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Radar for Small-Scale Land-Use Mapping

Land-use regions were delimited using radar imagery, but additional testing is needed to verify the utility of the method employed.

ABSTRACT: *Small-scale (1:250,000 and smaller) land-use maps are a major concern not only to geographers but also to national and regional planners. Unfortunately, such maps are usually out of date by the time they are printed. An interpretation key consisting of five physical and cultural characteristics of the environment evident on radar imagery is used to create land-use regions. Regions and borders interpreted from radar are compared with those found on two existing land-use maps created by traditional methods. Radar imagery can be used to create a small-scale land-use map with regions comparable to those found on existing land-use maps. However, the radar regions depict something more than land use and should be termed rural landscape regions. Perhaps the optimum application would involve the use of radar imagery to update existing maps and in combination with established methods to create new maps. Radar imagery is a useful tool for this application and should be further investigated.*

INTRODUCTION

WITH TODAY'S growing population pressures on agricultural resources and arable land, current and accurate small-scale land-use maps (1:250,000 and smaller) are a necessity. Such maps and data are essential for local, regional, and national planning in both the economically more advanced countries of the world and in the developing nations. The purpose and nature of these maps is not to isolate or portray detailed features but provide the observer with an overall picture. As visual heuristics land-use maps support land-use data and can be used to focus attention on areas in need of more detailed investigation. Such maps are, then, an outline of more complex entities (e.g., crop types or soil capabilities) and offer a condensed and averaged representation.

With the demands of today's society, faster and better methods of land-use mapping are a necessity if such maps are to be viable planning aids. Whereas considerable work has been done in applying photography to small-scale land-use mapping very little has been done with regard to non-photographic sensors (aside from the recent Earth Resources Technology Satellite experiments). The potential of such sensors as multispectral scanners and radar is virtually unknown. Obviously this is unrealistic with so much of the world dependent on, but lacking, land-use data. Only after the utility of such remote-sensing systems has been documented can it be determined if the accrued benefits will exceed the expense of implementing them. It was with such work and demands in mind that the present analysis was undertaken.

The purpose of this study was to investigate the utility of Side-Looking Airborne Radar (SLAR) for general land-use mapping at a small scale (1:250,000 or smaller). As used here, land use pertains to general classes of land use or landscape regions (e.g., mixed farming with woodland) not particular elements such as crop type on a field-by-field basis. Of the few studies related to this end, three have probably received the widest exposure. Simpson concentrated on delimiting *built up* areas and attained marked success in separating rural and urban lands in New England, but did not attempt a more detailed classification.[1] Utilizing two small test areas (approximately 160 square miles each) Barr and Miles developed a method of employing radar imagery as a supplement to conventional photographs for regional site selection of highways.[2] Only the study completed by Nunnally devoted itself entirely to examining radar as a land-use mapping tool.[3] Using a test area 50 miles long near Asheville, North Carolina, Nunnally delimited 11 distinct and rather detailed area districts. Although the regions appeared to correlate with some known detailed land-use types, he concluded that the regions did not all belong the same hierarchical level. Owing to the size of the study area, he also considered that the interpretations were not sufficiently complete, and additional study was warranted to demonstrate the eventual value of radar in determining regional boundaries.

What was needed for examination was an extensive area of varied topography and land use. Such a broad diverse expanse would provide an idea of the consistency of radar imagery as a mapping base in delimiting land-use regions between environments. In addition, an evaluation could be made as to how well a land-use map created from radar imagery compared with more traditional maps in regard to compatibility of boundaries and region descriptions. Specifically, it would be possible to discern if radar imagery could be employed to update maps presently being used.

In a further attempt to explore the potential of radar imagery for such small-scale land-use mapping, this study utilized radar imagery that covered an area approximately 12 miles wide and 1500 miles long, stretching from eastern Minnesota to northern Utah — an area flown by an aircraft using the Westinghouse AN/APQ-97 K-band SLAR system. As this imagery (at a scale of approximately 1:180,000) covered several heterogeneous topographic and land-use regions, it was believed to be an adequate test of the potential of using radar imagery as a mapping tool to delimit such small-scale, land-use, landscape regions as: mostly cropland, mostly pasture, or grazing.

Key Selection

The first step in this direction was the development of a key for land-use regionalization. To facilitate the evolution of the key's components, features of the environment that were manifested on the radar imagery were divided into two broad categories: physical and cultural. As each of these environmental aspects affects the other, it was possible to detect differences in land-use practices by studying variations in this relationship. Upon further investigation it became clear that, owing to their compatibility and complementarity, physical and cultural characteristics visible on radar imagery and relevant to land-use mapping could be condensed into the following five components:

- *Surface Configuration*. The topography and drainage network of an area. Specifically, the relative relief, slope, and general geomorphic-physical setting of an area visible on radar imagery.
- *Natural Vegetation*. The indigenous plant communities found on the land (e.g., riparian) as opposed to messicol vegetation such as hay fields or cropped fields.
- *Field Patterns and Size*. The location and shape of fields in relation to the overall scene.
- *Settlement Pattern*. The relative density, arrangement, and location of farms and towns.
- *Transportation/Communications Network*. The location, relative density, and directions of roads and railroads. Since portions of high tension power lines are somewhat *visible* on radar, they were included as a secondary part of this characteristic.

Considered separately, differences in each of these characteristics were noticeable along the study strip and changes could be detected. More importantly, these physical and cultural phenomena visible on radar imagery formed different land-use regions. The procedure employed to define these regions is discussed in the following paragraphs.

Creation of a Land Use Region

Ideally, any regionalization endeavor should strive for maximum inter-region variation and minimum intra-region variation. The result will be the greatest contrast between regions and greatest homogeneity within. Yet, the characteristics used in defining regions must be allowed some individual flexibility, permitting the exact degree of homogeneity to change from region to region. For example, in one instance the chief difference between two regions may be the field pattern, with vegetation of minor importance. Within-region variation allowable of field pattern would be minimal because a minor change in this component will be a major factor in locating the border. Vegetation changes would be a contributing factor, but minor changes would not be as significant. The situation would be reversed, however, if grazing were the dominant activity in a semiarid area. It must also be remembered that the spatial pattern of composite regions is different from the pattern of the components considered individually. Each characteristic, in effect, acts as a piece of the puzzle and, like the puzzle, the appearance of the whole is distinct from the appearance of the parts.

To be classified as a region, the combination and intermixing of the relevant environmental characteristics had to appear homogeneous and distinct if compared to adjacent areas. That is, terrain differences on the imagery had to be sufficiently noticeable, using the five characteristics, that a distinction or change in land use could be recognized. By definition, delimiting borders and creating land-use regions requires arbitrary decisions. Such a process is customary in small-scale mapping efforts.[4] In attempting to create land-use regions with radar imagery such discretionary measures were essential.

In this study, the imagery was first analyzed with regard to each of the five characteristics to determine where and how the spatial pattern of the individual elements changed. As the radar imagery was a continuous film strip, it was possible to describe areas and changes sequentially using transparent overlays. Relative locations of these features or characteristics were also noted. The imagery and overlays were then examined to determine how the composite spatial pattern (i.e., the land use or landscape) had changed. Using the five characteristics, borders were drawn separating the regions. Admittedly, this is a qualitative approach and assessment. Although statistically valid sampling techniques are highly desirable and are being explored, they are beyond the scope of this report. As will be shown in this study, sufficient information is available by this qualitative method to support the validity of radar imagery as a tool for small-scale land-use mapping efforts. Not only is it possible to create such a map, but the regions created are remarkably compatible in extent to those found on more traditional maps.

Fourteen separate land-use regions were fashioned after analyzing the radar imagery of the entire study area. This regions are listed below and their relative locations indicated in Figure 1. In Table 1 each radar land-use region is briefly described in terms of the five items used to characterize it. Inasmuch as the matrix descriptions are limited by space, the reader is cautioned against evaluating the region on this basis alone. It is intended to provide only an outline of the regions.

I. Commercial Cropland and Livestock.
II. Commercial Cropland with Pasture and Coppice Woodlands.
III. Subhumid Cropland with Pasture.
IV. Subhumid Pasture with Irrigated and Dryland Farming.
V. Semiarid Limited Grazing and Pasture — Dissected Hills.
VI. Forest, Meadow and Limited Grazing — Low Mountains.
VII. Semiarid Pasture and Grazing — Tablelands.
VIII. Semiarid Limited Grazing — Dissected Low and High Hills.
IX. Limited Grazing with Sparse Scrub — High Hills.
X. Mostly Ungrazed Semiarid Foothills with Mining.
XI. Semiarid Tablelands with Limited Grazing and River Valley Cropland.
XII. Mining and Mostly Ungrazed Scrub—Semiarid Tablelands and Low Mountains.

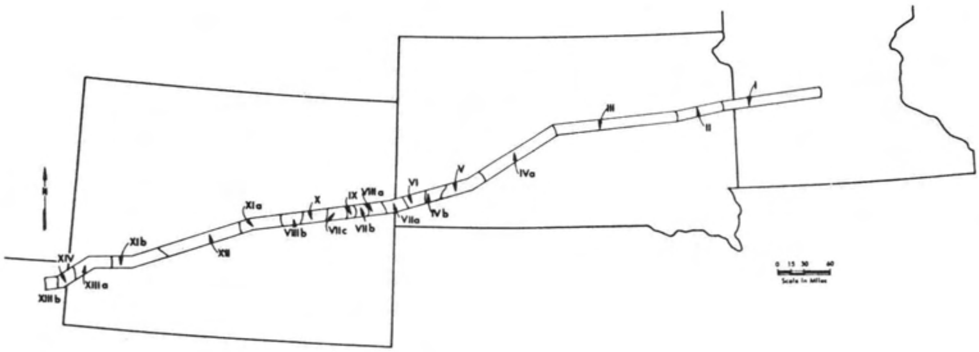

FIG. 1. Radar land-use regions and study area.

TABLE 1. CHARACTERISTICS OF LAND-USE REGIONS AS INTERPRETED FROM RADAR IMAGERY.

Region	Surface Configuration	Vegetation	Field Pattern and Size	Settlement Pattern	Transportation/ Communication Network
I	no evidence of steep slope and relief; topography appears very gentle—almost level land.	bumpy areas around farmsteads are windbreaks; trees along river banks; many ponds and lakes. Light gray grainy areas indicate marshes.	grid pattern of rectangular fields, some abutting stream banks; variety of gray tones and textures indicate variety of crops; fields are generally small, 40-80 acres.	farmsteads closely spaced; small towns rather frequent and probably act as service centers for rural community.	number of farmsteads and field pattern imply a rather dense road net, major roads intersect at towns, many secondary roads visible; portions of power lines also visible.
II	some evidence of erosion and relief visible in form of streams and waterways in fields. General picture is one of gentle rolling plains.	coppices of trees in mottled fields inferred from coarse medium gray appearance; coarse, irregular light gray and white areas hint of marshy areas with reeds and grasses; streams and rivers are suggested by non-rectangular field borders.	rectangular pattern apparent but many fields conform to natural borders and are irregular in shape; little contrast in tone between fields; fields appear larger than in Region I.	farmsteads appear periodically in rectangular field pattern; spaced farther apart and less distinct than in Region I. Settlements are similar in size and frequency.	grid pattern visible but fewer roads and power lines create a coarser network than Region I.
III	generally, area appears of gentle relief and continuation of rolling plains of Region II. Some relief and erosion evident; presence of small dams and ponds.	no marshy areas or lakes; absence of windbreaks; trees seem confined to stream banks.	larger fields but still rectangular grid pattern; some fields have diamond pattern typical of small grain harvest; other mottled fields contain ponds suggesting pasture.	farmsteads and towns spaced farther apart; bright return of farmsteads—perhaps due to metal roofs, seem to be more buildings per farm due to size and brightness of high return area.	coarse road net in a grid pattern; fewer roads appear.
IV	much more diverse topography than previous regions; gentle relief and small streams and faintly visible tributaries; areas of moderate or sharp relief and small plateaus; visible erosion apparent on slopes.	lack of tone and texture contrast along streams hints of fewer trees than previously; gray tone is lighter and texture on slopes is coarser than on level areas suggesting a low profile vegetation pattern.	some rectangular fields but no grid pattern; tone and texture suggest open pastures; small farm ponds; circular fields indicate irrigation in river valley; some strip cropping visible.	farmsteads few and scattered, appear at irregular intervals; no towns visible.	absence of grid pattern of roads except coarse network in river valley; area traversed by only one or two major roads.
V	areas of steep relief visible along with plateaus; much dissection and erosion, but no major drainage system visible; numerous streams and gullies flow away from plateaus.	no natural vegetation detectable along stream banks; some low profile vegetation inferred on slopes.	a few large rectangular fields visible on plateaus; dissected terrain and lack of fields suggest grazing; existence of few ponds on plateaus.	no towns or farmsteads visible.	very few roads cross region.
VI	rugged relief with visible folds and faults indicate an area of low mountains or high hills.	coarse pebbly image texture on slopes is suggestive of forest vegetation; smooth medium gray areas in valleys imply meadows.	rectangular fields in valley floor, much of area appears to be pasture or grazing due to presence of farm ponds and lack of field borders; fields are usually large in area often with non-distinct, irregular borders.	farmsteads visible only on valley floors.	roads visible only in valleys, appear to traverse the region rather than form grid pattern for intra-region service.
VII	extensive plateau-like area with some gentle hills, some steep relief; erosion quite	coarse texture along river banks suggests a few small trees along river banks; absence of such	a few rectangular fields faintly visible but most of region seems to contain natural pas-	farmsteads not readily visible, mainly confined to river valley and lowland with a few scat-	no grid pattern; roads lead to farmsteads or cross the region connecting distant points;

	evident on slopes and dissected hills.	texture on plateaus and slopes is more characteristic of lower vegetation cover such as brush grasses.	tures, presence of scattered stock-farm ponds.	tered buildings visible in pasture areas or slopes.	portions of one or two power lines detectable.
VIII	highly dissected with low and high hills; ubiquitous local relief; entire area void of level land.	pebbly surface along stream banks hints of riparian vegetation, salt and pepper appearance of some slopes suggests a low, more sparse vegetation; complex dendritic drainage system.	no fields visible; dominant feature is farm ponds, suggestive of grazing; rugged topography apparently has virtually prohibited cultivation.	no towns visible, only a few scattered farmsteads, probably ranches.	no roads visible.
IX	most of region is sloping with streams and gullies; a few groups of small hills—probably small buttes with steep slopes, almost no level land.	scattered pebbly texture along river bank suggesting some trees; salt and pepper appearance in some portions infers sparse scattered vegetation with bare soil areas.	a few ponds are visible but a field pattern is absent; open expanses suggest grazing.	no settlements or farmsteads visible.	no roads visible.
X	much dissection but absence of high return indicates an area of moderate relief—foothills; essentially linear drainage network; absence of flat land in uplands or bottomlands.	larger streams seem to have riparian vegetation; smaller tributary streams appear to have low vegetation; mottled gray tones in region hint of sparse desert vegetation cover.	no fields visible; rectangular ponds clustered around buildings.	no towns and few buildings visible; buildings in clusters; given the location, bright return areas around buildings and ponds are suggestive of steep relief from slag piles.	only minor roads leading to buildings are detectable.
XI	rolling hills, dissected areas; a dome; sand dunes; steep relief among ridges and dry stream beds—the latter having few tributaries.	concentrations of vegetation along stream banks; some low vegetation, perhaps scrub, along slopes.	some small rectangular fields in river valley but remainder of area seems to be grazing; almost no farm ponds, except in river valley.	farmsteads mainly along the river and main roads; no towns visible.	roads confined to river valley.
XII	much of region is vast tableland, dendritic drainage pattern; steep relief and dissection very apparent on slopes; hills and ridges.	no indications of trees; on tablelands vegetation appears to be low but more dense than sparse; scrub vegetation inferred on slopes.	no field pattern detectable.	buildings located around rectangular ponds; ponds appear larger than in previous regions; high relief near ponds; layered appearance of these landforms suggests mine tailings; no farms visible, buildings similar to those in Region X.	minor roads lead to buildings; only one major road visible.
XIII	areas of steep alope visible across entire region along with rugged mountains; terrain varies from river valley to a layered, terraced area to mountains.	pockets of coarse texture in eroded valleys; plateau area and some slopes hint of brush and low trees; grassland and shorter vegetation inferred from less coarse texture on tops of hills and plateaus.	no fields visible but two large reservoirs are visible; due to terrain, grazing is probably only activity.	no towns visible; a few houses or clusters of buildings visible in river basin.	only two roads visible—one to a reservoir; the other appears as a highway traversing the area.
XIV	a large valley between two mountainous areas; appears level.	white and light gray areas along meandering streams similar to those of Region I. Other tone and texture changes used to infer riparian vegetation.	field pattern not distinct; extensive, irregularly shaped fields along with a few large rectangular fields—perhaps hay or pasture.	some farmsteads scattered across the valley floor with a town along one side of valley.	road network more complete than surrounding regions—retains a fragmented grid appearance.

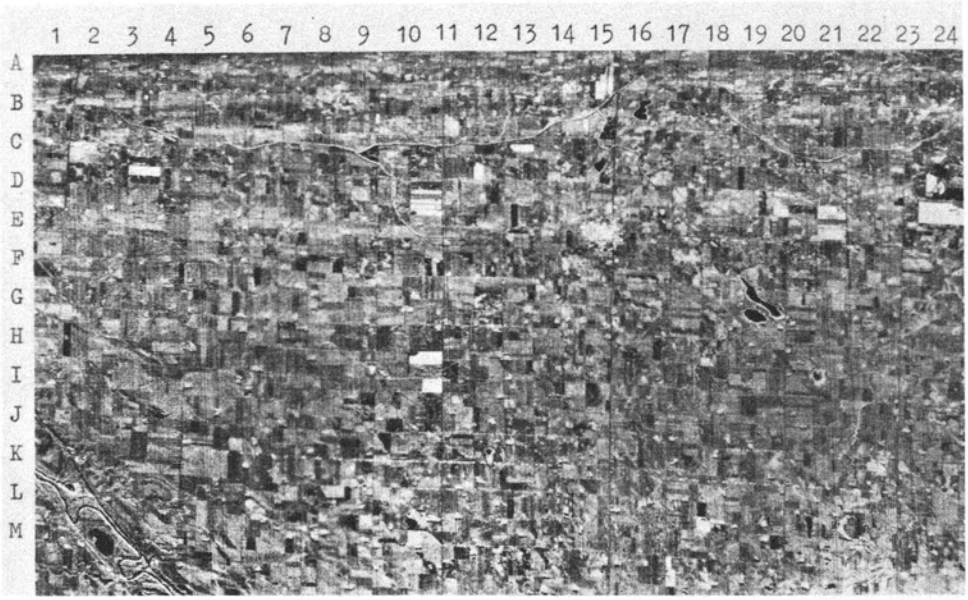

FIG. 2. SAMPLE OF REGION I: COMMERCIAL CROPLAND AND LIVESTOCK

Surface Configuration. There is no evidence of shadow or slopes on the image. High (bright) return, indicative of steep relief, is also absent. Rather, the topography appears to be very gentle with almost level land.

Natural Vegetation. Trees composing windbreaks around farmsteads are manifested as "bumpy" or "popcorn" areas of bright coarse texture (for example, G4, H4). Trees along river banks appear in various parts of the image as sinuous lines (B1 and B13). Ponds and lakes, evident as areas of no *return* on the image, dot the scene whereas wet marshy habitats are detectable by their grainy texture and white to light gray tone (see E18, M22).

Field Pattern and Size. Although a few fields abut stream banks and field borders are not always distinct, the general impression is one of a grid pattern of rectangular fields. The many shades of gray and variety of textures visible imply that a variety of crops are grown. By studying the road network it is evident that most of the fields are small (e.g., 40 to 80 acres) in size.

Settlement Pattern. Farmsteads are closely spaced and reflect the influence of the field pattern and road network in their location. Two small towns, that probably function as service centers for the rural community, are visible at E15 and J22 in Figure 2.

Road Network. A fairly dense road net is implied by the number of farmsteads and the rectangular field pattern. Two major roads, visible as black lines on the image, intersect in the larger town (D15) whereas sections of other roads can be detected in scattered portions of the image. Portions of two power lines are also visible in the lower portion of the radar image.

This region is termed Commercial Cropland and Livestock for the following reasons: The area is extensively cultivated and evidently contains a variety of crops in rectangular fields. Fields containing ponds, small lakes, or wet spots, would be difficult to cultivate; they are probably left in pasture for animals. The land is of gentle relief, and contains a rather complex road network and numerous farmsteads, indicating that the farms are not large in acreage, but that the land is farmed intensively. The presence of windbreaks, location of trees along stream banks, and frequency of water bodies indicate that the area receives ample moisture for cultivation.

XIII. Scrub, Scrub Forest with Limited Grazing — Low Mountains and High Hills.
XIV. Mountain Valley Hay and Pasture.

Examples of two of these regions are provided in Figures 2 and 3. Each region is first characterized according to its five environmental features and illustrated with a sample of radar imagery representative of the region. In each instance, a concluding statement summarizes the characteristic features and identifies the region by name. The reader may notice that the regions are often characterized by what appear to be negative statements. This is explained by the fact that the regions were delimited after studying collateral and comparative information derived from adjacent areas (Table 1). Thus a region was defined not only by the presence of features, but also by the absence of features found in preceding or succeeding regions — in short, a combination of what was seen as well as what was not seen in the region.

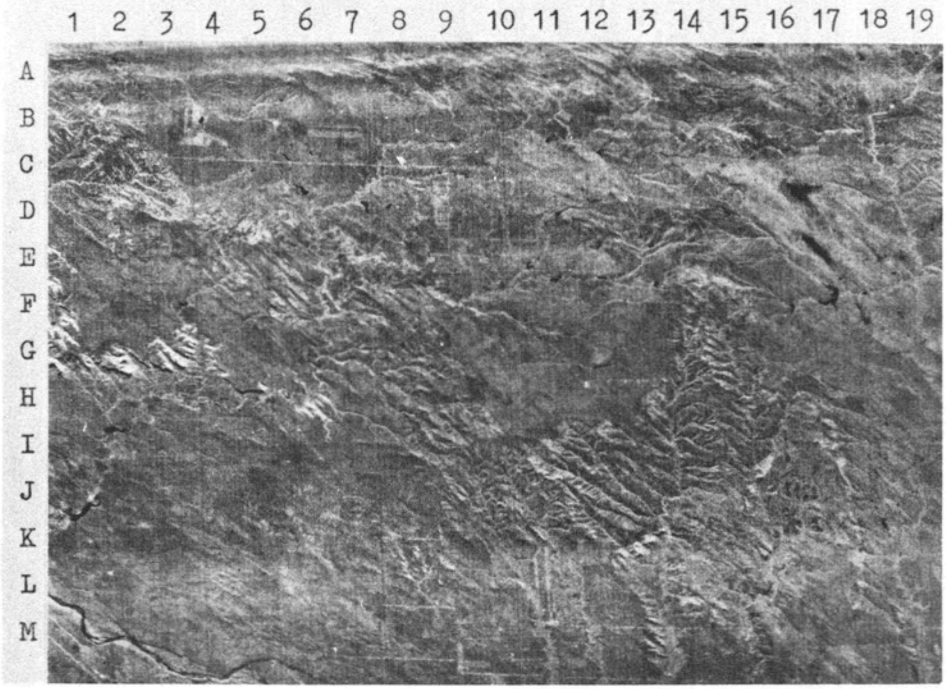

FIG. 3. SAMPLE OF REGION VII: SEMIARID PASTURE AND GRAZING—TABLELANDS

Surface Configuration. Region VII is an extensive plateau-like area but also contains a few gentle hills and some steep relief. A plateau can be seen at G11 along with some gentle hills in the upper right corner. The plateaus appear as smooth, medium-gray areas on the radar imagery whereas the slopes and hills are highlighted by bright and shadow areas such as those seen at F2. Erosion is quite evident on the slopes and dissected hilly section.

Natural Vegetation. The image texture along the river bank, visible at L1 and J13, is coarser than that visible on the adjacent terrain, e.g., L3. As with Region IV, this seems to imply a few small trees along the river. The absence of coarse textures on the plateaus and slopes is perhaps more characteristic of lower vagetation cover such as brush and grasses.

Field Pattern and Size. Although a few rectangular fields are faintly visible at B6 and L9, most of the region seems to contain natural pastures, identifiable by a lack of sharp contrasts in gray tones on the plateaus and the absence of visible field borders. The presence of scattered stock ponds, seen as black dots around E10, supports this observation.

Settlement Pattern. Farmsteads are not readily interpretable and seem to be confined to the river valley or lowland, although a few scattered buildings are detectable in the pasture areas on the plateaus. (See G11 and B5 for example).

Road Network. No grid pattern exists in this region. Instead, the roads lead to farmsteads or seem to cross the region in a straight line connecting distant points, as opposed to connecting settlements within the region, e.g., Region I. Portions of one or two power lines are detectable as a series of white dots but are not evident in this sample.

Trees are apparently confined to the river bank as the coarse bumpy texture often indicative of trees on radar imagery is confined there. This texture is absent in the rest of the region suggesting that vegetation in those areas away from the river is low profile. As much dissection and erosion are also evident on the slopes, Region VII is considered semiarid. The existence of extensive pasture areas, a lack of field borders, and a scarcity of farmsteads and settlements, in conjunction with the drainage network, seem to support this contention of semiaridity. Last, as can be seen in this sample, farm ponds are found throughout the region. As roughly half of the area consists of plateaus, the region was referred to as: Semiarid Pasture and Grazing — Tablelands.

As the illustrations are only portions of the entire regions used in analysis, the reader should not attempt to identify regions solely on the basis of visible differences in the samples. Some features (e.g., farm ponds or vegetation differences) are not as distinct as on the original imagery. Too, some features described in the text may be absent in the sample or may be more evident in other portions of the region. The imagery illustrations should be considered a representative *average* of the region.

The land-use map and its component regions attest to the use of radar imagery as a tool for small-scale land-use mapping. It is possible to detect certain land-use characteristics on the imagery and use them to formulate land-use regions. However, the uniqueness of such a map, and concomitantly, its compatibility with more traditional land-use maps has not been evaluated. This facet is treated in the following paragraphs.

Uniqueness and Compatibility with Other Land-Use Maps

Following the completion of the radar land-use map an attempt was made to answer the question, "Are the radar land-use regions unique, or are they comparable to those found on other maps?" Two of the most widely known and most up-to-date land-use maps of the United States were selected for comparison with the radar land-use map. "Major Land Uses" (scale 1:7,500,000) by J. R. Anderson was published in 1970 in the *National Atlas*.[5] Essentially this map is a revision of J. R. Marschner's classic map, "Land Use and Its Patterns in the United States," published in 1950.[6] "Land Resource Regions and Major Land Resource Areas of the United States," (scale 1:10,000,000) by M. E. Austin was the other map selected for comparison.[7] Austin's map and its accompanying handbook were published in 1965 by the Soil Conservation Service of the United States Department of Agriculture as an aid to state, regional, and national planning. Both authors relied heavily on county agricultural statistics as a data source along with earlier maps.

Anderson's categories and regions are primarily based on one factor, agricultural county statistics. Consequently, his land-use regions strongly reflect their agricultural character. In contrast, the land-use regions created from radar imagery are more comprehensive — a combination of physical and cultural characteristics of the landscape that were visible on the radar imagery. The study area contained six of Anderson's land-use regions in ten divisions. Upon comparison with the radar land-use map, eight common borders and four common divisions were found (Table 2). These were located across the study area rather than concentrated in one portion of it. Compatibility was fairly even between environments rather than a high concentration only in one portion of the study area.

In comparing Anderson's map with the radar land-use map, two observations are in order. First, more detailed regions were created using radar imagery. The radar regions often seem to be sub-categories, or finer distinctions of land-use categories derived by Anderson. Notice, for example, that the three divisions of land use recorded from radar imagery as Regions IVa, V, and IVb are referred to as one region, "Subhumid Grassland and Semiarid Grazing Land," by Anderson, but share a common border. The format and scale of radar imagery did permit different and often more detailed land-use data to be gleaned from smaller unit areas than was possible where county statistical data were used as a mapping base. If one were updating a previous land-use map such as Anderson's these radar regions would probably be grouped together to coincide with Anderson's. For example, radar Regions VIIa and b, VIII, and IX would be condensed into one to agree with Anderson's region identified as "Subhumid Grassland and Semiarid Grazing Land" (Table 2).

The second item of note consists of two instances where possible errors in Anderson's map were observed. Part "C" of Region VII "Semiarid Pasture and Grazing—Tablelands" was identified by Anderson as "Mostly Cropland" — a cropland "island" surrounded by a subhumid grassland and semiarid grazing land-use region (Table 2). Although some fields were visible in this area of eastern Wyoming on the radar imagery, such a concentration as suggested by Anderson was not evident even by observations in the field. Yet, it is interesting to note the areal similarity of this portion of Region VII to Anderson's region. Perhaps this is a situation where statistical data were out of date, or an error was made in the collection of data by field observers or in printing the map.

The last two divisions of the study area (Regions XIV and XIIIb) were also in agreement with Anderson by boundary but not necessarily by type of land use described. Anderson classified Region XIIIb of the radar map as "Desert Shrubland Grazed" and Region XIV as "Irrigated Land." The difference in maps between the former region is essentially terminology (i.e., "Desert Shrubland Grazed" — Anderson, versus "Scrub, Scrub Forest with Limited Grazing — Low Mountains and High Hills"). In the second region, XIV, much improved pasture and grazing activity were observed during field checking rather than the "Irrigated Land" of Anderson. This is another instance where Anderson probably derived his classification by interpreting a larger area (i.e., a county) than that visible on radar. The irrigation may have ex-

TABLE 2. COMMON BORDERS AND DIVISIONS

RADAR LAND-USE REGIONS	LAND-USE REGIONS
I. Commercial Cropland and Livestock;	1a. Mostly Cropland
II. Commercial Cropland with Pasture and Coppice Woodlands;	
III. Subhumid Cropland with Pasture	2. Cropland and Grazing Land
IVa. Subhumid Pasture with Irrigated and Dryland Farming	3a. Subhumid Grassland and Semiarid Grazing Land
V. Semiarid Limited Grazing and Pasture; Dissected Hills	
IVb. Subhumid Pasture with irrigated and Dryland Farming	
VI. Forest, Meadow, and Limited Grazing; Low Mountains	4. Forest and Woodland—Grazed
VIIa. Semiarid Pasture and Grazing Tablelands	3b. Subhumid Grassland and Semiarid Grazing Lands
VIIIa. Semiarid Limited Grazing: Dissected Low and High Hills	
VIIb. Semiarid Pasture and Grazing; Tablelands	
IX. Limited Grazing with Sparse Scrub; High Hills	
VIIc. Semiarid Pasture and Grazing; Tablelands	1b. Mostly Cropland
X. Mostly Ungrazed Semiarid Foothills with Mining	3c. Subhumid Grassland and Semiarid Grazing Land
VIIIb. Semiarid Limited Grazing; Dissected Low and High Hills	
XIa. Semiarid Tablelands with Limited Grazing and River Valley Cropland	
XII. Mining and Mostly Ungrazed Scrub; Semiarid Tablelands and Low Mountains	
XIb. Semiarid Tablelands with Limited Grazing and River Valley Cropland	5a. Desert Shrubland—Grazed
XIIIa. Scrub, Scrub Forest with Limited Grazing; Low Mountains and High Hills	
XIV. Mountain Valley Hay and Pasture	6. Irrigated Land
XIIIb. Scrub, Scrub Forest with Limited Grazing; Low Mountains and High Hills	5b. Desert Shrubland—Grazed

isted but occurred in that portion of the county outside the flight path. In addition, the radar imagery was of a different period than the census data employed by Anderson. The discrepancy of regions again points to the possible role of radar as a tool for revising land-use maps. The "Irrigated Land" could have been more accurately located on the map using radar imagery than was done by interpolating county data.

As only four regions possessed similar borders on a one-to-one basis (Table 2), it is obvious that the radar land-use regions did not in this instance duplicate those derived using agricultural statistics. Although the results could not be considered compatible at first glance, it is a relatively simple matter to improve this relationship. For example, by combining radar land-use regions on the basis of borders held in common with Anderson's map, it is possible to duplicate 8 of the 10 land-use divisions created by Anderson. (Note divisions and common borders in Regions 3a through 5b on Table 2). However, this derived similarity should not be considered as an unqualified endorsement of radar imagery. The incompatibility and limitations of the maps' data sources make it extremely difficult to recommend one method as a replacement for the other. Each technique has certain advantages and limitations. It is suggested that the optimum approach may be a combination of the two techniques.

Radar imagery offers two advantages in land-use mapping. First, a rather detailed small-scale land-use map, reflecting various landscape elements visible on the radar imagery, can be created. Second, it should prove possible, with radar imagery, to revise existing land-use maps and locate land-use divisions more accurately. Radar imagery could be used to delineate borders and the extent of land-use regions in many instances, and the traditional statistical technique could be used to categorize the regions as to content or type of land use. The incompatibility of these two data sources would be minimized by this approach.

The discrepancy between Anderson's map and the radar land-use map illustrates a possible role of radar in small scale land-use mapping — accurate updating and checking of previously derived land use maps. The comparison of the map by M. E. Austin with the radar land-use map substantiates this belief. Moreover, the classification and description of the radar land-use regions are placed in a more proper perspective.

To optimize uniformity and applicability at state, regional, and national planning levels, Austin divided the United States into 20 regions and 156 sub-regions. Most of the statements concerning land use were based on recent state reports of soil and water conservation needs. From these data Austin created his map using the following criteria to separate regions: land use, elevation and topography, climate, water, and soil. Additional supportive data included other maps, and county agricultural statistics and reports. Obviously, the regions of this map were based on a more diverse data base than that of Anderson's. In fact, Austin refers to his divisions as land-resource regions rather than land-use regions. As can be seen in Table 3. soil type and topography were deciding factors for Austin in delimiting a region.

The diversity of criteria used by Austin to define regions most closely coincided with those used in this study. One might expect then, that the similarity between Austin's borders and regions with the radar borders and regions might be greater than that found if Anderson's map is compared with the radar map. Austin delimited 9 regions with 11 divisions and 10 borders in the study area. If compared with the radar map, 6 regions or divisions, and 8 borders were found to be similar (Table 3).

Moving from east to west in the study area, the first distinction made by Austin was the division between "Loess, Till, and Sandy Prairie," and "Central Iowa and Minnesota Till Prairies." In addition to the variation in soils, Austin noted a difference in the frequency of wooded areas, urban sites, and pastureland between the two regions. Although a discrimination was not made at this point with radar imagery, it is of note that a radar border was drawn further west (Regions I and II) based on similar criteria. It is suggested that Austin's use of soils as a factor explains the discrepancy. It is the only difference in criteria between the two maps in this case.

As indicated in Table 3 the next six divisions that occur are identical on both maps. Aside from a distinction in soils used by Austin, the regions were delimited by both methods on the basis of similar characteristics (i.e., landscape patterns, climate/ecology — the climate being inferred by the ecology on the radar imagery, and topography). Note, however, that the two sections of radar Region IV were recorded as two different entities by Austin (Regions 4 and 6a). His distinction between the two is based on the fact that one area has an average of 20 more freeze-free days than the other — a distinction impossible to make from radar. In another instance, the two sections of the region termed "Black Hills

TABLE 3. LAND-RESOURCE REGIONS

RADAR LAND-USE REGIONS	LAND-RESOURCE REGIONS
I. Commercial Cropland and Livestock;	1. Central Iowa and Minnesota Till Prairies
II. Commercial Cropland with Pasture and Coppice Woodlands;	2. Loess, Till, and Sandy Prairies
III. Subhumid Cropland with Pasture	3. Black Glaciated Plains
IVa. Subhumid Pasture with Irrigated and Dry-land Farming	4. Rolling Pierre Shale Plains
V. Semiarid Limited Grazing and Pasture; Dissected Hills	5a. Pierre Shale Plains and Badlands
IVb. Subhumid Pasture with Irrigated and Dry-land Farming	6a. Black Hills Foot Slopes
VI. Forest, Meadow, and Limited Grazing; Low Mountains	7. Black Hills
VIIa. Semiarid Pasture and Grazing; Tablelands	6b. Black Hills Foot Slopes
VIIIa. Semiarid Limited Grazing; Dissected Low and High Hills	5b. Pierre Shale Plains and Badlands
VIIb. Semiarid Pasture and Grazing Tablelands	
IX. Limited Grazing with Sparse Scrub; High Hills	
VIIc. Semiarid Pasture and Grazing Tablelands	
X. Mostly Ungrazed Semiarid Foothills with Mining	8. Northern Rolling High Plains
VIIIb. Semiarid Limited Grazing; Dissected Low and High Hills	
XIa. Semiarid Tablelands with Limited Grazing and River Valley Cropland	
XII. Mining and Mostly Ungrazed Scrub; Semi-arid Tablelands and Low Mountains	9. Central Desertic Basins, Mountains and Plateaus
XIb. Semiarid Tablelands with Limited Grazing and River Valley Cropland	
XIIIa. Scrub, Scrub Forest with Limited Grazing; Low Mountains and High Hills	
XIV. Mountain Valley Hay and Pasture	
XIIIb. Scrub, Scrub Forest with Limited Grazing; Low Mountains and High Hills	

Foot Slopes" by Austin (Region 6a and 6b) were classified as separate land-use regions (Regions IVb and VIIa) on the following basis using radar imagery. As interpreted from radar, the area to the west, Region VIIa, seemed to have fewer fields, fewer ponds — indicators of grazing, and appeared less humid due to the different drainage pattern, than the region to the east of the Black Hills (Region IVb). The area to the west also appeared as a tableland on radar, although the area to the east contained hills and a more diverse topography. Thus, in each of the two above instances (i.e., Region IVa and IVb and Region 6a and 6b) and area was separated into two land-use regions by one method and combined into one land-resource region by the other. Because different but somewhat similar criteria were employed to define regions in the same area, the question remains as to which, if either, method is more consistent.

Employing the regions derived by Austin, the remainder of the study area is composed of three land-resource regions — "Pierre Shale Plains and Badlands" (Region 5b); "Northern Rolling High Plains" (Region 8); and "Central Desertic Basins, Mountains and Plateaus" (Region 9). The combination of these first two regions (Region 5b and Region 8) corresponds to seven regions or parts thereof created from radar imagery (Table 3). As much finer distinctions between regions were made using radar, one might wonder why at least some of Austin's borders were not found to be similar to those detected on radar imagery. Two possibilities are advanced in this connection. First, as the names imply, the primary distinction among Austin's regions, in this instance, was a variation in surface configuration and soils. Obviously, if such changes were gradual and generalization used to draw the border, it could have been located elsewhere if radar imagery was used. Second, the area imaged by radar was 12 miles wide, and changes noted by Austin could have been outside of this area. In addition, factors not visible on radar imagery, such as average annual temperature and ground water, were used by Austin to delimit regions.

The border delimiting Austin's last region in the study area was similar to one created from radar separating Region XIa and Region XII. A change in topography, field pattern, vegetation and climate (the climate being inferred by the ecology on the radar imagery), was observed on both maps at this point. However, although Austin designated the entire following area as one land-resource region, four regions were created using radar imagery. Finer distinctions in land use were noted if radar was used as a base. For example, radar Region XIV was identified as a mountain valley, visible on the radar imagery, and was considered as a distinct land-use region in this study, but was included into a larger land-resource region by Austin (Region 9).

As was the situation when Anderson's land-use map was used for comparison, disagreements resulted as to the number and extent of regions delimited. This should be expected, however, if different data bases are utilized. What is surprising and of major importance is the number of similar regions found in light of the fact that only a 12-mile wide swath was used for analysis in this study.

If the entire state of South Dakota or Wyoming had been imaged, as would probably be the case in a mapping program, it is likely that most of Austin's map could be duplicated by using radar imagery and the characteristics developed in this study. Due to the amount of agreement between the radar regions and Austin's "land-resource regions," it is believed that, similar to Austin's, the regions delimited from radar are in fact regions of something other than just land use in the traditional sense. The radar regions are characterized by a mixture of physical and cultural features and not solely by agricultural production. In effect, they describe a composite landscape and could be termed rural landscape regions.

The potential of radar imagery in small-scale land-use/rural-landscape mapping and the technique developed in this study appear promising. However, this study was only a beginning. Many questions and unknowns remain.

Summary and Conclusions

A majority of land-use regions created from radar imagery corresponded to land-use regions created by other methods. Eight of the 10 land-use divisions (80 percent) compiled by Anderson and 7 of the 11 divisions (74 percent) compiled by Austin were found to be similar to land-use divisions or combinations of divisions created from radar. On a one-to-one comparison, six radar regions were similar to Austin's map and four to Anderson's. It is believed that those points of disagreement between the radar land-use map and the other land-use maps were primarily a result of differences in the regionalization decisions. Specifically, there were instances where the radar land-use regions appeared to be a finer distinction in land-use than that derived by other methods.

In these situations, the radar regions could be termed sub-regions of more generalized land-use or land-resource regions.

The results of these comparisons are encouraging. It can be assumed that broader imagery coverage (e.g., whole states) might make the regionalization process easier inasmuch as the map-maker would be able to delimit whole areas rather than searching for boundaries across a narrow sample. It should also prove feasible to use radar imagery to update and/or revise existing land-use/landscape maps. Perhaps a very desirable application would be as a base map for heuristic purposes.

In this light, it is believed that the following avenues of research should be pursued. Other areas of the United States should be mapped using radar imagery to determine if the characteristics used in this study can be employed to delimit regions (rural landscapes) in other environments.

Second, examining large political units should eliminate many of the problems inherent in studying only a traverse and hopefully improve the results. Last, and implied in the above suggested studies, the research design used in this study should be analyzed and implemented by other interpreters to see if they can use or, if necessary, refine the methodology created here.

This study indicates that radar imagery is a useful tool in small-scale land-use mapping and should be explored further. Land-use regions were delimited using radar imagery, but additional testing is needed to verify the utility of the method employed. Radar imagery obviously provides a different perspective of our environment than that to which we may be accustomed. Although some success was evident in the comparisons, the categories used do not fit the normal concept of land use traditionally employed. This poses, then, not a map-making problem but a map-utilization problem — a concern aptly voiced by Anderson in his trenchant article, "Land-Use Classification Schemes."[8]

The radar land-use map is usable and understandable, but it is also different from the typical image of land use. The questions posed are: (1) "Will it be looked upon by map users as a viable tool producing usable maps, or will they demand a continuation of the traditional land-use categories and methods?" and (2) "Would it be possible to combine the radar and traditional land-use categories to produce a usable map? At present, the answers are unknown and will probably remain so until the radar land-use map and the concepts underlying its development are evaluated to determine their validity and utility.

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