FACTORS AFFECTING WILDLIFE-RELATED POWER OUTAGES IN ELECTRICAL SUBSTATIONS

By

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INTRODUCTION

Western Farmers Electric Cooperative (WFEC) operates in a broad area from northern Texas through southern, central, and northwestern and central Oklahoma (54 counties) to south-central Kansas. A variety of events cause electrical outages in the WFEC system. Weather and equipment failure are the leading causes, but some outages are caused by wildlife. Various species cause a significant number of power outages each year, producing substantial economic loss. Cost estimates range from \$500 to > \$140,000 per outage through equipment replacement or repairs (K. Fletcher, WFEC, pers. commun.). These estimates do not include related downtime that would substantially increase lost revenue during high demand periods. These power failures also represent considerable customer inconvenience and influence the public image of WFEC. For the 1987-1996 period, 203 outages were attributed to snakes, various songbirds, hawks, owls, raccoons (Procyon lotor), and squirrels (Sciurus spp.). Approximately 65% of these outages were attributed to snakes. Snake-related outages were believed to result from the pursuit of nesting birds by predatory snakes.

The interaction between electrical structures and wildlife has long been recognized (Michener 1928). Past studies have dealt with why birds and animals are killed by electricity and ways to prevent these deaths, but little research has evaluated the concomitant problem of economic loss to the electric power industry. The problem with wildlife-related power outages is not new, but little is known about it. There is little information in the recent wildlife damage literature regarding wildlife-related power outages and alleviating subsequent damage. No papers in the last 5 Great Plains Wildlife

Damage Control Conference Proceedings and the most recent Eastern Damage Control Proceedings dealt with this form of wildlife damage.

Available information on wildlife-related power outages comes from electric companies. Quincy (1993) conducted a study for Florida Power and Light to control bird damage and nesting in substations. They began using spray-on silicon, "heat shrink" tubing, and preformed insulation to protect critical areas where birds can cause outages. This method was successful, but installation and replacement costs were high. Durand et al. (1993) identified nesting and roosting bird species in substations and described those areas in the substation used by birds. They recommended discontinuing use of mercury lights (mercury lights attract insects), standardizing structures and equipment, and use of scare tactics. Other studies have dealt with avian-related outages, electrocution, and collisions with transmission lines (Bevanger 1994, Faanes 1987, Steenhof et al. 1993).

No literature has dealt with damage to substations at a landscape level. I analyzed the substation at a landscape level to determine how the surrounding habitat affects wildlife use and damage occurrence to that substation. I also sought to characterize damage and potential causative factors (substation configuration, landscape features, etc.). As an outcome, I sought to make recommendations related to damage control to minimize outages and subsequent loses. My goals were to reduce economic loss to WFEC, inconvenience by cooperative users, and animal mortality. I hypothesized that bird numbers and nesting activity were related to damage frequency. I also predicted that frequently damaged substations would have a greater prey base (i.e., bird numbers and nesting activity) for foraging snakes than undamaged or infrequently damaged substations, based on the assumption that snakes cued in on bird activity. If true, a reduction in bird activity and nesting would decrease the prey base, which would reduce foraging snakes and reduce outages. I further hypothesized that bird numbers, nests, and outage frequency were all related to substation design type. Finally, I predicted that wildlife use and outage frequency of a substation were linked to landscape features, such as edge, number of patches, and landscape diversity, surrounding that substation.

Objectives

1. To characterize geographic, species, and seasonal distributions of wildlife-related outages to electrical substations in the WFEC system.
2. To examine the role of lighting and other deterrents in eliminating bird nesting and damage to WFEC substations.
3. To describe habitat associations and land-use practices surrounding WFEC substations and relate these to the extent of damage.

LITERATURE REVIEW

Michener (1928) recognized problems involving avian interactions with powerlines and poles nearly 70 years ago. He examined the success of perching guards on transmission poles to prevent flashovers, which are electrical arcs over an insulator that persist until the voltage is lowered sufficiently to cause it to break. Michener (1928) believed that strings of bird excrement were the cause. He reported beneficial results with the use of saw-tooth guards and bird pans over the center insulator to prevent large birds from perching. This technique, however, was not completely successful, and installation and maintenance costs were high. A similar study by a group of companies for the

Electric Power Research Institute (1988) showed that bird excrement was not a major cause of outages on powerlines.

Major causes of avian mortality associated with electrical structures are electrocutions (Cornwell 1971, Faanes 1987) and collisions with powerlines (Krapu 1974). Feerar et al. (1991) reported ≤1,200 raptors per year die on the 300 km of powerlines in and around Doñana National Park in southwestern Spain. Mortality was greater in natural areas than in human-influenced habitats; electrocution was the cause of death >50% of the time. The endangered Spanish imperial eagle (Aquila adalberti) was electrocuted in the area. The principal known cause of death for wild-fledged whooping cranes (Grus americana) is collision with powerlines (Lingle 1987). Sandhill cranes (Grus canadensis) also suffer mortality from collisions with powerlines. Most deaths occur from collisions with the smaller, less visible static wire that offers protection from lightning and is located highest on the power line (Krapu 1974, Faanes 1981).

Avian mortality at electrical structures is likely due to higher use of these areas by some birds. Knight and Kawashima (1993) found that red-tailed hawks (Buteo jamaicensis) and common ravens (Corvus corax) were more abundant along linear right-of-ways. Raven and red-tailed hawk nests were more abundant along powerlines than either the adjacent suitable habitat or highways. Steenhof et al. (1993) reported that raptors and ravens began nesting on towers within 1 year of its construction. They discovered 133 pairs of raptors and ravens nesting along a 596-km section of transmission line in Idaho. Gilmer and Wiehe (1977) found that nesting pairs of raptors selected transmission towers for nesting when nearby sites seemed equally suitable.

Bevanger (1994) studied the causes of collision and electrocution accidents involving birds and powerlines and recommended actions to alleviate such problems. He suggested removing earth wires; modifying line, pole and tower designs; installing underground cables; and conspicuous marking of lines, poles, and towers to alleviate the problems. Increasing visibility of powerlines by using markers is the most cost-effective method for reducing bird collisions (Archibald 1987). Morkill and Anderson (1991) evaluated effectiveness of color markers (i.e., yellow aviation balls) on static lines to reduce collisions with powerlines by sandhill cranes. Collisions and mortality were greater on unmarked lines. In a similar study, Alonso et al. (1994) used colored PVC spirals to mark the ground wire. Birds avoided flying over the marked sections or increased their altitude as they did. The authors cited a decrease in mortality that was similar to other groundwire marking studies.

Landscape-level management also may be important to mitigate wildlife-electric utility interactions. Dedon and Colson (1987) investigated bird-caused powerline outages for Pacific Gas and Electric Company (PG&E) and found that areas with the most damage occurred near daily and migratory flyways. They proposed recommendations concerning equipment modification. Bevanger (1994) concluded that careful planning of future transmission lines could minimize damage. Planning should include mapping of (1) topographic features that may be flight lanes for migrating birds or are important for movement of local species, (2) topographic items such as cliffs that force birds to fly over powerlines, (3) important avian areas to minimize fragmentation, and (4) local climate conditions such as fog frequency and prevailing wind direction.

The aforementioned studies dealt with measures to control animal mortality from electric damage, but less is known about wildlife damage to facilities and operations of the electrical generation industry. Power failures represent an important inconvenience for customers and economic losses to electric companies. Few studies have looked at economic losses of electric companies and cooperatives and solutions from their perspective. Conover et al. (1995) reviewed economic losses caused by wildlife. He did not discuss economic losses of the electric industry due to wildlife, probably because of the scarcity of data on this problem.

The literature that exists on wildlife-related outages has been generated by power companies. Quincy (1993) conducted a study for Florida Power and Light (FPL) to evaluate and control bird damage to substations. A team from FPL located areas in the substation where animal-caused outages occurred. To correct the problem, the team installed "heat shrink" tubing and spray-on silicone, and preformed insulation on critical areas. The utility did not experience an outage at these substations for >3 years after the installation. Despite their success, these protective devices deteriorate under heat and ultraviolet rays and must be re-installed. The cost to install the insulation ranged from $46,000 to $54,000 per substation and was a drawback. Although less expensive than a $300,000 transformer, several reinstallations of the insulation becomes prohibitive in cost. Florida Power and Light also attempted the use of plastic owls to repel birds with no success (Quincy 1993).

Durand et al. (1993) reported that substations of Hydro-Quebec offered excellent nesting sites for birds, although most bird species were unknown. Of 24 species observed in the substation, 11 species produced 627 nests in 83% of the 80 substations. The main nesting species were the common grackle (Quiscalus quiscula) and the starling (Sturnus vulgaris). Durand et al. (1993) reported that birds also used substations for feeding and roosting. They recommended discontinuing the use of mercury lights in substations because they attract insects. Mercury lights could be replaced with low-pressure sodium bulbs that do not emit the blue band that attracts insects. Durand et al. (1993) also suggested the standardization of structures and equipment used by Hydro-Quebec to reduce nesting opportunities and to make equipment less sensitive to bird damage. Finally, they recommended use of scaring tactics, although they did not elaborate on specifics.

METHODS

Outage Characteristics

A survey of WFEC wildlife-related power outages was made from power failure reports from 1 January 1987 to 31 December 1996. Outage reports included: date, time of outage, substation name, cooperative name, duration of outage, damage to substation, and probable cause. Those reports allowed categorization of WFEC substations into three levels: (1) substations that received frequent wildlife damage (>0.3 incidents/yr), (2) substations that received occasional wildlife damage (0.1-0.2 incidents/yr), and (3) substations that received no damage (0 incidents/yr). Twenty-two substations were level 1 substations and all were selected for further study. Twenty substations each from levels 2 and 3 were selected randomly from a larger population for further study (Fig. 1). Selected substations were limited to Oklahoma. Substations also were analyzed by design type. Substations were classified as either being lattice- or low-profile-designed. Bird surveys, nesting counts, vegetation analysis, and cover board checks were conducted from April to July in 1996 on all 62 sites.

Bird, Nest, and Cover Board Surveys

Bird surveys and nest counts at all substations were conducted four times at about 2-week intervals during May and June of 1996 on each selected substation. Bird surveys were 10 minutes in length, performed between dawn and 1100 hours, and visual and auditory observations were recorded. Binoculars (7 x 35) aided in visual observations. I parked the vehicle >50 m from the substation, exited, and slowly approached the substation. At a point about 20 m from the substation, when I could easily see all activity inside the substation, the survey began. Initially, I counted all birds inside the substation. After obtaining an inside count, I retreated to a corner of the WFEC property about 40-50 m from the substation and remained for approximately 2.5 minutes recording any species seen or heard. I repeated this for all four corners. At this distance, I could easily record bird species entering or leaving the substation. Observations of individual birds were placed into one of three classes: (1) occurring inside the substation, (2) within a 50-m radius of the substation, or (3) ≥50 m from the substation. If a bird occurred inside the substation or <50 m from the substation, the species and number of that species was recorded. If the bird occurred ≥50 m from the substation, the species was recorded only as being present. Because bird surveys were standard for all 62 substations, I was able to obtain an index of bird use per substation. Nest counts were made during each visit to a substation. Nests were counted and recorded as occurring in the high voltage side (69-138 kV), the low voltage side (7.2-14.4 kV), or the transformer.

Six cover boards measuring 0.33 x 0.66 m were placed at 40 of the 62 substations. These boards were placed outside of the substation to sample populations of reptiles and amphibians (Grant et al. 1991, Fitch 1992). Two sides of the substation site with the most suitable habitat (i.e., grassland, woodland, forest, etc.) received three boards. Boards were checked during each visit to a substation. In 1996, checks were made in April-July. In 1997, checks were made in April-June.

Analyses were conducted to relate bird species, bird numbers, and nesting densities to damage incidence (i.e., outages). Repeated-measures analyses of variance were used to compare bird species diversity, bird numbers, and nesting density among the three groups of substations during all survey periods. Each substation was considered a replicate. Alpha level was set at $P < 0.05$.

Tests of Bird Deterrents

During the second year of the study, experimentation with bird-deterrent devices was initiated. I examined the efficacy of sodium iodide-lights and electronic noisemakers to reduce nesting in substations. Forty-two substations with the highest nesting density were selected randomly from substation levels 1 and 2 in this phase of the study. Three treatments were included in the design: sodium iodide lighting, electronic noisemakers, and control. Ten substations each were selected randomly to be a replicate of the two treatments. The remaining 22 substations were used as controls.

Electronic bird repellents (Wytek, Sisters, Oregon, USA) emitted electronic bird distress calls of the three most common substation nesting birds (house sparrow, starling, common grackle). These units were mounted on the outer substation fence at the low-voltage end, aiming inward. Two sodium-iodide lights were mounted on the feeder stand in the low-voltage side of the substation. Sodium-iodide lights were recommended for use because bright lights were reported to upset roosting and nesting birds inside the substation causing birds to eventually leave (Southern Engineering 1996). These lights do not attract insects because they do not emit the blue band of light, that attracts them and in turn, foraging birds and bats (Southern Engineering 1996).

The same procedure for collecting data that was used in 1996 was used from May to July 1997 to assess the effect of control methods on bird species diversity, abundance, and nest density. An analysis of covariance was used to test for treatment differences in numbers nests and birds. Data from 1996 were used as the covariate and treatment was the main factor. Tukey's honest significant difference multiple comparison test (Zar 1984) was used for mean comparisons. Alpha level was set at $P < 0.05$.

Microhabitat Sampling

Microhabitat sampling was conducted once for each substation during June and July of 1996. Sampling was conducted ≤50 m from the substation (Fig. 3). A random direction was selected for the first sampling circles at 5, 20 and 50 m (Fig. 3). The first point (A) was 5 m from the substation fence in the selected direction away from the center of the substation (Fig. 4). A 0.5-m^2 plot frame was placed on the point. Percent cover of each of 11 classes of cover (grasslike, forb, woody, stem, half-shrub, vine, rock, soil, stem, road, litter, and structure) was recorded by ocular estimation into 10 classes of percent cover: trace, 0-1%, 1-2%, 2-5%, 5-10%, 10-25%, 25-50%, 50-75%, 75-95%, and 95-100% (Bonham 1989). At this same point, canopy density and vertical cover were measured with a cover pole (Griffith and Youtie 1988) were measured. From point A, 5 m was stepped off in another random direction and the same recordings were made (point

B). Three additional sampling frames were read 5 m from point A at 90°, 180°, and 270° angles from a second random direction. The result was cover data from the center of a 5-m radius circular plot and at 4 points on the edges of the plot. Vertical cover pole readings also were taken half-way between points A and B for a total of 9 pole readings. A woody stem count was made inside the 5-m circular plot. This procedure was repeated at 20 and 50 m from the substation in the first random direction. Three more sampling sets were completed at 90°, 180°, and 270° from the original direction for a total of 12 plots per substation, or 60 subsamples per substation (Fig. 4)

I conducted a one-way analysis of variance to test for differences in microhabitat characteristics between damage levels. Each substation was considered a replicate. Tukey's honest significant difference multiple comparison test (Zar 1984) was used for mean comparisons. Alpha level was set at $P < 0.05$.

Landscape Analysis

Using a geographic information system (GIS), aerial photographs of a 2.25-km^2 square that was centered on the substation were digitized to study how landscape types (e.g., forest, woodland, pasture, prairie, cropland, riparian zones) and land uses (e.g., timber, grazing, farming) around the substation were correlated with damage occurrences. Aerial photographs were taken October, 1995 and September, 1996 and were obtained for all 62 selected substations from WFEC. Using polyester inking transparencies, habitat types inside the 2.25-km^2 square were traced from photographs. Habitat types were placed into one of 21 habitat classes: highway, county road, secondary road, water, forest riparian, prairie riparian, riparian, residential, urban, rural residential, cropland, native pasture, improved pasture, forest, commercial forest, woodland, shrubland, industrial, WFEC substation, barren, and other. Transparencies were digitally scanned using an Eagle 3640 (ANA Tech, Littleton, CO) flatbed scanner. Digitized photos were imported into the software package Line Trace Plus (USDA) and edited, registered, and exported into. All images were cleaned and coverages built in PC ArcInfo (ESRI, Redwoods, CA). ArcInfo coverages were imported into ArcView (ESRI, Redwoods, CA), and polygons were attributed. Attributed coverages in ArcView were imported back into ArcInfo and converted into raster format (ERDAS 16 bit).

The software package FRAGSTATS (McGarigal and Marks, 1995) was used to calculate landscape metrics of all 62 digital photographs. Landscape indices were: number of patches, patch density, mean patch size, patch-size standard deviation, total edge, edge density, landscape-shape index, Shannon's diversity index, Simpson's diversity index, Shannon's evenness index, Simpson's evenness index, and Contagion index (McGarigal and Marks 1995). Number of patches was the number of patches in the landscape. Patch density was the number of patches in the landscape divided by total landscape area. Mean patch size was the total landscape area divided by number of patches. Total edge was the sum of all edge segments. Edge density was the sums of the lengths of all edge segments in the landscape, divided by total landscape area. Landscape shape index equaled one when the landscape consists of a single square patch; it increased without limit as the landscape became more irregular or as the length of edge within the landscape increased, or both. Shannon's diversity index and Simpson's diversity index are similar indices; they increased as number of different patch types increased or the proportional distribution of area among patch types became more equitable, or both. Both diversity indexes equaled zero when the landscape contained only one patch (no diversity).

Shannon's evenness index and Simpson's evenness index both approach zero as the distribution of area among the different patch types becomes increasingly uneven (dominated by 1 type) and equal one when distributions of area among patch types are perfectly even. Contagion index is near zero when the distribution of adjacencies among unique patch types becomes increasingly uneven and equals 100 when all patch types are equally adjacent to all other patch types (McGarigal and Marks 1995).

I conducted a one-way analysis of variance to test for differences in landscape indices among damage levels. Each substation was considered a replicate . Tukey's honest significant difference multiple comparison test was used for mean comparisons (Zar 1984). Alpha level was set at $P < 0.05$.

RESULTS

Outage Characteristics

Distribution of wildlife-related outages was characterized by analyzing WFEC outage reports from 1987-1995. WFEC averaged 20.1 outages per year during this period with no apparent trend (Fig. 5). A total of 147 substations never incurred a wildlife-related outage during 1987-1995, and only 22 substations had damage occurring 3 or more times (Fig. 6). Those 22 represented 8.8% of the substations but received 47.1% of the outages ($\chi^2 = 339.78$, 1 df, $P < 0.001$). Most outages occurred during spring and summer (Fig. 7), with 72% of all outages in May, June, and July. Snakes were responsible for 65% of wildlife-related outages. Other species or groups of species responsible were owls, small birds, raccoons, squirrels and hawks. In this study, 56.5% of the substations were the low profile design and incurred 66.4% of the outages ($\chi^2 = 4.48$, 1 df, $0.05 > P > 0.025$).

WFEC averaged 20.1 wildlife outages per year from 1987 to 1995, but this average may be an underestimate of the true total. Reported outages were confirmed as being due to wildlife when a carcass or traces of an animal's hair or skin was found in or around the damaged substation. Some outage reports listed cause as unknown. It is possible for an animal to cause an outage without dying or leaving any sign, thus producing an undetected wildlife outage.

Nest Counts - 1996

A total of 3,875 nests was counted during 4 survey periods at 62 substations between May and July 1996. There was an average of 15.6 nests per substation per survey (range 0-66). Average nests per substation increased ($P < 0.001$) over all 4 surveys and were higher ($P < 0.001$) in level 1 substations. Level 1 substations consistently had more nests ($P < 0.001$) in both the high-voltage and low-voltage side than level 2 or 3 substations (Table 1). Nests were more abundant in the low-voltage side during all surveys and damage levels. Substations of the low-profile design had more nesting ($P < 0.001$) over all surveys and all damage levels than substations of the lattice design (Table 1).

No nesting occurred in two lattice-design substations (one outage combined during 1987-1996). Because nests were not cleaned between surveys, nest counts increased with each succeeding survey. The largest increase in nests occurred between survey 1 and 2 (the last 2 weeks of May).

Nest Counts - 1997

A total of 4,224 nests was counted during the survey periods in May-July 1997. Each substation was surveyed 4 times during this period. There was an average of 17.0 nests per substation per survey (range 0-54). Nest counts increased ($P < 0.001$) over all 4 surveys. Nests were more abundant in the low-voltage side during all survey periods.

Treatments had no effect on average nests per substation ($P = 0.236$, Table 2). There was no treatment effect on nesting density in the high side ($P = 0.184$) or the low side of the substation ($P = 0.135$).

Birds - 1996

Totals of 6,234 birds and 77 bird species were counted during all survey periods from May to July 1996. Most birds were observed during the May 18 to June 4, 1996 survey period. House sparrows (Passer domesticus) (seen during 213 of 248 substation surveys), European starlings (Sturnus vulgaris) (127 of 248), and common grackles (Quiscalus quiscula) (103 of 248) were the most commonly observed bird species inside the substation. Eastern meadowlarks (Sturnella magna) (181 of 248), mourning doves (Zenaida macroura) (133 of 248), and northern mockingbirds (Mimus polyglottos) (119 of 248) were the most commonly observed bird species outside the substation. Nineteen species were observed inside the substation, 69 species were observed <50 m from the substation, and 70 species were observed >50 m from the substation.

An average of 25 birds was observed at each substation during each survey (Table 3). Average birds per substation were higher ($P < 0.001$) in level 1 substations than level 2 or 3 substations; more birds were observed at level 1 than at level 3 substations for all surveys. Inside the substation, birds were more abundant in highly damaged substations than undamaged ones ($P = 0.024$). For birds observed <50 m, there was no difference between damage levels. Average number of birds per substation was higher for low-profile substations ($P = 0.050$) compared with lattice-design substations over all survey periods and damage levels (Table 3).

Birds - 1997

Totals of 5,827 birds and 105 species were counted during all survey periods from May to July, 1997 (Appendix B). Most birds were observed during the June 15 to July 3, 1997 survey period. The most commonly observed species were identical to those observed in 1996. House sparrows (seen during 208 of 248 substation surveys), European starlings (124 of 248), and common grackles (90 of 248) were the most commonly observed bird species inside the substation. Eastern meadowlarks (180 of 248), mourning doves (151 of 248), and northern mockingbirds (124 of 248) were the most commonly observed bird species outside the substation. Eighteen species were observed inside the substation, 61 were observed <50 m from the substation, and 98 species were observed >50 m from the substation.

Treatments had no effect on average birds per substation within 50 m ($P = 0.516$) of the substation (Table 4). Analysis of covariance indicated a difference among treatments inside the substation ($P = 0.0304$). Mean separation tests on the differences between years indicated that electronic noisemakers significantly reduced number of birds inside the substation (Table 4). Electronic noisemakers reduced ($P = 0.0415$) abundance of the most common substation nester, the house sparrow, inside the substation. Treatments had no statistical effect ($P > 0.050$) on the abundance of the common grackle, the second most common substation nester. Lighting increased ($P = 0.022$) the third most common nester, the starling, inside the substation.

Reptiles and Amphibians - 1996

Success rate of cover boards was 0.76% (8 captures of 1,050 checks). Prairie racerunner (Cnemidophorus sexlineatus viridis) was the most commonly observed species ($n = 6$). The low success rate may have been due to infrequent and untimely checks. The black rat snake (Elaphe obsoleta) and western ribbon snake (Thamnophis proximus) were other observed species. Sample size was too small to allow statistical analysis of reptiles and amphibians.

Reptiles and Amphibians - 1997

Success rate of cover boards was 15.2% (109 of 718) including small mammals (Table 5). The success rate for only reptiles and amphibians was 12.7% (91 of 718). Prairie racerunner, Great plains narrowmouth toad (Gastrophryne olivacea), and prairie ringneck snake (Diadophis punctatus arnyi) were the most commonly observed reptiles and amphibian species.

Microhabitat

Analysis of vegetation data netted two significant results over all categories and distances (Table 6). Cover of grasslike plants at 20 m from the substation was higher ($P = 0.005$) at level 3 substations. Soil cover at 20 m was significantly lower ($P = 0.030$) at level 3 substations. Foliage density, as measured by cover pole readings and woody stem counts, did not vary across damage levels at all three distances (Table 7). There was a difference in canopy cover at 20 m from the substations among damage levels ($P = 0.044$), however, mean separation tests were unable to distinguish among levels. Mean canopy cover (%) averaged (± SE) 0.24 ± 0.1 for level 1 substations, 0.47 ± 0.1 for level 2 substations, and 0.24 ± 0.1 for level 3 substations.

Landscape Analysis

Analysis of landscape indices indicated dramatic differences surrounding substations of different damage levels. Number of patches, patch density, total edge, edge density, landscape index, Shannon's diversity index, and Simpson's diversity index were significantly higher (all tests $P < 0.001$, Table 8) for damage level 1 substations than level 2 or 3 substations. Level 1 substations had a higher ($P = 0.005$) Simpson's evenness index than level 2 or 3 substations. Mean patch size and patch-size standard deviation were significantly lower (both $P < 0.001$) for damage level 1 substations.

DISCUSSION

Outage Characteristics

The temporal pattern of wildlife-related outages clearly was related to the seasonality of bird nesting and snake activity. The majority of outages occurred in late spring and early summer during peak periods of bird nesting in the substation structures and snake foraging activity. This pattern has been observed for years by WFEC personnel (G. Jacobs, pers. commun.). bird-related outages outnumbered snake-related outages in April (Fig. 7). After birds begin nesting, foraging snakes are attracted to bird activity and scent. Snake damage increases, peaking in June and remaining high until August. Some snakes are opportunistic feeders and, hungry or not, will eat all the food they can find in one place. This behavior can be serious for the electric industry. When snakes hunt nests inside substations, they may continue to hunt until they find all the bird nests or have caused an outage. Large snakes can easily cause an outage by simultaneously touching two live phases. On Guam, brown tree snakes (Boiga irregularis) cause electrical outages every 3-4 days as a result of their climbing and foraging (M. E. Pitzler, USDA-APHIS, pers. commun.).

Management techniques of WFEC to reduce snake-related outages have focused on providing barriers to snake access to bird nesting sites. Most barriers are electrical barriers around substation bases. Electrical fencing often is used to control the movements of wild animals (McKillop and Sibly 1988). However, the use of such barriers to control snake dispersal has been limited.

My project shifted the focus from predator (snake) to prey (birds). I predicted that frequently-damaged substations would have greater bird numbers and nesting activity than undamaged or infrequently damaged substations, based on the assumption that snakes cued in on bird activity and eventually caused outages. Data from the first year of the study supported this prediction. Bird abundance and nest numbers were related to damage rate and design type. Apparently, the larger the prey base available at the substation, the greater the probability that a wildlife-related outage would occur. A reduction in bird activity and nesting would decrease the prey base, reducing outages.

Nest Counts

House sparrows, grackles, and starlings were the most common nesters in substations. Nine species of birds were observed nesting inside the substation during both years: house sparrow, grackle, starling, western kingbird (Tyrannus verticalis), scissor-tailed flycatcher (Tyrannus forficatus), mourning dove, eastern bluebird (Sialia sialis), eastern kingbird (Tyrannus tyrannus), killdeer (Charadrius vociferus), and house finch

(Carpodacus mexicanus). The three most common species appeared to show nest-site selection. Sparrows preferentially used the low voltage side of the substation, rarely using the high voltage side unless most nest sites were occupied on the low side. Grackles and starlings preferred nesting in the high side. Sparrows, grackles, and starlings often assembled in flocks (>10 birds) within the substation. However, only one species is abundant inside the substation at a time. Grackles appeared to dominate other species, perhaps because of their size.

The lack of a treatment effect by deterrents on the number of nests in the high-voltage side of the substation was not unexpected. Because more outages, bird activity, and nesting occur in the low voltage side, lighting and electronic noisemakers were concentrated only on the low side of the substation. Few outages occur in the high side of the substation. The high voltage requires the use of long insulators (approximately 2-3 m). Only an unusually large bird or snake can cause an outage in the high side. Also, because of the different design, birds find fewer places to nest in the high side relative to the low side.

Treatments also had no effect on low-side substation nesting, a surprising result considering the low side is the focal point of birds and damage. Lights were intended to simulate sunlight conditions 24 hours a day, deterring birds from nesting. Although lights were mounted on the low side, the complexity of the low-side design created shadows that may have allowed birds to nest, yet avoid the night lighting. Lighting may have been more effective if installed in greater numbers than the 2 per substation we used. Vandalism also may be a consideration in lighting substations.

Bird Surveys

The observation of greater bird activity in the low-profile substations was surprising. The low-profile types were designed, at least in part, to minimize animal activity. However, low-side stands contain 8-12 ideal nesting locations for small passerine birds (house sparrows, in this case). With 4 stands per substation, ≥32 nest sites are available in each low-profile substation on the low voltage side alone. These nest sites are small cavities created by two support beams, and it was not uncommon to observe a nest in each of these potential nest sites. It is possible for WFEC to install physical barriers that would eliminate nesting in these sites (G. Jacobs, pers. commun.). These barriers would dramatically reduce nesting in the substation. More importantly, it would nearly eliminate nesting in the low side of low-profile design substations. Other nest sites include the transformer, feeder stand, and high side switches. The higher bird abundance and nesting activity in low-profile substations compared with lattice-designed substations was associated with a high proportion of frequently-damaged low profile sites than would be expected by chance alone.

It was not surprising that treatments had no effect on birds <50 m or >50 m from the substation because efforts were concentrated inside the substations. In 1996, we observed no difference among damage levels for birds outside the substation. In any case, reduction in bird activity outside the substation may not reduce outages inside the substation.

Lighting did not deter birds inside the substation. Lights either had no behavioral effect on birds, or birds were able to locate shadowed areas. The increase of starlings with lighting was unexpected. Starling nesting did not increase, so the cause of the increased starling use is not known.

Deterrents

Electronic noisemakers decreased bird numbers inside the substation and reduced the most common nesting bird, the house sparrow. They did not, however, decrease nests inside the substation. Outages were linked more closely with substation nesting, not bird activity or number. While I was able to reduce birds at substations, the fewer birds may have increased their nest production. I do not believe that electronic noisemakers would reduce wildlife-related outages because of the lack of nest reduction.

Alarm-distress calls have proven ineffective in reducing black-crowned night heron (Nycticorax nycticorax) and great blue heron (Ardea herodias) predation on rainbow trout (Oncorhynchus mykiss) fingerlings in a fish rearing facility (Andelt and Hopper 1996). Flashing lights and the Scarey Man Fall Guy (R. Royal, Midnight, MS), a 1.46-m tall plastic mannequin that intermittently inflates with air, bobs up and down, illuminates, and emits a high-pitched wail, also have proven ineffective in deterring heron predation on trout (Andelt et al. 1997). The Scarey Man® Fall Guy reduced double-crested cormorants (Phalacrocorax auritus) at catfish ponds in Mississippi, but birds quickly became habituated to the deterrent (Stickley et al. 1995). These studies, coupled with our data, indicate that birds quickly habituate to noisemakers and distress calls. Effectiveness, if any, is quick and short-lived. Electronic deterrents and distress calls have been thoroughly evaluated and proven ineffective.

Pyrotechnics have proven effective in reducing herons at a fish rearing facility (Andelt et al. 1997) and deterring fish-eating birds from catfish ponds (Stickley and

Andrews 1989). However, this technique would not be cost-effective for WFEC, or other electric cooperatives. Pyrotechnics proved most effective when fired on consecutive days, and ineffective when fired on non-consecutive days. WFEC has over 250 substations in their system located in three states. Firing pyrotechnics at every site on consecutive days would be impossible. Even if pyrotechnic firing were limited only to highly damaged substations (*n* = 22), consecutive-day firing would be expensive and logistically difficult as these 22 substations are distributed throughout Oklahoma. The most effective method for pyrotechnics at aquaculture facilities was firing for 14 consecutive days followed by 22 consecutive days of no firing. For WFEC, this would require firing at 22 sites located throughout Oklahoma on 14 consecutive days, a method they would not employ and I do not recommend. This method has been tested and proven effective on fish-eating birds but has not been tested on the more aggressive and abundant house sparrow.

Reptiles and Amphibians

We used cover boards because they yield a high percentage of snakes and could be checked when convenient or left unattended and installation involved relatively little time and expense (Fitch 1992). However, snakes caught were mainly small, secretive species that were not responsible for wildlife-related power outages. Cover board success rate was low in 1996. Substation visits were made at 2-week intervals, typically during early morning hours or during high afternoon temperatures. More board checks were made in 1996 because checks were made during microhabitat sampling in July. The board checks during this period were made mostly during peak afternoon temperatures. No checks were made in July 1997. Cover boards must be checked when snakes are most likely to take shelter under them. Fitch (1992) found it unsuccessful to check boards when temperatures were either too hot or too cold for boards to be attractive. Boards were positioned in April 1996 and checks began immediately after. It has been suggested that cover board success rates vary with age of board (Grant et al. 1991). Success rates appear to increase the longer a board is in place (≥2 months). Most checks in 1996 were made within 2 months of board placement. It is possible that several months were needed for microhabitat under the board to change to suitable habitat. Checks of the same boards in 1997 resulted in a much higher success rate. Low success in 1996 also could be due to a dry spring and early summer.

Microhabitat

Lack of statistical differences at the microhabitat level supports my belief that wildlife use of the substation is related to the surrounding landscape. I measured ground cover in 11 categories at 3 distances. Two of the 33 tests of analyses of variance were significant. I was testing at the 0.05 level, which would give one significant result in 20 tests by chance alone and I attribute the two significant results in 33 tests to chance. The absence of differences suggested that birds selected substations on a larger scale than ≤50 m.

Landscape Analysis

The concentration of nearly 50% of all wildlife-related outages at only 9% of the substations suggested that some common factor in the landscape surrounding those frequently-damaged substations is associated with the damage. Substations in the WFEC system are located throughout the state of Oklahoma in a variety of habitats. Some are located in closed-canopy forests, while others are located in intense farming and agricultural areas. It was not uncommon for a undamaged substation to be <25 km from a highly damaged substation. Because of the paucity of highly damaged sites, landscape characteristics and land-use practices surrounding substations likely play a role in determining if a substation receives wildlife-related outages. Ten of the 12 landscape indices that I tested were associated with number of outages. Patchiness of landscapes surrounding substations was associated directly with the incidence of wildlife-related outages. However, it should be noted that several indices, such as number of patches, patch density, mean patch size, total edge, and edge density are autocorrelated.

Higher wildlife abundance near substations increases outage potential. Obvious differences can be detected from comparing digitized habitat maps of level 1 and level 3 substations (Appendix A). For example, the substation at Owens Prairie (Appendix A), the highest damaged substation, had noticeable differences compared with the undamaged substation at Lone Wolf (Appendix A). The area surrounding the substation at Owens Prairie was a more complex landscape with more patches, edge, and habitat types than the substation at Lone Wolf. Edge has long been associated with increases in the abundance of several wildlife species (Leopold 1933). While not all wildlife species are attracted to edge, in general terms, more edge means more wildlife.

Wildlife biologists have argued recently that Leopold's hypothesis of edge pertained only to certain species and have challenged the idea that edge increases wildlife abundance (Yahner 1988). Much recent research has focused on avian population declines, especially of neotropical migrants in the eastern United States, in increasingly fragmented landscapes (Askins et al. 1990, Robinson 1992). Increased fragmentation of temperate forests is widely believed to be causally related to a decline in some neotropical migrant passerines (Robinson 1992). While fragmentation decreases the total area of habitat and increases the amount of edge habitat, the most important factor producing the decline in bird populations is not believed to be fragmentation but increased nest predation near edge habitat (Yahner 1988, Paton 1994).

Higher levels of nest predation near edges may result from higher predator activity near edges than in habitat interiors. Predator activity is often concentrated at edges (Gates and Giffen 1991). Marini et al. (1995) described four non-exclusive hypotheses that may explain higher predator activity near edges: (1) predator foraging intensity is higher in areas with higher prey density (Johnston and Odum 1956, Martin 1988); (2) predators may be more abundant on edges that in interiors (Bider 1968); (3) predator diversity may be higher on edges than in interiors (Bider 1968); or (4) predators may forage along travel lanes (Bider 1968). Whatever the cause, the association between edges and higher predator activity explains the increased predation (e.g. snake activity) in substations surrounded by complex fragmented landscapes.

Leopold (1933) speculated that greater wildlife diversity at edges resulted from the variety of vegetation at edges or availability of different habitats in close proximity. Ranney et al. (1981) reported that forest edges supported up to 50% more timber basal area, had a higher tree species composition, and contained a higher tree density. Avian species richness and density are often high near edges, particularly at shrubby, abrupt, forest edges bordering openings (Strelke and Dickson 1980, Morgan and Gates 1982). This high diversity reflects more varied vegetative strata at these edges and leads to a high nest density, primarily of edge or mixed-habitat species (Chasko and Gates 1982, Gates and Giffen 1991). Species diversity is related to habitat complexity (James and Warner

1982). Habitat structure is important in determining the distribution of breeding birds (Hawrot and Niemi 1996). It is probable that a complex landscape comprised of many habitats and edges would support a more diverse bird community than would a more homogeneous landscape. Similar to results presented here, Hawort and Niemi (1996) found that avian species diversity was associated with abundance of edge.

In my study, damage levels and bird abundance were higher at complex landscapes with more edge and patches. Smaller patches have a high proportion of boundary areas with surrounding habitats than larger patches. Bowers et al. (1996) reported that Microtus pennsylvanicus with home ranges on fragment edges had larger body sizes, reproduced more frequently, and had longer residence times than those in more continuous habitats. These differences suggest that edge may be of higher quality than non-edge. If true, landscapes with high proportions of edge would contain more high-quality habitats and support higher densities of wildlife than less complex habitats with less edge (Bowers and Matter 1997).

Much of the edge in landscapes surrounding substations was created by secondary roads and trails. Roadside vegetation can be of high value for wildlife (Bennet 1991). Laursen (1981) reported that species richness was correlated positively with vegetation width at each roadside and with densities of certain species. Gravel and surfaced roads are a source of grit for birds (Dhindsa et al. 1988). The warmth retained in the road surface and the openness of the road edge are attractive for reptile basking (Bennet 1991). Birds also may use roads for assistance in thermoregulation. The open space above roads provides a flight path and foraging space. Utility poles provide additional perching sites. Road-killed animals attract various wildlife predators (Bennett 1991). Additionally, in some areas, roadside vegetation may be the last remnants of native vegetation in the area and can allow many species, especially birds, to persist in the altered landscape (Bennett 1991).

Riparian, or streamside, zones were present in the landscape around nearly all level one substations. Riparian zones often contain suitable snake and bird habitat. Gates and Giffen (1991) found a higher avian species richness, density, and diversity at a forest-stream ecotone. They suggested that, because of increased nesting, conditions at forest-stream edges might be conducive to increased nest predation. Predator activity is often concentrated at the interface between adjacent habitats (Chasko and Gates 1982, Gates 1991). The farther a substation is from a riparian zone, the farther a foraging snake must travel to cause an outage.

Use of aerial photographs to describe landscape characteristics could be beneficial to WFEC or other electric cooperatives in future substation site selection. For example, if WFEC must construct a new substation and has several options for the location of the site, an aerial photograph taken of those sites can be used to generate landscape indices to determine which site will be less likely to receive wildlife outages. If WFEC does not have selection options, and a substation must be constructed at a specific site, landscape indices can determine if that substation will be a likely candidate for wildlife outages. Western Farmers could then concentrate efforts and resources (snake fencing, nesting barriers, maintained area around sub) on the substation if it is likely to receive outages. If it is not likely to receive outages, those resources could be spent on other substations.

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Table 1. Avian nesting density (mean ± SE) by damage level and location within substations in the WFEC system in Oklahoma in 1996.

Survey period	Location	Damage Level 1 (High) (n=22)	2 (Low) (n=20)	3 (None) (n=20)	Overall P-values Level	Survey	Level*Survey
1 (28 Apr-17 May)	Low Side	7.1 ± 1.4	7.1 ± 1.7	3.7 ± 1.1	<0.001	<0.001	0.984
	High Side	2.7 ± 0.6	2.9 ± 0.8	1.1 ± 0.4	<0.001	0.004	0.920
	Transformer	1.1 ± 0.3	0.8 ± 0.3	1.0 ± 0.4	0.016	0.947	0.967
	Total	10.9 ± 1.7	10.8 ± 2.3	5.7 ± 1.4	<0.001	<0.001	0.972
2 (18 May-4 Jun)	Low Side	11.8 ± 2.2	12.4 ± 2.4	8.5 ± 1.7			
	High Side	4.8 ± 0.9	4.1 ± 0.9	2.1 ± 0.6			
	Transformer	1.5 ± 0.5	0.6 ± 0.3	1.1 ± 0.4			
	Total	18.1 ± 2.6	17.1 ± 3.0	11.7 ± 2.0			
3 (5 Jun-19 Jun)	Low Side	14.9 ± 2.7	14.8 ± 2.4	9.1 ± 1.8			
	High Side	5.8 ± 1.0	4.6 ± 1.1	2.4 ± 0.7			
	Transformer	1.1 ± 0.3	0.8 ± 0.4	1.4 ± 0.5			
	Total	21.8 ± 3.0	20.1 ± 3.2	12.8 ± 2.2			

4 (20 Jun-4 July)	Low Side	16.4 ± 2.9	14.8 ± 2.9	9.8 ± 2.0
	High Side	6.4 ± 1.1	4.8 ± 1.2	2.7 ± 0.7
	Transformer	1.9 ± 0.3	0.6 ± 0.3	1.1 ± 0.4
	Total	23.8 ± 3.4	20.2 ± 3.6	13.6 ± 2.4

Table 2. Avian nesting density by treatment types and survey periods in electrical substations in the WFEC system in Oklahoma in 1996 and 1997.

			Average nesting density per substation (mean ± SE)		
Treatment	Survey	Date	*n*	High side	Low side
Control	1	29 Apr-17 May 1996	21	3.1 ± 0.8	5.7 ± 1.4
	1	3 May-18 May 1997	21	4.0 ± 0.8	6.0 ± 1.3
	2	20 May-1 Jun 1996	21	4.7 ± 0.8	9.0 ± 1.8
	2	20 May-4 Jun 1997	21	6.6 ± 1.3	8.7 ± 1.8
	3	3 Jun-20 Jun 1996	21	5.9 ± 1.2	10.4 ± 2.0
	3	2 Jun-16 Jun 1997	21	6.8 ± 1.4	11.4 ± 2.3
	4	21 Jun-7 Jul 1996	21	5.9 ± 1.2	11.2 ± 2.3
	4	15 Jun-3 Jul 1997	21	7.0 ± 1.5	12.6 ± 2.5
Lighting	1	29 Apr-17 May 1996	10	3.2 ± 0.9	11.2 ± 2.5
	1	3 May-18 May 1997	10	4.8 ± 1.7	11.9 ± 2.6
	2	20 May-1 Jun 1996	10	5.8 ± 1.7	18.0 ± 3.6
	2	20 May-4 Jun 1997	10	6.0 ± 1.7	17.0 ± 3.2

	3	3 Jun-20 Jun 1996	10	6.2 ± 1.5	22.1 ± 3.5
	3	2 Jun-16 Jun 1997	10	7.8 ± 2.2	19.7 ± 3.8
	4	21 Jun-7 Jul 1996	10	7.5 ± 2.0	23.1 ± 3.8
	4	15 Jun-3 Jul 1997	10	6.9 ± 2.0	23.5 ± 4.1
Electronic Noisemakers	1	29 Apr-17 May 1996	10	2.0 ± 0.7	6.4 ± 2.0
	1	3 May-18 May 1997	10	1.9 ± 0.7	13.0 ± 3.2
	2	20 May-1 Jun 1996	10	3.1 ± 1.0	13.9 ± 3.5
	2	20 May-4 Jun 1997	10	3.2 ± 0.8	16.3 ± 3.5
	3	3 Jun-20 Jun 1996	10	3.5 ± 0.8	18.1 ± 4.0
	3	2 Jun-16 Jun 1997	10	4.5 ± 1.1	18.6 ± 3.6
	4	21 Jun-7 Jul 1996	10	3.6 ± 1.0	19.6 ± 5.0
	4	15 Jun-3 Jul 1997	10	3.7 ± 1.0	19.7 ± 4.5

Table 3. Avian abundance (mean ± SE) by damage level and location at substations in the WFEC system in Oklahoma in 1996.

Survey period	Location	Damage level			Overall P-values		
		1 (High) (n=22)	2 (Low) (n=20)	3 (None) (n=20)	Level	Survey	Level*Survey
1 (28 Apr-17 May)	Inside	22.2 ± 1.8a	18.4 ± 2.6ab	17.1 ± 2.6b	0.001	0.257	0.958
	<50 m	10.7 ±1.2	9.9 ± 1.1	14.5 ± 2.5	0.425	0.120	0.126
	>50 m	9.8 ± 0.9a	10.9 ± 0.8b	9.0 ± 0.7ab	0.011	<0.001	0.911
	Total	42.8 ± 2.3a	39.1 ± 2.4ab	40.5 ± 3.2b	0.007	<0.001	0.818
2 (18 May-4 Jun)	Inside	27.3 ± 2.1	21.3 ± 2.7	17.2 ± 2.6			
	<50 m	11.7 ± 1.4	10.6 ± 1.0	11.5 ± 0.9			
	>50 m	13.5 ± 1.0	15.1 ± 0.7	14.0 ± 0.8			
	Total	52.5 ± 2.6	47.0 ± 2.8	42.6 ± 2.9			
3 (5 Jun-19 Jun)	Inside	28.5 ± 3.5	23.0 ± 3.5	18.3 ± 3.0			
	<50 m	14.3 ± 1.3	13.1 ± 1.7	12.4 ± 1.0			
	>50 m	14.1 ± 0.8	17.1 ± 1.0	15.1 ± 1.22			
	Total	56.9 ± 4.0	53.2 ± 2.9	45.7 ± 3.7			

4 (20 Jun-4 Jul)	Inside	26.5 ± 2.9	22.9 ± 3.8	21.6 ± 4.2
	<50 m	17.0 ± 2.4	12.5 ± 1.1	11.9 ± 1.5
	>50 m	14.6 ± 1.0	15.7 ± 1.1	15.1 ± 1.3
	Total	58.2 ± 3.7	51.0 ± 3.6	48.6 ± 4.6

Table 4. Avian abundance by treatment types and survey periods in electrical substations in the WFEC system in Oklahoma.

			Average Nesting Density per Substation (mean ± SE)		
Treatment	Survey	Year	*n*	Inside Sub	Within 50m of Sub
Control	1	29 Apr-17 May 1996	21	10.4 ± 1.5	7.1 ± 1.2
	1	3 May-18 May 1997	21	9.1 ± 1.4	3.6 ± 0.5
	2	20 May-1 Jun 1996	21	12.9 ± 1.2	8.5 ± 1.2
	2	20 May-4 Jun 1997	21	11.2 ± 1.5	3.4 ± 0.5
	3	3 Jun-20 Jun 1996	21	11.2 ± 2.4	7.4 ± 0.6
	3	2 Jun-16 Jun 1997	21	12.3 ± 2.0	5.0 ± 1.0
	4	21 Jun-7 Jul 1996	21	8.6 ± 1.4	8.4 ± 1.2
	4	15 Jun-3 Jul 1997	21	12.5 ± 2.2	6.2 ± 1.0
Lighting	1	29 Apr-17 May 1996	10	11.8 ± 1.4	6.9 ± 1.2
	1	3 May-18 May 1997	10	12.6 ± 1.2	4.8 ± 0.7
	2	20 May-1 Jun 1996	10	14.3 ± 1.6	6.1 ± 1.3
	2	20 May-4 Jun 1997	10	15.6 ± 2.1	4.6 ± 1.5
	3	3 Jun-20 Jun 1996	10	14.7 ± 1.9	7.9 ± 0.8
	3	2 Jun-16 Jun 1997	10	15.7 ± 1.4	5.2 ± 0.7
	4	21 Jun-7 Jul 1996	10	15.7 ± 1.3	5.6 ± 0.9
	4	15 Jun-3 Jul 1997	10	18.3 ± 3.3	6.3 ± 1.5

Electronic Noisemakers	1	29 Apr-17 May 1996	10	11.8 ± 1.7	4.2 ± 1.1
	1	3 May-18 May 1997	10	11.3 ± 1.7	5.1 ± 1.2
	2	20 May-1 Jun 1996	10	12.9 ± 1.6	6.2 ± 1.3
	2	20 May-4 Jun 1997	10	9.4 ± 1.7	4.0 ± 0.7
	3	3 Jun-20 Jun 1996	10	18.0 ± 3.8	11.3 ± 2.4
	3	2 Jun-16 Jun 1997	10	10.2 ± 1.8	4.0 ± 0.8
	4	21 Jun-7 Jul 1996	10	13.2 ± 2.7	8.3 ± 1.5
	4	15 Jun-3 Jul 1997	10	11.2 ± 2.6	8.9 ± 3.9

Table 5. Species observed during cover board checks at electrical substations in the WFEC system in Oklahoma during April-June, 1997. Total board checks = 718.

Species	Total
Mammals	
White-footed mouse (Peromyscus spp.)	17
Rat (Rattus rattus)	1
Reptiles	
Ringneck snake (Diadophis punctatus)	12
Ground snake (Sonara semiannulata)	8
Black rat snake (Elaphe obsoleta)	5
Prairie kingsnake (Lampropeltis calligaster)	5
Lined snake (Tropidoclonion lineatum)	3
Rough earth snake (Virginia striatula)	1
Speckled kingsnake (Tantilla nigriceps)	1
Prairie racerunner (Cnemidophorus sexlineatus viridis)	15
Southern prairie skink (Eumeces septentrionalis)	3
Great plains skink (Eumeces obsoletus)	2
Six-lined racerunner (Cnemidophorus sexlineatus sexlineatus)	1
Amphibians	
American toad (Bufo americanus)	2
Fowler's toad (Bufo woodhousii fowleri)	1
Dwarf American toad (Bufo americanus charlesmithi)	1
Southern leopard frog (Rana utricularia)	1
Spotted chorus frog (Pseudacris clarkii)	1
Smallmouth Salamander (Ambystoma texanum)	1

Table 6. **Ground cover (%) by category for areas within 50 m at electrical substations in the WFEC in Oklahoma in 1996.**

Distance (m) from substation	Cover category	Damage Level: Level 1 (High) (N=22)	Level 2 (Low) (N=20)	Level 3 (None) (N=20)	Treatment level p-value
5	building	0.17 ± 0.2	0	0	0.392
	crop	0	0.16 ± 0.1	0.90 ± 0.9	0.512
	forb	3.94 ± 0.8	4.57 ± 0.8	4.66 ± 1.0	0.810
	grasslike	22.05 ± 2.1	20.06 ± 1.9	26.55 ± 2.7	0.179
	half-shrub	0	0	0.06 ± 0.1	0.365
	litter	25.65 ± 2.3	20.33 ± 2.2	21.62 ± 2.5	0.266
	road	17.15 ± 2.5	20.00 ± 2.9	14.63 ± 2.8	0.490
	rock	20.28 ± 1.4	22.09 ± 3.7	22.16 ± 2.3	0.922
	soil	10.14 ± 1.5	10.86 ± 1.7	7.94 ± 1.6	0.474
	vine	0.03 ± 0.0	0.52 ± 0.4	0.65 ± 0.4	0.252
	woody	0.01 ± 0.0	0.03 ± 0.0	0	0.342
20	building	0	0.19 ± 0.2	0	0.365
	crop	0.04 ± 0.0	0	0.70 ± 0.7	0.467
	forb	7.54 ± 1.4	8.06 ± 1.1	8.68 ± 1.5	0.759

	grasslike	28.20 ± 2.3	23.90 ± 1.8	35.17 ± 2.6	0.005
	half-shrub	0.27 ± 0.2	0.58 ± 0.6	0.42 ± 0.3	0.899
	litter	32.02 ± 3.0	26.32 ± 1.8	25.97 ± 2.6	0.197
	road	17.04 ± 2.2	16.21 ± 2.2	15.79 ± 2.5	0.918
	rock	1.98 ± 1.2	5.10 ± 2.7	2.37 ± 0.9	0.427
	soil	11.97 ± 2.0	17.83 ± 3.0	8.49 ± 1.9	0.030
	vine	0.11 ± 0.1	1.78 ± 1.0	1.53 ± 0.9	0.128
	woody	0.23 ± 0.2	0.29 ± 0.2	0.27 ± 0.2	0.936
50	building	0	3.64 ± 1.7	1.22 ± 1.2	0.073
	crop	3.46 ± 2.3	2.65 ± 1.7	2.09 ± 1.6	0.866
	forb	11.46 ± 2.4	10.98 ± 2.4	11.09 ± 1.5	0.923
	grasslike	28.77 ± 3.8	30.62 ± 2.6	34.07 ± 3.1	0.406
	half-shrub	0.19 ± 0.2	0.21 ± 0.2	0.75 ± 0.4	0.322
	litter	23.84 ± 2.9	26.73 ± 2.8	29.07 ± 3.1	0.449
	road	5.70 ± 2.0	5.78 ± 2.0	6.83 ± 2.2	0.839
	rock	0.07 ± 0.0	0.34 ± 0.3	0.34 ± 0.3	0.884
	soil	23.21 ± 4.6	15.35 ± 3.8	10.55 ± 2.6	0.096
	vine	0.57 ± 0.4	0.77 ± 0.5	2.68 ± 1.7	0.393
	woody	1.15 ± 0.6	1.88 ± 0.8	1.16 ± 0.6	0.656

Table 7. Microhabitat data for areas within 50 m of electrical substations in the WFEC system in Oklahoma in 1996.

Distance (m) from substation	Variable		Subclass	Damage Level (mean ± SE) Level 1(High)	Level 2 (Low)	Level 3 (None)
5	Cover pole (%)		0.0-0.5 m	62.96 ± 3.1	55.69 ± 4.3	64.86 ± 4.5
			0.5-1.0 m	9.26 ± 2.2	12.78 ± 2.7	10.83 ± 2.7
			1.0-1.5 m	0.02 ± 0.8	3.19 ± 1.3	1.25 ± 0.5
			1.5-2.0 m	0.53 ± 0.4	0.97 ± 0.5	0.42 ± 0.2
			2.0-3.0 m	0.26 ± 0.2	0.56 ± 0.6	0.28 ± 0.3
			>3.0m	0.26 ± 0.2	1.11 ± 1.1	0.28 ± 0.3
	Woody stem count	Hardwood	<5 cm	0	0.95 ± 0.5	0.25 ± 0.2
			5-10 cm	0	0.50 ± 0.4	0
			10-25 cm	0	0.20 ± 0.2	0
		Conifer	<5 cm	0.33 ± 0.3	0.15 ± 0.1	0
20	Cover pole (%)		0.0-0.5 m	71.83 ± 3.0	69.72 ± 3.7	77.36 ± 3.5
			0.5-1.0 m	12.17 ± 3.2	14.72 ± 2.8	17.50 ± 3.4

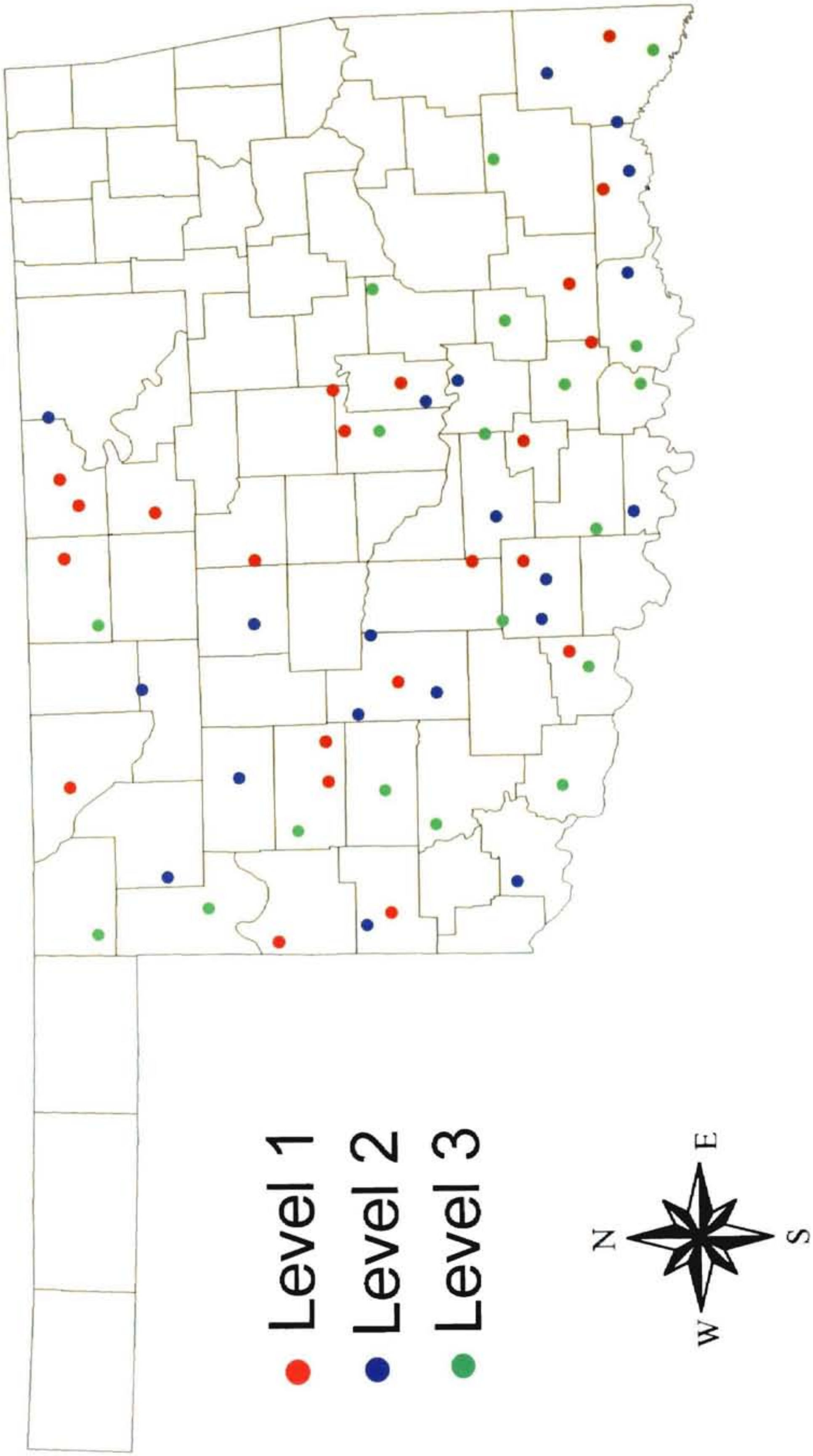
			1.0-1.5 m	1.98 ± 0.9	3.75 ± 1.3	3.89 ± 2.0
			1.5-2.0 m	0.66 ± 0.5	2.64 ± 1.1	1.81 ± 1.0
			2.0-3.0 m	0.53 ± 0.5	2.50 ± 1.2	0.83 ± 0.6
			>3.0m	0.26 ± 0.3	2.64 ± 1.3	0.69 ± 0.5
	Woody stem count	Hardwood	<5 cm	4.38 ± 2.4	5.75 ± 2.4	1.15 ± 0.7
			5-10 cm	0.05 ± 0.0	0.90 ± 0.5	0.20 ± 0.2
			10-25 cm	0	0.25 ± 0.2	0
			25-45 cm	0	0.05 ± 0.0	0
			>45 cm	0	0.05 ± 0.0	0
		Conifer	<5 cm	0.29 ± 0.2	0.15 ± 0.2	0.10 ± 0.1
			10-25 cm	0	0.30 ± 0.3	0
50	Cover pole (%)		0.0-0.5 m	82.01 ± 3.9	80.97 ± 3.3	83.61 ± 3.2
			0.5-1.0 m	23.54 ± 4.6	27.92 ± 4.0	23.19 ± 4.2
			1.0-1.5 m	10.98 ± 2.8	10.00 ± 2.5	8.47 ± 3.3
			1.5-2.0 m	7.14 ± 2.3	6.25 ± 2.1	7.78 ± 3.0

		2.0-3.0 m	5.56 ± 2.3	5.97 ± 2.1	6.25 ± 2.1
		>3.0m	5.82 ± 2.5	5.83 ± 2.2	6.81 ± 2.1
Woody stem count	Hardwood	<5 cm	10.86 ± 3.4	17.85 ± 6.3	11.75 ± 4.4
		5-10 cm	0.52 ± 0.3	1.50 ± 0.6	1.85 ± 0.8
		10-25 cm	0.81 ± 0.4	0.40 ± 0.2	0.95 ± 0.5
		25-45 cm	0.29 ± 0.2	0.50 ± 0.3	0.50 ± 0.0
		>45 cm	0	0	0.05 ± 0.0
	Conifer	<5 cm	0.29 ± 0.2	1.20 ± 1.1	0
		5-10 cm	0.28 ± 0.2	0.85 ± 0.6	0.15 ± 0.2
		10-25 cm	0.43 ± 0.4	0.15 ± 0.2	0.05 ± 0.0
		25-45 cm	0	0.10 ± 0.1	0
		>45 cm	0	0	0

Table 8. Landscape indices derived from aerial photo interpretation of 2.25-km^2 area surrounding electrical substations in the WFEC system in Oklahoma.

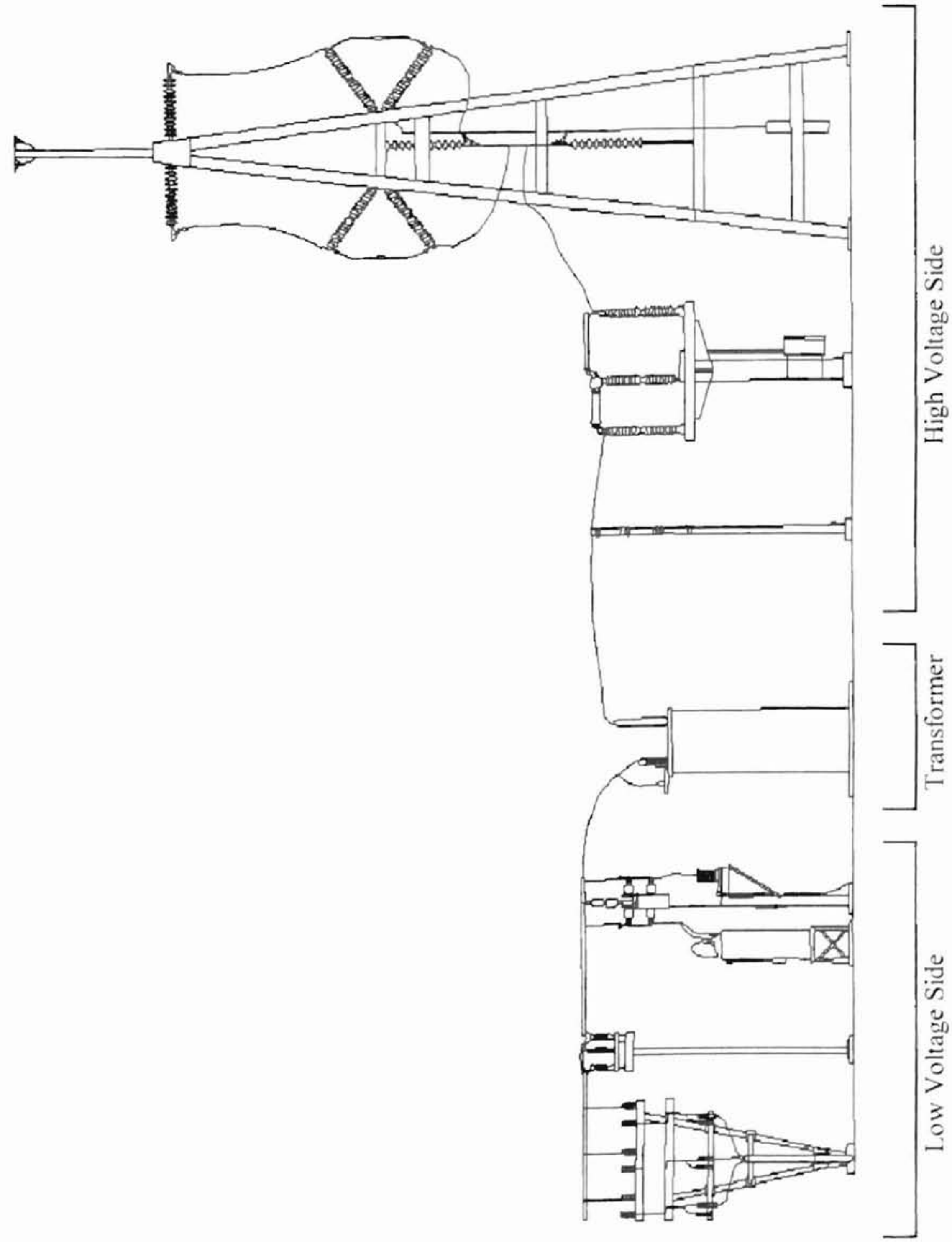
Landscape	Damage level			Results	
metric	Level 1 (High)	Level 2 (Low)	Level 3 (None)	F-test	*P*-value
Patches (*n*)	108.68 ± 10.3	49.05 ± 4.2	45.60 ± 3.6	26.07	<0.001
Patch density (*n*/100 ha)	46.73 ± 4.4	21.09 ± 1.8	19.63 ± 1.6	26.06	<0.001
Mean patch size (ha)	2.48 ± 0.2	5.40 ± 0.4	5.68 ± 0.4	25.31	<0.001
Patch size std dev	6.48 ± 0.5	11.63 ± 0.8	11.72 ± 0.7	22.56	<0.001
Total edge (m)	30,942 ± 2113	21,096 ± 1402	19,246 ± 831	16.14	<0.001
Edge density (m/ha)	133.05 ± 9.1	90.71 ± 6.0	82.85 ± 3.5	16.13	<0.001
Landscape index	6.07 ± 0.3	4.46 ± 0.2	4.16 ± 0.1	16.13	<0.001
Shannon's diversity index	3.05 ± 0.1	2.4 ± 0.1	2.41 ± 0.1	21.14	<0.001
Simpson's diversity index	0.91 ± 0.0	0.88 ± 0.0	0.86 ± 0.0	10.20	<0.001
Shannon's evenness index	0.69 ± 0.0	0.66 ± 0.0	0.68 ± 0.0	0.46	0.633
Simpson's evenness index	0.93 ± 0.0	0.88 ± 0.0	0.89 ± 0.0	5.92	0.005
Contagion (%)	58.62 ± 0.9	60.37 ± 1.0	60.24 ± 1.0	1.07	0.349

Figure 1. Substations selected from the WFEC population for sampling. Level 1 => 0.3 incidents/yr.; level 2 = 0.1-0.2 incidents/yr.; level 3 = 0 incidents/yr.



Level 1
Level 2
Level 3
N
E
S
W

Figure 2. Low-profile designed electrical substation in the WFEC system in Oklahoma.



High Voltage Side
Transformer
Low Voltage Side

Figure 3. Layout for small-scale habitat sampling within 50 m of each substation, consisting of 12, 5-m radius circular plots.

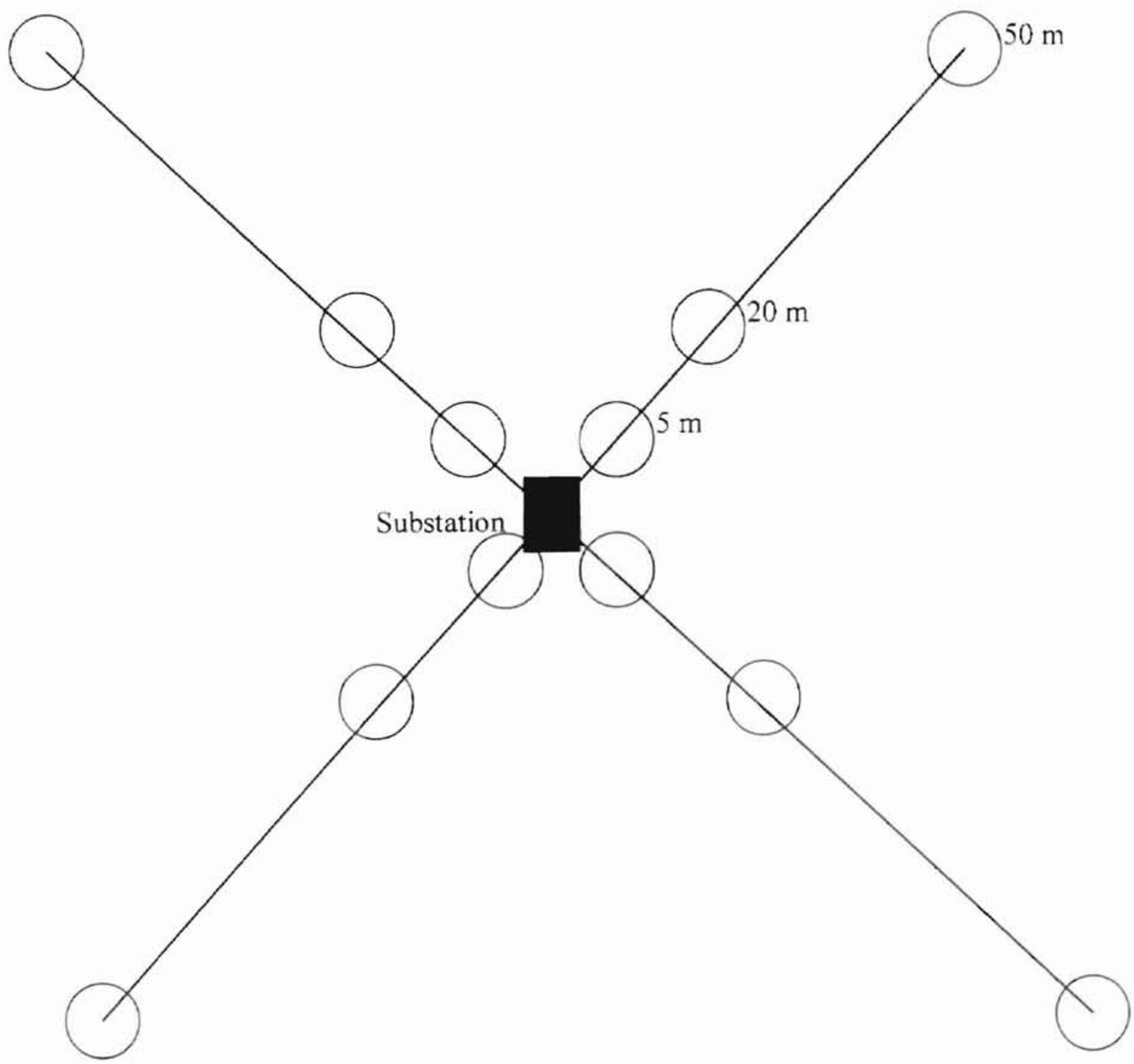

50 m
20 m
5 m
Substation

Figure 4. Design of plot layout for vegetation sampling around each substation. Circular plots were centered 5, 20, or 50 m from each substation. Point A represents the center of the circular plot located at a random direction from the center of the substation. Points labeled B represent locations from 0.5-m^2 sampling frames and cover pole readings on the periphery of the circular plot. Points labeled C represent locations for cover pole readings only.

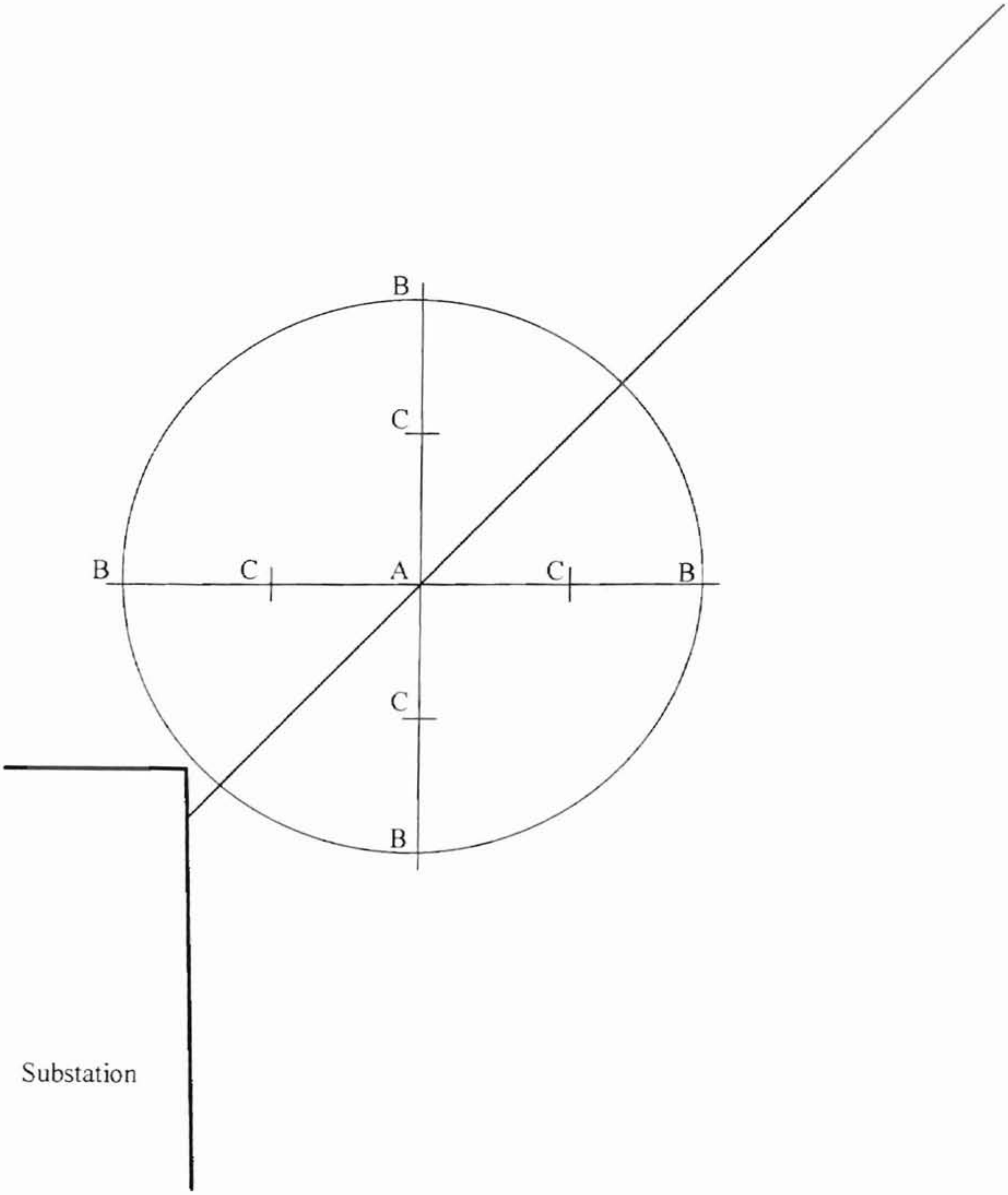

B
C
B
C
A
C
B
C
B
Substation

Figure 5. Frequency of wildlife-related power outages (by year) in the WFEC system in Oklahoma from 1987 to 1995.

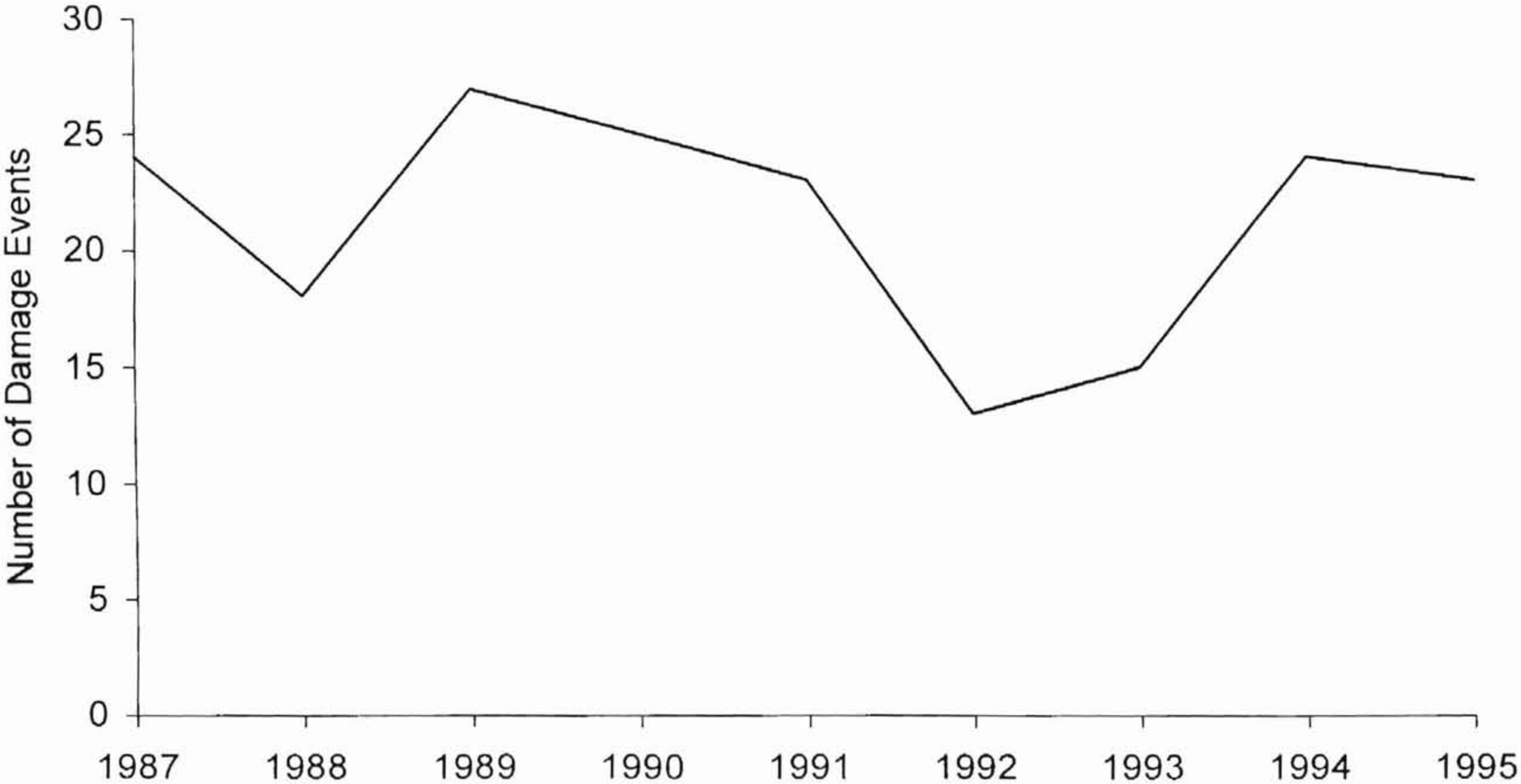

Number of Damage Events
0
5
10
15
20
25
30
1987
1988
1989
1990
1991
1992
1993
1994
1995

Figure 6. Distribution of substations that received 0 to 7 wildlife-related outages in Oklahoma from 1987 to 1995.

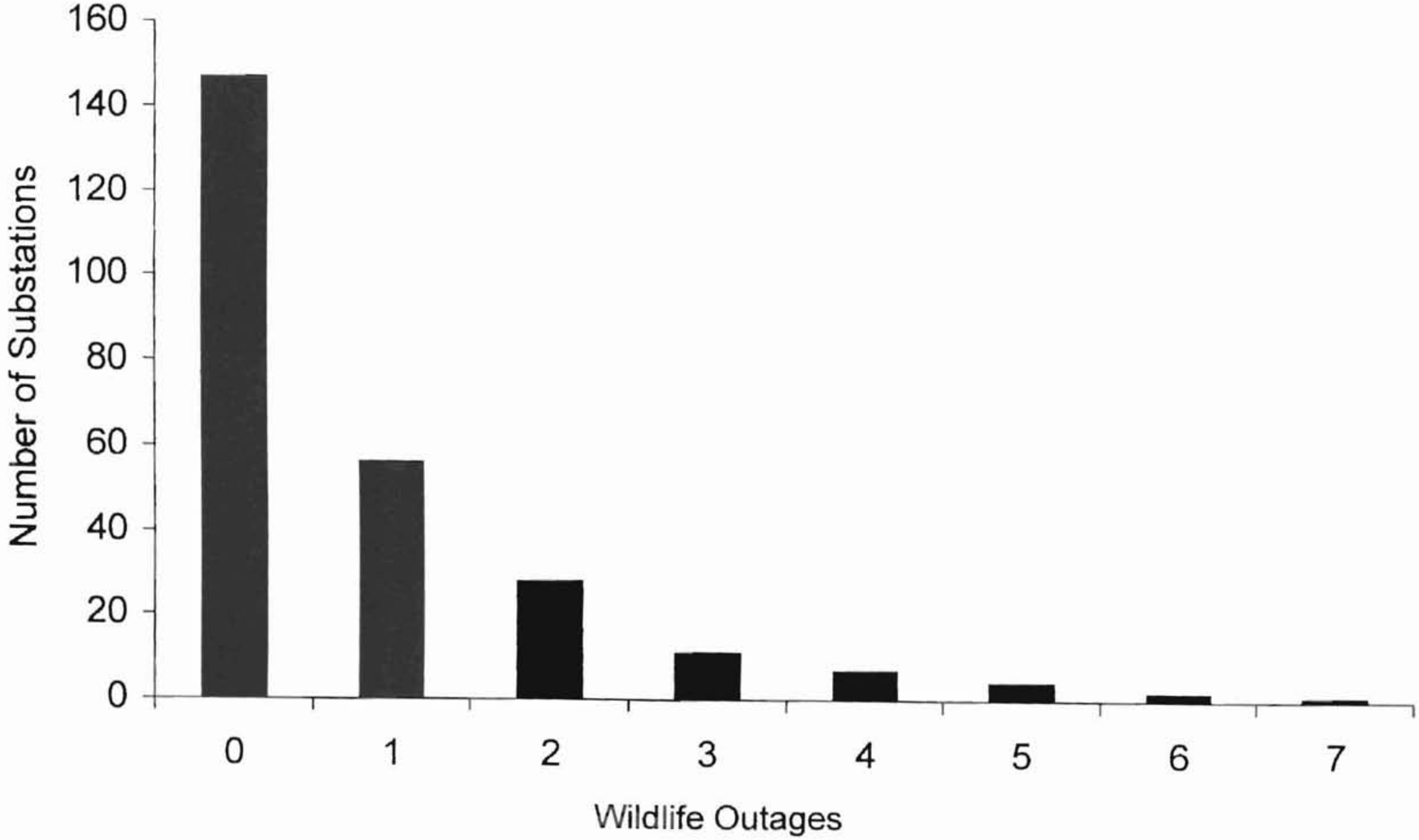
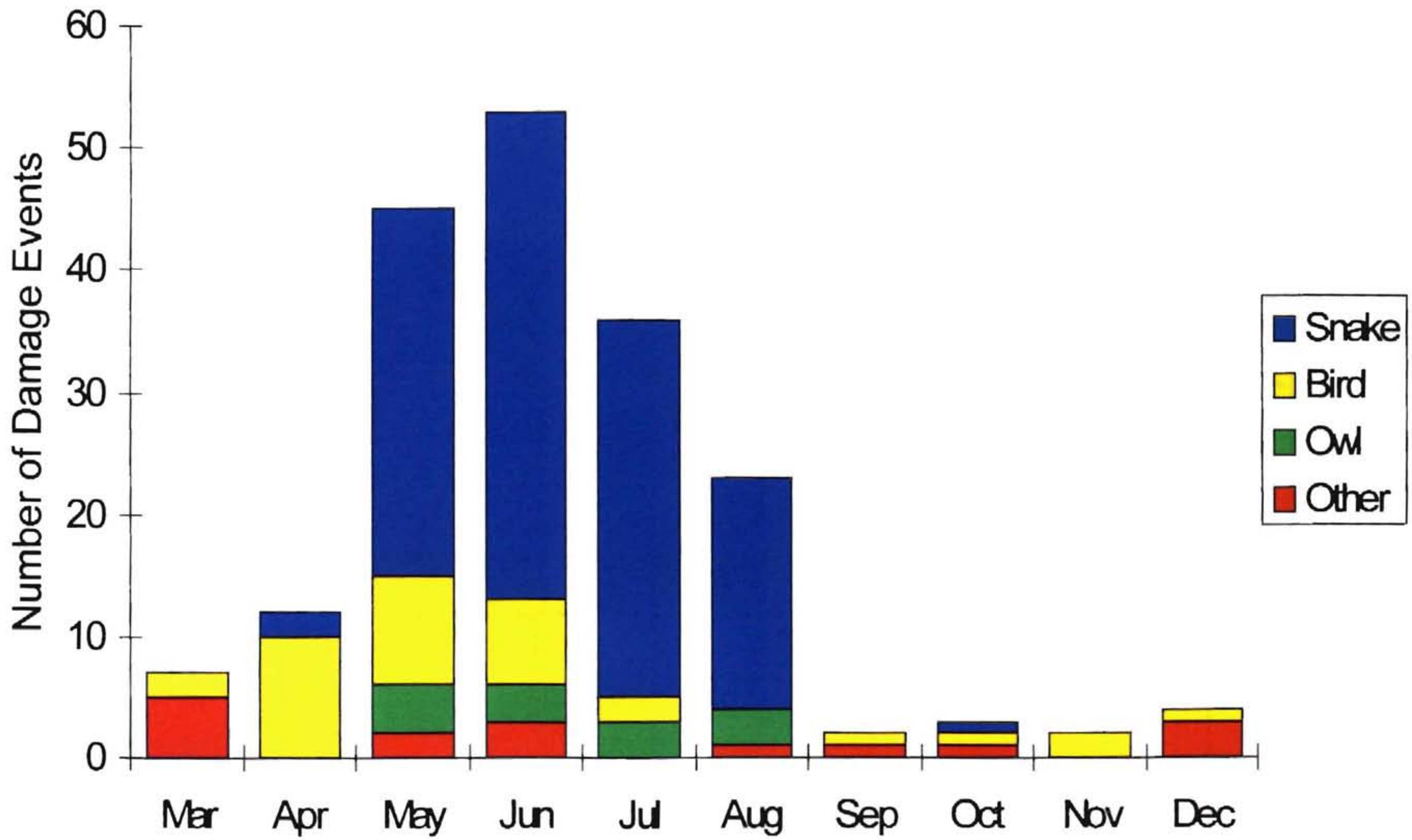

160
140
120
100
80
60
40
20
0
Number of Substations
0
1
2
3
4
5
6
7
Wildlife Outages

Figure 7. Number of wildlife-related outages (by month and animal type) in the WFEC system in Oklahoma from 1987 to 1995.


Number of Damage Events
0
10
20
30
40
50
60
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Snake
Bird
Owl
Other

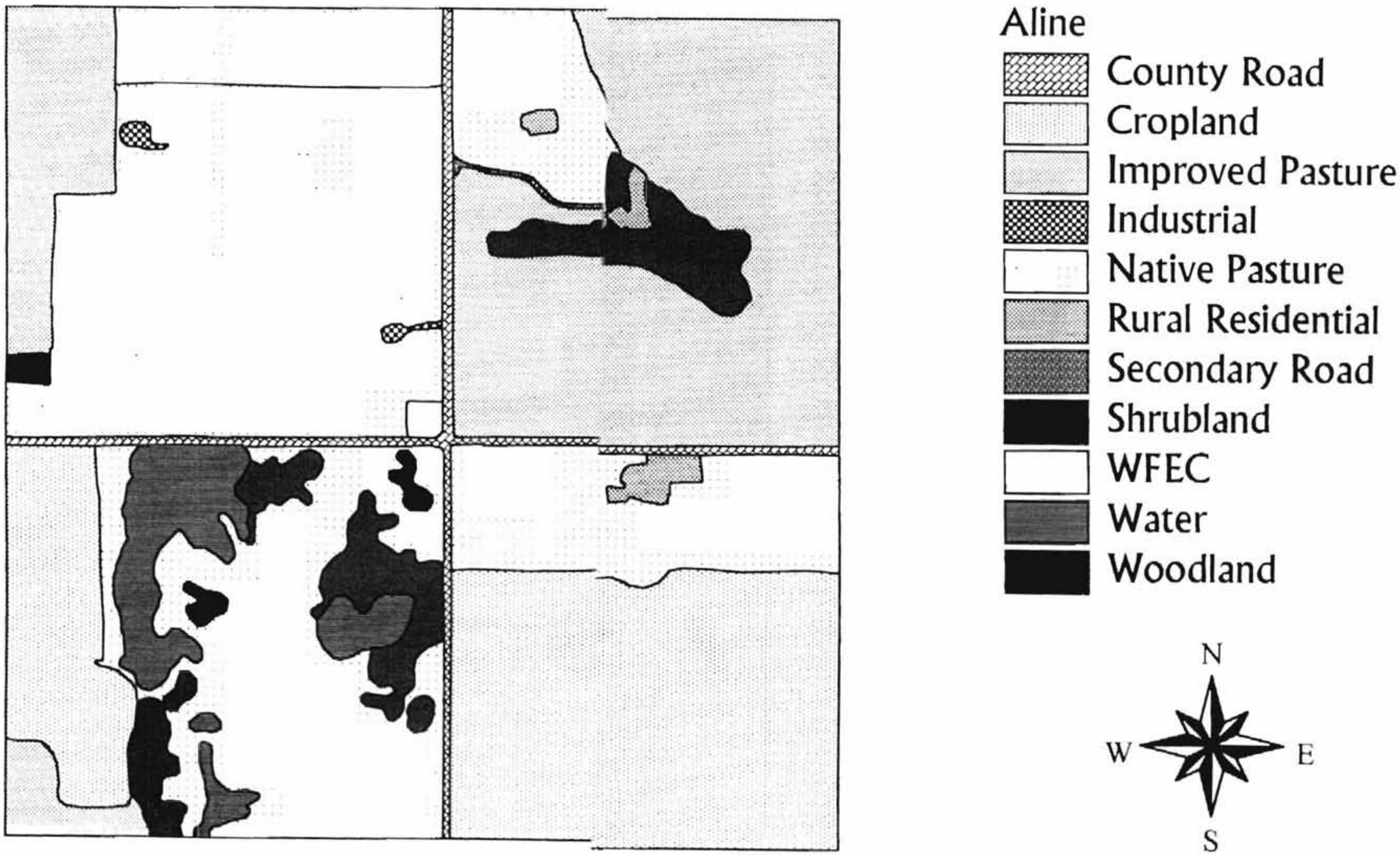
APPENDIX A.

Classified habitat maps of the 62 selected substation sites. Maps are 1.5 km on a side.

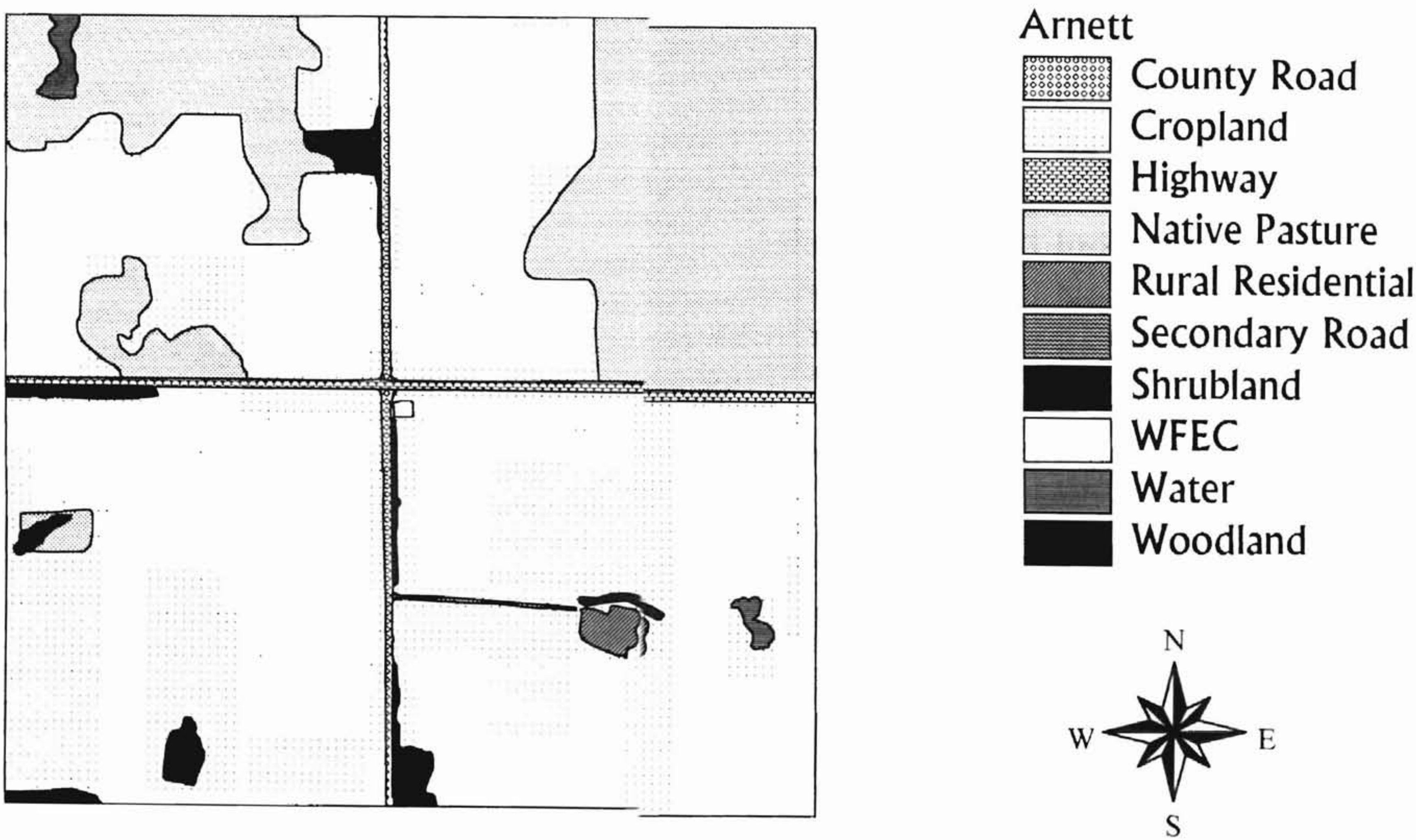
Name of Substation	Number of Outages (1987-1996)	Damage Level	Page
ALINE	1	2	66
ARNETT	0	3	67
BEAVER RIVER	1	2	68
BENNINGTON	1	2	69
BETHEL	0	3	70
BLACKWELL	4	1	71
BRADLEY	7	1	72
BUTLER	0	3	73
CLINTON	5	1	74
COALGATE	0	3	75
COGAR	1	2	76
CORDELL	1	3	77
DURHAM	3	1	78
DUSTIN	0	3	79
ELMORE CITY	2	2	80
EMPIRE	1	2	81
ERICK	6	1	82
ESSAQUANDALE	0	3	83
FARGO	2	2	84
FRANCIS	1	2	85
FREDERICK	0	3	86
FREEDOM	5	1	87
FROGVILLE	1	2	88
FT SUPPLY	0	3	89
GYPSUM	2	2	90
HARRISBURG	2	2	91
HAWORTH	0	3	92
HAZEL	1	2	93
HEALDTON	0	3	94

HYDRO	1	2	95
INGRAM	0	3	96
KIERSEY	0	3	97
KINGFISHER	1	2	98
LANE	4	1	99
LONE WOLF	0	3	100
MARLOW	2	3	101
MT RIVER	3	1	102
NASH	0	3	103
NEWKIRK	3	1	104
NUMA	3	1	105
OAKLAWN	4	1	106
ONEY	3	1	107
OWENS PRAIRIE	7	1	108
PERRY	4	1	109
PINE RIDGE	1	2	110
PRAGUE	3	1	111
REAGAN	0	3	112
S COLEMAN	4	1	113
S TALOGA	1	2	114
S WILSON	1	2	115
SARDIS	0	3	116
STRATFORD	0	3	117
SWEETWATER	1	2	118
TEXOMA	0	3	119
TWIN LAKES	5	1	120
UNITED CLAY	6	1	121
VALLIANT	1	2	122
W RED HILL	3	1	123
WALTERS	3	1	124
WEATHERFORD	3	1	125
WEBB CITY	1	2	126
WESTBANK	3	1	127

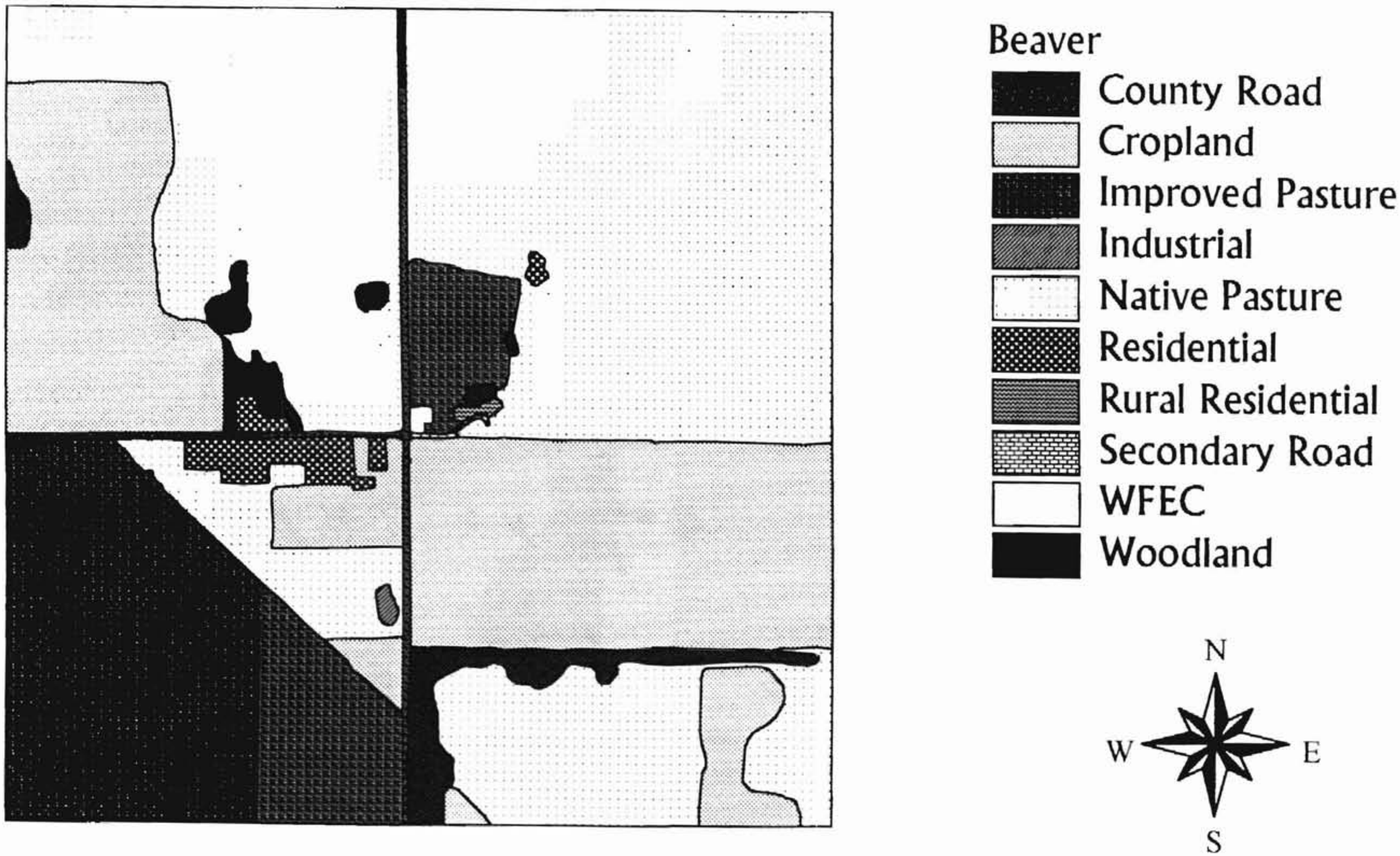
Aline


Aline
County Road
Cropland
Improved Pasture
Industrial
Native Pasture
Rural Residential
Secondary Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

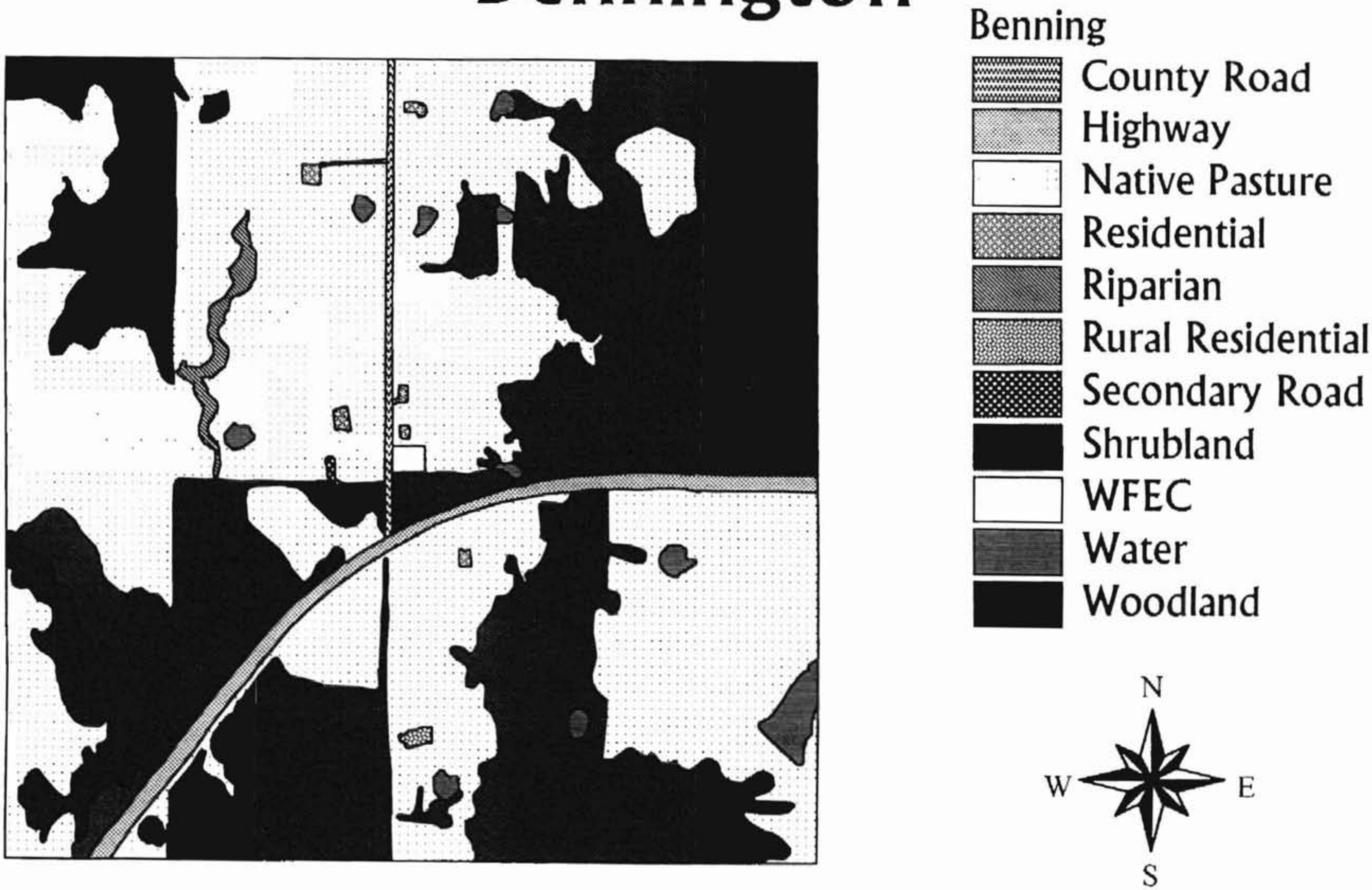
Arnett


Arnett
County Road
Cropland
Highway
Native Pasture
Rural Residential
Secondary Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

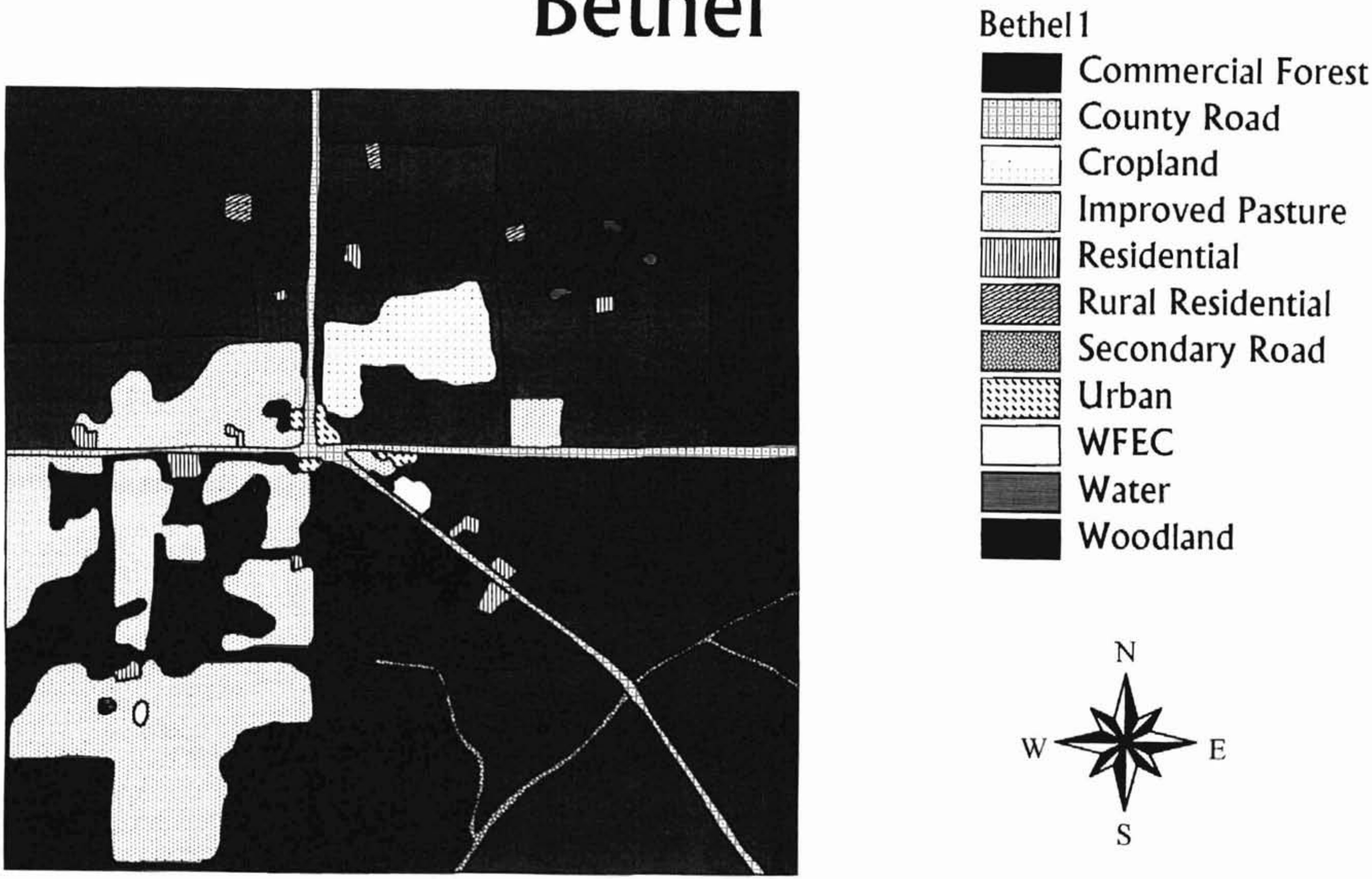
Beaver River



Bennington

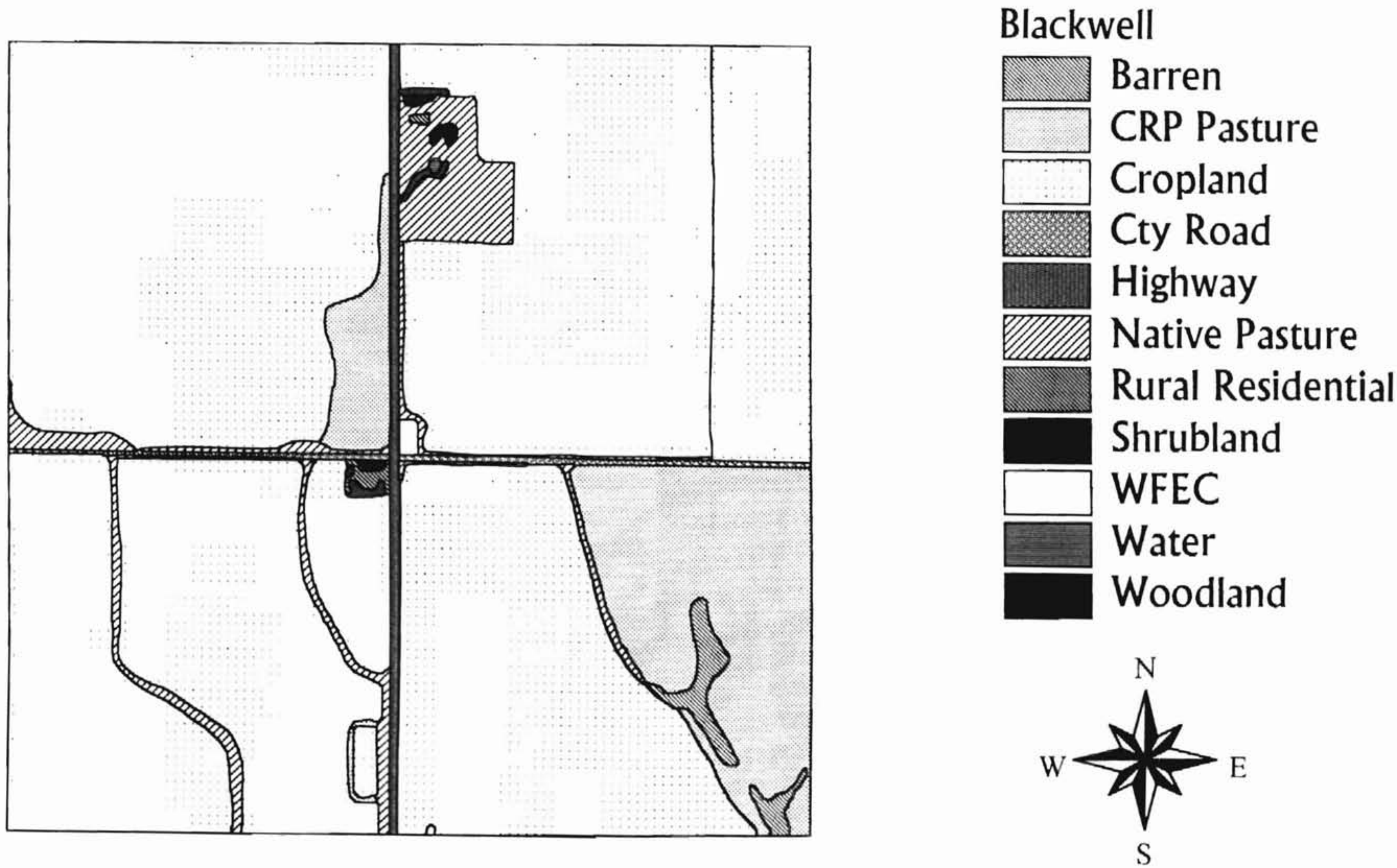

Benning
County Road
Highway
Native Pasture
Residential
Riparian
Rural Residential
Secondary Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

Bethel

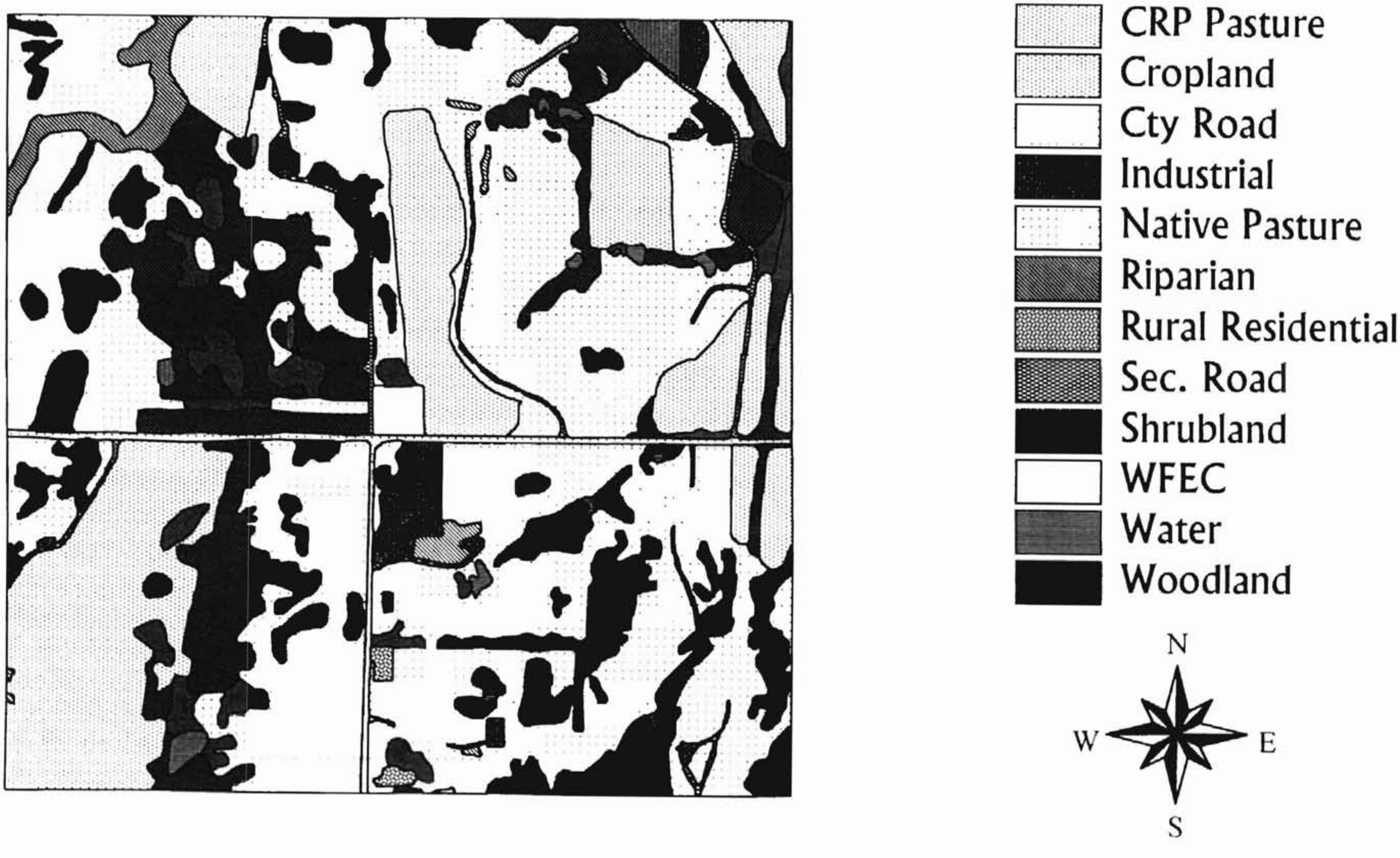


Bethel1
Commercial Forest
County Road
Cropland
Improved Pasture
Residential
Rural Residential
Secondary Road
Urban
WFEC
Water
Woodland
N
W
E
S

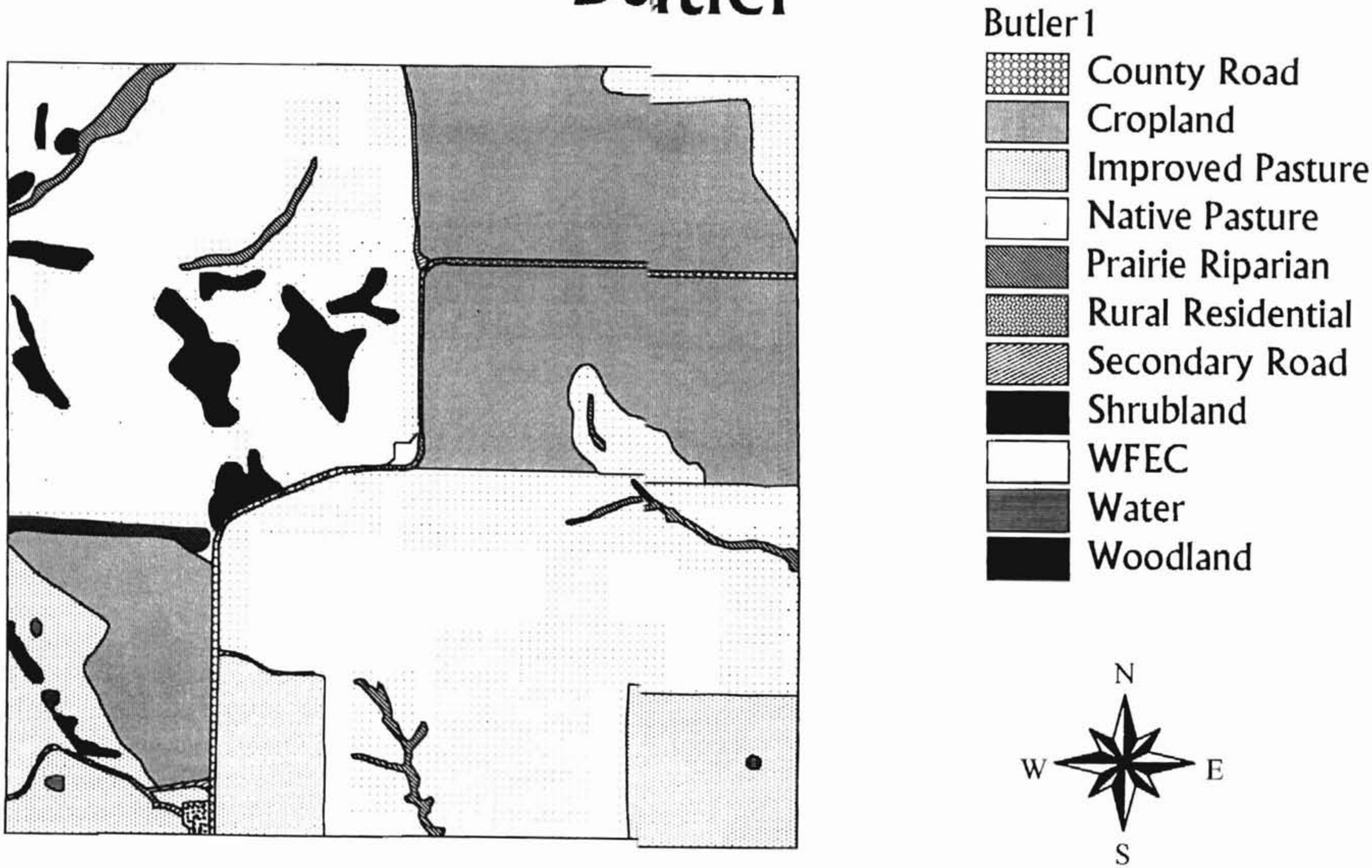
Blackwell


Blackwell
Barren
CRP Pasture
Cropland
Cty Road
Highway
Native Pasture
Rural Residential
Shrubland
WFEC
Water
Woodland
N
W
E
S

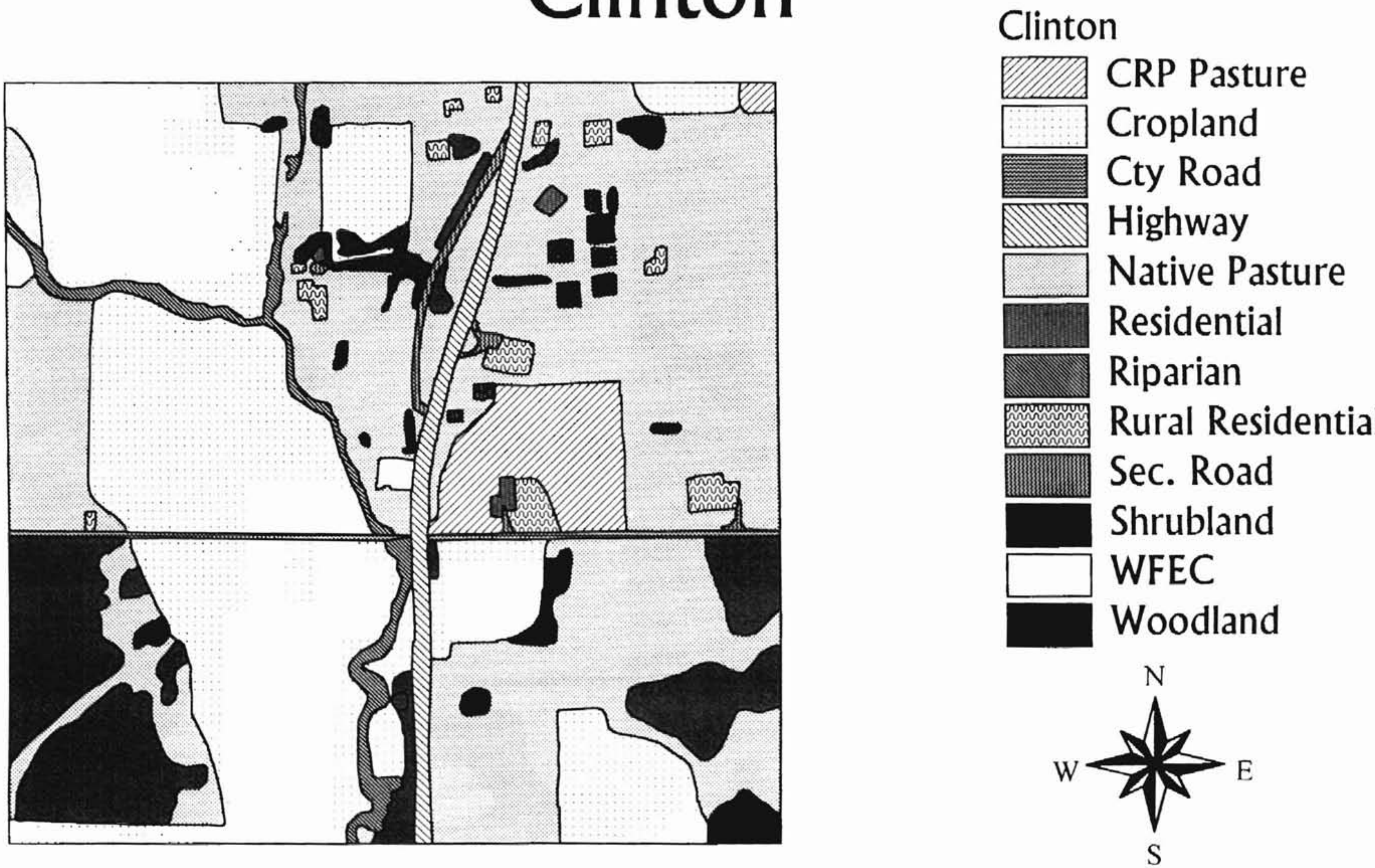
Bradley


Bradley
Barren
CRP Pasture
Cropland
Cty Road
Industrial
Native Pasture
Riparian
Rural Residential
Sec. Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

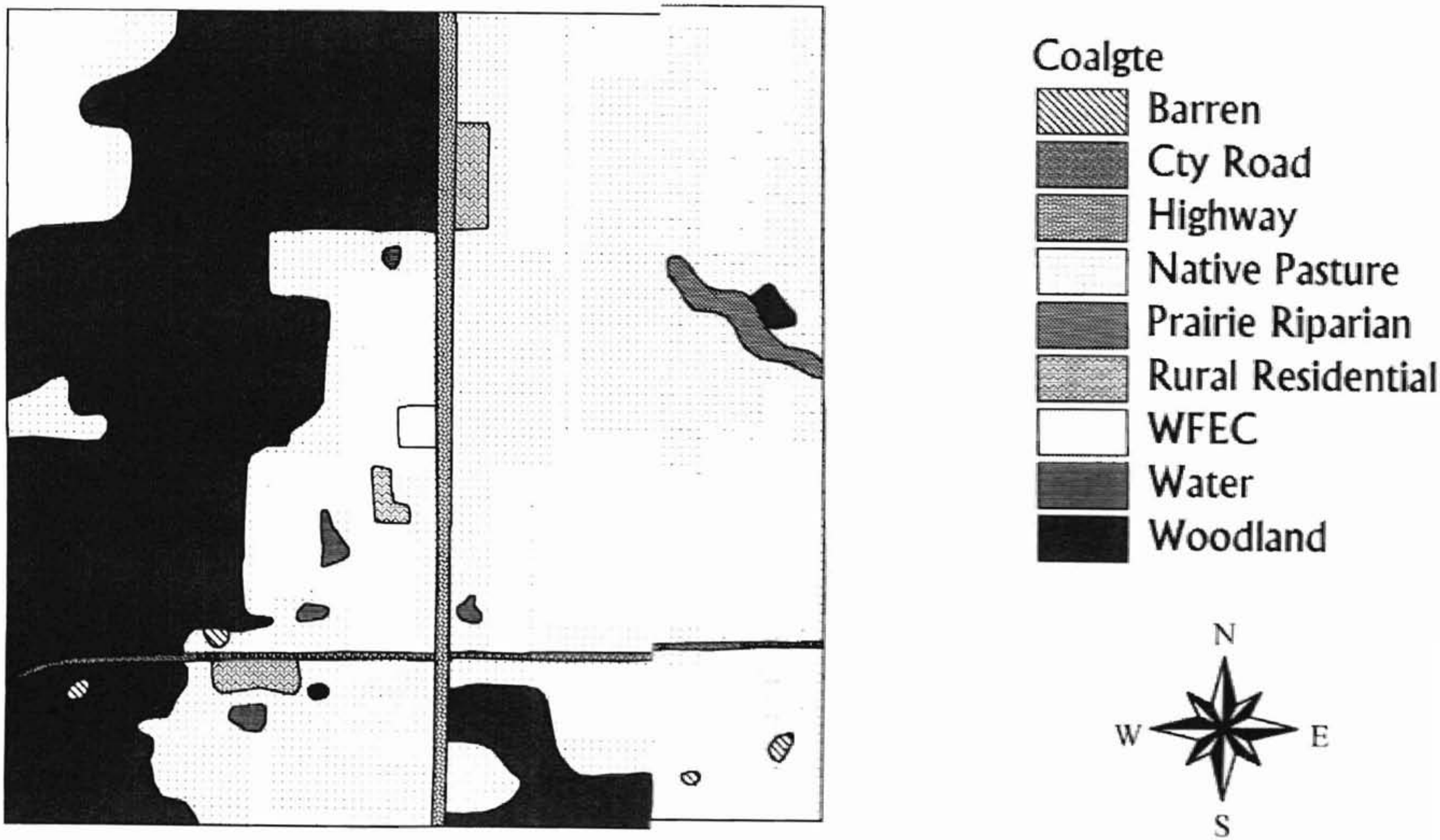
Butler


Butler1
County Road
Cropland
Improved Pasture
Native Pasture
Prairie Riparian
Rural Residential
Secondary Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

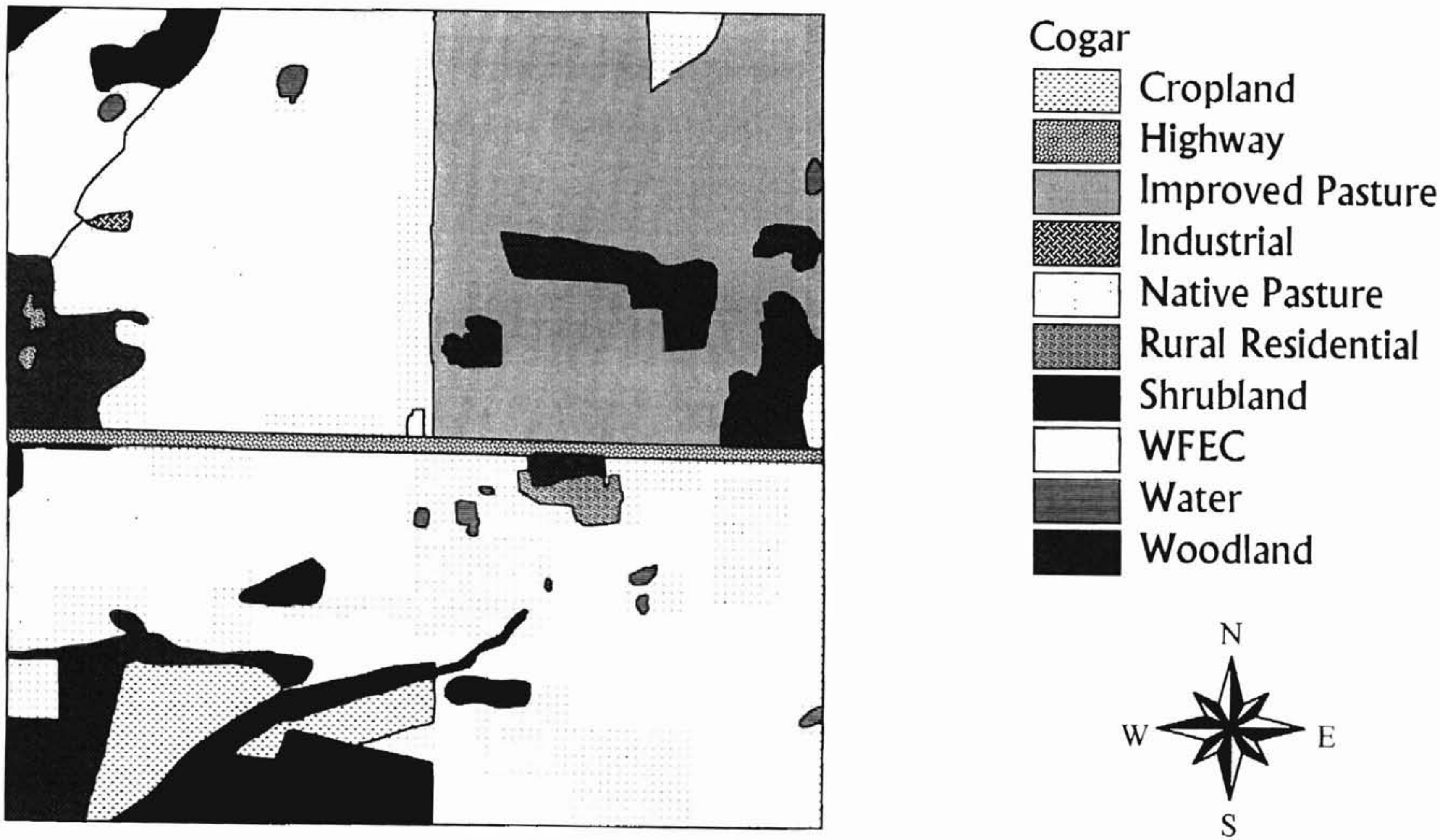
Clinton


Clinton
CRP Pasture
Cropland
Cty Road
Highway
Native Pasture
Residential
Riparian
Rural Residential
Sec. Road
Shrubland
WFEC
Woodland
N
W
E
S

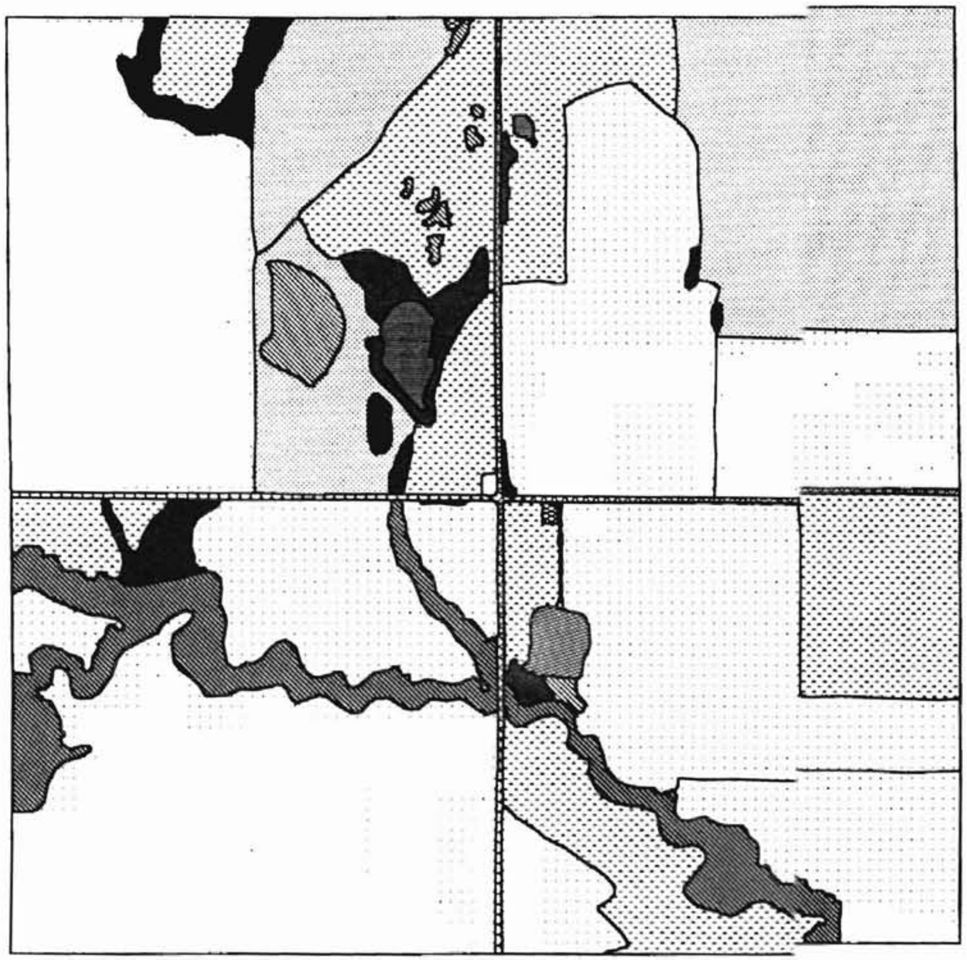
Coalgate

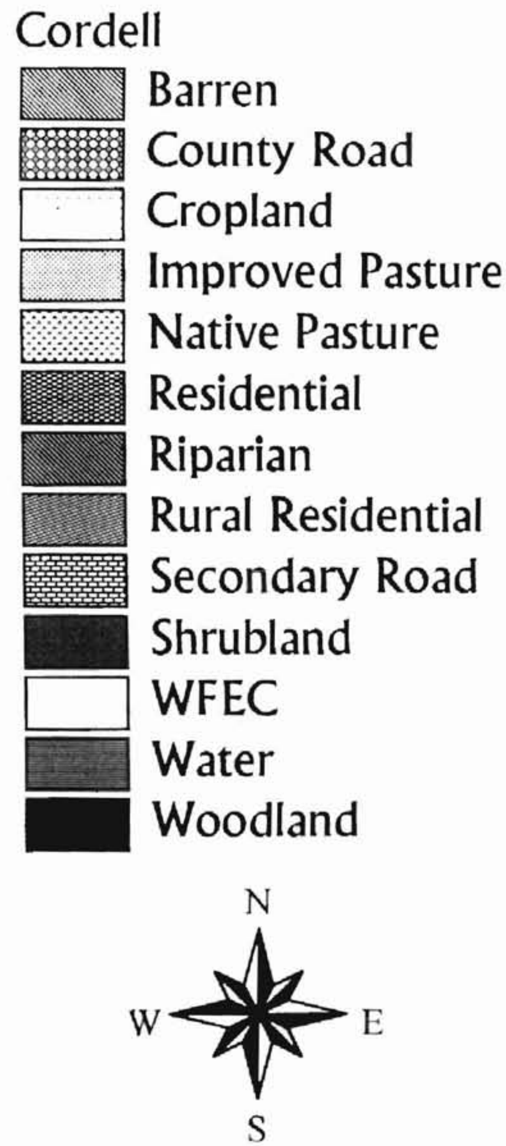

Coalgte
Barren
Cty Road
Highway
Native Pasture
Prairie Riparian
Rural Residential
WFEC
Water
Woodland
N
W
E
S

Cogar

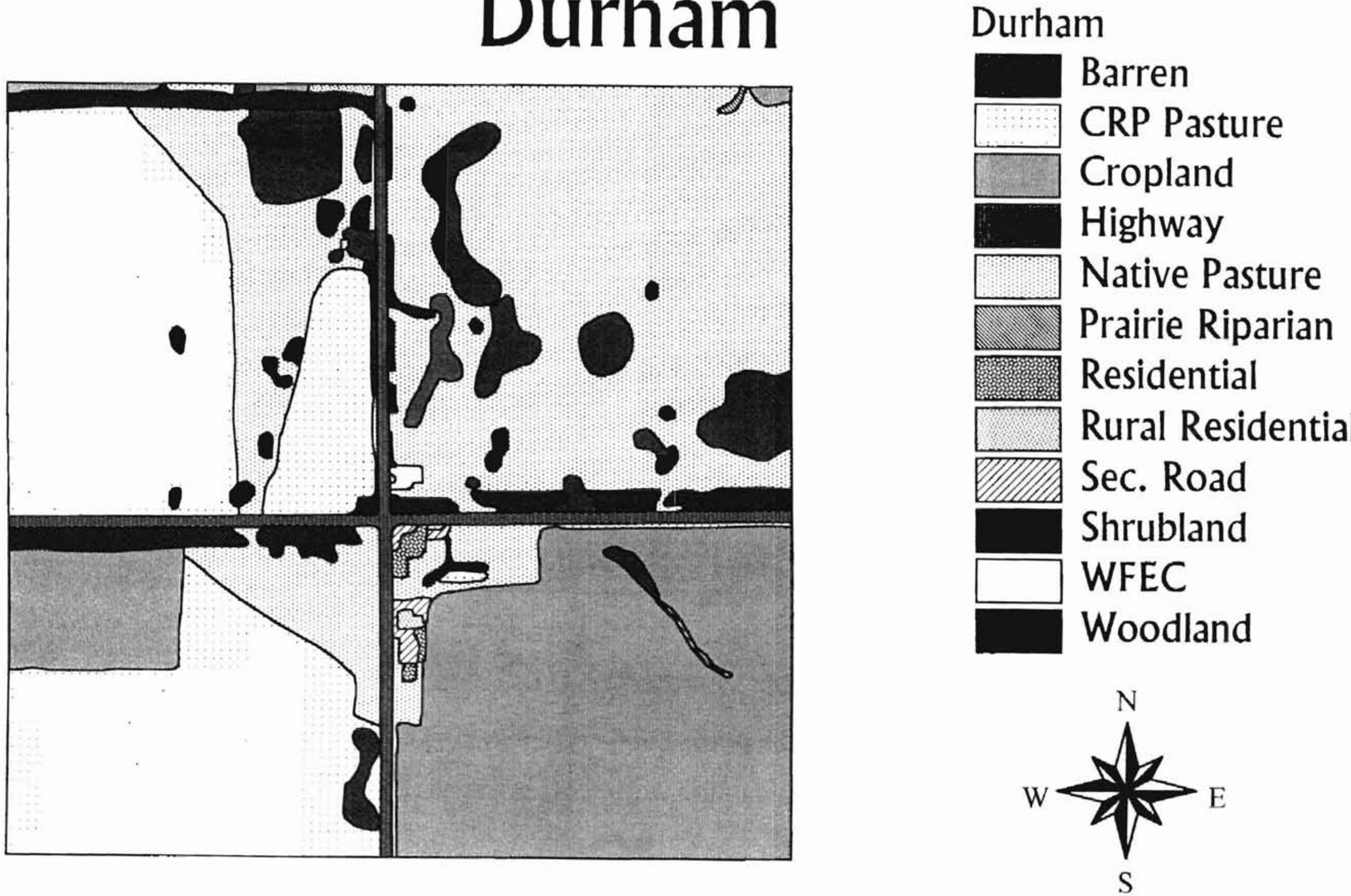

Cogar
Cropland
Highway
Improved Pasture
Industrial
Native Pasture
Rural Residential
Shrubland
WFEC
Water
Woodland
N
W
E
S

Cordell

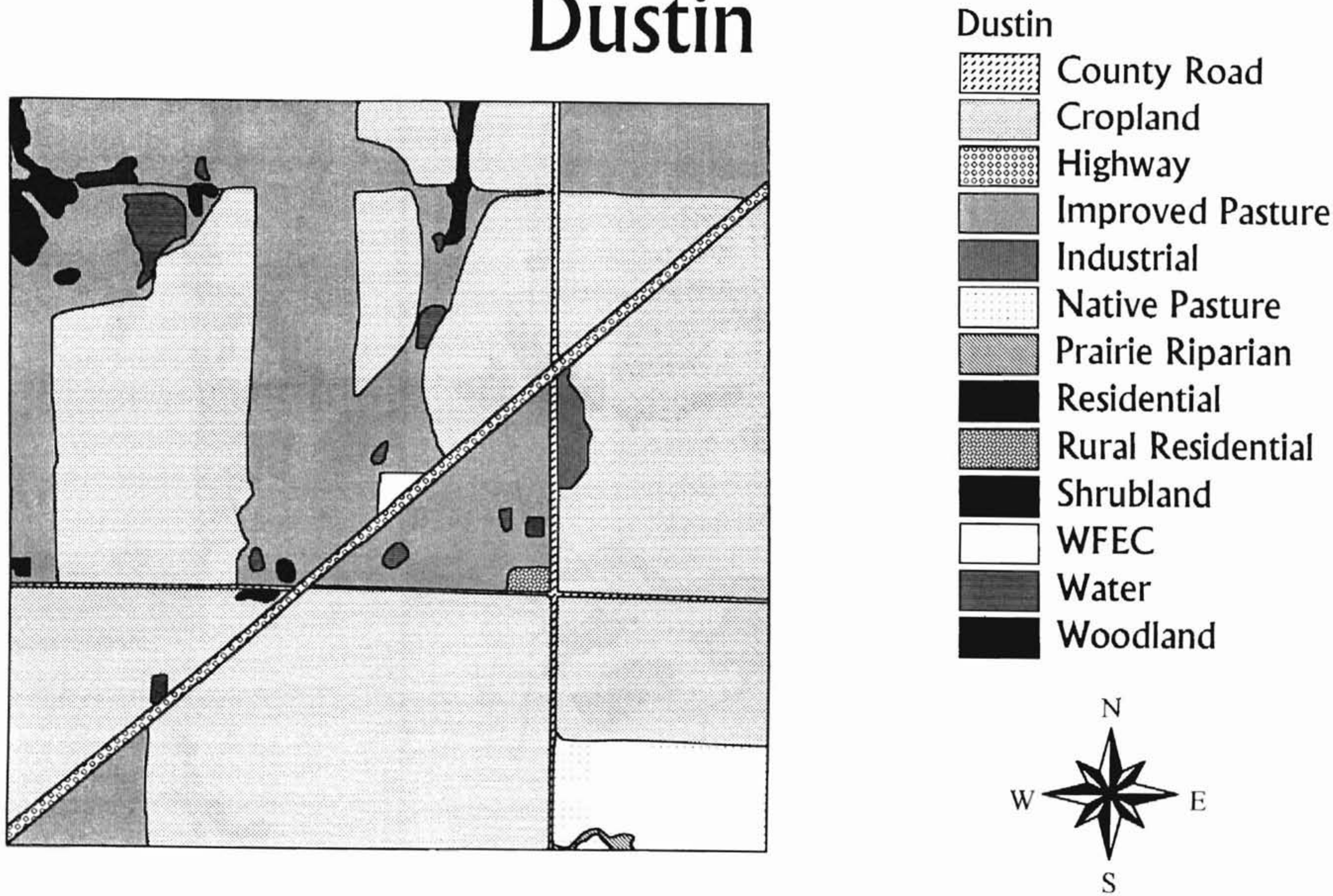



Cordell
Barren
County Road
Cropland
Improved Pasture
Native Pasture
Residential
Riparian
Rural Residential
Secondary Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

Durham


Durham
Barren
CRP Pasture
Cropland
Highway
Native Pasture
Prairie Riparian
Residential
Rural Residential
Sec. Road
Shrubland
WFEC
Woodland
N
W
E
S

Dustin


Dustin
County Road
Cropland
Highway
Improved Pasture
Industrial
Native Pasture
Prairie Riparian
Residential
Rural Residential
Shrubland
WFEC
Water
Woodland
N
W
E
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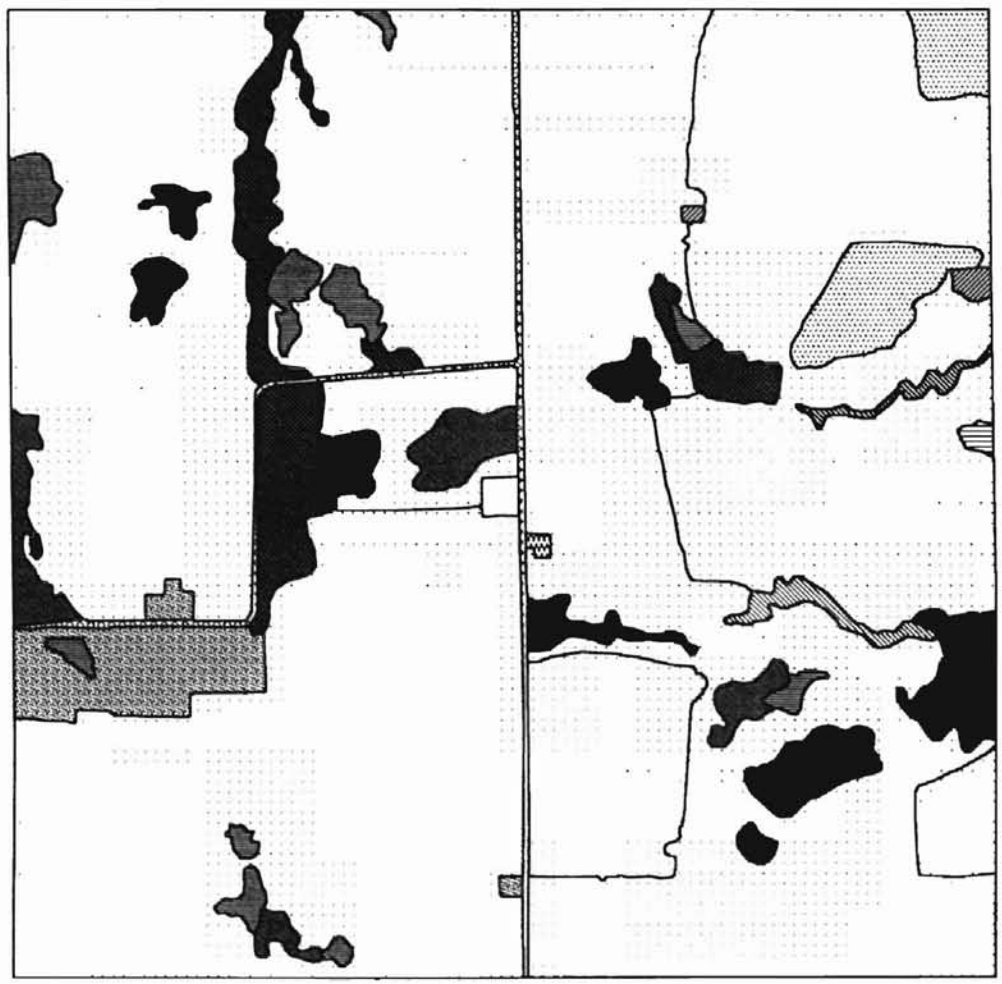
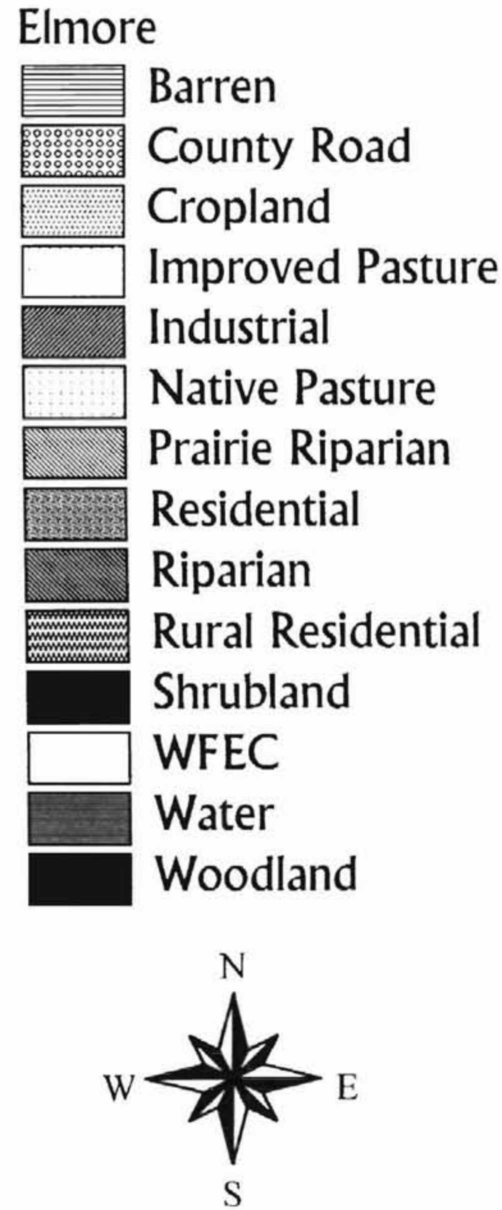
Elmore City

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Industrial
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Residential
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Rural Residential
Shrubland
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Woodland
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W
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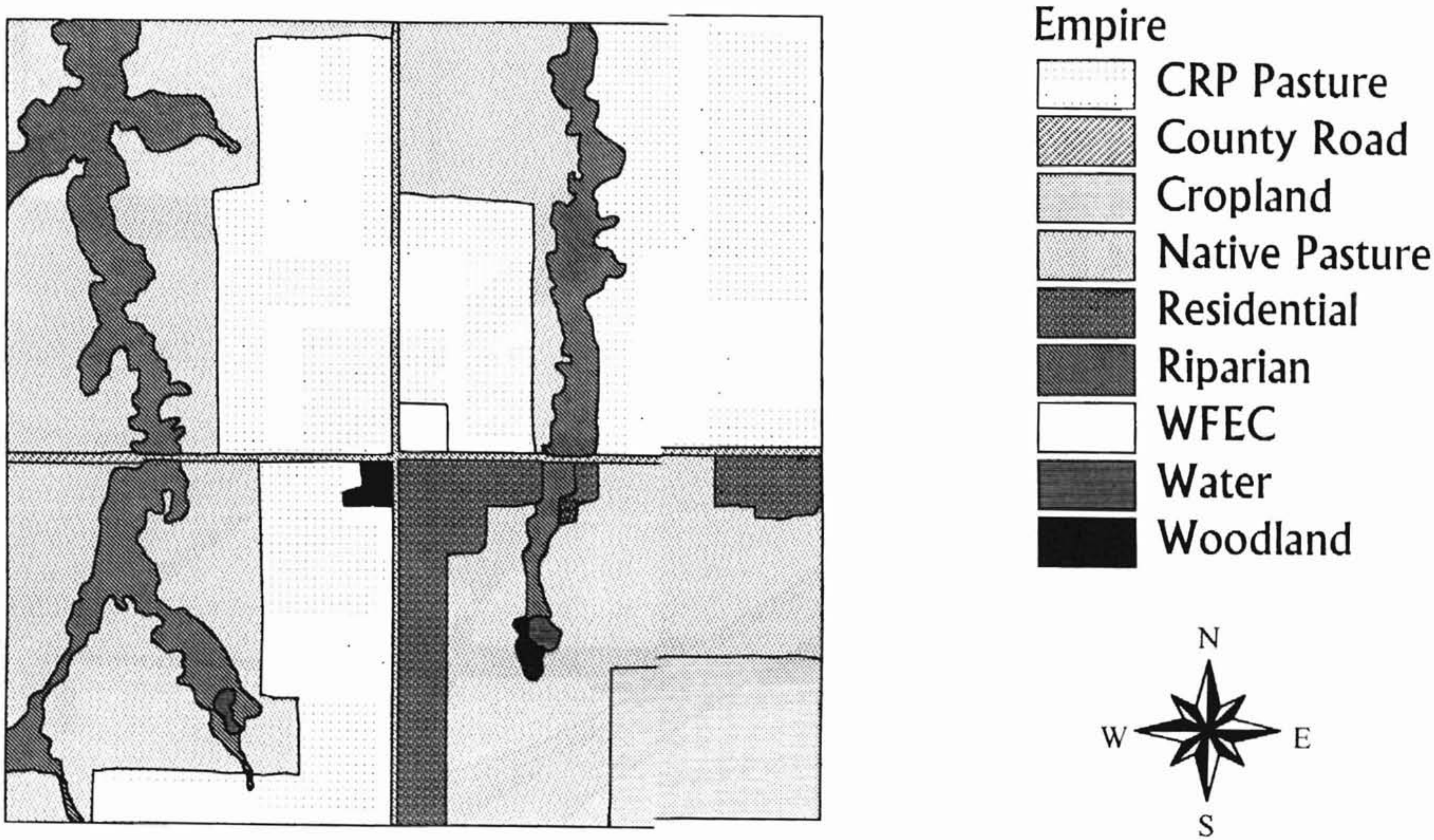
S

Empire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Residential
Riparian
WFEC
Water
Woodland
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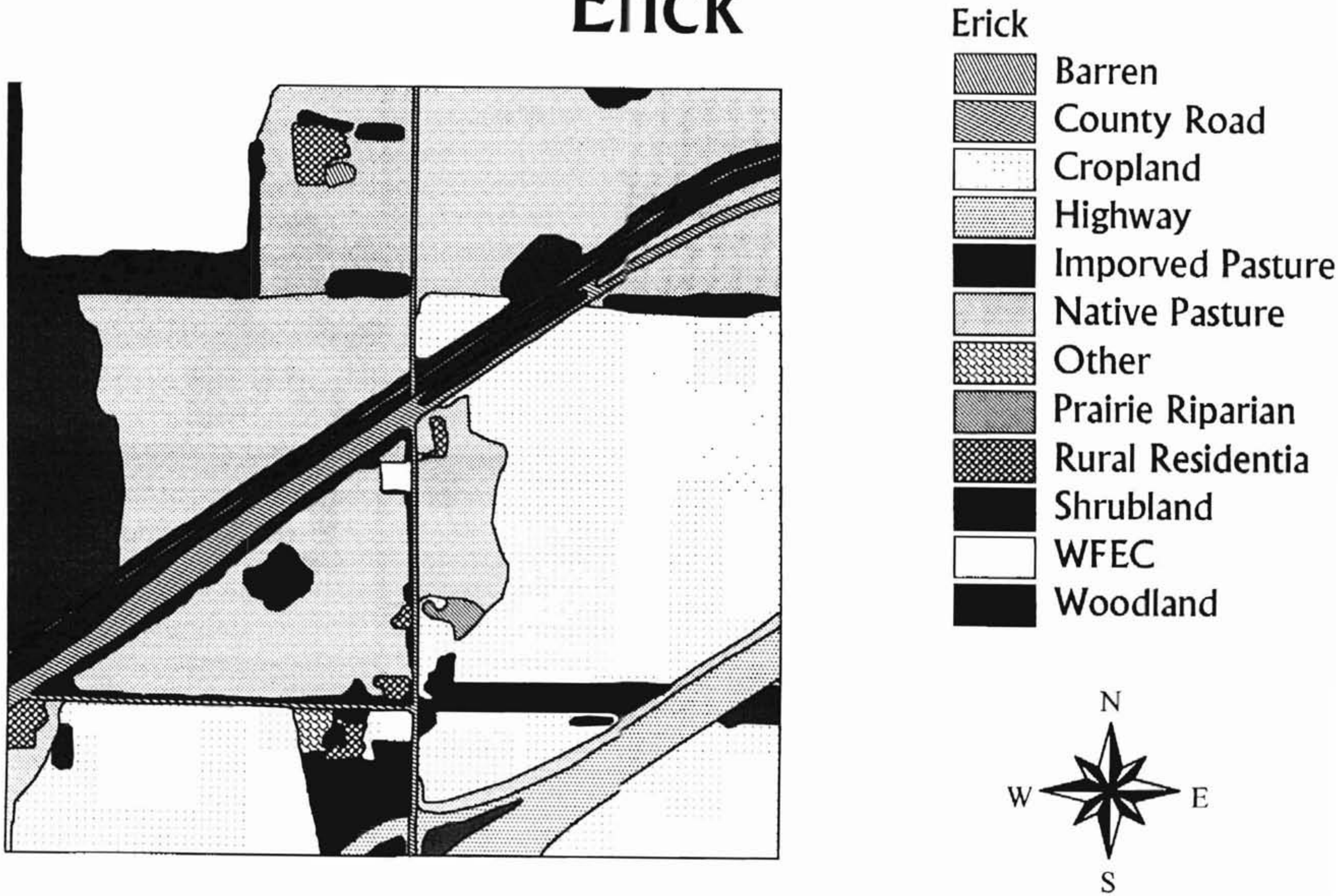
E
S

Erick


Erick
Barren
County Road
Cropland
Highway
Imporved Pasture
Native Pasture
Other
Prairie Riparian
Rural Residentia
Shrubland
WFEC
Woodland
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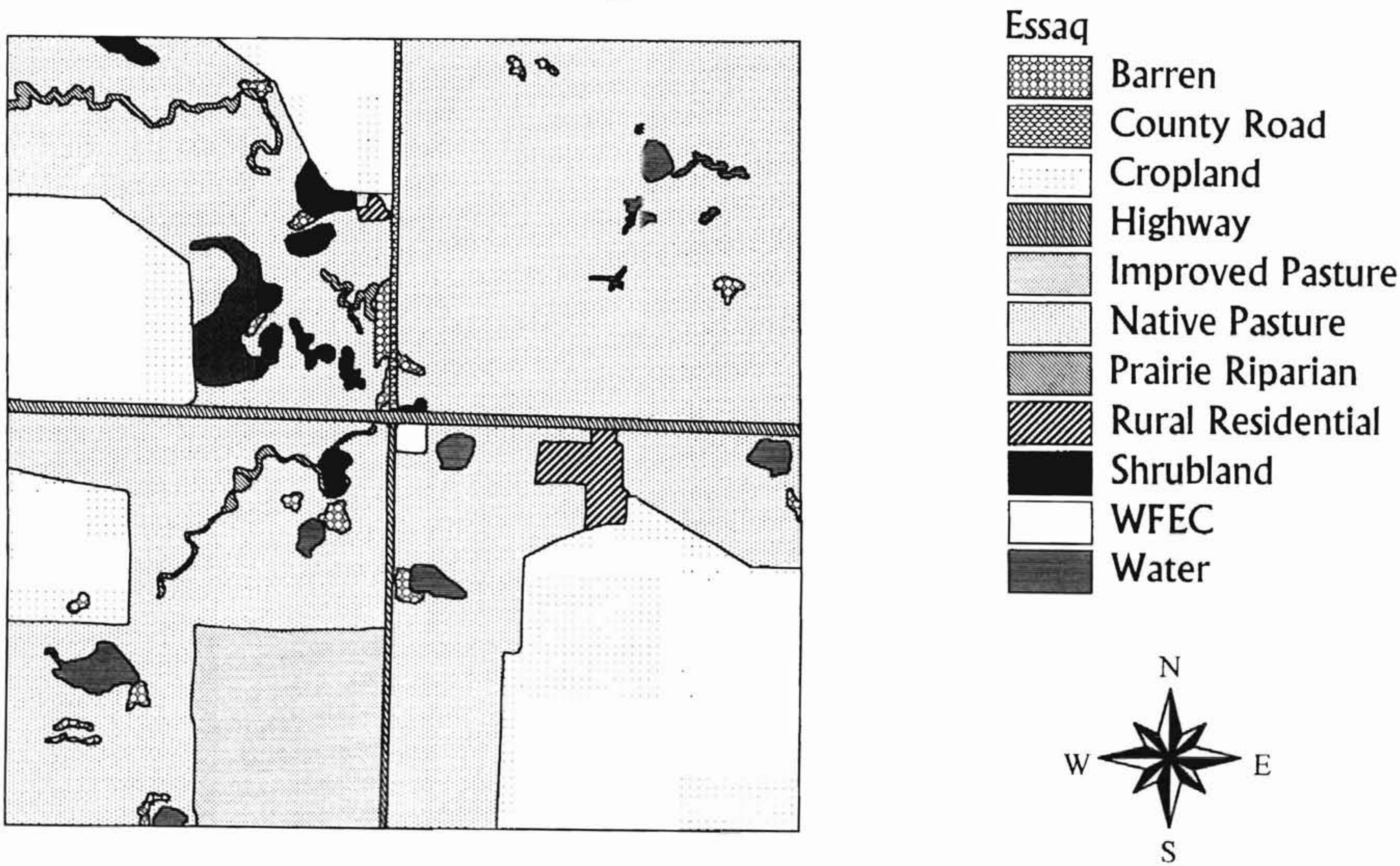
W
E
S

Essaquandale



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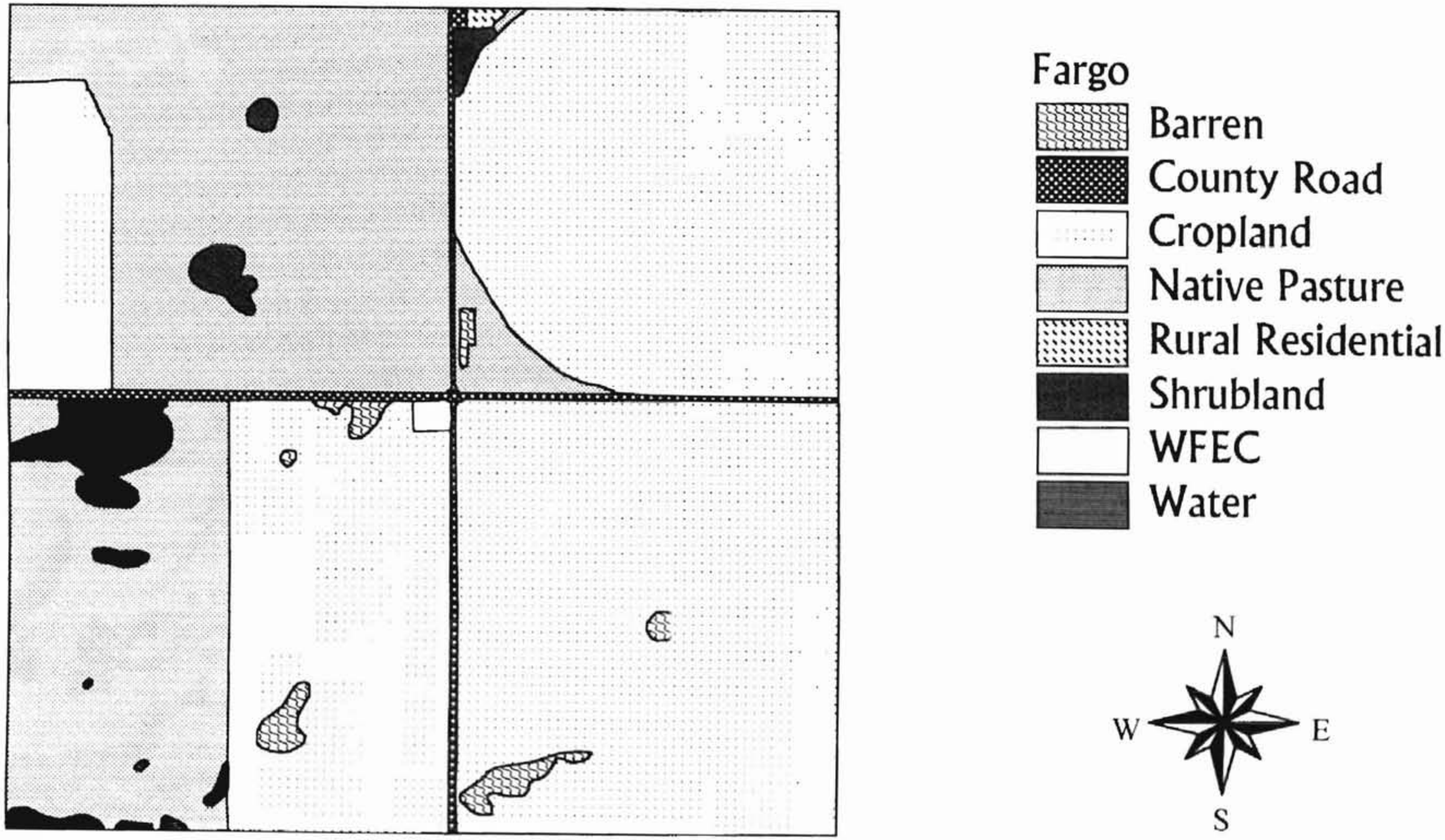
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Shrubland
WFEC
Water
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W
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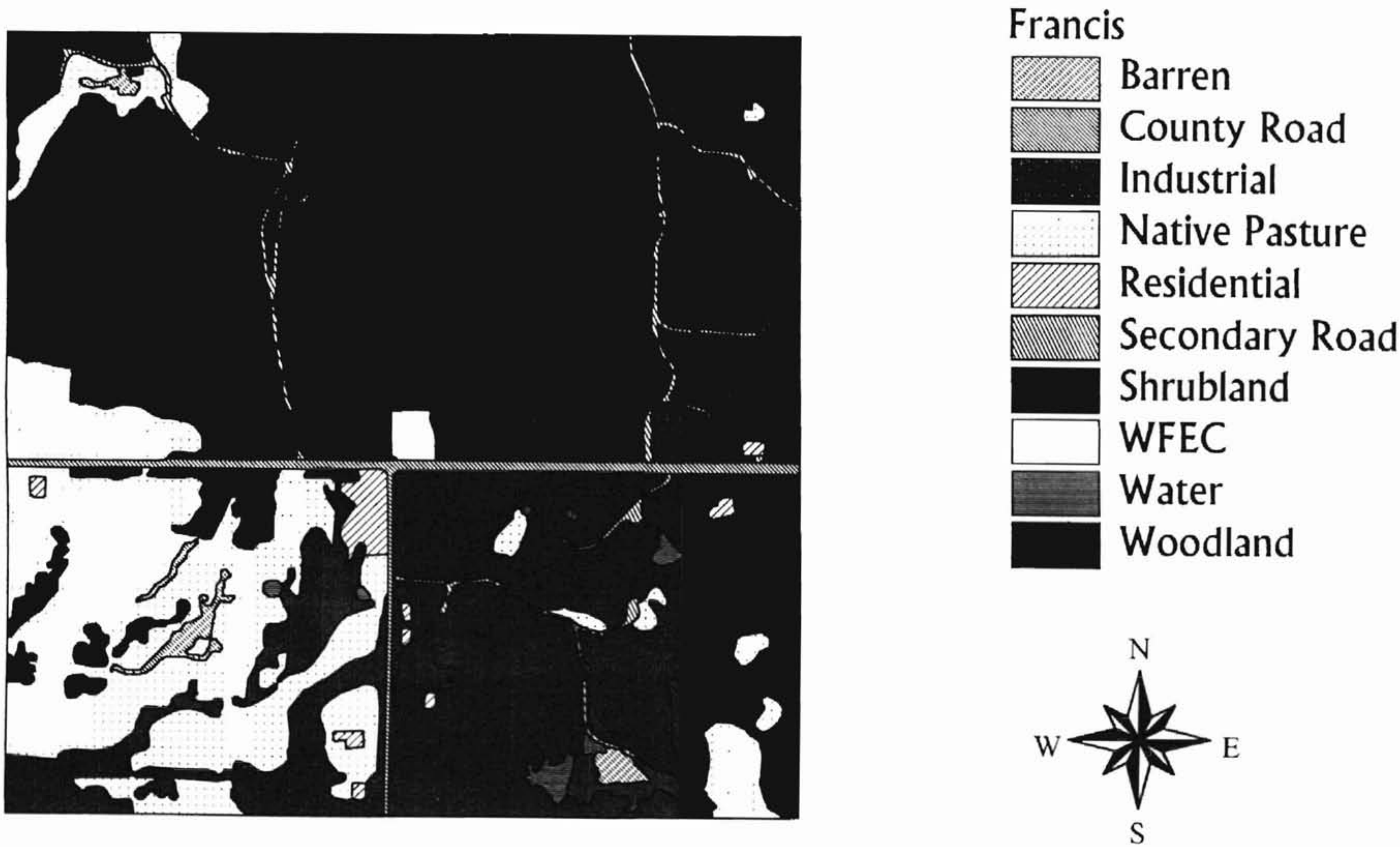
Francis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WFEC
Water
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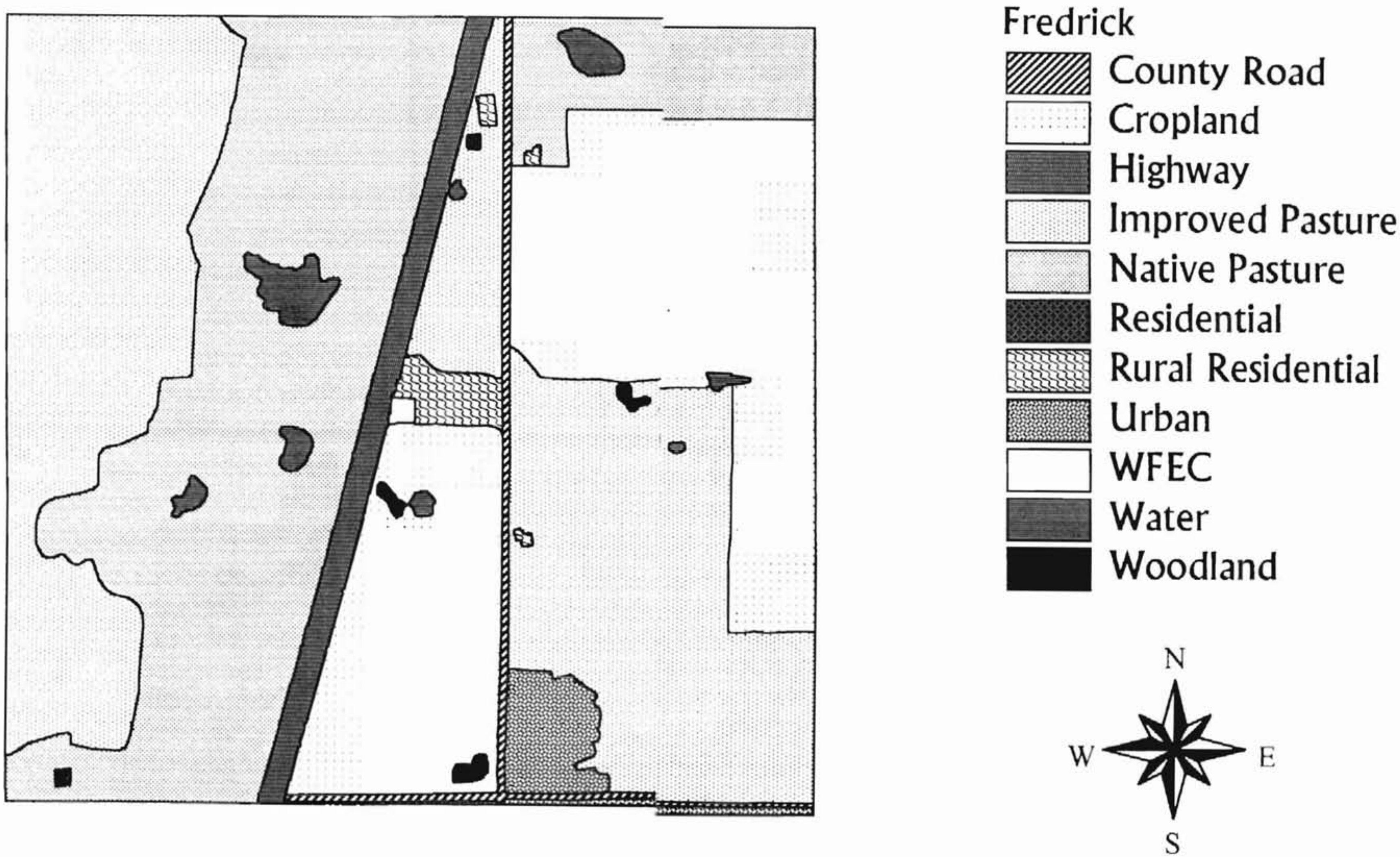
Frederick



Fredrick
County Road
Cropland
Highway
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Native Pasture
Residential
Rural Residential
Urban
WFEC
Water
Woodland
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W
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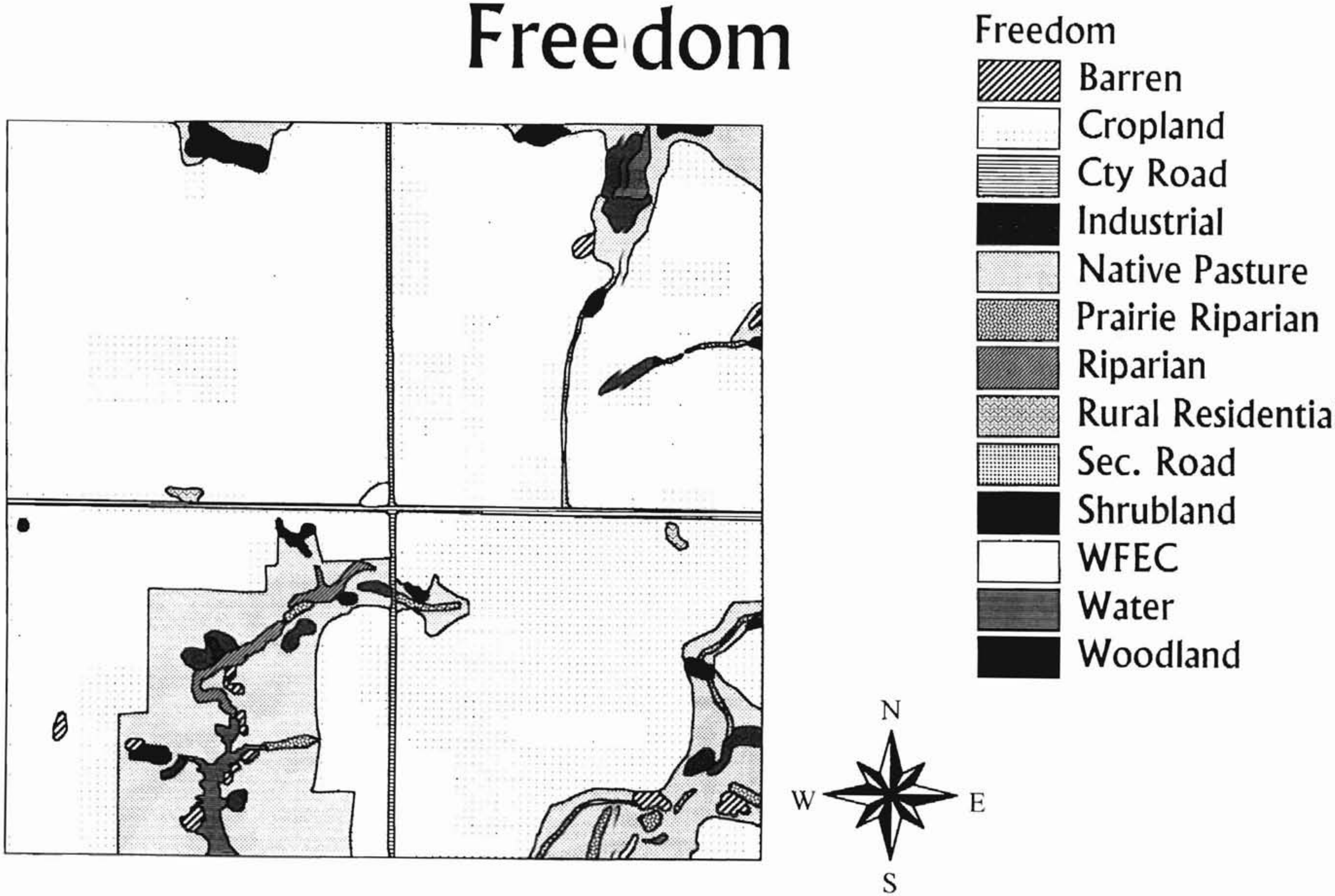
S

Freedom



Freedom
Barren
Cropland
Cty Road
Industrial
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Prairie Riparian
Riparian
Rural Residential
Sec. Road
Shrubland
WFEC
Water
Woodland
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W
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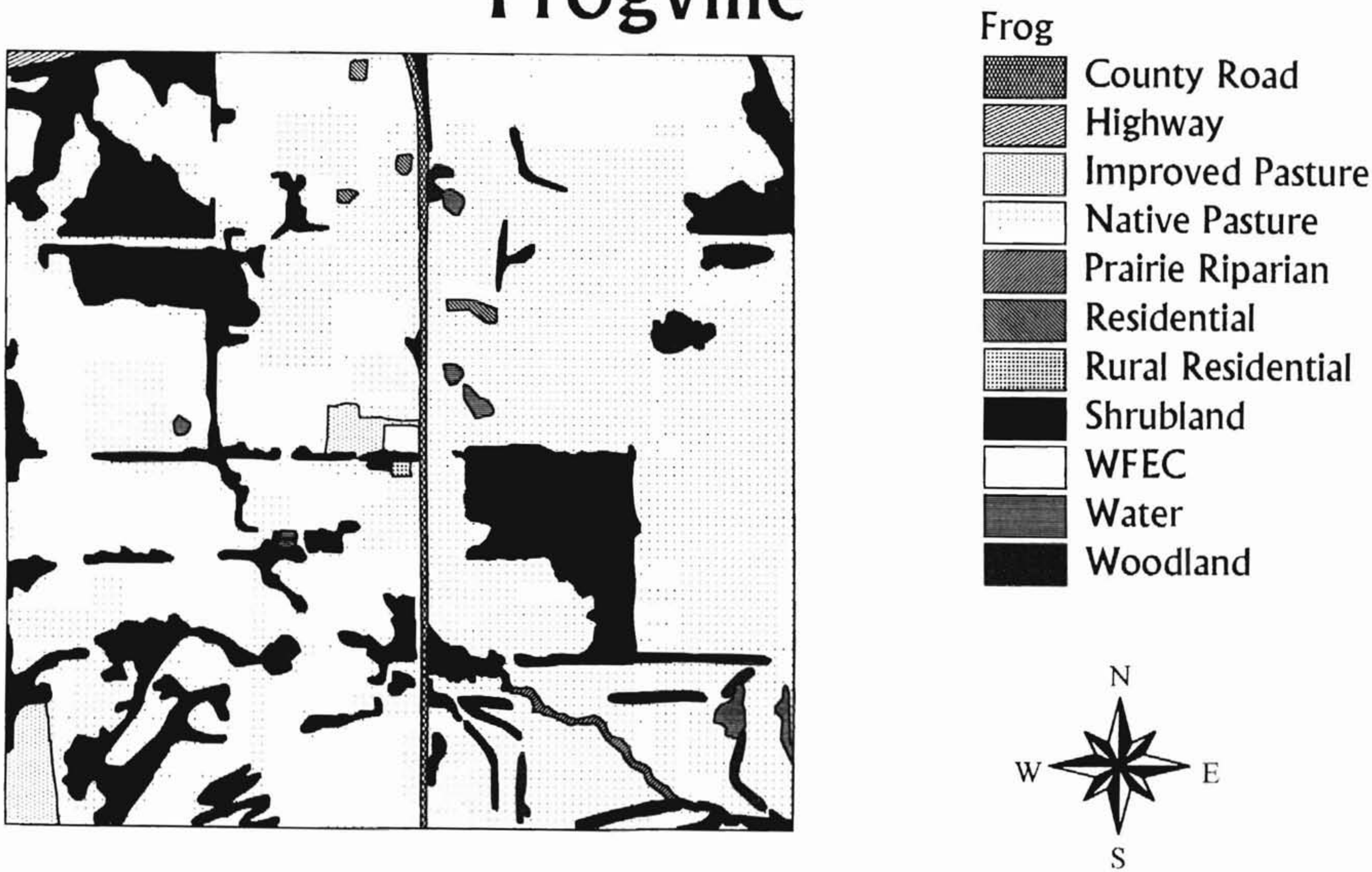
Frogville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County Road
Highway
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Residential
Rural Residential
Shrubland
WFEC
Water
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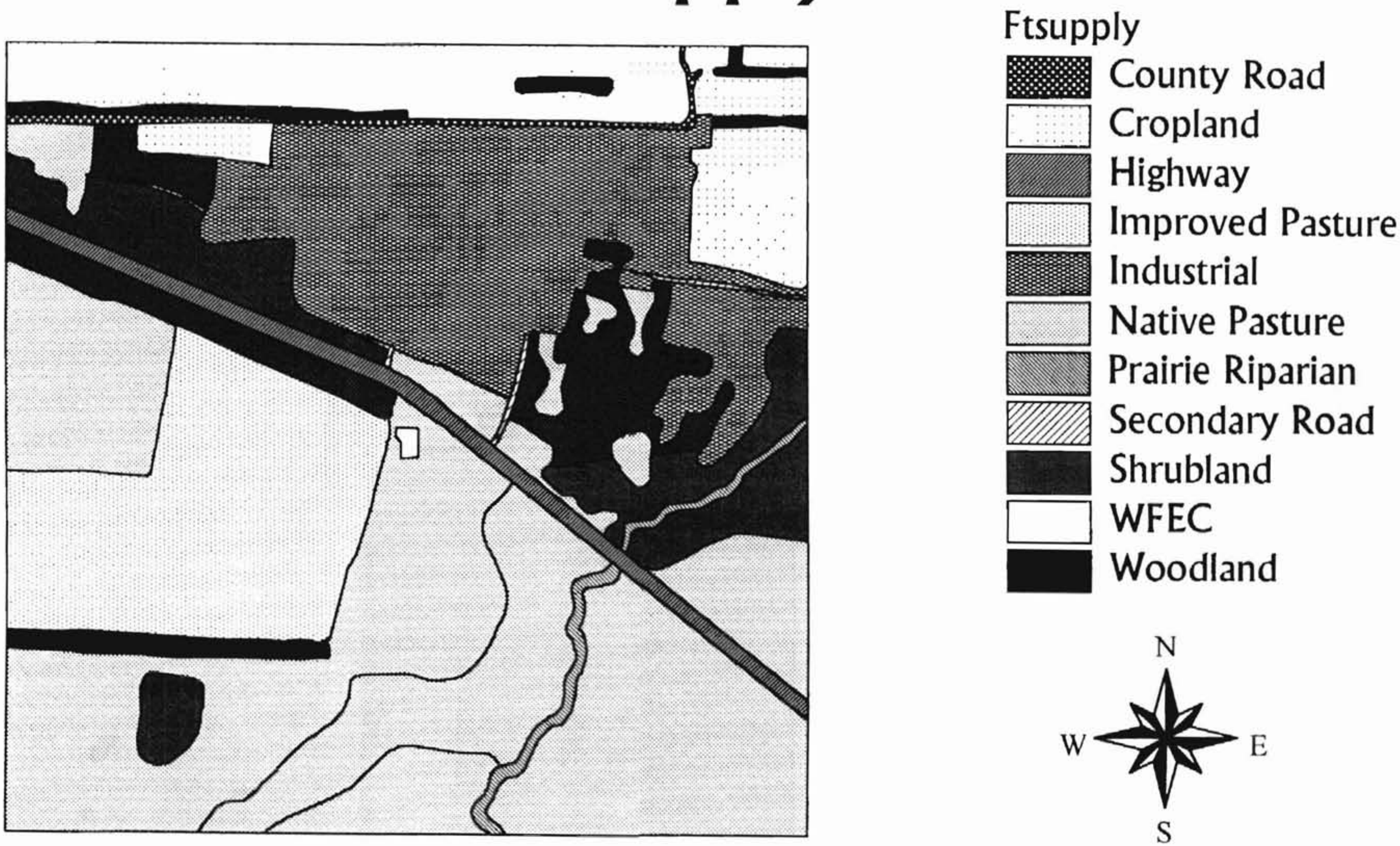
S

Ft Supply


Ftsupply
County Road
Cropland
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Native Pasture
Prairie Riparian
Secondary Road
Shrubland
WFEC
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W
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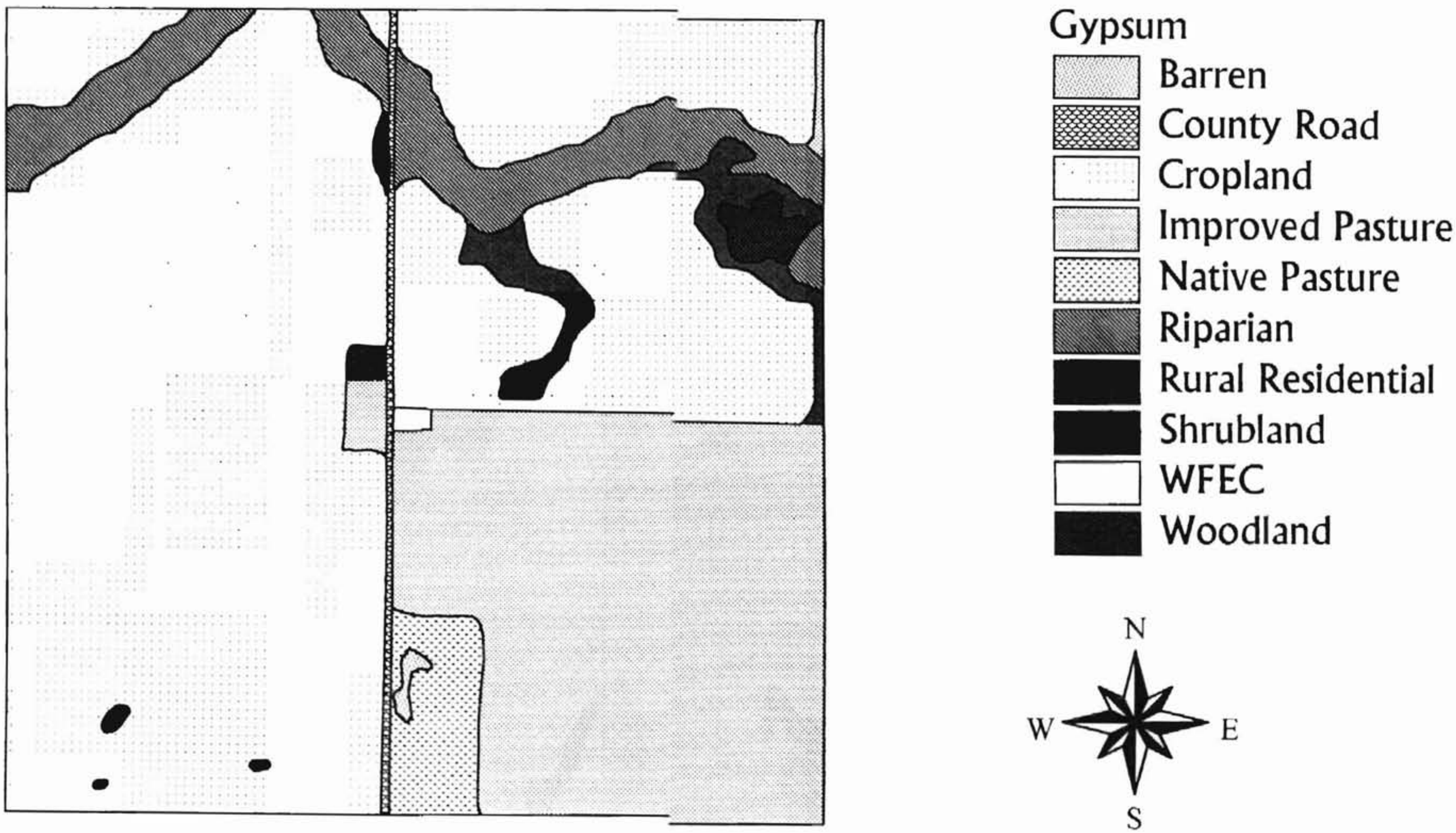
S

Gypsum


Gypsum
Barren
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Native Pasture
Riparian
Rural Residential
Shrubland
WFEC
Woodland
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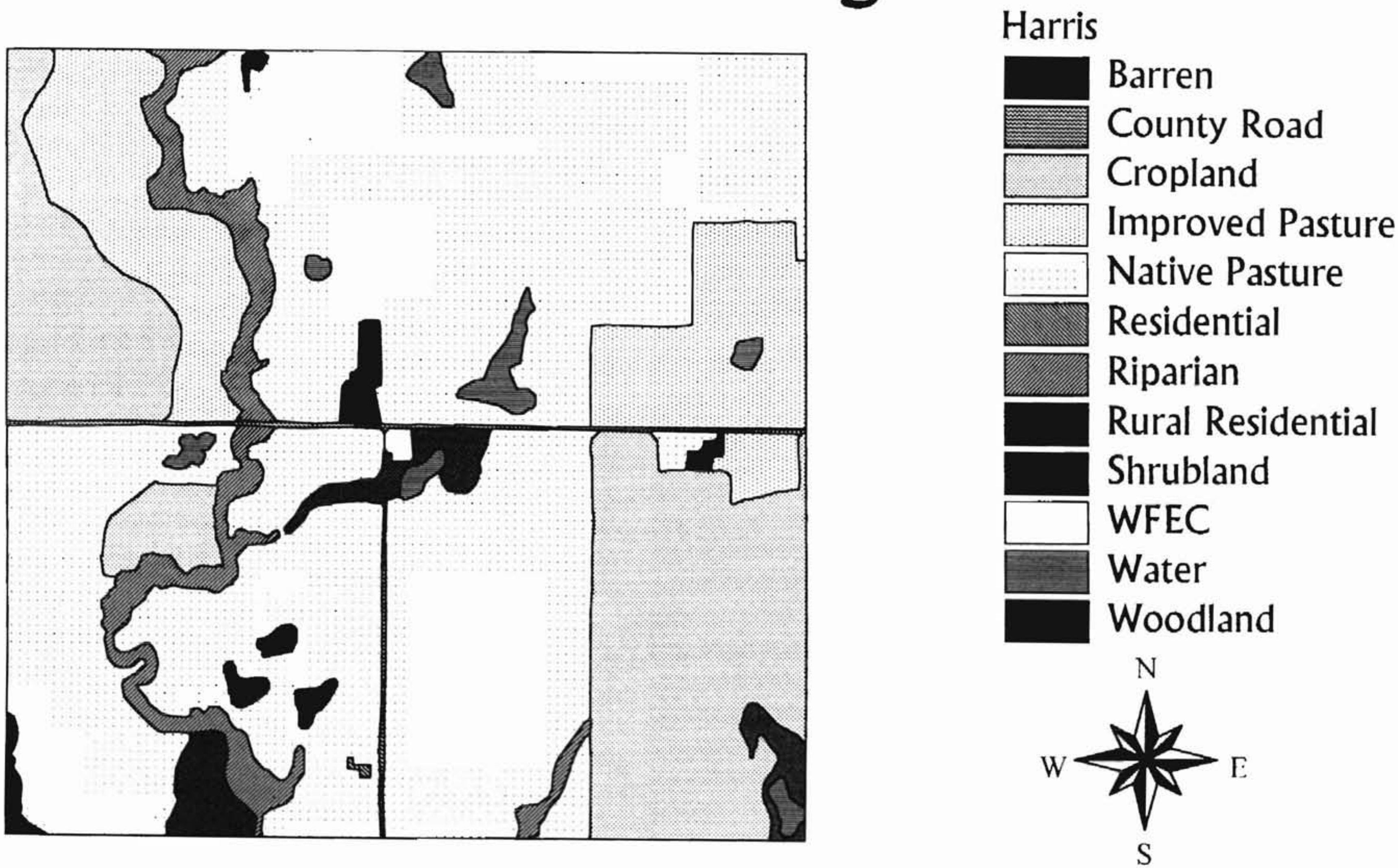
W
E
S

Harrisburg


Harris
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County Road
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Residential
Riparian
Rural Residential
Shrubland
WFEC
Water
Woodland
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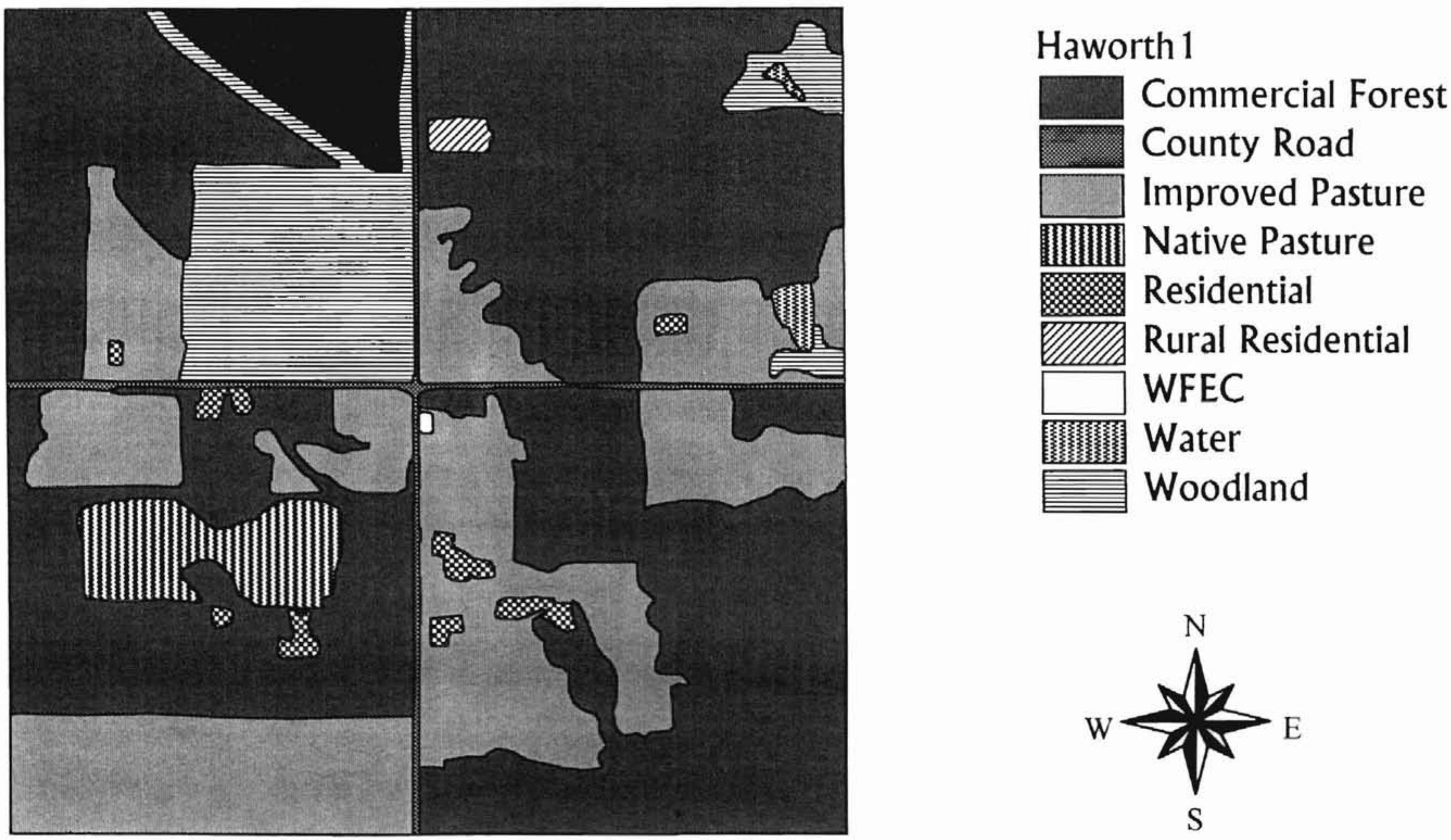
W
E
S

Haworth



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Native Pasture
Residential
Rural Residential
WFEC
Water
Woodland
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W
E
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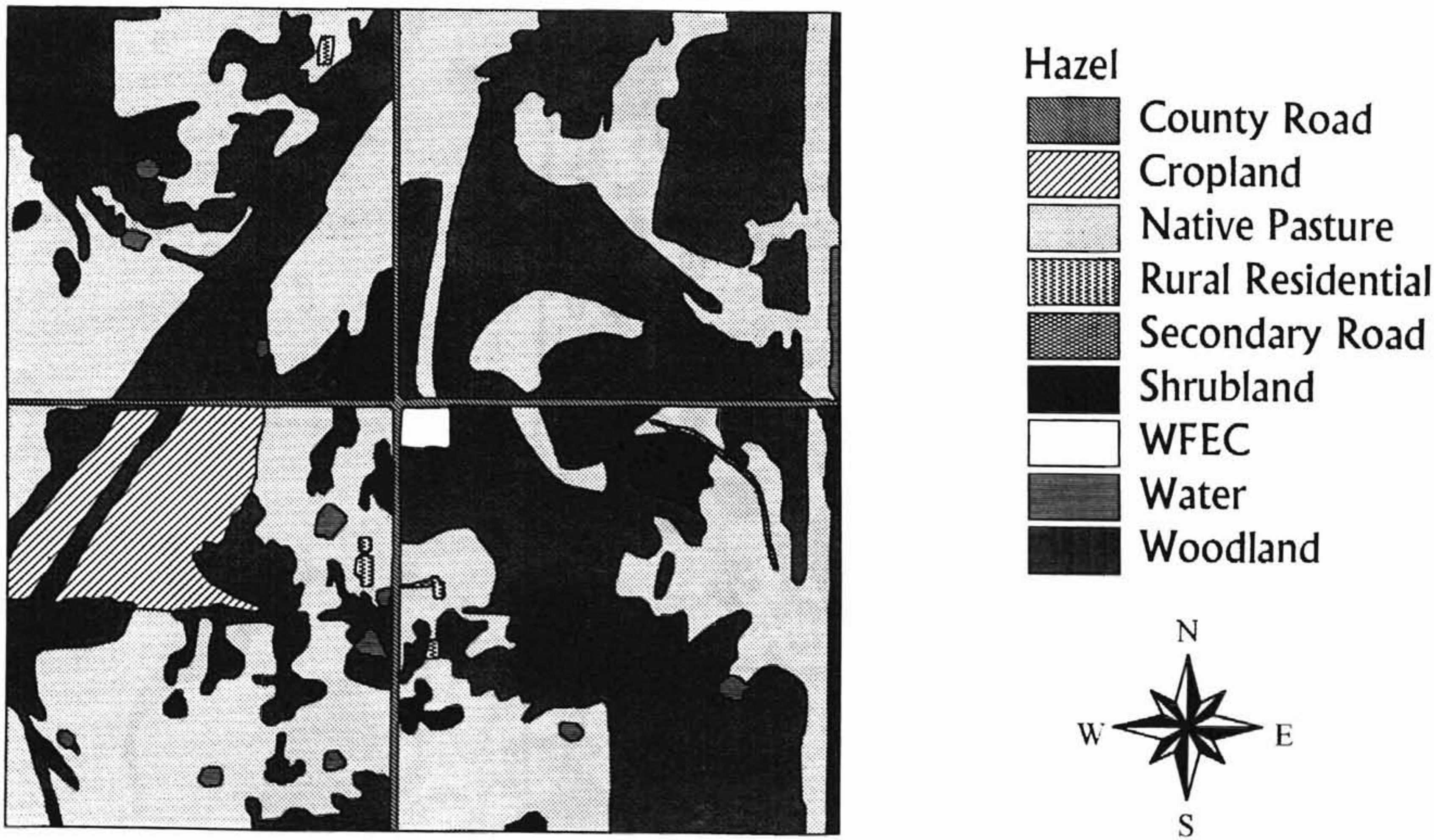
Hazel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County Road
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Native Pasture
Rural Residential
Secondary Road
Shrubland
WFEC
Water
Woodland
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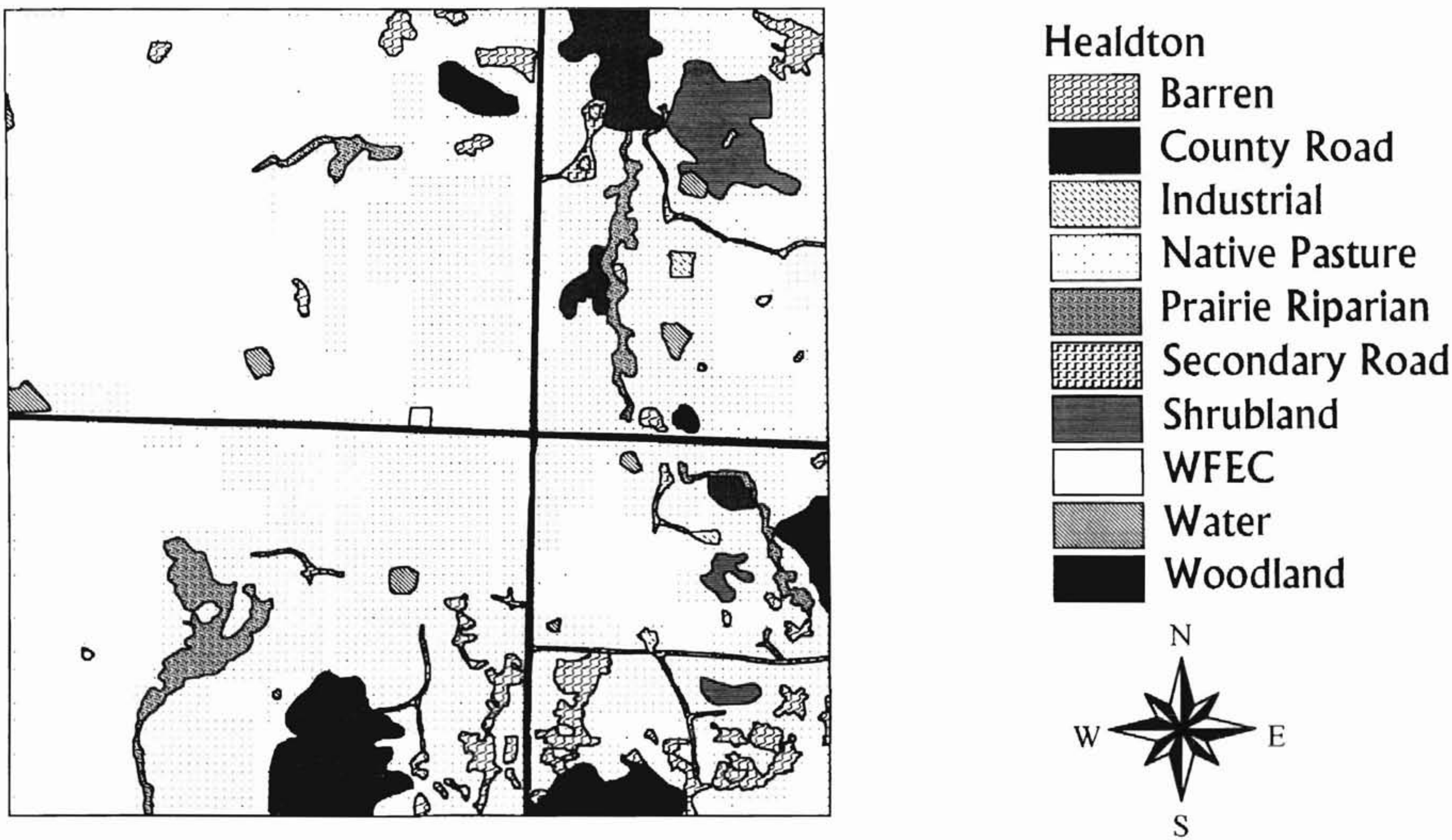
W
E
S

Healdton


Healdton
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Native Pasture
Prairie Riparian
Secondary Road
Shrubland
WFEC
Water
Woodland
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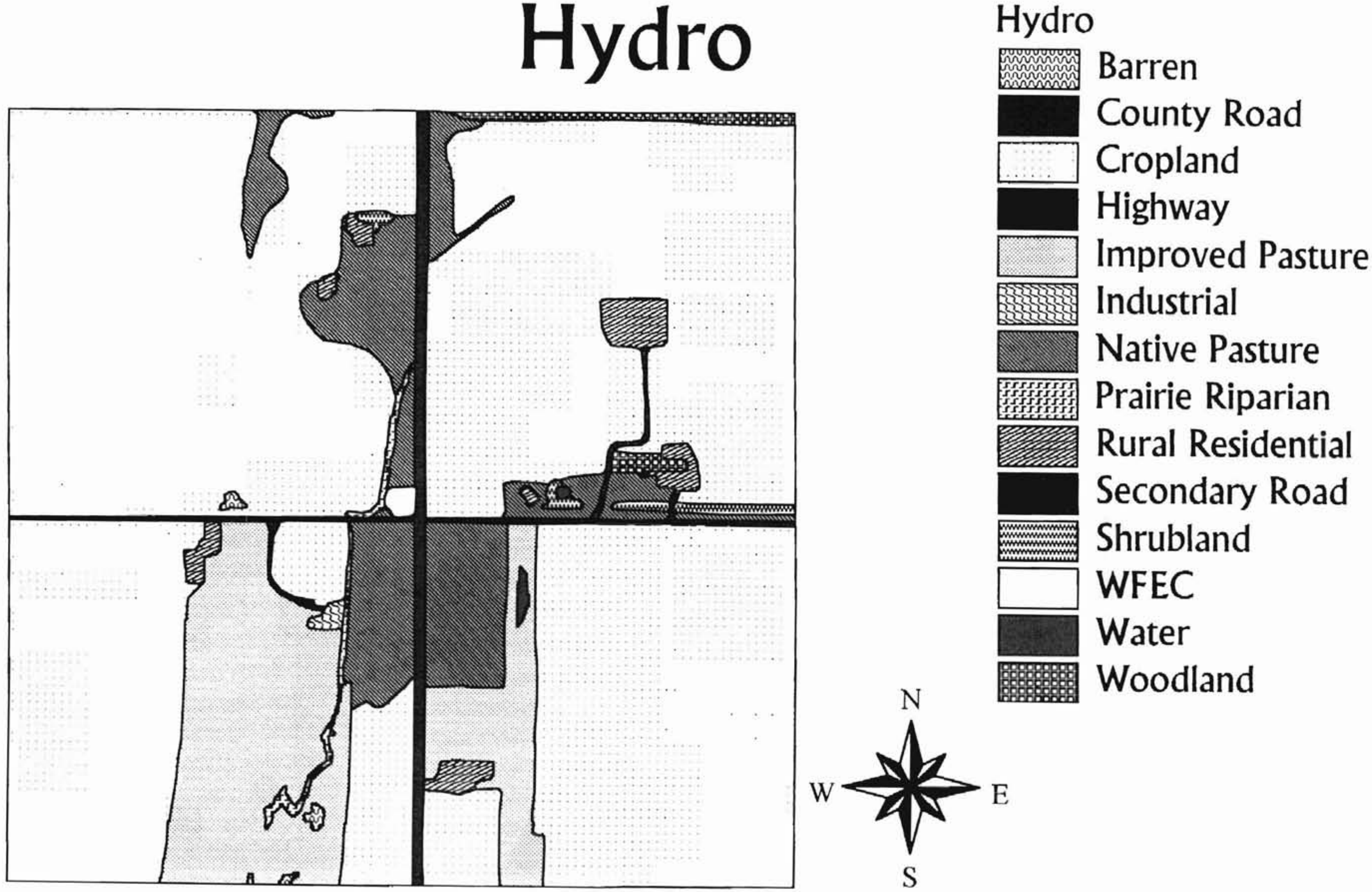
W
E
S

Hydro


Hydro
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County Road
Cropland
Highway
Improved Pasture
Industrial
Native Pasture
Prairie Riparian
Rural Residential
Secondary Road
Shrubland
WFEC
Water
Woodland
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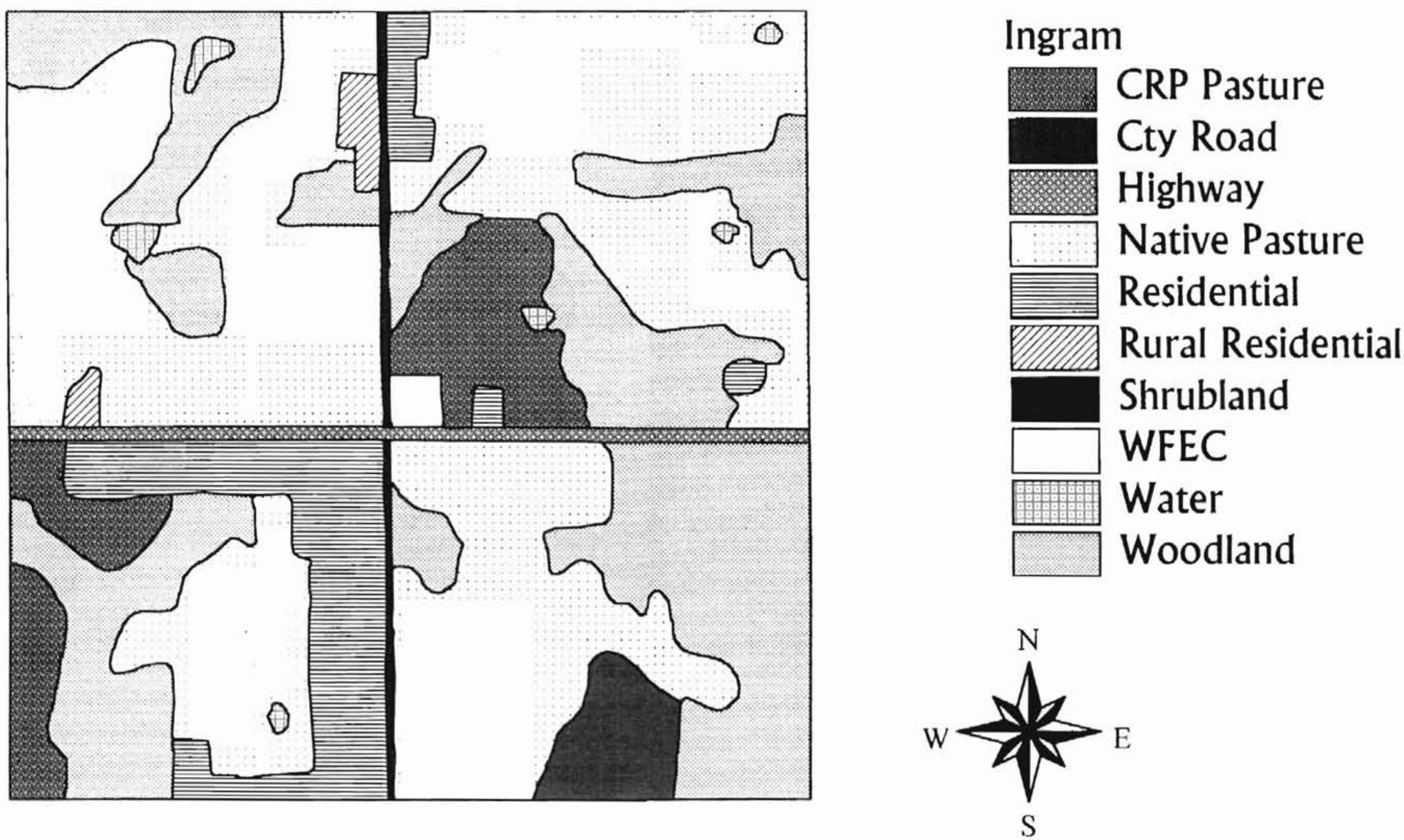
S
W
E

Ingram


Ingram
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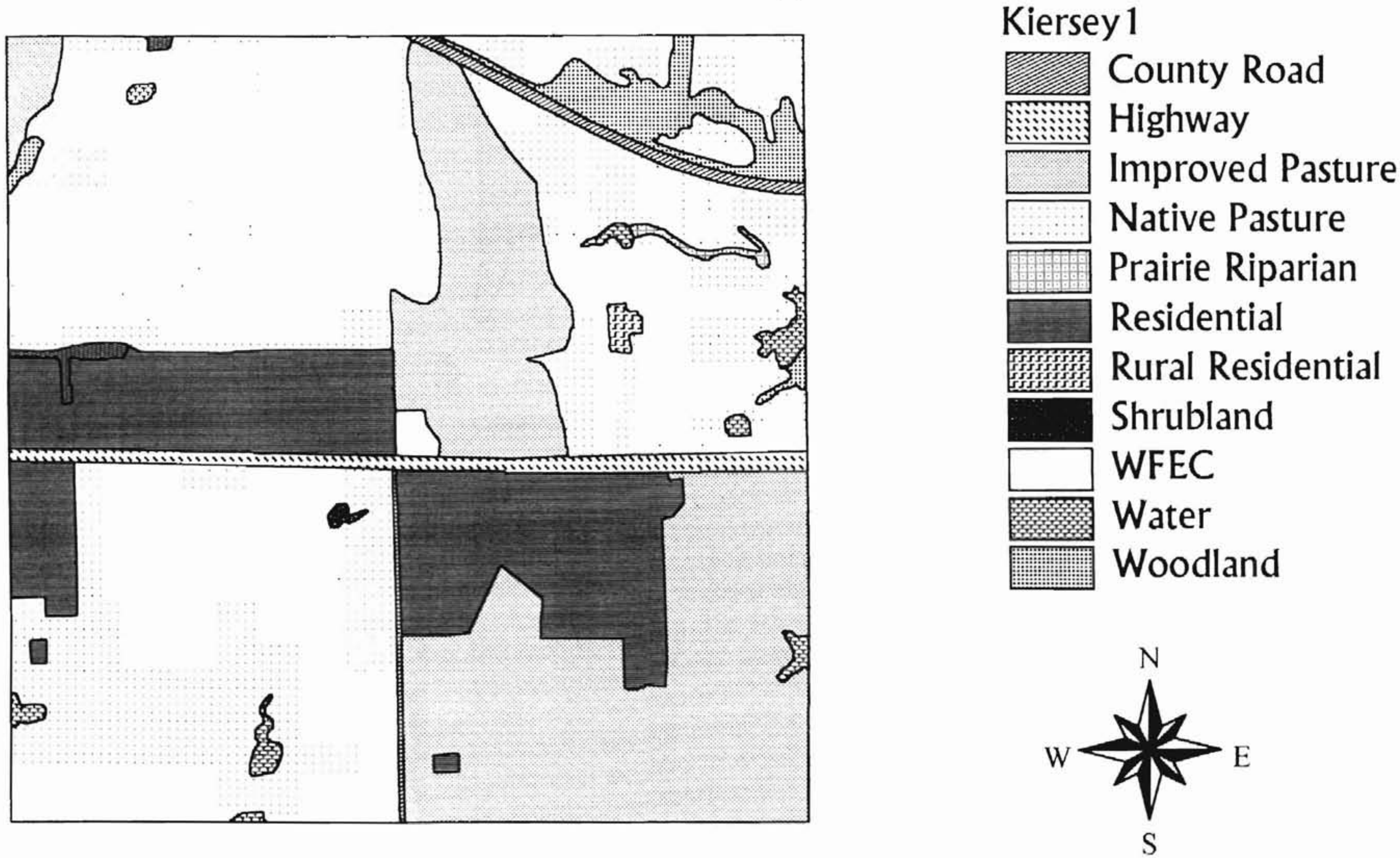
Cty Road
Highway
Native Pasture
Residential
Rural Residential
Shrubland
WFEC
Water
Woodland
N
W
E
S

Kiersey


Kiersey1
County Road
Highway
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Native Pasture
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Residential
Rural Residential
Shrubland
WFEC
Water
Woodland
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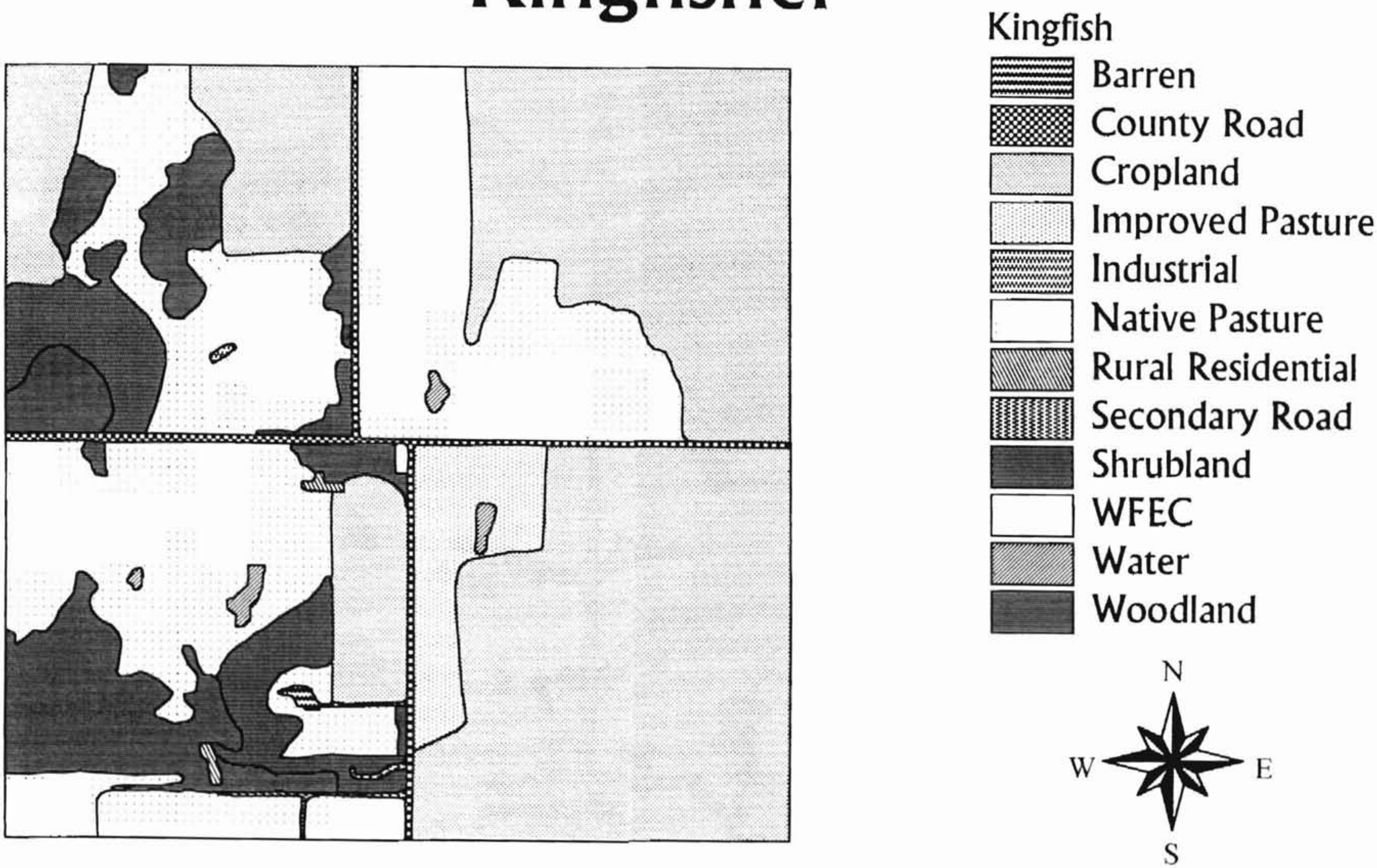
W
E
S

Kingfisher


Kingfish
Barren
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Rural Residential
Secondary Road
Shrubland
WFEC
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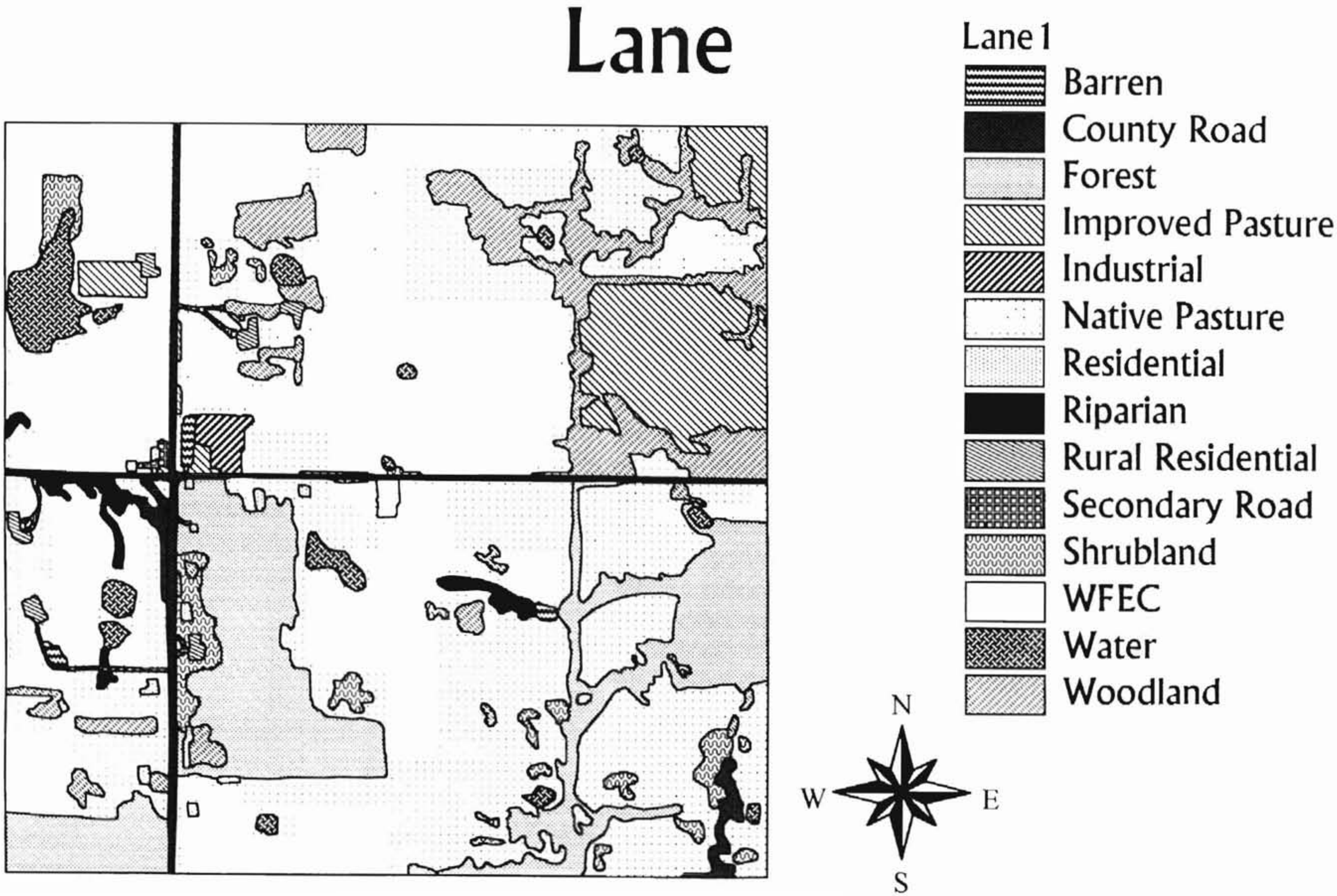
Lane
Lane1
Barren
County Road
Forest
Improved Pasture
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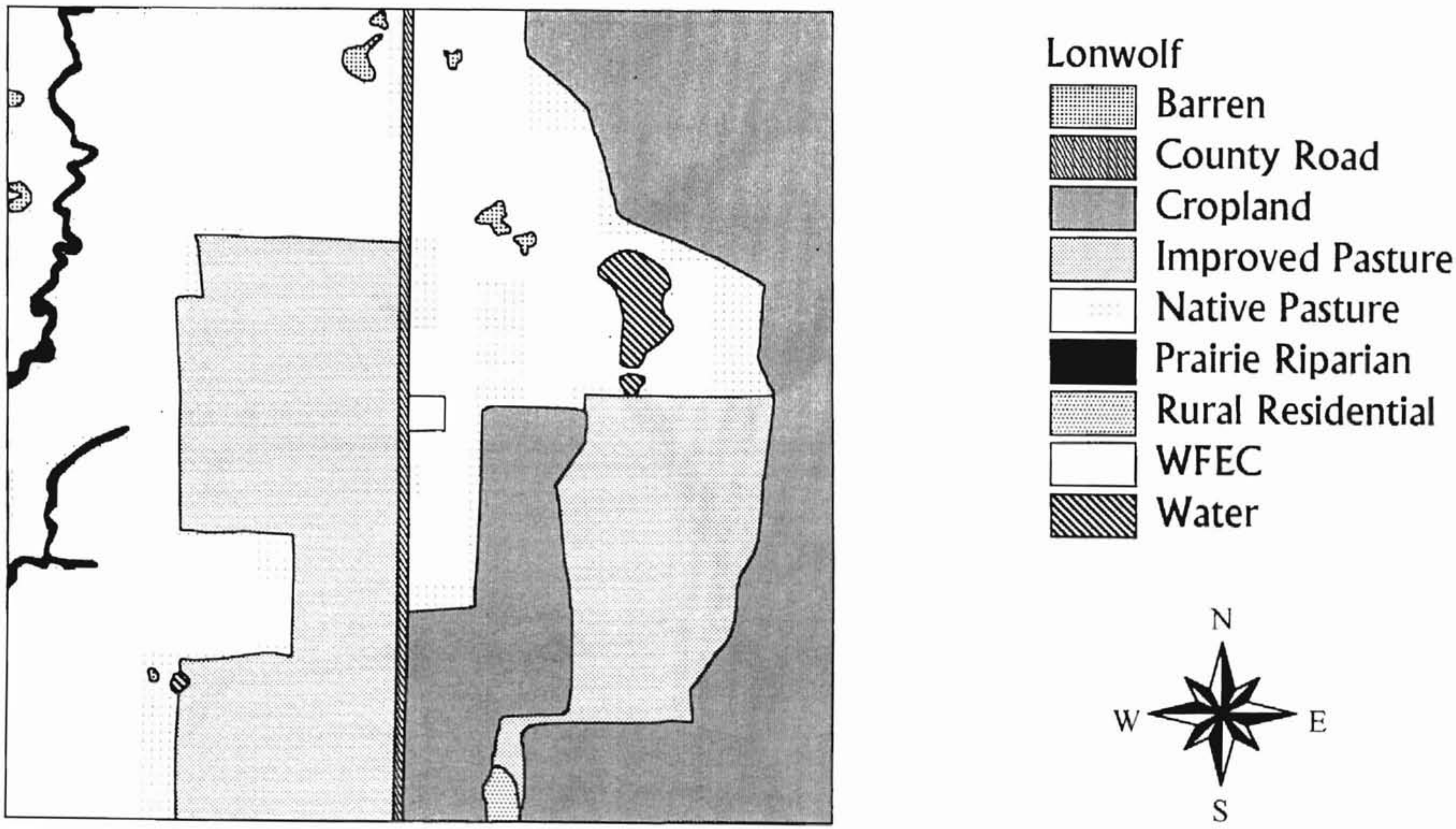
Native Pasture
Residential
Riparian
Rural Residential
Secondary Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

Lone Wolf


Lonwolf
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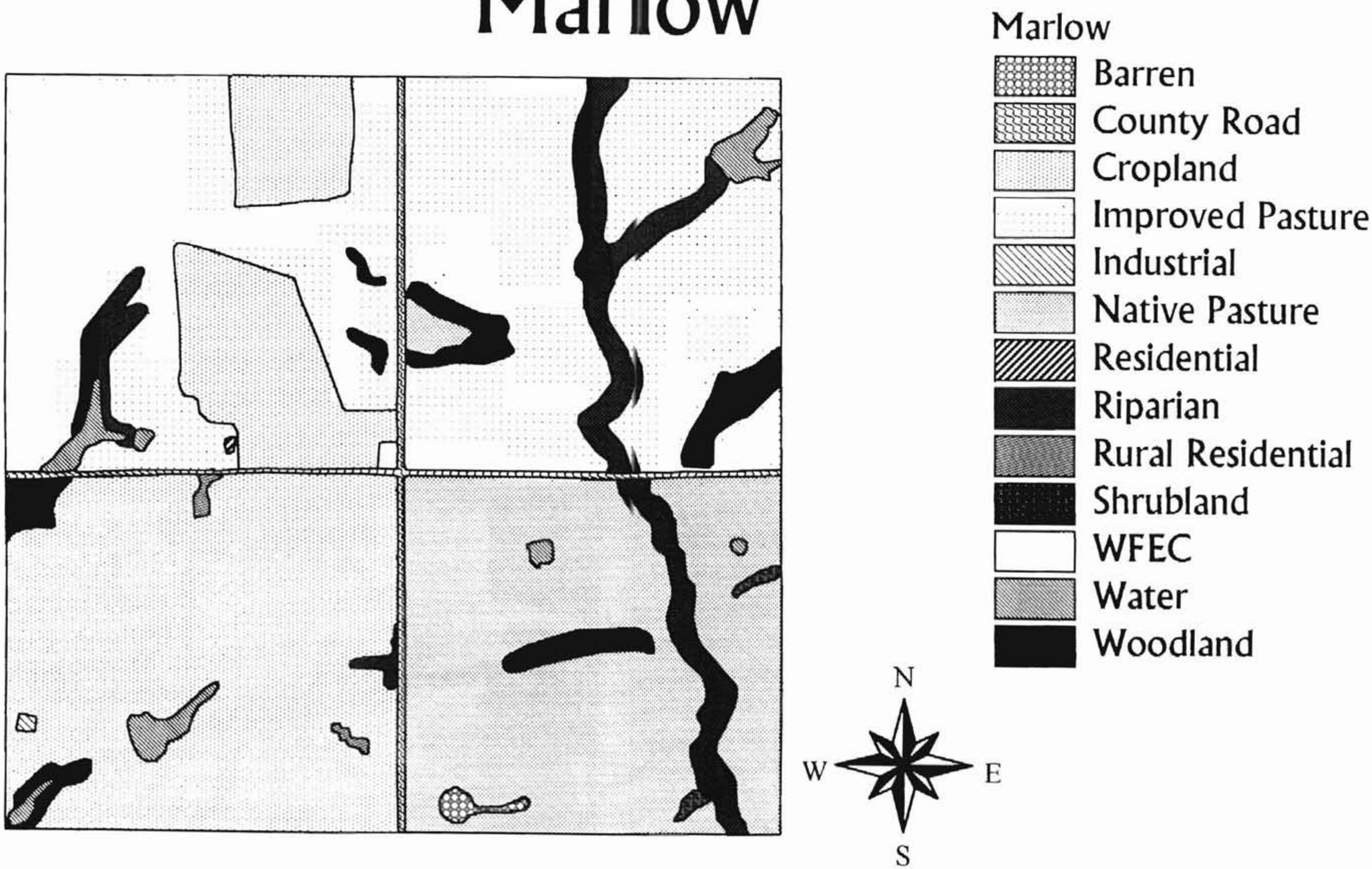
County Road
Cropland
Improved Pasture
Native Pasture
Prairie Riparian
Rural Residential
WFEC
Water
N
W
E
S

Marlow


Marlow
Barren
County Road
Cropland
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Industrial
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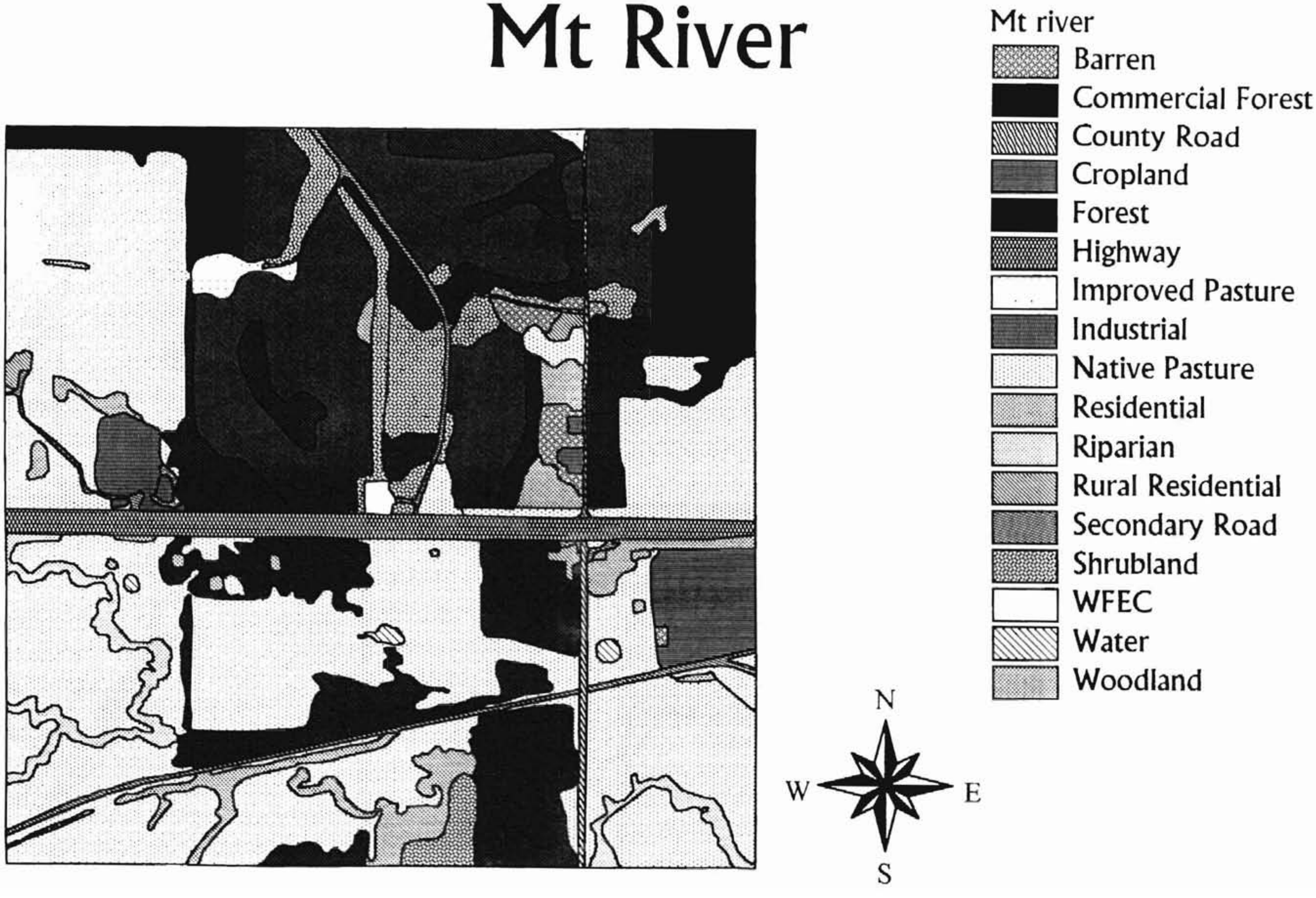
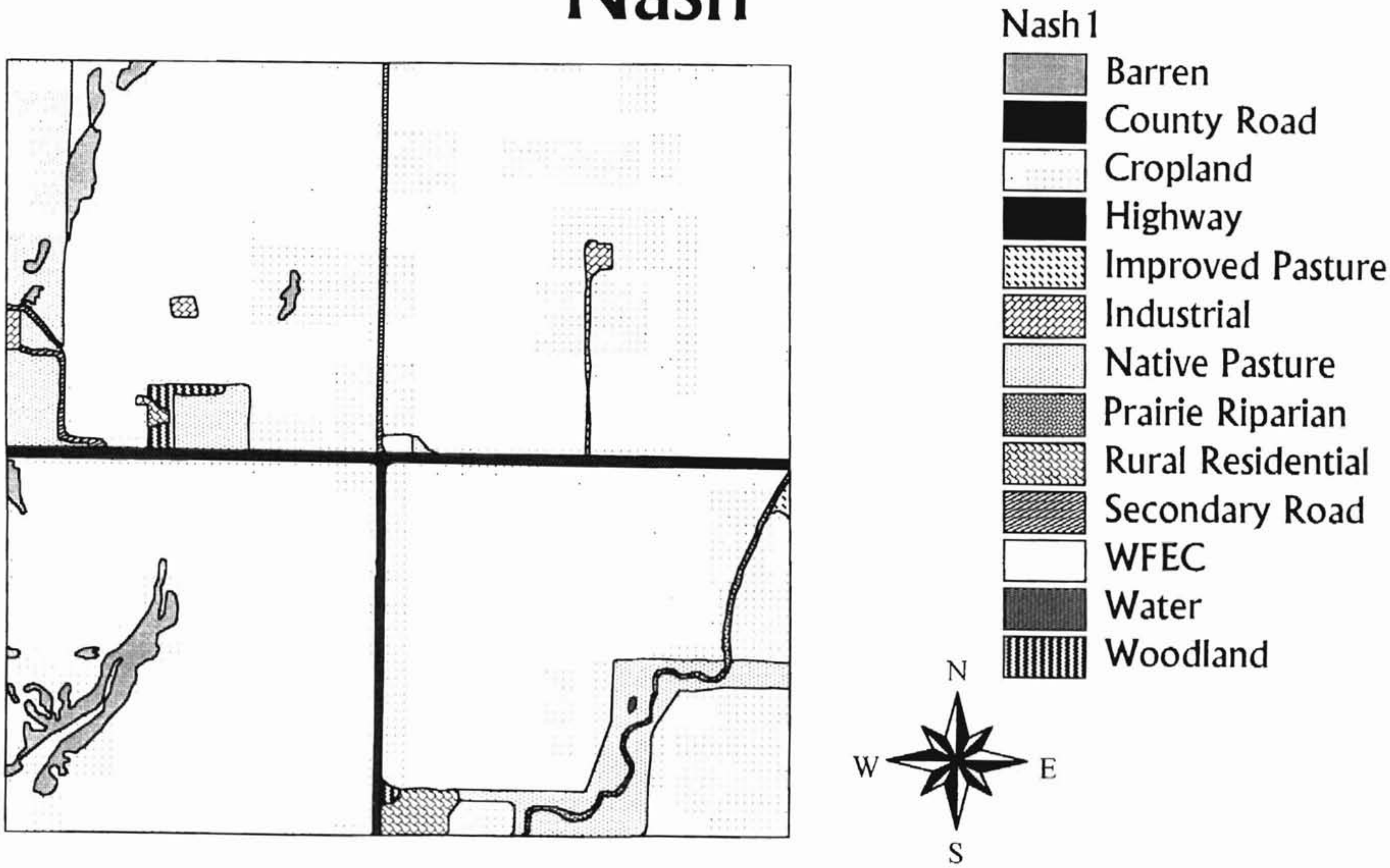
Residential
Riparian
Rural Residential
Shrubland
WFEC
Water
Woodland
N
W
E
S

Mt River


Mt river
Barren
Commercial Forest
County Road
Cropland
Forest
Highway
Improved Pasture
Industrial
Native Pasture
Residential
Riparian
Rural Residential
Secondary Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

Nash


Nash 1
Barren
County Road
Cropland
Highway
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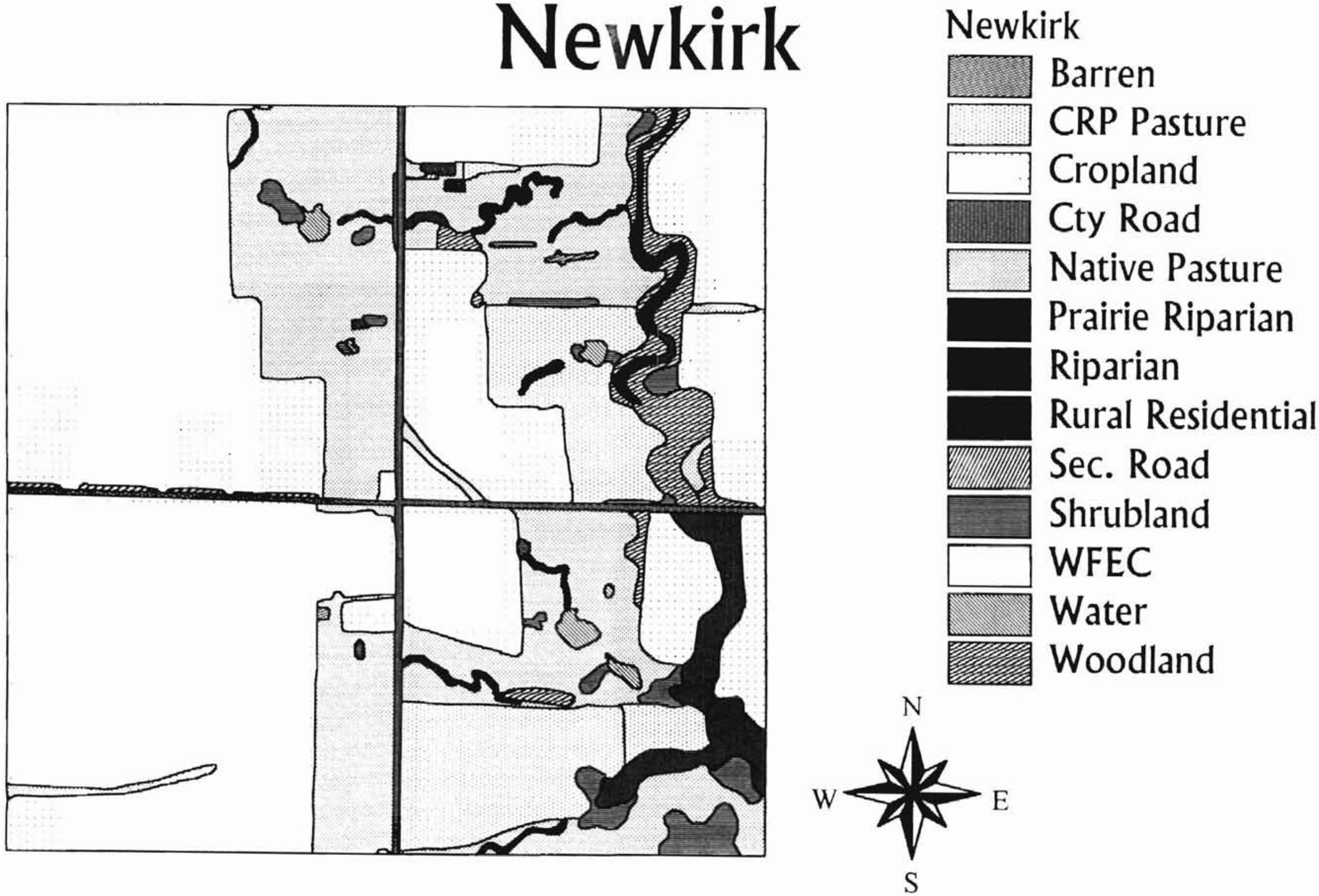
Industrial
Native Pasture
Prairie Riparian
Rural Residential
Secondary Road
WFEC
Water
Woodland
N
W
E
S

Newkirk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Barren
CRP Pasture
Cropland
Cty Road
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Prairie Riparian
Riparian
Rural Residential
Sec. Road
Shrubland
WFEC
Water
Woodland
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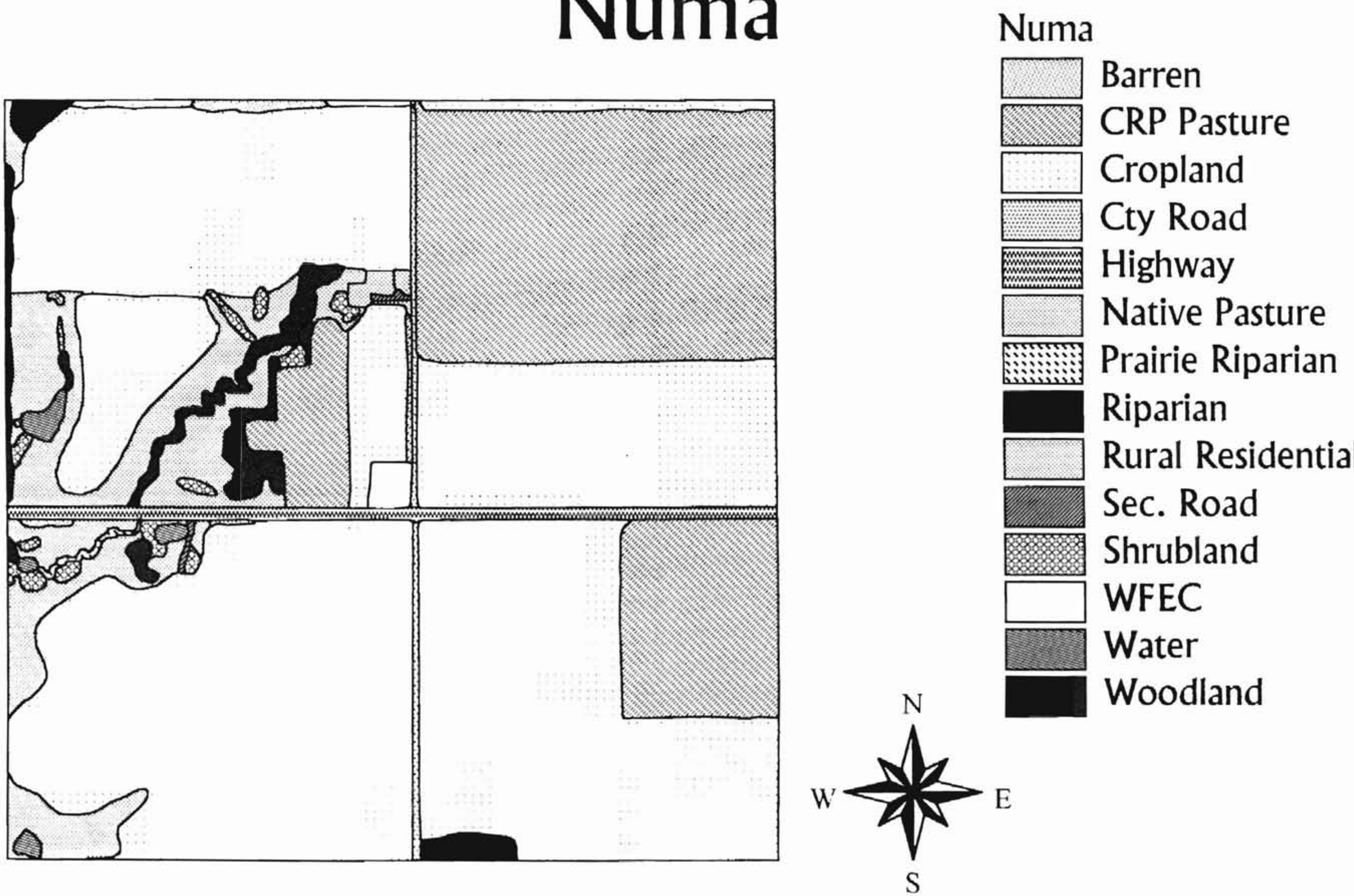
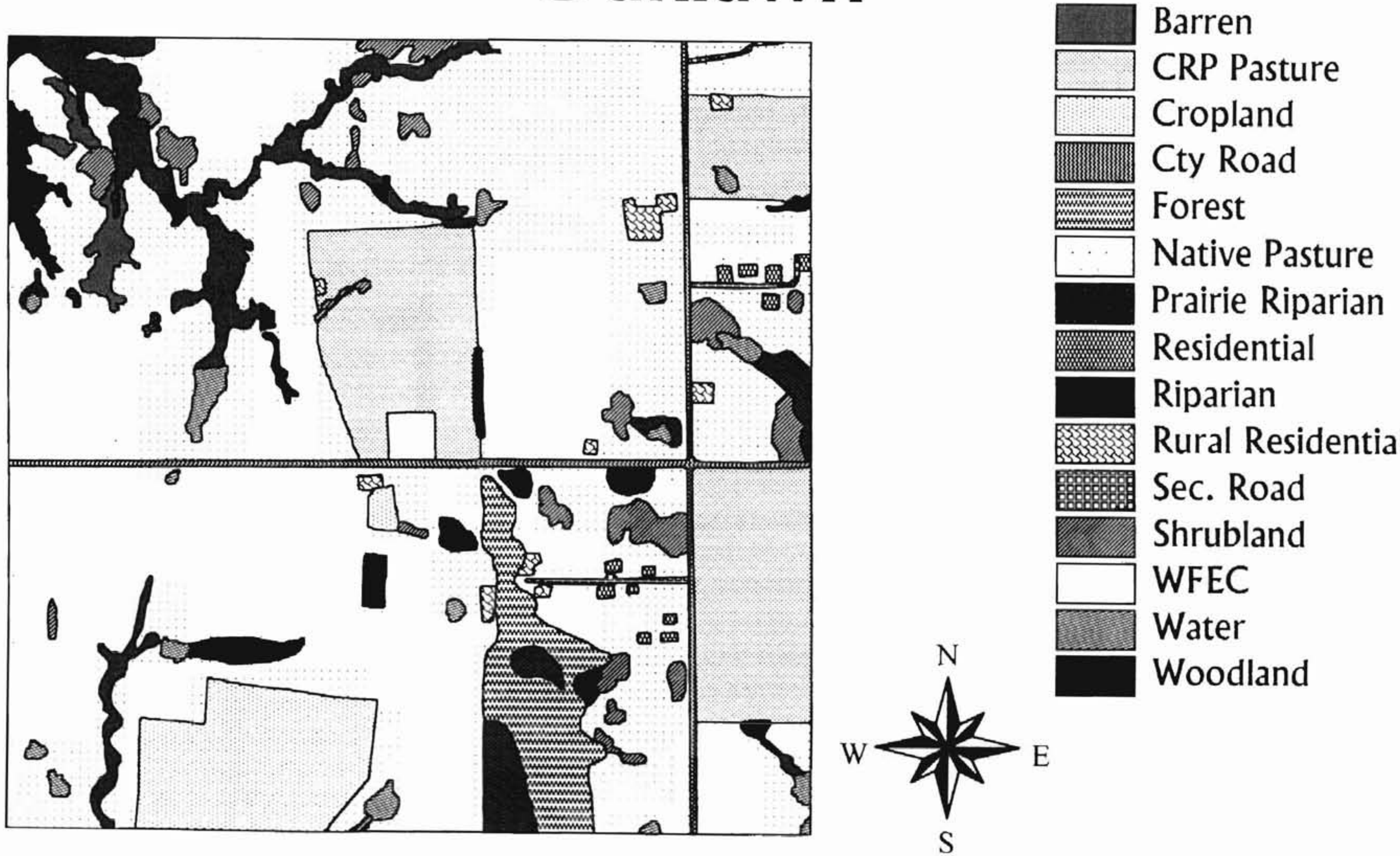
W
E
S

Numa


Numa
Barren
CRP Pasture
Cropland
Cty Road
Highway
Native Pasture
Prairie Riparian
Riparian
Rural Residential
Sec. Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

Oaklawn


Oaklawn1
Barren
CRP Pasture
Cropland
Cty Road
Forest
Native Pasture
Prairie Riparian
Residential
Riparian
Rural Residential
Sec. Road
Shrubland
WFEC
Water
Woodland
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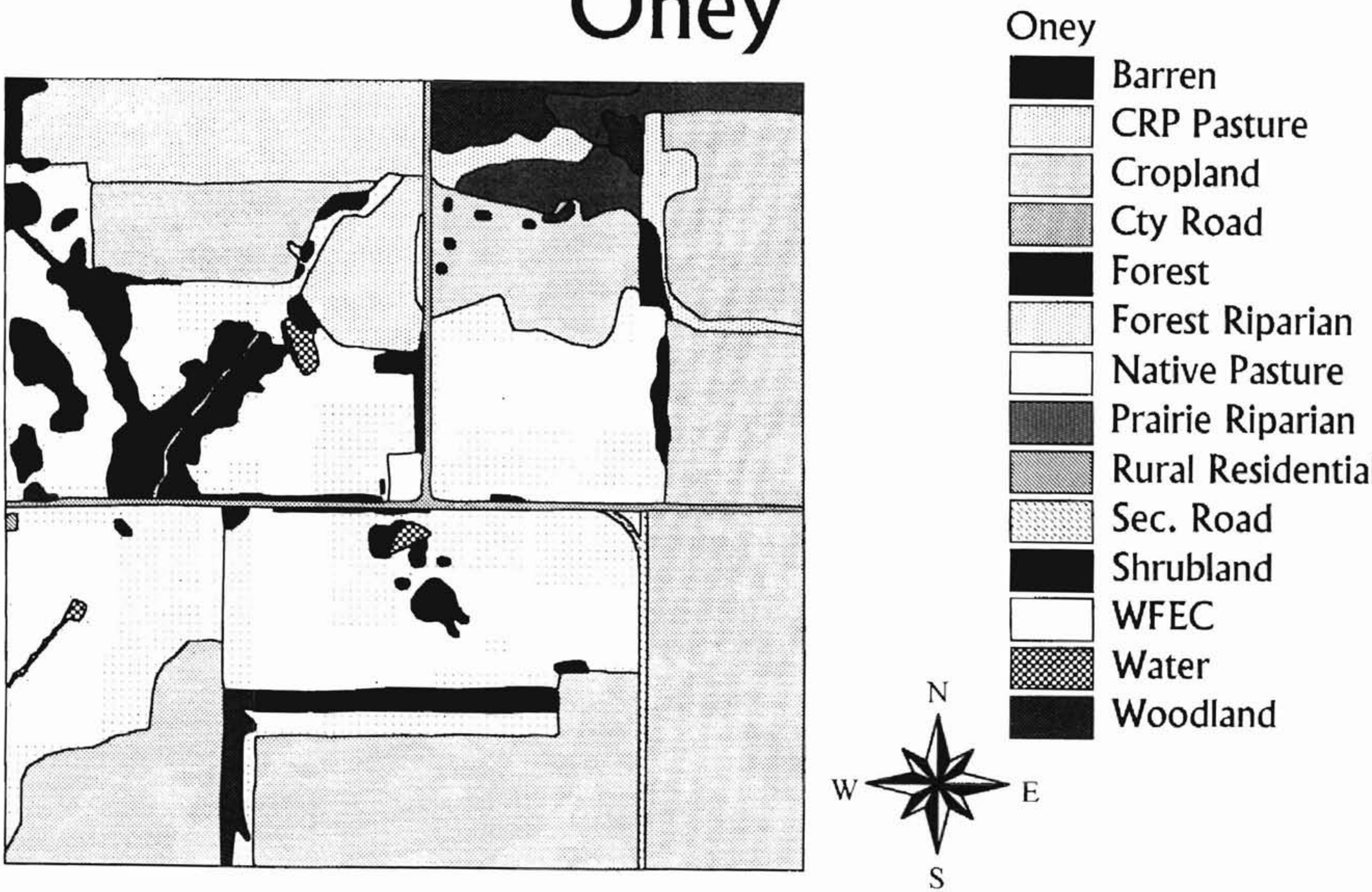
W
E
S

Oney



Oney
Barren
CRP Pasture
Cropland
Cty Road
Forest
Forest Riparian
Native Pasture
Prairie Riparian
Rural Residential
Sec. Road
Shrubland
WFEC
Water
Woodland
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W
E
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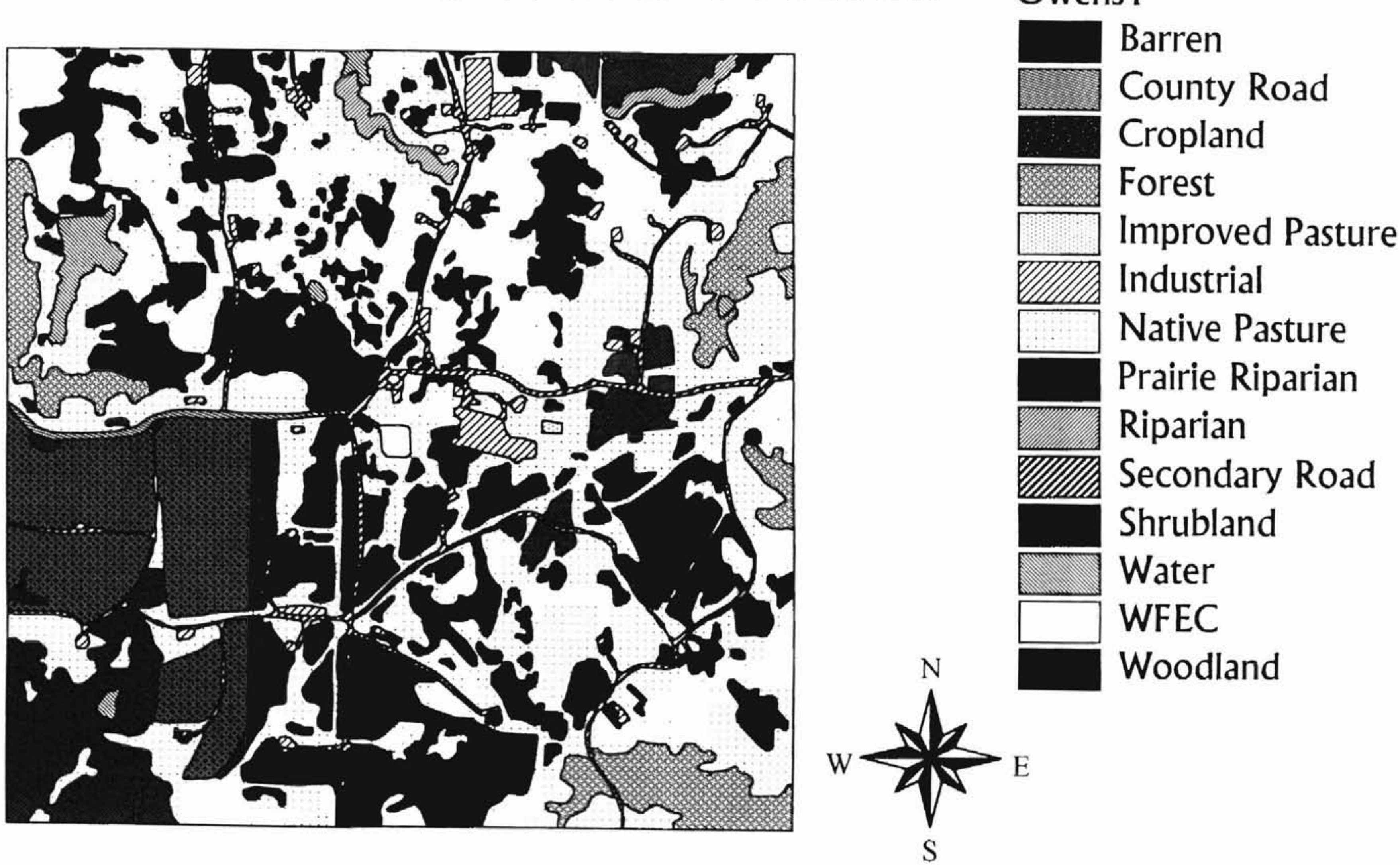
Owens Prairie



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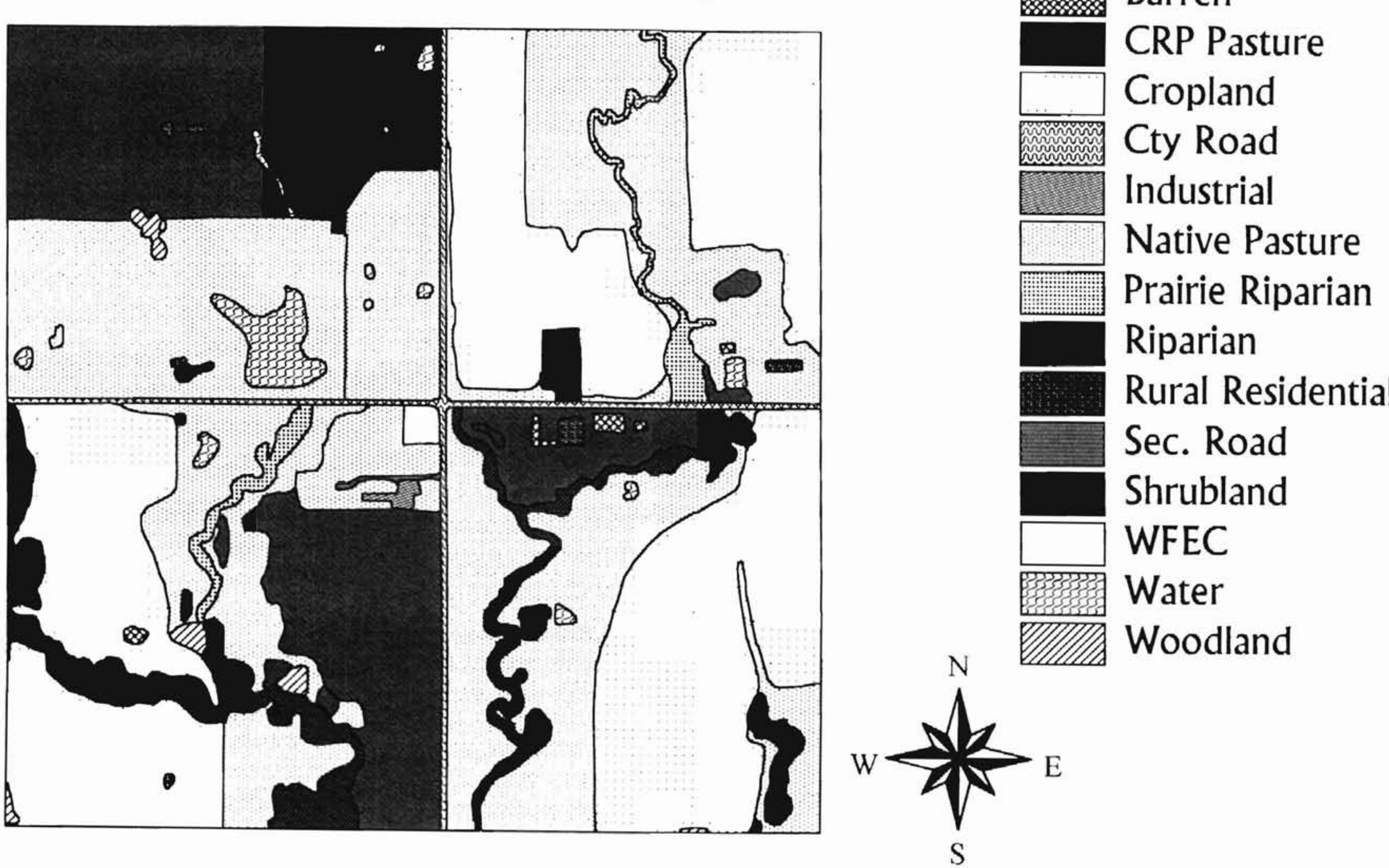
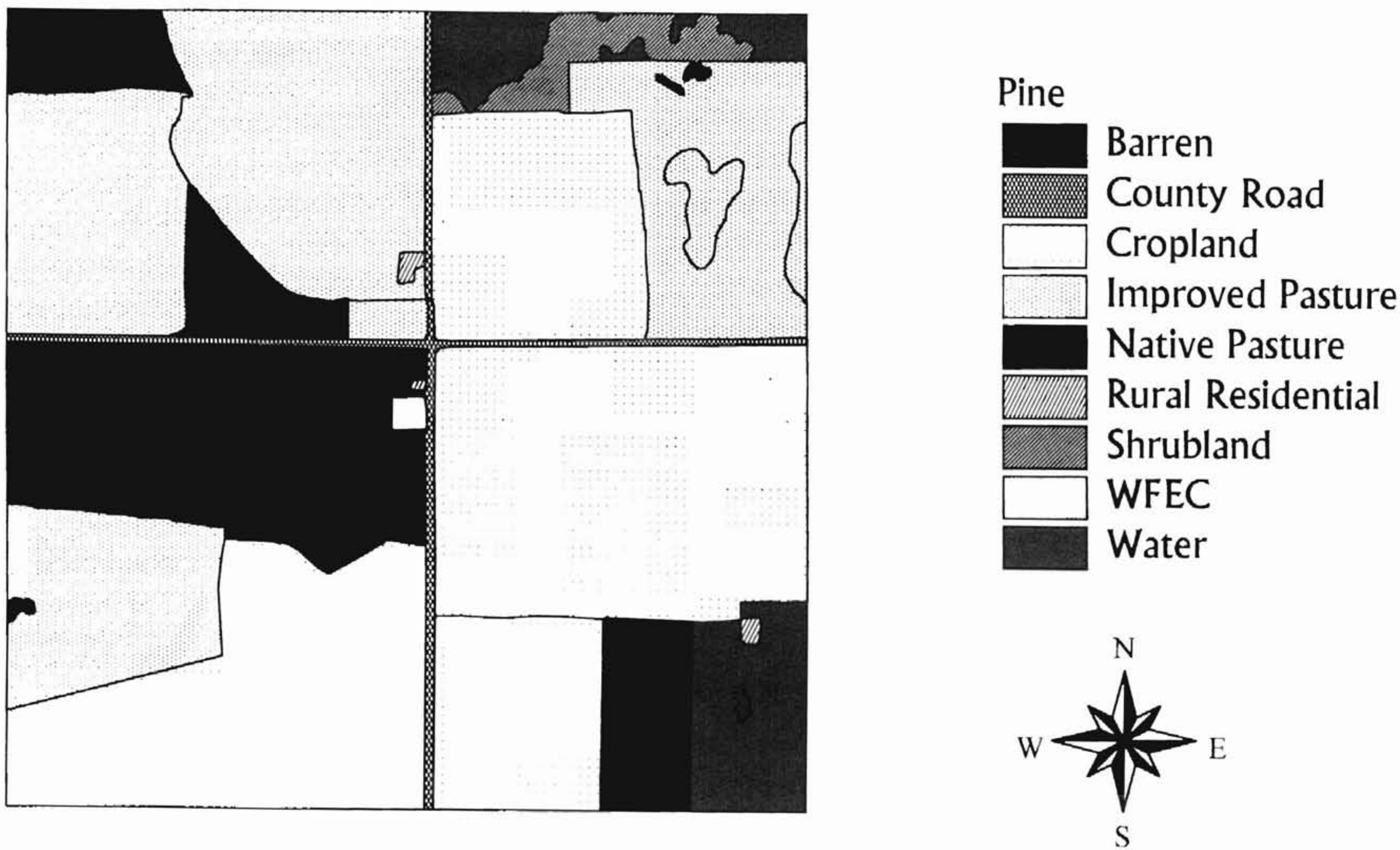
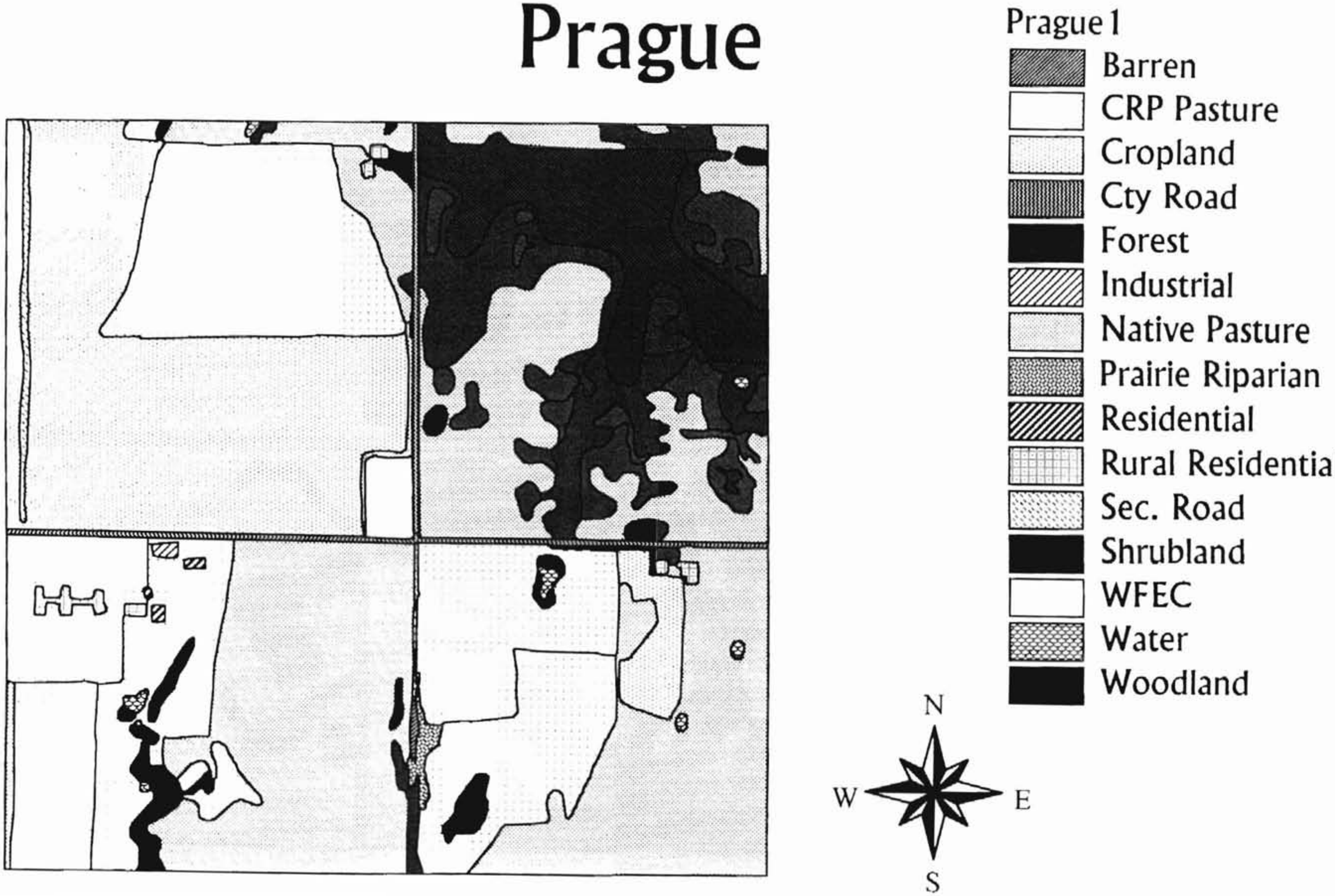

Perry
Barren
CRP Pasture
Cropland
Cty Road
Industrial
Native Pasture
Prairie Riparian
Riparian
Rural Residential
Sec. Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

Pine Ridge



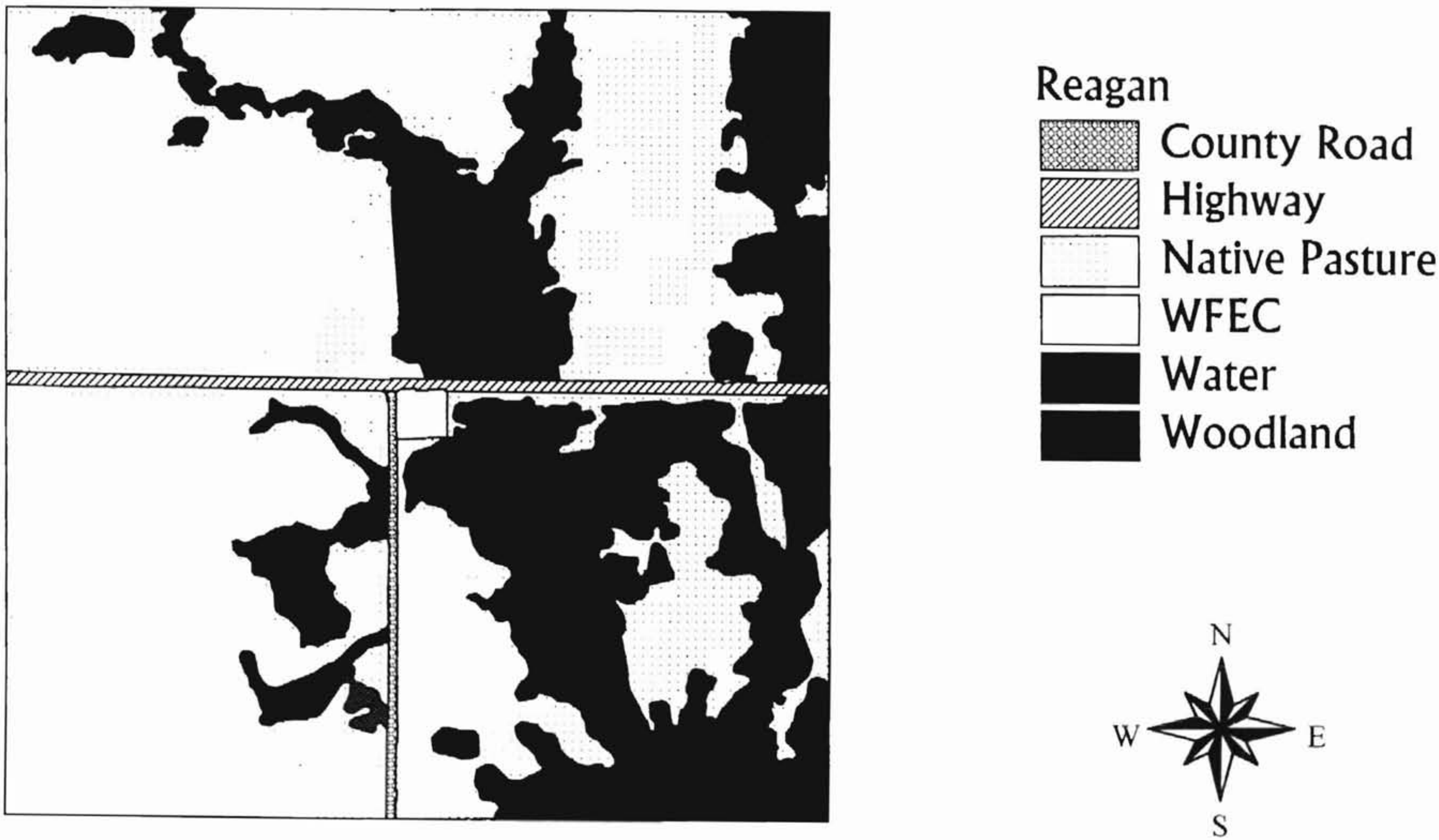
Pine
Barren
County Road
Cropland
Improved Pasture
Native Pasture
Rural Residential
Shrubland
WFEC
Water
N
W
E
S

Prague



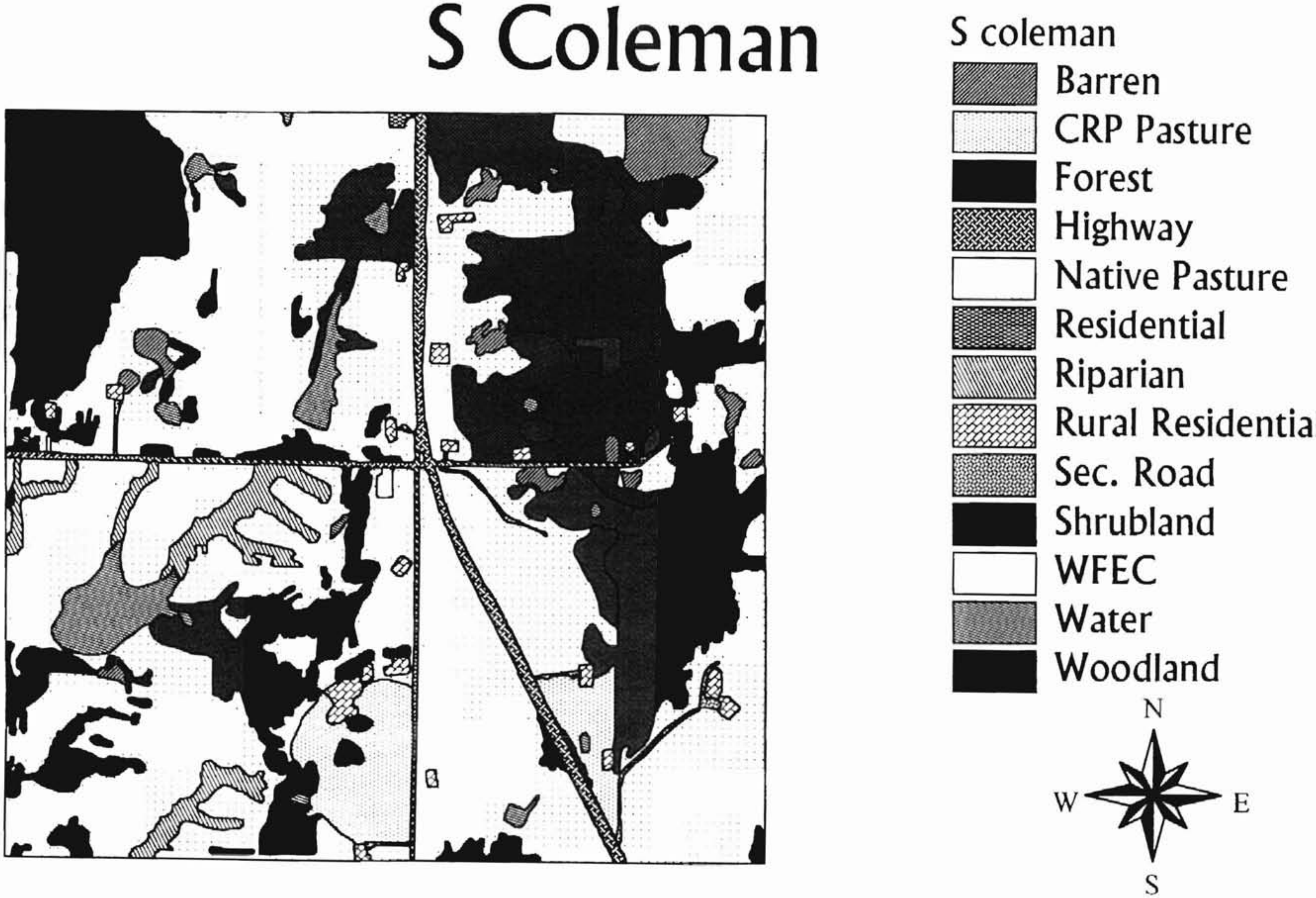
Prague1
Barren
CRP Pasture
Cropland
Cty Road
Forest
Industrial
Native Pasture
Prairie Riparian
Residential
Rural Residential
Sec. Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

Reagan

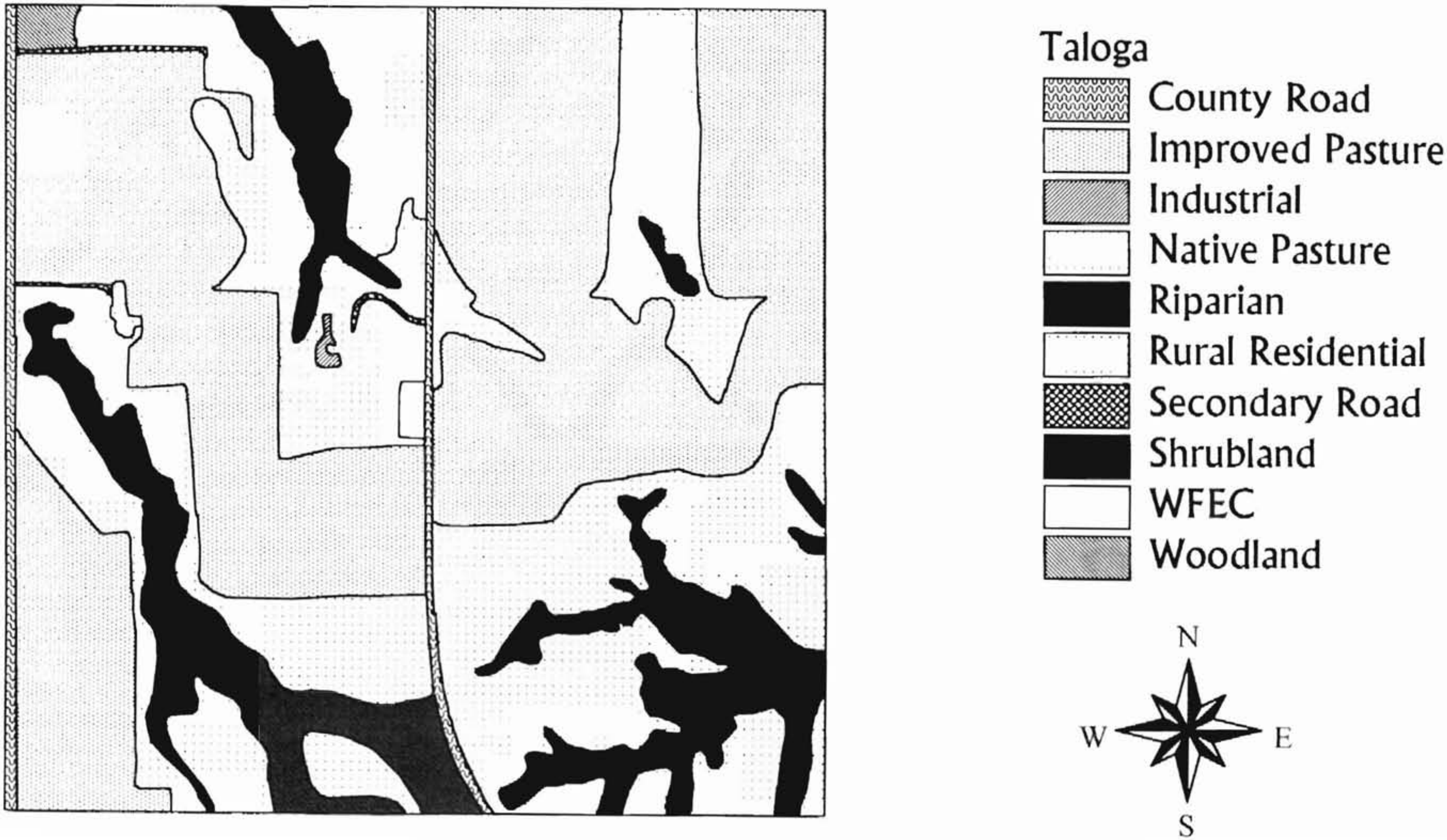


Reagan
County Road
Highway
Native Pasture
WFEC
Water
Woodland
N
W
E
S

S Coleman


S coleman
Barren
CRP Pasture
Forest
Highway
Native Pasture
Residential
Riparian
Rural Residential
Sec. Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

S Taloga


Taloga
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Riparian
Rural Residential
Secondary Road
Shrubland
WFEC
Woodland
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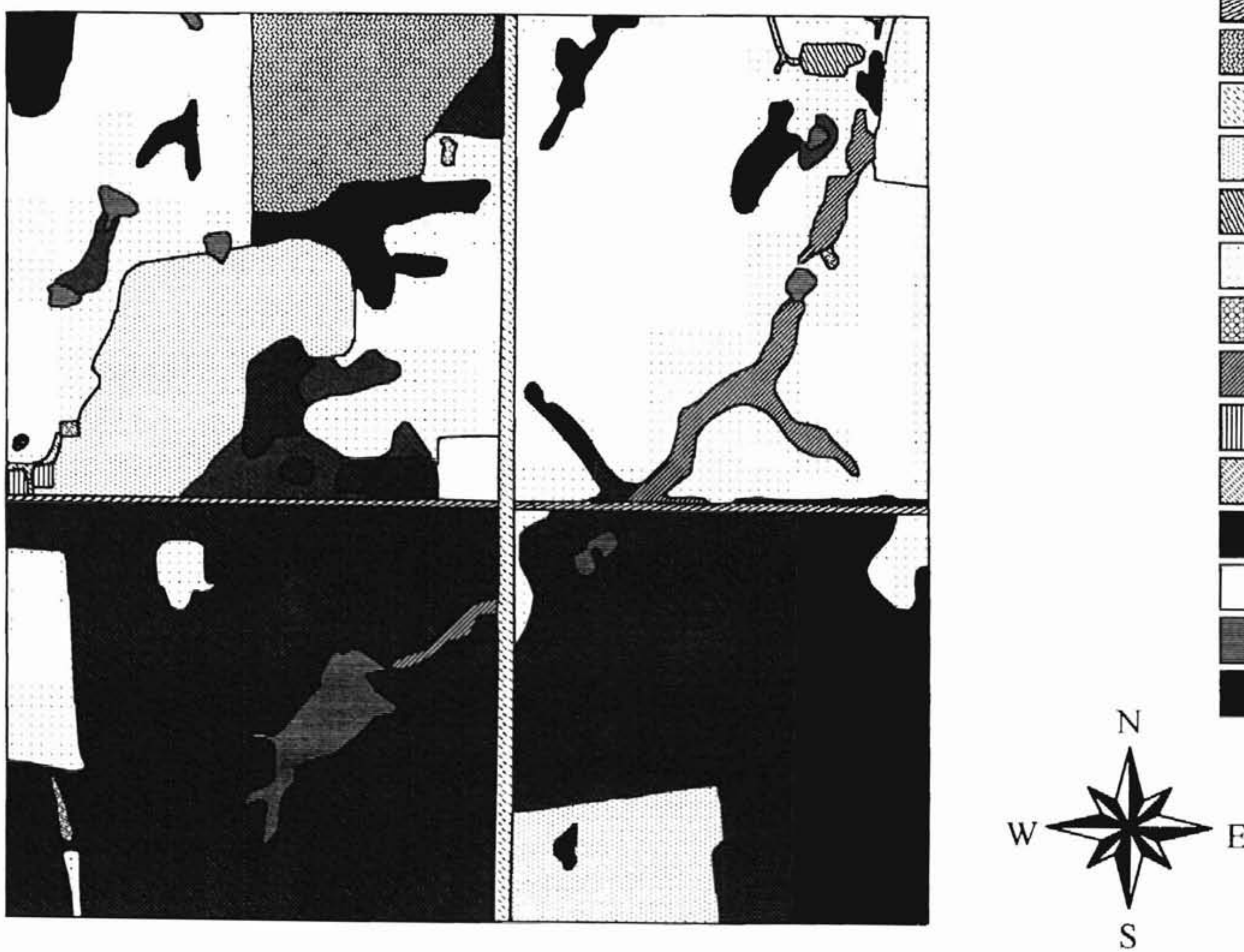
W
E
S

S Wilson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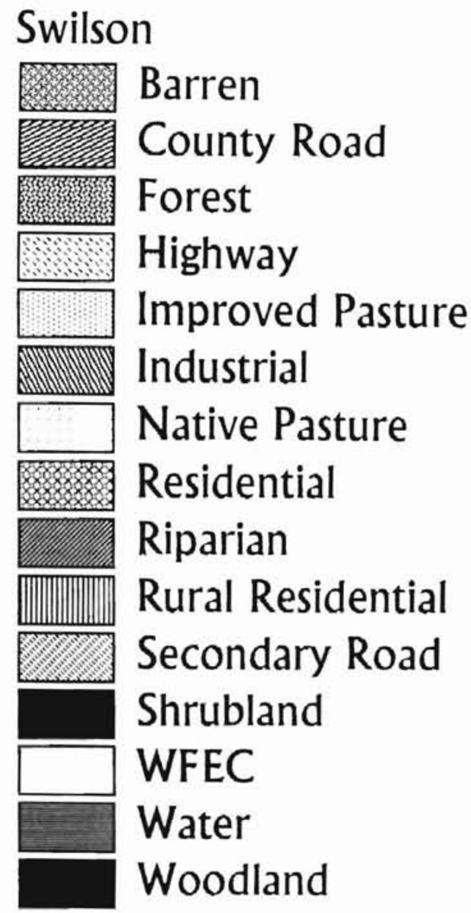
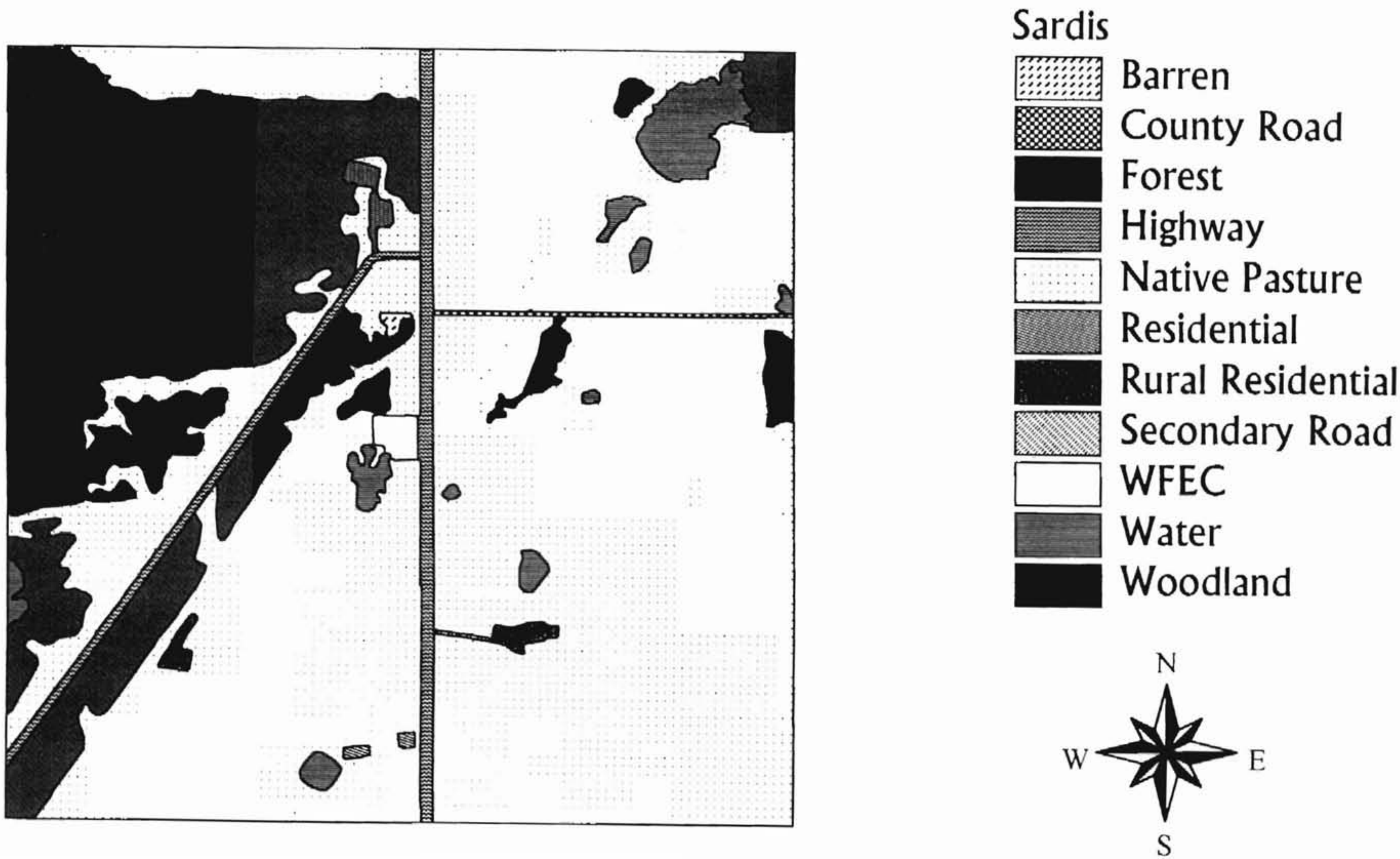
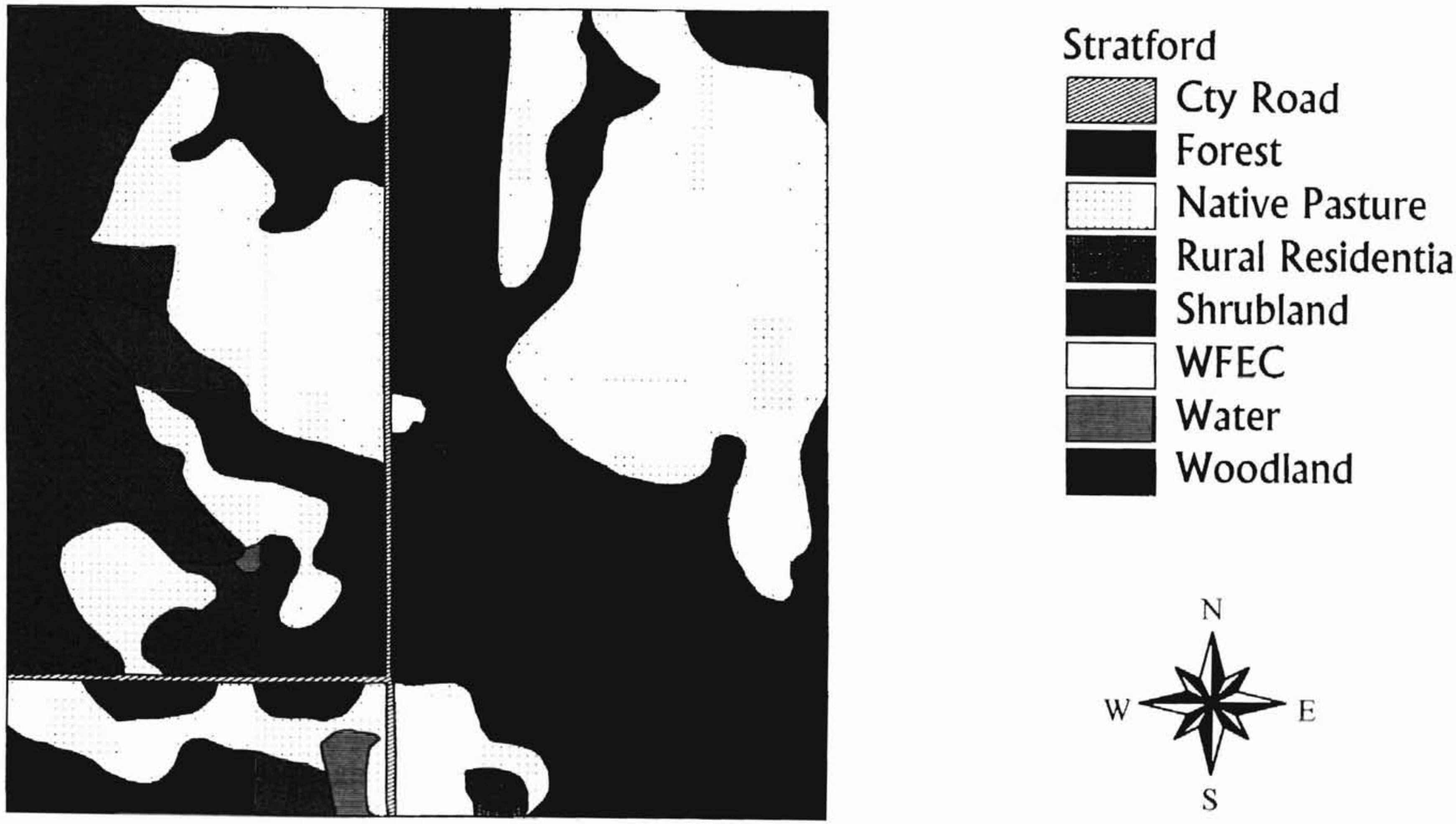

Swilson
Barren
County Road
Forest
Highway
Improved Pasture
Industrial
Native Pasture
Residential
Riparian
Rural Residential
Secondary Road
Shrubland
WFEC
Water
Woodland

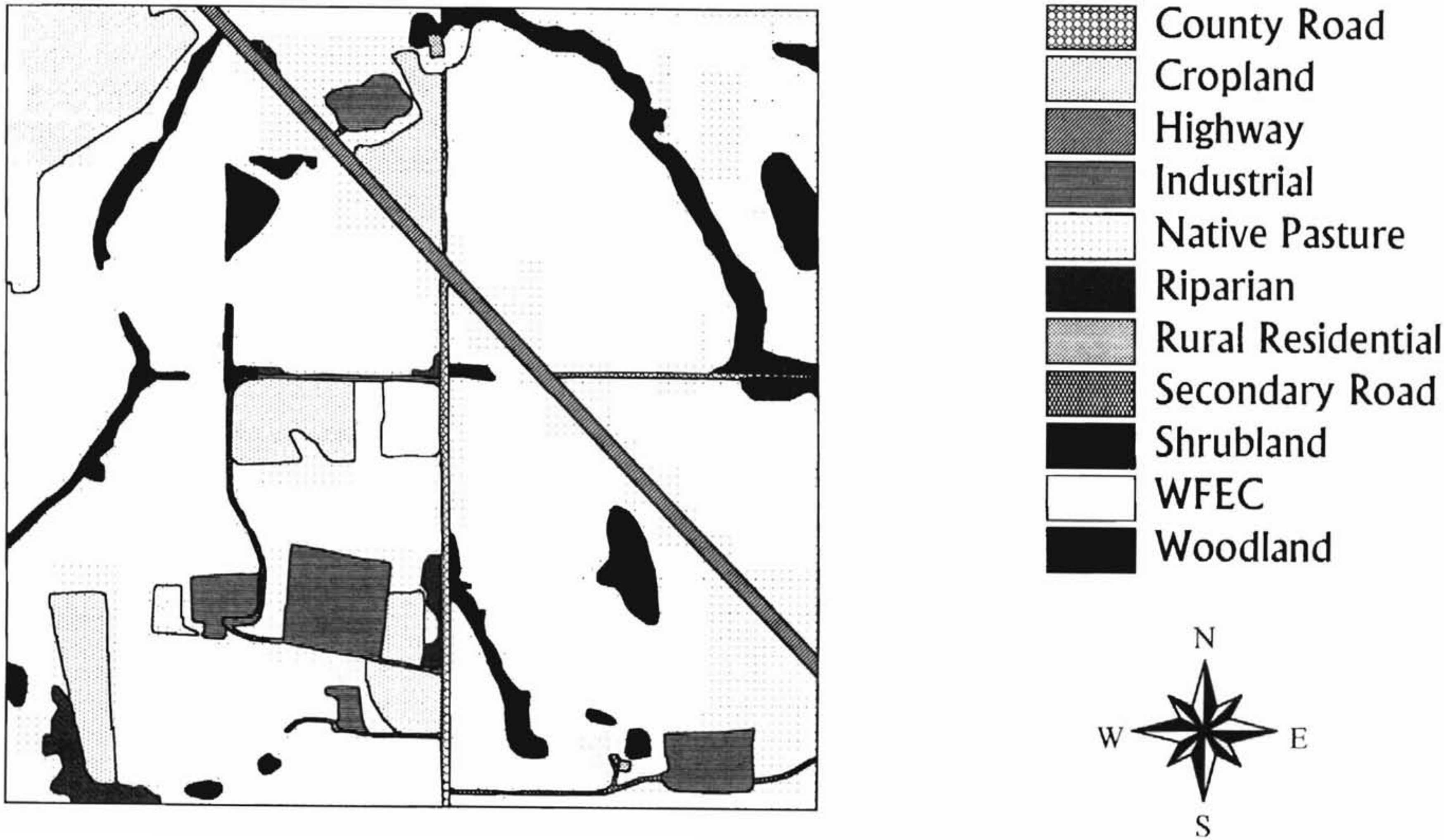
Sardis


Sardis
Barren
County Road
Forest
Highway
Native Pasture
Residential
Rural Residential
Secondary Road
WFEC
Water
Woodland
N
W
E
S

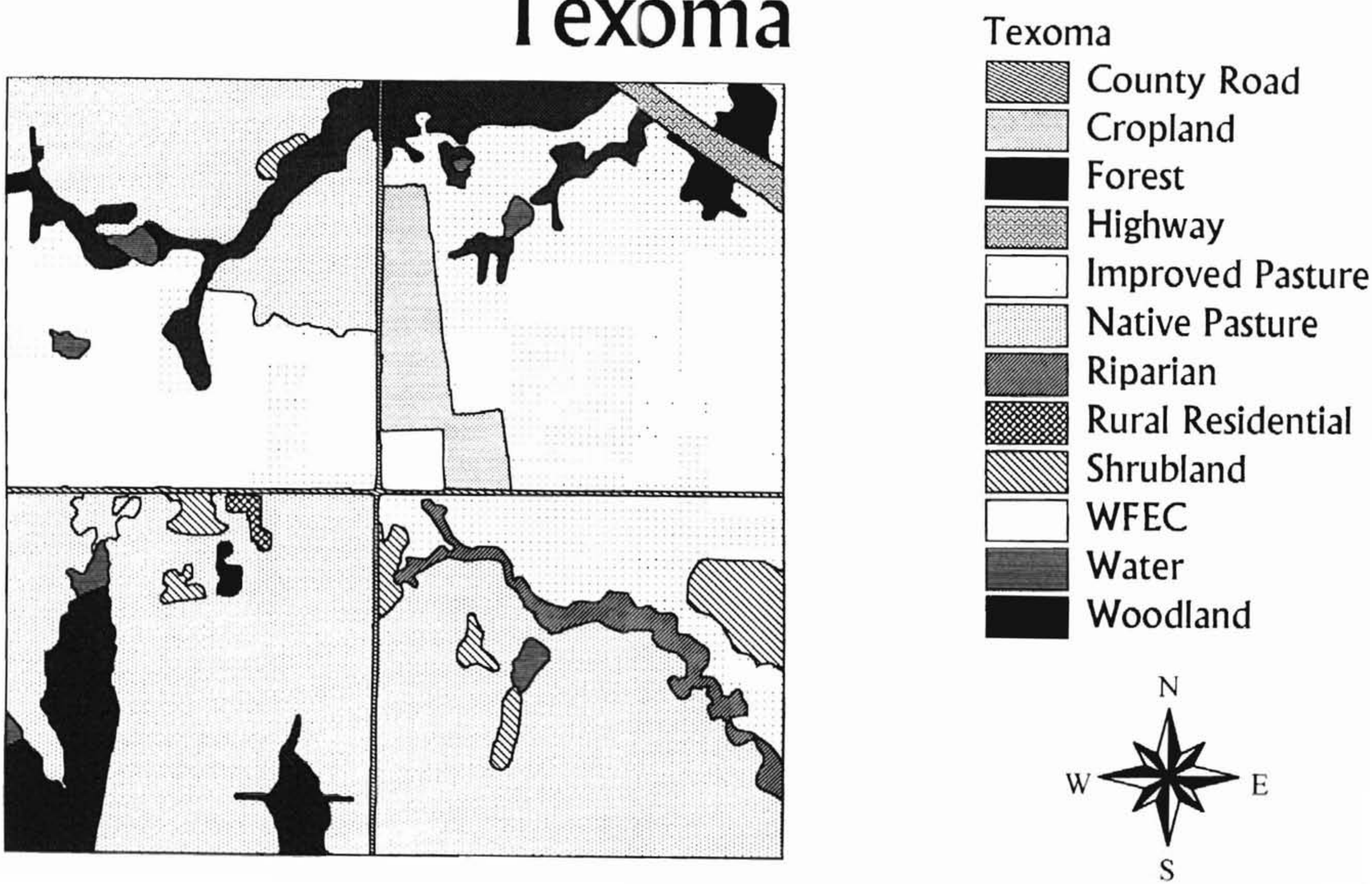
Stratford


Stratford
Cty Road
Forest
Native Pasture
Rural Residential
Shrubland
WFEC
Water
Woodland
N
W
E
S

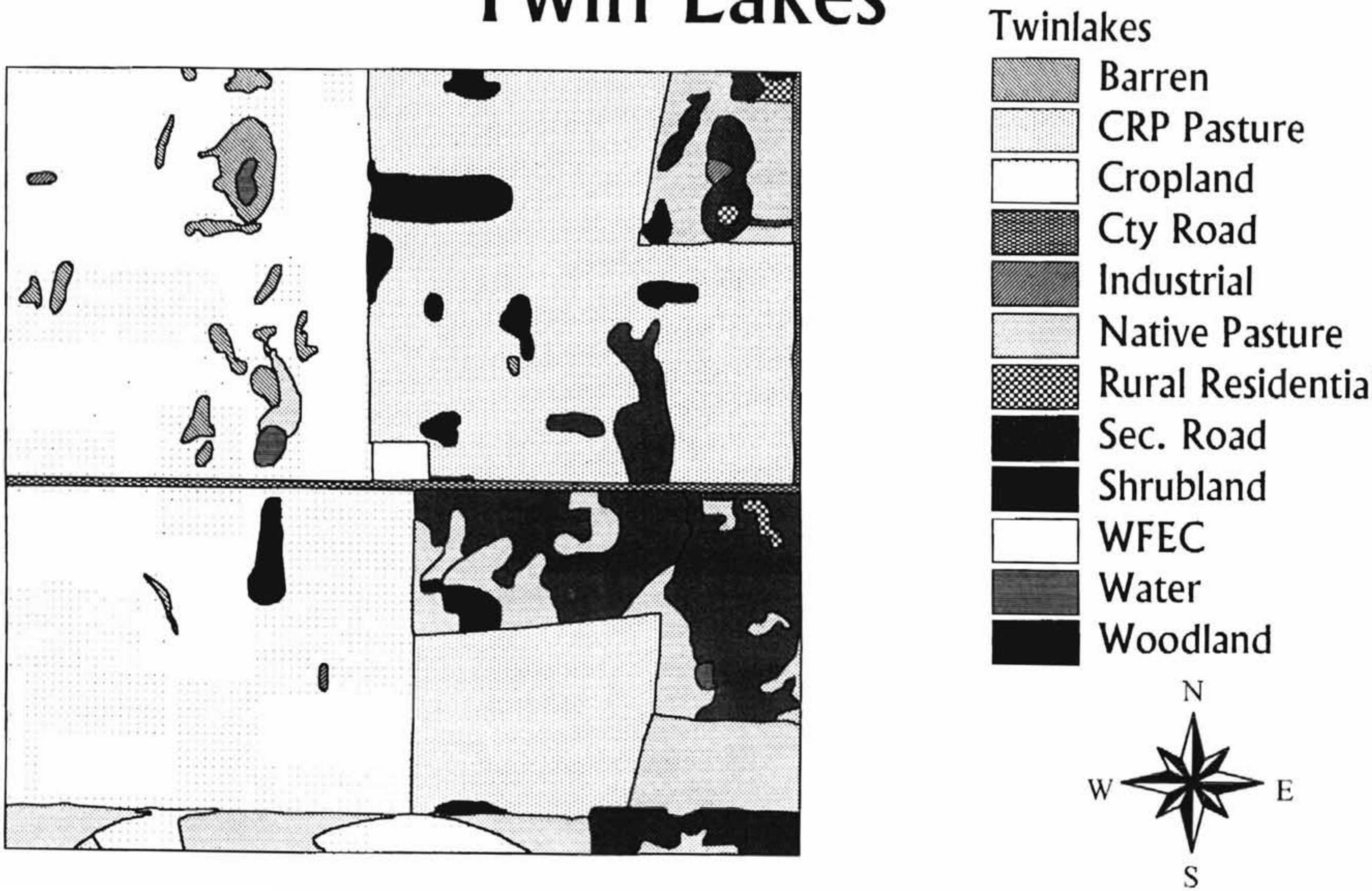
Sweetwater


Sweetwa
County Road
Cropland
Highway
Industrial
Native Pasture
Riparian
Rural Residential
Secondary Road
Shrubland
WFEC
Woodland
N
W
E
S

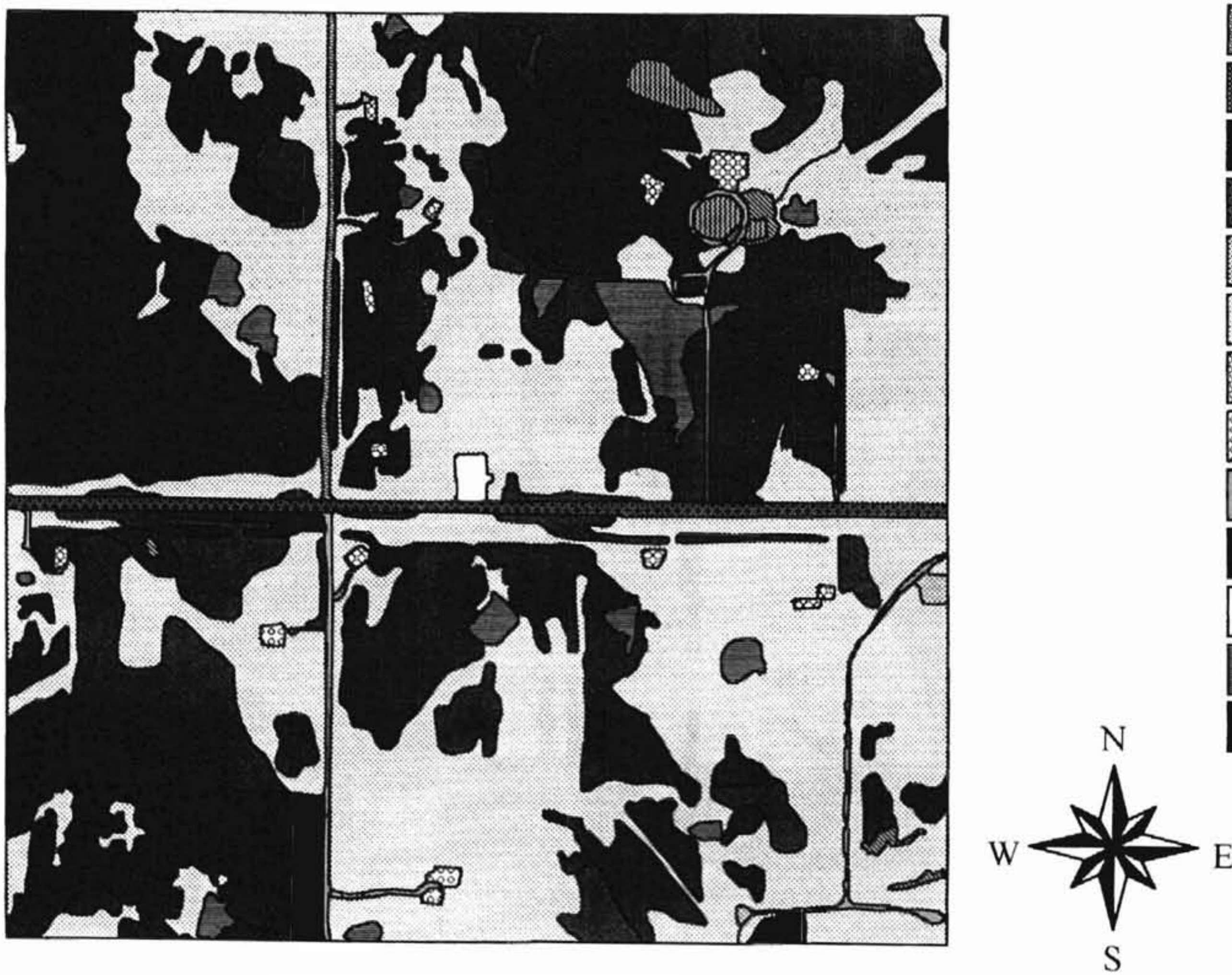
Texoma


Texoma
County Road
Cropland
Forest
Highway
Improved Pasture
Native Pasture
Riparian
Rural Residential
Shrubland
WFEC
Water
Woodland
N
W
E
S

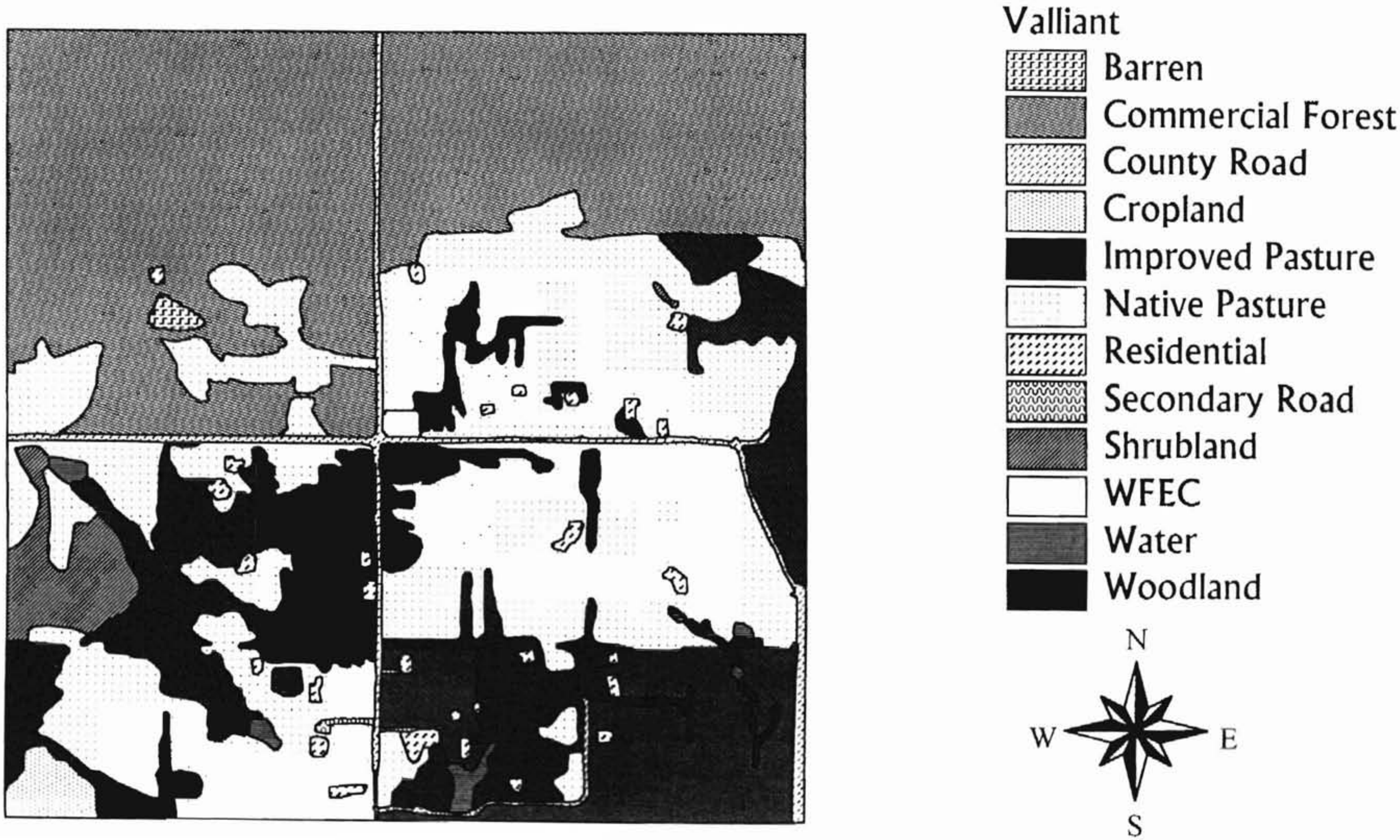
Twin Lakes


Twinlakes
Barren
CRP Pasture
Cropland
Cty Road
Industrial
Native Pasture
Rural Residential
Sec. Road
Shrubland
WFEC
Water
Woodland
N
W
E
S

United Clay


N
W
E
S
United clay
Barren
County Road
Cropland
Forest
Highway
Industrial
Native Pasture
Residential
Rural Residential
Secondary Road
Shrubland
WFEC
Water
Woodland

Valliant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Commercial Forest
County Road
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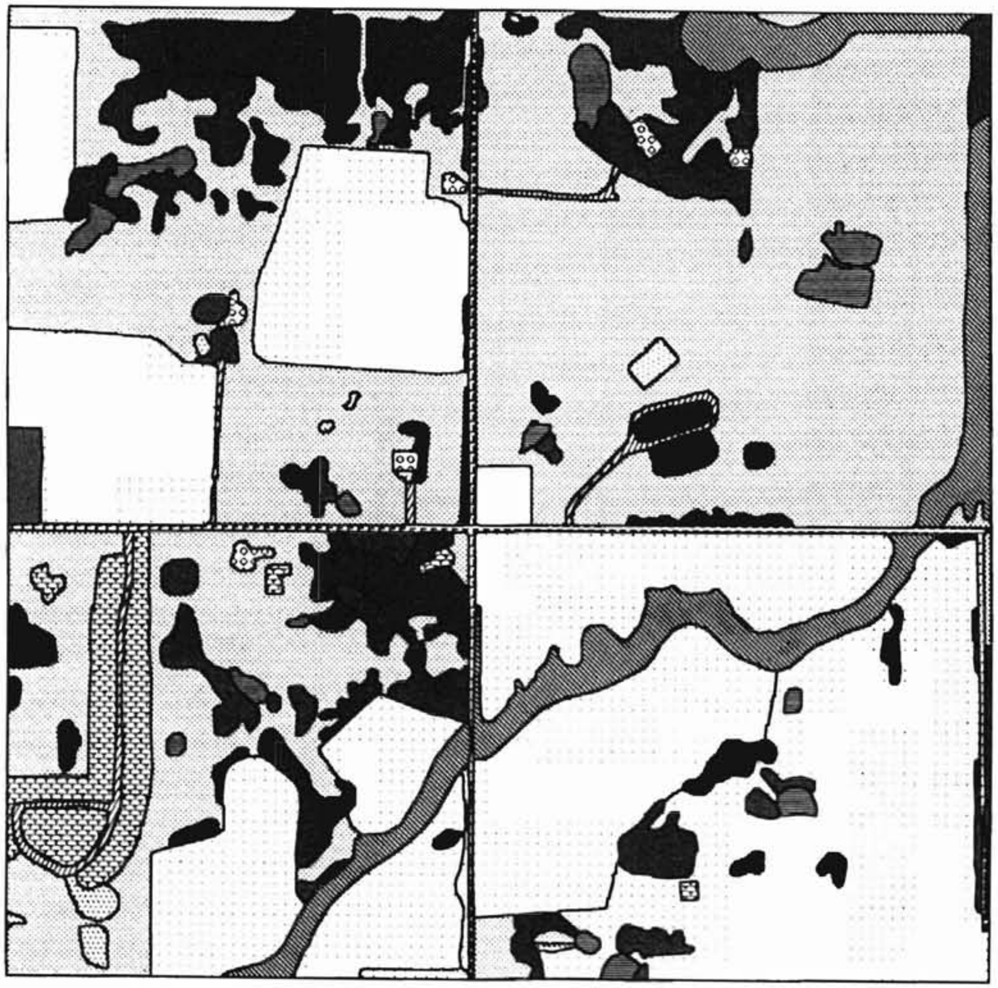
W Red Hill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Residential
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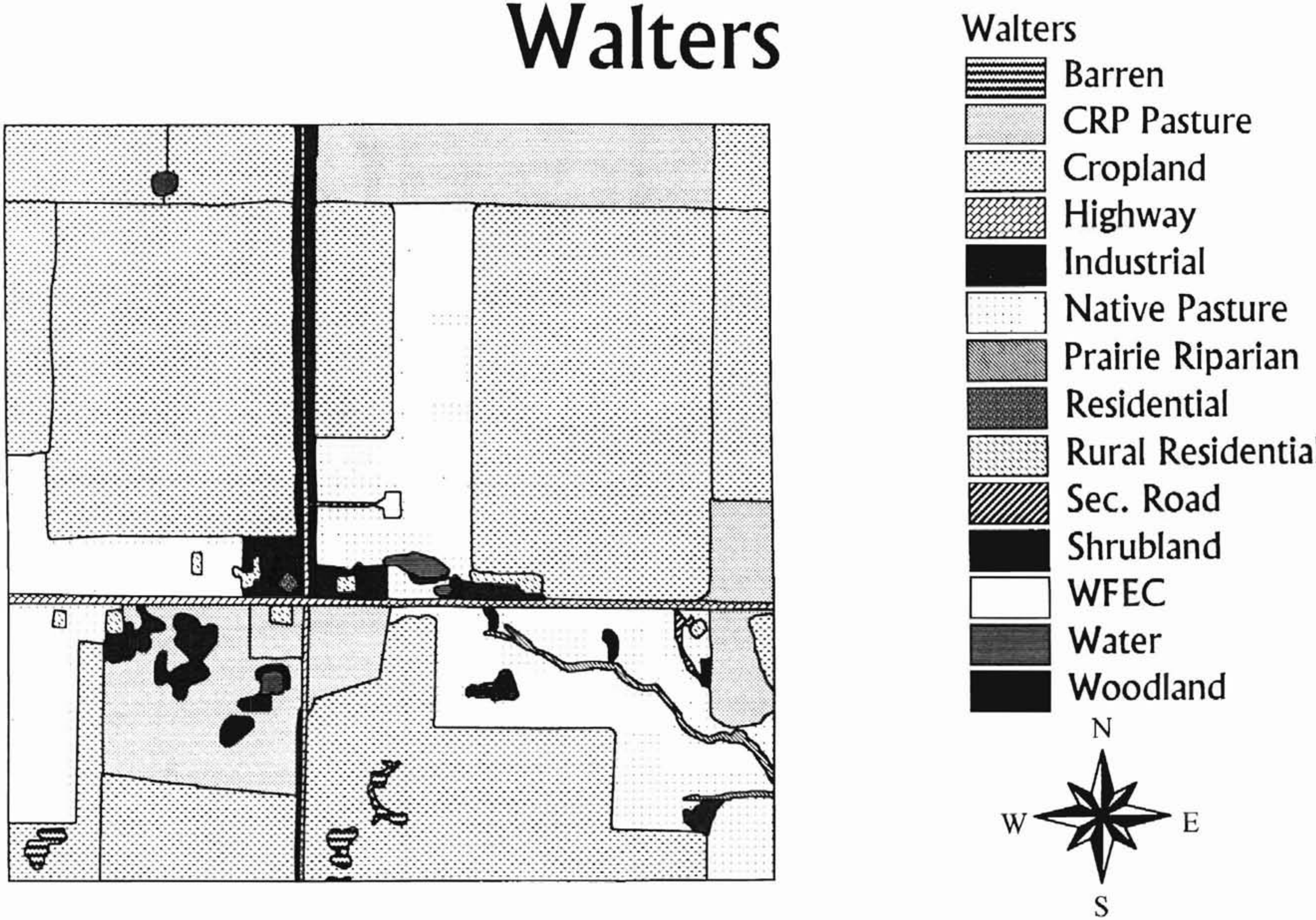
Walters



Walters
Barren
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Cropland
Highway
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Native Pasture
Prairie Riparian
Residential
Rural Residential
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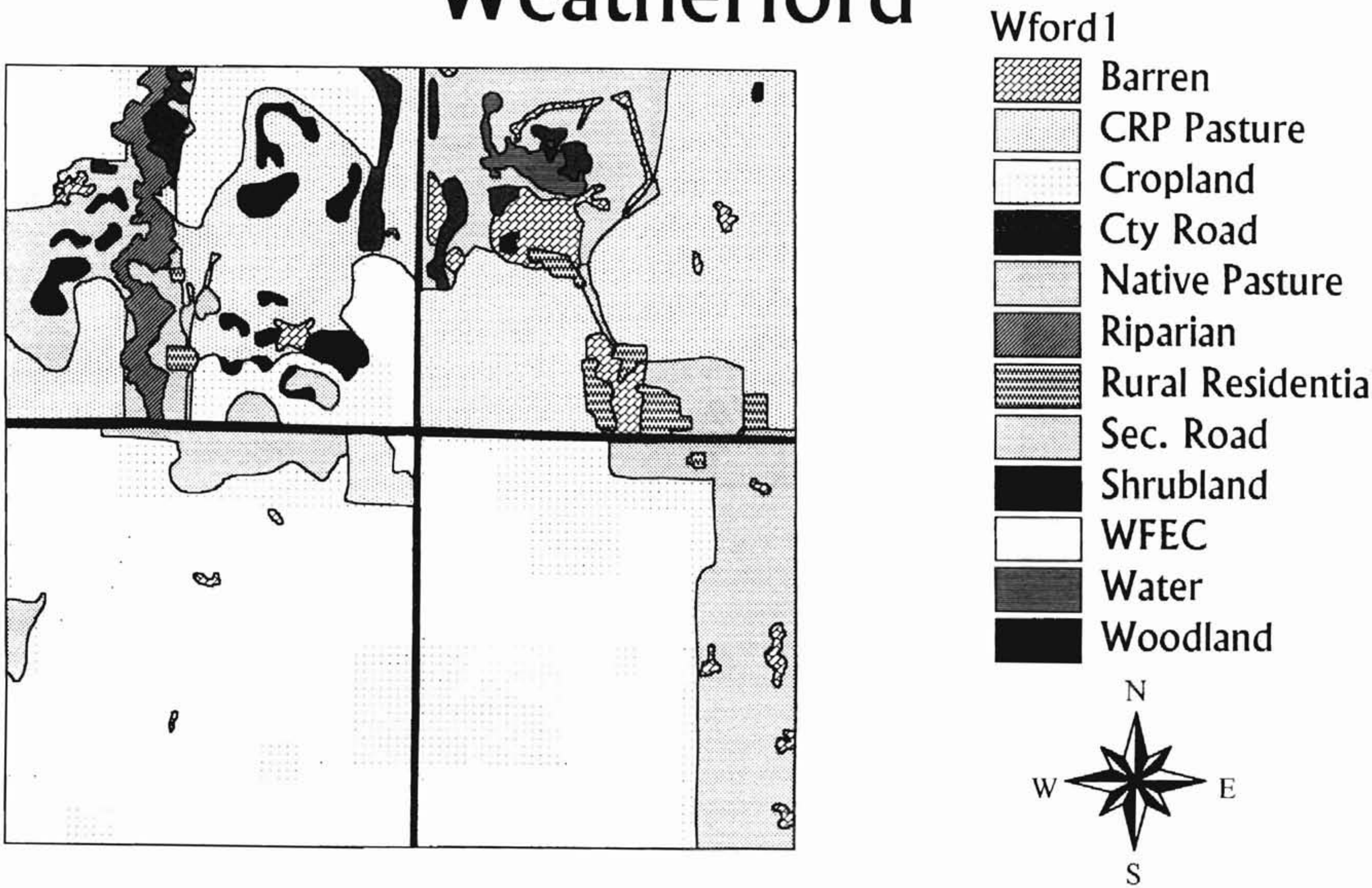
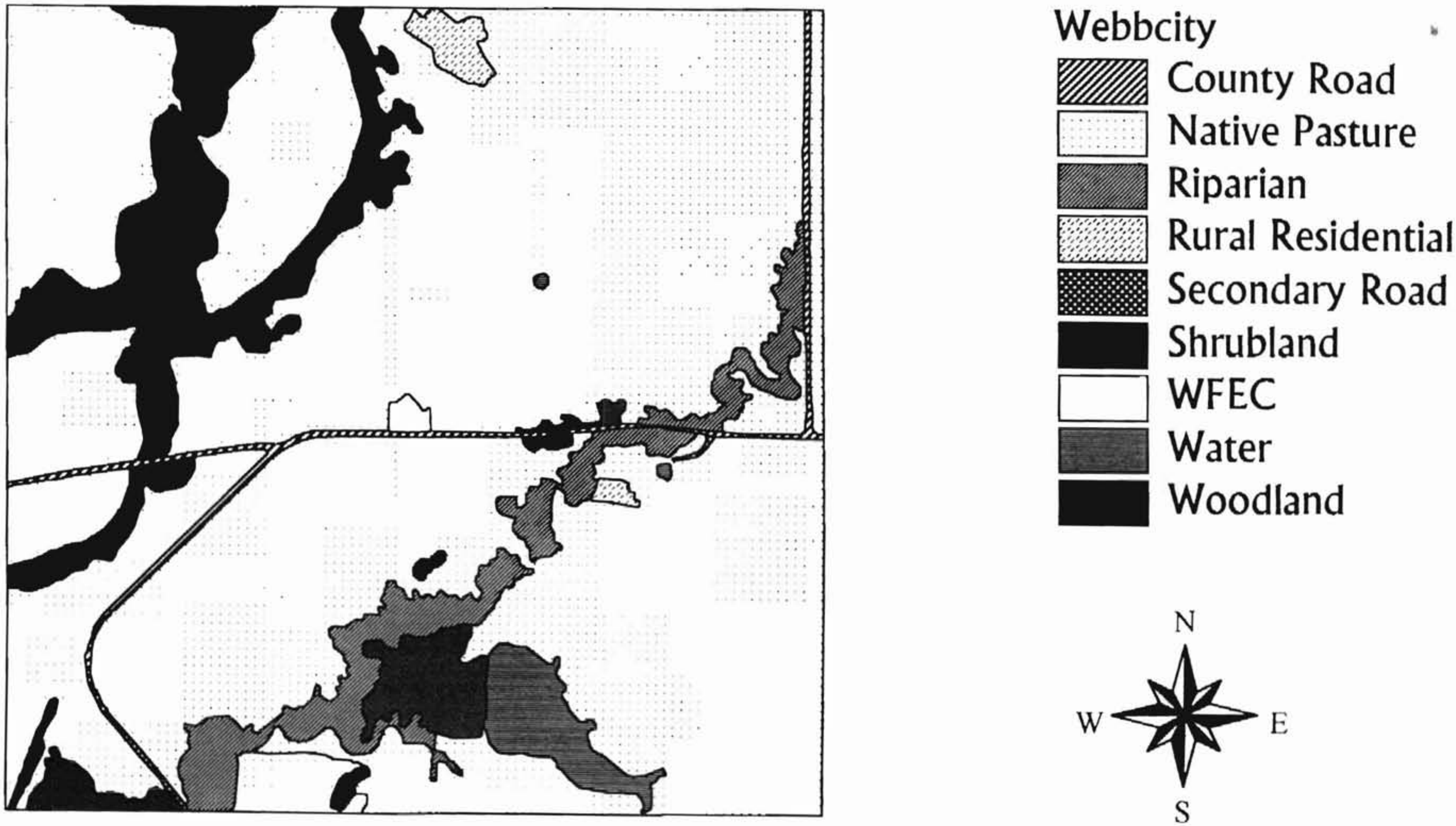
Weatherford



Webb City



Webbcity
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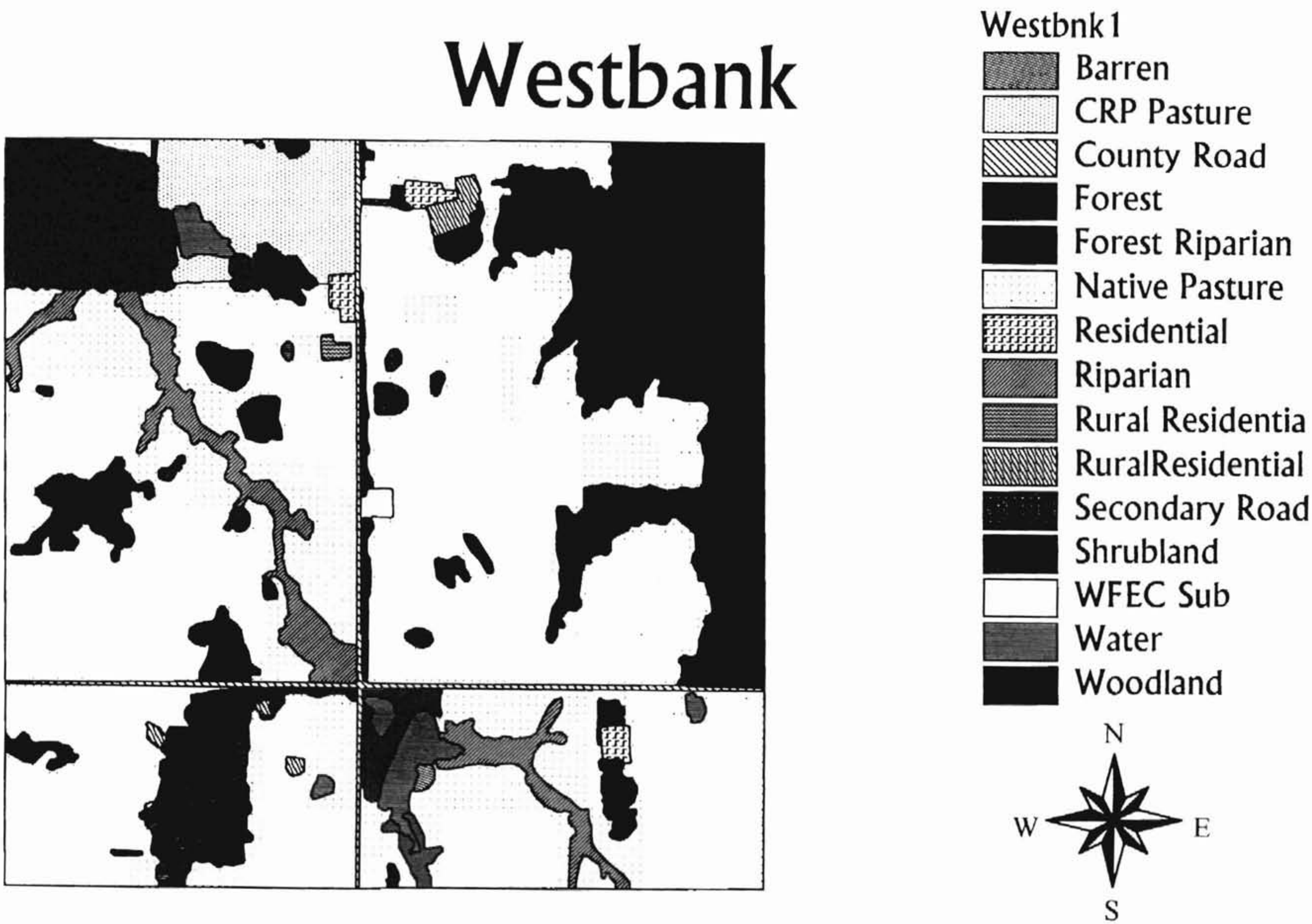
Westbank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APPENDIX B. List of bird species and number observed for 1996-97 bird surveys at 62 electrical substations in the WFEC in Oklahoma.

Species	1996	1997	Total
House Sparrow (Passer domesticus)	2142	2013	4155
European Starling (Sturnus vulgaris)	590	537	1127
Common Grackle (Quiscula quiscula)	618	482	1100
Eastern Meadowlark (Sturnella magna)	257	206	463
Mourning Dove (Zenaida macroura)	201	233	434
Western Kingbird (Tyrannus verticalis)	207	220	427
Barn Swallow (Hirundo rustica)	205	159	364
Scissor-tailed Flycatcher (Tyrannus forficatus)	165	148	313
Northern Mockingbird (Mimus polyglottos)	160	137	297
Dickcissel (Spiza americana)	121	104	225
American Crow (Corvus brachyrhynchos)	101	113	214
Northern Cardinal (Cardinalis cardinalis)	71	138	209
Red-winged Blackbird (Agelaius phoeniceus)	125	72	197
Killdeer (Charadrius vociferus)	82	110	192
Northern Bobwhite (Colinus virginianus)	106	80	186
Eastern Bluebird (Sialia sialis)	88	75	163
Lark Sparrow (Chondestes grammacus)	70	62	132
Field Sparrow (Spizella pusilla)	66	62	128
Brown-headed Cowbird (Molothrus ater)	54	44	98
Blue Jay (Cyanocitta cristata)	53	39	92

Turkey Vulture (Cathartes aura)	34	58	92
Yellow-billed Cuckoo (Coccyzus americanus)	47	43	90
Carolina Chickadee (Parus carolinensis)	32	52	84
Blue Grosbeak (Guiraca caerulea)	23	40	63
Tufted Titmouse (Parus bicolor)	32	30	62
Grasshopper Sparrow(Ammodramus savannarum)	16	45	61
Red-headed Woodpecker (Melanerpes erthrocephalus)	28	32	60
Western Meadowlark (Sturnella neglecta)	30	28	58
Eastern Kingbird (Tyrannus tyrannus)	34	24	58
Painted Bunting (Passerina ciris)	27	30	57
Cedar Waxwing (Bombycilla cedrorum)	55	0	55
American Robin (Turdus migratorus)	32	21	53
Red-tailed Hawk (Buteo jamaicensis)	28	23	51
Red-bellied Woodpecker (Melanerpes carolinus)	21	26	47
Indigo Bunting (Passerina cyanea)	25	17	42
Purple Martin (Progne subis)	26	15	41
Common Nighthawk (Chordeiles minor)	24	11	35
Cliff Swallow (Hirundo pyrrhonota)	18	16	34
Downy Woodpecker (Picoides pubescens)	16	16	32
Carolina Wren (Thryothorus ludovicianus)	13	18	31
American Goldfinch (Carduelis tristis)	17	10	27
Bewick's Wren (Thryomanes bewickii)	10	16	26
Cattle Egret (Bubulcus ibis)	10	25	35

American Kestral (Falco sparverius)	7	15	22
Chimney Swift (Chaetura pelagica)	5	16	21
Orchard Oriole (Icterus spurius)	6	12	18
Mississippi Kite (Ictinia mississippiensis)	11	7	18
Blue Gray Gnatcatcher (Polioptila caerulea)	6	10	16
Loggerhead Shrike (Lanius ludovicianus)	10	5	15
Common Yellowthroat (Geothlypis trichas)	1	14	15
Song Sparrow (Melospiza melodia)	4	10	14
Northern Oriole (Icterus galbula)	7	7	14
Red-eyed Vireo (Vireo olivaceus)	6	6	12
Rudy-throated Hummingbird (Archilochus colubris)	5	5	10
Black Vulture (Coragyps atratus)	8	2	10
Great Blue Heron (Ardea herodias)	6	3	9
White-breasted Nuthatch (Sitta carolinensis)	0	8	8
Chipping Sparrow (Spizella passerina)	0	8	8
House Finch (Carpodacus mexicanus)	5	3	8
Northern Rough-winged Swallow (Stelgidopteri serripennis)	2	6	8
Eastern Wood Peewee (Contopus virens)	4	3	7
Great Crested Flycatcher (Myiarchus crinitus)	6	1	7
Mallard (Anas platyrhynchos)	1	6	7
Horned Lark (Eremophila alpestris)	0	6	6
Eastern Phoebe (Sayornis phoebe)	1	4	5
Rock Dove (Columba livia)	0	5	5

Black and White Warbler (Mniotilla varia)	0	5	5
Northern Flicker (Colaptes auratus)	0	5	5
Pileated Woodpecker (Dryocopus pileatus)	1	4	5
Ruby-crowned Kinglet (Regulus calendula)	0	4	4
Brown Thrasher (Toxostoma rufum)	2	2	4
Great Egret (Casmerodius albus)	0	4	4
Kentucky Warbler (Oporornis formosus)	1	3	4
Yellow-breasted Chat (Icteris virens)	0	3	3
Hairy Woodpecker (Picoides villosus)	2	1	3
Great-tailed Grackle (Quiscalus mexicanus)	1	2	3
Clay-colored Sparrow (Spizella pallida)	0	2	2
Bell's Vireo (Vireo bellii)	2	0	2
Canada Goose (Branta canadensis)	2	0	2
Pine Warbler (Dendroica pinus)	0	2	2
Yellow-bellied Sapsucker (Sphyrapicus varius)	0	2	2
American Redstart (Setophaga ruticilla)	0	2	2
White-eyed Vireo (Vireo griseus)	0	2	2
Little Blue Heron (Egretta caerulea)	0	2	2
Wood Duck (Aix sponsa)	0	2	2
Yellow-headed Blackbird (Xanthocephalus xanthocephalus)	1	1	2
Belted Kingfisher (Ceryle alcyon)	1	1	2
Northern Harrier (Circus cyaneus)	0	2	2
Yellow-rumped Warbler (Dendroica coronata)	0	1	1

Blue-winged Teal (Anas discors)	0	1	1
Yellow-throated Warbler (Dendroica dominica)	0	1	1
Barred Owl (Strix varia)	0	1	1
Rufous-sided Towhee (Pipilo erythrophthalmus)	0	1	1
Prairie Warbler (Dendroica discolor)	0	1	1
Prothonotary Warbler (Protonotari citrea)	1	0	1
Red-cockaded Woodpecker (Picoides borealis)	1	0	1
Nashville Warbler (Vermivora ruficapilla)	0	1	1
Lincoln's Sparrow (Melospiza lincolnii)	0	1	1
Orange-crowned Warbler (Vermivora celata)	0	1	1
Red-shouldered Hawk (Buteo lineatus)	1	0	1
Northern Parula (Parula americana)	0	1	1
Yellow Warbler (Dendroica petechia)	0	1	1
Yellow-crowned Night Heron (Nyctanassa violacea)	0	1	1
Gray Catbird (Dumetella carolinensis)	0	1	1
Green-backed Heron (Butorides striatus)	0	1	1
Swainson's Hawk (Buteo swainsoni)	0	1	1
Warbling Vireo (Vireo gilvus)	0	1	1
Dark-eyed Junco (Junco hyemalis)	0	1	1
Chuck-will's Widow (Caprimulgus carolinensis)	1	1	1
Cooper's Hawk (Accipiter cooprii)	0	1	1
Louisiana Waterthrush (Seiurus motacilla)	0	1	1
Summer Tanager (Piranga rubra)	0	1	1

Black-capped Vireo (Vireo atricapillus)	0	1	1
Harris' Sparrow (Zonotrichia querula)	0	1	1
White-throated Sparrow (Zonotrichia albicollis)	0	1	1
Total Birds	6198	5827	12065
Total Species	77	105	115

VITA

John B. James

Candidate for the Degree of

Master of Science

Thesis: FACTORS AFFECTING WILDLIFE RELATED POWER OUTAGES IN ELECTRICAL SUBSTATIONS

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