecture
for the Bob Cardoza CLASS Fund Research Grant

August 25, 2021

Wonmin Sohn, Ph.D. (PI)
Assistant Professor
School of Planning, Design & Construction
Michigan State University

Human Ecology Building
552 W. Circle Drive, Rm 201C
East Lansing, MI 48824
Email: wonmin@msu.edu
Phone: 517-353-0677

Research Assistant:
Zhicheng Xu, Ph.D. student

TABLE OF CONTENTS

Page

Executive summary 1
1. Introduction 2
2. Method 3
  2.1. Data construct and analysis 3
    2.1.1. Imperviousness variables measurement 4
    2.1.2. Land use pattern variables measurement 4
3. Results 5
4. Next tasks 9
References 10
Appendix 12

Executive summary

This study empirically assesses the longitudinal impacts of the development composition and spatial patterns of green infrastructure on urban runoff in two Midwestern regions: the Chicago-Naperville and Detroit-Warren-Ann Arbor combined statistical areas (CSAs). These two regions have demonstrated contradictory land development trends in response to population changes occurring in the last few decades. Local investments have focused more on infill housing development to accommodate population growth in the Chicago-Naperville CSA, while the constrained tax revenues in the shrinking Detroit-Warren-Ann Arbor CSA have led municipalities to focus on revitalizing blighted vacant lots, renovating them to be open green spaces for city beautification. Yet, due to climate change, increasing storm intensity and frequency are continuing to threaten both regions and exacerbate flood exposure more than ever before. This study hypothesizes that the contrasting trends in demographic transition and land development approaches in these areas have distinctively shaped the trajectory of flood risk over time. The major purposes of this study are to: 1) monitor the temporal and spatial patterns of floods and land use in association with demographic changes in both budding and depopulated regions, and 2) identify the longitudinal impacts of the quantity and quality of urban development and green infrastructure on runoff depth and peak flow. The research findings will be useful to policymakers, developers, water resource managers, and communities seeking to formulate strategies for future land development and green infrastructure plans in response to demographic changes, while also securing local flood storage capacity.

After successful completion of the first quarterly task of delineating watersheds in the study area and computing hydrologic variables, the second quarterly task focused on quantifying the composition and configuration of green infrastructure and developed areas at consistent intervals from 2001 to 2016; geospatial and statistic tools such as ArcGIS, FRAGSTATS, and STATA were used to accomplish this goal.

1. Introduction

Urbanization has led to the increasing use of impervious surfaces, converting vegetated areas into impermeable materials. As a consequence, the hydrological cycle of watersheds in urban areas has shifted (Barnes et al., 2000; Yao et al., 2016). Due to limited infiltration and evapotranspiration (as compared to what is seen in natural areas), these impermeable surfaces are inadequate to handle excess runoff during heavy storm events, thus impacting the quality and quantity of surface water and leading to urban flooding (Barnes et al., 2000; Chithra et al., 2015). For this reason, impervious surfaces are a significant factor in analyzing stormwater runoff and the hydrologic performance of urban watersheds. Two parameters related to impervious surfaces have been used widely to evaluate and quantify urban imperviousness: total impervious area (TIA), which quantifies the whole fraction of impervious surfaces, and directly connected impervious area (DCIA), a subset of TIA connecting buried sewer systems and through which urban runoff is directly transported to receiving water bodies (Ebrahimian et al., 2016; Sohn et al., 2020; Yao et al., 2016). Hydraulic connectivity is the ratio of DCIA to TIA and is often used to measure the benefit resulting from low impact development (Sohn et al., 2017). Previous studies have demonstrated that runoff depth can double or even triple if impervious surfaces increase by 10% to 20% or 35% to 50%, respectively (Arnold & Gibbons, 1996). Yao et al. (2016) used the Storm Water Management Model to cross-sectionally evaluate the rainfall-runoff process in small urban drainage watersheds, finding that TIA and DCIA were positively associated with total and peak runoff depth, regardless of storm intensity and duration. After controlling for a set of climate, geophysical, and land use factors, Sohn et al. (2020) longitudinally analyzed the contribution of impervious surfaces to runoff yields for 2010 to 2017, revealing that both TIA and DCIA had positive correlations with runoff depth and peak flow.

In addition to the amount, the spatial pattern of developed areas is another contributing factor to urban flooding (Brody et al., 2014). Various studies have evaluated their effects on flood loss and vulnerability. For example, Brody et al. (2014) found that a sprawling pattern of well-developed urban area with low-intensity and low-density communities exacerbated urban runoff, resulting in greater flood losses. Conversely, a connected pattern of high- and medium-intensity development helped mitigate flood loss. Brody et al. (2008) argued that replacing natural wetlands with developed areas threatened the hydrological system of a watershed and led to a significant increase in local claims of flood damage in eastern Texas. Similarly, Olivera and DeFee (2007) revealed that the saturation of developed patches in a highly urbanized watershed in Houston, Texas promoted connections among impervious surfaces and led to an increase in stormwater conveyance to downstream channels.

To compensate for the adverse impacts of impervious surfaces, green infrastructure (GI) has been known to be an effective strategy for mitigating stormwater runoff and urban flooding (Carter et al., 2018; Lennon et al., 2014; Mei et al., 2018). Numerous studies have focused on exploring the relationship between GI patterns and urban flooding to further understand the effectiveness of GI in mitigating runoff yields under diverse climate and geographic conditions. Kim and Park (2016) and Li et al. (2020) used landscape spatial pattern indicators developed by McGarigal (2015) to quantify GI configurations and empirically explore their impacts on urban runoff. Bai et al. (2018) also compared landscape indicators between flood-prone and non-flood-prone areas and evaluated the hydrological performance of green space by area. These cross-sectional studies showed that the size, edge, and connectivity of GI had a negative impact on both runoff depth and peak flow (Bai et al., 2018; Kim & Park, 2016; Li et al., 2020), while the shape had an insignificant effect (Kim &

Park, 2016). Additionally, Kim et al. (2021) demonstrated that more cohesive patterns of forests in urban subregions helped to reduce flood vulnerability. Yet, limited longitudinal studies have explored the relationship between GI patterns and flood vulnerability, and assessments of the long-term risk are lacking (Kim et al., 2021; Yuan et al., 2019). Zhang et al. (2015) investigated the time-series impact of green space conversion on stormwater runoff in multiple urban subregions, concluding that GI with increased largest patch indexes was more effective at decreasing runoff over time.

This project builds upon these previous efforts by examining time-series cross-sectional GI configurations in Midwestern CSAs in the US that have had contrasting trajectories of population shifts and land use development over the last several decades. The two CSAs being examined are Chicago-Naperville and Detroit-Warren-Ann Arbor.

2. Method

2.1. Data construct and analysis

This second-quarter task focuses on measuring the imperviousness and land use composition and configuration variables in the two subject CSAs at five-year intervals from 2001 to 2016 (see Table 1). The major data source is the National Land Cover Dataset (NLCD) provided by the United States Geological Survey (USGS).

Table 1. Construct variables and data sources.

Construct	Variable	Formula/Description	Unit	Data Source
Land use pattern variables				
Size and edge	Percentage of Landscape (PLAND)	$\sum_{j=1}^{n} a_{ij}/A \times (100)$	%	USGS's NLCD
	Edge Density (ED)	$\sum_{k=1}^{m} e_{ik} \,/\, A \times (10000)$	Meters per hectare	USGS's NLCD
	Largest Patch Index (LPI)	$\max_{j=1}^{n} (a_{ij}) \,/\, A \times (100)$	%	USGS's NLCD
Shape	Shape Index (SHAPE)	$\frac{.25p_{ij}}{\sqrt{a_{ij}}}$	None	USGS's NLCD
	Contiguity Index (CONTIG)	$\frac{\left[\frac{\sum_{r=1}^{z} c_{ijr}}{a_{ij}^{*}}\right] - 1}{v - 1}$	None	USGS's NLCD
Isolation / fragmentation	Proximity Index (PROX)	$\sum_{s=1}^{n} \frac{a_{ijs}}{h_{ijs}^{2}}$	None	USGS's NLCD
	Euclidean Nearest Neighbor Distance (ENN)	h_{ij}	Meters	USGS's NLCD
Connectivity	Patch Cohesion Index (COHESION)	$\left[1 - \frac{\sum_{j=1}^{n} p_{ij}^{*}}{\sum_{j=1}^{n} p_{ij}^{*}\sqrt{a_{ij}^{*}}}\right]\left[1 - \frac{1}{\sqrt{z}}\right]^{-1} \times (100)$	None	USGS's NLCD

Connectance Index (CONNECT)	$\left[\frac{\sum_{j \neq k}^{n} c_{ijk}}{\frac{n_i\,(n_i-1)}{2}}\right](100)$	%	USGS's NLCD
Imperviousness variables			
Mean TIA	Average impervious ratio in 2001, 2006, 2011, and 2016	%	USGS's NLCD
Hydraulic connectivity	$DCIA/_{TIA} \times (100)$	%	-

Land use patterns of GI (including forest, grassland, shrub, and wetland classes) and developed areas are separately computed.
USGS's NLCD = United States Geological Survey's National Land Cover Dataset; TIA = total impervious area; DCIA = directly connected impervious area.
Notes: a_{ij} = area (m^2) of patch ij; A = total landscape area (m^2); e_{ik} = total length (m) of edge in landscape involving patch type (class) i; p_{ij} = perimeter (m) of patch ij; c_{ijr} = contiguity value for pixel r in patch ij; v = sum of the values in a 3 x 3 cell template; a_{ij}^{*} = area of patch ij in terms of number of cells; a_{ijs} = area (m^2) of patch ijs within specified neighborhood (m) of patch ij; h_{ijs} = distance (m) between patch ijs and patch ijs, based on patch edge-to-edge distance computed from cell center to cell center; h_{ij} = distance (m) from patch ij to the nearest neighboring patch of the same type (class), based on patch edge-to-edge distance, computed from cell center to cell center; c_{jik} = joining between patch j and k (0 = unjoined, 1 = joined) of the corresponding patch type (i), based on a user-specified threshold distance; n_i = number of patches in the landscape of the corresponding patch type (class); Z = total number of cells in the landscape.
FRAGSTATS Formula source: Mcgarigal (2015)

2.1.1. Imperviousness variables measurement

Two imperviousness parameters, TIA and hydraulic connectivity (i.e., the ratio of DCIA to TIA), were computed as independent variables representing development composition. Based on the 30-m resolution of the NLCD impervious surface dataset, the research team used ArcGIS to calculate the mean TIA values for individual watersheds in 2001, 2006, 2011, and 2016.

DCIA is known to be a better measure than TIA for evaluating the effectiveness of GI (Sohn et al., 2020). Based on the theory developed by Boyd et al. (1993) related to DCIA calculation, the slope of a graph plotting runoff against rainfall equals the fraction of DCIA when rainfall is low. To factor out potential outliers that may produce runoff from disconnected impervious surfaces (non-DCIA), Boyd et al. (1993) applied a 1-mm deviated criterion to exclude them and suggested a successive ordinary least squares (OLS) regression model to estimate the DCIA value. This method was further developed by Ebrahimian et al. (2016), and a successive weighted least squares (WLS) method suggested to avoid the bias resulting from heteroscedastic residuals in the OLS model. In the present research, we adopted both OLS and WLS based on the identification of heteroscedastic residuals in historic rainfall and runoff data. Due to limited sample points and unreliable DCIA estimations from short-term rainfall and runoff datasets, a longer dataset term was necessary to ensure estimation reliability. As a result, the 20-year rainfall and runoff data obtained from the Parameter Elevation Regressions on Independent Slopes model and USGS gauge stations (1999-2018) were plotted for each watershed, and DCIA was analyzed using STATA statistical software. It was verified if the DCIA value was less than the TIA value. Finally, the hydraulic connectivity for each watershed was calculated by the ratio of DCIA to TIA.

2.1.2. Land use pattern variables measurement

To examine the longitudinal changes of GI and developments' spatial patterns, the 30-m resolution land cover maps extracted from the NLCD for the years 2001, 2006, 2011, and 2016 were reclassified into GI, developed areas, and other. GI included four land use types: forest, shrub, grassland, and wetland. Based on the NLCD's Anderson Land Cover Classification System, deciduous forest (41), evergreen forest (42), mixed forest (43), shrub/scrub (52), grassland/herbaceous (71), woody wetland (90), and emergent herbaceous wetland (95) were defined as combined GI, in addition to the four individual classes. Meanwhile, developed low intensity (22), developed medium intensity (23), and developed high intensity (24) were reclassified into developed areas. Open water (11), developed open space (21), barren land (31), pasture/hay (81), and cultivated crops (82) were combined into the "other" class. In order to compute the spatial pattern indicators, ArcGIS was used to crop the reclassified land use maps by each watershed; these were then forced into FRAGSTATS version 4.2, a spatial pattern analysis software program developed by McGarigal (2015),

Based on a review of previous studies focusing on the hydrologic performance of GI (Bai et al., 2018; Biao et al., 2015; Kim & Park, 2016; Li et al., 2020), the nine most frequently and widely used FRAGSTATS indicators at the class level were selected to analyze the spatial and temporal trends of land use amount/patterning (i.e., size, edge, shape, isolation/fragmentation, and connectivity) (see Table 1): percentage of landscape (PLAND), edge density (ED), largest patch index (LPI), shape index (SHAPE), contiguity index (CONTIG), proximity index (PROX), Euclidean nearest neighbor distance (ENN), patch cohesion index (COHESION), and connectance index (CONNECT). The size and edge of each land use pattern were analyzed by PLAND, ED, and LPI (McGarigal, 2015). PLAND was used to measure the size proportion of a land use in a watershed. A higher PLAND value represented a much larger area of selected land use. ED and LPI, demonstrating the shape of the patch, quantified the ratio of the edge parameter to the area and the percentage of the largest patch in the watershed, respectively. Higher ED and LPI values indicated patches in a watershed that were more complex and had more dominant edges. The shape of the land use pattern was measured by SHAPE and CONTIG, denoting the complexity and contiguity of the patches (McGarigal, 2015). Higher SHAPE and CONTIG values indicated more complex and irregular shapes. Additionally, the spatial distributions of land uses were analyzed by isolation/fragmentation and connectivity. Regarding the isolation/fragmentation level, PROX, the proximity of the same type of patches within a pre-specified search radius, and ENN, the distance between the nearest patches of the same class, have both been used widely (McGarigal, 2015). Higher PROX and ENN values demonstrated less isolated patterns. Finally, the physical connectivity of land use was evaluated by COHESION and CONNECT (McGarigal, 2015). COHESION represented the connection of each patch, and similarly, CONNECT exhibited the percentage of connectivity within a pre-specified search radius. Based on previous research on forested and neutral landscapes, the search radius of landscape indicators has often been set to 500 m (Caprio et al., 2009; Neel et al., 2004). A 500-m search radius was also used in this study to compute PROX and CONNECT.

In sum, nine indexes quantifying configuration of the combined GI, developed area, and four individual classes (i.e., forest, grassland, shrub, and wetland) were calculated for 99 watersheds via FRAGSTATS for the years 2001, 2006, 2011, and 2016.

3. Results

Overall, TIA slowly but steadily showed an increasing trend in both the Chicago-Naperville and Detroit-Warren-Ann Arbor CSAs from 2001 to 2016 (see Tables 2 and 3). The Chicago region experienced more notable changes. In addition, the mean TIA in the Chicago region was much greater over time than that of the Detroit region, while the hydraulic connectivity was comparable.

Table 2. Imperviousness variables for the Chicago-Naperville CSA.

Variable	Year	Mean	Std.	Range
TIA	2001	20.41	15.04	0.92-55.65
	2006	21.40	15.07	0.97-57.85
	2011	21.92	15.08	1.00-58.34
	2016	22.11	15.08	1.00-58.46
Hydraulic connectivity*	2001-2016	58.66	28.64	0-100

* One watershed (FID 82) was excluded from this analysis, due to insufficient observations of runoff depth.

Table 3. Imperviousness variables for the Detroit-Warren-Ann Arbor CSA.

Variable	Year	Mean	Std.	Range
TIA	2001	13.14	13.19	0.87-41.36
	2006	13.47	13.43	0.88-41.59
	2011	13.72	13.62	0.88-41.78
	2016	13.86	13.74	0.88-41.98
Hydraulic connectivity	2001-2016	57.58	28.52	0-100

Overall, there was an obvious contrasting trend in spatial patterns between GI and developed areas for both CSAs during the study period (see Tables 4 and 5). Urbanization has continuously proceeded, while the quantity and quality of GI has degraded over time. In contrast to the trajectory of GI patterning, developed areas increased in a more connected and clustered fashion.

When examining individual types of GI together, regarding the ***size and edges***, the average amount of combined GI, forest, grass, and wetland classes (except shrubs) in the 99 watersheds decreased with a lower edge density from 2001 to 2016, while the amounts of developed area had 6.8% and 4.4% growth and more complex edge shapes in 2016 in both the Chicago and Detroit regions, respectively (see Appendix Tables 1 and 2). Conversely, the ***shape*** of each land use did not demonstrate notable changes in the Detroit region. Only GI experienced slight regularization in the Chicago region. In terms of ***isolation/fragmentation and connectivity***, developed areas became more connected and aggregated over time, while individual and combined GI revealed an increasing tendency towards isolation and fragmentation as the PROX value decreased.

Table 4. Mean values of GI and developed area configurations in the Chicago-Naperville CSA from 2001 to 2016.

Construct	Index	Land use	Year			
			2001	**2006**	**2011**	**2016**
Size & Edge	PLAND	GI	15.66 (11.05)	15.00 (10.82)	14.50 (10.60)	14.50 (10.57)
		DA	40.48 (28.58)	42.11 (28.48)	42.95 (28.42)	43.24 (28.42)
	ED	GI	28.56 (16.47)	27.15 (16.05)	26.59 (15.82)	26.69 (15.86)
		DA	55.80 (25.37)	57.48 (25.67)	58.92 (26.12)	59.56 (26.38)
	LPI	GI	2.54 (2.44)	2.24 (2.14)	2.17 (2.08)	2.20 (2.05)
		DA	36.74 (30.10)	38.37 (30.00)	39.09 (29.97)	39.36 (29.97)
Shape	SHAPE	GI	1.52 (0.10)	1.49 (0.10)	1.47 (0.10)	1.47 (0.10)
		DA	1.31 (0.10)	1.31 (0.09)	1.31 (0.09)	1.30 (0.08)
	CONTIG	GI	0.41 (0.07)	0.40 (0.07)	0.39 (0.07)	0.39 (0.07)
		DA	0.18 (0.03)	0.18 (0.03)	0.18 (0.03)	0.18 (0.03)
Isolation / Fragmentation	PROX	GI	103.32 (90.46)	96.23 (87.16)	89.76 (80.60)	91.82 (84.10)
		DA	4554.92 (7033.49)	5002.70 (7498.13)	5186.81 (7654.01)	5253.22 (7718.54)
	ENN	GI	179.21 (148.10)	178.23 (140.15)	178.04 (136.88)	176.49 (132.51)
		DA	84.23 (14.12)	82.96 (14.36)	82.58 (14.29)	82.57 (14.24)
Connectivity	COHESION	GI	93.55 (7.19)	93.24 (7.24)	93.09 (7.22)	93.09 (7.29)

		DA	98.45 (3.05)	98.62 (2.88)	98.66 (2.84)	98.69 (2.82)
	CONNECT	GI	4.03 (5.49)	4.03 (5.48)	4.03 (5.46)	3.99 (5.43)
		DA	4.72 (7.59)	4.80 (7.61)	4.84 (7.66)	4.75 (6.92)

Note. Standard deviations are in parenthesis. GI = green infrastructure; DA = developed area.

Table 5. Mean values of GI and developed area configurations in the Detroit-Warren-Ann Arbor CSA from 2001 to 2016.

Construct	**Index**	**Land use**	**Year**			
			2001	**2006**	**2011**	**2016**
Size & Edge	PLAND	GI	27.43 (16.90)	27.22 (17.05)	27.09 (17.15)	27.11 (17.20)
		DA	24.73 (24.27)	25.21 (24.60)	25.57 (24.87)	25.82 (25.07)
	ED	GI	44.95 (19.96)	44.54 (20.00)	44.52 (20.29)	44.40 (20.07)
		DA	57.51 (40.51)	58.07 (40.40)	58.26 (40.31)	59.01 (40.88)
	LPI	GI	1.80 (1.84)	1.75 (1.79)	1.74 (1.81)	1.74 (1.81)
		DA	20.09 (24.17)	20.46 (24.54)	20.75 (24.83)	21.00 (25.11)
Shape	SHAPE	GI	1.57 (0.089)	1.56 (0.079)	1.56 (0.082)	1.56 (0.083)
		DA	1.26 (0.060)	1.26 (0.058)	1.26 (0.060)	1.26 (0.055)
	CONTIG	GI	0.43 (0.069)	0.43 (0.068)	0.43 (0.067)	0.43 (0.068)
		DA	0.17 (0.024)	0.17 (0.025)	0.17 (0.024)	0.17 (0.023)
Isolation / Fragmentation	PROX	GI	186.73 (155.58)	184.87 (156.93)	183.84 (157.76)	184.06 (159.46)
		DA	4026.01 (6883.65)	4141.77 (7013.19)	4213.53 (7030.89)	4387.48 (7244.28)
	ENN	GI	114.89 (46.03)	115.93 (47.16)	116.48 (46.46)	115.35 (46.74)
		DA	93.34 (17.54)	92.72 (17.55)	92.49 (17.51)	92.20 (17.59)
Connectivity	COHESION	GI	94.94 (2.42)	94.87 (2.47)	94.81 (2.56)	94.78 (2.59)
		DA	95.23 (6.10)	95.28 (6.09)	95.33 (6.06)	95.36 (6.04)
	CONNECT	GI	2.74 (3.84)	2.70 (3.75)	2.70 (3.74)	2.65 (3.59)
		DA	1.59 (2.31)	1.59 (2.30)	1.63 (2.44)	1.62 (2.40)

Note. Standard deviations are in parenthesis. GI = green infrastructure; DA = developed area.

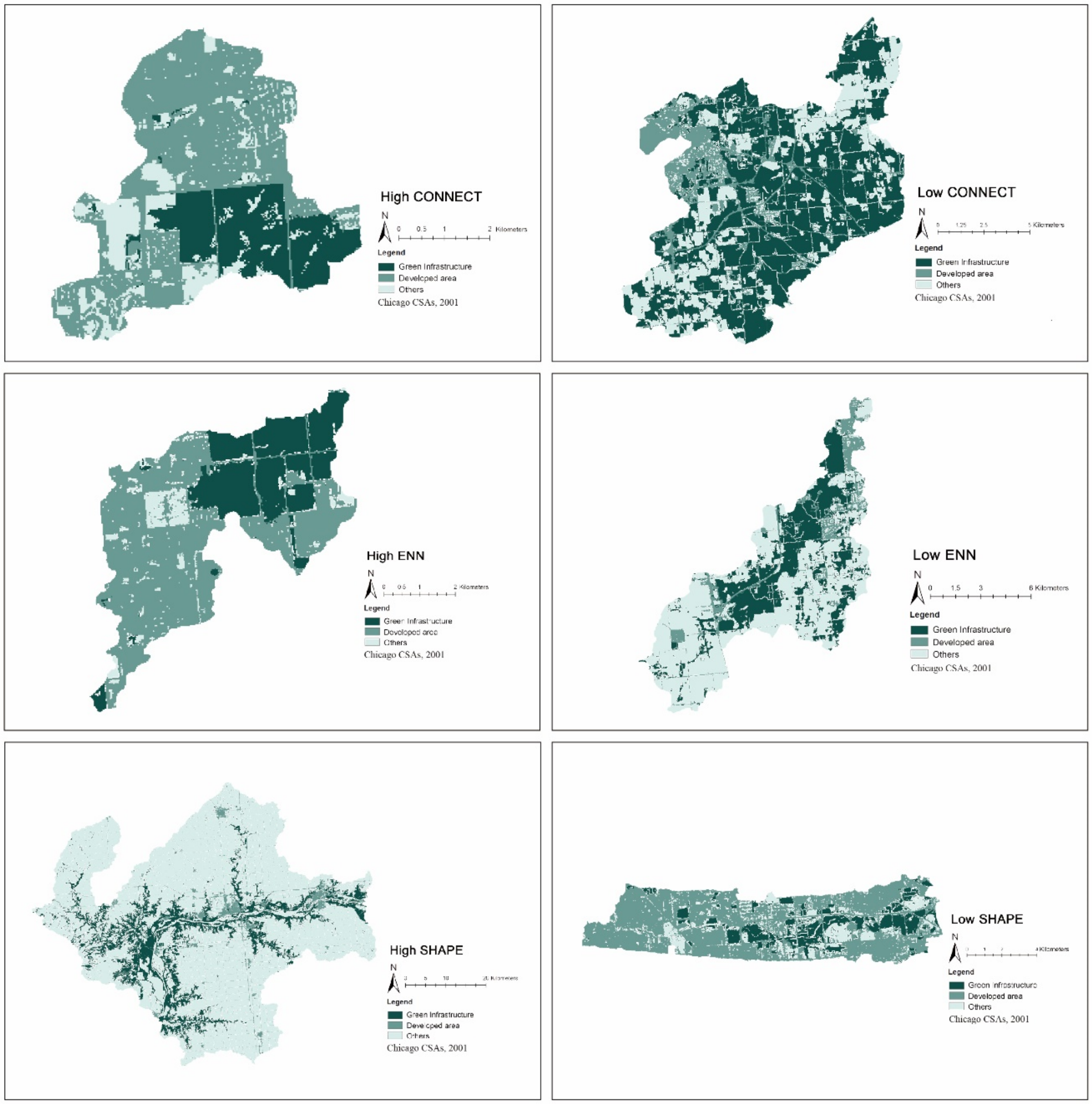

Figure 1. Six watersheds with contrasting GI features (CONNECT, ENN, and SHAPE).

As shown in Figure 1, watersheds with lower ENN and higher CONNECT values showed more connected and less isolated GI patterns. Higher SHAPE values represented more complex and irregular GI shapes.

4. Next tasks

The next tasks for the third quarterly report will focus on measuring climate variables (e.g., precipitation and antecedent wetness) and geophysical variables (e.g., slope, saturated hydraulic conductivity, and the number of dams and/or reservoirs) and developing statistical models. ArcGIS software will be used to extract the selected variables from the National Hydrology Dataset Plus, Soil Survey Geographic Database, and National Inventory of Dams.

Task	Major Activities	2021										2022	
		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Task 1: Watershed delineation	Activity 1 – Watershed delineation												
	Activity 2 – Verification												
Task 2: Variables measurement	Activity 3 – Measurement of hydrologic variables												
	Activity 4 – Measurement of imperviousness variables												
	Activity 5 – Measurement of GI pattern variables												
	Activity 6 – Measurement of climate and geophysical variables												
Task 3: Data analysis	Activity 7 – Statistical modeling												
Task 4: Documentation and dissemination	Activity 8 – Report writing, manuscript publication, and conference presentation												

References

Arnold, C. L., & Gibbons, C. J. (1996). Impervious surface coverage: The emergence of a key environmental indicator. *Journal of the American Planning Association*, *62*(2), 243–258. https://doi.org/10.1080/01944369608975688

Bai, T., Mayer, A. L., Shuster, W. D., & Tian, G. (2018). The hydrologic role of urban green space in mitigating flooding (Luohe, China). *Sustainability (Switzerland)*, *10*(10), 1–13. https://doi.org/10.3390/su10103584

Barnes, K. B., Morgan, J. M., & Roberge, M. C. (2000). *Impervious surfaces and the quality of natural and built environments*. https://www.researchgate.net/publication/251630988_IMPERVIOUS_SURFACES_AND_THE_QUALITY_OF_NATURAL_AND_BUILT_ENVIRONMENTS

Boyd, M. J., Bufill, M. C., & Knee, R. M. (1993). Pervious and impervious runoff in urban catchments. *Hydrological Sciences Journal*, *38*(6), 463–478. https://doi.org/10.1080/02626669309492699

Brody, S., Blessing, R., Sebastian, A., & Bedient, P. (2014). Examining the impact of land use/land cover characteristics on flood losses. *Journal of Environmental Planning and Management*, *57*(8), 1252–1265. https://doi.org/10.1080/09640568.2013.802228

Brody, S. D., Zahran, S., Highfield, W. E., Grover, H., & Vedlitz, A. (2008). Identifying the impact of the built environment on flood damage in Texas. *Disasters*, *32*(1), 1–18. https://doi.org/10.1111/J.1467-7717.2007.01024.X

Caprio, E., Ellena, I., & Rolando, A. (2009). Assessing habitat/landscape predictors of bird diversity in managed deciduous forests: A seasonal and guild-based approach. *Biodiversity and Conservation*, *18*(5), 1287–1303. https://doi.org/10.1007/S10531-008-9478-1

Carter, J. G., Handley, J., Butlin, T., & Gill, S. (2018). Adapting cities to climate change - exploring the flood risk management role of green infrastructure landscapes. *Journal of Environmental Planning and Management*, *61*(9), 1535–1552. https://doi.org/10.1080/09640568.2017.1355777

Chithra, S. V., Harindranathan Nair, M. V., Amarnath, A., & Anjana, N. S. (2015). Impacts of impervious surfaces on the environment. *Engineering Science Invention*, *4*(5), 27–31.

Ebrahimian, A., Wilson, B. N., & Gulliver, J. S. (2016). Improved methods to estimate the effective impervious area in urban catchments using rainfall-runoff data. *Journal of Hydrology*, *536*, 109–118. https://doi.org/10.1016/J.JHYDROL.2016.02.023

Kim, H. W., & Park, Y. (2016). Urban green infrastructure and local flooding: The impact of landscape patterns on peak runoff in four Texas MSAs. *Applied Geography*, *77*, 72–81. https://doi.org/10.1016/j.apgeog.2016.10.008

Kim, M., Song, K., & Chon, J. (2021). Key coastal landscape patterns for reducing flood vulnerability. *Science of The Total Environment*, *759*, 143454. https://doi.org/10.1016/J.SCITOTENV.2020.143454

Lennon, M., Scott, M., & O'Neill, E. (2014). Urban design and adapting to flood risk: the role of green infrastructure. *Urban Design*, *19*(5), 745–758.

Li, L., Van Eetvelde, V., Cheng, X., & Uyttenhove, P. (2020). Assessing stormwater runoff reduction capacity of existing green infrastructure in the city of Ghent. *International Journal of Sustainable Development and World Ecology*, *27*(8), 749–761. https://doi.org/10.1080/13504509.2020.1739166

Mcgarigal, K. (2015). *Fragstats help* (Issue April).

Mei, C., Liu, J., Wang, H., Yang, Z., Ding, X., & Shao, W. (2018). *Integrated assessments of green infrastructure for flood mitigation to support robust decision-making for sponge city construction in an urbanized watershed*. https://doi.org/10.1016/j.scitotenv.2018.05.199

Neel, M. C., McGarigal, K., & Cushman, S. A. (2004). Behavior of class-level landscape metrics across gradients of class aggregation and area. *Landscape Ecology*, *19*(4), 435–455.

https://doi.org/10.1023/B:LAND.0000030521.19856.CB
Olivera, F., & DeFee, B. B. (2007). Urbanization and its effect on runoff in the Whiteoak Bayou watershed, Texas. *Journal of the American Water Resources Association*, *43*(1), 170–182. https://doi.org/10.1111/J.1752-1688.2007.00014.X
Sohn, W., Kim, J.-H., & Li, M.-H. (2017). Low-impact development for impervious surface connectivity mitigation: assessment of directly connected impervious areas (DCIAs). *Journal of Environmental Planning and Management*, *60*(10), 1871–1889. https://doi.org/10.1080/09640568.2016.1264929
Sohn, W., Kim, J. H., Li, M. H., Brown, R. D., & Jaber, F. H. (2020). How does increasing impervious surfaces affect urban flooding in response to climate variability? *Ecological Indicators*, *118*, 106774. https://doi.org/10.1016/J.ECOLIND.2020.106774
Yao, L., Wei, W., & Chen, L. (2016). How does imperviousness impact the urban rainfall-runoff process under various storm cases? *Ecological Indicators*, *60*, 893–905. https://doi.org/10.1016/J.ECOLIND.2015.08.041
Yuan, Y., Fang, G., Yan, M., Sui, C., Ding, Z., & Lu, C. (2019). Flood-Landscape ecological risk assessment under the background of urbanization. *Water*, *11*(7), 1418.
Zhang, B., Xie, G. di, Li, N., & Wang, S. (2015). Effect of urban green space changes on the role of rainwater runoff reduction in Beijing, China. *Landscape and Urban Planning*, *140*, 8–16. https://doi.org/10.1016/j.landurbplan.2015.03.014

Appendix

Table 1. Land use configuration variables in the Chicago-Naperville CSA.

Construct	Index	Land use type	Year	Mean	Std.	Range
Size & Edge	PLAND	Combined GI	2001	15.66	11.05	0.09-55.97
			2006	15.00	10.82	0.09-55.43
			2011	14.50	10.60	0.09-54.88
			2016	14.50	10.57	0.09-54.79
		Forest	2001	8.49	6.25	0.06-30.12
			2006	8.20	6.16	0.06-29.97
			2011	8.02	6.07	0.06-29.83
			2016	7.97	6.03	0.06-29.72
		Grass	2001	2.39	2.80	0.003-17.82
			2006	2.10	2.63	0.003-17.18
			2011	1.91	2.52	0.003-17.29
			2016	1.89	2.49	0.003-17.08
		Shrub	2001	0.37	0.72	0-3.71
			2006	0.37	0.67	0-3.82
			2011	0.33	0.61	0-3.30
			2016	0.33	0.56	0-2.85
		Wetland	2001	4.41	3.96	0-16.17
			2006	4.33	3.86	0-16.02
			2011	4.24	3.84	0-15.99
			2016	4.31	3.89	0-16.06
		Developed area	2001	40.48	28.58	2.11-89.92
			2006	42.11	28.48	2.17-89.98
			2011	42.95	28.42	2.21-90.28
			2016	43.24	28.42	2.22-90.46
	ED	Combined GI	2001	28.56	16.47	0.85-65.29
			2006	27.15	16.05	0.85-65.48
			2011	26.59	15.82	0.85-65.55
			2016	26.69	15.86	0.85-65.44
		Forest	2001	24.80	15.63	0.52-69.82
			2006	23.86	15.31	0.52-69.26
			2011	23.47	15.10	0.52-69.18
			2016	23.51	15.17	0.52-69.15
		Grass	2001	9.96	9.01	0.04-37.36
			2006	8.83	8.25	0.04-36.89
			2011	8.09	7.58	0.04-36.27
			2016	8.11	7.55	0.04-36.25
		Shrub	2001	1.98	3.39	0-16.00
			2006	2.09	3.27	0-16.25
			2011	1.81	3.01	0-14.75
			2016	1.88	3.00	0-14.69
		Wetland	2001	13.86	9.79	0-39.59
			2006	13.68	9.70	0-39.45
			2011	13.41	9.67	0-39.34
			2016	13.57	9.66	0-39.48
		Developed area	2001	55.80	25.37	13.76-116.03
			2006	57.48	25.67	13.80-116.00
			2011	58.92	26.12	13.94-116.67
			2016	59.56	26.38	14.01-117.23
	LPI	Combined GI	2001	2.54	2.44	0.02-10.97

			2006	2.24	2.14	0.02-11.02
			2011	2.17	2.08	0.02-11.09
			2016	2.20	2.05	0.02-10.98
		Forest	2001	1.04	1.20	0.02-5.81
			2006	0.99	1.16	0.02-5.81
			2011	0.96	1.13	0.02-5.81
			2016	0.95	1.13	0.02-5.81
		Grass	2001	0.39	1.03	0.003-8.10
			2006	0.32	0.98	0.003-8.01
			2011	0.33	1.01	0.003-8.07
			2016	0.32	1.00	0.003-8.03
		Shrub	2001	0.07	0.13	0-0.73
			2006	0.07	0.13	0-0.75
			2011	0.06	0.12	0-0.63
			2016	0.07	0.12	0-0.80
		Wetland	2001	0.71	0.71	0-2.98
			2006	0.70	0.69	0-2.88
			2011	0.68	0.67	0-2.64
			2016	0.70	0.68	0-2.91
		Developed area	2001	36.74	30.10	0.09-89.74
			2006	38.37	30.00	0.09-89.93
			2011	39.09	29.97	0.09-90.24
			2016	39.36	29.97	0.09-90.41
Shape	SHAPE	Combined GI	2001	1.52	0.10	1.10-1.76
			2006	1.49	0.10	1.10-1.74
			2011	1.47	0.10	1.10-1.74
			2016	1.47	0.10	1.10-1.74
		Forest	2001	1.55	0.11	1.16-1.81
			2006	1.54	0.12	1.16-1.80
			2011	1.52	0.12	1.16-1.81
			2016	1.53	0.12	1.16-1.80
		Grass	2001	1.39	0.14	1.00-1.86
			2006	1.35	0.13	1.00-1.86
			2011	1.32	0.13	1.00-1.86
			2016	1.32	0.12	1.00-1.86
		Shrub	2001	1.15	0.46	0-1.74
			2006	1.21	0.33	0-1.60
			2011	1.14	0.45	0-1.64
			2016	1.21	0.37	0-1.76
		Wetland	2001	1.46	0.21	0-1.77
			2006	1.46	0.20	0-1.76
			2011	1.45	0.21	0-1.76
			2016	1.45	0.21	0-1.77
		Developed area	2001	1.31	0.10	1.16-1.91
			2006	1.31	0.09	1.16-1.76
			2011	1.31	0.09	1.16-1.73
			2016	1.30	0.08	1.16-1.63
	CONTIG	Combined GI	2001	0.41	0.07	0.13-0.56
			2006	0.40	0.07	0.13-0.55
			2011	0.39	0.07	0.13-0.56
			2016	0.39	0.07	0.13-0.55
		Forest	2001	0.40	0.06	0.19-0.54
			2006	0.40	0.06	0.19-0.54

			2011	0.39	0.06	0.19-0.54
			2016	0.39	0.06	0.19-0.54
		Grass	2001	0.30	0.09	0-0.43
			2006	0.28	0.09	0-0.43
			2011	0.27	0.08	0-0.42
			2016	0.26	0.08	0-0.42
		Shrub	2001	0.23	0.13	0-0.59
			2006	0.23	0.09	0-0.45
			2011	0.23	0.12	0-0.59
			2016	0.24	0.11	0-0.53
		Wetland	2001	0.32	0.08	0-0.46
			2006	0.32	0.08	0-0.46
			2011	0.32	0.08	0-0.46
			2016	0.31	0.08	0-0.47
		Developed area	2001	0.18	0.03	0.11-0.23
			2006	0.18	0.03	0.11-0.22
			2011	0.18	0.03	0.11-0.24
			2016	0.18	0.03	0.11-0.23
Isolation/ Fragmentation	PROX	Combined GI	2001	103.32	90.46	0.07-470.10
			2006	96.23	87.16	0.07-480.07
			2011	89.76	80.60	0.07-408.07
			2016	91.82	84.10	0.07-452.05
		Forest	2001	41.05	39.56	0-237.29
			2006	39.49	38.22	0-238.41
			2011	38.26	38.29	0-245.97
			2016	37.98	37.95	0-240.51
		Grass	2001	9.69	23.55	0-181.74
			2006	8.26	24.51	0-202.99
			2011	7.69	23.92	0-200.16
			2016	7.79	25.64	0-214.42
		Shrub	2001	1.69	3.65	0-26.79
			2006	1.39	3.07	0-21.56
			2011	1.56	2.76	0-27.14
			2016	1.48	3.12	0-23.89
		Wetland	2001	27.04	33.05	0-211.16
			2006	26.96	34.64	0-242.96
			2011	25.24	28.32	0-160.37
			2016	27.61	36.26	0-252.71
		Developed area	2001	4554.92	7033.49	2.80-46688.53
			2006	5002.70	7498.13	2.88-46995.99
			2011	5186.81	7654.01	2.91-45233.58
			2016	5253.22	7718.54	2.93-44705.26
	ENN	Combined GI	2001	179.21	148.10	76.89-901.05
			2006	178.23	140.15	77.56-854.31
			2011	178.04	136.88	77.06-833.50
			2016	176.49	132.51	76.80-854.31
		Forest	2001	186.27	190.24	86.38-1253.75
			2006	186.44	188.92	87.00-1253.75
			2011	184.67	184.69	87.09-1253.75
			2016	187.58	192.15	86.89-1253.75
		Grass	2001	330.06	425.73	0-3250.11
			2006	329.91	427.56	0-3250.11
			2011	303.38	289.83	0-2081.01

			2016	309.58	259.55	0-1449.33
		Shrub	2001	822.08	1234.16	0-6198.40
			2006	715.87	1424.49	0-10961.88
			2011	797.80	2309.74	0-19629.17
			2016	1134.60	3242.25	0-24367.09
		Wetland	2001	219.07	182.98	0-1345.78
			2006	225.39	221.38	0-1751.51
			2011	222.88	192.06	0-1345.78
			2016	208.59	132.60	0-750.37
		Developed area	2001	84.23	14.12	66.92-137.37
			2006	82.96	14.36	64.86-137.50
			2011	82.58	14.29	64.86-137.16
			2016	82.57	14.24	63.20-136.97
Connectivity	COHESION	Combined GI	2001	93.55	7.19	41.26-98.16
			2006	93.24	7.24	41.26-98.32
			2011	93.09	7.22	41.26-98.30
			2016	93.09	7.29	41.26-98.32
		Forest	2001	90.50	6.69	47.21-97.17
			2006	90.05	7.13	47.21-97.17
			2011	89.86	7.21	47.21-97.18
			2016	89.87	7.06	47.21-97.17
		Grass	2001	78.97	15.01	0-97.41
			2006	77.48	14.99	0-97.48
			2011	76.64	15.14	0-97.47
			2016	76.36	14.86	0-97.51
		Shrub	2001	59.16	27.76	0-93.48
			2006	62.45	21.00	0-92.36
			2011	59.58	26.44	0-93.41
			2016	62.26	23.81	0-94.67
		Wetland	2001	87.22	15.93	0-97.56
			2006	87.26	15.94	0-97.55
			2011	87.07	15.93	0-97.41
			2016	87.07	16.08	0-97.67
		Developed area	2001	98.45	3.05	77.81-99.97
			2006	98.62	2.88	78.35-99.98
			2011	98.66	2.84	78.50-99.98
			2016	98.69	2.82	78.55-99.98
	CONNECT	Combined GI	2001	4.03	5.49	0.09-39.17
			2006	4.03	5.48	0.09-39.17
			2011	4.03	5.46	0.09-39.17
			2016	3.99	5.43	0.09-39.17
		Forest	2001	4.21	4.94	0-20.34
			2006	4.36	5.18	0-20.64
			2011	4.30	5.06	0-21.57
			2016	4.34	5.21	0-21.21
		Grass	2001	4.06	5.09	0-27.78
			2006	4.56	8.13	0-61.90
			2011	5.25	8.31	0-57.14
			2016	4.42	5.90	0-39.29
		Shrub	2001	9.90	18.43	0-100
			2006	9.28	20.11	0-100
			2011	8.85	17.37	0-100
			2016	10.34	20.59	0-100

		Wetland	2001	5.77	9.94	0-64.29
			2006	5.85	10.13	0-64.29
			2011	5.79	9.99	0-64.29
			2016	5.85	10.04	0-64.29
		Developed area	2001	4.72	7.59	0.02-53.33
			2006	4.80	7.61	0.02-53.33
			2011	4.84	7.66	0.02-53.33
			2016	4.75	6.92	0.02-42.86

Table 2. Land use configuration variables in the Detroit-Warren-Ann Arbor CSA.

Construct	**Index**	**Land use type**	**Year**	**Mean**	**Std.**	**Range**
Size & Edge	PLAND	Combined GI	2001	27.43	16.90	4.35-58.87
			2006	27.22	17.05	4.23-58.78
			2011	27.09	17.15	4.20-59.07
			2016	27.11	17.20	4.14-59.03
		Forest	2001	15.92	10.18	1.99-39.24
			2006	15.74	10.22	2.04-39.03
			2011	15.71	10.34	1.86-39.61
			2016	15.61	10.32	1.86-39.19
		Grass	2001	0.37	0.27	0.03-1.09
			2006	0.34	0.24	0.03-1.01
			2011	0.31	0.23	0.03-0.96
			2016	0.35	0.26	0.03-0.99
		Shrub	2001	0.03	0.02	0.002-0.09
			2006	0.07	0.06	0.001-0.25
			2011	0.09	0.09	0-0.31
			2016	0.09	0.18	0-0.97
		Wetland	2001	11.76	7.21	1.06-26.18
			2006	11.72	7.26	1.04-26.10
			2011	11.61	7.21	1.04-25.87
			2016	11.70	7.29	1.04-26.14
		Developed area	2001	24.73	24.27	1.77-74.22
			2006	25.21	24.60	1.78-74.51
			2011	25.57	24.87	1.78-74.73
			2016	25.82	25.07	1.79-75.06
	ED	Combined GI	2001	44.95	19.96	10.54-73.84
			2006	44.54	20.00	10.35-73.08
			2011	44.52	20.29	10.34-74.28
			2016	44.40	20.07	10.30-73.25
		Forest	2001	42.90	22.06	8.68-90.95
			2006	42.41	22.17	8.53-91.00
			2011	42.18	22.34	8.53-91.51
			2016	42.10	22.33	8.53-90.80
		Grass	2001	2.34	1.57	0.19-6.05
			2006	2.21	1.42	0.19-5.48
			2011	2.06	1.36	0.19-5.18
			2016	2.29	1.52	0.25-6.24
		Shrub	2001	0.24	0.16	0.03-0.63
			2006	0.50	0.39	0.01-1.84
			2011	0.64	0.57	0-2.02
			2016	0.51	0.70	0-3.83
		Wetland	2001	30.90	16.42	3.87-57.25

			2006	30.79	16.58	3.83-56.87
			2011	30.75	16.68	3.83-57.37
			2016	30.73	16.62	3.83-56.92
		Developed area	2001	57.51	40.51	12.86-141.15
			2006	58.07	40.40	12.93-141.25
			2011	58.26	40.31	12.93-141.77
			2016	59.01	40.88	12.95-143.73
	LPI	Combined GI	2001	1.80	1.84	0.23-8.38
			2006	1.75	1.79	0.22-8.29
			2011	1.74	1.81	0.22-8.41
			2016	1.74	1.81	0.22-8.41
		Forest	2001	1.08	1.32	0.11-5.99
			2006	1.08	1.31	0.11-5.89
			2011	1.08	1.33	0.11-6.04
			2016	1.07	1.31	0.11-5.90
		Grass	2001	0.034	0.032	0.0037-0.13
			2006	0.031	0.026	0.0048-0.10
			2011	0.028	0.025	0.0037-0.09
			2016	0.031	0.027	0.0037-0.10
		Shrub	2001	0.007	0.009	0.0009-0.04
			2006	0.012	0.012	0.0011-0.04
			2011	0.010	0.009	0-0.04
			2016	0.015	0.031	0-0.16
		Wetland	2001	0.678	0.44	0.09-1.57
			2006	0.671	0.44	0.09-1.57
			2011	0.666	0.43	0.09-1.57
			2016	0.667	0.44	0.09-1.57
		Developed area	2001	20.09	24.17	0.13-73.40
			2006	20.46	24.54	0.13-73.69
			2011	20.75	24.83	0.14-73.92
			2016	21.00	25.11	0.14-74.23
Shape	SHAPE	Combined GI	2001	1.57	0.089	1.36-1.70
			2006	1.56	0.079	1.36-1.66
			2011	1.56	0.082	1.35-1.67
			2016	1.56	0.083	1.32-1.66
		Forest	2001	1.59	0.058	1.41-1.70
			2006	1.58	0.051	1.43-1.65
			2011	1.58	0.058	1.38-1.65
			2016	1.58	0.061	1.38-1.66
		Grass	2001	1.30	0.15	1.02-1.9
			2006	1.28	0.16	1.02-1.9
			2011	1.27	0.16	1.02-1.9
			2016	1.27	0.16	1.03-1.9
		Shrub	2001	1.23	0.12	1-1.42
			2006	1.23	0.10	1-1.39
			2011	1.22	0.27	0-1.44
			2016	1.12	0.42	0-1.54
		Wetland	2001	1.52	0.065	1.36-1.62
			2006	1.53	0.060	1.35-1.62
			2011	1.53	0.061	1.36-1.61
			2016	1.53	0.065	1.33-1.61
		Developed area	2001	1.26	0.060	1.17-1.44
			2006	1.26	0.058	1.17-1.43

			2011	1.26	0.060	1.17-1.44
			2016	1.26	0.055	1.17-1.40
	CONTIG	Combined GI	2001	0.43	0.069	0.24-0.52
			2006	0.43	0.068	0.25-0.52
			2011	0.43	0.067	0.27-0.52
			2016	0.43	0.068	0.25-0.52
		Forest	2001	0.409	0.038	0.27-0.47
			2006	0.406	0.035	0.28-0.45
			2011	0.406	0.036	0.28-0.45
			2016	0.403	0.037	0.28-0.45
		Grass	2001	0.25	0.095	0.02-0.60
			2006	0.24	0.096	0.02-0.60
			2011	0.23	0.098	0.02-0.60
			2016	0.23	0.098	0.03-0.60
		Shrub	2001	0.19	0.069	0-0.30
			2006	0.20	0.070	0-0.31
			2011	0.23	0.086	0-0.33
			2016	0.21	0.115	0-0.43
		Wetland	2001	0.40	0.060	0.23-0.52
			2006	0.40	0.057	0.23-0.52
			2011	0.40	0.055	0.23-0.52
			2016	0.41	0.058	0.23-0.52
		Developed area	2001	0.17	0.024	0.14-0.24
			2006	0.17	0.025	0.14-0.24
			2011	0.17	0.024	0.14-0.24
			2016	0.17	0.023	0.14-0.24
Isolation/ Fragmentation	PROX	Combined GI	2001	186.73	155.58	8.52-521.10
			2006	184.87	156.93	8.54-524.18
			2011	183.84	157.76	8.54-521.79
			2016	184.06	159.46	8.54-529.81
		Forest	2001	64.67	56.85	5.33-223.15
			2006	63.52	56.48	5.43-221.92
			2011	63.33	56.67	5.42-221.67
			2016	62.42	56.80	5.37-220.55
		Grass	2001	0.93	0.72	0-2.74
			2006	0.81	0.59	0-2.17
			2011	0.79	0.59	0-1.96
			2016	0.83	0.59	0-2.04
		Shrub	2001	0.18	0.21	0-0.78
			2006	0.27	0.25	0-0.97
			2011	0.33	0.27	0-0.96
			2016	0.88	3.25	0-17.10
		Wetland	2001	39.95	34.01	1.66-135.63
			2006	39.47	33.84	1.20-136.05
			2011	39.27	33.95	1.20-134.15
			2016	39.55	34.17	1.20-136.13
		Developed area	2001	4026.01	6883.65	3.36-25675.71
			2006	4141.77	7013.19	3.57-25980.43
			2011	4213.53	7030.89	3.58-25886.75
			2016	4387.48	7244.28	3.61-26041.21
	ENN	Combined GI	2001	114.89	46.03	77.96-268.68
			2006	115.93	47.16	78.44-268.74
			2011	116.48	46.46	79.15-267.27

			2016	115.35	46.74	79.26-263.39
		Forest	2001	125.26	49.97	81.34-277.36
			2006	126.11	51.17	82.08-279.84
			2011	126.31	50.96	82.03-278.34
			2016	126.30	51.45	82.65-273.55
		Grass	2001	440.04	291.14	0-1656.35
			2006	430.69	288.87	0-1656.35
			2011	446.81	283.39	0-1656.35
			2016	409.29	231.58	0-1355.08
		Shrub	2001	1716.41	1395.86	0-7139.45
			2006	1156.58	1100.79	0-5783.37
			2011	1072.56	1325.42	0-7139.45
			2016	1255.93	1395.16	0-7516.79
		Wetland	2001	140.89	63.37	92.81-378.98
			2006	144.48	71.57	93.75-432.51
			2011	145.64	72.10	93.62-432.51
			2016	143.78	71.73	92.25-432.51
		Developed area	2001	93.34	17.54	67.36-121.44
			2006	92.72	17.55	67.20-121.41
			2011	92.49	17.51	66.91-121.15
			2016	92.20	17.59	66.11-121.15
Connectivity	COHESION	Combined GI	2001	94.94	2.42	89.55-97.47
			2006	94.87	2.47	89.18-97.49
			2011	94.81	2.56	89.25-97.50
			2016	94.78	2.59	89.17-97.51
		Forest	2001	92.42	3.52	79.56-96.68
			2006	92.47	3.11	82.66-96.67
			2011	92.31	3.66	78.76-96.69
			2016	92.25	3.66	78.78-96.66
		Grass	2001	68.84	13.25	11.42-83.41
			2006	67.51	13.52	10.59-80.01
			2011	66.82	13.59	11.42-80.01
			2016	66.73	13.38	14.86-80.01
		Shrub	2001	55.47	16.47	0-75.39
			2006	59.20	16.67	0-77.03
			2011	59.10	20.08	0-75.41
			2016	55.82	24.88	0-88.63
		Wetland	2001	91.92	2.66	86.46-96.20
			2006	91.88	2.74	86.23-96.19
			2011	91.81	2.78	86.17-96.15
			2016	91.85	2.78	86.19-96.11
		Developed area	2001	95.23	6.10	80.32-99.95
			2006	95.28	6.09	80.24-99.95
			2011	95.33	6.06	80.25-99.95
			2016	95.36	6.04	80.25-99.95
	CONNECT	Combined GI	2001	2.74	3.84	0.12-14.49
			2006	2.70	3.75	0.12-14.08
			2011	2.70	3.74	0.12-14.05
			2016	2.65	3.59	0.12-12.72
		Forest	2001	1.90	2.66	0.10-11.23
			2006	1.91	2.66	0.10-11.07
			2011	1.92	2.67	0.10-11.07
			2016	1.94	2.73	0.10-11.07

	Grass	2001	4.15	10.41	0-54.55
		2006	3.93	10.08	0-53.03
		2011	4.01	10.42	0-54.55
		2016	4.13	10.46	0-54.55
	Shrub	2001	8.28	21.40	0-100
		2006	2.92	9.46	0-50
		2011	2.96	9.47	0-50
		2016	3.19	9.49	0-50
	Wetland	2001	2.30	3.67	0.11-15.97
		2006	2.15	3.37	0.11-15.98
		2011	2.17	3.39	0.11-15.98
		2016	2.18	3.32	0.11-15.34
	Developed area	2001	1.59	2.31	0.06-10.34
		2006	1.59	2.30	0.06-10.26
		2011	1.63	2.44	0.06-11.21
		2016	1.62	2.40	0.06-10.96