

INTEGRATING DEMOGRAPHIC AND LANDSAT (TM) DATA AT A WATERSHED SCALE¹

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ABSTRACT: Recurrent calls for integrated resource management urge that an understanding of human activities and populations be incorporated into natural resource research, management, and protection efforts. In this paper, we hypothesize that watersheds can be a valuable geography for organizing an inquiry into the relationship between humans and the environment, and we present a framework for conducting such efforts. The framework is grounded in the emerging field of landscape ecology and incorporates demographic theory and data. Demography has been advanced by technological capabilities associated with the 1990 Census. Employing Geographic Information System (GIS) tools, we couple Landsat Thematic Mapper (TM) land cover data with census-derived housing density data to demonstrate the operation of our framework and its utility for better understanding human-landscape interactions. In our investigation of the Kickapoo Watershed and two sub-watersheds, located in southwestern Wisconsin, we identify relationships between landscape composition and the distribution and social structure of human populations. Our findings offer insight into the interplay between people and biophysical systems. (KEY TERMS: demography; housing density; land cover classification; landscape ecology; remote sensing; Geographic Information Systems; resource management; social analysis; watershed.)

INTRODUCTION

Applied studies of biological and social systems can proceed at an infinite number of spatial and temporal scales. No single spatial scale is appropriate for addressing all research questions (Levin, 1992), and the selection of any spatial unit can be considered arbitrary from the perspective of one or another natural process or human activity (Forman, 1995). For

these reasons, the choice of a spatial scale will depend upon a number of factors including the availability of time, data, or other resources, the driving hypotheses of the researchers, the needs of a particular community, or the objectives or mandate of a resource management agency.

Where measurable and manageable in extent, the selection of a watershed or drainage basin as the spatial unit for research efforts is valuable for addressing questions of water quality, quantity, and allocation, and for identifying land use practices that affect the same. Research at the watershed scale proceeds on the understanding that "the myriad of physical, chemical, and biological processes occurring within an ecosystem are interrelated" (Hornbeck and Swank 1992:239; Johnson *et al.*, 1997). The value of watershed-scale research has been recognized at both state and federal levels of government (Hadden *et al.*, 1993; Herrmann, 1997). In this article, we suggest that the selection of the watershed as a spatial unit also supports the study of human activities and lends insight into the relationship between human and biological systems. Such an insight has utility in the development of resource management and protection policies. The selection of the watershed as a geographic unit for resource management, and the imprecise application of the term "watershed" where the term "ecoregion" would be more appropriate, has been criticized (Omernik and Bailey, 1997). Our purpose in this paper is not to refute that criticism. Instead, we

¹Paper No. 98106 of the *Journal of the American Water Resources Association*. Discussions are open until October 1, 2000.

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endeavor to demonstrate that, whatever the geographic unit of analysis, human demographic and economic data are both available and can contribute to the study of natural and anthropogenic relationships for resource management and protection efforts (Omernik and Bailey, 1997).

Our emphasis on landscape-scale analysis, an analysis that can include watersheds, can be attributed to three emerging trends in natural resource management. First is the recognition that ecologically sustainable resource management requires an understanding of the relationship between human social structure and behavior and the condition of biophysical resources (Christensen *et al.*, 1996). However, not until recently have these human and biophysical spheres been studied simultaneously in natural resources management efforts to facilitate human community development consistent with resource management and protection (FEMAT, 1993; Quigley *et al.*, 1996). Second, recent sociological research suggests that the formation of a social-biophysical ecosystem, consisting of biophysical and social attributes joined in a spatial scale, facilitates the study and enhancement of ecological processes (Field and Burch, 1988; Machlis *et al.*, 1997; Love, 1997). Finally, writers like Newmark (1985) and Knight and Landres (1998) argue that, to be effective, resource management must work across the boundaries of individual ownership units and at larger spatial scales. Particularly where the quality and allocation of water resources are involved, the watershed is one such spatial scale in which individual ownership units can be aggregated for analysis or to achieve management objectives.

However, while numerous authors concede that social structure is relevant to watershed management and protection efforts, very little systematic information on the social structure of watersheds has been compiled or is available to scientists or resource managers. Measures of social structure in the watershed literature are either missing (Collins and Pess, 1997) or have taken a number of disparate approaches, including economic modeling (Chang *et al.*, 1994), watershed land use planning (Osterman *et al.*, 1989; Willmer, 1992), and an attention to values (Hyman and Wernstedt, 1995).

We posit that there is a social and cultural fabric woven into a watershed's biophysical ecosystem, and that it is identifiable using economic and demographic data. The intent of the present paper is to illustrate the contribution that a decennial census database can make to describing this social fabric and to pursuing integrated watershed-scale analysis. Our research is guided by two central questions: (1) can we effectively link biophysical data and demographic data within a watershed to describe relationships between humans

and their watershed environment? and (2) can we demonstrate the relevance of these relationships to the management and use of the natural resource base within the spatial unit under study?

UNDERSTANDING THE SOCIAL CHARACTERISTICS OF WATERSHEDS: JUSTIFICATIONS AND PREVIOUS RESEARCH

In the late 1960s, geographers advanced the use of water as an organizing principle for research in earth and social sciences:

"[T]he study of water provides a logical link between an understanding of physical and social environments. . . . Not only is [water] a commodity which is directly used by man, but it is often the mainspring for extensive economic development, commonly an element in man's aesthetic experience, and always a major formative factor of the physical and biological environment which provides the stage for his activities" (Chorley, 1969:3).

An understanding of the human activities occurring within a watershed is essential for achieving water quality, quantity, and habitat-related objectives (Wear *et al.*, 1998). One method by which to achieve such an understanding is to introduce social, economic, and demographic data from the decennial census to watershed-scale research and policy-making efforts. This census-derived data, we argue, can reflect human settlement and population characteristics in the watershed. Although research at the watershed scale has acknowledged the part that humans play in shaping water resource issues, demographic information is not always incorporated where it could enhance that research.

For example, in one watershed-scale discussion, Shrubsole (1992) tracks the history and contributions of the Grand River Conservation Commission to multi-jurisdictional watershed management. The author acknowledges that agencies with resource management mandates need to "provide a mechanism to broaden the management perspective, enhance legitimacy, and provide for collaboration among relevant public and private participants" (Shrubsole, 1992:234). Missing from the discussion, however, is any mention of the role that social, economic, and demographic data can play both in identifying participants in the decision-making process and in gaining an understanding of the people who occupy the watershed.

Wernstedt and Paulsen (1995) undertook a study of salmon recovery options available to resource managers in the Columbia River basin. Their study employed a system-wide modeling and analysis of financial costs and biological effects of fish- and wildlife-enhancing programs. The objective of the systems analysis was to inform decision makers about the efficacy and consequences of least-cost mitigation efforts (Wernstedt and Paulsen, 1995). The analysis could have been enhanced had information on the economic status of consumers, upon whom the costs will ultimately fall, been incorporated. Resource decision makers for whom the authors devised the cost-benefit models would undoubtedly benefit from knowing the extent to which consumers are willing and/or able to bear the increased economic burden of salmon recovery efforts.

Fortunately, there are exceptions to this critique, where human demographic or economic information is explicitly included. On the Northwest Coast, Wernstedt (1995) undertook a study of the regional distributional implications of natural resource management decisions regarding salmon populations in the Columbia River basin. Wernstedt argues that the interest in, demand for, and economic burdens of salmon recovery efforts will vary within the region, both between urban and rural populations, and across urban and rural populations, depending upon which recovery strategy is chosen. Wernstedt's very relevant research and hypotheses centered on a compelling natural resource issue within a watershed. Importantly, the author does include data relating human populations in the area. Wernstedt employs industry, occupation, and income data, at the county level and state level, taken from the US Census Bureau's decennial census; data from Occupational Employment Statistics Survey of the US Bureau of Labor Statistics; data from state employment and labor offices; and data from the US Internal Revenue Service (Wernstedt, 1995). By incorporating social and demographic data, Wernstedt obtains a more pragmatic understanding of the natural resource issue, an understanding that could facilitate a more efficient and effective resolution to salmon recovery in the Columbia River basin.

THEORETICAL FOUNDATIONS: INTEGRATING LANDSCAPE ECOLOGY WITH DEMOGRAPHY

Landscape ecologists study the interactions between landscape pattern and ecological processes at different temporal and spatial scales (Risser *et al.*, 1984; Risser, 1987) and are concerned with: (1) the

development and maintenance of spatial heterogeneity; (2) interactions across heterogeneous landscapes; (3) the influence of heterogeneity on biotic and abiotic processes; and (4) management of that heterogeneity on both natural and human landscapes (Risser, 1987). Spatially, a landscape is a mosaic of patches, edges (boundaries between distinct patches), and an embedding matrix (Forman, 1995). Where identifiable, the matrix constitutes the background or dominant ecosystem in a landscape, and either constrains or supports patch connectivity and the movement of organisms and materials between landscape elements (Forman, 1995).

Diverse and heterogeneous landscapes can be characterized by three fundamental attributes: structure, function, and change (Risser, 1987). A landscape has a **structure** consisting of energy, species, and materials in spatial relationships and within distinctive ecosystems. The spatial arrangement of those elements gives each landscape its unique *pattern*. The pattern of a landscape shapes and is shaped by that landscape's **functions** or *processes*, which include, for example, disturbance regimes, nutrient flows, photosynthesis, and sedimentation. Finally, each landscape will undergo **changes** in structure and function over time. Changes to the landscape may occur seasonally, daily, in response to a climatic event, as a result of natural and human disturbances, or through species extinction or colonization.

Landscape ecology as a field of study considers humans as actors in, and therefore a part of, the landscape (Risser *et al.*, 1984). As a result, principles of landscape ecology provide a foundation for applied sciences such as wildlife management, conservation biology, and urban and regional planning (Risser *et al.*, 1984). Research in landscape ecology frequently acknowledges human impacts on the landscape (Delcourt and Delcourt, 1988; Franklin and Forman, 1987) and increasingly seeks to incorporate human measures (Wear *et al.*, 1998; LaGro, 1998; Radeloff *et al.*, in press).

Concepts borrowed from landscape ecology, including those of "structure" and "function" and the study of landscape "change," are applicable to the organization of human society. We pair these concepts with principles from the fields of demography and social area analysis to illustrate the compatibility of these separate disciplines (Galpin, 1915; Sauer, 1925; Hawley, 1998; McKenzie, 1982).

At a landscape scale, a population's structure is described by its size, composition, concentration, and distribution (Hauser and Duncan, 1959). Social institutions of economy, family, and community also convey structure (Park, 1982). These institutional and population components, in concert with the elements

of ecosystems described above, constitute a landscape's structure and determine spatial arrangements and boundaries between and within patches. Social system functions consist of relationships and interactions between and among population members and institutions (McKenzie, 1982). Social system functions include birth, death, migration, nurturing, education, employment, bartering, production, rule definition and implementation, and governance. The interactions between social structure and function and the structural and functional attributes of the biophysical landscape foster distinctive social-cultural systems and shape the manner in which environmental attitudes and behaviors are incorporated into these systems (Field and Burch, 1988; Greider and Garkovich, 1994). All societies undergo changes in their structure and functions. Some examples of social changes include population growth or decline, shifts in economy from agricultural subsistence to industry, technological innovation, and economic or educational enrichment. These changes invariably affect the relationship of that social system with the biophysical environment (Park, 1982).

Merging landscape ecology with demography allows us to: (1) operate at the landscape or regional scale; (2) integrate biophysical, demographic, and economic data simultaneously; and (3) address current efforts to undertake ecosystem management. For purposes of clarity and simplicity, we limit our discussion in the remainder of this paper to landscape and demographic *structure*. We have selected a single indicator for both social and biophysical landscape structure. We employ land cover as an indicator of biophysical landscape structure; the land cover of a patch and the association of heterogeneous patches will offer an insight into the species present within and the ongoing processes in an ecosystem. We have selected housing density to represent social structure in the watershed. Housing density not only serves as a proxy for population size in the watershed, but also reflects the distribution of the human population in the watershed. The distribution of a population has implications for patch size, shape, and connectivity; in sum, for the structure of the biophysical landscape.

THE KICKAPOO RIVER WATERSHED

The Kickapoo River Valley of Southwest Wisconsin encompasses a 1,980 square kilometer watershed in parts of four counties located at the western edge of the state (Figure 1). Prompted by a gubernatorial initiative to improve water quality, stimulate rural

development, and improve the quality of rural life for its residents, the Kickapoo Watershed has been the subject of numerous disciplinary studies for several decades (School of Natural Resources, 1996; Kuczynski *et al.*, 1999). It is our intention that the research discussed herein both draw from and contribute to the substantial body of work conducted in this region. The Kickapoo Watershed is approximately 96 kilometers long with an average width of 15 to 25 kilometers, and is comprised of five sub-watersheds (Figure 1). Having escaped the glacial scouring of the most recent ice age, the watershed consists of regionally uncharacteristic steep and varied topography (School of Natural Resources, 1996). The Kickapoo Watershed is heavily forested, with approximately half of the land covered by forests (Heasley and Guries, 1998). In part as a result of active fire suppression, timber harvesting, and livestock grazing, the composition of the Kickapoo's forests is in transition from oak-hickory communities to shade-tolerant maple-basswood forests (Kline and Cottam, 1979; Hix and Lorimer, 1990; Lorimer and Frelich, 1994).

The topography and natural resources of the Kickapoo shape the cultural and social structure of the watershed in numerous ways. For example, the steep slopes of the watershed constrain road and railroad construction and somewhat isolate the Kickapoo from the surrounding region and ready access to and from markets. Similarly, the topography of the Kickapoo influences land use in the watershed: the ridgetops and valley bottoms are devoted to human settlements and agriculture, and the slopes, too steep to plow, are largely forested. Additionally, the shift of forest communities in the Kickapoo from economically valuable oak to shade-tolerant maple-basswood has potential implications for forest-related occupations available to Kickapoo residents (Heasley and Guries, 1998).

Conversely, human activities in the watershed have impacts on biological processes and systems. Erosion and sedimentation resulting from historical land use and settlement practices in the steep Kickapoo River Valley had profound effects on water quality and flood events in the watershed (Heasley and Guries, 1998). The transition in forest structure from oak-hickory to shade-tolerant maple-basswood communities has implications for the size and composition of wildlife populations. It is these interrelationships, between human populations and the landscape in which these human populations reside, that must be addressed in long-term water resource planning, management, and protection endeavors. Furthermore, it is these relationships that can best be elucidated by employing the integrated analysis we illustrate below.

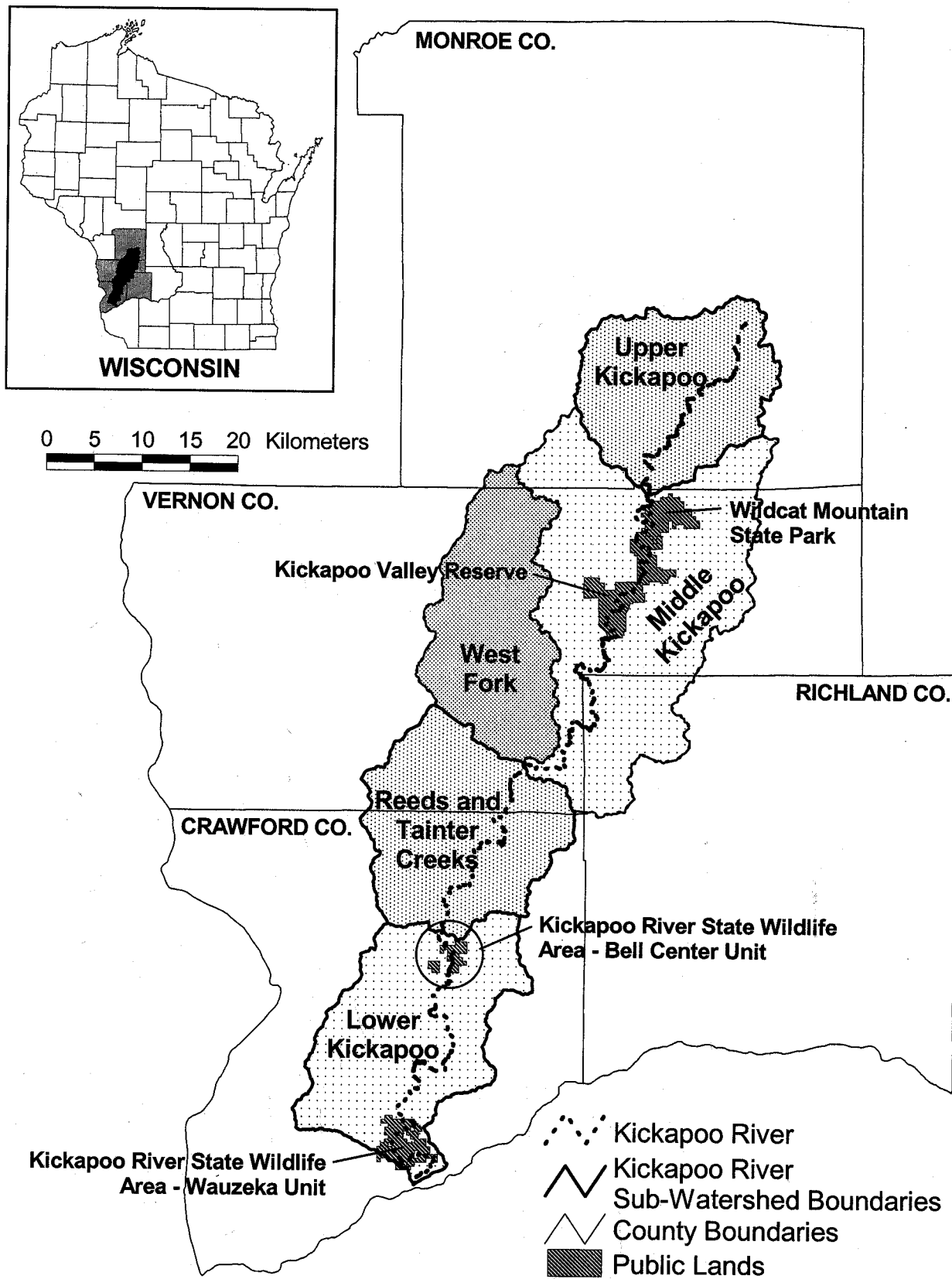


Figure 1. The Kickapoo River Watershed and Its Five Sub-Watersheds.

METHODOLOGY

Data Sources: Census Geography and Satellite Classification

Housing density and other demographic data were acquired from the U.S. Census Bureau, 1990 Census of Population and Housing (U.S. Bureau of the Census, 1991). Basic population and housing data are acquired from every household that completes the decennial census form, and are available at the "census block," the smallest unit of geography for which data are reported. Census blocks are aggregated into census block groups for reporting more detailed social and economic data such as the respondent's income, industry and occupation, and educational attainment (U.S. Bureau of the Census, 1993). This more detailed demographic information is collected on the census "long form," but only from a sampling of households in each decennial census. In order to achieve reasonable statistical precision for small, sparsely settled rural areas such as the Kickapoo Watershed, the Census Bureau increases the sampling rate relative to that used in more densely settled cities. The sampling rate of housing units receiving the census "long form" in the rural portions of the Kickapoo Counties was approximately 50 percent. That is, the more detailed data are based on a sample of roughly every other housing unit throughout the Watershed (U.S. Bureau of the Census, 1991). All enumerated census data is available digitally, for integration into a GIS, through a Topologically Integrated Geographic Encoding and Referencing System (TIGER) (Klosterman and Lew, 1992).

Census blocks within and adjacent to the Kickapoo Watershed boundaries were assembled to constitute the territory of the Kickapoo Watershed and its five sub-watersheds. Because census geography and biophysical areas such as watersheds rarely have common boundaries, it was necessary to spatially interpolate the census data to conform to the sub-watershed boundaries (Long and Voss, 1998; Voss and Long, 1999). To calculate the housing density within a census block, the total number of housing units was divided by land area (in square kilometers). Housing density was assigned uniformly across each census block. Census blocks were assigned to one of six housing density classes (Table 1, Figure 2A).

Land cover data employed in this paper were derived from Landsat (TM) satellite imagery having a 30x30 meter pixel size (or resolution). Each pixel contains a single land cover attribute, and that attribute is assigned according to the predominant spectral signal, or reflectance, received for that pixel (Lillesand *et al.*, 1998). Nine land cover classes were identified

for the Kickapoo Watershed: water, barren, urban, wetland, forested wetland, coniferous forest, deciduous forest, grassland, and agriculture (Figure 2B).

TABLE 1. Housing Density Classes for the Kickapoo Watershed.

Density Class	Housing Units per Square Kilometer
1	No Housing Units
2	< 2 Units / km ²
3	2-4 Units / km ²
4	4-8 Units / km ²
5	8-16 Units / km ²
6	> 16 Units / km ²

Integrating Census Data and Land Cover Classification in a Geographic Information System

We used a Geographic Information System (GIS) to integrate the land cover and census data (Radeloff *et al.*, in press). A polygon coverage (digital map) of the housing density data was converted to a raster coverage with the same spatial resolution and geographic projection as the Landsat (TM) land cover classification data (30 m). The overlay of the two raster maps resulted in a new raster map with 36 possible class combinations (nine land cover classes times six housing density classes). This map allowed us to compute the total area of each land cover type within each of the six housing density classes (e.g., total area of grasslands that contain a housing density of ≥ 16 units per square kilometer).

Census and satellite data were collected and are presented for the entire Kickapoo Watershed. Two sub-watersheds, the West Fork and the Lower Kickapoo, are the focus of detailed discussion.

RESULTS

Housing Densities in the Entire Kickapoo Watershed and in Two Kickapoo Sub-Watersheds

The Kickapoo is clearly a rural watershed, with low housing density across the landscape (Figure 2A). Nevertheless, there are structural differences between the West Fork and Lower Kickapoo sub-watersheds (Table 2). The highest portion of land in the West Fork sub-watershed falls into housing density class (HDC) Three, with between two to four

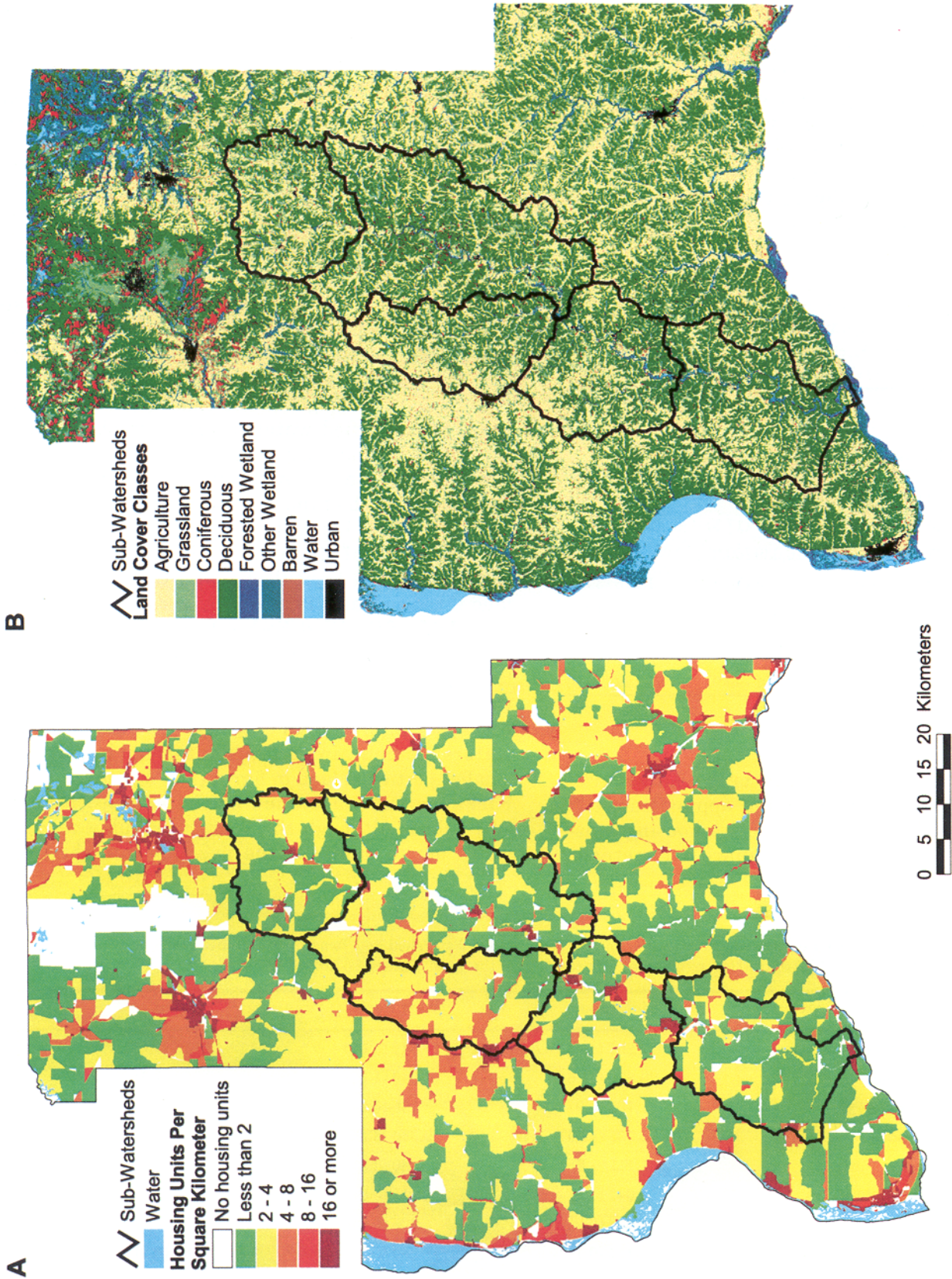


Figure 2. (A) Housing Density in the Kickapoo River Watershed in Six Density Classes; and (B) Land Cover in the Kickapoo River Watershed in Nine Land Cover Classes as Identified by Landsat (TM).

housing units per square kilometer. In contrast, two-thirds of the Lower Kickapoo sub-watershed land falls into HDC Two, having a housing density of less than two housing units per square kilometer. Portions of three incorporated places, Cashton, Westby, and Viroqua, lie along the Western edge of the West Fork and are identifiable on Figure 2A by their relatively high Class Six housing densities. In the Lower Kickapoo, portions of Mount Sterling, Eastman, and Wauzeka are also identifiable on Figure 2A by their relatively high Class Six housing densities.

TABLE 2. Absolute Area and Relative Portion of the Kickapoo Watershed and Two Sub-Watersheds in Each Housing Density Class in Hectares and as a Percentage of the Total Watershed or Sub-Watershed Area.

Housing Density Class	Kickapoo	West Fork	Lower
1	8,048 (4.5)	753 (2.7)	1,784 (5.1)
2	80,950 (45.1)	4,845 (17.5)	22,433 (63.9)
3	75,643 (42.1)	16,639 (60.3)	8,820 (25.1)
4	9,822 (5.5)	4,358 (15.8)	1,218 (3.5)
5	2,277 (1.3)	433 (1.6)	557 (1.6)
6	2,717 (1.5)	565 (2.0)	302 (0.9)
Total	179,465 (100)	27,601 (99.9)	35,122 (99.9)

Neither sub-watershed can be fairly characterized as particularly housing-dense, but approximately 20 percent of land in the West Fork has a housing density of four housing units per square kilometer or

greater (HDCs Four, Five, and Six combined). In contrast, only 6 percent of the land in the Lower Kickapoo sub-watershed and only 8 percent of the entire Kickapoo Watershed land have a housing density of four housing units per square kilometer or greater. The West Fork, then, is slightly less rural than either the Lower Kickapoo sub-watershed or the entire Kickapoo Watershed.

Land Cover in the Entire Kickapoo Watershed and in Two Kickapoo Sub-Watersheds

Land cover in the Kickapoo Watershed is dominated by both deciduous forests and agriculture (Table 3, Figure 2B). Landsat (TM)-identified forested wetlands and urban and barren lands in the entire Kickapoo Watershed are negligible. The small portion of Landsat (TM)-identified water in the watershed can be explained by the narrow channel of the Kickapoo River and tributaries, by the presence of overhanging trees along much of the waterway, and by the limited resolution of the Landsat.

A majority of the area of the West Fork sub-watershed is in agriculture, and that agricultural land is concentrated in a wide band running along the west flank of the West Fork sub-watershed. The West Fork sub-watershed contains an absolutely and relatively greater portion of land in agriculture than both the Lower Kickapoo sub-watershed and the entire Kickapoo Watershed. In contrast, the West Fork sub-watershed contains an absolutely and relatively smaller portion of land in forest than either the Lower Kickapoo sub-watershed or the entire Kickapoo Watershed. Although the West Fork sub-watershed ranks fourth in size of the five sub-watersheds, 25

TABLE 3. Absolute Area and Relative Portion of the Kickapoo Watershed and Two Sub-Watersheds in Nine Land Cover Classes in Hectares and as a Percentage of the Total Watershed or Sub-Watershed Area.

Land Cover Classification	Kickapoo	West Fork	Lower
Agriculture	77,257 (43.0)	14,542 (52.7)	13,975 (39.8)
Grassland	20,879 (11.6)	2,946 (10.7)	2,577 (7.3)
Coniferous	1,702 (0.9)	166 (0.6)	204 (0.6)
Deciduous	73,705 (41.1)	9,354 (33.9)	16,560 (47.2)
Forested Wetland	1,111 (0.6)	30 (0.1)	518 (1.5)
Other Wetland	2,641 (1.5)	217 (0.8)	822 (2.3)
Barren	1,664 (0.9)	229 (0.8)	321 (0.9)
Water	171 (0.1)	30 (0.1)	87 (0.2)
Urban	329 (0.2)	82 (0.3)	52 (0.1)
Total Area	179,465 (100)	27,601 (100)	35,122 (100)

percent of the urban lands in the entire Kickapoo Watershed are found in this sub-watershed.

The terrain of the Lower Kickapoo sub-watershed is both more hilly and more forested than the West Fork sub-watershed (Figure 2B). The Lower Kickapoo sub-watershed contains a relatively greater portion of land in forest and a relatively lower portion of land in agriculture than the entire Kickapoo Watershed. Agricultural lands in the Lower Kickapoo sub-watershed are concentrated on the valley bottom and along the western edge of the sub-watershed. Approximately one-third of the Kickapoo Watershed wetlands and 47 percent of the Kickapoo Watershed forested wetlands are located within the Lower Kickapoo sub-watershed.

Land Cover and Housing Density in the Entire Kickapoo Watershed and in Two Kickapoo Sub-Watersheds

Housing density data integrated with land cover data for the entire Kickapoo Watershed and for two sub-watersheds are presented in Figure 3. These graphs display the relative portion of each land cover class in each housing density class. The two sub-watersheds maintain a unique pattern (landscape structure) of land cover in each housing density class when compared to each other and to the Watershed as a whole.

The Kickapoo Watershed. The relative portion of forested land rises as housing density decreases, and peaks in HDC Two (48.5 percent of the land in HDC Two is in forest or forested wetlands). The relative portion of land in agriculture peaks at 56.6 percent of the land in HDC Four and tapers gradually to a low in HDC Two of 38 percent of the land in that housing density class. The relative portion of land in grasslands is somewhat the inverse of the agricultural lands, with a low of 10.4 percent of the land in HDC Four and a high of 13.5 percent in both HDCs One and Six. The relative portion of land in wetlands and forested wetlands combined is highest in HDCs One, Five, and Six. Wetlands and forested wetlands comprise 10.1 percent of the land in HDC One, 6.5 percent of the land in HDC Five, and less than 2 percent of the land in HDCs Two, Three, and Four.

West Fork Sub-Watershed. In the West Fork sub-watershed, the relative portion of land in agriculture is high in all housing density classes, with a range of 37.6 percent of the land in agriculture in HDC Two to 70.9 percent of the land in agriculture in the highest housing density class. When comparing Figure 2A with Figure 2B, both the higher housing

densities and the land cover classified as agricultural lie along the western, non-forested flank of the sub-watershed. The relative portion of land in forest rises and falls in a bell-shaped curve with housing density. The lowest portion of forested land is found in the highest housing density class; only 9.6 percent of the land in HDC Six is forested. There are no forested wetlands in HDCs Four, Five, and Six. The relative portion of Landsat (TM)-identified grasslands peaks in HDC Five (14.2 percent of the housing density class) and is lowest in HDCs One and Six (9.4 percent of the housing density class).

Lower Kickapoo Sub-Watershed. The relative portion of land in forest and forested wetlands is high in all housing density classes. In HDC Six, 17.5 percent of the land is forested; this is almost twice the relative portion of forested land in the same housing density class as the West Fork. Like the West Fork sub-watershed, HDC Two contains the highest relative portion of forested land; 52.7 percent of the land is forested in HDC Two. The relative portion of land in agriculture increases in a linear relationship with housing density from a low of 35.4 percent in HDC One to a high of 63.4 percent in HDC Six. Similarly, the relative portion of land in grassland increases as housing density increases from a low of 6.6 percent in HDC One to a high of 13 percent in HDC Six. However, with the exception of the change from HDC One to Two, the relative amount of Landsat (TM) identified forest land decreases as housing density class increases. Land in wetlands and forested wetlands comprises 20 percent of the land in HDC One and 11.2 percent of the land in HDC Five, but only 0.1 percent of the land in HDC Six.

INCORPORATING ADDITIONAL DEMOGRAPHIC DATA INTO OUR CASE STUDY

Before we undertake a discussion of the integrated data, we first introduce additional demographic and housing data taken from a sampling of households in the Kickapoo Watershed (see Appendix). These data allow us to create a more complete picture of the people in the watershed and to illustrate the differences in the social structure of the two sub-watersheds.

The Lower Kickapoo sub-watershed is larger than the West Fork sub-watershed by 7500 hectares, yet its population is roughly half that of the West Fork (Table 4). This difference in population size may be explained by the presence of Westby and Viroqua along the western edge of the West Fork sub-watershed. Westby and Viroqua had 1990 populations of 1,866 and 3,922, respectively, and are relatively

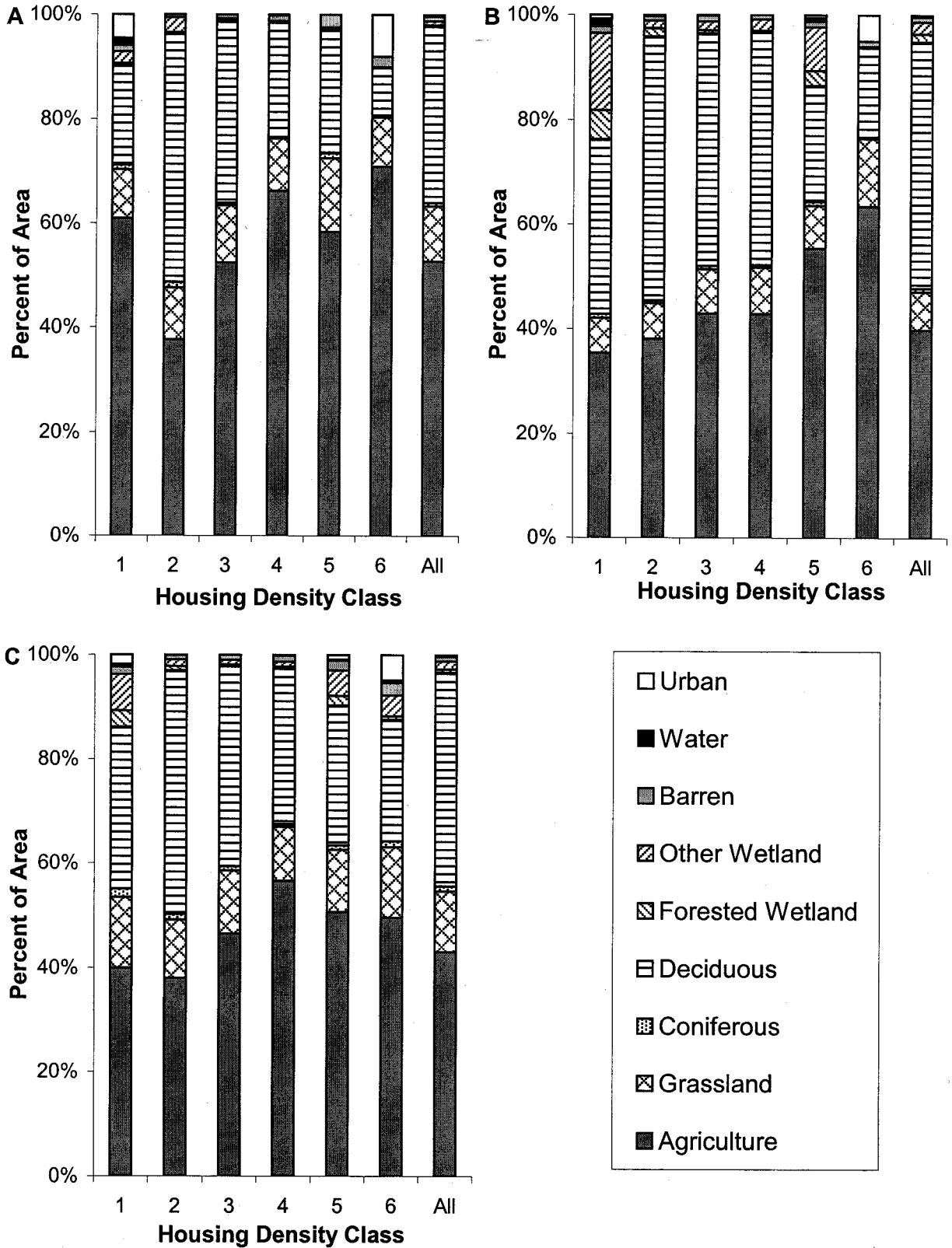


Figure 3. Landsat (TM) Land Cover Classification as a Percentage of Housing Density Class in Two Sub-Watersheds and in the Entire Kickapoo Watershed: (A) the West Fork Sub-Watershed; (B) the Lower Kickapoo Sub-Watershed; (C) the Entire Kickapoo Watershed.

large communities in the Kickapoo watershed (U.S. Bureau of the Census, 1991). The remainder of the sixteen incorporated places in the watershed had 1990 populations of less than 800 persons (U.S. Bureau of the Census, 1991). The population of the West Fork sub-watershed is older than the population of the Lower Kickapoo sub-watershed; nearly 40 percent of the West Fork's population is aged 65 or greater compared with only 13 percent of the Lower Kickapoo. Employment in the agriculture, forestry, and fishing industries is high for the entire Kickapoo Watershed, but is higher in the Lower Kickapoo than in the West Fork. In contrast, the West Fork has a higher portion of its population employed in the health and education services. The West Fork is home to 30 percent each of the entire Kickapoo Watershed persons employed in both education and health services. Although a larger portion of the West Fork population aged 15 or higher lacks a high school diploma, the West Fork accounts for 37.2 percent of the entire Kickapoo Watershed population having a professional degree.

The Lower Kickapoo sub-watershed has a higher portion of vacant housing units than the West Fork sub-watershed, and a disproportionate number of vacant units for the entire watershed (Table 5). Housing density and population size are higher in the West Fork than in the Lower Kickapoo, but both the area and proportion of land in agriculture are higher in the West Fork than in the Kickapoo. Consistent with this finding, the portion of housing units identified as census-defined "farm residences" is absolutely

greater in the West Fork sub-watershed. Farm residences comprise a greater proportion of housing units in the Lower Kickapoo, however.

ANALYSIS AND DISCUSSION

The combination of census data with land cover data allows an analysis of the social and biological structure of the watershed that is not possible when viewing the data sets independently. In combining the two data sets, we can better understand the current social and biophysical landscape structure of the sub-watersheds and begin to anticipate changes in both the social and biological structure of the Kickapoo Watershed. Different landscape structures within the sub-watersheds will both affect and be affected by social and biological landscape processes (functions) in the sub-watershed communities. Differences in the social and economic structure of the West Fork and the Lower Kickapoo sub-watersheds may not only help to explain the structure of that sub-watershed's landscape but may also lead to different trajectories of change in the sub-watershed.

For example, the high portion of residents of the West Fork sub-watershed aged 65 or greater may be a cause or consequence of the similarly high concentration of the Kickapoo watershed population employed in health services. In either case, an expanding older population forecasts changes in land tenure and possibly in land use. Land currently in agriculture may

TABLE 4. Social and Demographic Characteristics for the Entire Kickapoo Watershed and for Two Sub-Watersheds.

Variable	Kickapoo	West Fork	Lower
Persons	18,807	4593 (24.4)	2579 (13.7)
Persons Age 65 or Greater	3941 (20.9)	1712	335
Portion of Population Without a High School Diploma	3659 (26.2)	1018	
Portion of Population With a Professional Degree	313 (2.2)	117	53
Persons Employed in Agriculture, Forestry, or Fisheries	2359 (29.2)	430	344
Persons Employed in Health Services	611 (7.6)	189	65
Persons Employed in Educational Services	559 (6.9)	170	89

TABLE 5. Housing Characteristics for the Entire Kickapoo Watershed and for Two Sub-Watersheds.

Variable	Kickapoo	West Fork	Lower
Housing Units	7764 (100)	1908 (24.6)	1152 (14.8)
Vacant Housing Units	1054 (13.6)	167	264
Vacant Units Identified as for Recreational or Seasonal Use	485 (46)	58	139
Housing Units That Are Census-Defined Farm Residences	1580 (20.3)	304	232

be converted to housing units, supporting further growth in the West Fork population. Alternatively, the growing Amish population within West Fork sub-watershed and in the vicinity of the incorporated community Cashton may sustain or even increase the relative portion of agricultural lands in this sub-watershed (Heasley and Guries, 1998).

Census data report employment by industry for areas as small as block groups. However, for purposes of understanding the impact of the agricultural and forestry industries, resource-dependent industries that have an impact on water quality, census data have certain limitations: respondents in the agricultural and forestry industries are grouped together, making difficult an analysis of the relative importance of the two different industries to a region. Once land cover classification information is integrated with the census data on a sub-watershed level, however, it is possible to begin teasing apart the industry information to infer the relative importance of these industries to a region. For the West Fork sub-watershed, for example, we can theorize that a greater portion of the population employed in the "agriculture, forestry, and fisheries" sector is in agriculture: a higher portion of the land cover is in agriculture than in forest. In contrast, analysis of the high portion of the Lower Kickapoo sub-watershed in forest cover, when combined with census data, makes possible a series of very different conclusions about the relative importance of the forestry and agriculture sectors in the Lower Kickapoo. The high concentration of forests and forested wetlands in the Lower Kickapoo sub-watershed may also support a high level of recreational activity, which could explain the high number of vacant housing units in the Lower Kickapoo sub-watershed identified for seasonal or recreational use. High absentee ownership and/or the seasonal or recreational use of property in a region may produce different land use practices or priorities and affect the management of forest and water resources in that region.

The integration of housing density with land cover classification data is also useful for observing the relationship between land use, human settlement, and landscape structure. In the Kickapoo Watershed and in both the West Fork and Lower sub-watersheds, for example, the relative portion of land in forest cover decreases as housing density increases. The absence of higher-density housing units in forested land in the Kickapoo may simply be explained by the steep slopes of the Watershed upon which much of the forests grow. The steep slopes make both agricultural endeavors and the construction of housing difficult, if not impossible. Additionally, however, the construction of higher-density housing units may be incompatible with the retention of forested land. This latter

explanation has implications for the design of land use policies and forest management plans in the Kickapoo Watershed and in other forested regions. As housing density increases, the fragmentation of forested lands increases. The fragmentation of an ecosystem may affect species composition and landscape structure, with implications for management objectives (Franklin and Forman, 1987). It is interesting to note that wetlands and forested wetlands are lowest in HDCs Two, Three, and Four in the entire Kickapoo Watershed and in the Lower sub-watershed, but are highest in HDC Two in the West Fork sub-watershed. Trends in wetlands and forested wetlands, however, are not consistently associated with relatively low or high portions in the housing density classes of either agriculture, forest, or grasslands. Water-resource managers may wish to focus particular attention on the structural qualities of a watershed landscape that promote or impede the retention of wetlands, particularly as lands are converted from zero housing density to one of the lower housing density classes.

For water quality personnel, knowledge of the spatial relationship between problem waterways and agricultural or higher-housing-density land can facilitate targeted efforts to improve land use practices or undertake landowner education efforts. Resource managers who have available integrated information about both the landscape and the social and demographic structure of a region can tailor their management plans and approaches to be effective in that region. Similarly, such information could be valuable to planners or others interested in maintaining stream-side habitat or setting aside land for water quality objectives. Although the resolution employed in this project does not provide the precision necessary for the identification of individual ownership parcels, it provides resource managers with an initial identification of critical sites, particularly when information about water quality is available.

CONCLUSION

If current trends continue, resource management will increasingly be conducted at a landscape scale, and management programs will be designed to incorporate humans as part of that landscape. Watersheds, having well-defined boundaries, provide an easy way to determine who is "in" or "out" of the social structure of a landscape. As a result, watersheds may help us to better articulate boundary-drawing on other ecologically definable landscapes, including but not limited to deserts, forests, and forest-savanna complexes. The utility of such an approach is significant; the

recent disciplinary emergence of landscape ecology, when combined with theories from demography and social area analysis, offers a theoretical perspective for integrating social and ecological science at comparable scales. To achieve the goal of better incorporating humans, we suggest that social structure, as represented through demographic data, can become an integral component of resource management. In this paper we have begun to explore a means by which to integrate social structure into watershed research and analysis. In our case study of the Kickapoo Watershed, social structure is represented by housing density and landscape structure is represented by land cover. We have supplemented basic housing density information with additional information about the population and housing units in the watershed. By integrating the two data sets at a landscape scale, we believe we have offered a first step towards improving our understanding of the relationship between humans and the environment.

APPENDIX

USING DATA FROM THE DECENNIAL CENSUS

Definitions of the demographic and economic census variables employed in this case study.

Educational attainment is reported, from a sample of the population on the census "long form," of individuals aged 15 or greater. Respondents are grouped by the highest level of education completed or the highest degree received (Bureau of Census, 1993:B-4).

Professional degrees include medicine, dentistry, theology, law, chiropractic, optometry, and veterinary medicine, but not barber school, cosmetology, or training for a specific trade (Bureau of Census, 1993:B-5).

Information about a respondent's **Industry** is reported for employed persons aged 16 or greater, and answers are related to the kind of business conducted by the person's employing organization. Respondents wrote descriptions of their employment that were keyed to 235 separate categories and 13 major industry groups by the Census Bureau (Bureau of Census, 1993:B-19).

A **Housing Unit** can include a single family detached house, apartment, condominium, mobile home, group of rooms, or single occupied room. A housing unit can be occupied or vacant, and, if occupied, can house a single person, family, or combination of related or unrelated persons. A **Vacant**

housing unit is one that is for sale or rent, or, if there are persons in the housing unit on enumeration day, all those persons have a usual place of residence elsewhere. The housing unit could be used seasonally for farm work, as a vacation home, or for hunting or other recreation. Identification of the (intended) use of a vacant housing unit as seasonal or otherwise is completed by the census employee (Bureau of Census, 1993:B-48).

A **Farm Residence** is an occupied one-family house or mobile home located in a census-defined rural area and that satisfies the following census-defined requirements: (1) the housing unit is located on a property of one acre or more and (2) at least \$1000 worth of agricultural products were sold from the property in 1989 (Bureau of Census, 1993:B-41).

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