Landscape Ecology **13:** 65–77, 1998.

Landscape context of rural residential development in southeastern Wisconsin (USA)

James A. LaGro Jr.
Department of Landscape Architecture & Institute for Environmental Studies, 1450 Linden Drive, University of Wisconsin, Madison, Wisconsin 53706, USA

(Received and accepted: 14 April 1997)

Key words: urbanization, rural land use, housing, landscape change, private sewage systems, public policy

Abstract

Private on-site sewage systems serve residential development in rural landscapes throughout the United States. In the State of Wisconsin, three major types of private sewage systems facilitate residential development on sites that span gradients in slope, soil permeability, depth to bedrock, and depth to water-table. *Conventional* soil-absorption sewage treatment systems are constructed on sites with minimal physiographic constraints; more highly engineered *alternative* sewage treatment systems are installed on sites with moderate to severe constraints; *holding tanks* provide no on-site sewage treatment and are employed on sites with the most severe physiographic limitations. An environmental impact statement (EIS), prepared in 1979 on the proposed widespread use of alternative private sewage systems, suggested that alternative systems might facilitate in-fill development on poor sites near existing cities and lead to compact, higher density development patterns.

The research reported in this paper tested the validity of this EIS scenario by comparing development patterns associated with a sample of conventional systems, alternative systems, and holding tanks installed during the 1980s in Ozaukee County, Wisconsin. Land use data, soils data, and other site attribute data were assembled and analyzed in a vector geographic information system (GIS). Because each type of private sewage system has a unique set of siting criteria, the three sets of sampled systems are located in significantly different physiographic regions within the County. Collectively, installations of all three systems facilitated scattered residential development throughout the rural landscape. This development consists of relatively small residential patches dispersed within an agricultural matrix. Wastewater management technology, if not constrained by public policies or other socioeconomic factors, can be an important anthropogenic factor influencing both the process and pattern of landscape change.

Introduction

The weakening "friction of distance"

Spatial variability in climate, physiography, and other natural resources has influenced human settlement patterns throughout history (Loesch 1954; Christaller 1966; Johnson 1970). A variety of technological advances, combined with road and highway expansion, however, have gradually reduced the influence of environmental attributes on urban growth and development patterns. In the United States and in other highly industrialized nations, the resultant weakening "friction of distance" has facilitated population redistribution from large cities to relatively small cities, villages, and rural areas. This migration from urban to rural areas reverses a long-standing demographic trend within the United States (Wardwell 1980). "Small towns" and rural areas, moreover, have become the preferred places of residence for more than one-third of the adults in the United States (Fuguitt and Brown 1990). Factors contributing to the decentralization of population include improvements in transportation infrastructure, advances in telecommunication technologies, shifts in employment from extractive and manufacturing industries to the service sector, and a reduction in the differences between urban and rural lifestyles (Wardwell 1980; Fuguitt et al. 1989).

Population growth and redistribution have precipitated extensive conversions of rural land to residential, commercial, and other "built-up" uses. Between 1982 and 1992, approximately 5.7 million ha in the United States were converted to development, which includes urban and suburban areas, rural communities, dwellings, roads, railroads, airports, and any other built-up area greater than 0.10 ha (Kellog et al. 1994). This newly developed land increased the nation's built-up area by 17.1%. Although developed areas covered only 4.9% of the nation's land base in 1992, this built-up land is spatially dispersed over a wide geographic area. Residential development, in particular, routinely occurs beyond the boundaries of cities, villages, and other incorporated municipalities.

In the last half of the 20th century, the influence of physiographic conditions on residential development patterns in the United States have declined. Extensive highway networks and a variety of telecommunications linkages have greatly enhanced human movement and communication among urban, suburban, and rural areas. Consequently, commuting is a feasible option for individuals who work in cities and suburbs, but who wish to live in rural areas. Individuals can now reside within the rural landscape and easily drive to nearby urban areas for work, education, and a variety of cultural amenities. Seeking the "best of both worlds," these individuals enjoy the amenities associated with a rural lifestyle, without foregoing access to the employment and cultural opportunities found in nearby cities and suburbs.

Various institutional and technological factors facilitate the diffusion of residential and other development over a range of spatial scales. Cellular telephones, facsimile machines, and modems are telecommunication technologies that weaken the effects of distance on the spatial arrangement of many economic activities at the regional scale. The world's stock exchanges, for example, are now accessible electronically from virtually any city on earth. Transportation and telecommunication connectivity also vastly expands the geographic area in which many manufacturing enterprises may be profitably located. For example, access to a nearby airport and interstate highway, combined with a full spectrum of telecommunication linkages, allows a major computer manufacturer to thrive in the state of South Dakota, a relatively sparsely populated area in the Western United States. Moving down in spatial scale, the connectivity of extensive highway systems influences the location of individual residences within or near expanding metropolitan areas. A worker who is willing to commute 30 minutes each way by automobile can now reside in a rural area that may be 30 km or more from his or her place of employment. Finally, at the landscape scale, advances in on-site wastewater management technology have diminished the influence of physiographic constraints on spatial patterns of rural residential development (Popper 1981; LaGro 1996). In rural areas without direct access to municipal sewerage infrastructure, unsewered residential development now routinely occurs on sites with shallow bedrock, shallow water-table, and poorly drained soils.

Unsewered residential development in the State of Wisconsin

In the State of Wisconsin, located in the north central region of the United States, dwellings that are not physically linked to municipal sewage treatment facilities are served by three major types of private sewage systems: conventional systems (Figure 1a), alternative systems (Figure 1b), and holding tanks (Figure 1c). Conventional private sewage systems are below-grade soil-absorption treatment systems that operate properly on flat to gently sloping sites with relatively permeable soils containing a combination of sand, silt, and clay. Alternative private sewage systems and holding tanks, in contrast, are installed on sites where one or more physiographic constraints preclude the use of conventional systems. Alternative sewage treatment systems have mounded drain-fields constructed, either at or above existing site grades, with sand and coarse aggregate fill. The installation of alternative systems has been recommended for sites that are as little as 25 cm above the seasonal water-table (Converse and Tyler 1987). Holding tanks, the third major system type, are watertight containers that store the wastewater until it is pumped out and typically transported to a municipal sewage treatment facility.

Site conditions assessed by certified soil testers determine which type of private sewage system is permitted and installed on any given site in the State. Conventional systems are built on sites with minor soil, slope, bedrock, and water-table constraints; alternative systems (mounds) are constructed on sites with moderate limitations; holding tanks are installed on sites with the most severe physiographic constraints (Wisconsin Department of Industry, Labor and Human Relations 1990). An estimated 50–60% of the soils in Wisconsin are unsuitable for conventional on-site sewage treatment systems (Wisconsin Department of Health and Social Services 1979). These unsuitable soils are

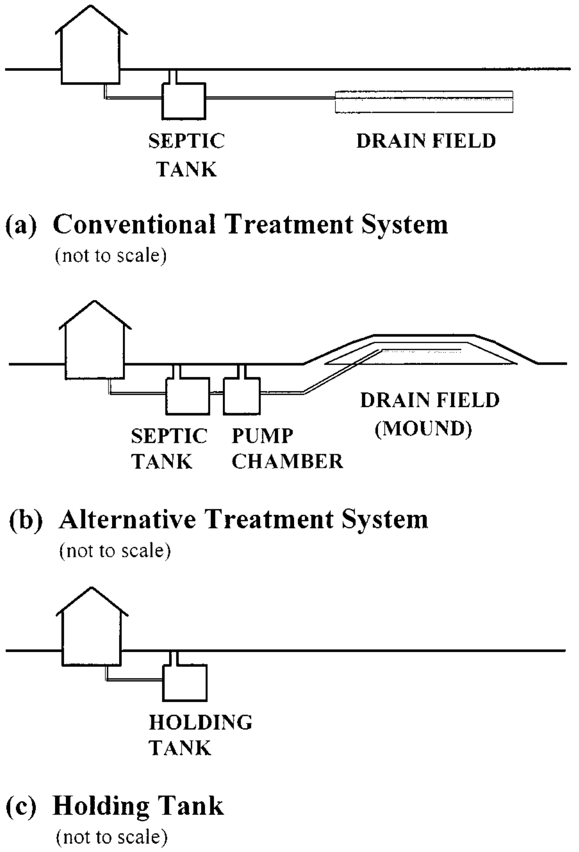

Figure 1. Schematic diagrams of three private sewage systems installed in Wisconsin. Source: LaGro (1996).

unevenly distributed, however, creating highly convoluted patterns of site suitability for conventional on-site sewage treatment. Prior to the availability of alternative systems and holding tanks, county health regulations confined new rural residential development to sites that were suitable for on-site soil absorption sewage treatment. Because this de facto land use control is no longer in effect, increasing numbers of rural residences in Wisconsin are served by holding tanks and alternative private sewage systems. From 1981 through 1990, for example, installations of alternative systems, holding tanks, and other minor non-conventional systems increased from 27.4% to 39.2% of the total number of private sewage systems annually installed in the State (LaGro 1996).

Research objectives

A Wisconsin Administrative Code amendment adopted in 1979 allowed the statewide installation of alternative private sewage systems (Wisconsin Department of Health and Social Services 1979). The environmental impact statement (EIS) prepared on the proposed amendment suggested that the installation of alternative sewage systems might slow the rate of prime farmland conversion, facilitate in-fill development on difficult sites near existing urban areas, and lead to compact, higher density development patterns. Hanson and Jacobs (1989) assessed the land use impacts of private sewage systems installed from 1981 through 1985 in two metropolitan and six non-metropolitan counties in Wisconsin. They found that conventional systems were somewhat more clustered than alternative (mound) systems and holding tanks, but there was little difference among the three systems in the rates at which agricultural and forested lands were converted to residential uses.

The research summarized in this paper extends that line of inquiry by examining the development patterns facilitated by private sewage system installation in a metropolitan county within southeastern Wisconsin. This study's primary objective was to determine if, over a ten-year period, there were significant differences among the three types of installed sewage systems in four landscape attributes: 1) pre-development land use, 2) site suitability for farming, 3) density of surrounding housing development, and 4) distance to the nearest city or village. If significant differences were found, this could lend support to the 1979 EIS scenario suggesting potential growth management benefits of alternative private sewage systems. A second objective was to describe the morphology and landscape context of the residential areas, or patches, in which the sampled private sewage systems are located. In spite of the substantial impacts of urban development on landscape structure and function (Engels and Sexton 1994; Holland et al. 1995; Medley et al. 1995; Comeleo et al. 1996), there has been little empirical research on the spatial patterns of residential development beyond the urban-rural fringe.

Methods

Study area

Ozaukee County, Wisconsin is one of the four counties within the Milwaukee metropolitan statistical area (MSA). The County is bordered on the east by Lake Michigan, on the south by Milwaukee County (metropolitan), on the west by Washington County (metropolitan), and on the north by Sheboygan County (non-metropolitan). The minor civil divisions (MCD) in Ozaukee County consist of three cities, seven villages, and six unincorporated townships. Each township is typically divided into a grid of 36 rectilinear sections created by the federal government's public land survey, which was authorized by Congress in the Ordinance of 1785 (Cochrane 1979). A township section, approximately 640 acres (259 ha) in area, is commonly subdivided into quarter sections (120 acres) and quarter-quarter sections (40 acres).

Ozaukee County's non-urbanized landscape consists of nearly level to rolling farmland, with the largest contiguous wooded areas located primarily on steeper topography bordering Lake Michigan and major drainage corridors. The parent materials of most soils in the County were deposited during the Wisconsin glaciation (10,000 BP). The Milwaukee River flows north to south in the County, dividing the better-drained soils west of the river from the more poorly-drained soils near Lake Michigan (Figure 2). Incomplete drainage of this poorly dissected landscape has resulted in the formation of many small scattered marshes and lakes (US Department of Agriculture 1970).

This county was chosen for this study for four reasons: 1) more than half of Ozaukee County's land area is unsuitable for conventional soil absorption sewage treatment systems, 2) permits issued during the 1980s for new private sewage systems were relatively evenly distributed in the County between conventional systems, alternative systems, and holding tanks, 3) the County's rural areas continue to experience intense land development associated with out-migration from urban population centers in Ozaukee, Washington, and Milwaukee Counties, and 4) large-scale (1:4,800) aerial photographs and land use maps of the County were available for 1980 and 1990 from the Southeastern Wisconsin Regional Planning Commission (SEWRPC).

Data collection

Records of all private sewage system permits issued in Ozaukee County during the 1980s were acquired from the Wisconsin Department of Industry, Labor, and Human Relations (DILHR). A random sample of 90 permits, stratified by sewage system type, was selected from the 539 permits issued for new private sewage systems in the County's six townships. The sample consisted of 30 conventional system permits, 30 alternative system permits, and 30 holding tank permits. Because the purpose of the sample was to test hypotheses concerning site differences among the three sewage system types, equal numbers of permits were selected from each of the three sample strata (Levy and Lemeshow 1991). The sample did not include permits issued for experimental systems, for systems installed in villages and cities, and for the repair or replacement of failed private sewage systems.

Sources of site attribute data included 1990 rectified aerial photographs, 1980 and 1990 land use maps, and other assorted maps (Table 1). Land use at the location of the building served by a sampled sewage system was recorded directly from the 1980 and 1990 land use maps. In 28 cases where the 1980 land use was "residential, under development," pre-development land use was determined from 1970 land use maps. The soil association and the soil series at the site of each sampled sewage system were derived, respectively, from a general soils map (US Department of Agriculture 1970) and from soil series maps drawn over panchromatic aerial photographs (Southeastern Wisconsin Regional Planning Commission 1966). Site limitations for conventional soil absorption sewage treatment systems were derived from tables accompanying the county Soil Survey. The boundaries of villages and cities in Ozaukee and adjacent counties were acquired as digital data processed from US Bureau of the Census TIGER files. In addition, the centroids of the buildings served by the sampled sewage systems were digitized, and distances from the buildings to the nearest village or city were computed electronically with a vector-based geographic information system (GIS).

Several additional site attributes were recorded for the sampled systems that serve single-family houses. A circular quadrat equivalent in area to 10 acres (4.05 ha, radius = 113.4 m) was drawn in ink on a sheet of clear mylar. The center point of this circular quadrat was placed on the rectified aerial photograph at the centroid of each single-family house served by a sampled sewage system. The neighboring houses within the quadrat were then counted. These data were used to compute housing densities in the vicinity of the houses served by sampled systems. The final step was to assess the morphology and context of each residential patch containing a sampled private sewage system. Residential patches and the land uses/covers adjacent to each patch were digitized from the 1990 land use maps. The following attributes of each residential patch were measured: area, fractal dimension ($D = \log(\text{area})/\log(\text{perimeter}/4)$), and percentage of the

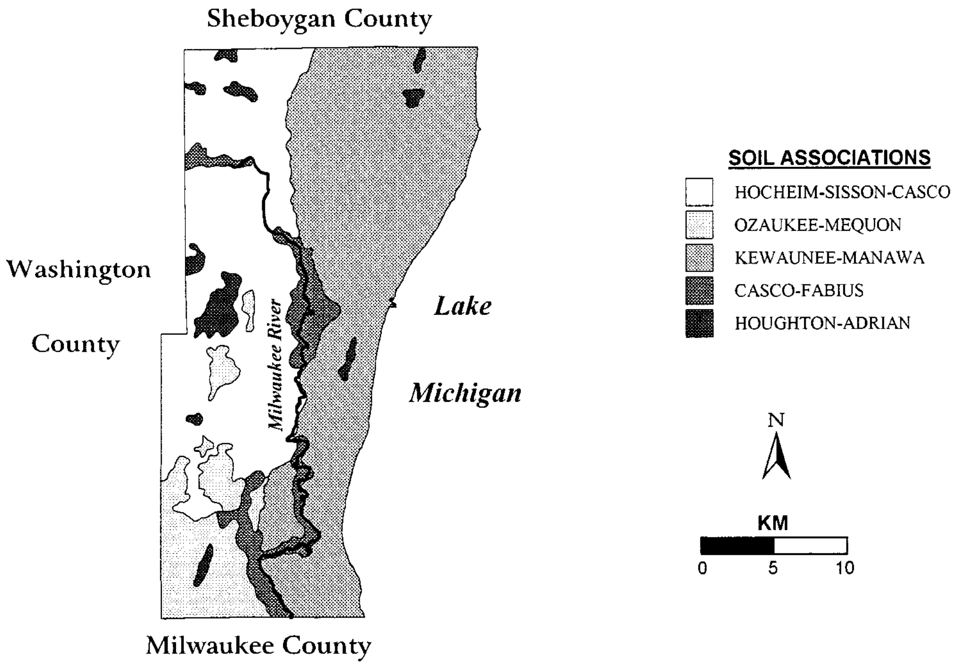

Figure 2. Soil associations in Ozaukee County, Wisconsin.

Table 1. Sources of attribute data collected for each sampled private sewage system.

Attribute	Source	Scale
Pre-development & post-development land use	SEWRPC land use maps (1970, 1980, 1990)	1:4,800
Housing density	SEWRPC rectified aerial photographs	1:4,800
Parcel size	Ozaukee County tax assessment records	None[1]
Distance from nearest village or city	US Census Bureau TIGER digital maps	1:24,000
Road system access	SEWRPC aerial photographs	1:4,800
	Ozaukee County road maps	1:63,360
Site limitations for soil absorption sewage treatment systems	SEWRPC soils series maps	1:12,000
Soil associations	USDA soil survey (general soils map)	1:126,720

1 = tabular data

patch perimeter adjacent in 1990 to six different classes of undeveloped land use/cover.

Data analysis

Several variables in this study violated the normality and equal variance assumptions of parametric statistical analysis. Therefore, the Kruskal-Wallis one-way ANOVA on ranks (Glantz 1992) was employed to determine if differences in the median values of these attributes were significantly different among the three types of private sewage systems. When a significant difference was found, Dunnett's all pairwise comparison procedure was employed to identify the source of the difference. Chi-square tests were performed to determine if there were significant differences among the three sewage system types for the following categorical variables: general soil association, pre-development land use class, post-development land use class, and class of road providing site access. The median x and y coordinates of each sample of sewage systems were also compared for significant differences using the Kruskal-Wallis one-way ANOVA on ranks. Medians were used instead of means because the x and y coordinate data for the conventional and alternative systems were not normally distributed.

Table 2. Private sewage system permits issued in Ozaukee County from January 1, 1980 through December 31, 1989; these data exclude permits for repairs and for installations of experimental systems.

	Townships	Villages	Cities	Totals
Conventional				
New	186	1	19	206
Replacement	40	0	1	41
Alternative				
New	131	1	28	160
Replacement	135	2	31	168
Holding Tank				
New	222	0	57	279
Replacement	111	2	41	154
Totals	825	6	177	1,008

Source: Wisconsin Department of Industry, Labor and Human Relations (DILHR) permit records.

Results

Physiographic context of unsewered development

During the 1980s, the population residing in Ozaukee County's six townships grew by only 2.2%, and yet the number of housing units in the townships increased by 10.3% (US Bureau of the Census, 1993). This differential between population and housing unit growth rates reflects the nationwide trend toward smaller households (Fuguitt et al. 1989). In 1990 the townships held 21.6% of Ozaukee County's population, 20.2% of the housing units, and 73.1% of the County's total surface area of 600.9 km^2. Moreover, private sewage systems in 1990 served 95% of the townships' year-round housing units (US Bureau of the Census 1993). More than one-third of the private sewage system permits issued during the 1980s were for the replacement of failed conventional treatment systems (Table 2). On suitable sites and with regular maintenance, conventional systems can provide trouble-free service for more than twenty years (Wisconsin Department of Health and Social Services 1979).

The three different sets of siting criteria have led to visibly different spatial distributions of installed holding tanks, alternative systems, and conventional systems (Figure 3). All of the conventional systems and two-thirds of the alternative systems are located west of the Milwaukee River on the better drained soils of the Hocheim-Sisson-Casco association (Table 3). Conversely, nearly all of the holding tanks and one-third of the alternative systems are located east of the Milwaukee River on the soil associations that include somewhat poorly to very poorly drained soils. A 2 × 3 contingency table was created by grouping each of the three types of private sewage systems into two soil association categories: 1) the Hocheim-Sisson-Casco association and 2) the four remaining soil associations. The Hocheim-Sisson-Casco association comprises 41.9% of the surface area within the six townships, and this is the only association comprised entirely of well-drained soils. Each of the other four soil associations includes soils that are somewhat poorly drained to very poorly drained. There are highly significant ($p < 0.001$) differences among conventional systems, alternative systems, and holding tanks in the distributions of each sample of systems within the two soil association categories.

Table 3. Location of sampled private sewage systems, by soil association.

	Conventional	Alternative	Holding tanks	Totals
Casco-Fabius	0	0	3	3
Hocheim-Sisson-Casco	30	20	3	53
Houghton-Adrian	0	1	0	1
Kewaunee-Manawa	0	8	23	31
Ozaukee-Mequon	0	1	1	2
Totals	30	30	30	90

Descriptions:[1]
Casco-Fabius: well-drained and somewhat poorly drained soils that have a subsoil of clay loam and sandy clay loam; on stream terraces.
Hocheim-Sisson-Casco: well-drained soils that have a subsoil of loam to clay loam; on uplands and terraces and in lakebeds.
Houghton-Adrian: very poorly drained organic soils in basins and depressions.
Kewaunee-Manawa: well-drained to somewhat poorly drained soils that have a subsoil of clay to silty clay loam; on uplands.
Ozaukee-Mequon: well-drained to somewhat poorly drained soils that have a subsoil of silty clay loam and silty clay; on uplands.

[1]Source: US Department of Agriculture (1970).

The spatial distributions of these sampled private sewage systems can be quantitatively compared after determining each sample's geographic center. This statistic is simply the mean longitude and latitude of each population of points (Garson and Biggs 1992). Although the coordinate data for the holding tank sample were normally distributed, this was not true for the conventional systems or for the alternative systems. Consequently, the median coordinate values for each sample were compared with the Kruskal-Wallis

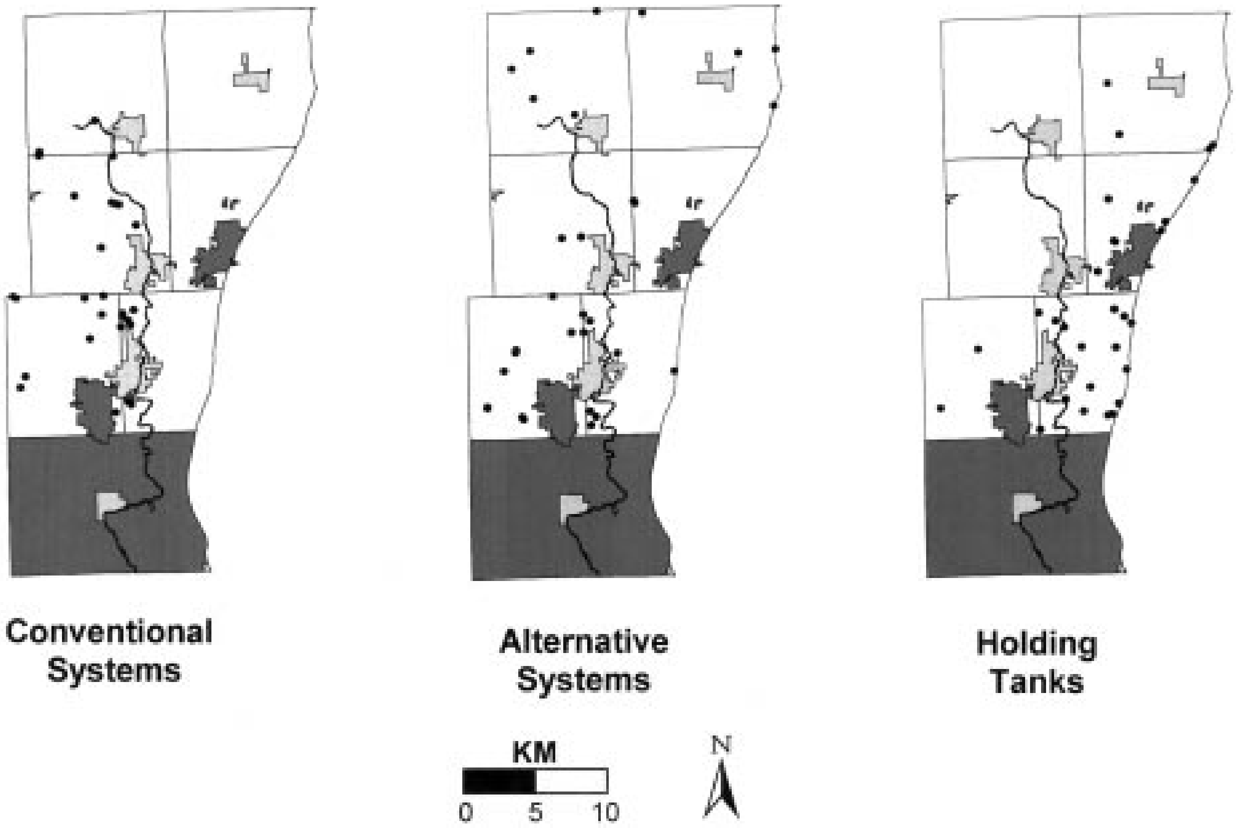

Figure 3. Locations of sampled conventional systems, alternative systems, and holding tanks installed in Ozaukee County during the 1980s (shaded areas are cities and villages).

one-way ANOVA on ranks. The median y-coordinate values among the three sewage system types are not significantly different ($p = 0.465$). However, there are highly significant differences ($p < 0.001$) among the median x-coordinate values. Each pairwise comparison (e.g., conventional v. alternative) among the three system types revealed statistically significant differences ($p < 0.05$) in the x-coordinate values. These differences occur primarily because of two factors: 1) the east-west gradient in soil and sub-soil permeability (Figure 2), and 2) the different siting criteria employed for each of the three private sewage systems. The distances between the geographic medians of these three samples are shown graphically in Figure 4.

Inspection of the soil series maps suggests that 48% of the sampled sites are severely to very severely limited for conventional soil-absorption sewage treatment systems. If the certified soil testers correctly evaluated the sampled sites, one would expect that none of the conventional systems and all of the holding tanks would be located on sites with severe or very severe physiographic constraints. According to the soil series maps, however, 23% of the conventional sewage systems, 40% of the alternative systems, and 80% of the holding tanks are located on sites with severe or very severe physiographic limitations. These limitations, and the number of systems affected by each constraint, are high water-table (5), steep slopes (7), flooding (2), slow substratum permeability (4), and slow soil permeability (26). These results are probably influenced by the soil series map scale (1:12,000). The soil survey did not map relatively small pockets of land that, for example, are either suitable or unsuitable for conventional sewage system drain-fields. Consequently, small unsuitable sites can be expected to occur within otherwise unsuitable map units. This is a potentially significant limitation in using medium to small-scale soils maps for siting unsewered development.

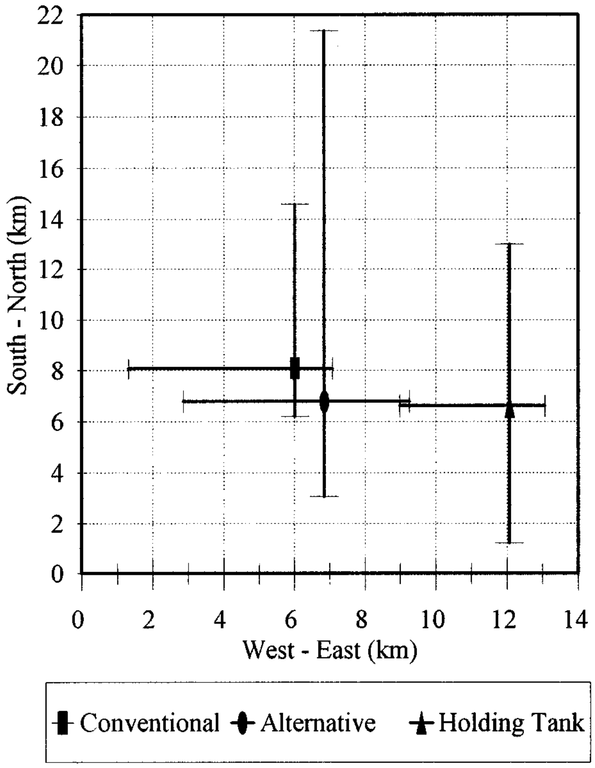

Figure 4. Relative locations of the medians, 25th percentiles, and 75th percentiles of the x and y coordinate distributions of each private sewage system sample (n = 30).

Land use context of unsewered development

Ozaukee County is a relatively small metropolitan county, ranking last in surface area (1,556.07 km^2) among the 72 counties in Wisconsin. Every township in the County is adjacent to at least one incorporated city or village, and the median distance to the nearest city or village is only 1.96 km for the entire sample of private sewage systems. Although the EIS of 1979 suggested that alternative systems would facilitate infill development near cities, the median distance to the nearest city or village from conventional systems, alternative systems, and holding tanks is not significantly ($p = 0.492$) different.

The sampled sewage systems serve primarily residential development. Two of the 90 sampled systems serve commercial buildings, and one other system serves a mobile home. The remaining 87 (97%) sewage systems serve detached single-family houses. Four of these houses are located in residential areas classified by SEWRPC as “low-density” (0.5–1.5 dwelling units/net residential ha), and 83 houses are located in residential areas of “suburban-density” (1.6–5.4 dwelling units/net residential ha). The median building lot, or land parcel, area for each system type was 2.00 ac (0.81 ha); the smallest land parcel among the three system types was 0.84 ac (0.34 ha). Although most of the residential development is classified as suburban density, the development is not typically contiguous with existing urban centers. The quadrat data show that relatively sparse housing development surrounds each single-family house. The median number of houses located in 1990 within the 10 acre (4.05 ha) circular quadrat (113 m radius) was 3.0 for holding tanks, alternative systems, and conventional systems. At 19% of the single-family sites, there was only one other house within the quadrat. There were no other houses within the quadrat at 23% of the single-family sites.

Unsewered residential development in Ozaukee County has occurred largely within the rural landscape’s agricultural matrix. The development served by 66% of all sampled sewage systems occurred on land that in the previous two decades was used for crops or pasture (Table 4). Moreover, land formerly classified as prime farmland was converted to development served by 31% of the sampled sewage systems. Prime farmland in southeastern Wisconsin must meet three criteria: 1) the farmed area comprises a contiguous tract of at least 35 acres (14.18 ha); 2) at least one-half of the farmed area is covered by soils that meet the US Natural Resource Conservation Service standards for national prime farmland or farmland of statewide importance; 3) the farmed area is located in a block of farmland at least 100 acres (40.5 ha) in size (Southeastern Wisconsin Regional Planning Commission 1991). Although the EIS suggested that alternative systems would help deflect development away from prime farmland, there are no significant ($p = .373$) differences among the three system types in the rates of prime farmland conversion.

Land use within the 10-acre circular quadrats also reflects the complexity of this landscape mosaic. In no case was the area within the quadrat devoted entirely to residential land use (Table 5). Several different land uses occur within the quadrats, with undeveloped land comprising on average approximately half of each circular area (Figure 5). Moreover, approximately 44% of the sampled private sewage systems serve single-family houses built along short dead-end roads or cul-de-sacs, and 46% of the sampled systems serve single-family houses located along either collec-

Table 4. Summary of pre-1980 land use at the sites of sampled private sewage systems.

Land use class	Conven-tional	Alter-native	Holding tank	Totals Totals
Farmstead	1	3	3	7
Cropland	13 (4)	11 (8)	17 (12)	41 (24)
Pasture	9 (3)	6 (1)	3	18 (4)
Open (unused-rural)	5	7	4	16
Woodland	2	3	3	8
Totals	30 (7)	30 (9)	30 (12)	90 (28)

( ) = number of systems installed on land classified as prime farmland.

tor roads or arterial highways. The remaining 10% of the systems are located along less-traveled local roads that are intermediate, within the county's road system hierarchy, between collector roads and cul-de-sacs. There are no significant ($p = .674$) differences among the three sewage system types in the roads providing access to buildings served by the sampled systems.

Rural residential patch morphology

The 87 single-family houses served by sampled private sewage systems are located within 77 discrete residential patches. These residential patches are generally small in area, with straight edges that form shapes ranging from complex polygons to simple rectangles and squares. Approximately 48% of the patches are 1.0 ha or smaller in area, and less than 3% of the patches are larger than 10.0 ha. Consequently, the frequency distribution of residential patch area is highly skewed. Housing within these patches generally falls into one of two categories: 1) a single house located along an arterial highway or collector road, or 2) an enclave of houses loosely clustered along a cul-de-sac or short loop road. The rectilinear morphology of this residential development is reflected in the relatively large median fractal dimension ($D = 1.93$) of the entire sample of patches.

These findings suggest that rural residential development in Ozaukee County contributes to both the "dissection" and "perforation" of the rural landscape. These are two of several possible anthropogenic disturbance patterns contributing to landscape change (Forman 1995). *Dissection* is a linear disturbance pattern that occurs as newly constructed roads and utility corridors bisect woodlands, wetlands, and other undeveloped areas. *Perforation* produces a patchy, rather than a linear disturbance pattern. This occurs when isolated houses and small residential subdivisions are built within the landscape's agricultural matrix, rather than adjacent to existing urban areas (Figure 6). The landscape context of residential development within this county's rural landscape is reflected in two statistics: 1) 53.3% of the residential patches were adjacent in 1990 to either water, wetland, or woodlands, and 2) 66.2% of the patches were adjacent to either prime or non-prime agricultural land (Table 6).

Discussion

Public policy implications

Public policy has historically had far-reaching consequences on the ownership and use of land in the United States. The federal government's public land survey of the late 18th and early 19th centuries, for example, facilitated the distribution of vast tracts of land to westward migrating settlers. The government's distribution of rectilinear parcels of land – often in 40 acre (16.2 ha) blocks – had a fundamental impact on the spatial configuration of farmsteads in the Midwest (Cochrane 1979; Dandekar 1994). In Ozaukee County, installations of sampled conventional systems, alternative systems, and holding tanks have facilitated residential development that is dispersed throughout the rural landscape. Sewage systems of each type are spatially distributed in distinctly different physiographic regions within the County. Moreover, holding tanks and alternative systems have not, to any greater extent than conventional systems, promoted in-fill development at the urban fringe.

Residential development has typically occurred in rural locations where open space buffers are maintained between older and newer residential patches. This early stage of the "leapfrog" land development process is not unique to Wisconsin. In Ulster County, New York, for example, small rural residential patches developed prior to 1985 were typically surrounded by forested and agricultural land (LaGro 1994). As rural housing development continues in these and other urbanizing landscapes, however, in-fill development eventually occurs simply because the remaining tracts of undeveloped land have diminished in both size and number.

In Wisconsin, unsewered residential development routinely occurs on sites with wet or slowly permeable soils, shallow bedrock, or an elevated water-table.

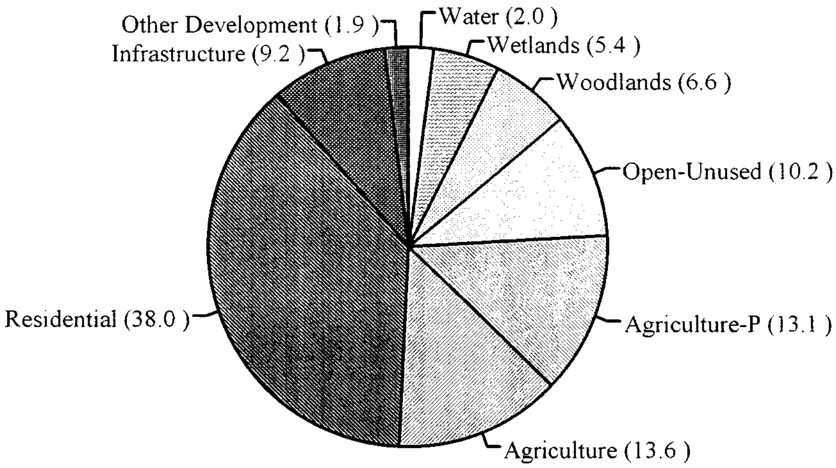

Figure 5. Mean land use percentages of the10 acre (4.05 ha) circular quadrats centered on the buildings served by all sampled private sewage systems (n = 90).

Table 5. Summary statistics for land use percentages of the 10 acre (4.05 ha) circular quadrats centered on the buildings served by sampled private sewage systems (n = 90).

Land use class	Mean	Standard deviation	Median	Minimum	Maximum
Water	2.0	6.1	0.0	0.0	36.4
Wetlands	5.4	11.8	0.0	0.0	62.9
Woodlands	6.6	13.6	0.0	0.0	70.6
Open (unused)	10.2	14.7	1.6	0.0	65.2
Agriculture (prime)	13.1	22.0	0.0	0.0	85.0
Agriculture (other)	13.6	19.0	2.0	0.0	79.9
Residential	38.0	23.9	34.3	0.0	90.6
Infrastructure	9.2	8.5	7.8	0.0	70.0
Other development	1.9	6.8	0.0	0.0	36.6

Notes:[1]
Open (unused) = rural open areas, including steeply sloping unwooded rural land not used for pasture or other related agricultural purposes.
Residential = single-family houses, mobile homes, and land under development for residential uses.
Infrastructure = transportation, communication, and utility uses.
Other development = retail, industrial, government and administration, and non-public recreation uses.

[1]Source: Southeastern Wisconsin Regional Planning Commission (1991).

Although not common, some townships in the State prohibit the use of holding tanks, and effectively prevent unsewered development on sites with the most severe physiographic constraints. Nevertheless, further advances in on-site wastewater management technology can be expected. The State agency that regulates the installation of wastewater management systems has recently proposed a major shift in public policy to encourage innovation in private sewage system design. The agency hopes to stimulate improvements in on-site wastewater management technologies by establishing performance standards for on-site sewage treatment. These performance standards would replace the existing detailed design specifications to which new and replacement systems must conform.

If newer generations of alternative private sewage systems can economically neutralize the biological pathogens and chemical pollutants contained in sewage effluent, even the most problematic rural sites could be developed for residential uses. Residential development could then be sited on steeper slopes and on land with shallower depths to bedrock and to the water

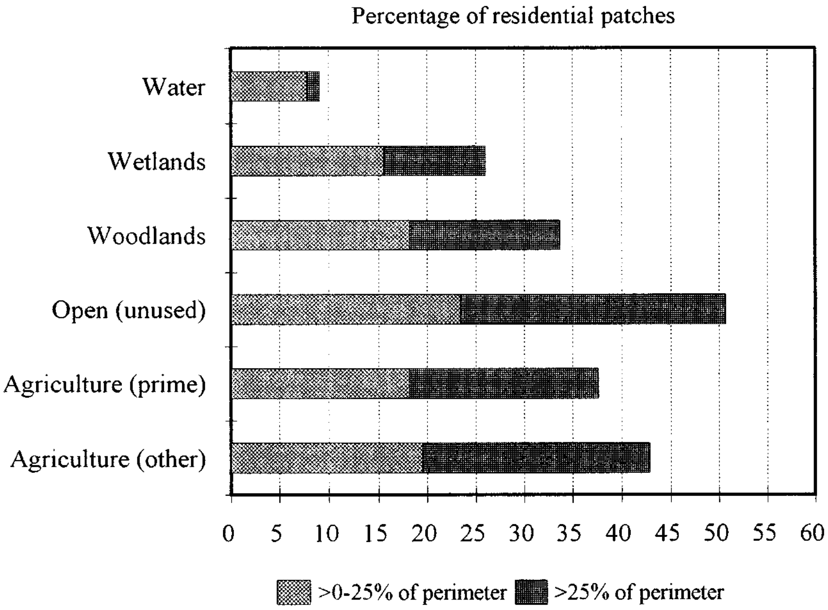

Figure 6. Percentages of residential patches (N = 77) adjacent to six classes of undeveloped land.

Table 6. Summary statistics for the percentage of residential patches (N = 77) adjacent to undeveloped land use/cover, by percentage of patch perimeter.

Adjacent land use	Percentage of residential patch perimeter					
	0%	> 0–25%	> 25–50%	> 50–75%	> 75%	Totals
Agriculture (prime)	62.3	18.2	6.5	6.5	6.5	100.0
Agriculture (other)	57.1	19.5	9.1	13.0	1.3	100.0
Agriculture (prime or other)	33.8	22.1	15.6	16.9	11.7	100.0
Open (unused)	49.4	23.4	15.6	9.1	2.6	100.0
Woodland	66.2	18.2	9.1	3.9	2.6	100.0
Wetland	74.0	15.6	10.4	0.0	0.0	100.0
Water	90.9	7.8	1.3	0.0	0.0	100.0
Woodland or Wetland or Water	46.8	22.1	22.1	6.5	2.6	100.0
Any undeveloped class	2.6	5.2	14.3	44.2	33.8	100.0

Note: percentages in each row may not add to 100.0 due to rounding error.

table. Consequently, land use planning and management become increasingly important for the protection of environmental quality and, ultimately, the quality of life. In the absence of effective growth management policies, advances in wastewater management technology will quite likely facilitate the continued spatial dispersion of new residential development in rural landscapes.

Future research

Virtually every landscape on earth has been influenced, to some degree, by human activities. Human societies exert powerful forces that continue to substantially impact landscape structure and function (Goudie 1994; Pimentel et al. 1994; Nassauer 1995; Kamada and Nakagoshi 1996). The conversion of rural land to urban uses is one of many anthropogenic disturbances having important implications for landscape ecology (Zonneveld and Forman 1990; McDonnell and Pickett 1993). Unlike the spread of pests, pathogens, storms, or fires across landscapes (Turner and Dale 1991), this particular anthropogenic disturbance regime is not the result of any immutable biological or physical laws of nature. Rather, these land use changes are a direct result of the technologies, institutions, and values of the indigenous human population. Unlike most non-anthropogenic disturbances, the effects of residential development on landscape structure and function may persist indefinitely.

The future is uncertain, however, and rural land use trends in the United States could be substantially altered by major geopolitical events, further technological advances, or significant shifts in public policy. New residential development might be less scattered, for example, if petroleum imports were suppressed by an oil embargo of the magnitude and duration experienced in the early 1970s. Similarly, the elimination of government subsidies allowing income tax deductions for home mortgage interest payments would significantly increase the costs of low density, single-family houses – the nation's most common form of rural residential development. Although rural land use controls are often highly controversial, local governments have the authority to implement a wide variety of growth management strategies.

Research by landscape ecologists can help policy makers and the general public understand the linkages between land use spatial patterns, environmental quality, and quality of life. Therefore, a substantial proportion of basic research in landscape ecology should be guided by questions concerning the role of humans as agents of landscape change. In addition, applied research should seek solutions to fundamental problems faced by land use planners and policy makers (Vitousek 1994; Naiman 1996). A crucial challenge in the United States and in other industrialized nations is to identify development patterns that can maintain – or even restore – landscape structure and function, yet can also accommodate a broad spectrum of residential preferences. Complicating this endeavor, of course, are continued population growth, ongoing highway expansion, and inexorable advances in a wide variety of modern technologies.

Acknowledgments

This research was supported by a US Department of Agriculture Hatch grant (#3488), and by additional support from the School of Natural Resources within the College of Agricultural and Life Sciences at the University of Wisconsin-Madison. Graduate students who worked on this project are Linda Harring, Michael Koutnik, and Martin Smith. The author appreciates the constructive suggestions made by Robert Gardner and the anonymous reviewers.

References

Christaller, W. 1966. Central Places in Southern Germany. (translated from Die Zentralen Orte in Süddeutschland, 1933, by C.W. Baskin). Prentice-Hall, Englewood Cliffs, NJ.

Cochrane, W.W. 1979. The Development of American Agriculture: a Historical Analysis. University of Minnesota Press, Minneapolis.

Comeleo, R.L., J.F. Paul, P.V. August, J. Copeland, C. Baker, S.S. Hale and R.W. Latimer. 1996. Relationship between watershed stressors and sediment contamination in Chesapeake Bay estuaries. Landscape Ecology, 11(5): 307–319.

Converse, J.C. and E.J. Tyler. 1987. On-site wastewater treatment using Wisconsin mounds on difficult sites. Transactions of the American Society of Agricultural Engineers, 30(2): 362–368.

Dandekar, H.C. 1994. Farm Type in the American Midwest: a Reflection of Government Policy. In Ordering Space: Types in Architecture and Design. pp. 97–116. Edited by K.A. Franck and L.H. Schneekloth. Van Nostrand Reinhold, New York.

Engels, T.M. and C.S. Sexton. 1994. Negative correlation of blue jays and golden-cheeked warblers near an urbanizing area. Conservation Biology, 8(1): 286–290.

Forman, R.T.T. 1995. Some general principles of landscape and regional ecology. Landscape Ecology, 10(3): 133–142.

Fuguitt, G.V., D.L. Brown and C.L. Beale. 1989. Rural and Small Town America. Russell Sage Foundation, New York.

Fuguitt, G.V. and D.L. Brown. 1990. Residential preferences and population redistribution: 1972–1988. Demography, 27(4): 589–600.

Garson, G.D. and R.S. Biggs. 1992. Analytic Mapping and Geographic Databases. Sage University Paper series on Quantitative Applications in the Social Sciences, 07-087. Sage, Newbury Park, California.

Glantz, S.A. 1992. Primer of Biostatistics, 3rd Ed. McGraw-Hill, New York.

Goudie, A. 1994. The Human Impact on the Natural Environment, 4th Ed. The MIT Press, Cambridge, Massachusetts.

Hanson, M.E. and H.M. Jacobs. 1989. Private sewage system impacts in Wisconsin: implications for planning and policy. Journal of the American Planning Association, (Spring): 169–180.

Holland, C.C., J. Honea, S.E. Gwin and M.E. Kentula. 1995. Wetland degradation and loss in the rapidly urbanizing area of Portland, Oregon. Wetlands, 15(4): 336–345.

Johnson, E.A.J. 1970. The Organization of Space in Developing Countries. Harvard University Press, Cambridge, Massachusetts.

Kamada, M. and N. Nakagoshi. 1996. Landscape structure and the disturbance regime at three rural regions in Hiroshima Prefecture, Japan. Landscape Ecology, 11(1): 15–25.

Kellog, R.L., G.W. TeSelle and J.J. Goebel. 1994. Highlights from the 1992 National Resources Inventory. Journal of the Soil and Water Conservation Society, 49(6): 521–527.

LaGro, J.A., Jr. 1994. Population growth beyond the urban fringe: implications for rural land use policy. Landscape and Urban Planning, 28: 143–158.

LaGro, J.A., Jr. 1996. Designing without nature: unsewered residential development in rural Wisconsin. Landscape and Urban Planning, 35: 1–9.

Levy, P.S. and S. Lemeshow. 1991. Sampling of Populations: Methods and Applications. Wiley and Sons, New York.

Loesch, A. 1954. The Economics of Location. Yale University Press, New Haven, Connecticut.

McDonnell, M.J. and S.T.A. Pickett (Editors). 1993. Humans as Components of Ecosystems. Springer-Verlag, New York.

Medley, K.E., S.T.A. Pickett and M.J. McDonnell. 1995. Forest-landscape structure along an urban-to-rural gradient. Professional Geographer, 47(2): 159–168.

Naiman, R.J. 1996. Water, society and landscape ecology. Landscape Ecology, 11(4): 193–196.

Nassauer, J.I. 1995. Culture and changing landscape structure. Landscape Ecology, 10(4): 229–327.

Pimentel, D., R. Harman, M. Pacenza, J. Pecarsky and M. Pimentel. 1994. Natural resources and an optimum human population. Population and Environment, 15: 347–369.

Popper, F.J. 1981. Unshaping growth. American Land Forum, 2(2): 8–14.

Southeastern Wisconsin Regional Planning Commission. 1966. Soils of Southeastern Wisconsin. Planning Report No. 8. Waukesha, Wisconsin.

Southeastern Wisconsin Regional Planning Commission. 1991. Land Use Classifications and Codes. Southeastern Wisconsin Regional Land Use Inventory – 1990. Waukesha, Wisconsin.

Turner, M.G. and D.H. Dale. 1991. Modeling landscape disturbance. In Quantitative Methods in Landscape Ecology. pp. 232–351. Edited by M.G. Turner and R.H. Gardner. Springer-Verlag, New York.

US Bureau of the Census. 1983. 1980 Census of Population. Vol I. Characteristics of the Population. US Government Printing Office, Washington, DC.

US Bureau of the Census. 1993. 1990 Census of Population. Vol I. Characteristics of the Population. US Government Printing Office, Washington, DC.

US Department of Agriculture. 1970. Soil Survey: Ozaukee County, Wisconsin. US Government Printing Office, Washington, DC.

Vitousek, P.M. 1994. Beyond global warming: ecology and global change. Ecology, 75(7): 1861–1876.

Wardwell, J.M. 1980. Toward a theory of urban-rural migration in the developed world. In New Directions in Urban-Rural Migration. pp. 71–114. Edited by D.L. Brown and J.M. Wardwell. Academic Press, New York.

Wisconsin Department of Health and Social Services. 1979. Final Environmental Impact Statement for Three Alternate Systems (Mounds) for On-Site Individual Wastewater Disposal in Wisconsin. Madison, Wisconsin.

Wisconsin Department of Industry, Labor and Human Relations. 1990. Onsite Sewage Systems: Plan Submittal Manual. Madison, Wisconsin.

Zonneveld, I.S. and R.T.T. Forman (Editors). 1990. Changing Landscapes: An Ecological Perspective. Springer-Verlag, New York.