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Scientific Investigations Report 2008–5095

U.S. Department of the Interior
U.S. Geological Survey

Cover. Left: **Logan River, Utah.** Right: **Urbanization in the Salt Lake basin, Utah** *(photographs taken by Elise M. Giddings, formerly with the U.S. Geological Survey)***.**

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By Thomas F. Cuffney and James A. Falcone

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U.S. Geological Survey, Reston, Virginia: 2009

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Suggested citation:
Cuffney, T.F., and Falcone, J.A., 2009, Derivation of nationally consistent indices representing urban intensity within and across nine metropolitan areas of the conterminous United States: U.S. Geological Survey Scientific Investigations Report 2008–5095, 36 p.
[Available online at http://pubs.water.usgs.gov/sir2008-5095]

Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with credible scientific information that helps to enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (*http://www.usgs.gov/*). Information on the Nation's water resources is critical to ensuring long-term availability of water that is safe for drinking and recreation and is suitable for industry, irrigation, and fish and wildlife. Population growth and increasing demands for water make the availability of that water, now measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, State, and local information needs and decisions related to water-quality management and policy (*http://water.usgs.gov/nawqa*). The NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. From 1991 to 2001, the NAWQA Program completed interdisciplinary assessments and established a baseline understanding of water-quality conditions in 51 of the Nation's river basins and aquifers, referred to as Study Units (*http://water.usgs.gov/nawqa/studyu.html*).

Multiple national and regional assessments are ongoing in the second decade (2001–2012) of the NAWQA Program as 42 of the 51 Study Units are reassessed. These assessments extend the findings in the Study Units by determining status and trends at sites that have been consistently monitored for more than a decade, and filling critical gaps in characterizing the quality of surface water and ground water. For example, increased emphasis has been placed on assessing the quality of source water and finished water associated with many of the Nation's largest community water systems. During the second decade, NAWQA is addressing five national priority topics that build an understanding of how natural features and human activities affect water quality, and establish links between sources of contaminants, the transport of those contaminants through the hydrologic system, and the potential effects of contaminants on humans and aquatic ecosystems. Included are topics on the fate of agricultural chemicals, effects of urbanization on stream ecosystems, bioaccumulation of mercury in stream ecosystems, effects of nutrient enrichment on aquatic ecosystems, and transport of contaminants to public-supply wells. These topical studies are conducted in those Study Units most affected by these issues; they comprise a set of multi-Study-Unit designs for systematic national assessment. In addition, national syntheses of information on pesticides, volatile organic compounds (VOCs), nutrients, selected trace elements, and aquatic ecology are continuing.

The USGS aims to disseminate credible, timely, and relevant science information to address practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, regional, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

Matthew C. Larsen
Associate Director for Water

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Conversion Factors, Acronyms, Abbreviations, and Definitions

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Metropolitan area abbreviations and land-cover definitions

ATL	Atlanta, Georgia (GA), metropolitan area
BIR	Birmingham, Alabama (AL), metropolitan area
BOS	Boston, Massachusetts (MA), metropolitan area
DEN	Denver, Colorado (CO), metropolitan area
DFW	Dallas-Fort Worth, Texas (TX), metropolitan area
EUSE	Effects of Urbanization on Stream Ecosystems Studies
GIS	Geographic information system
HUDEN	Housing-unit density
LDI	Landscape Development Intensity
MGB	Milwaukee-Green Bay, Wisconsin (WI), metropolitan area
NAWQA	National Water-Quality Assessment Program
NHD	National Hydrography Data
NLCD01	National Land Cover Data 2001
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
P_NLCD1_2	Percentage of developed land in basin
POR	Portland, Oregon (OR), metropolitan area
RAL	Raleigh-Winston Salem, North Carolina (NC), metropolitan area
ROADDEN	Road density
SLC	Salt Lake City, Utah (UT), metropolitan area
TRI	Toxics release inventory
USGS	U.S. Geological Survey
USEPA	U.S. Environmental Protection Agency

Statistical and mathematical abbreviations and definitions

MA-NUII	Metropolitan area national urban intensity index
MA-UII	Metropolitan area urban intensity index
NUII	National urban intensity index
R^2	Regression coefficient
$\geq$	Greater than or equal to
$>$	Greater than
$<$	Less than
%	Percentage
ρ	Spearman rank correlation coefficient
$\lvert\rho\rvert$	Absolute value of the Spearman rank correlation coefficient

Derivation of Nationally Consistent Indices Representing Urban Intensity within and across Nine Metropolitan Areas of the Conterminous United States

By Thomas F. Cuffney and James A. Falcone

Abstract

Two nationally consistent multimetric indices of urban intensity were developed to support studies of the effects of urbanization on streams in nine metropolitan areas of the conterminous United States: Atlanta, Georgia; Birmingham, Alabama; Boston, Massachusetts; Dallas-Fort Worth, Texas; Denver, Colorado; Milwaukee-Green Bay, Wisconsin; Portland, Oregon; Raleigh, North Carolina; and Salt Lake City, Utah. These studies were conducted as a part of the U.S. Geological Survey's National Water-Quality Assessment Program. These urban intensity indices were used to define gradients of urbanization and to interpret biological, physical, and chemical changes along these gradients. Ninety census, land-cover, and infrastructure variables obtained from nationally available databases were evaluated. Only variables that exhibited a strong and consistent linear relation with 2000 population density were considered for use in the indices. Housing-unit density (HUDEN), percentage of basin area in developed land (P_NLCD1_2), and road density (ROADDEN) were selected as the best representatives of census, land-cover, and infrastructure variables. The metropolitan area national urban intensity index (MA-NUII) was scaled to represent urban intensity within each metropolitan area and ranged from 0 (little or no urban) to 100 (maximum urban) for sites within each metropolitan area. The national urban intensity index (NUII) was scaled to represent urban intensity across all nine metropolitan areas and ranged from 0 to 100 for all sites. The rates at which HUDEN, P_NLCD1_2, and ROADDEN changed with changes in population density varied among metropolitan areas. Therefore, these variables were adjusted to obtain a more uniform rate of response across metropolitan areas in the derivation of the NUII. The NUII indicated that maximum levels of urban intensity occurred in the West and Midwest rather than in the East primarily because small inner-city streams in eastern metropolitan areas are buried and converted to storm drains or sewers and because of higher density development in the Western and Central United States. The national indices (MA-NUII, NUII) were compared to indices that were derived independently for each metropolitan area (MA-UII) based on variables that were of local interest. The MA-UIIs, which were based on 5 to 40 variables, tended to overestimate urban intensity relative to the national indices particularly when the MA-UII was composed of large numbers of variables that were not linearly related to population density as in Denver, Dallas-Fort Worth, and Milwaukee-Green Bay.

Introduction

The U.S. Geological Survey (USGS) is studying the effects of urbanization on the biological, physical, and chemical characteristics of streams as a part of the Effects of Urbanization on Stream Ecosystems (EUSE) studies of the National Water-Quality Assessment (NAWQA) Program. Nine EUSE studies (fig. 1) have been completed in metropolitan areas associated with Atlanta, GA (ATL); Birmingham, AL (BIR); Boston, MA (BOS); Dallas-Fort Worth, TX (DFW); Denver, CO (DEN); Milwaukee-Green Bay, WI (MGB); Portland, OR (POR); Raleigh, NC (RAL); and Salt Lake City, UT (SLC). Biological, physical, and chemical responses to urbanization were studied using a common experimental design (Coles and others, 2004; Tate and others, 2005) that selects representative sites along a gradient of urban intensity from rural to highly urbanized in each metropolitan area. Confounding effects of natural environmental factors were minimized by limiting each study to an area with relatively homogeneous natural environmental features (for example, similar stream size, ecoregion [Omernik, 1987], climate, and potential natural vegetation).

The urban gradient is defined using a multimetric index of urban intensity based on census, land-cover, and infrastructure variables (McMahon and Cuffney, 2000; Coles and others, 2004; Tate and others, 2005) obtained from local and national data (Tate and others, 2005; Falcone and others, 2007). The use of a multimetric index emphasizes the multivariate nature of urbanization and compensates for variability in the derivation of the characteristics of urbanization. For example, census data are derived from census blocks that vary in size from very large in rural areas (counties) to very small (city blocks) in heavily populated urban areas. Consequently, basin-level census values (for example, population density, housing

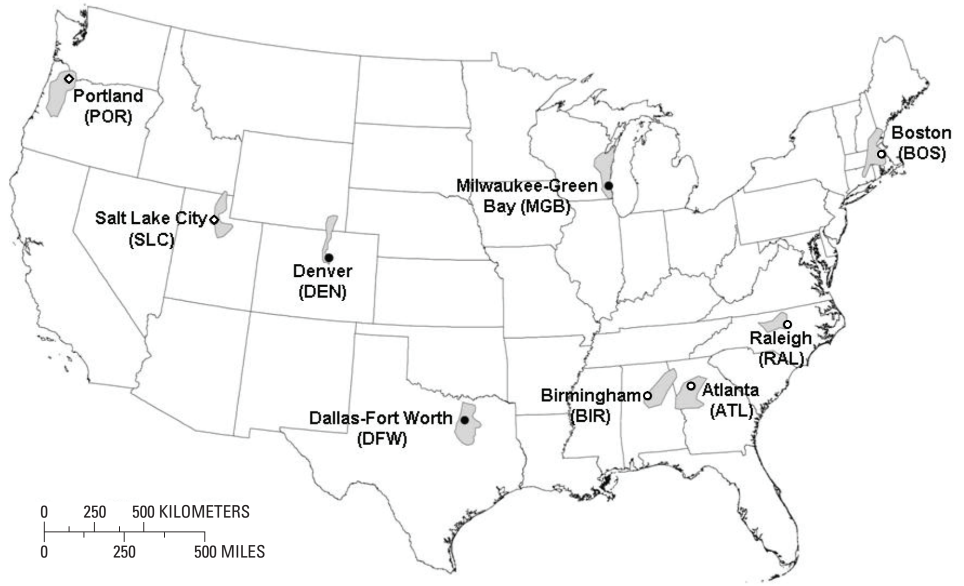

Figure 1. Location of the nine metropolitan areas included in the EUSE studies. The shaded areas show the spatial extent of each study area. Open circles designate eastern metropolitan areas, solid circles designate central metropolitan areas, and open diamonds designate western metropolitan areas.

density, median income) were derived from a larger number of census blocks in urban areas than in rural areas (Falcone and others, 2007). In contrast, national land-cover data derived from satellite images with a constant pixel size provide a more consistent spatial scale across the country. A multimetric approach tends to offset errors in any one measurement and has been employed to great effect in biomonitoring and is applicable to non-biological variables (Karr, 1981, 1993; Yoder and Rankin, 1995; Barbour and others, 1996).

The urban intensity index is meant to characterize the changes that occur as an increasing population alters the landscape and directly and indirectly changes the physical, chemical, and biological characteristics of streams (fig. 2). Construction of buildings, roads, sewers, and other elements of urban infrastructure can lead to deforestation, increased sedimentation, increased imperviousness, reduced infiltration, and increased runoff, which can alter the structure of the riparian zone leading to changes in light penetration, bank stability, organic matter inputs, and water temperature. Sedimentation and changes in hydrology can alter instream habitats by burying substrates or changing the timing, magnitude, and duration of high and low flows. Increased residential and commercial chemical use can add contaminants, such as pesticides and metals, to water and sediment. Collectively, these changes can affect the biota of a stream leading to a loss of biodiversity and ecosystem function (McDonnell and Pickett, 1990; Sala and others, 2000; Paul and Meyer, 2001; Fitzpatrick and others, 2004; Brown and others, 2005; Sprague and others, 2006).

Population density was chosen as the central determinant of urban intensity in the EUSE studies because urban effects arise primarily from the goods and services (for example, roads, housing, utilities, and transportation) associated with supporting an increasing population density. Consequently, each of the nine urban studies derived a multimetric index of urban intensity based on a set of census, land-cover, and infrastructure variables that were correlated with population density and deemed appropriate for studying the process of urbanization in the respective metropolitan area. This metropolitan area urban intensity index (MA-UII) was constructed from as few as 5 (Atlanta, Raleigh) to as many as 40 (Dallas-Fort Worth) variables depending on the aspects of urbanization that were emphasized within each metropolitan area (Coles and others, 2004; Tate and others, 2005; Sprague and others, 2006; Gregory and Calhoun, 2007; K.D. Richards and others, U.S. Geological Survey, written commun., 2007; Moring, 2008; Waite and others, 2008). While the locally derived MA-UII was suitable for representing the urban gradient in individual studies, it was not appropriate for comparing responses to urbanization among metropolitan areas or across the Nation because of differences in the composition of the MA-UII. This report addresses this issue by developing two national urban intensity indices—metropolitan (MA-NUII) and national (NUII)—from nationally consistent variables that were scaled to represent urban intensity within (MA-NUII) and across (NUII) metropolitan areas.

Purpose and Scope

The purpose of this report is to describe the derivation of nationally consistent urban intensity indices for the NAWQA Program EUSE studies and to compare these national indices (MA-NUII, NUII) to locally derived urban intensity indices (MA-UII) for the nine metropolitan areas studied. These indices provide a consistent framework in which to interpret and compare changes in physical, chemical, and biological characteristics along gradients of urban intensity both locally and nationally.

Methods

The nine urban studies were conducted using a common study design (McMahon and Cuffney, 2000; Coles and others, 2004; Cuffney and others, 2005; Tate and others, 2005)

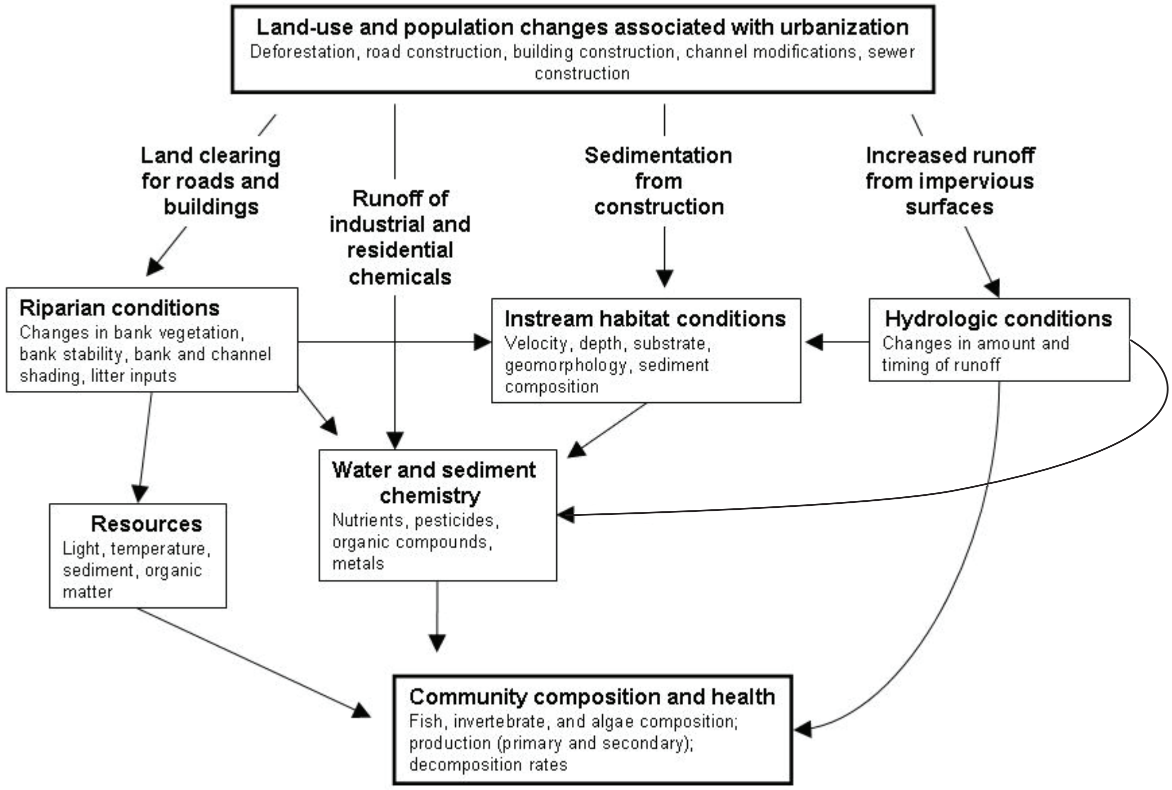

Figure 2. Conceptual model showing examples of how land-use and population characteristics associated with urbanization can affect physical, chemical, and biological characteristics of streams.

derived from nationally available geographic information system (GIS) variables (Falcone and others, 2007) to define a population of candidate basins (typically basins drained by second to third order streams) from which 28–30 basins were selected to represent a gradient of urbanization. Local and national GIS variables that represented the natural environmental setting (for example, ecoregion, climate, elevation, stream size) were used to minimize the effects of environmental variability by dividing candidate basins into groups with relatively homogenous environmental features. GIS variables that were associated with urbanization (for example, census, land cover, and infrastructure) were used to derive a multimetric index of urban intensity (MA-UII) that ranged from 0 (little or no urban) to 100 (maximum urban) in each metropolitan area. Study sites were selected to provide a relatively uniform distribution across the urban gradient (0 to 100) within as homogeneous an environmental setting as possible. The urban intensity index used to select sites (MA-UII) was derived independently for each urban study and incorporated from 5 to 40 variables (Coles and others, 2004; Tate and others, 2005; Sprague and others, 2006; Gregory and Calhoun, 2007; K.D. Richards and others, U.S. Geological Survey, written commun., 2007; Moring, 2008; Waite and others, 2008) depending on the urban factors that were deemed of interest in the study area. Selected variables from the GIS data developed by each urban study were compiled, updated, and used to derive two national urban intensity indices. Unlike the MA-UII, the variables used to derive the national indices did not vary among metropolitan areas. The metropolitan area national urban intensity index (MA-NUII) was scaled independently for each urban area, and the national urban intensity index (NUII) was scaled to represent urban intensity nationally (that is, scaled across the 265 sites from the 9 metropolitan areas).

Compilation of GIS Data

National urban intensity indices were derived from 90 GIS variables (table 1A) for drainage basins with boundaries that were developed primarily from USGS 30-meter (m) National Elevation Data (U.S. Geological Survey, 2005a); a small number of basin boundaries were refined using higher-resolution data (Coles and others, 2004; Tate and others, 2005; Falcone and others, 2007). Variables were derived for the entire basin (basin-level statistics) except the riparian land-cover variables, which were calculated as a 100-m corridor on either side of the stream midline. Streams were defined on the basis of the USGS National Hydrography Data (NHD) 1:100,000 stream set (U.S. Geological Survey, 2005b).

Population density was calculated from 2000 census block data (GeoLytics, 2001). All other census variables were calculated from 2000 census block-group data. Road characteristics (RDLENGTH, ROADDEN, RDARDEN,

Table 1. GIS-derived variables that were considered in the development of urban intensity indices (A) nationally and (A and B) for individual metropolitan areas. The variables used in the construction of the national urban intensity indices (MA-NUII and NUII) are shown in bold.

[%, percentage; km^2, square kilometer; <, less than; >, greater than; km, kilometer; m, meter; mm/hr, millimeter per hour]

Category	Abbreviation	Description
A. National variables (available in all metropolitan areas)		
Census data		
Energy source		
	PHUT	Occupied housing units using utility gas (natural gas) as fuel (%)
	PHLP	Occupied housing units using liquid petroleum gas as fuel (%)
	PHEL	Occupied housing units using electricity as fuel (%)
	PHOIL	Occupied housing units using oil as fuel (%)
	PHWOOD	Occupied housing units using wood as fuel (%)
Ethnicity		
	PPWHITE	Proportion of population race, white
	PPBLACK	Proportion of population race, black
	PPNAM	Proportion of population race, Native American
	PPASIA	Proportion of population race, Asian
	P_US	Proportion of citizens born in United States
	P_INSTAT	Proportion of citizens born in State of residence
	P_OUTST	Proportion of citizens born in other States in the United States
	P_NONUS	Proportion of citizens not born in United States
	PC_CTY95	Proportion of citizens living in same county more than 5 years
	PC_ST95	Proportion of citizens living in same State more than 5 years
Housing age		
	PHU_L5	Proportion of housing units built between 1995 and 2000
	PHU_L10	Proportion of housing units built between 1990 and 2000
	PHU_L20	Proportion of housing units built between 1980 and 2000
	PHU_G20	Proportion of housing units built prior to 1979
	PHU_G30	Proportion of housing units built prior to 1969
	PHU_G40	Proportion of housing units built prior to 1959
	PHU_G50	Proportion of housing units built prior to 1949
	PHU_G60	Proportion of housing units built prior to 1939
Housing occupancy		
	HHDEN	Household density (occupied housing units/km^2)
	HUDEN	Density of housing units (housing units/km^2)
	PHO_G4P	Proportion of households occupied by 4 or more people
	PP_SH95	Percent of population living in same house as in 1995
	P_OWN	Proportion of occupied housing units that are owner occupied
	P_RENT	Proportion of occupied housing units that are renter occupied
	PHFAM	Proportion of households occupied by a family
	PHNONFAM	Proportion of households occupied by a non-family
	PHO_L3P	Proportion of households occupied by less than 3 people
	P_OCCUPY	Proportion of housing units that are occupied
	P_VACANT	Proportion of housing units that are vacant
	PH_1PERS	Proportion of households occupied by 1 person
	PH_2PERS	Proportion of households occupied by 2 persons
	PH_3PERS	Proportion of households occupied by 3 persons
	PH_4PERS	Proportion of households occupied by 4 persons
	PH_5PERS	Proportion of households occupied by 5 persons
	PH_6PERS	Proportion of households occupied by 6 persons
	PH_7PERS	Proportion of households occupied by 7 or more persons

Table 1. GIS-derived variables that were considered in the development of urban intensity indices (A) nationally and (A and B) for individual metropolitan areas. The variables used in the construction of the national urban intensity indices (MA-NUII and NUII) are shown in bold. — Continued

[%, percentage; km^2, square kilometer; <, less than; >, greater than; km, kilometer; m, meter; mm/hr, millimeter per hour]

Category	Abbreviation	Description
Census data (continued)		
Income		
	PHHI_L10	Proportion of households with annual income < $10,000
	PHHI_L20	Proportion of households with annual income < $20,000
	PHHI_L30	Proportion of households with annual income < $30,000
	MEDHHI	Median household income (dollars)
	PM_GT16E	Proportion of male population > 16 years of age and employed
	PF_GT16E	Proportion of female population > 16 years of age and employed
	PPOP_POV	Proportion of population with income below the poverty level
	PFAM_POV	Proportion of families with income below the poverty level
	PHH_POV	Proportion of households with income below the poverty level
	PERCAPIN	Per Capita income
	MFAMINC	Median family household income
	MNFAMINC	Median non-family household income
Population		
	POPDEN00	2000 population density (people/km^2)
	POP90_00	Proportional change in population from 1990 to 2000
	PPURBAN	Proportion of population living in urban area
	PPRURAL	Proportion of population living in rural area
	PP_L5Y	Proportion of population < 5 years old
	PHS_G25	Proportion of population > 25 years old with high school degree
	PBCH_G25	Proportion of population > 25 years old with bachelors degree
	POCC_G65	Proportion of housing units occupied by persons > 65 years of age
	PPMALE	Proportion of population that is male
	PPFEMALE	Proportion of population that is female
	PM_GT25Y	Proportion of male population > 25 years of age
	PF_GT25Y	Proportion of female population > 25 years of age
NLCD01 Level 1 land cover		
Percentage of basin area		
	P_NLCD1_1	Water
	P_NLCD1_2	Developed
	P_NLCD1_3	Barren
	P_NLCD1_4	Forest
	P_NLCD1_5	Shrubland
	P_NLCD1_7	Herbaceous upland natural/semi-natural vegetation (grassland)
	P_NLCD1_8	Crops and pasture
	P_NLCD1_9	Wetlands
	NLCD1_IS	Mean percent impervious surface in the basin (NLCD data)
	NOAA_1KM_IS	Mean percent impervious surface in the basin (NOAA 1 km data)
Percentage of riparian buffer (approximately 100-m area each side of stream centerline)		
	P_NLCD1_B1	Water
	P_NLCD1_B2	Developed
	P_NLCD1_B3	Barren
	P_NLCD1_B4	Forest
	P_NLCD1_B5	Shrubland
	P_NLCD1_B7	Herbaceous upland natural/semi-natural vegetation (grassland)
	P_NLCD1_B8	Crops and pasture
	P_NLCD1_B9	Wetlands
	NLCD1_BIS	Mean percent impervious surface in the riparian zone

Table 1. GIS-derived variables that were considered in the development of urban intensity indices (A) nationally and (A and B) for individual metropolitan areas. The variables used in the construction of the national urban intensity indices (MA-NUII and NUII) are shown in bold. — Continued

[%, percentage; km^2, square kilometer; <, less than; >, greater than; km, kilometer; m, meter; mm/hr, millimeter per hour]

Category	Abbreviation	Description
Infrastructure		
	RDLENGTH	Length of TIGER roads in basin (km) in basin
	ROADDEN	Road density in basin (km/km^2)
	RDARDEN	Road area index density (km/km^2)
	RDTRDEN	Road traffic index density (km/km^2)
	D_PSCOUNT	Point-source dischargers in basin (number/100 km^2)
	D_TRICOUNT	Toxics Release Inventory sites in basin (number/100 km^2)
B. Local variables (available in some metropolitan areas, but not nationally)		
Category	**Abbreviation**	**Description**
Census data		
Ethnicity		
	P_NWHT99	Percent of 1999 population that is non-white
Housing age		
	PHOUSL80	Percent of 1990 housing units built before 1980
Housing occupancy		
	PHH2	Proportion of households that are two-person households
	P_HU3RM	Proportion of total housing units that have three bedrooms
	P_FHHF90	Percent of families with female head of household
Population		
	POP90_99	Percentage change in population density between 1990 and 1999
	SEI_2	Socio-economic index 2
	SEI_3	Socio-economic index 3
	SEI_4	Socio-economic index 4
	SEI_5	Socio-economic index 5
NLCD01 Level 2 land cover		
Percentage of basin area		
	P_NLCD1_21	Low-intensity residential
	P_NLCD1_22	High-intensity residential
	P_NLCD1_23	Commercial/industrial/transportation
	P_NLCD1_41	Deciduous forest
	P_NLCD1_42	Evergreen forest
	P_NLCD1_43	Mixed forest
	P_NLCD1_81	Pasture/hay
	P_NLCD1_82	Row cops
	P_NLCD1_85	Urban/recreational grasses
	P_NLCD1_95	Wetlands, emergent herbaceous wetlands
Infrastructure		
	P_SEWER	Percent of housing units on public sewer
	DAMDEN	Dam density (number/100 hectares)
Miscellaneous		
	PHSG2	Hydrologic soil group B, minimum infiltration rate 4-8 mm/hr (percent basin area)
	PLITH_146	Percent of basin area in lake sediment and playa
	WELLPCT	Proportion of watershed with well-drained soils

RDTRDEN) were derived from Census 2000 TIGER roads (GeoLytics, 2001). Point-source discharge count density (DPSCOUNT, number of discharge permits per 100 square kilometers (km^2) was derived from the U.S. Environmental Protection Agency (USEPA) National Pollutant Discharge Elimination System (NPDES) (U.S. Environmental Protection Agency, 2005a). Toxics release inventory (TRI) count density (D_TRICOUNT, number of TRI dischargers per 100 km^2) was derived from the USEPA Toxics Release Inventory database (U.S. Environmental Protection Agency, 2005b).

Land-cover data for ATL, BOS, BIR, RAL, and SLC were based on the National Land Cover Data 2001 (NLCD01) dataset (U.S. Geological Survey, 2005c). Land-cover data for POR were derived (Falcone and others, 2007) by using the NLCD01 class structure to process data from the National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (National Oceanic and Atmospheric Administration, 2005). NOAA land-cover classes were recoded to match the NLCD01 classes. Land-cover data for DEN, DFW, and MGB were derived using identical methods and protocols as the NLCD01 program (Falcone and Pearson, 2006). The 16 NLCD01 land-cover classes (Multi-Resolution Land Characteristics Consortium, 2008) were aggregated into 8 Anderson Level 1 classes. For example, “deciduous forest,” “evergreen forest,” and “mixed forest” were aggregated into “forest” (Anderson and others, 1976) because the broader Level 1 classes were deemed to be more reliable than the Level 2 classes (Falcone and others, 2007).

Some of the GIS variables used to develop the MA-UII were not used in the derivation of national indices (table 1B) because these variables were not available nationally (for example, P_HU3RM and P_FHHF90), were thought to be inconsistent among metropolitan areas (for example, Level 2 NLCD01 data), or were not amenable to calculation at the national level (for example, socioeconomic indices SEI_2, SEI_3, SEI_5 [McMahon and Cuffney, 2000], which are compilations of census variables obtained from principal components analysis within each metropolitan area). The BOS, BIR, and SLC studies were conducted before 2000 census and 2001 NLCD data were available so the MA-UII for these metropolitan areas (Coles and others, 2004; Tate and others, 2005) was based on projected 1999 census and 1992 NLCD data. The national indices (MA-NUII, NUII) for BOS, BIR, and SLC, however, are based on 2000 census and 2001 NLCD data. The SLC MA-UII was unique in that it included soil and lithographic characteristics (PHSG2, PLITH_146, WELLPCT) of the drainage basins.

Derivation of Metropolitan Area Urban Intensity Indices (MA-UII)

The MA-UII indices were derived independently for each metropolitan area on the basis of a compilation of GIS variables (census, land cover, infrastructure) that were correlated (Spearman rank correlation, $|\rho| \geq 0.5$) with population density (SPSS, Inc., 1999). The variables that were used to create the MA-UII varied among metropolitan areas depending on which variables were deemed important for understanding urbanization. Each variable was range standardized as follows:

$$X_{rs} = [(X_i - X_{min})/(X_{max} - X_{min})]*100$$

where:

X_i = value of variable (for example, HHDEN) at site

X_{min} = minimum value of X over all sites

X_{max} = maximum value of X over all sites

X_{rs} = range standardized X_i

Variables that were negatively correlated with population density were adjusted by subtracting the range-standardized value from 100. This ensured that all range-standardized variables increased with increasing population density. Values of all range-standardized variables used in the MA-UII (for example, HHDEN, P_NLCD1_2, ROADDEN) were averaged for each site to produce a preliminary index. The preliminary index values were range standardized to produce a final urban intensity index (MA-UII) that ranged from 0 (little or no urban) to 100 (maximum urban) for each metropolitan area (McMahon and Cuffney, 2000). The calculation of the MA-UII is illustrated in table 2 for a hypothetical set of data.

Derivation of National Urban Intensity Indices (MA-NUII, NUII)

The MA -NUII and NUII indices were derived by identifying census, land-cover, and infrastructure variables that were strongly correlated ($|\rho| \geq 0.7$) with population density (POPDEN00) for each of the nine urban studies. These variables were plotted against POPDEN00 to determine the form and consistency of the response across the range of population density. Variables that were strongly correlated with POPDEN00 and that exhibited a consistent linear response across the entire range of population density were further evaluated by examining the relation (linear regression) among variables within each data source (census, land cover, infrastructure). Redundant (that is, highly related) variables were eliminated to obtain a subset with equal representation of each data source. Linear regressions and correlations were calculated using SYSTAT 9 (SPSS, Inc., 1999).

Once a consistent set of variables was identified, the MA-NUII was calculated separately for each metropolitan area by using the same procedures as were used to derive the MA-UII (range standardization, adjustment of negatively correlated variables, averaging the range-standardized variables, and range standardizing the averages). This produced an index that ranged from 0 (little or no urban) to 100 (highest urban) for each metropolitan area based on a nationally consistent set of variables.

Table 2. Hypothetical example illustrating the calculation of the national urban intensity indices (MA-UII, MA-NUII) for a metropolitan area with 30 sites (data are shown for nine sites). The index variables (VAR1–VAR3) are correlated with 2000 population density (POPDEN00) and range standardized using the maximum and minimum values for each variable. Variables that are negatively correlated with population density (VAR3) are adjusted by subtracting the unadjusted value from 100. The range-standardized values are averaged to form the preliminary index, and the preliminary index is range standardized to form the MA-UII or MA-NUII.

					Range-standardized variables					
		Values of index variables					VAR3			
Site	POPDEN00	VAR1	VAR2	VAR3	VAR1	VAR2	Unadjusted	Adjusted	Preliminary index	MA-UII or MA-NUII
1	30.42	12.90	4.36	10.55	0.94	1.42	100.00	0.00	0.79	0.0
2	408.23	130.80	52.98	4.48	18.78	52.38	32.29	67.71	46.3	46.6
3	148.65	65.88	20.00	7.10	8.95	17.81	61.48	38.52	21.8	21.5
:	:	:	:	:	:	:	:	:	:	:
14	1,235.1	541.5	94.2	1.6	80.9	95.5	0.3	99.7	92.0	93.4
15	1,212.4	667.7	98.4	2.0	100.0	100.0	4.7	95.3	98.4	100.0
16	789.9	281.0	72.2	3.8	41.5	72.5	25.1	74.9	63.0	63.7
:	:	:	:	:	:	:	:	:	:	:
28	472.6	166.8	55.9	4.6	24.2	55.5	33.6	66.4	48.7	49.0
29	292.5	116.8	38.8	5.8	16.7	37.5	46.8	53.2	35.8	35.8
30	1,083.3	446.8	96.9	1.8	66.6	98.4	2.0	98.0	87.7	88.9
Maximum:		667.7	98.4	10.6	100.0	100.0	100.0	100.0	98.4	100.0
Minimum:		6.7	3.0	1.6	0.0	0.0	0.0	0.0	0.8	0.0
Correlation with POP-DEN00		0.98	0.89	-0.97						

The derivation of the NUII involved the same variables and range standardization techniques as were used to derive the MA-NUII. However, the range standardization occurred over all sites from the nine metropolitan areas, and variables were adjusted to account for differences in the rates at which the index variables responded to changes in population density among metropolitan areas. Variables were adjusted by deriving regression equations that related the value of each variable to population density in each urban area. These regression equations were used to predict the value of the variable at the maximum population density observed over all nine urban studies. The observed values were expressed as a percentage of the predicted value and then range standardized over all sites (nine metropolitan areas combined) following the procedures used for MA-UII and MA-NUII (range standardization, adjustment of negatively correlated variables, averaging the range-standardized variables, and range standardizing the averages) to produce an index (NUII) that varied from 0 to 100 over all sites from the nine metropolitan areas rather than separately for each area. As a result, the NUII ranged from 0 (little or no urban) to 100 (highest urban), but each metropolitan area did not necessarily encompass sites that ranged from 0 to 100.

Derivation and Comparison of Urban Intensity Indices

This report focuses on the derivation of the national urban intensity indices (MA-NUII, NUII); consequently, only brief overviews of the GIS data and MA-UII results are presented here. A more detailed presentation of the GIS data and the methods used to derive these data can be found in Falcone and others (2007). The MA-UII results that are reported here (table 3, p. 25) are detailed in Coles and others (2004), Tate and others (2005), Sprague and others (2006), Gregory and Calhoun (2007), K.D. Richards and others, U.S. Geological Survey, written commun. (2007), Moring (2008), and Waite and others (2008).

Metropolitan Area Urban Intensity Indices (MA-UII)

The urban intensity indices that were derived independently for each metropolitan area (MA-UII) differed substantially in the number of variables that were incorporated into the index (table 4) with as many as 40 (DFW) and as

Table 4. Census, land-cover, and infrastructure variables that were used to construct the metropolitan area urban intensity index (MA-UII) for each metropolitan area. Abbreviations are described in table 1.

Metropolitan area	Variables incorporated into MA-UII
Boston (BOS)	
Census	P_FHHF90, PHOUSL80, P_RENT, P_NWHT99, POP90_99, SEI_2, SEI_3, SEI_5
Basin land cover	P_NLCD1_2, P_NLCD1_4, P_NLCD1_21, P_NLCD1_22, P_NLCD1_23, P_NLCD1_42, P_NLCD1_43, P_NLCD1_82, P_NLCD1_85
Riparian land cover	P_NLCD1_B2, P_NLCD1_B4
Infrastructure	ROADDEN, D_PSCOUNT, DAMDEN, D_TRICOUNT
Raleigh (RAL)	
Census	POPDEN00, HHDEN
Basin land cover	P_NLCD1_2
Riparian land cover	P_NLCD1_B2
Infrastructure	ROADDEN
Atlanta (ATL)	
Census	HUDEN
Basin land cover	P_NLCD1_2, P_NLCD1_4
Riparian land cover	P_NLCD1_B2
Infrastructure	ROADDEN
Birmingham (BIR)	
Census	SEI_2
Basin land cover	P_NLCD1_2, P_NLCD1_4, P_NLCD1_21, P_NLCD1_22, P_NLCD1_23, P_NLCD1_41, P_NLCD1_43, P_NLCD1_81, P_NLCD1_85
Riparian land cover	P_NLCD1_B2, P_NLCD1_B4
Infrastructure	ROADDEN, P_SEWER
Milwaukee-Green Bay (MGB)	
Census	PHEL, PHOIL, PHWOOD, PPBLACK, PPWHITEPPASIA, P_US, P_INSTAT, P_OUTST, P_NONUS, PHU_G50, PHU_G60, HHDEN, HUDEN, PP_SH95, P_OWN, P_RENT, PF_GT16E, SEI_2, SEI_4, PPURBAN, PPRURAL, PHS_G25, PBCH_G25, PPMALE, PPFEMALE
Basin land cover	P_NLCD1_2, P_NLCD1_5, P_NLCD1_8, NLCD1_IS
Riparian land cover	P_NLCD1_B5, P_NLCD1_B8, NLCD1_BIS
Infrastructure	RDARDEN, RDTRDEN
Denver (DEN)	
Census	HUDEN, PPURBAN, POP90_00, PC_ST95, PM_GT16E, PHH2, P_HU3RM, PH_2PERS, PHU_G60, PHWOOD, PHLP,
Basin land cover	P_NLCD1_2, P_NLCD1_7, P_NLCD1_8, P_NLCD1_95
Riparian land cover	
Infrastructure	RDARDEN
Dallas-Fort Worth (DFW)	
Census	PHLP, PHWOOD, PHUT, PPWHITE, PPASIA, P_US, P_INSTAT, P_OUTST, PHU_G50, PHU_G60, HHDEN, HUDEN, PHO_L3P, P_OCCUPY, P_VACANT, PP_SH95, PH_2PERS, POCC_G65, PPURBAN, PPRURAL, MNFAMINC, SEI_2, SEI_3, SEI_4, PBCH_G25, PHS_G25
Basin land cover	P_NLCD1_2, P_NLCD1_5, P_NLCD1_7, P_NLCD1_8, NLCD1_IS
Riparian land cover	P_NLCD1_B2, P_NLCD1_B5, P_NLCD1_B7, P_NLCD1_B8, NLCD1_BIS
Infrastructure	ROADDEN, RDARDEN, RDTRDEN, D_TRICOUNT
Salt Lake City (SLC)	
Census	SEI _2, POP90_99
Basin land cover	P_NLCD1_2, P_NLCD1_4, P _NLCD1_5
Riparian land cover	P_NLCD1_B2, P_NLCD1_B4, P_NLCD1_B5
Infrastructure	ROADDEN, P_SEWER
Other	PLITH_146, PHSG2, WELLPCT
Portland (POR)	
Census	PHLP, PHWOOD, PHUT, PASIA, P_US, PHU_G60, HHDEN, HUDEN, PPURBAN, PPRURAL, PP_SH95, SEI_3
Basin land cover	P_NLCD1_2, P_NLCD1_3, P_NLCD1_4, P_NLCD1_5, NLCD1_IS
Riparian land cover	P_NLCD1_B2, P_NLCD1_B3, P_NLCD1_B4, P_NLCD1_B5, NLCD1_BIS
Infrastructure	ROADDEN, RDTRDEN

few as 5 (ATL, RAL) variables defining urban intensity. The distribution of variables among the major sources of data (census, land cover, and infrastructure) varied widely, with some metropolitan areas having nearly equal distribution (ATL, RAL) and others (DEN, DFW, MGB) having a preponderance (65–75 percent) of census variables. The greatest commonality among MA-UII variables used by the various studies was for land cover (P_NLCD1_2, included in nine of nine metropolitan areas) and infrastructure (ROADDEN, included in seven of nine metropolitan areas). There was considerably less commonality among the census variables that were incorporated into the MA-UII. Measures of housing density (HHDEN or HUDEN) and socioeconomic indices were included most often (six of nine metropolitan areas). The RAL MA-UII included population density in the index whereas all other indices excluded population density as a component of the index (table 4).

Selection of Variables for National Urban Intensity Indices

The census, land-cover, and infrastructure variables that were strongly correlated with population density varied among metropolitan areas (table 5). The largest numbers of strong correlations were seen among the land-cover and infrastructure variables. Census variables showed surprisingly few consistent correlations with population density. Variables that were strongly correlated with population density generally showed one of two forms of response—either a consistent linear response across the range of population density (HUDEN, fig. 3A) or a curvilinear response in which the variable responded only over a portion of the population gradient (PPURBAN, fig. 3B). Variables that showed a nearly linear response provided a consistent representation of change across the entire population density gradient and were suitable

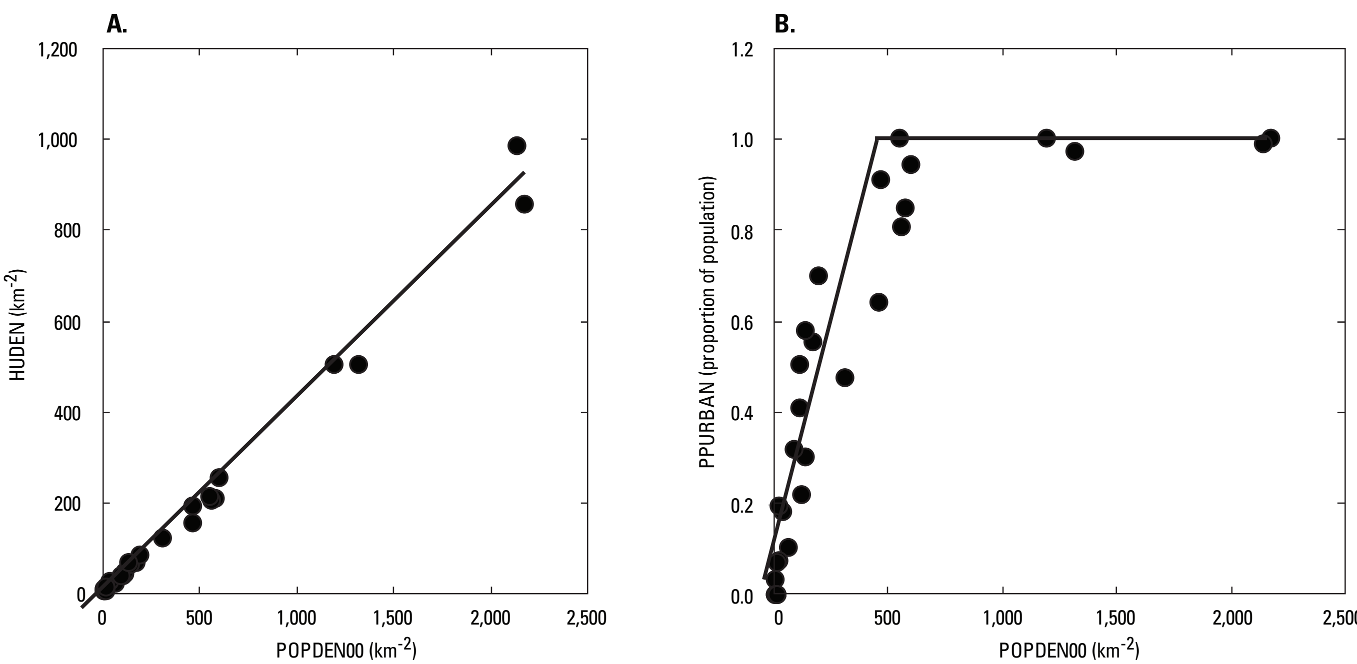

Figure 3. Response of the (A) HUDEN and (B) PPURBAN census variables in relation to population density (POPDEN00) for the Milwaukee-Green Bay (MGB) metropolitan area. Abbreviations are explained in table 1.

Table 5A. Spearman rank correlations between 2000 population density (POPDEN00) and variables considered in the derivation of nationally consistent urban intensity indices (MA-NUII, NUII). Bold entries indicate a correlation (|ρ|) ≥ 0.7.

[|ρ|, absolute value of Spearman rank correlation; ≥, greater than or equal to]

Abbreviation (see table 5B)	BOS	RAL	ATL	BIR	MGB	DEN	DFW	SLC	POR
Census data									
Energy source									
PHUT	**0.81**	**0.84**	**0.88**	0.47	**0.81**	0.47	0.64	0.52	**0.78**
PHLP	**-0.73**	**-0.92**	**-0.94**	-0.69	**-0.89**	-0.58	**-0.93**	-0.45	**-0.78**
PHEL	**0.70**	-0.45	-0.34	-0.23	0.62	0.31	0.28	-0.30	0.00
PHOIL	**-0.73**	-0.30	-0.30	-0.42	**-0.82**	-0.21	-0.09	-0.14	-0.41
PHWOOD	**-0.92**	**-0.83**	**-0.86**	-0.51	**-0.90**	-0.62	**-0.73**	0.08	**-0.90**
Ethnicity									
PPWHITE	**-0.84**	0.00	-0.26	-0.51	**-0.80**	-0.26	-0.53	-0.46	-0.62
PPBLACK	**0.77**	-0.13	0.12	0.53	**0.76**	0.47	0.40	0.57	0.65
PPNAM	-0.20	0.36	0.25	-0.25	0.20	0.07	-0.09	0.32	0.29
PPASIA	0.68	0.42	0.65	0.58	**0.84**	0.36	**0.77**	0.44	**0.74**
P_US	**-0.82**	-0.65	**-0.80**	-0.41	**-0.80**	-0.38	-0.52	-0.45	**-0.81**
P_INSTAT	**0.73**	-0.34	**-0.84**	-0.14	**-0.79**	0.24	**-0.73**	-0.34	-0.56
P_OUTST	**-0.80**	0.15	**0.84**	0.13	**0.72**	-0.40	0.59	0.14	0.20
P_NONUS	0.19	0.26	0.59	0.25	0.66	0.34	0.48	0.66	0.64
PC_CTY95	-0.01	0.36	0.46	0.51	0.44	0.04	0.45	0.04	0.41
PC_ST95	-0.26	-0.40	-0.27	-0.19	0.02	0.63	-0.26	-0.01	0.49
Housing age									
PHU_L5	-0.43	-0.42	-0.10	-0.36	0.03	-0.47	-0.02	-0.14	0.41
PHU_L10	-0.36	-0.41	-0.11	-0.46	0.11	-0.41	-0.01	-0.20	0.30
PHU_L20	-0.69	-0.32	0.09	-0.49	0.10	-0.30	0.09	-0.17	0.17
PHU_G20	0.69	0.32	-0.09	0.48	-0.11	0.30	-0.10	0.17	-0.17
PHU_G30	0.62	0.31	-0.29	0.32	-0.11	0.13	-0.28	0.01	-0.04
PHU_G40	0.53	0.30	-0.55	0.17	-0.30	-0.05	-0.48	-0.07	-0.25
PHU_G50	0.29	0.24	**-0.71**	-0.10	**-0.74**	-0.42	**-0.79**	-0.38	-0.58
PHU_G60	0.15	0.09	**-0.83**	-0.22	**-0.80**	-0.54	**-0.86**	-0.46	**-0.73**
Housing occupancy									
HHDEN	**1.00**	**0.99**	**0.98**	**0.97**	**0.99**	**0.99**	**0.99**	**0.90**	**0.99**
HUDEN	**1.00**	**0.99**	**0.99**	**0.97**	**0.99**	**0.98**	**0.98**	**0.88**	**0.99**
PHO_G4P	-0.19	-0.21	0.07	-0.54	-0.37	-0.27	0.25	-0.27	-0.36
PP_SH95	0.40	-0.52	-0.54	-0.37	**-0.78**	-0.24	-0.62	0.07	**-0.80**
P_OWN	-0.59	-0.63	-0.14	-0.39	-0.60	-0.41	-0.40	-0.22	-0.51
PHFAM	-0.40	-0.58	-0.12	-0.49	-0.46	-0.44	-0.08	-0.20	-0.47
PHNONFAM	0.40	0.58	0.12	0.49	0.46	0.44	0.08	0.20	0.47
PHO_L3P	-0.58	**-0.77**	-0.01	-0.28	-0.32	-0.41	-0.63	0.17	-0.15
P_OCCUPY	0.68	0.19	**0.79**	0.07	0.13	0.35	0.64	0.57	0.42
P_VACANT	-0.68	-0.19	**-0.79**	-0.07	-0.19	-0.35	-0.66	-0.56	-0.42
P_RENT	0.59	0.63	0.14	0.39	0.60	0.41	0.40	0.22	0.51
PH_1PERS	0.62	0.60	0.01	0.44	0.43	0.48	0.04	0.20	0.45
PH_2PERS	-0.46	-0.39	-0.22	0.01	-0.23	-0.54	-0.59	0.16	-0.40
PH_3PERS	-0.28	-0.55	0.25	-0.58	0.06	0.20	0.25	0.44	0.43
PH_4PERS	-0.24	-0.37	0.11	-0.35	-0.28	-0.26	0.20	0.08	-0.31
PH_5PERS	0.03	-0.21	-0.11	-0.54	-0.45	-0.32	0.23	-0.19	-0.40
PH_6PERS	-0.20	0.01	0.08	-0.02	-0.48	0.10	0.18	-0.39	-0.23
PH_7PERS	0.05	0.23	0.07	0.13	-0.27	-0.04	0.09	-0.21	-0.55
Income									
PHHI_L10	0.29	0.06	-0.66	-0.14	0.16	0.21	-0.46	-0.03	0.03
PHHI_L20	0.44	0.04	-0.64	-0.03	0.01	0.34	-0.50	-0.08	-0.06
PHHI_L30	0.17	0.03	-0.65	-0.03	0.02	0.37	-0.48	0.12	-0.05

Table 5A. Spearman rank correlations between 2000 population density (POPDEN00) and variables considered in the derivation of nationally consistent urban intensity indices (MA-NUII, NUII). Bold entries indicate a correlation (|ρ|) ≥ 0.7. — Continued

[|ρ|, absolute value of Spearman rank correlation; ≥, greater than or equal to]

Abbreviation (see table 5B)	BOS	RAL	ATL	BIR	MGB	DEN	DFW	SLC	POR
Income (continued)									
MEDHHI	0.18	0.04	0.67	0.06	0.21	-0.26	0.49	0.16	0.17
PM_GT16E	-0.55	-0.06	0.28	-0.12	-0.39	-0.23	0.49	-0.15	0.13
PF_GT16E	-0.68	-0.20	0.59	0.16	-0.52	-0.19	0.47	-0.25	0.23
PPOP_POV	0.23	0.17	-0.43	-0.08	0.05	0.10	-0.33	-0.06	0.33
PFAM_POV	0.41	0.07	-0.43	-0.13	0.20	0.22	-0.40	-0.08	0.38
PHH_POV	0.15	0.10	-0.56	-0.17	0.08	0.07	-0.42	-0.07	0.08
PERCAPIN	0.30	0.18	**0.75**	0.24	0.41	-0.28	0.45	0.33	0.37
MFAMINC	0.31	0.12	0.69	0.08	0.35	-0.25	0.44	0.23	0.25
MNFAMINC	0.11	0.22	0.67	0.32	0.46	-0.16	0.59	0.35	0.21
Population									
POP90_00	-0.60	-0.33	0.03	-0.51	0.21	-0.22	0.00	-0.05	0.24
PPURBAN	**0.96**	**0.93**	**0.96**	**0.90**	**0.96**	**0.86**	**0.92**	0.68	**0.92**
PPRURAL	**-0.96**	**-0.93**	**-0.96**	**-0.90**	**-0.96**	**-0.86**	**-0.92**	-0.68	**-0.92**
PP_L5Y	0.07	-0.08	0.11	-0.43	0.09	-0.10	0.45	-0.36	0.53
PHS_G25	-0.11	-0.36	-0.57	-0.41	**-0.82**	0.08	**-0.70**	-0.08	-0.65
PBCH_G25	0.15	0.25	**0.85**	0.41	0.59	-0.12	0.50	0.31	0.48
POCC_G65	0.65	0.16	-0.53	0.34	0.24	0.48	-0.57	0.21	0.11
PPMALE	-0.57	-0.08	0.02	-0.51	-0.60	-0.41	-0.26	-0.58	-0.30
PPFEMALE	0.57	0.08	-0.02	0.51	0.59	0.41	0.20	0.58	0.30
PM_GT25Y	-0.68	-0.06	-0.13	-0.56	-0.65	-0.35	-0.22	-0.51	-0.61
PF_GT25Y	0.68	0.06	0.13	0.56	0.64	0.35	0.08	0.51	0.61
2001 NLCD Level 1 basin land cover									
Percentage of basin area									
P_NLCD1_1	0.30	-0.38	-0.05	-0.37	-0.03	0.15	-0.44	0.32	0.32
P_NLCD1_2	**0.97**	**0.94**	**0.98**	**0.94**	**0.98**	**0.95**	**0.91**	**0.89**	**0.98**
P_NLCD1_3	-0.29	-0.63	-0.15	-0.31	-0.18	-0.42	0.37	-0.12	**-0.76**
P_NLCD1_4	**-0.92**	**-0.85**	**-0.91**	**-0.83**	-0.47	0.29	0.01	**-0.84**	**-0.91**
P_NLCD1_5	**-0.82**	**-0.88**	-0.68	**-0.72**	**0.73**	-0.21	**-0.82**	**-0.81**	**-0.85**
P_NLCD1_7	-0.36	**-0.89**	**-0.85**	**-0.75**	-0.36	**-0.81**	-0.70	-0.06	-0.31
P_NLCD1_8	-0.65	**-0.90**	-0.58	**-0.77**	**-0.86**	-0.70	-0.62	-0.06	0.00
P_NLCD1_9	0.20	-0.57	-0.30	-0.40	-0.62	-0.36	0.02	0.05	-0.03
NLCD1_IS	**0.94**	**0.80**	**0.97**	**0.92**	**0.97**	**0.94**	**0.93**	**0.94**	**0.98**
NOAA_1KM_IS	**0.98**	**0.88**	**0.98**	**0.96**	**0.95**	**0.94**	**0.98**	**0.91**	**0.97**
Percentage of riparian buffer									
P_NLCD1_B1	0.27	-0.29	0.13	-0.23	-0.06	0.30	-0.13	0.33	0.17
P_NLCD1_B2	**0.94**	**0.90**	**0.96**	**0.89**	**0.94**	**0.91**	**0.84**	**0.80**	**0.97**
P_NLCD1_B3	-0.52	-0.42	0.05	-0.07	-0.01	-0.43	0.31	-0.11	**-0.84**
P_NLCD1_B4	**-0.87**	**-0.82**	**-0.82**	**-0.70**	-0.34	0.27	0.08	**-0.77**	**-0.83**
P_NLCD1_B5	**-0.79**	**-0.79**	-0.57	-0.60	**0.77**	-0.32	**-0.83**	-0.55	**-0.87**
P_NLCD1_B7	-0.07	-0.67	-0.64	-0.47	-0.38	**-0.82**	**-0.70**	0.00	-0.31
P_NLCD1_B8	-0.17	**-0.85**	-0.30	-0.68	**-0.82**	**-0.71**	-0.62	0.02	-0.01
P_NLCD1_B9	0.29	-0.44	-0.25	-0.31	-0.40	-0.27	0.13	0.22	-0.09
NLCD1_BIS	**0.90**	**0.79**	**0.95**	**0.86**	**0.93**	**0.91**	**0.86**	**0.90**	**0.97**
Infrastructure									
RDLENGTH	**0.89**	0.47	**0.85**	0.63	0.65	0.32	**0.72**	**0.74**	0.65
ROADDEN	**0.99**	**0.96**	**0.98**	**0.84**	**0.94**	**0.95**	**0.94**	**0.89**	**0.95**
RDARDEN	**0.97**	**0.93**	**0.98**	**0.8**	**0.94**	**0.95**	**0.94**	**0.76**	**0.95**
RDTRDEN	**0.96**	**0.88**	**0.95**	**0.79**	**0.93**	**0.92**	**0.93**	0.68	**0.95**
D_PSCOUNT	0.63	0.09	0.33	0.3	0.33	0.35	-0.05	-0.09	0.15
D_TRICOUNT	**0.87**	0.46	**0.74**	0.23	0.15	0.16	**0.79**	0.31	0.62

Table 5B. Description of GIS-derived variables used to develop nationally consistent urban intensity indices.

[km/km^2, kilometer per square kilometer; km^2, square kilometer]

Category	Abbreviation	Description
Census data		
Energy source	PHUT	Percent of occupied housing units using utility gas (natural gas) as fuel
	PHLP	Percent of occupied housing units using liquid petroleum gas as fuel
	PHEL	Proportion of occupied housing units using electricity as fuel
	PHOIL	Percent of occupied housing units using oil as fuel
	PHWOOD	Percent of occupied housing units using wood as fuel
Ethnicity	PPWHITE	Proportion of population race = white
	PPBLACK	Proportion of population race = black
	PPNAM	Proportion of population race = native american
	PPASIA	Proportion of population race = asian
	P_US	Proportion of citizens born in US
	P_INSTAT	Proportion of citizens born in State of Residence
	P_OUTST	Proportion of citizens born in other States in the US
	P_NONUS	Proportion of citizens not born in US
	PC_CTY95	Proportion of citizens living in same county more more than 5 years (since 1995)
	PC_ST95	Proportion of citizens living in same State more more than 5 years (since 1995)
Housing age	PHU_L5	Proportion of housing units built between 1995-2000
	PHU_L10	Proportion of housing units built between 1990-2000
	PHU_L20	Prorportion of housing units built between 1980-2000
	PHU_G20	Proportion of housing units built prior to 1979 (1939 or earlier to 1979)
	PHU_G30	Proportion of housing units built prior to 1969 (1939 or earlier to 1969)
	PHU_G40	Proportion of housing units built prior to 1959 (1939 or earlier to 1959)
	PHU_G50	Proportion of housing units built prior to 1949 (1939 or earlier to 1949)
	PHU_G60	Proportion of housing units built prior to 1939
Housing occupancy	HHDEN	Household density (occupied housing units per square kilometer)
	PHO_G4P	Proportion of households occupied by 4 or more people
	PP_SH95	Percent of population living in same house as in 1995
	P_OWN	Proportion of occupied housing units that are owner occupied, in 2000 (%)
	HUDEN	Density of housing units (housing units/square kilometer)
	PHFAM	Proportion of households occupied by a family
	PHNONFAM	Proportion of households occupied by a non-family
	PHO_L3P	Proportion of households ocuupied by less than 3 people
	P_OCCUPY	Proportion of housing units that are occupied
	P_VACANT	Proportion of housing units that are vacant
	P_RENT	Proportion of occupied housing units that are renter occupied, in 2000 (%)
	PH_1PERS	Proportion of households occupied by 1 person
	PH_2PERS	Proportion of households occupied by 2 persons
	PH_3PERS	Proportion of households occupied by 3 persons
	PH_4PERS	Proportion of households occupied by 4 persons
	PH_5PERS	Proportion of households occupied by 5 persons
	PH_6PERS	Proportion of households occupied by 6 persons
	PH_7PERS	Proportion of households occupied by 7 or more persons
Income	PHHI_L10	Proportion of households with income less than $10,000, in 2000
	PHHI_L20	Proportion of households with household income less than $20,000 per year
	PHHI_L30	Proportion of households with income less than $30,000, in 2000
	MEDHHI	Median household income, in 2000 (dollars)
	PM_GT16E	Proportion of male population greater than 16 years of age that are employed
	PF_GT16E	Proportion of female population greater than 16 years of age that are employed
	PPOP_POV	Proportion of population with income below the poverty level
	PFAM_POV	Proportion of families with income below the poverty level
	PHH_POV	Proportion of households with income below the poverty level
	PERCAPIN	Per capita income
	MFAMINC	Median family household income
	MNFAMINC	Median non-family household income

Table 5B. Description of GIS-derived variables used to develop nationally consistent urban intensity indices. — Continued

[km/km^2, kilometer per square kilometer; km^2, square kilometer]

Category	Abbreviation	Description
Census data (continued)		
Population	POPDEN00	2000 population density (people/square kilometer)
	POP90_00	Proportional change in population from 1990 – 2000
	PPURBAN	Proportion of population living in urban area
	PPRURAL	Proportion of population living in rural area
	PP_L5Y	Proportion of population less than 5 years old
	PHS_G25	Proportion of population greater than 25 years old that have High School degrees
	PBCH_G25	Proportion of population greater than 25 years old that have Bachelors degree
	POCC_G65	Proportion of housing units occupied by persons greater than 65 years of age
	PPMALE	Proportion of population that is male
	PPFEMALE	Proportion of population that is female
	PM_GT25Y	Proportion of male population greater than 25 years of age
	PF_GT25Y	Proportion of female population greater than 25 years of age
2001 NLCD Level I basin land cover		
Percentage of basin area	P_NLCD1_1	Aggregated NLCD 2001 "level 1" category: water
	P_NLCD1_2	Aggregated NLCD 2001 "level 1" category: developed
	P_NLCD1_3	Aggregated NLCD 2001 "level 1" category: barren (includes all level 2 barren and unconsolidated categories)
	P_NLCD1_4	Aggregated NLCD 2001 "level 1" category: forest
	P_NLCD1_5	Aggregated NLCD 2001 "level 1" category: shrubland (includes all level 2 shrub and scrub categories)
	P_NLCD1_7	Aggregated NLCD 2001 "level 1" category: herbaceous upland natural/semi-natural vegetation (grassland)
	P_NLCD1_8	Aggregated NLCD 2001 "level 1" category: crops and pasture
	P_NLCD1_9	Aggregated NLCD 2001 "level 1" category: wetlands
	NLCD1_IS	NLCD 2001 mean percent impervious surface in the basin
	NOAA_1KM_IS	Mean percent impervious surface in the basin derived from NOAA 1 kilometer resolution data for 1990s
Percentage of riparian buffer (approximately 100 m area each side of stream centerline)	P_NLCD1_B1	Aggregated NLCD 2001 "level 1" category: water
	P_NLCD1_B2	Aggregated NLCD 2001 "level 1" category: developed
	P_NLCD1_B3	Aggregated NLCD 2001 "level 1" category: barren (includes all level 2 barren and unconsolidated categories)
	P_NLCD1_B4	Aggregated NLCD 2001 "level 1" category: forest
	P_NLCD1_B5	Aggregated NLCD 2001 "level 1" category: shrubland (includes all level 2 shrub and scrub categories)
	P_NLCD1_B7	Aggregated NLCD 2001 "level 1" category: herbaceous upland natural/semi-natural vegetation (grassland)
	P_NLCD1_B8	Aggregated NLCD 2001 "level 1" category: crops and pasture
	P_NLCD1_B9	Aggregated NLCD 2001 "level 1" category: wetlands
	NLCD1_BIS	NLCD 2001 mean percent impervious surface in the riparian zone
Infrastructure		
	RDLENGTH	Length of TIGER roads in watshed (km), excludes non-paved or access roads, bike paths, etc.
	ROADDEN	Road density in watershed (km/km^2)
	RDARDEN	Road area index density (road length multiplied by an area factor and normalized by watershed area: km/km^2)
	RDTRDEN	Road traffic index density. Road length multiplied by a traffic factor (by type of road) normalized by watershed area (km/km^2)
	D_PSCOUNT	Density (no./100 km^2) of point source dischargers in watershed (EPA database - NPDES)
	D_TRICOUNT	Density (no./100 km^2) of Toxics Release Inventory sites in watershed

for index development. Curvilinear responses represented change over only a portion of the gradient and were not suitable for index development. Only 9 of the 89 variables that were examined showed a consistent linear response across the population density gradient in all nine urban areas (table 6) and were candidates for inclusion in the MA-NUII and NUII indices.

Of the nine candidate variables, two were census (HHDEN, HUDEN), five were land-cover (P_NLCD1_2, NLCD1_IS, NOAA_1KM_IS, P_NLCD1_B2, NLCD1_BIS), and two were infrastructure (ROADDEN, RDARDEN) variables (table 6). The HUDEN and HHDEN census variables were strongly related to one another ($R^2 \geq 0.99$ for linear regression relating HUDEN to HHDEN) for all nine urban studies indicating that these variables provide essentially identical information. HUDEN was selected to represent census variables in the national indices because the derivation of HUDEN was less complex and less prone to error than the derivation of HHDEN, which involved both the estimation of housing density (HUDEN) and the proportion of housing units that are occupied.

Of the five land-cover (NLCD01) variables that were strongly related to POPDEN00 in all nine metropolitan areas, the percentage of basin area in developed land (P_NLCD1_2) was consistently more strongly related to changes in population density (table 6) than were the measures of impervious surface (NLCD1_IS, NOAA_1KM_IS, and NLCD1_BIS) or developed land in the stream buffer (P_NLCD1_B2). This was particularly noticeable in the RAL urban study where correlations between population density and measures of impervious surface were lower than correlations with measures of developed land (table 5). Measures of developed land in the basin (P_NLCD1_2) and stream buffer (P_NLCD1_B2) provided essentially the same information as evidenced by the strong linear relation among these two variables (R^2 for linear regressions ranged from 0.90 to 0.98 for the nine studies). Consequently, P_NLCD1_2 was chosen to represent land cover in the derivation of the national indices.

The two infrastructure variables that were consistently and strongly related to population density (ROADDEN and RDARDEN) showed a very strong relation (R^2 for linear regression of ROADDEN with RDARDEN ranged from 0.98 to 1.00 for the nine studies) indicating that these two variables convey the same information regarding changes with population density. ROADDEN was selected for inclusion in the national indices because the derivation of this variable was less complex than RDARDEN, which required estimating road length and width.

Metropolitan Area National Urban Intensity Index (MA-NUII)

The metropolitan area national urban intensity index (MA-NUII) derived for each of the nine urban areas based on the census (HUDEN), land-cover (P_NLCD1_2), and infrastructure (ROADDEN) variables showed strong and consistent relations with POPDEN00 for each of the nine metropolitan areas. The MA-NUII was individually scaled (range standardized) for each metropolitan area and ranged from 0 (lowest urban) to 100 (highest urban) for each metropolitan area (table 3). This is the same scaling that was used to produce the MA-UII (table 2).

National Urban Intensity Index (NUII)

While urban intensity can be described by a nationally consistent set of census, land-cover, and infrastructure variables (HUDEN, P_NLCD1_2, and ROADDEN), the rates at which these variables change in response to changes in population density varied among metropolitan areas (fig. 4A, C, and E). Developed land (P_NLCD1_2) and road density (ROADDEN) showed the most variability, and housing-unit

Table 6. National land-cover data (NLCD), census, and infrastructure variables that showed consistent linear responses to changes in 2000 population density for nine metropolitan areas. The range in slopes (b), regression coefficients (R^2), and significance levels (p) across the nine metropolitan areas are shown. Abbreviations are described in table 1.

[<, less than]

Variable group	Variable	b	R^2	p
Census	HHDEN	0.329–0.429	0.87–0.99	<0.001
	HUDEN	0.342–0.447	0.86–0.99	<0.001
NLCD-basins	P_NLCD1_2	0.045–0.072	0.75–0.99	<0.001
	NLCD1_IS	0.020–0.030	0.52–0.98	<0.001
	NOAA_1KM_IS	0.023–0.033	0.71–0.97	<0.001
NLCD-riparian	P_NLCD1_B2	0.035–0.068	0.65–0.98	<0.001
	NLCD1_BIS	0.015–0.024	0.50–0.97	<0.001
Infrastructure	ROADDEN	0.004–0.007	0.67–0.98	<0.001
	RDARDEN	0.005–0.007	0.62–0.98	<0.001

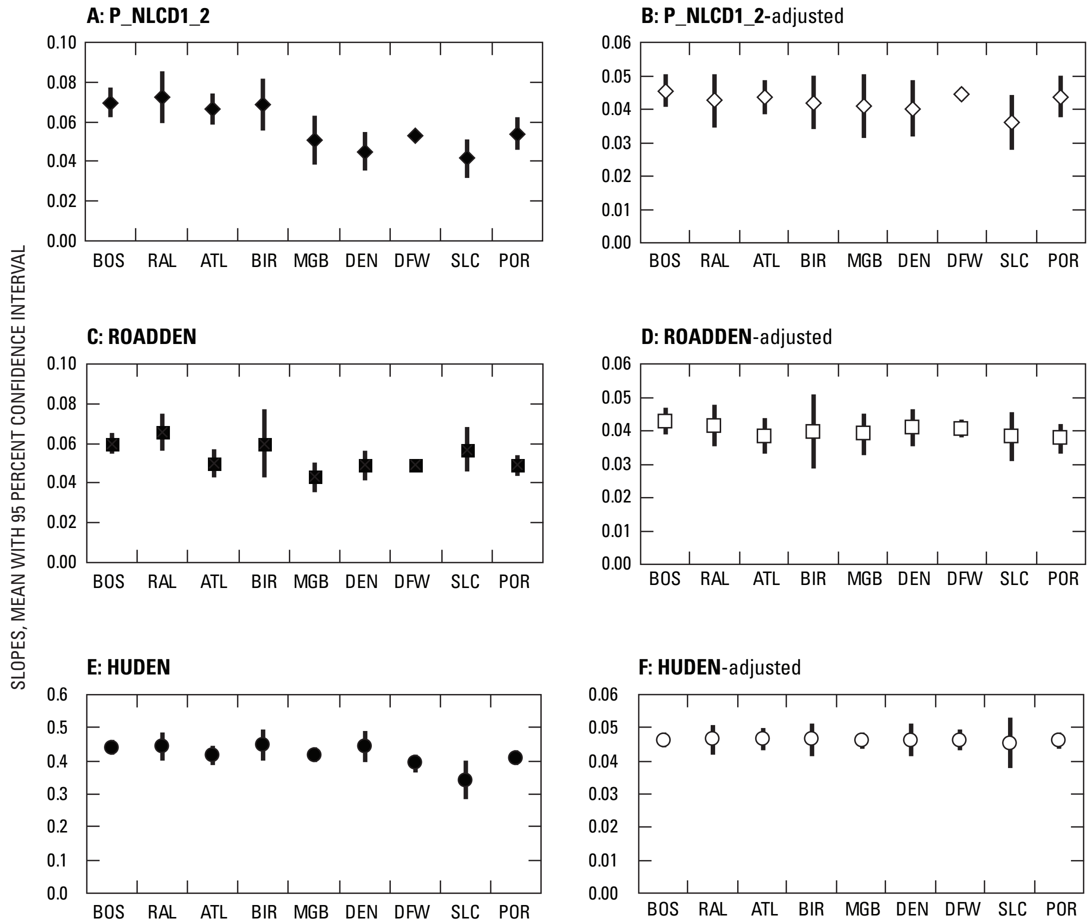

Figure 4. Slopes (mean with 95 percent confidence interval) relating MA-NUII variables and POPDEN00 before and after adjusting for differences in the response rates among metropolitan areas. Abbreviations are explained in table 1.

density (HUDEN) showed the least. Examination of the plots used to develop these regressions (fig. 5A and B) showed that the rates (regression slopes) differed (0.072 for RAL and 0.045 for DEN) as did the maximum population density observed in each metropolitan area (1,860 km^{-2} for DEN and 1,294 km^{-2} for RAL). Surprisingly, maximum population densities measured in the eastern metropolitan areas (ATL, BIR, BOS, RAL) were lower than those in the central (DEN, DFW, MGB) and western (SLC, POR) metropolitan areas (fig. 6) even though the East has a much longer history of urban development. This indicates that development in the EUSE basins of the Central and Western United States tends to occur on a smaller proportion of the river basin than it does in the East. That is, for a given level of population density, there is a larger amount of developed land in the East than in the central or western metropolitan areas. This indicates that in terms of two of the dimensions of landscape pattern that can be used to describe sprawl—population density and percent developed land—the eastern metropolitan areas show a relatively high level of sprawl compared with the western studies (Galster and others, 2006).

The derivation of the NUII takes into account the differences that were observed in response rates and maximum population densities among metropolitan areas. Linear regressions (table 7) were used to convert each NUII variable (HUDEN, P_NLCD1_2, ROADDEN) to a percentage of the value that was projected to occur at the maximum population density observed for all sites in the nine urban studies (2,174.5 km^{-2} for MGB). For example, the regressions developed for P_NLCD1_2 in figure 5A were used to predict the value that would occur at a population density of 2,174.5 km^{-2} (table 7 projected values of 170 for RAL and 112 for DEN). The P_NLCD1_2 values were then expressed as a percentage of the projected value. The rescaled P_NLCD1_2 data yielded response slopes that were then comparable among metropolitan areas (fig. 4B and 5B). The HUDEN and ROADDEN data were converted in the same way to produce response rates that were comparable among metropolitan areas (fig. 4D and F). The NUII was calculated by range standardizing these adjusted values (percentages of projected values) over the data for all nine metropolitan areas (table 3). This produced an urban intensity index (NUII) that ranged

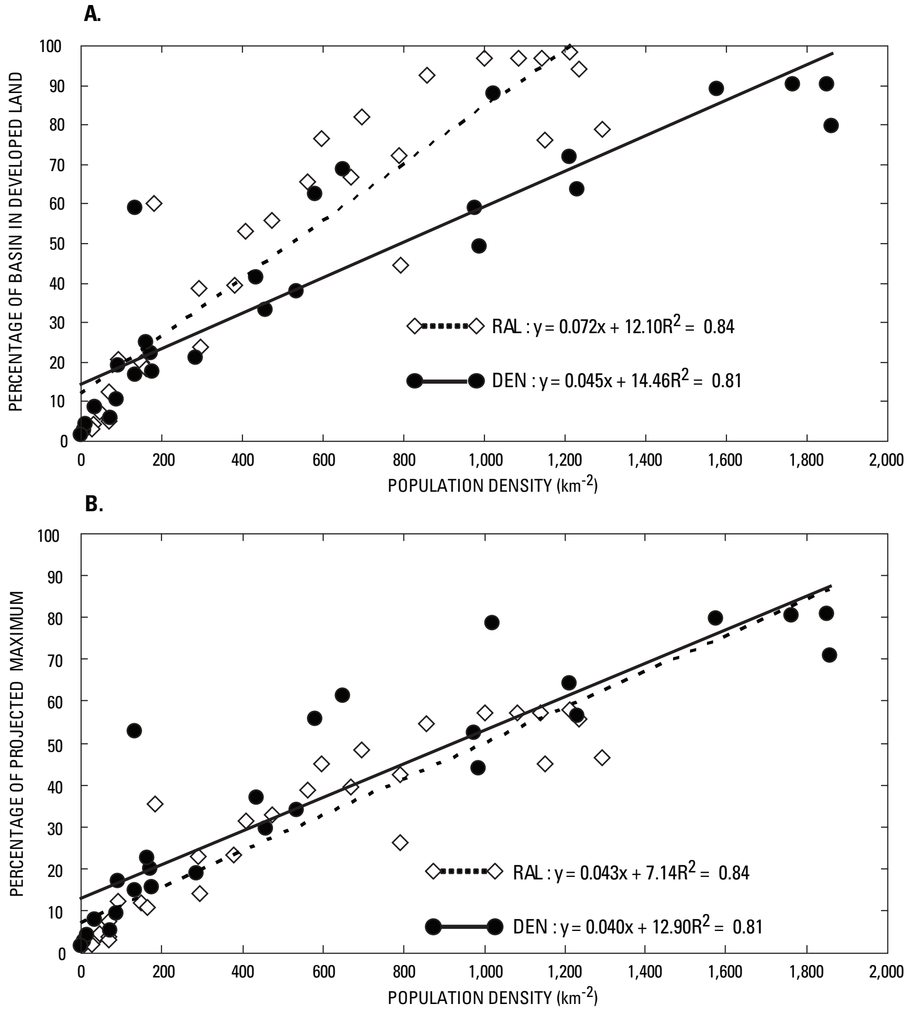

Figure 5. Linear regressions relating percentage developed land (P_NLCD1_2) to population density in Denver (DEN) and Raleigh (RAL) (A) before and (B) after adjusting the data for differences in response rates and maximum population density.

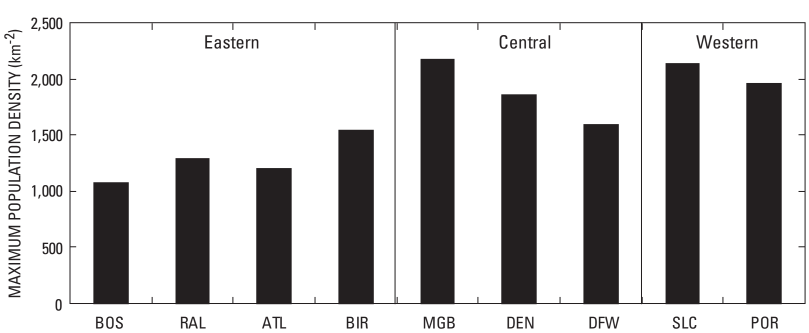

Figure 6. Maximum population density (km^{-2}) for sampling sites in each of the nine metropolitan areas.

Table 7. Linear regressions used to project the value of the urban intensity index variables at the maximum level of population density (2,174.5) observed in nine urban studies (projected value). The projected values are expressed as a percentage of the maximum value observed in each study (percentage of observed maximum).

[Y = a + bX, a = intercept, b = slope; R^2, regression coefficient; P, significance value for regression; N, number of sites; <, less than]

Variable	Urban area	a	b	R^2	P	N	Projected value	Percentage of observed maximum
HUDEN: housing density								
	BOS	-6.65	0.4392	0.99	<0.001	30	948	48
	RAL	-9.10	0.4418	0.96	<0.001	30	952	70
	ATL	-8.57	0.4166	0.98	<0.001	30	897	64
	BIR	-10.11	0.4474	0.95	<0.001	30	963	76
	MGB	-5.11	0.4180	0.99	<0.001	30	904	109
	DEN	-7.08	0.4416	0.95	<0.001	28	953	108
	DFW	-4.50	0.3929	0.98	<0.001	29	850	84
	SLC	9.39	0.3421	0.86	<0.001	30	753	113
	POR	-2.09	0.4084	0.99	<0.001	28	886	83
P_NLCD1_2: percent developed land in basin								
	BOS	1.74	0.0697	0.95	<0.001	30	153	50
	RAL	12.09	0.0724	0.84	<0.001	30	170	58
	ATL	8.40	0.0661	0.94	<0.001	30	152	56
	BIR	14.50	0.0688	0.83	<0.001	30	164	58
	MGB	13.65	0.0508	0.75	<0.001	30	124	80
	DEN	14.46	0.0449	0.81	<0.001	28	112	81
	DFW	3.67	0.0529	0.99	<0.001	29	119	75
	SLC	24.85	0.0416	0.77	<0.001	30	115	84
	POR	6.34	0.0541	0.91	<0.001	28	124	79
ROADDEN: road density								
	BOS	1.43	0.0060	0.96	<0.001	30	14	54
	RAL	1.95	0.0066	0.89	<0.001	30	16	71
	ATL	1.64	0.0050	0.91	<0.001	30	13	57
	BIR	2.09	0.0060	0.67	<0.001	30	15	78
	MGB	1.99	0.0043	0.88	<0.001	30	11	92
	DEN	1.67	0.0049	0.92	<0.001	28	12	89
	DFW	1.38	0.0049	0.98	<0.001	29	12	79
	SLC	2.18	0.0057	0.84	<0.001	30	15	93
	POR	1.89	0.0049	0.94	<0.001	28	13	80

from 0 to 100 over the 265 sites in the nine metropolitan areas rather than from 0 to 100 in each metropolitan area as did the MA-UII and MA-NUII. The NUII expresses urban intensity as a percentage of the value that would, theoretically, occur at the maximum observed population density based on observed response rates.

Comparison of the MA-UII, MA-NUII, and NUII

The levels of urban intensity obtained for each site differed depending on the index used to characterize urbanization (fig. 7). With the exception of DEN, DFW, and MGB, however, the three indices were all linearly related ($R^2 = 0.84 – 0.99$, b = 0.93–1.03, $P < 0.001$) and the relations among sites that had been originally defined by the MA-UII were preserved (fig. 8A). DEN, DFW, and MGB (fig. 8B) showed a non-linear relation with MA-NUII with little response in MA-NUII until MA-UII > 25. This pattern resulted from including large numbers of variables in the MA-UII that had a curvilinear or indeterminate relation with population density (table 8). Variables that exhibited a curvilinear response tended to change rapidly at low to moderate levels of population density but only very slowly or not at all at moderate to high levels (for example, PPURBAN

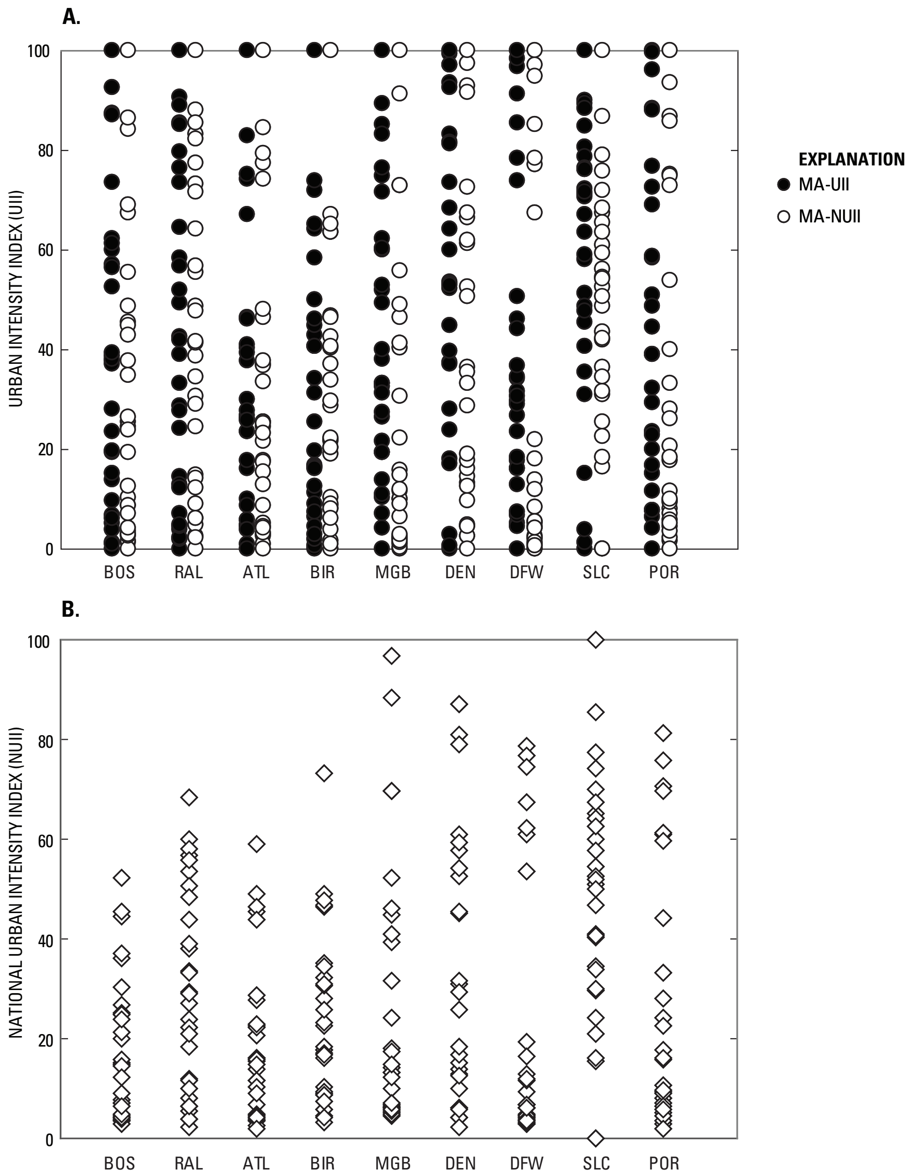

Figure 7. Distribution of sites in each metropolitan area based on the (A) MA-UII and MA-NUII indices or the (B) NUII index.

evident in DFW where the national index (MA-NUII) revealed a large gap in the representation of the urban intensity gradient (no sites between 22 and 67) that did not appear with the MA-UII (12 sites between 22 and 67, fig. 7A).

The MA-NUII and NUII differ only in how they are scaled (independently for each metropolitan area and collectively for all nine metropolitan areas). Rescaling to form the NUII is based on the regression of each of the index variables (HUDEN, P_NLCD1_2, and ROADDEN) with population density. Since the slopes of these regressions differ among the three variables within and among metropolitan areas, this rescaling can change how sites rank along the urban gradient. However, the correlation (Spearman rank) between NUII and MA-NUII index scores within each metropolitan area ranged from 0.996 to 1.000, indicating that rescaling had little effect on the relation among sites within a metropolitan area. The major difference produced by the national scaling is the maximum level of urbanization that is achieved in each metropolitan area (fig. 7B). For example, the maximum value for NUII in BOS is 52 (site BOS_aber) compared to 100 in SLC (site SLC_m300) even though both of these sites had MA-UII and MA-NUII values of 100 (table 3). The population density associated with BOS_aber (1,042 km^{-2}) is far less than the maximum population density observed among all nine metropolitan areas (site MGB_linc 2,174.5 km^{-2}). In contrast, the SLC_m300 site had a population density (2,136 km^{-2}) that was close to the maximum for all nine metropolitan areas. All of the eastern metropolitan areas (BOS, RAL, ATL, BIR) had lower maximum population densities than did the central or western metropolitan areas (fig. 6); consequently, the maximum NUII in the eastern metropolitan areas was lower than in the central or western areas (fig. 7B). Therefore, on the basis of the NUII, small streams (second to third order) in the eastern metropolitan areas encompassed a smaller proportion of the national urban intensity gradient than did similar streams in the Western and Central United States.

in fig. 3B). Variables with an indeterminate response were significantly correlated with population density, but the form of the response was poorly defined. Inclusion of large numbers of variables with curvilinear or indeterminate responses to population density in DEN, DFW, and MGB (≥ 63 percent of MA-UII variables) overestimated urban intensity at low to moderate levels of population density compared to indices derived from nationally consistent variables (MA-NUII and NUII). Consequently, the urban gradients in MGB, DEN, and DFW have far more sites at the lower end of the gradient when urban intensity is expressed as MA-NUII or NUII than when it is expressed as MA-UII (fig. 8B). This was particularly

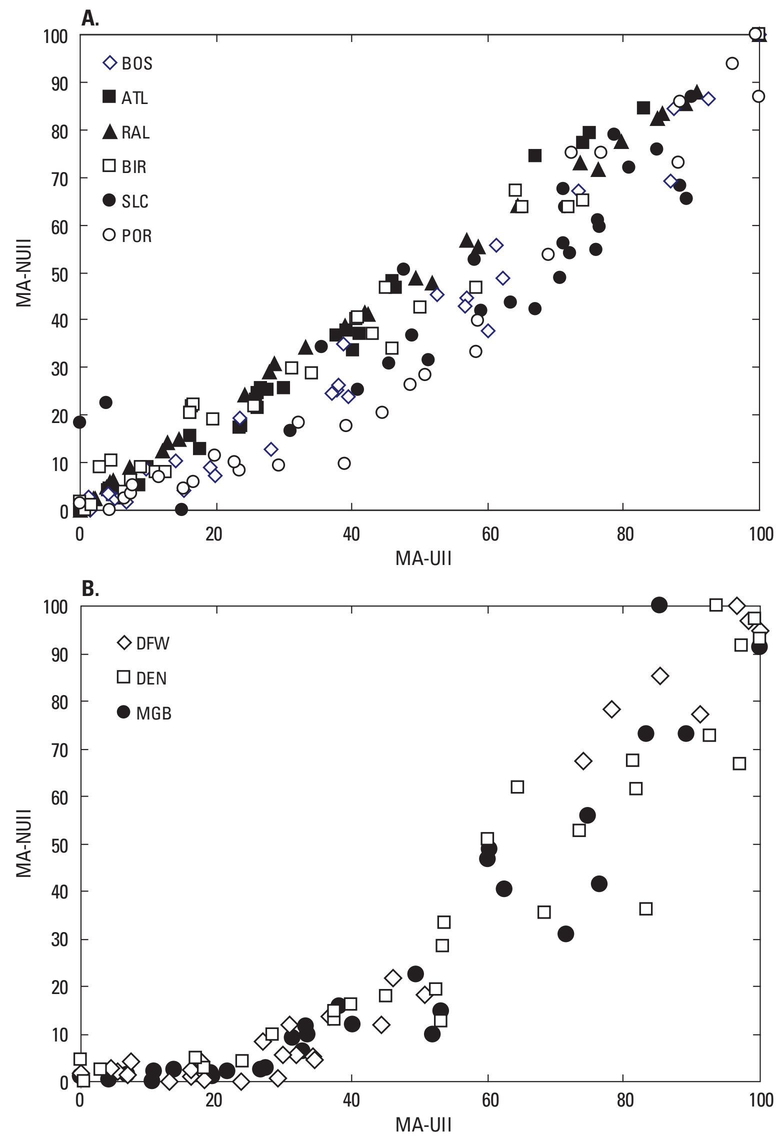

Figure 8. Relation between the MA-UII and MA-NUII indices for the nine metropolitan areas showing (A) linear and (B) curvilinear responses.

Table 8. Percentage of variables used in the construction of the metropolitan area urban intensity index (MA-UII) that showed a linear, curvilinear, or indeterminate relation with population density.

Metropolitan area	Number of variables in MA-UII	Percentage of variables with response form: Linear	Curvilinear	Indeterminate
BOS	23	69.6	17.4	13.0
RAL	5	100.0	0.0	0.0
ATL	5	100.0	0.0	0.0
BIR	14	92.9	7.1	0.0
MGB	35	34.3	42.9	22.9
DEN	16	31.3	37.5	31.3
DFW	40	37.5	45.0	17.5
SLC	13	61.5	15.4	23.1
POR	24	50.0	37.5	12.5

Summary and Conclusions

The indices that were derived to characterize urban intensity (MA-UII, MA-NUII, and NUII) are multimetric representations of changes in population density. Population density was chosen as the focus of these studies because the effects of urbanization arise primarily from the goods and services required to maintain a population within a drainage basin. These goods and services represent a complex, interacting set of factors, such as transportation (roads, railroads, airports), housing (building and maintaining homes and yards), manufacturing, retail sales, and utilities (water, sewer, electricity, gas), that directly or indirectly affect the biological, chemical, and physical characteristics of streams. Population density provides a useful surrogate for these and other changes associated with urbanization and has the advantage of having been monitored consistently for a long period of time. We chose a multimetric representation of population density (housing density, percentage of developed land, and road density) in order to capture part of the multivariate nature of urbanization, to address the inconsistent spatial scale of census data (census blocks are large in rural areas, small in urban areas), and to address situations where basins may have been highly modified for human use without having a large resident population (for example, airports, rail yards, and large factories).

The most common representations of urban intensity in the literature focus on single variables such as population density, percent impervious surface, road density, and percent developed or urban lands. Population density, road density, and developed or urban lands are directly addressed in the urban intensity indices (MA-NUII and NUII) either because they are a component of the index (ROADDEN, P_NLCD1_2) or are strongly correlated with the index (POPDEN00). Measures of imperviousness are not directly addressed in the indices though they were considered in the development of these indices. Impervious surface appears frequently in the literature as a surrogate for urban intensity (Arnold and Gibbons, 1996; Center for Watershed Protection, 2003; Morse, Huryn, and Cronan, 2003) that provides a direct linkage between changes in stream hydrology and effects on stream biota and ecological processes (Poff and others, 1997; Konrad and Booth, 2005). Even though impervious surface (NLCD1_IS, NLCD1_BIS, NOAA_1KM_IS) was strongly correlated with population density, it was not included in the national urbanization indices (MA-NUII, NUII) because it was essentially redundant with percentage of developed land (P_NLCD1_2), and in the RAL area developed land was more closely associated with population density than was impervious surface. Impervious surface was included in some MA-UIIs (MGB, DFW, POR) even though it was highly correlated with other variables.

Multimetric indices of urbanization are far less commonly used to represent urbanization than are single variables. The Landscape Development Intensity (LDI) index (Brown and Vivas, 2005) is one of the few multimetric urban intensity indices that have been used to interpret the effects of urbanization. The LDI index quantifies urbanization as an aggregation of human activity derived by combining land-cover classes with the amount of nonrenewable energies and related services that are associated with each land-cover class. The information necessary for calculating the LDI index was not available at the national level, so an LDI index was not calculated that could be compared with the indices used to characterize urban intensity.

Characteristics of a National Index

Ideally, a national urban intensity index should be capable of representing changes in urban intensity that are consistent across metropolitan areas; that is, a given change in the index (for example, five intensity units) should indicate equivalent changes in all metropolitan areas. The index should be constructed from nationally consistent variables that are important indicators of urbanization across the country, that represent changes in urban intensity across the entire urban gradient, that have similar rates of response in all urban areas, and that are nationally scaled. Most urban studies concentrate on urbanization within a single area and cannot directly address these issues. The EUSE studies provided a unique opportunity to develop national urban intensity indices by addressing all these issues in multiple urban areas.

The indices of urban intensity that were originally developed independently for each metropolitan area (MA-UII) cannot provide a national characterization of urban intensity because of the diversity of variables used to construct the index, inconsistency in the form of the response to population density (linear, curvilinear, indeterminate), and inappropriate scaling. Compared to the national indices (MA-NUII, NUII), the MA-UII tended to overestimate urban intensity, and the resulting distributions of sites along the urban gradient were skewed toward the low end of the gradient or contained gaps (DFW). The MA-NUII provided a better national representation of changes along the population gradient because it was based on a nationally consistent set of variables (HUDEN, P_NLCD1_2, ROADDEN) that had a consistent linear response to population density and that were evenly distributed among categories of urban variables. The MA-NUII, however, was scaled to represent urbanization only within a metropolitan area and could not represent differences in urban intensity among metropolitan areas.

The NUII addressed the deficiencies in the MA-NUII by scaling across all sites in the nine metropolitan areas and by adjusting for differences in the rates at which index variables (HUDEN, P_NLCD1_2, ROADDEN) respond to changes in population density among metropolitan areas (slopes of the regression with POPDEN00). Expressing the index variables as a percentage of the value that was predicted to occur at the maximum population density observed over all nine metropolitan areas successfully adjusted the variables so that the rate of change was nearly constant among metropolitan areas (fig. 4B, D, and F). However, there are a number of drawbacks associated with this approach that make it less than an ideal method of deriving a nationally consistent index. First, this approach requires estimating values at population densities well beyond what were actually measured, which is a statistically tenuous situation. Second, the rescaled (that is, predicted) values sometimes do not make sense (for example, P_NLCD1_2 values in excess of 100 percent, table 7). Last, scaling the values to the maximum population density observed among all sites results in an index that is dependent on that maximum value. That is, the index values could change if the maximum population density changes, which might occur if urban areas are added, deleted, or monitored over time. Given these drawbacks, the current NUII can best be described as a work in progress and we continue to explore approaches for deriving a nationally consistent urban intensity index that is capable of representing urbanization across the country.

Even though the NUII is not a perfect representation of urban intensity, it did reveal patterns in urban intensity that were not evident with MA-UII or MA-NUII. That is, maximum urban intensities in eastern metropolitan areas (BOS, RAL, ATL, BIR) were much lower relative to that of metropolitan areas in the Central and Western United States (fig. 7B). This was an unexpected result that seemed to imply that similar levels of urbanization in the East are associated with lower population density and less compact development than in the Central and Western United States. However, these results need to be interpreted in light of the design of the EUSE studies, which looked at relatively small streams (second to third order) that were still connected to the landscape (that is, were above ground and not confined to manmade channels). In the inner-city areas of many of the eastern metropolitan areas where population density is high (for example, downtown Boston, MA), there are no small streams to study because they have been effectively converted to sewers either by burying the streams in culverts (Elmore and Kaushal, 2008) or placing them in cement-lined channels. This restricts the study of streams in these areas to suburban areas with lower population density. In addition, the scarcity of water in the West may lead to higher density and more compact suburban development than in the East because of the expense of maintaining large lawns. Estimates of population densities in eastern cities may also have been reduced because of the greater integration of commercial and industrial areas within these cities and the movement of population from city centers to suburban and rural areas.

Future Development of Urban Intensity Indices

The urban intensity indices that are described in this report (MA-UII, MA-NUII, NUII) were developed to provide a mechanism for objectively selecting sites that represent a gradient of urban intensity and interpreting biological, chemical, and physical responses. The progression from MA-UII to MA-NUII to NUII constituted a refinement, in terms of consistency and scaling, in the development of the urban intensity index with the objective of providing a more nationally comparable representation of urban intensity. However, the indices and their component variables are not directly linked to physical, chemical, or biological changes in streams. Such linkages are a major objective of the analyses conducted in the EUSE studies, and further development of urban intensity indices will be based on urban variables that have been shown to drive physical, chemical, and biological responses rather than on population density. The goal of this effort is to derive an index that can represent equivalent changes in stream conditions across the Nation. That is, a change of 10 urban intensity units would correspond to equivalent changes in indicators of response such as hydrologic variability, invertebrate taxa richness, or percentage of eutrophic algae. Development of this index will more directly tie urban intensity to its effect and should be a valuable contribution to managers and policy makers that must deal with the consequences of development.

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Table 3. Urban intensity indices and variables used to calculate the national urban intensity indices (MA-NUII, NUII) for nine metropolitan areas.

[POPDEN00, 2000 population density; HUDEN, housing unit density; P_NLCD1_2, percentage of basin areas in developed land; ROADDEN, road density; MA-UII, metropolitan area urban intensity index; MA-NUII, metropolitan area national urban intensity index; NUII, national urban intensity index; BOS, Boston, Massachusetts; RAL, Raleigh, North Carolina; ATL, Atlanta, Georgia; BIR, Birmingham, Alabama; MGB, Milwaukee-Green Bay, Wisconsin; DEN, Denver, Colorado; DFW, Dallas-Fort Worth, Texas; SLC, Salt Lake City, Utah; POR, Portland, Oregon; R, river; nr, near; Rd, road; abv, above; Cr, creek; SR, secondary road; Blvd, boulevard; Br, branch; N, north; blw, below; Trib, tributary; ab, above; St, street; Pkwy, parkway; WY, way; Dr, drive; CR, county road; Fm, farm-to-market road; Ih, interstate highway; WWTP, wastewater-treatment plant; L, little; S Fk, south fork; SF, south fork; Ave, avenue]

Metropolitan area	USGS station number	USGS Station name	Station abbreviation	POPDEN00	HUDEN	P_NLCD1_2	ROADDEN	MA-UII	MA-NUII	NUII
BOS	01072540	Little R nr Lebanon, ME	BOS_lime	34.73	17.81	2.45	1.23	0.00	1.40	3.44
BOS	01072650	Greatworks R nr North Berwick, ME	BOS_grea	103.26	40.10	8.04	2.20	14.00	10.42	7.88
BOS	01072845	Isinglass R Batchelder Rd nr center Strafford, NH	BOS_isin	34.60	16.59	1.83	1.36	6.80	1.70	3.58
BOS	01072904	Bellamy R at Bellamy Rd nr Dover, NH	BOS_bell	88.40	37.12	7.98	1.94	19.20	8.83	7.11
BOS	01073260	Lamprey R Cotton Rd nr Deerfield, NH	BOS_lamp	31.46	11.79	1.15	1.15	1.40	0.00	2.75
BOS	01073458	North R at Route 152 nr Nottingham, NH	BOS_nort	36.89	14.74	2.55	1.47	5.20	2.44	3.94
BOS	010734833	Little R at Cartland Rd at Lee, NH	BOS_linh	45.75	18.89	2.39	1.66	4.00	3.61	4.51
BOS	01089743	Little Suncook R Blackhall Rd at Epsom, NH	BOS_lsun	37.69	22.57	3.28	1.41	6.10	3.05	4.25
BOS	01090477	Black Brook Dunbarton Rd nr Manchester, NH	BOS_blab	57.55	25.79	0.93	1.53	1.10	2.84	4.12
BOS	01094005	Baboosic R Bedford Rd nr Merrimack, NH	BOS_babo	117.72	42.21	4.92	2.08	9.70	8.60	6.96
BOS	01095220	Stillwater R nr Sterling, MA	BOS_stil	55.50	22.45	3.16	1.65	15.20	4.18	4.80
BOS	01096544	Stony Brook at School Street at Chelmsford, MA	BOS_ston	227.66	82.97	21.50	3.36	37.80	25.34	15.28
BOS	010965852	Beaver Brook at North Pelham, NH	BOS_beav	354.77	129.60	30.63	3.76	38.70	34.86	20.02
BOS	01096710	Assabet R at Allen Street at Northborough, MA	BOS_assa	381.66	136.59	35.69	3.76	60.00	37.62	21.42
BOS	01096945	Elizabeth Brook off White Pond Rd nr Stow, MA	BOS_eliz	110.66	37.46	10.34	2.50	28.20	12.71	9.01
BOS	01097270	Fort Pond Brook at R Rd nr South Acton, MA	BOS_fort	255.83	94.17	18.34	3.34	37.00	24.67	14.92
BOS	01097476	Sudbury R at Concord Street at Ashland, MA	BOS_sudb	257.48	98.77	24.40	3.09	38.00	26.45	15.86
BOS	01101500	Ipswich R at South Middleton, MA	BOS_ipsw	454.80	169.53	43.29	4.83	62.20	48.77	26.92
BOS	01102345	Saugus R at Saugus Iron-works at Saugus, MA	BOS_saug	865.75	375.16	64.45	7.00	87.40	84.30	44.46
BOS	01102500	Aberjona R (head of Mystic River) at Winchester, MA	BOS_aber	1,041.96	458.03	76.43	7.84	100.00	100.00	52.24
BOS	011032058	Charles R at Maple Street at North Bellingham, MA	BOS_char	479.01	212.24	34.74	4.26	52.60	45.35	25.18
BOS	01105000	Neponset R at Norwood, MA	BOS_nepo	460.63	184.58	38.56	4.21	57.00	44.72	24.92
BOS	01105500	East Branch Neponset at Canton Junction, MA	BOS_enep	574.24	243.00	44.68	4.98	61.30	55.64	30.30
BOS	01105581	Monatiquot R at River Street at Braintree, MA	BOS_mona	699.78	296.52	53.68	5.72	73.40	67.30	36.07
BOS	01106468	Matfield R at North Central Street at East Bridgewater, MA	BOS_matf	1,068.02	458.62	60.13	6.59	92.60	86.60	45.56

Table 3. Urban intensity indices and variables used to calculate the national urban intensity indices (MA-NUII, NUII) for nine metropolitan areas. — Continued

[POPDEN00, 2000 population density; HUDEN, housing unit density; P_NLCD1_2, percentage of basin areas in developed land; ROADDEN, road density; MA-UII, metropolitan area urban intensity index; MA-NUII, metropolitan area national urban intensity index; NUII, national urban intensity index; BOS, Boston, Massachusetts; RAL, Raleigh, North Carolina; ATL, Atlanta, Georgia; BIR, Birmingham, Alabama; MGB, Milwaukee-Green Bay, Wisconsin; DEN, Denver, Colorado; DFW, Dallas-Fort Worth, Texas; SLC, Salt Lake City, Utah; POR, Portland, Oregon; R, river; nr, near; Rd, road; abv, above; Cr, creek; SR, secondary road; Blvd, boulevard; Br, branch; N, north; blw, below; Trib, tributary; ab, above; St, street; Pkwy, parkway; WY, way; Dr, drive; CR, county road; Fm, farm-to-market road; Ih, interstate highway; WWTP, wastewater-treatment plant; L, little; S Fk, south fork; SF, south fork; Ave, avenue]

Metro-politan area	USGS station number	USGS Station name	Station abbreviation	POPDEN00	HUDEN	P_NLCD1_2	ROADDEN	MA-UII	MA-NUII	NUII
BOS	01109000	Wading R (head of Threemile River) nr Norton, MA	BOS_wade	230.63	88.02	23.49	2.84	39.50	23.98	14.66
BOS	01109595	Middle R off Sutton Lane at Worcester, MA	BOS_midd	483.79	221.87	28.53	4.16	56.60	42.84	23.89
BOS	01110000	Quinsigamond R at North Grafton, MA	BOS_quin	693.85	337.58	50.20	5.79	87.00	69.19	36.96
BOS	01112262	Mill R at Summer Street nr Blackstone, MA	BOS_mill	208.45	80.96	15.44	2.73	23.40	19.39	12.33
BOS	01193340	Blackledge R abv Lyman Brook nr North Westchester, CT	BOS_blal	89.75	33.18	6.38	1.81	19.80	7.19	6.30
RAL	02081190	Tar R nr Berea, NC	RAL_tar	9.40	6.70	3.01	1.03	0.00	0.00	2.33
RAL	02081510	Foundry Branch at mouth nr Oxford, NC	RAL_fondry	408.23	130.80	52.98	5.78	38.89	38.82	27.19
RAL	0208500600	Cates Creek nr Hillsborough, NC	RAL_cates	148.65	65.88	20.00	2.94	14.54	15.00	12.03
RAL	0208501535	Strouds Cr at St Marys Rd nr Hillsborough, NC	RAL_stroud	70.70	32.74	12.42	2.45	7.21	9.12	8.22
RAL	02085430	Deep Creek nr Moriah, NC	RAL_deep	30.42	12.90	4.36	1.58	1.95	2.55	4.01
RAL	0208725055	Black Cr at Weston Parkway nr Cary, NC	RAL_black	1,293.49	564.74	78.96	8.22	79.56	77.54	53.54
RAL	0208726370	Richlands Creek at Schenk Forest nr Cary, NC	RAL_rschen	182.46	85.26	60.14	4.32	33.16	34.39	23.90
RAL	0208726995	Hare Snipe Creek at SR 1822 nr Leesville, NC	RAL_hare	1,151.87	530.83	76.09	7.70	73.62	73.18	50.62
RAL	0208730725	Beaverdam Creek at Glenwood Avenue at Raleigh, NC	RAL_beaver	1,235.15	541.50	94.16	10.21	90.80	88.00	60.04
RAL	0208732610	Pigeon House Br at Crabtree Blvd at Raleigh, NC	RAL_pigeon	1,212.39	667.68	98.41	11.52	100.00	100.00	68.29
RAL	02087580	Swift Creek nr Apex, NC	RAL_swift	789.91	280.99	72.19	6.49	58.55	55.36	38.12
RAL	0208758440	Dutchmans Br at SR 1386 nr McCullers Crossrds, NC	RAL_dutch	380.39	139.73	39.29	4.60	28.61	30.74	22.21
RAL	0208794025	Camp Branch abv SR 1390 nr Holly Springs, NC	RAL_camp	162.56	82.82	18.22	2.65	12.88	14.33	11.68
RAL	0209517912	N Buffalo Creek at Greensboro, NC	RAL_nbuff	1,000.92	490.22	96.91	9.26	85.59	83.35	56.71
RAL	0209647280	Service Creek abv Dry Creek at Burlington, NC	RAL_serv	561.65	226.35	65.65	5.96	49.29	48.65	33.67
RAL	0209647295	Dry Cr abv Service Creek at Burlington, NC	RAL_dry	1,141.07	453.53	96.81	10.55	89.17	85.58	58.10
RAL	0209651815	Branch Creek blw NC 54 nr Graham, NC	RAL_branch	858.36	300.58	92.63	9.05	76.36	71.62	48.46
RAL	0209665940	Rock Cr Trib at Stoney Cr Golf Course nr Sedalia, NC	RAL_rtrib	93.61	29.47	20.67	2.60	12.18	12.32	10.12
RAL	0209665990	Rock Cr abv Rock Cr Trib nr Whitsett, NC	RAL_rock	47.43	23.81	7.28	1.77	3.85	4.70	5.40

Table 3. Urban intensity indices and variables used to calculate the national urban intensity indices (MA-NUII, NUII) for nine metropolitan areas. — Continued

[POPDEN00, 2000 population density; HUDEN, housing unit density; P_NLCD1_2, percentage of basin areas in developed land; ROADDEN, road density; MA-UII, metropolitan area urban intensity index; MA-NUII, metropolitan area national urban intensity index; NUII, national urban intensity index; BOS, Boston, Massachusetts; RAL, Raleigh, North Carolina; ATL, Atlanta, Georgia; BIR, Birmingham, Alabama; MGB, Milwaukee-Green Bay, Wisconsin; DEN, Denver, Colorado; DFW, Dallas-Fort Worth, Texas; SLC, Salt Lake City, Utah; POR, Portland, Oregon; R, river; nr, near; Rd, road; abv, above; Cr, creek; SR, secondary road; Blvd, boulevard; Br, branch; N, north; blw, below; Trib, tributary; ab, above; St, street; Pkwy, parkway; WY, way; Dr, drive; CR, county road; Fm, farm-to-market road; Ih, interstate highway; WWTP, wastewater-treatment plant; L, little; S Fk, south fork; SF, south fork; Ave, avenue]

Metropolitan area	USGS station number	USGS Station name	Station abbreviation	POPDEN00	HUDEN	P_NLCD1_2	ROADDEN	MA-UII	MA-NUII	NUII
RAL	0209679804	Little Alamance Cr at SR 2309 nr Graham, NC	RAL_lalam	695.14	306.51	82.12	7.73	64.36	64.08	43.73
RAL	0209695780	Brooks Cr at Eddie Perry Rd nr Bynum, NC	RAL_brooks	27.39	16.63	3.14	1.61	2.14	2.40	3.96
RAL	0209697900	Pokeberry Creek nr Pittsboro, NC	RAL_poke	69.46	30.10	6.00	2.20	4.44	5.97	6.30
RAL	02097355	Bolin Cr abv Franklin St nr Chapel Hill NC	RAL_bolin	790.72	263.25	44.35	5.37	42.46	41.19	29.39
RAL	02097464	Morgan Creek nr White Cross, NC	RAL_morgan	70.55	27.94	5.19	2.40	4.93	6.21	6.47
RAL	0209750881	Wilson Cr at mouth nr Chapel Hill, NC	RAL_wilson	295.14	169.27	23.73	3.83	24.14	24.36	18.47
RAL	02099238	Bull Run at NC 29/70 nr Jamestown, NC	RAL_bull	669.41	273.07	66.81	4.78	51.82	47.64	33.09
RAL	02099480	Richland Creek nr Archdale, NC	RAL_rich	597.14	243.08	76.39	7.10	56.83	56.85	38.89
RAL	02100295	Hasketts Cr blw SR 2149 nr Central Falls, NC	RAL_hasket	472.59	166.77	55.91	5.77	41.86	41.64	29.10
RAL	02100634	Vestal Creek nr Asheboro, NC	RAL_vestal	292.52	116.80	38.78	4.48	27.85	29.02	21.01
RAL	0211583580	Bowen Branch nr mouth at Winston-Salem, NC	RAL_bowen	1,083.27	446.77	96.91	9.59	85.05	82.21	55.82
ATL	02204230	Big Cotton Indian Cr at GA 138 nr Stockbridge, GA	ATL_bci	471.98	166.45	43.21	4.40	46.44	46.59	27.85
ATL	02204468	Walnut Creek at Airline Road nr Mcdonough, GA	ATL_wal	218.02	68.09	24.80	3.02	29.96	25.47	15.98
ATL	02206314	Jackson Creek at Lester Road nr Lilburn, GA	ATL_jac	1,015.41	377.48	67.00	5.90	74.12	77.33	45.62
ATL	02208150	Alcovy R at New Hope Road nr Grayson, GA	ATL_alc	277.86	89.91	39.67	3.15	40.21	33.69	20.59
ATL	02213450	Little Tobesofkee Creek nr Bolingbroke, GA	ATL_ltob	7.32	5.14	3.59	1.11	5.85	2.47	3.40
ATL	02217293	Little Mulberry R at GA 211 nr Hoschton, GA	ATL_lmul	192.78	57.95	20.38	2.73	26.07	21.48	13.79
ATL	02217471	Beech Creek at GA 211 nr Statham, GA	ATL_bch	123.17	32.53	16.38	2.61	23.70	17.61	11.55
ATL	02218700	Apalachee R nr Bethlehem, GA	ATL_apa	131.81	43.96	17.84	2.34	23.53	17.42	11.57
ATL	02221000	Murder Creek nr Monticello, GA	ATL_mur	6.86	6.41	3.81	1.17	4.84	2.97	3.67
ATL	02334885	Suwanee Creek at Suwanee, GA	ATL_suw	267.63	102.49	42.56	3.43	41.05	37.18	22.52
ATL	02335870	Sope Creek nr Marietta, GA	ATL_sop	901.05	348.69	72.51	7.12	83.00	84.57	49.17
ATL	02335910	Rottenwood Cr (Interstate N Pkwy) nr Smyrna, GA	ATL_rot	1,197.72	577.23	85.41	6.45	100.00	100.00	59.09
ATL	02336635	Nickajack Creek at US 78/278, nr Mableton, GA	ATL_nic	899.66	357.05	66.17	6.55	75.04	79.32	46.45

Table 3. Urban intensity indices and variables used to calculate the national urban intensity indices (MA-NUII, NUII) for nine metropolitan areas. — Continued

[POPDEN00, 2000 population density; HUDEN, housing unit density; P_NLCD1_2, percentage of basin areas in developed land; ROADDEN, road density; MA-UII, metropolitan area urban intensity index; MA-NUII, metropolitan area national urban intensity index; NUII, national urban intensity index; BOS, Boston, Massachusetts; RAL, Raleigh, North Carolina; ATL, Atlanta, Georgia; BIR, Birmingham, Alabama; MGB, Milwaukee-Green Bay, Wisconsin; DEN, Denver, Colorado; DFW, Dallas-Fort Worth, Texas; SLC, Salt Lake City, Utah; POR, Portland, Oregon; R, river; nr, near; Rd, road; abv, above; Cr, creek; SR, secondary road; Blvd, boulevard; Br, branch; N, north; blw, below; Trib, tributary; ab, above; St, street; Pkwy, parkway; WY, way; Dr, drive; CR, county road; Fm, farm-to-market road; Ih, interstate highway; WWTP, wastewater-treatment plant; L, little; S Fk, south fork; SF, south fork; Ave, avenue]

Metro-politan area	USGS station number	USGS Station name	Station abbreviation	POPDEN00	HUDEN	P_NLCD1_2	ROADDEN	MA-UII	MA-NUII	NUII
ATL	02336728	Utoy Creek at Great Southwest Pkwy nr Atlanta, GA	ATL_uto	915.15	369.47	60.56	5.92	66.99	74.28	43.89
ATL	02336822	Mill Creek at Morning Side Dr nr Hiram, GA	ATL_mil	202.11	66.78	22.06	3.26	26.64	25.61	16.00
ATL	02336876	Powder Springs Cr Oglesby Rd Powder Springs, GA	ATL_pow	312.51	106.70	35.56	3.83	37.69	36.68	22.19
ATL	02336968	Noses Creek at Powder Springs Rd Powder Springs, GA	ATL_nos	513.28	182.52	43.08	4.51	46.01	48.10	28.74
ATL	02337395	Dog R at North Helton Road nr Winston, GA	ATL_dog	71.40	34.07	13.45	2.42	16.27	15.45	10.41
ATL	02338280	Whooping Creek at GA 5 nr Whitesburg, GA	ATL_whp	56.13	25.29	7.28	1.77	9.87	8.83	6.87
ATL	02338375	Centralhatchee Cr Armstrong Mill Rd, Ctrlhtche, GA	ATL_cen	16.66	6.90	4.77	1.47	8.62	5.03	4.74
ATL	02338523	Hillabahatchee Creek at Thaxton Rd nr Franklin,GA	ATL_hil	7.75	4.62	2.81	0.91	0.86	1.04	2.65
ATL	02339480	Oseligee Creek at County Rd 92 nr Fredonia, AL	ATL_ose	21.67	5.88	5.91	1.33	4.44	4.67	4.56
ATL	02340282	House Creek at GA 103 nr Whitesville, GA	ATL_hou	10.91	5.78	4.94	1.15	5.88	3.32	3.85
ATL	02344340	Morning Creek at GA 54 nr Fayetteville, GA	ATL_mor	352.43	133.09	38.35	3.54	39.28	37.88	23.06
ATL	02344480	Shoal Creek nr Griffin, GA	ATL_sho	186.24	70.79	22.91	2.96	26.09	24.53	15.49
ATL	02344737	Whitewater Cr at Willow Pond Rd nr Fayetteville, GA	ATL_whw	186.65	67.15	25.08	2.97	27.59	25.26	15.87
ATL	02344797	White Oak Creek at Cannon Road nr Raymond, GA	ATL_who	153.43	59.57	25.73	2.62	25.92	23.18	14.76
ATL	02344887	Red Oak Creek at GA 362 nr Gay, GA	ATL_rdo	24.34	7.70	4.46	1.31	4.00	4.09	4.26
ATL	02346358	Turnpike Creek nr Milner, GA	ATL_tur	48.00	24.69	10.96	2.23	17.65	12.81	8.95
ATL	02347748	Auchumpkee Cr at Allen Rd nr Roberta, GA	ATL_auc	5.06	2.58	2.33	0.78	0.00	0.00	2.09
BIR	02388518	Little Dry Creek at US 27 at Rome, GA	BIR_ldry	460.47	146.34	55.76	5.07	43.00	37.14	28.09
BIR	02397939	Chappel Creek at Long Branch Rd nr Trion, GA	BIR_chapp	28.48	24.08	4.30	1.52	0.00	1.74	4.57
BIR	02398001	Town Branch nr Summerville, GA	BIR_town	409.66	177.16	57.72	7.44	45.00	46.69	35.10
BIR	02400675	Unnamed Trib to Big Wills Cr at SR 35 nr Fort Payne, AL	BIR_utrwil	332.19	112.71	49.27	7.31	40.60	40.23	30.68
BIR	02400725	Mush Creek nr Portersville, AL	BIR_mush	8.92	6.59	5.29	1.10	0.74	0.00	3.20
BIR	02400800	Little Wills Cr at Collins Chapel Rd at Collinsville, AL	BIR_lwill	58.16	9.43	8.87	1.91	6.60	3.93	5.91

Table 3. Urban intensity indices and variables used to calculate the national urban intensity indices (MA-NUII, NUII) for nine metropolitan areas. — Continued

[POPDEN00, 2000 population density; HUDEN, housing unit density; P_NLCD1_2, percentage of basin areas in developed land; ROADDEN, road density; MA-UII, metropolitan area urban intensity index; MA-NUII, metropolitan area national urban intensity index; NUII, national urban intensity index; BOS, Boston, Massachusetts; RAL, Raleigh, North Carolina; ATL, Atlanta, Georgia; BIR, Birmingham, Alabama; MGB, Milwaukee-Green Bay, Wisconsin; DEN, Denver, Colorado; DFW, Dallas-Fort Worth, Texas; SLC, Salt Lake City, Utah; POR, Portland, Oregon; R, river; nr, near; Rd, road; abv, above; Cr, creek; SR, secondary road; Blvd, boulevard; Br, branch; N, north; blw, below; Trib, tributary; ab, above; St, street; Pkwy, parkway; WY, way; Dr, drive; CR, county road; Fm, farm-to-market road; Ih, interstate highway; WWTP, wastewater-treatment plant; L, little; S Fk, south fork; SF, south fork; Ave, avenue]

Metro-politan area	USGS station number	USGS Station name	Station abbreviation	POPDEN00	HUDEN	P_NLCD1_2	ROADDEN	MA-UII	MA-NUII	NUII
BIR	02401350	Big Canoe Cr at Canoe Creek Rd nr Springville, AL	BIR_bigca	34.93	24.22	2.77	1.46	1.80	1.03	4.13
BIR	02401355	Unnamed Trib to Big Canoe Cr nr Springville, AL	BIR_utrbc	93.35	15.71	12.67	3.42	4.50	10.32	10.44
BIR	02401749	Williams Branch nr Jacksonville, AL	BIR_willi	307.88	97.02	40.18	4.86	34.10	28.55	22.53
BIR	02401760	Little Tallaseehatchee Cr nr Weaver, AL	BIR_ltal	81.62	42.13	9.62	2.62	11.20	7.97	8.91
BIR	02403380	Snow Cr blw Anniston , AL	BIR_snow	413.80	211.65	52.16	6.23	50.00	42.51	32.38
BIR	02406930	Shirtee Creek nr Odena, AL	BIR_shirt	245.13	104.76	42.43	4.83	31.20	29.65	23.22
BIR	02423120	Cahaba R abv Trussville, AL	BIR_cahar	112.37	51.01	13.50	2.32	9.00	8.83	9.35
BIR	0242339580	Little Cahaba R nr Markeeta, AL	BIR_lcabr	286.35	65.53	26.52	3.89	19.60	19.11	16.25
BIR	02423397	Little Cahaba R blw Leeds, AL	BIR_lcale	275.21	84.86	36.33	3.31	25.60	21.77	17.71
BIR	02423515	Patton Creek nr Bluff Park blw Patton Chapel, AL	BIR_patto	911.51	378.74	83.44	7.95	64.20	66.96	48.99
BIR	02423536	Buck Creek at Buck Creek Rd at Alabaster, AL	BIR_buck	254.23	90.27	33.28	3.54	16.40	21.63	17.78
BIR	0242354650	Cahaba Valley Cr at Indian Trail Rd nr Indian Springs, AL	BIR_cvci	319.71	106.90	31.72	3.65	16.80	22.18	18.30
BIR	0242354750	Cahaba Valley Cr at Cross Creek Rd at Pelham, AL	BIR_cvc	266.21	104.00	30.10	3.30	16.30	20.38	17.05
BIR	02423576	Shades Cr at Lakeshore Drive nr Mountain Brook, AL	BIR_shade	490.04	225.18	53.93	5.20	40.80	40.56	30.86
BIR	02423581	Shades Cr at Samford University at Homewood, AL	BIR_shasam	562.05	268.95	59.30	1.81	46.10	33.94	25.73
BIR	02423590	Unnamed Trib to Shades Creek nr Oxmoor, AL	BIR_utsha	597.78	400.26	85.15	6.38	71.90	63.68	46.51
BIR	02423620	Little Shades Cr at State Highway 150 nr Bessemer, AL	BIR_lshad	28.09	13.56	26.56	1.40	2.80	8.95	8.64
BIR	02423729	Dry Creek at Spring Cr Rd nr Montevallo, AL	BIR_dry	96.15	39.53	13.47	2.27	12.60	8.12	8.80
BIR	0242372950	Spring Cr at County Rd 16 nr Moores Crossroads, AL	BIR_sprin	57.67	33.74	11.74	1.90	7.50	6.08	7.38
BIR	02456900	Fivemile Creek at Fivemile Rd nr Huffman, AL	BIR_fivfi	1,016.07	387.39	76.53	7.52	65.20	63.52	46.85
BIR	02456980	Fivemile Creek at Lawson Rd nr Tarrant City, AL	BIR_filaw	905.69	347.55	69.85	3.46	58.30	46.59	34.63
BIR	02458150	Village Creek at East Lake in Birmingham, AL	BIR_villa	809.51	339.96	79.23	8.46	74.00	65.22	47.88

Table 3. Urban intensity indices and variables used to calculate the national urban intensity indices (MA-NUII, NUII) for nine metropolitan areas. — Continued

[POPDEN00, 2000 population density; HUDEN, housing unit density; P_NLCD1_2, percentage of basin areas in developed land; ROADDEN, road density; MA-UII, metropolitan area urban intensity index; MA-NUII, metropolitan area national urban intensity index; NUII, national urban intensity index; BOS, Boston, Massachusetts; RAL, Raleigh, North Carolina; ATL, Atlanta, Georgia; BIR, Birmingham, Alabama; MGB, Milwaukee-Green Bay, Wisconsin; DEN, Denver, Colorado; DFW, Dallas-Fort Worth, Texas; SLC, Salt Lake City, Utah; POR, Portland, Oregon; R, river; nr, near; Rd, road; abv, above; Cr, creek; SR, secondary road; Blvd, boulevard; Br, branch; N, north; blw, below; Trib, tributary; ab, above; St, street; Pkwy, parkway; WY, way; Dr, drive; CR, county road; Fm, farm-to-market road; Ih, interstate highway; WWTP, wastewater-treatment plant; L, little; S Fk, south fork; SF, south fork; Ave, avenue]

Metro-politan area	USGS station number	USGS Station name	Station abbreviation	POPDEN00	HUDEN	P_NLCD1_2	ROADDEN	MA-UII	MA-NUII	NUII
BIR	02461200	Valley Creek at Cleburn Avenue at Powderly, AL	BIR_valle	1,545.30	729.81	95.72	11.88	100.00	100.00	73.35
BIR	02461670	Five Mile Creek at Nevel Rd nr McCalla, AL	BIR_fivne	174.13	60.52	36.46	3.23	16.20	20.41	16.65
MGB	04072233	Lancaster Brook at Shawano Avenue at Howard, WI	MGB_lanc	114.69	40.69	11.66	2.91	33.33	9.97	13.08
MGB	04078085	Black Otter Creek nr Hortonville, WI	MGB_blot	67.76	21.82	5.36	1.67	26.49	2.57	6.76
MGB	04081897	Sawyer Creek at Westhaven Rd at Oshkosh, WI	MGB_sawy	111.73	39.07	13.80	1.75	32.60	6.41	10.05
MGB	04084429	Mud Creek at Spencer Rd at Appleton, WI	MGB_mudc	465.35	190.00	58.83	5.29	62.31	40.22	39.35
MGB	04084468	Garners Creek at Park Street at Kaukauna, WI	MGB_garn	580.74	206.80	68.95	5.90	60.03	46.58	44.73
MGB	04085046	Apple Creek at Sniderville, WI	MGB_appl	121.42	46.96	17.59	2.70	33.29	11.48	14.34
MGB	040850683	Ashwaubenon Creek at South Bridge Rd nr Depere, WI	MGB_ashw	23.16	10.21	5.70	1.62	21.51	2.11	6.26
MGB	040851235	Bower Creek Trib at Lime Kiln Rd nr Bellevue, WI	MGB_bowr	176.74	67.16	24.40	3.07	37.97	15.90	18.16
MGB	040851325	Baird Creek at Superior Rd at Green Bay, WI	MGB_bair	43.05	25.39	5.48	1.42	19.20	1.81	6.16
MGB	04085188	Rio Creek at Pheasant Rd nr Rio Creek, WI	MGB_rioc	11.74	7.01	3.53	1.28	10.48	0.00	4.48
MGB	040851932	Kewaunee R Trib at Lowell Rd nr Luxemburg, WI	MGB_kewa	16.29	10.82	4.37	1.81	13.78	2.38	6.51
MGB	04085270	Jambo Creek at Jambo Creek Rd nr Mishicot, WI	MGB_jamb	10.91	5.25	3.71	1.53	0.00	0.93	5.25
MGB	040853145	Black Creek at Curran Rd nr Denmark, WI	MGB_blak	10.28	4.45	3.23	1.42	4.18	0.31	4.72
MGB	04085322	Devils R at Rosencrans Rd nr Maribel, WI	MGB_devl	16.47	10.72	4.00	1.76	10.81	2.05	6.23
MGB	040854395	Point Creek at Ucker Point Rd nr Newton, WI	MGB_poin	14.24	9.74	5.02	1.45	19.50	1.23	5.52
MGB	04085455	Meeme R at Washington Rd nr Cleveland, WI	MGB_meme	16.33	6.02	5.04	1.56	6.96	1.53	5.73
MGB	04086699	Pigeon Creek at Williamsburg Dr at Theinsville, WI	MGB_pign	143.07	64.03	14.92	2.36	51.83	9.88	13.19
MGB	040869415	Lincoln Creek at 47th Street at Milwaukee, WI	MGB_linc	2,174.50	857.33	97.56	9.32	100.00	91.26	88.28
MGB	04087030	Menomonee R at Menomonee Falls, WI	MGB_meno	310.10	121.74	30.39	3.75	49.47	22.35	24.04
MGB	0408703164	Lily Creek at Good Hope Rd nr Menomonee Falls, WI	MGB_lily	471.74	151.81	77.99	6.19	60.29	48.91	46.03

Table 3. Urban intensity indices and variables used to calculate the national urban intensity indices (MA-NUII, NUII) for nine metropolitan areas. — Continued

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Metropolitan area	USGS station number	USGS Station name	Station abbreviation	POPDEN00	HUDEN	P_NLCD1_2	ROADDEN	MA-UII	MA-NUII	NUII
MGB	04087070	Little Menomonee R at Milwaukee, WI	MGB_ltme	564.27	204.98	44.28	3.95	71.54	30.76	31.74
MGB	040870856	Underwood Cr at Watertown Plank Rd at Elm Grove, WI	MGB_undw	555.67	209.85	86.05	6.78	74.82	55.85	52.33
MGB	04087118	Honey Creek nr Portland Avenue at Wauwatosa, WI	MGB_hony	2,143.96	984.88	99.06	10.38	85.24	100.00	96.86
MGB	04087204	Oak Creek at South Milwaukee, WI	MGB_oakc	600.92	252.20	62.93	4.63	76.37	41.37	40.88
MGB	04087213	Root R at Layton Avenue at Greenfield, WI	MGB_root	1,197.98	504.03	92.84	8.08	89.25	73.03	69.56
MGB	040872393	Hoods Creek at Brook Rd nr Franksville, WI	MGB_hood	92.61	35.78	16.30	2.24	31.26	8.97	12.14
MGB	04087258	Pike R at Cth A nr Kenosha, WI	MGB_pikr	198.14	83.24	27.32	2.37	53.05	14.88	17.43
MGB	04087270	Pike Creek at 43rd Street at Kenosha, WI	MGB_pikc	1,319.13	503.10	87.25	8.62	83.23	73.02	69.61
MGB	05527729	Kilbourn Ditch at 6Oth Street nr Kenosha, WI	MGB_kilb	24.30	12.21	7.43	1.67	27.36	2.98	6.99
MGB	055437901	Fox R at River Rd nr Sussex, WI	MGB_foxr	140.35	65.99	20.15	2.36	39.99	11.78	14.74
DEN	06713500	Cherry Creek at Denver, CO	DEN_cherry	1,859.76	1,033.29	79.61	9.11	99.24	97.34	87.22
DEN	393557105033101	Dutch Cr at Weaver Park nr Columbine Valley, CO	DEN_dutch	1,211.47	437.46	72.02	7.20	97.03	66.61	57.78
DEN	393613104511401	Cottonwood Cr ab Newark WY at Greenwood Village, CO	DEN_cotton	135.44	86.58	59.05	3.63	83.21	36.30	30.92
DEN	393948105053501	Bear Creek blw Estes Rd at Lakewood, CO	DEN_breste	534.07	221.68	38.01	4.44	68.34	35.41	31.62
DEN	394107105021001	Sanderson Gulch abv Lowell Ave at Denver, CO	DEN_sander	1,851.26	797.86	90.42	10.93	93.65	100.00	87.09
DEN	394409105020501	Lakewood Gulch abv Knox Street at Denver, CO	DEN_lakew	1,576.03	737.84	89.26	9.67	100.00	92.91	80.99
DEN	394553105075101	Lena Gulch at Lewis Meadows Park at Wheat Ridge, CO	DEN_lena	648.48	307.68	68.76	7.35	81.76	61.30	52.46
DEN	394629105063101	Clear Creek blw Kipling at Wheat Ridge, CO	DEN_clear	581.98	251.58	62.57	6.20	73.54	52.68	45.25
DEN	394919105074601	Ralston Creek abv Simms at Arvada, CO	DEN_ralst	436.25	144.03	41.40	4.23	53.64	33.32	29.25
DEN	394921105015701	Little Dry Ck blw Lowell St nr Westminster, CO	DEN_litdry	1,764.34	646.07	90.37	10.07	97.25	91.60	79.12
DEN	395324105035001	Big Dry Ck blw Hyland Cr at Westminster, CO	DEN_bigdry	459.61	181.37	33.27	3.47	53.24	28.60	25.95
DEN	395554105085601	Rock Creek abv Rock Creek Pkwy, at Superior, CO	DEN_rock	175.36	54.37	17.40	2.19	37.26	13.13	12.80
DEN	395707105100401	Coal Creek abv Mccaslin Rd at Superior, CO	DEN_coal	8.09	8.62	2.80	1.36	18.22	2.66	4.29

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Metro-politan area	USGS station number	USGS Station name	Station abbreviation	POPDEN00	HUDEN	P_NLCD1_2	ROADDEN	MA-UII	MA-NUII	NUII
DEN	395958105113501	Dry Creek abv Baseline Rd nr Boulder CO	DEN_drybas	91.66	36.08	19.21	2.57	37.24	14.59	13.77
DEN	400000105125400	South Boulder Cr at Baseline Rd nr Boulder Colo	DEN_sbould	72.94	50.14	5.82	1.09	23.89	4.36	5.98
DEN	400023105142301	Bear Cr abv Wellman Feeder Canal at Boulder, CO	DEN_brwell	975.86	452.49	58.90	7.20	64.25	61.80	54.25
DEN	400217105123701	Boulder Creek blw 61st Street nr Boulder, CO	DEN_bould	986.84	419.82	49.38	5.50	60.07	50.71	45.33
DEN	400607105094401	Dry Creek blw Niwot Rd at Niwot, CO	DEN_dryniw	171.40	77.06	22.18	2.25	39.76	16.10	15.29
DEN	400810105071301	Left Hand Creek abv Pike Rd at Longmont, CO	DEN_lhand	87.79	33.93	10.44	2.23	28.22	9.77	10.03
DEN	400855105090501	Dry Creek blw Airport Rd nr Longmont, CO	DEN_dryair	34.56	10.80	8.68	1.28	17.05	4.84	5.97
DEN	400925105023201	Spring Gulch at Sandstone Ranch Park nr Longmont, CO	DEN_spgulc	163.22	79.13	25.15	2.39	44.90	17.88	16.69
DEN	402549105043101	Dry Creek at US 287 at Loveland, CO	DEN_dry287	285.89	142.81	20.94	2.61	52.31	19.18	18.32
DEN	403035105035301	Mail Creek nr mouth at Fort Collins, CO	DEN_mail	1,022.80	293.14	88.05	8.48	92.61	72.63	61.07
DEN	403048105042701	Fossil Cr at College Ave at Fort Collins, CO	DEN_fossil	134.48	49.70	16.60	2.20	53.02	12.69	12.42
DEN	403308105001601	Boxelder Creek at mouth nr Fort Collins, CO	DEN_boxel	13.44	5.91	4.42	1.18	2.97	2.59	4.20
DEN	403356105024001	Spring Creek at Edora Park at Fort Collins, CO	DEN_spcree	1,232.16	538.17	63.49	7.43	81.30	67.50	59.46
DEN	410714104480101	Crow Cr abv Morrie Ave at Cheyenne, WY	DEN_crow	35.76	13.18	8.72	1.20	0.00	4.64	5.84
DEN	413659104370001	Bear Cr abv Little Bear Cr nr Phillips, WY	DEN_brphil	0.22	0.49	1.46	0.85	0.61	0.00	2.14
DFW	08049490	Johnson Cr nr Duncan Perry Rd Grand Prairie, TX	DFW_johnsn	1,591.25	662.31	88.80	9.10	96.63	100.00	78.78
DFW	08049580	Mountain Cr nr Venus, TX	DFW_mount	89.94	25.52	4.79	1.74	34.17	5.27	6.79
DFW	08049955	Fish Cr at Belt Line Rd Grand Prairie, TX	DFW_fish	1,320.93	433.80	70.22	8.04	91.21	77.11	60.93
DFW	08052740	Doe Branch at Fishtrap Rd nr Prosper, TX	DFW_doe	34.78	11.68	6.71	1.76	31.69	5.45	6.85
DFW	08057200	White Rock Cr at Greenville Ave Dallas, TX	DFW_white	1,514.71	716.78	83.94	8.18	98.37	96.95	76.92
DFW	08057431	Fivemile Cr nr Simpson Stuart Rd Dallas, TX	DFW_5mile	1,131.16	401.55	61.60	6.87	73.99	67.30	53.69
DFW	08057475	Parsons Slough nr Davis Rd nr Crandall, TX	DFW_parsn	317.40	109.60	21.28	3.19	46.02	21.88	19.26
DFW	08059530	Tickey Cr nr CR 400 nr Princeton, TX	DFW_tickey	105.09	34.80	9.37	1.98	26.81	8.52	9.20
DFW	08059571	Wilson Cr nr Gray Branch Rd nr Mckinney, TX	DFW_wilson	25.91	13.75	6.49	1.54	34.48	4.53	6.21
DFW	08061536	Spring Cr at Naaman School Rd nr Garland, TX	DFW_spring	1,483.12	548.86	86.01	9.45	100.00	94.81	74.36

Table 3. Urban intensity indices and variables used to calculate the national urban intensity indices (MA-NUII, NUII) for nine metropolitan areas. — Continued

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Metropolitan area	USGS station number	USGS Station name	Station abbreviation	POPDEN00	HUDEN	P_NLCD1_2	ROADDEN	MA-UII	MA-NUII	NUII
DFW	08061740	Duck Cr at Town East Blvd nr Mesquite, TX	DFW_duck	1,474.19	553.43	78.89	7.76	85.36	85.25	67.54
DFW	08061780	Buffalo Cr nr Trinity Rd at Forney, TX	DFW_buftri	100.27	31.66	15.16	2.31	44.33	12.05	11.73
DFW	08061952	South Mesquite Cr at Lawson Rd nr Mesquite, TX	DFW_smesq	1,270.01	473.87	71.94	7.71	78.25	78.40	62.12
DFW	08061995	Mustang Cr at Fm 2757 nr Crandall, TX	DFW_muscra	138.09	29.57	17.35	2.54	36.69	13.75	12.95
DFW	08062020	Buffalo Cr nr Fm 148 nr Crandall, TX	DFW_bufcra	64.18	15.50	7.21	1.68	29.72	5.50	6.91
DFW	08062090	Red Oak Cr nr Hampton Rd nr Red Oak, TX	DFW_redoak	226.57	77.53	15.26	3.26	50.72	18.21	16.40
DFW	08062525	Walker Cr nr Oil Field Rd nr Rosser, TX	DFW_walker	13.40	7.43	2.32	1.18	16.25	1.09	3.69
DFW	08062550	Bois D'Arc Creek nr CR 4072 nr Rosser, TX	DFW_bois	34.57	8.40	4.56	1.74	17.65	4.32	6.01
DFW	08062600	Grays Cr at Cr 1603 nr Rice, TX	DFW_grays	5.24	3.46	2.48	0.94	12.94	0.00	2.89
DFW	08062805	Williams Cr nr Fm 1836 nr Kemp, TX	DFW_will	23.82	8.24	1.56	1.01	23.65	0.16	3.03
DFW	08063047	Bynum Cr nr Fm 308 nr Malone, TX	DFW_bynum	5.63	2.46	2.75	1.37	0.00	1.81	4.17
DFW	08063300	Pin Oak Cr nr Fm 73 nr Coolidge, TX	DFW_pinoak	8.56	5.46	3.11	1.38	5.29	2.15	4.43
DFW	08063510	Little Pin Oak Cr nr Ih 45 nr Richland, TX	DFW_lpin	3.28	1.50	5.13	1.37	4.43	2.72	4.83
DFW	08063555	S Fk Chambers Cr nr CR 102 nr Maypearl, TX	DFW_sfkcha	16.16	6.91	3.34	1.39	16.22	2.33	4.58
DFW	08063565	Mill Cr at Lowell Rd nr Milford, TX	DFW_mill	11.22	2.44	2.80	1.27	6.82	1.42	3.90
DFW	08063574	Big Onion Cr at Feaster Rd nr Bardwell, TX	DFW_bigoni	11.79	3.65	2.55	1.06	18.30	0.52	3.27
DFW	08063595	South Prong Cr at Fm 876 nr Waxahachie, TX	DFW_sprong	19.68	11.01	2.28	1.06	29.05	0.77	3.48
DFW	08063692	Mustang Cr at Moseley Rd nr Ennis, TX	DFW_musenn	131.72	57.41	13.87	2.10	30.78	11.90	11.78
DFW	08064695	Tehuacana Cr at Rural Rd 27 nr Wortham, TX	DFW_tehuac	24.95	10.08	6.94	1.49	7.28	4.35	6.06
SLC	10167800	L Cottonwood Cr at Crestwood Park at Salt Lake City, UT	SLC_lccre	1,418.90	460.13	90.83	9.32	80.80	71.89	69.99
SLC	400927111354501	Hobble Creek at 800 East at Springville, UT	SLC_h800	367.85	104.67	33.41	4.21	40.80	25.43	24.18
SLC	400959111363201	Hobble Creek at Center Street at Springville, UT	SLC_hcen	496.33	145.40	39.63	4.91	45.50	30.91	29.59
SLC	401442111402201	Provo R at 800 North at Salt Lake City, UT	SLC_p800	1,259.36	338.32	72.26	7.47	71.10	56.11	54.39
SLC	401653111400301	Provo R at 3700 North at Provo, UT	SLC_p3700	542.86	149.81	43.26	4.55	51.30	31.45	30.04
SLC	401850111392201	Provo R at Highway 189 at Provo, UT	SLC_p189	14.15	43.98	20.54	3.34	30.90	16.44	15.44

Table 3. Urban intensity indices and variables used to calculate the national urban intensity indices (MA-NUII, NUII) for nine metropolitan areas. — Continued

[POPDEN00, 2000 population density; HUDEN, housing unit density; P_NLCD1_2, percentage of basin areas in developed land; ROADDEN, road density; MA-UII, metropolitan area urban intensity index; MA-NUII, metropolitan area national urban intensity index; NUII, national urban intensity index; BOS, Boston, Massachusetts; RAL, Raleigh, North Carolina; ATL, Atlanta, Georgia; BIR, Birmingham, Alabama; MGB, Milwaukee-Green Bay, Wisconsin; DEN, Denver, Colorado; DFW, Dallas-Fort Worth, Texas; SLC, Salt Lake City, Utah; POR, Portland, Oregon; R, river; nr, near; Rd, road; abv, above; Cr, creek; SR, secondary road; Blvd, boulevard; Br, branch; N, north; blw, below; Trib, tributary; ab, above; St, street; Pkwy, parkway; WY, way; Dr, drive; CR, county road; Fm, farm-to-market road; Ih, interstate highway; WWTP, wastewater-treatment plant; L, little; S Fk, south fork; SF, south fork; Ave, avenue]

Metro-politan area	USGS station number	USGS Station name	Station abbreviation	POPDEN00	HUDEN	P_NLCD1_2	ROADDEN	MA-UII	MA-NUII	NUII
SLC	403707111463701	Big Cottonwood Cr abv WWTP at Salt Lake City, UT	SLC_bcwtp	0.00	5.56	48.15	0.90	0.00	18.44	16.17
SLC	403755111514201	L Cottonwood Cr at Wheeler Farm at Salt Lake City, UT	SLC_lcwh	1,504.37	520.77	93.37	9.55	84.90	75.74	74.10
SLC	403927111523601	L Cottonwood Cr at Murray Park at Salt Lake City, UT	SLC_lcmu	1,760.71	607.82	96.84	12.15	90.10	86.78	85.34
SLC	403945111501001	Big Cottonwood Cr at Cottonwood Mall Salt Lake City, UT	SLC_bcmal	981.06	379.61	85.29	9.60	71.30	67.49	65.29
SLC	404000111515801	Big Cottonwood Cr at 900 East at Salt Lake City, UT	SLC_bc900	1,297.26	522.69	91.94	11.05	78.80	79.01	77.33
SLC	404140111481601	Mill Creek at 3060 East at Salt Lake City, UT	SLC_m3060	1,218.08	431.56	67.72	10.37	89.40	65.37	64.22
SLC	404143111500101	Mill Creek at 2000 East Salt Lake City, UT	SLC_m2000	1,256.70	492.50	65.26	10.90	88.40	68.23	67.54
SLC	404218111525601	Mill Creek at 300 East at Salt Lake City, UT	SLC_m300	2,136.14	849.45	96.91	13.62	100.00	100.00	100.00
SLC	404317111503601	Parleys Cr at Sugarhouse Park at Salt Lake City, UT	SLC_parl	501.54	316.55	65.46	7.34	58.20	52.59	51.05
SLC	404349111512201	Emigration Cr at 1200 East at Salt Lake City, UT	SLC_ewmin	1,011.13	448.29	67.75	8.29	76.20	60.94	60.07
SLC	404430111495301	Emigration Cr at 1300 South at Salt Lake City, UT	SLC_e1300	596.63	228.54	56.68	5.60	59.10	41.78	40.20
SLC	405854111534801	Farmington Cr at Frontage Rd at Farmington, UT	SLC_farm	470.53	125.48	50.52	6.02	48.80	36.61	34.60
SLC	410041111581101	Baer Creek at Frontage Rd at Kaysville, UT	SLC_bafr	671.06	201.25	76.77	3.97	63.40	43.64	41.13
SLC	410148111535301	Baer Creek at Fruit Heights, UT	SLC_ba1800	34.00	15.40	0.00	0.00	15.10	0.00	0.00
SLC	410231111565001	Holmes Creek at Main Street at Layton, UT	SLC_holm	1,023.04	314.38	65.29	10.16	76.60	59.37	57.59
SLC	410250111571501	North Fork of Holmes Cr at Main Street at Layton, UT	SLC_nkho	807.06	236.04	58.65	5.42	67.00	42.32	40.71
SLC	410342111574201	Kays Creek at Layton, UT	SLC_kayl	1,164.57	281.08	67.63	8.42	76.00	54.57	52.61
SLC	410453111570001	Kays Creek at 1000 East at Layton, UT	SLC_k1000	1,066.79	227.07	62.25	7.70	70.60	48.81	46.80
SLC	410501111555201	South Fork of Kays Creek at Layton, UT	SLC_sfk	1,036.67	256.32	69.58	8.37	72.10	54.14	51.94
SLC	410522111541201	SF Kays Cr at Fernwood Picnic Area at Salt Lake City, UT	SLC_fern	0.63	17.75	0.00	0.00	1.30	0.09	0.11
SLC	411407111580501	Ogden R at Washington Avenue at Ogden, UT	SLC_owas	598.43	400.31	57.63	6.26	47.70	50.55	49.99
SLC	411413111554601	Ogden R at Valley Drive Ogden, UT	SLC_oval	75.78	15.68	26.77	5.44	3.80	22.62	20.99

Table 3. Urban intensity indices and variables used to calculate the national urban intensity indices (MA-NUII, NUII) for nine metropolitan areas. — Continued

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Metro-politan area	USGS station number	USGS Station name	Station abbreviation	POPDEN00	HUDEN	P_NLCD1_2	ROADDEN	MA-UII	MA-NUII	NUII
SLC	411413111564101	Ogden R at Harrison Avenue at Ogden, UT	SLC_ohar	501.49	239.52	39.97	4.77	35.60	34.42	33.71
SLC	414258111502001	Logan R at Golf Course Rd at Salt Lake City, UT	SLC_log	1,144.24	443.90	74.35	8.53	71.50	63.64	62.42
POR	14199710	Nate Creek nr Colton, OR	POR_nate	21.46	15.11	1.89	1.73	15.23	4.39	5.20
POR	14205400	East Fork Dairy Cr nr Meacham Corner, OR	POR_efdar	3.59	2.96	0.53	1.24	0.00	1.54	3.01
POR	14206347	Rock Creek at Quatama Rd nr Hillsboro, OR	POR_rocor	441.93	182.72	28.22	3.53	50.88	28.21	24.15
POR	14206435	Beaverton Creek at SW 216th Ave nr Orenco, OR	POR_beave	1,468.55	603.50	82.89	8.79	100.00	86.80	70.58
POR	14206750	Chicken Creek nr Sherwood, OR	POR_chick	246.00	64.85	22.03	3.52	44.67	20.50	17.78
POR	14206950	Fanno Creek at Durham, OR	POR_fanno	1,512.27	641.50	84.32	9.99	96.09	93.60	75.82
POR	14211315	Tryon Creek blw Nettle Creek nr Lake Oswego, OR	POR_tryon	1,105.79	489.99	59.55	9.25	72.44	75.01	60.85
POR	434745123040200	Silk Creek nr Cottage Grove, OR	POR_silk	52.58	23.27	3.46	2.48	23.57	8.16	8.06
POR	435212122483300	Lost Creek nr Dexter, OR	POR_lost	3.67	0.76	0.16	1.51	6.45	2.31	3.56
POR	440257123103200	Amazon Creek nr Danebo Rd at Eugene, OR	POR_amazo	1,237.51	559.28	61.94	8.15	76.72	74.98	61.19
POR	443326123165200	Oak Creek at Corvallis, OR	POR_oak	107.09	65.33	7.13	2.03	39.03	9.71	9.48
POR	445029122592600	Battle Creek nr Turner, OR	POR_battl	497.42	207.57	32.99	4.07	58.26	33.09	27.98
POR	445551123015800	Pringle Creek at Salem, OR	POR_pring	1,282.44	534.56	88.71	8.88	88.27	85.95	69.76
POR	450022123012400	Claggett Creek at Keizer, OR	POR_clagg	1,958.20	731.10	97.81	9.32	99.63	100.00	81.24
POR	450955122291200	Milk Creek at Camp Adams, OR	POR_milk	26.96	6.17	2.27	2.50	11.53	6.99	7.10
POR	451734122585400	Chehalem Creek at Newberg, OR	POR_cheha	76.36	29.38	8.60	2.21	29.31	9.22	8.98
POR	452149123194900	North Yamhill Creek nr Yamhill, OR	POR_nyamh	1.46	1.38	0.63	1.76	7.61	3.41	4.39
POR	452231122200000	Deep Creek nr Sandy, OR	POR_deep	57.55	18.96	4.38	1.84	16.72	5.86	6.36
POR	452337122243500	North Fork Deep Creek at Barton, OR	POR_nfdep	115.67	40.80	27.06	2.63	39.15	17.78	15.76
POR	452414122213200	Tickle Creek nr Boring, OR	POR_tickl	207.93	69.51	19.03	3.16	32.11	18.32	16.12
POR	452526122364400	Kellogg Creek at Milwaukie, OR	POR_kello	1,125.14	445.28	81.00	7.24	88.06	72.93	59.55
POR	452912122291200	Johnson Creek at Circle Ave, OR	POR_johns	553.03	212.80	41.94	4.97	58.71	39.85	33.19
POR	453506123125700	Iler Creek nr Forest Grove, OR	POR_iler	3.97	1.71	0.41	0.86	4.35	0.00	1.86
POR	454321122352300	Curtin Creek nr Vancouver, WA	POR_curti	646.50	228.54	72.42	5.63	69.02	53.73	44.17
POR	454510122424900	Whipple Creek nr Salmon Creek, WA	POR_whipp	264.72	95.01	37.56	3.22	48.55	26.24	22.49

Table 3. Urban intensity indices and variables used to calculate the national urban intensity indices (MA-NUII, NUII) for nine metropolitan areas. — Continued

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Metropolitan area	USGS station number	USGS Station name	Station abbreviation	POPDEN00	HUDEN	P_NLCD1_2	ROADDEN	MA-UII	MA-NUII	NUII
POR	454543122524900	South Scappose Creek at Scappose, OR	POR_sscap	38.55	16.33	3.25	1.76	7.79	5.03	5.71
POR	454549122295800	Salmon Creek nr Battleground, WA	POR_salmo	75.44	23.27	13.21	2.48	19.88	11.57	10.79
POR	455122122310600	Rock Creek nr Battleground, WA	POR_rocwa	55.79	15.38	7.51	2.73	22.87	10.15	9.59

Prepared by:
USGS Enterprise Publishing Network
Raleigh Publishing Service Center
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