COST, ACCURACY AND CONSISTENCY COMPARISONS OF LAND USE MAPS MADE FROM HIGH-ALTITUDE AIRCRAFT PHOTOGRAPHY AND ERTS IMAGERY

By

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U.S. Geological Survey

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16. Abstract

Accuracy analyses for the land use maps of the Central Atlantic Regional Ecological Test Site were performed for a 1-percent sample of the area. Researchers compared Level II land use maps produced at three scales, 1:24,000, 1:100,000, and 1:250,000 from high-altitude photography, with each other and with point data obtained in the field. They employed the same procedures to determine the accuracy of the Level I land use maps produced at 1:250,000 from high-altitude photography and color composite ERTS imagery.

The accuracy of the Level II maps was 84.9 percent at 1:24,000, 77.4 percent at 1:100,000, and 73.0 percent at 1:250,000. The accuracy of the Level I 1:250,000 maps produced from high-altitude aircraft photography was 76.5 percent and for those produced from ERTS imagery was 69.5 percent.

The cost of Level II land use mapping at 1:24,000 was found to be high (\$11.93 per km^2). The cost of mapping at 1:100,000 (\$1.75) was about 2 times as expensive as mapping at 1:250,000 (\$.88), and the accuracy increased by only 4.4 percent. Level I land use maps, when mapped from high-altitude photography, were about 4 times as expensive as the maps produced from ERTS imagery, although the accuracy is 7.0 percent greater. The Level I land use category that is least accurately mapped from ERTS imagery is urban and built-up land in the non-urban areas; in the urbanized areas, built-up land is more reliably mapped.

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COST-ACCURACY-CONSISTENCY COMPARISONS OF LAND USE MAPS MADE FROM HIGH-ALTITUDE AIRCRAFT PHOTOGRAPHY AND ERTS IMAGERY

By Katherine Fitzpatrick

Abstract

Accuracy analyses for land use maps of the 74,712-km^2 Central Atlantic Regional Ecological Test Site were performed for a 1-percent sample of the area. Researchers compared Level II land use maps produced at three scales, 1:24,000, 1:100,000, and 1:250,000 from high-altitude photography, with each other and with point data obtained in the field. They employed the same procedures to determine the accuracy of the Level I land use maps produced at 1:250,000 from high-altitude photography and color-composite ERTS imagery.

The accuracy of the Level II maps was 84.9 percent at 1:24,000, 77.4 percent at 1:100,000, and 73.0 percent at 1:250,000. Between 1:23,000 and 1:100,000 the generalization due to the smaller scale was measured as 4.6 percent, and between 1:100,000 and 1:250,000 the generalization was 4.1 percent. The accuracy of the Level I 1:250,000 maps produced from high-altitude aircraft photography was 76.5 percent and for those produced from ERTS imagery was 69.5 percent. The difference in measured land use areas between the aircraft and ERTS maps, resulting from the coarser resolution of ERTS imagery, was 4.6 percent.

Accuracy estimates were compared to the costs of producing the maps. The cost of Level II land use mapping at 1:24,000 was found to be high (\$11.93 per km^2) and was not offset by the slight increase in accuracy. The cost of mapping at 1:100,000 (\$1.75) was about 2 times as expensive as mapping at 1:250,000 (\$.88), whereas the accuracy increased by only 4.4 percent. Level I land use maps at 1:250,000, when mapped from high-altitude photography, were about 4 times as expensive as the maps produced from ERTS imagery, although the accuracy is 7.0 percent greater. The Level I land use category that is least accurately mapped from ERTS imagery is urban and built-up land in the non-urban areas; in the urbanized areas built-up land is more reliably mapped.

INTRODUCTION

The Central Atlantic Regional Ecological Test Site (CARETS) project was sponsored jointly by NASA and the U.S. Geological Survey to evaluate Earth Resources Technology Satellite (ERTS, later renamed LANDSAT) and high-altitude aircraft data as inputs to a regional land resources information system. The study area includes 74 counties, 18 independent cities, and the District of Columbia, within the Chesapeake Bay and Delaware Bay regions.

The CARETS map format was based on the Universal Transverse Mercator (UTM) grid system, and 50 x 50-km photomosaics were constructed at a scale of 1:100,000 from high-altitude aircraft photography. Researchers used these photomosaics as the mapping base for the 1970 land use maps and for the 1972 land use change maps. The land use classification system used (appendix A) is an earlier version of that proposed by the Interagency Steering Committee on Land Use Information and Classification, presented in USGS Circular 671 (appendix B). The revision of this classification, based on user response and actual mapping experience, is presented in appendix C (USGS Professional Paper 964, in press). Researchers compiled Level II land use maps at a scale of 1:100,000 using the high-altitude aircraft photography acquired at a scale of 1:120,000. They also compiled Level I land use maps at 1:250,000 scale, corresponding to the standard 1° x 2° USGS topographic map format, using color-composite ERTS imagery enlarged to 1:250,000 scale.

The research to determine a measure of accuracy began simultaneously with the land use mapping of the Norfolk Test Site, the initial mapping area of CARETS. Several field verification excursions were made during the map compilation process between 1971 and 1973. This field work was designed to correct the land use maps, where possible, and to provide an indication of those land use categories that would require revision or redefinition. Various field methodologies were employed to obtain field data, both to verify the land use maps and to provide needed information about the applicability of the two-level land use classification system for use with remote-sensor data.

During this process no overall measure of the accuracy of the land use as mapped vis-a-vis the classification system was achieved. The purpose of this report is to present the findings of a comprehensive evaluation of the accuracy of the CARETS land use maps as well as an evaluation of the usefulness of the two-level land use classification system. The mapping accuracy is evaluated at three scales--1:24,000, 1:100,000, and 1:250,000--and the accuracy at these scales is compared to the costs for mapping at the same scales.

Particular thanks and acknowledgement are given to Brian J. L. Berry of the University of Chicago, for his recommendations and direction in the research design, and for his advice throughout. Appreciation must also be extended to Harry F. Lins, a colleague in the Geography Program, for his essential contribution as aircraft pilot and navigator in the field operations and to Cheryl Hallam of the Geography Program for her contribution as computer programmer.

STATEMENT OF THE PROBLEM

Several questions have emerged during experimental land use mapping at medium and small scales from high-altitude aircraft photography and Earth Resources Technology Satellite (ERTS) imagery:

The land use classification system used by the CARETS project (appendix A) was a prototype scheme developed for use with remote-sensor systems. The first question is whether the classes of this scheme can be validly discriminated using the high-altitude aircraft photography and ERTS imagery.

Another question relates to reliability and accuracy of the land use maps. Several variables are relevant here: the number of land use classes to be identified, the scale of the maps, and the size of the uniformly coded polygon chosen as the minimum mapping unit. Generally, one may assume that accuracy is greater for land use mapped from high-altitude photography at large scales, and decreases as scale decreases or as detail is aggregated.

Cost benefit factors are relevant here too, and the question of the validity of the general assumption that costs vary directly with accuracy may be raised.

A fourth question relates to the accuracy and consistency of maps based on the high-altitude photography and the ERTS imagery at a common scale (1:250,000), and how the costs compare. The data retrievable per unit area from high-altitude aerial photography far exceed those obtainable from ERTS imagery. A question remains, however, as to whether in maps at 1:250,000 scale the loss of detail of ERTS data vis-a-vis aircraft data might be so slight as to call into question use of the more costly, although higher resolution, aircraft photography for users who require maps at 1:250,000 and area measurements derived therefrom.

This paper addresses the questions outlined above, using data from the Central Atlantic Regional Ecological Test Site (CARETS), which was analyzed by the Geographic Research and Analysis staff of the U.S. Geological Survey.

RESEARCH DESIGN

SAMPLING PROCEDURE

The study was restricted in size to a 1-percent sample of the 74,712-km^2 area of CARETS. The author chose a random stratified sampling technique to select the sample sites (Berry and Baker, 1968), within a prior stratification of the area into urban and non-urban parts to assure proper representation of both urban and non-urban land use. The author also used a 5 x 5-km sampling unit in non-urban areas and a 2 x 2-km unit within urban areas where land use is more complex and parcels are smaller. The sampling units were large enough to field check economically, and they were chosen by means of a geographic sampling method that ensured that all parts of the CARETS region were represented. This method was selected with an underlying assumption that there is no periodicity to the CARETS land use patterns.

The 5 x 5-km non-urban sample sites were selected at random for each mosaic using a 5-km UTM grid overlay. Random numbers were selected from a table to choose the coordinates of the lower left corner of the grid cell. Sample sites that fell more than 50 percent outside of the CARETS boundary or totally in water areas were discarded. Sample sites that fell on the boundary but more than 50 percent within the CARETS area were moved inside. The rule followed was that those extending over the northern boundary be moved south, those extending over the eastern or western boundary be moved west or east, respectively, and those extending over the southern boundary be moved north along the UTM grid lines. Sample sites falling in the urbanized areas were not used in the sampling of non-urban areas. A total of 28 non-urban sites were selected.

The 2 x 2-km urban sample sites were selected from the urbanized areas as defined by the U.S. Bureau of the Census, 1972. The areas of all the urbanized areas in CARETS are presented in table 1. Fifteen 2 x 2-km urban sample sites, comprising 1 percent of the total CARETS urbanized area were distributed among urbanized areas according to the ratio of each urbanized area to the total. Within each urbanized area the sample sites were chosen using a 2-km UTM grid cell overlay and a random number table. The lower left corner coordinates were chosen from the table. As before, sites falling more than 50 percent outside the area were discarded; however, those on the boundaries were retained in order to include the urban-rural fringe in the sample.

A total of 760 km^2 (700 non-urban and 60 urban) thus was selected to evaluate the 74,712-km^2 area of the CARETS region. Figure 1 presents the locations of the non-urban sample sites, and figure 2 the locations of the urban sample sites.

Table 1.--CARETS Urbanized Areas and Allocation of Urban Sample Sites

Urbanized Areas	Mile^2*	Km^2	Acres	% of Total	No. of Sites
Atlantic City	67.1	173.9	42,944	3	0
Baltimore	309.6	802.5	198,144	13	2
Newport News - Hampton	143.3	371.4	91,712	6	1
Norfolk - Portsmouth	299.0	775.0	191,360	12	2
Petersburg - Colonial Heights	42.4	109.9	27,136	2	0
Philadelphia	751.8	1,948.7	481,152	31	5
Richmond	144.6	374.8	92,544	6	1
Vineland - Millville	85.3	221.1	54,592	3	0
Washington, D.C.	494.5	1,281.7	316,480	20	3
Wilmington	109.8	284.6	70,272	4	1
TOTAL	2,447.4	6,343.7	1,566,336	100	15

*Source: U.S. Bureau of the Census, 1972, U.S. Census of Population: 1970 NUMBER OF INHABITANTS, Final Report PC(1)-A1 United States Summary: U.S. Government Printing Office, Washington, D.C.

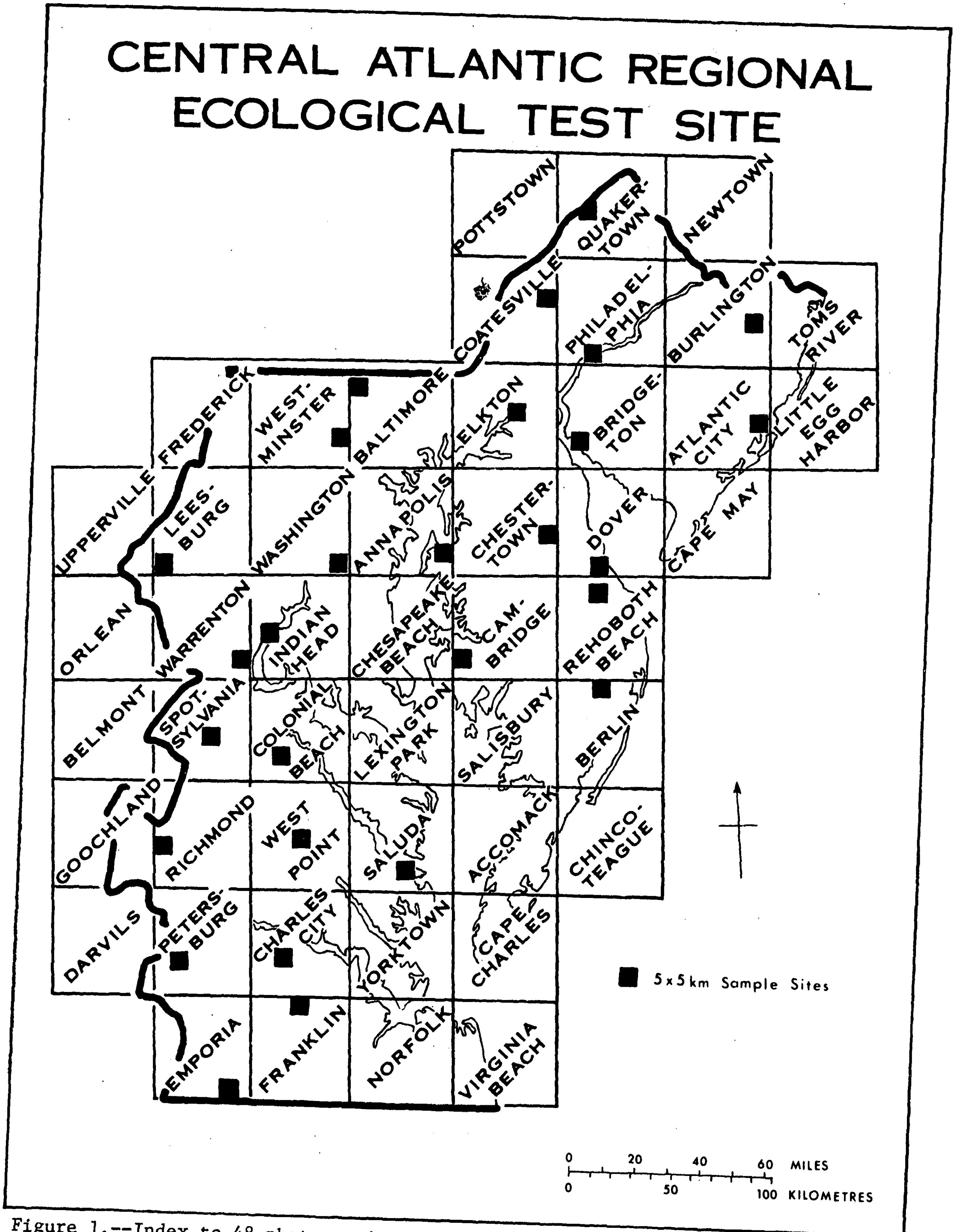

Figure 1.--Index to 48 photomosaics for CARETS 1:100,000-scale data base, and location of 5 x 5-km sample sites within nonurban areas.

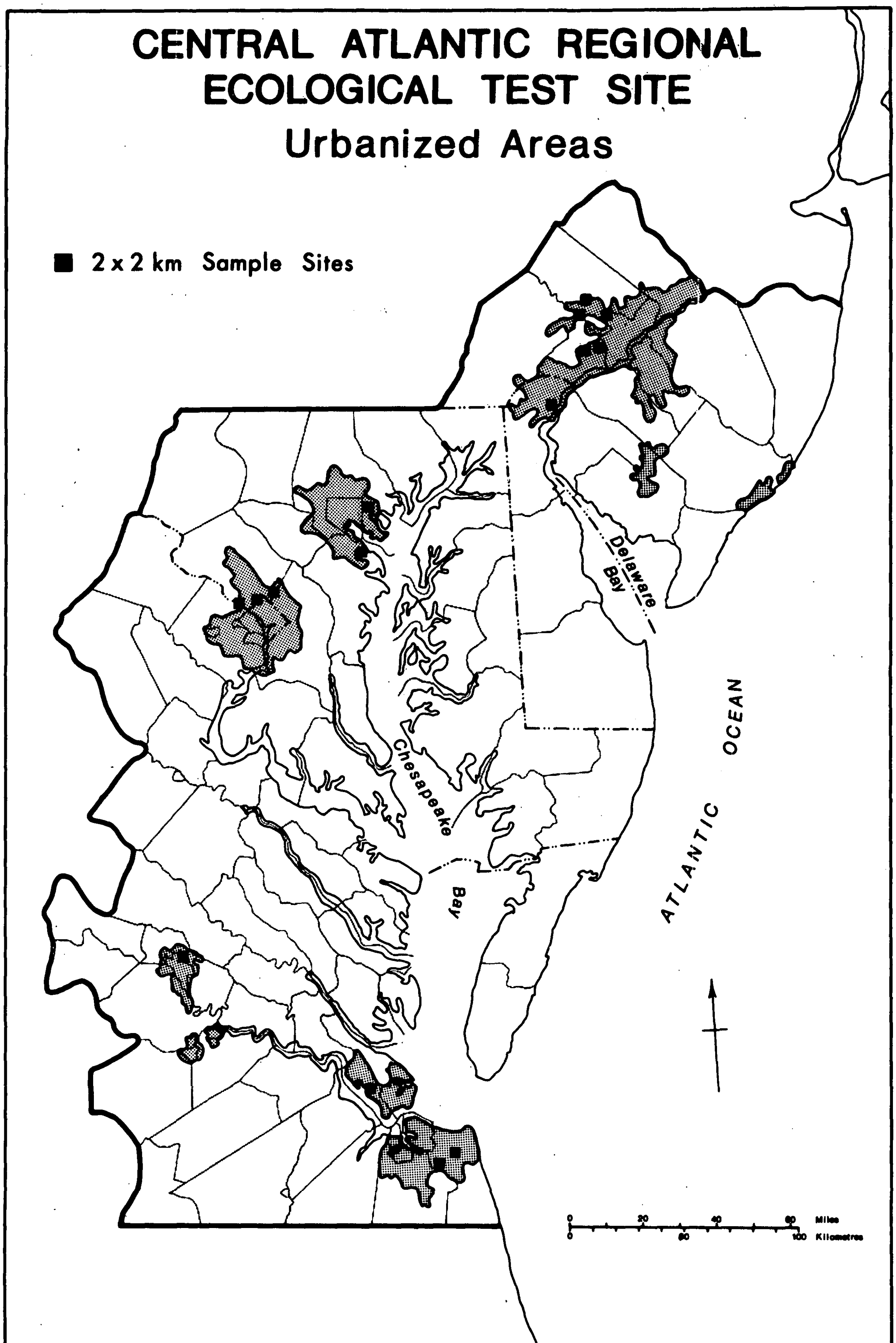

Figure 2--Location of 2 x 2-km sample sites within urban areas. Shaded areas represent urbanized areas defined by the U.S. Bureau of the Census, 1970 Census of Population, 1 & 2.

METHODS OF DERIVING ACCURACY MEASURES OF LAND USE DATA

For each of the sampling sites, four methods for determining accuracy were developed. The first involved the measurement and tabulation of the area of each land use at each scale mapped. Assuming that the most nearly correct land use map is the one prepared at the largest scale and having the most detail, one can then attempt to determine the reduction of accuracy resulting from reduced resolution and areal aggregation at the smaller scales. In some cases it also was possible to identify land use categories that had been most frequently misinterpreted and therefore had little or no reliability.

A second procedure involved taking point samples of Level II land uses at the center of each kilometre square. Land use identified by direct observation from a low-flying aircraft was compared to the land use of the same points interpreted from the high-altitude photography and mapped at three scales: 1:250,000, 1:100,000, and 1:24,000. In this way, assumptions about the accuracy of interpretations of the aerial photography could be checked.

The third measure of accuracy involved an attempt to quantify the precentage of error due to generalizing land use to the smallest mapping unit possible at 1:100,000. No land use smaller than 4 hectares was outlined at 1:100,000. A linear traverse was made in the field along roads cutting across certain sample sites. The land use was identified and recorded for comparison to mapped data.

Finally, point samples of the Level I land uses mapped at the scale of 1:250,000 using the high-altitude photography and ERTS imagery were compared to the field points to determine and compare the accuracy of the ERTS map.

RESEARCH PROCEDURES

MEASUREMENT OF GENERALIZATION FROM LARGER TO SMALLER SCALES

Each sample site was outlined with masking tape on the ERTS imagery, on the high-altitude aircraft photography, and on the Level I land use maps at 1:250,000 and 1:100,000 scales. Additional Level II land use maps of the sample sites were then compiled by enlarging the photography to the scale of 1:24,000 by means of a projecting system and remapping. Level II maps at 1:250,000 scale were mapped from the same high-altitude photography to a reduced photomosaic base.

The dot planimeter, which has been found to be the most accurate tool for manual measurement of areas (Yuill, 1970), was used to determine the area in hectares for each land use within the sample sites mapped. The dot planimeter is basically a uniform grid of dots. Each dot represents a portion of the area of the cell in which it is located. Researchers measured areas on the polygon map by laying the grid on the map and simply counting the number of dots within the polygon and every other dot on the boundary between polygons. They then converted the number of dots counted to an equivalent ground measure by multiplying this number by a conversion factor determined by the scale of the map being measured.

An identical dot grid having 25 dots per square centimetre was used at all three mapping scales. A single dot thus represented $4mm^2$. This unit was the smallest size land use cell identified at each scale. At a scale of 1:24,000, each dot or $4mm^2$ represented 0.23 hectares; at a scale of 1:100,000, each dot represented 4 hectares; and at a scale of 1:250,000, each dot represented 25 hectares.

The total area of each non-urban site was 25 km^2 and of each urban site, 4 km^2. When the sum of polygon measurements for a sample site deviated by more than 2 percent from the total area (25 km^2 and 4 km^2), the areas were remeasured. The small discrepancies that did occur are believed to be the cumulative errors resulting from the occasional miscount of dots, errors in outlining a 5 x 5-km square, and errors resulting from the use of dot grids made on a nonstable base material.

Areas of each land use were tabulated for each scale map (1:24,000, 1:100,000, and 1:250,000). The tables listing the area for each of the sample sites then were summed to give a single tabulation for all the sample sites. Next, tabular summaries were prepared to compare the land use data at the different scales and to show the effect of generalization from larger scales to smaller scales. Table 2 is one such summary comparing the number of hectares in each land use category at 1:24,000, 1:100,000, and 1:250,000, as mapped from the high-altitude aircraft photography. A second tabulation gives an indication, at the scale of 1:250,000, of the effects of the reduced resolution of ERTS in comparison to the high-altitude aircraft photography (table 3). The actual measurements obtained were adjusted to total 76,000 hectares to compensate for errors in manual processing.

Referring to table 2, one can calculate the total area at each scale that differs in land use classification from the next larger scale. By assuming that the land use is correctly mapped within the limitations of the minimum mapping unit for each scale, one can then consider that the discrepancy in area among three scales is due to generalizing the land use mapped to the smallest mapping unit for each scale. This area may then be expressed as a percentage of the total area mapped.

Table 2--Comparison of Area for Various Categories of Land Use Mapped at Three Scales from High-Altitude Photography (in hectares)

	L.U. CODE	1:24,000	1:100,000	1:250,000
URBAN AND BUILT-UP				
Residential	11	4,069	3,441	4,950
Commercial and services	12	340	464	300
Industrial	13	38	48	
Extractive	14	33	112	
Transportation, etc.	15	259	132	225
Institutional	16	961	1,289	875
Strip and clustered	17	60	48	
Mixed	18		16	
Open and other	19	409	400	325
Subtotal	1	6,169	5,950	6,675
AGRICULTURAL				
Cropland and pasture	21	21,544	23,156	23,875
Orchards, etc.	22	10	404	
Other	24	95	92	
Subtotal	2	21,649	23,652	23,875
FOREST LAND				
Heavy crown cover	41	33,740	31,550	30,950
Light crown cover	42	1,217	1,906	1,900
Subtotal	4	34,957	33,456	32,850
WATER				
Streams and waterways	51	334	404	75
Lakes	52		108	
Reservoirs	53	224	92	125
Bays and estuaries	54	9,316	9,150	8,850
Subtotal	5	9,874	9,754	9,050
NONFORESTED WETLAND				
Vegetated	61	3,273	3,088	3,500
Subtotal	6	3,273	3,088	3,500
BARREN LAND				
Sand other than beaches	72	6		
Beaches	74	10		
Other	75	62	100	50
Subtotal	7	78	100	50
TOTAL		76,000	76,000	76,000

Table 3.--Comparison of Area of Land Use Mapped at 1:250,000 Scale from High-Altitude Photography and ERTS Imagery (in hectares)

LEVEL I LAND USE	Land Use Code	From Aerial Photography	From ERTS Imagery
Urban & Built-up......	1	6,675	4,109
Agricultural..........	2	23,875	24,154
Forest Land...........	4	32,850	35,432
Water.................	5	9,050	9,687
Nonforested Wetland...	6	3,500	2,618
Barren Land...........	7	50	none
TOTAL		76,000	76,000

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For instance, the difference between category 11 at 1:24,000 and 1:100,000 is 628 hectares (4069 - 3441 ha) and for category 12 this difference is -124 hectares (340 - 464 ha). Only the absolute value difference is important here; whether the difference is an increase or decrease is irrelevant. An absolute summation of these differences (i.e., disregarding the sign) for categories 11 through 19 would give the total area in the urban category mapped differently at 1:24,000 and 1:100,000. By continuing this summation through all 22 Level II land use categories mapped, one would obtain the total area on both maps of differences in classification between the two scales. To calculate the total area on only one of these two maps, it is necessary to divide the total by 2.

The equation for this calculation of the area of difference between maps at two scales is:

$$\sum_{i=1}^{22} \frac{\left| h_{i1} - h_{i2} \right|}{2}$$

Where h_{i1} = hectares of land use i at one scale
h_{i2} = hectares of land use i at the next scale
and 22 = the number of land-use categories mapped

Therefore the difference due to generalization between 1:24,000 and 1:100,000 is 3,468 or 4.6 percent of the 76,000 total hectares measured. The difference due to generalization between 1:100,000 and 1:250,000 is 2,766 or 3.6 percent of the 76,000 total hectares measured. Notice, however, that the percent of difference is not cumulative; some of the differences due to generalization in proceeding from 1:100,000 to 1:250,000 cancel out differences that arise in generalizing from 1:24,000 to 1:100,000. In consequence, the difference due to generalization between 1:24,000 and 1:250,000 is 4,122 or 5.4 percent of the 76,000 total hectares measured.

One of the major land use categories that was not mapped consistently is urban land. At 1:24,000, small parcels of built-up land use may be distinguishable, whereas at 1:100,000, many of the smaller parcels are aggregated into the background of other uses. At 1:250,000, parcels of agricultural and forest land within and at the periphery of the urban setting are mapped as urban residential.

The main cause of the urban land discrepancies is the visual appearance of residential land on the photography at each scale. At 1:24,000, residential land appears as a clustering of individual homesteads, excluding the surrounding land use. At 1:100,000, separate residential developments, as well as linear residential settlements, appear on the photography. At this scale, small clusters of residential lots are seldom separated from agricultural land, resulting in the significant decrease in area mapped as residential. At 1:250,000, several tracts of urban developments merge to form a single land use pattern, including much land that may otherwise be interpreted as forest or agricultural land at a larger scale.

As scale was decreased, the area mapped as agricultural land increased, and the area mapped as forest land decreased. This indicates that an increase in minimum mapping area at ground scale allows fewer small forest patches (and small patches of all other uses) to be mapped, resulting in their inclusion in the surrounding agricultural or urban category.

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The area of difference between Level I land use maps at 1:250,000 mapped from high-altitude aircraft photography and ERTS imagery is 3,498 hectares by the formula:

$$\sum_{i=1}^{6} \frac{|h_{i3} - h_{i4}|}{2}$$

Where h_{i3} = hectares of land use i mapped at 1:250,000 scale from aircraft photography
h_{i4} = hectares of land use i mapped at 1:250,000 scale from ERTS imagery
and 6 = the number of land use categories mapped

The percentage of area mapped differently from the two sources is 3,498 divided by 76,000 or 4.6 percent. This generalization would be the result of sensor resolution differences rather than mapping scale differences as in the previous comparison because, in this case, the maps are at the same scale.

One of the land use categories in which the interpretation of ERTS imagery differed significantly from the interpretation of high-altitude aircraft photography was urban land: 1,566 hectares of built-up land as interpreted from high-altitude photography were mapped as cropland and pasture or forestland using ERTS imagery. In the urbanized areas, urban land was more readily identified from the ERTS imagery, indicating that where the settlement pattern is dense the signature is distinct. The ERTS color-infrared composities do not reveal the distinction between dispersed settlement and dissected agricultural patterns at the periphery of the urbanized areas because of the predominant vegetative response in the near-infrared wavelengths. Likewise, the ERTS color-infrared response for heavily wooded residential areas is nearly identical to that of forest.

In numerous instances, particularly in wetland areas either totally or partially submerged, nonforested wetlands were mapped as water. This condition seems most likely attributable to the opaqueness of water in the infrared wavelengths.

COMPARISONS WITH FIELD DATA

An additional measure of accuracy was made by comparing the Level II land use obtained from the high-altitude photography at the center of each 1-km grid for each site at the three scales, 1:24,000, 1:100,000, and 1:250,000 with observation of the land use at the same points in the field.

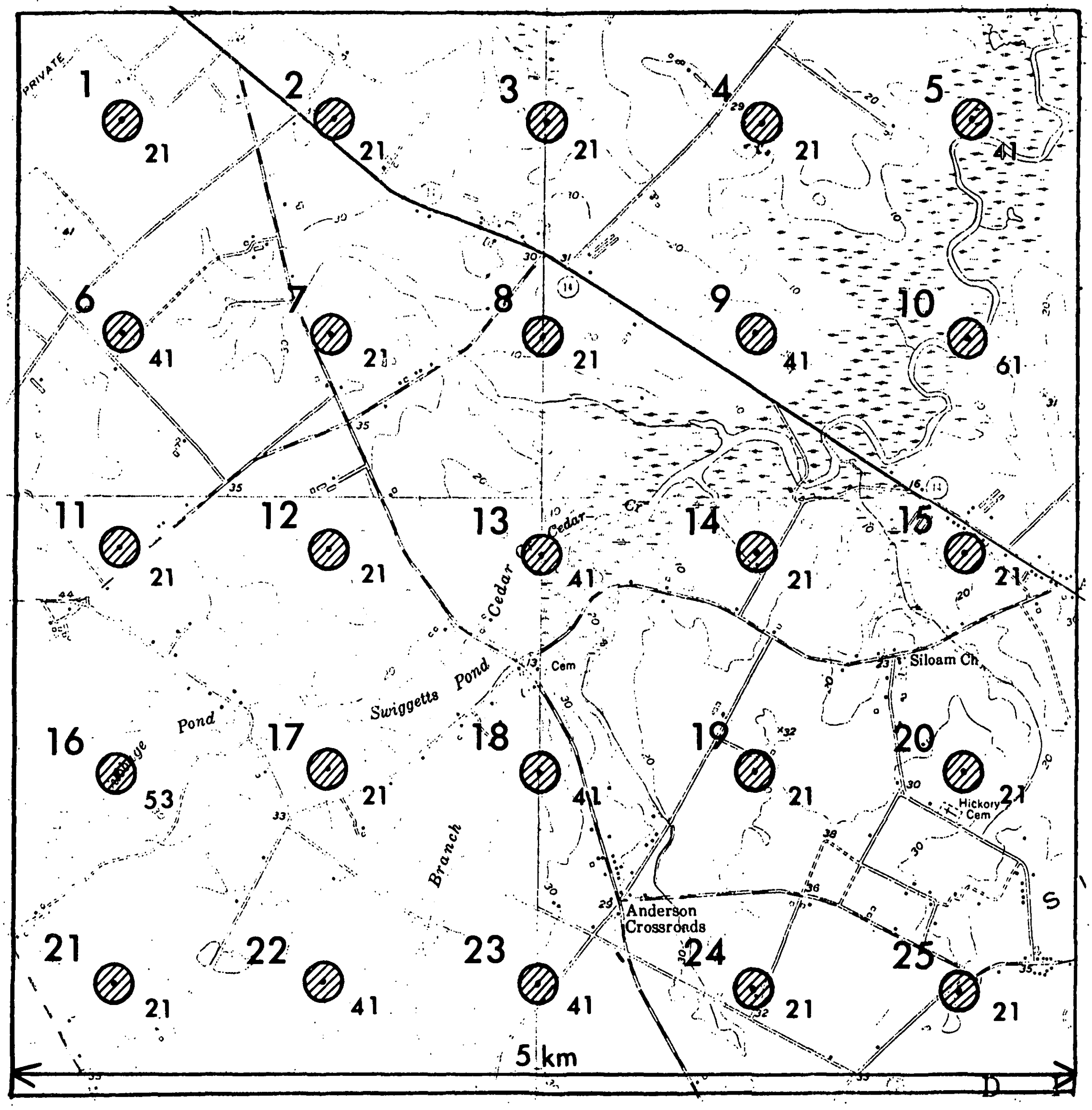
A 1-km grid cell overlay was prepared for each sample site at each scale land use map and the center of each cell marked by a dot. When this overlay was registered to the land use map, the land use at each point was tabulated on a computer coding sheet having a separate column for the land use at each scale of map. The field observations were made from a low-flying aircraft. The 25 points to be identified were plotted on a topographic map and the land use was recorded on this map as the plane passed over the field points. Where the field data differed from the topographic map data, the field researcher would look for signs of recent change, and note it on the topographic map. It was not possible to conduct field interviews to determine if change had occurred since 1972, and so only the rather obvious changes were noted. No estimate of the amount of change that had occurred is possible; however, it is assumed that any such changes would be insignificant.

Figure 3 is an example of the field points of the Dover site. The aircraft-identified land use then was entered in its column on the coding sheet. The tabulation of land use for the Dover site is given in table 4. Matrices comparing the aircraft-identified land use with the land use at each scale as determined from photography and ERTS imagery were generated by computer (see table 5, 6, and 7) for the urban and nonurban field-checked sample sites.

Tables 5, 6, and 7 reveal that the predominant Level II land uses are mapped with a higher degree of accuracy than those occurring less frequently. By comparing the number of correct occurrences of a given category with the number of field-identified occurrences of that category, one can determine the corresponding percent of accuracy. This can be drawn from the tables by dividing the number of points for each category along the diagonal by the total number of points at the base of each column. Specifically in the case of the land use map at 1:100,000, the accuracies of the four major land use categories, residential land (11), cropland and pasture (21), heavy crown cover forest (41), and bays and estuaries (54) are 74.5 percent, 83.6 percent, 80.1 percent, and 89.9 percent, respectively. The greatest accuracy at this scale is in the bays and estuaries category (54), where the photographic signature is easy to delineate. The least accurate of the four major land use categories, residential land (11), is also the category with the most complex signatures.

As can be seen from tables 5, 6, and 7, the accuracy percentage is highest at a scale of 1:24,000 and decreases as the scale decreases. The overall accuracy is 84.9 percent at 1:24,000, 77.4 percent at 1:100,000, and 73.0 percent at 1:250,000. Specific interpretation problems occurring at all three scales are found in three land use categories. The first problem area is that residential land (11) often

DOVER SITE



1:24,000 reduced 23%

N

EXPLANATION
21 - Cropland and pasture
41 - Heavy crown cover forest
53 - Reservoirs
61 - Vegetated nonforested wetlands

Figure 3.--Center points of 1-km grid cells plotted on the 1:24,000 topographic map labeled with the air-observed land use, for the Dover site.

Table 4.--Land Uses Identified at Field Points
and on Land Use Maps for the Dover Site
[see figure 3 for explanation of category numbers]

Point #	Field-Observed Land Use	Land Use 1:24,000	Land Use 1:100,000	Land Use 1:250,000	ERTS Level I Land Use, 1:250,000
1	21	21	21	21	2
2	21	21	21	21	2
3	21	21	41	21	2
4	21	21	21	21	4
5	41	41	41	41	6
6	41	21	41	21	2
7	21	21	21	21	2
8	21	21	21	41	4
9	41	41	41	41	4
10	61	41	61	21	2
11	21	21	21	21	2
12	21	21	21	21	2
13	41	41	41	41	4
14	21	21	21	21	2
15	21	21	21	21	2
16	53	54	53	21	2
17	21	21	41	21	2
18	41	41	21	21	2
19	21	21	21	21	2
20	21	21	21	21	2
21	21	21	21	21	2
22	41	21	21	41	4
23	41	21	41	41	2
24	41	21	21	21	2
25	21	21	21	21	2

Table 5.--Matrix of Field-identified Land Use and Land Use Determined from photography at Compilation Scale of 1:24,000, Mapped at 1:24,000

Field-identified Land Use

Land use as determined from photography 1:24,000

	11	12	13	14	15	16	17	19	21	22	23	41	42	51	53	54	61	72	TOTAL
11	38	2						1	2			1							44
12	1	2																	3
13			1																1
14																			0
15					1												1		2
16		1				5						1					2		9
17	1								1										2
19						1		2									1		4
21	6								188	2		20	4						220
22																			0
23																			0
41	4			1				2	16		1	287	17				4		332
42	1		1						4			3	5						14
51												1							1
53									1						1	1			3
54									1			1		2	1	88	2		95
61									1			1					26		28
72												1						1	2
TOTAL	51	5	2	1	1	6	0	5	214	2	1	316	26	2	2	89	36	1	

11 - Residential	22 - Orchards, etc.
12 - Commercial and services	23 - Feeding operations
13 - Industrial	41 - Heavy crown cover forest
14 - Extractive	42 - Light crown cover forest
15 - Transportation, etc.	51 - Streams and waterways
16 - Institutional	53 - Reservoirs
17 - Strip and clustered settlement	54 - Bays and estuaries
19 - Open and other	61 - Vegetated nonforested wetlands
21 - Cropland & Pasture	72 - Sand other than beaches

Matrix Total 760
Total Correct 645
Percent Correct 84.9

Table 6.--Matrix of Field-identified Land Use and Land Use Determined from photography at Compilation Scale of 1:120,000, Mapped at 1:100,000 Scale

Field-identified Land Use

Land use as determined from photography 1:100,000	11	12	13	14	15	16	19	21	22	23	41	42	51	52	53	54	61	72	TOTAL
11	38	2					1				4	1					1		47
12	2	2			1														5
13			1																1
14											2								2
15																	1		1
16		1				6					2					1	3		13
19	1						2	1											4
21	5		1					179	1		39	7				4	2		238
22																			0
23																			0
41	5						2	25	1	1	253	17				1	1		306
42								5			11	1							17
51											2					2		1	5
52											1								1
53															2				2
54								4			1					80	4		89
61				1							1		2			1	24		29
72																			0
TOTAL	51	5	2	1	1	6	5	214	2	1	316	26	2	0	2	89	36	1	

11 - Residential	23 - Feeding operations
12 - Commercial and services	41 - Heavy crown cover forest
13 - Industrial	42 - Light crown cover forest
14 - Extractive	51 - Streams and waterways
15 - Transportation, etc.	52 - Lakes
16 - Institutional	53 - Reservoirs
19 - Open and other	54 - Bays and estuaries
21 - Cropland and pasture	61 - Vegetated nonforested wetlands
22 - Orchards, etc.	72 - Sand other than beaches

Matrix Total 760
Total Correct 588
Percent Correct 77.4

Table 7.--Matrix of Field-identified Land Use and Land Use Determined from Photography at Compilation Scale of 1:120,000, Mapped at 1:250,000 Scale

Field-identified Land Use

Land use as determined from photography 1:250,000

	11	12	13	14	15	16	19	21	22	23	41	42	51	53	54	61	72	75	TOTAL
11	33	2			1	2	2	3			5								48
12		2																	2
13																			0
14																			0
15											1								1
16		1	1			3					1				2	1			9
19							2												2
21	7						1	160	1	1	54	7		1	4	2			238
22																			0
23																			0
41	11							44	1		252	15		1	5	1	1		331
42								1				3							4
51											1	1							2
53																			0
54								3			1				74	6			84
61			1	1		1		3					2		4	26			38
72																			0
75											1								1
	51	5	2	1	1	6	5	214	2	1	316	26	2	2	89	36	1		

11 - Residential
12 - Commercial and services
13 - Industrial
14 - Extractive
15 - Transportation, etc.
16 - Institutional
19 - Open and other
21 - Cropland & pasture
22 - Orchards, etc.
23 - Feeding operations
41 - Heavy crown cover forest
42 - Light crown cover forest
51 - Streams and waterways
53 - Reservoirs
54 - Bays and estuaries
61 - Vegetated nonforested wetlands
72 - Sand other than beaches
75 - Other barren land

Matrix Total 760
Total Correct 555
Percent Correct 73.0

is interpreted as cropland and pasture (21) or heavy crown cover forest (41). The second problem area (and the most inaccurately interpreted land use type) is light crown cover forest (42) which has been interpreted as either heavy crown cover forest (41) or cropland and pasture (21). The third land use type where inaccuracies occur frequently is nonforested wetland (61) incorrectly mapped as heavy crown cover forest (41), bays and estuaries (54), or other uses.

These classification errors occur at all three scales, revealing the difficulties in recognizing these land use signatures on the high-altitude aircraft photography.

Residential land (11) was misclassified as cropland and pasture (21) or heavy crown cover forest (41) for 22 percent of the points at 1:24,000, 19 percent at 1:100,000, and 35 percent at 1:250,000. In the rural areas this may be due to the tendency to see the area being mapped in terms of the general background land use type (an hypothesis that could be tested by comparing the location of the errors within the overall CARETS map).

Category 42, light crown cover forest, is a poorly defined land use category, and as borne out by the field verification statistics, it is rarely mapped correctly. Light crown cover forest includes all transition stages from brushland to a 40-percent crown forest. It is best to translate category 42 land use as forest, considering that light crown cover forest has since been dropped from the classification system.

Category 61, vegetated nonforested wetlands, is frequently confused with the adjacent land use categories, most frequently bays and estuaries (54), or heavy crown cover forest (41). Nonforested wetlands are often subject to tidal fluctuations and change their appearance seasonally. To utilize properly high-altitude color-infrared photography in mapping wetlands, seasonal coverage should be obtained. It is reasonable to question whether the significant decrease in accuracy for the wetland category at all three scales is entirely due to errors of misclassification. Field data, acquired 2 to 3 years after the mapping took place, would account for a significant portion of the loss of accuracy for a land use category subject to frequent variation. Therefore, field data should be collected at the time of data acquisition.

The overall accuracy of the Level I land use maps from the maps at the three scales is plotted by the land use categories in figure 4. Generally, the accuracy decreases as the scale decreases. Exceptions to this trend, however, can be singled out, from figure 4. For instance, nonforested wetlands are mapped most accurately at a scale of 1:24,000 and 1:250,000. Urban and built-up land is below the average accuracy at a scale of 1:250,000, and is most accurately mapped at a scale of 1:100,000. These exceptions to the general trend are the result of only one or two sample points, and show the 1:100,000 scale to be neither significantly more accurate for urban land nor significantly less accurate for the nonforested category.

FIELD COMPARISONS ALONG LINEAR TRAVERSES

A second method was employed in determining the accuracy of 1:100,000-scale Level II maps in comparison to the land use visible in the field. Traverses were made by road through the sample site and the land use along each side of the road was recorded in increments of tenths of a mile measured from the automobile odometer. Land use areas less than

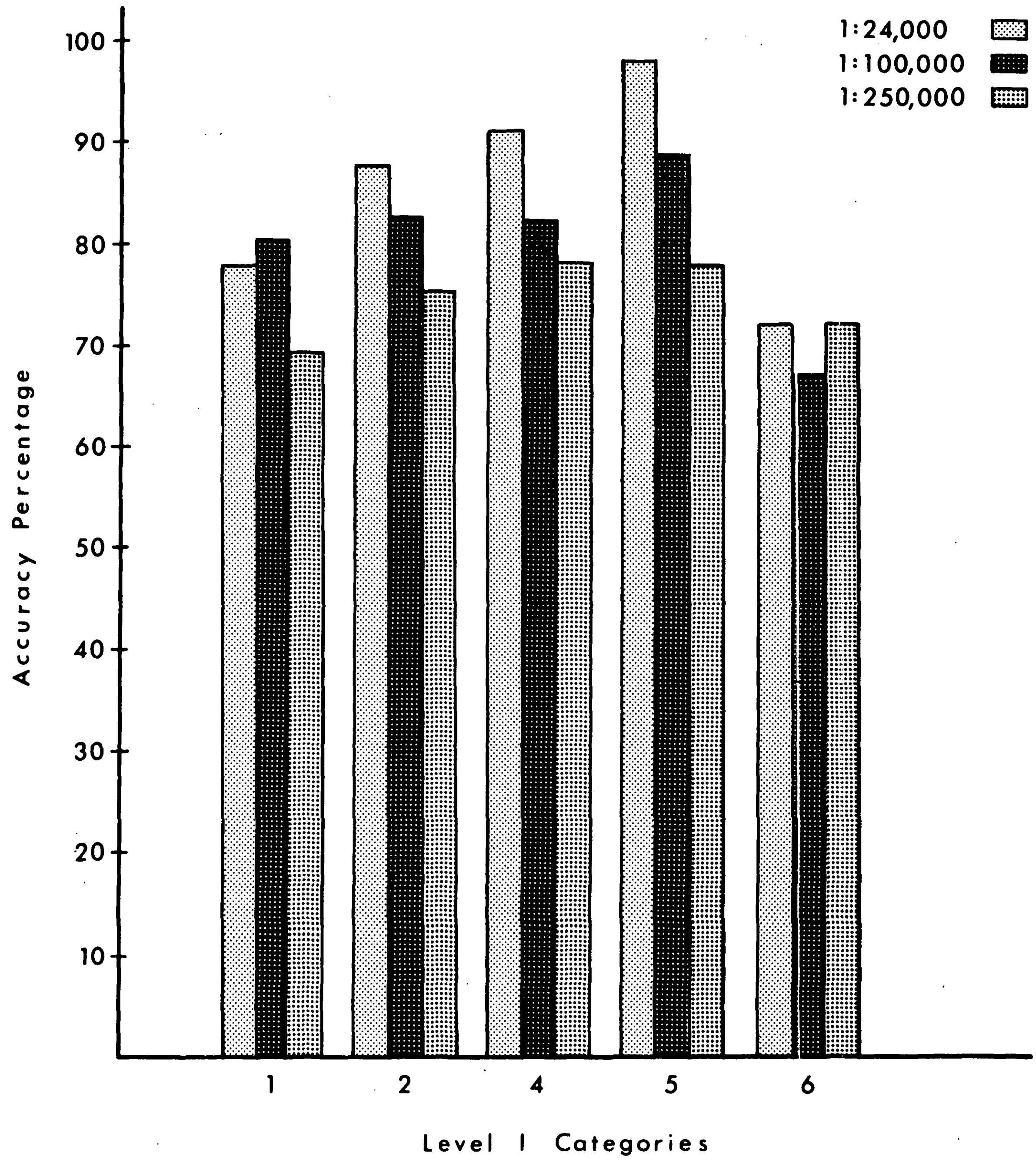
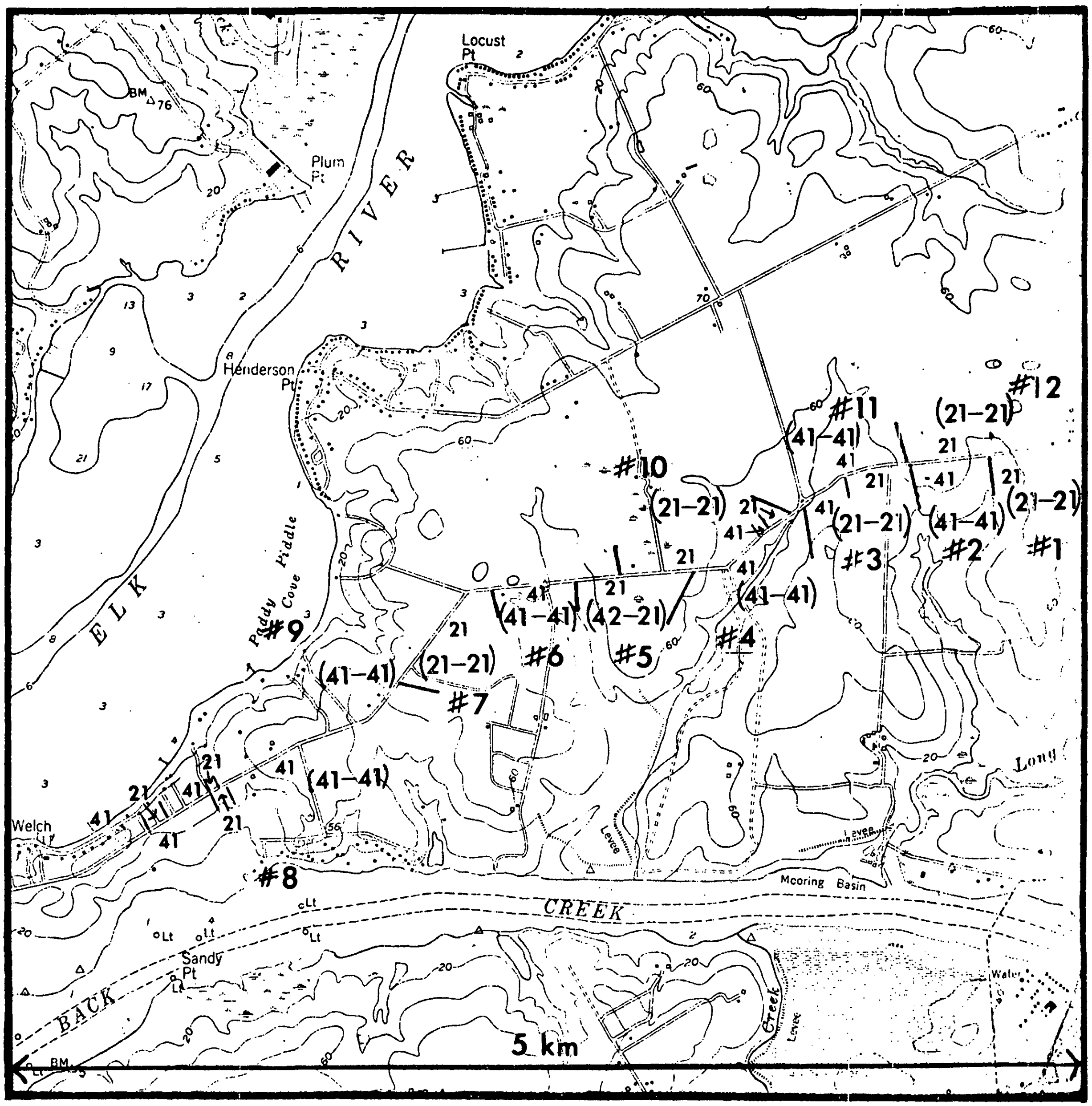


Figure 4.--A comparison of the accuracy of Level I land use interpretations at three scales derived from aircraft data for each land use category. Percentages derived from field check.

the minimum mapping unit (just over a tenth of a mile) were included in the surrounding land use. Topographic maps were used in the field to record the land use and the linear distance. Five non-urban and two urban sample sites were selected.

A comparison of this linear field data with the 1:100,000 land use map was possible using the Kargl reflecting projector, and the land use mapped at 1:100,000 scale was also recorded on the topographic map with a pencil of a different color. The land use maps at 1:24,000 scale were then overlayed on the field maps and again the land use categories were recorded on the topographic map. The result is an annotated topographic map as in figure 5 (lettering has been substituted for color). The three levels of land use information present on the field maps were then measured using a centimetre rule and entered on a computer coding form by sample site, linear segment, and land use category. Each segment unit with a set of land uses for the field-identified category and 1:100,000-map category was given a unique number. Where two or more land uses appeared at 1:24,000 scale within each of these numbered units, subunits were added using decimals. Each line entered was a unique example listing the field-recorded category, the 1:100,000 scale mapped land use, the 1:24,000 scale mapped land use, and the section length in metres. An example of the tabulation appears in table 8.

Two comparisons were performed by computer: (1) a comparison of field data to the 1:100,000 scale map and (2) a comparison of mapped data at 1:24,000 and 1:100,000 scales. The comparison of field data to 1:100,000 scale was to give a measure of the reliability of the land use



1:24,000 reduced 23%

N ↑

EXPLANATION

#1 – 12	Segment number
(41 – 41)	
(second number)	Land use at 1:100,000
(first number)	Field-identified land use
21 ————	Land use at 1:24,000

Figure 5.--Linear traverse of the Elkton site showing field-identified land use, land use mapped at 1:100,000 and land use mapped at 1:24,000 along one traverse. Illustration is at a scale of 1:24,000 reduced 23 percent.

Table 8.--Metres of Land Use Along a Linear Traverse Measured at the Elkton Site and from Land Use Maps at 1:100,000 and 1:24,000 scales

Site	Segment	Unit	Field Category	1:100,000 Category	1:24,000 Category	Length in metres
8	1	1	21	21	21	415
8	1	2	41	41	41	391
8	1	3.1	21	21	21	276
8	1	3.2	21	21	41	240
8	1	4	41	41	41	624
8	1	5	42	21	21	528
8	1	6	41	41	41	384
8	1	7	21	21	21	624
8	1	8.1	41	41	41	1080
8	1	8.2	41	41	21	72
8	1	8.3	41	41	41	960
8	1	9.1	41	41	41	672
8	1	9.2	41	41	21	120
8	1	9.3	41	41	41	216
8	1	9.4	41	41	21	48
8	1	9.5	41	41	41	2304
8	1	10.1	21	21	21	720
8	1	10.2	21	21	41	24
8	1	10.3	21	21	21	96
8	1	11	41	41	41	624
8	1	12	21	21	21	804

map. The comparison of the larger scale map to the one at 1:100,000 scale was for the purpose of ascertaining the degree of error at the smaller scale due to generalization to a minimum mapping unit.

Computer programs were run to generate a matrix comparing the lengths of each land use category identified in the field with the land use categories identified for the same traverses at 1:100,000 scale. This program was run for each site as well as for a composite of all the sites. It was then possible to compute the percent of direct correlation between the two scales. The matrix of this comparison for the composite of all sites is shown in table 9. Similar matrices were also generated comparing the mapped land use at 1:100,000 scale with that identified at 1:24,000 scale for each site, the composite of which is shown in table 10.

From these matrices it is possible to recognize the land use types most frequently in error on the map and to determine an accuracy percentage for each land use type or for the complete area sampled. It is also possible to account for land use differences between 1:100,000 and 1:24,000 scales due to generalization at the smaller scale. By summing the lengths of the segments of land use discrepancies less than 200 metres (the minimum unit length at 1:100,000 scale) and comparing this sum to the total length traversed, it is possible to compute the percent of inaccuracy due to generalization and to correct for this factor (table 11). For the seven sites sampled, this amounted to 4 percent of the total length.

If a linear traverse had been employed for all the sample sites in CARETS, it would be possible to compute the statistics of map reliability to the total area or to have map reliability statistics for each region of CARETS. Since only seven sample sites were traversed, mainly

Table 9--Metres of Field-identified Land Use and 1:100,000 Scale Mapped Land Use Along Linear Traverse for Seven Sites

Land Use Identified in the Field*

Land Use on the 1:100,000 Land use Maps	11	12	13	15	16	17	18	19	21	41	42	53	54	61	Total
11	13,284	408						132							
12	168	3,192													
13		504	336												
15				1,104											
16		264			696										
17						288			288						
18							120								
19		48					168	2,112							
21	528								45,162	2,040	2,208				
41	96								504	31,079	1,008				
42										15	2,352				
53												240			
54	24												576		
61	1,008										624			5,760	
															116,576

*see appendix A for land use categories

Table 10--Metres of Land Use Along Linear Traverses Identified from Maps at 1:100,000 and 1:24,000 Scales for Seven Sites

Land Use on the 1:24,000 Land use Maps

Land Use on the 1:100,000 Land-use Maps	11	12	13	15	16	17	18	19	21	24	41	42	53	54	61	73	TOTAL
11	13,680	120		24													
12	720	2,760														120	
13		312	336					192									
15				864								240					
16					888						72						
17						576											
18								120									
19	48	96						1,992				192					
21	1,368					1,128			45,330	312	1,800						
24																	
41	192								1,896		30,311	288					
42									1,056		552	639				120	
53													240				
54														600			
61	408	48		312					48		576	144		48	5,808		
73																	
																	116,576

*see appendix A for land use categories

Table 11.--Correlation of Mapped Data at 1:24,000 Scale with Data Mapped at 1:100,000 Scale, Linear Traverse Method

	Total length Traversed	Having identical land use categories at the two scales	Having different land use categories at the two scales	Sum of the length of units less than 200 metres; from column 2	Adjusted accuracy* of 1:100,000 maps
Metres	116,576	104,024	12,552	4,102	108,144
Percent of total length	100	89	11	4	93

*Areas less than 200 metres were considered accurate within the limitations of the map.

to test the possibility of using a linear traverse as a viable sampling measure, such a computation for all of CARETS would not be valid. For the sites sampled in the northeast portion of CARETS, the accuracy was determined to be 91 percent using this method (table 12).

According to table 9, the land use types creating the most mapping difficulties were categories 12 and 42. Category 12, commercial and services, was frequently confused with category 13, industrial, or category 16, institutional. The identifying key of a commercial site on high-altitude photography is that of a large building or complex of buildings surrounded by parking areas or loading docks and having no associated features such as swimming pools or playing fields that would indicate residential or institutional use. Where complexes of these large commercial buildings are adjacent to industrial sites, the land use might be incorrectly interpreted as institutional or industrial. Large residential or institutional buildings having spacious parking lots and, lacking features identifying them as residential or institutional land, are often misinterpreted as commercial.

Category 42, light crown cover forest, was mapped correctly only 40 percent of the time. In most cases, such land was mapped as category 21, cropland and pasture, category 41, heavy crown cover forest, or category 61, vegetated nonforested wetland. The problem in identifying category 42 is that its definition as forest with 10 to 40 percent crown cover permits the inclusion of a wide range of vegetative conditions from a recently clearcut forest, to aforesting cropland, to a lightly wooded pasture. Distinguishing the areas of category 42, however, requires the identification of a distinct signature on the photography, which the category's definition precludes. Even accurate field data are difficult to accrue for this category, since the category

Table 12.--Correlation of Mapped Data at 1:100,000 Scale with Field Data, Linear Traverse Method

	Total length	Having identical land use categories on map and in field	Having different land use categories on map and in field
Metres	116,576	106,301	10,275
Percent of total length	100	91	9

describes a situation of transition, and field work is sometimes conducted as much as 2 years after the mapping effort.

Occasionally, interpreters using high-altitude photography identified some forest stands as cropland or cropland as forest. Much of this error was due to the generalization attributable to minimum mapping area requirements. Field verification results revealed that 30 percent of the error observed in the mapping of agricultural land as forest was due to such generalization. Similar generalizations accounted for as much as 60 percent of the error in the mapping of forest as agricultural land. Not including the generalization differences between field data and mapped data, the actual interpretation error in mapping categories 21 and 41 was a little over 1 percent.

Of the land use types described, category 42 accounted for the greatest length in error with 3,840 metres of a possible 6,192 mapped as other categories.

COMPARISON OF 1:250,000 MAPS FROM ERTS IMAGERY AND HIGH-ALTITUDE PHOTOGRAPHY

The researchers also employed point sample comparisons to compare the accuracy of Level I land use identified on the high-altitude photography and mapped at 1:250,000, with the accuracy of the Level I land use mapped from the ERTS imagery at a scale of 1:250,000. The Level I land use at the center points of each 1-km cell within each sample site was identified on the ERTS maps and entered in a separate column on the computer coding sheets. It was then possible to generate matrices by computer, comparing the Level I land use identified on each map at a scale of 1:250,000 with the field data. See figure 6 for the matrix of data obtained for all the field sites.

Field-identified Land Use

Land Use Interpreted from High-Altitude Photography

	1	2	4	5	6	7	TOTAL
1	49	3	7	2	1		62
2	8	162	61	5	2		238
4	11	46	270	6	1	1	335
5		3	3	74	6		89
6	3	3		6	26		38
7			1				1
	71	217	342	93	36	1	TOTAL

Matrix Total 760
Total Correct 581
Percent Correct 76.5

Field-identified Land Use

Land Use Interpreted from ERTS imagery

	1	2	4	5	6	7	TOTAL
1	24	4	6				34
2	28	145	65	7	2	1	248
4	18	62	261	7	8		356
5	1	6	7	76	4		94
6			2	3	22		27
7			1				1
	71	217	342	93	36	1	TOTAL

Matrix Total 760
Total Correct 528
Percent Correct 69.5

1 - Urban and built-up
2 - Agricultural land
4 - Forest land
5 - Water
6 - Nonforested wetland

Figure 6.--Matrices of land use identified in the field and mapped at 1:250,000-scale from high-altitude aircraft photography and ERTS imagery.

The overall accuracy of the ERTS maps was found to be 69.5 percent as compared to 76.5 percent accuracy for the maps at a scale of 1:250,000 derived from high-altitude photography. The major land use type in discrepancy between the two maps was found to be urban land (1). See figure 7 for a comparison of the accuracy of ERTS imagery and high-altitude photography mapped at 1:250,000 by land-use type.

No urban and built-up land (1) identified in the field was correctly interpreted on the ERTS imagery in the non-urban sample sites. Of the 29 points identified as urban and built-up land in the field, 22 points were identified as cropland and pasture, and 6 were identified as forest land on the ERTS imagery. Of these same points identified on the high-altitude photography, 17 were mapped as urban land, and only 6 were interpreted as cropland and pasture and 4 as forest land. In these non-urban areas, the response of a small built-up area on ERTS imagery is lost in the stronger vegetative response and is mapped as cropland and pasture.

Within the urban sample sites, a little over half of the points identified as urban in the field were also classified as urban on the ERTS imagery (24 of a possible 42, or 57 percent). By comparison, an interpreter, using high-altitude photography at 1:120,000 and mapping to a mosaic at 1:250,000, identified 32 of a possible 42 points or 76 percent as urban. Color-composite prints or transparencies of ERTS imagery do show a distinct spectral response for urban areas. Where older residential areas have a predominance of tall trees or residential lot sizes of an acre or more, the vegetative spectral reflectance dominates to give a forest or agricultural signature. The forest signature

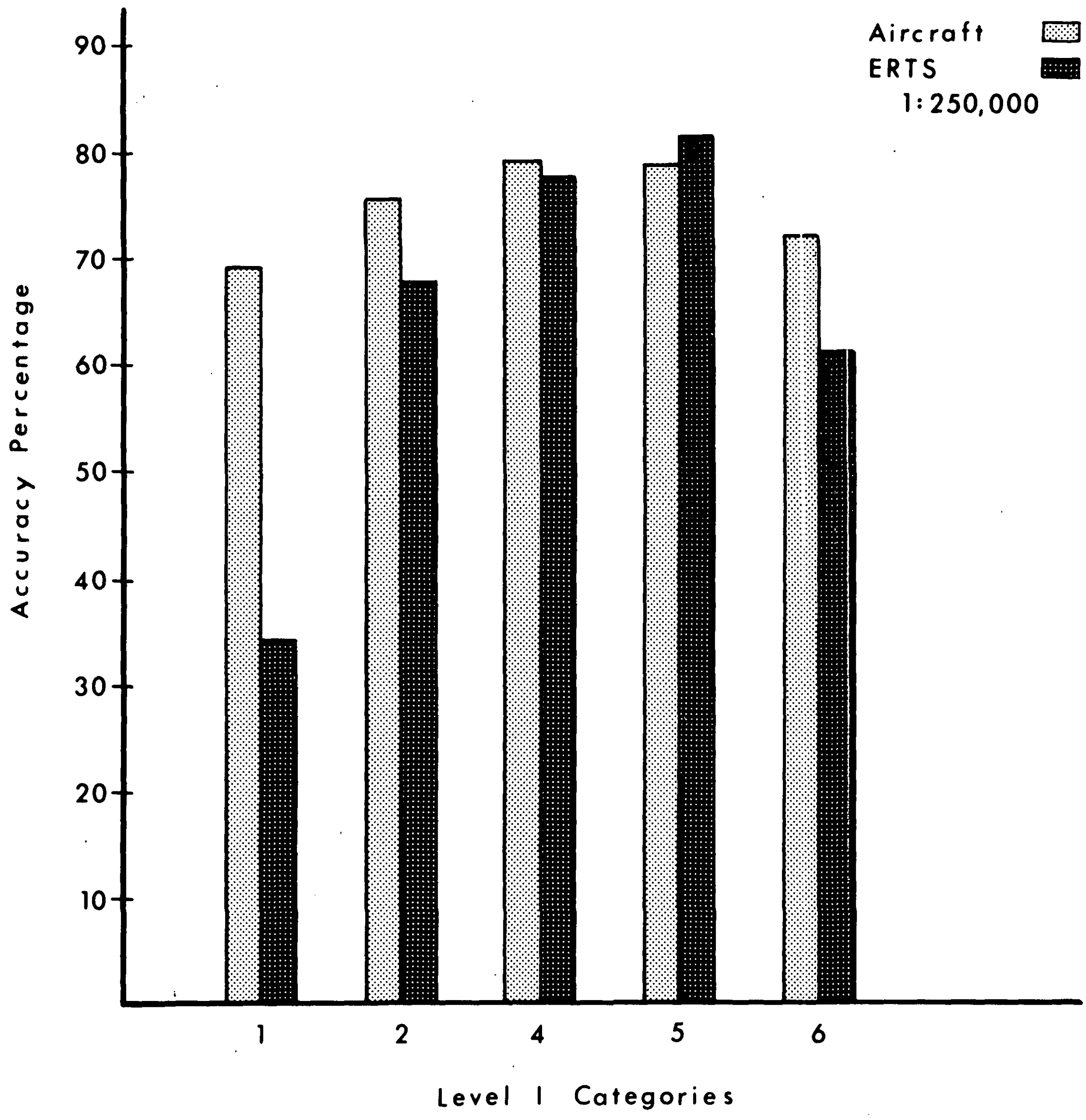


Figure 7.--A comparison of the accuracy of ERTS and aircraft land use interpretations for each Level I land use category.

more often dominated the urban residential signature in the more central urbanized areas, where one would expect older residential neighborhoods. The agricultural signature dominated at the periphery of the urbanized areas where population density is less and either large estate homes or new residential communities are adjacent to agricultural areas.

Occasionally forest or agricultural land within an urban setting was lost to the ERTS imagery because of low resolution and the small size of the forest or agricultural parcel.

ERTS imagery is most reliable for interpreting forest and water categories. Band 5 shows the greatest contrast for forest areas and band 7 is opaque to the reflectance from water, giving the strongest definition to this category. Where an intermixture of agricultural and forest land is dispersed across an area, some agricultural land may be mapped as forest as the forest has the stronger signature. Wetland is often misclassified as bay or estuary when the land is partially under water. In this case, both wetland vegetation and water are present and either of two categories defines one of the prevailing conditions. By definition, however, both vegetated nonforested wetland and bays and estuaries are mutually exclusive. By choosing the one category that has the strongest signature on ERTS imagery, the land use mapped may not be consistent with the land use identified in the field or on high-altitude aircraft photography.

RELATIVE COSTS

COST COMPARISON OF COMPILING LEVEL II MAPS AT THREE SCALES

The accuracy of the land use interpretation must be weighed against the cost of compilation. It was assumed at the outset that the larger scale land use maps were more accurate than the smaller scale maps. Now the question of whether costs vary directly with the accuracy and scale may be considered.

The costs to produce maps at these three scales from high-altitude aircraft photography is a function of several processes in the compilation, including acquisition of the data, interpretation, preparation for reproduction, and reproduction. Table 13 compares the 1975 mapping costs at each scale. Note that the costs to map at 1:250,000 and 1:24,000 are interpolated from the time spent in mapping for the sample areas, whereas the costs to map at 1 :100,000 are calculated from that of mapping the total CARETS area. The costs for data acquisition are those listed by the EROS Data Center in Sioux Falls, South Dakota.

The interpretation costs are based on a 1975 average standardized per hour cost of $20.00. A similar cost study was performed in the remote sensing community using 1973 costs and an inflation factor must be applied for a comparison (Earth Satellite Corporation and Booz-Allen Applied Research Corporation, 1974). To facilitate cross comparisons to other systems, the work hours involved are also included on table 13. From table 13 we can see that interpretation at 1:24,000 is approximately twice as expensive as interpretation at 1:100,000 and interpretation at 1:100,000 is 1.2 times more expensive than

Table 13.--Production Costs* per km^2 for Level II Land use Maps** at Three Scales

	1:24,000	1:100,000	1:250,000	REMARKS
Data Acquisition	$.14	$.06	$.05	Based on 50 frames for 10,000 km^2 1:24,000 each frame $28.00 1:100,000 each frame $12.00 1:250,000 each frame $10.00
Mosaic Construction	$6.00	$.70	$.16	Based on average estimate for mosaic construction by the Topographic Division (Interview with Bernard Kelley, USGS Topographic Division, 4/11/75)
Interpretation & Edit ($20/hr)	600 hrs/ 10,000 km^2 $1.20	300 hrs/ 10,000 km^2 $.60	250 hrs/ 10,000 km^2 $.50	Actual time from interpreting at 1:100,000 - estimates at 1:250,000 and 1:24,000 interpolated from sample site interpretation. Cost estimates based on USGS Topographic Division per hour rates, 1975
Cartographic ($12/hr)	200 hrs/ 10,000 km^2 $.24	100 hrs 10,000 km^2 $.12	80 hrs/ 10,000 km^2 $.10	Based on actual time for cartographic work at 1:100,000 interpolated to 1:24,000 and 1:250,000, and assumed to be 1/3 the interpretation time
Marginalia	$1.25	$.08	$.01	Based on actual costs to compile collars for CARETS maps at 1:100,000, and assumed to be the same per map at each scale
Reproduction	$.10	$.01	<$.01	USGS cost to produce positive film transparencies at scale
Publication Cost	$3.00	$.18	$.06	Cost of publication by the USGS (Interview with Bernard Kelley, USGS Topographic Div., 4/11/75)
TOTAL	$11.93	$1.75	$.88	

*1975 dollars

**At scales and formats conforming to the USGS 1:24,000 and 1:250,000 topographic map series and CARETS 50 x 50-km 1:100,000 photomosaics.

interpretation at 1:250,000. The cost of interpretation, however, is only a portion of the total cost to produce a land use map product.

To produce a land use map that meets national map accuracy standards for any scale, one must first prepare a gridded rectified mosaic. Constructing a black and white rectified mosaic costs $800 to $1,000 at a scale of 1:24,000 for a 7-1/2-minute sheet, $1,500 to $2,000 at a scale of 1:100,000 for a 50 x 50-km sheet, and $3,000 to $3,500 at a scale of 1:250,000 for a 1° x 2° sheet. These costs are based on using suitable quality photography at a scale of 1:76,000 or smaller. Production of a rectified mosaic adds considerably to the mapping cost. Short cuts are possible, however, if the map is compiled directly from the rectified photograph obtained at the mapping scale and using, as a control base, a reproduction of the black and blue line plates of an existing topographic map.

A film positive transparency of the black and blue line color separation plate is available from the USGS at a cost of $15.00 for a map sheet at the scale of 1:24,000, and $20.00 at the scale of 1:250,000. This is a cost of $.01 per km^2 at 1:250,000. Costs for rectifying high-altitude aircraft photography at the mapping scale include those for rectifying a frame of photography and the cost to have it enlarged or reduced to scale. The cost to rectify a 9-in. frame of film amounts to $20.00 per frame of film or $.10 per km^2. Once the film was rectified, reproductions from the USGS would cost about $.14 per km^2 at 1:24,000 and $.05 per km^2 at 1:250,000. The total cost of the black and blue line color separation plates and the rectified photography would amount to $.34 per km^2 at 1:24,000 and $.15 per km^2 at a scale of 1:250,000, based on 50 frames per 10,000 km^2 at $28.00 each at 1:24,000 scale, and $10.00 each at a scale of 1:250,000.

The savings by mapping using rectified photography and a black and blue line plate over mapping using a rectified mosaic as a base would be the difference between the cost per km^2 for the mosaic at each scale (table 13) and the costs listed above. This would be a difference between $6.00 and $.34 at 1:24,000, or $5.66 per km^2, and a difference between $.16 and $.15 at 1:250,000, or $.01 per km^2. These cost savings amount to 47 percent of the total mapping cost per km^2 at 1:24,000 and only 1.0 percent of the total cost per km^2 at 1:250,000.

No actual measure of the positional accuracy has been made of land use maps produced using a black and blue line plate reproduction. It must be assumed that some inaccuracies would be inherent in using this as a method of mapping, as there are few control points for registering the film to the line base. Registration would be more difficult using a black and blue line plate at 1:24,000 because of changes in streambeds or road patterns. Some inaccuracies may be present in the map base itself, and the positional accuracy of the land use map would vary according to the positional accuracy of the map base. With proper mapping techniques at 1:250,000, the positional accuracy of the land use map would approximate that of the base map.

To map at a scale of 1:100,000, a mosaic must be constructed, since no standard topographic map base exists at this scale, and cost savings here are not possible. The user receives an additional benefit, however, in that a gridded rectified mosaic is an accurate mapping base and is itself a valuable product. Copies of the mosaic may be made available to the user community to assist in reading the land use map, and provide visual clues as to the nature of the landscape.

Concern for producing an easily readable land use map and mosaic has lead the USGS to produce experimental 7-1/2-minute combination orthophotoquads and land use maps in conjunction with their standard topographic mapping. Costs to produce this product are high (approximately \$2,000 per quad, or \$13.00 per km^2), but costs would be less if this were an operational program.

After interpreting is completed, the rough draft must be inked by a cartographer and registered to a map collar containing all necessary marginalia. The cartographic costs were figured at a standardized cost of \$12.00 per hour. Marginalia costs are those actually incurred for the 50 x 50-km maps at 1:100,000 scale, which are considered to be the same for each map scale. Reproduction is figured at a cost per map sheet for maps at each of the three scales. Only the cost for one stable base film copy is included.

Once the map has been compiled, the cost of publication must be added to the costs of compilation. This cost is a direct function of the size of the maps being published. Approximately 16, 7-1/2-minute maps at 1:24,000 scale cover the area of a 50 x 50-km map at 1:100,000 scale, and 8 of these, in turn, cover the area of a 1°x 2°1:250,000 scale sheet. Both the 7-1/2-minute maps and the 50 x 50-km maps could be printed on a 24 x 30-in. sheet, and the 1°x2°sheet would require a 30 x 40-in. sheet. The publication costs for paper copies of black line map sheets are found to be \$450 at 1:24,000 and 1:100,000, and \$1,200 at 1:250,000. The cost per km^2 is then \$3.00 at 1:24,000, \$.18 at 1:100,000, and \$.06 at 1:250,000.

The total costs to produce a land use map at the three scales is given at the base of each column in table 13. These costs are based on standard 1975 salaries and overhead cost, and based on mapping the 74,712-km^2 of the CARETS area. Variations in cost would occur depending on the agency doing the work, the size of the area to be mapped, and the method and scale employed. Interpretation costs could vary, depending on the agency doing the mapping and the person hour cost involved.

The Geography Program found \$6.00 per hour plus 15 percent overhead to be the cost per hour in-house and paid as much as \$17.00 per hour for photointerpreters on contract outside the program in 1973. Table 13 has used the standardized cost per hour of \$20.00 to bring it closely in line to costs experienced in the overall remote sensing community in 1975, and all other costs are calculated as 1975 costs.

A comparison of the sum of the costs at each scale reveals that mapping at 1:24,000 scale costs \$11.93 per km^2 and is approximately 7 times more costly than mapping at 1:100,000 scale, which is only \$1.75 per km^2. The cost for mapping at 1:100,000 scale is about twice as expensive as mapping at 1:250,000 scale (\$.88). These cost differences may then be compared to the relative accuracy at each scale to obtain a judgement as to which scale is most beneficial for mapping at Level II.

COST COMPARISONS OF COMPILING LEVEL I MAPS AT 1:250,000 FROM HIGH-ALTITUDE PHOTOGRAPHY AND ERTS IMAGERY

The costs to map Level I land use at 1:250,000 scale according to the standard USGS topographic series format vary depending on the methods employed. This discussion is limited to mapping using the black-blue line plate at 1:250,000 as a mapping base, acquiring the photography or imagery at the mapping scale, and using the same minimum mapping unit. Only the costs to acquire the aircraft photography and ERTS imagery, to set up the mapping base, and to compile land use differ between the two systems. Table 14 includes all the costs involved in compiling and publishing a map at 1:250,000 including both costs that

Table 14.--Compilation and Publication Costs* per km^2 for a Level I Land use Map**

	High-Altitude Photography 1:250,000	ERTS 1:250,000	REMARKS
Data Acquisition	$.05	$.01	Based on 50 frames of high-altitude photography for 10,000 km^2 1:250,000 (4" x 5") at $10 ea. and a Cibachrome transparency from commercial firm at $41.50 (20" x 24") of ERTS imagery.
Mapping base/ no mosaic	$.15	$.01	Based on rectified high-altitude photography with a transparency of the black and blue line plate at 1:250,000, and on ERTS Cibachrome print with a transparency of the black and blue line plate: 50 1:250,000 high-altitude prints $10 ea. $500/10,000 km^2=$.05/km^2 50 prints rectification $20 ea. $1,000/10,000 km^2=$.10/km^2 1 black line base map $20 ea. $20/20,000 km^2=$.001/km^2
Interpretation $20/hr	80 hr/10,000 km^2 $.16	15 hr/10,000 km^2 $.03	Interpretation time, estimated for interpretation from 1:120,000 scale high-altitude photography and actual time for ERTS interpretation
Cartographic $12/hr	40 hr/10,000 km^2 $.05	8 hr/10,000 km^2 $.01	Cartographic time considered to be half the interpretation time, at Level I mapping
Marginalia	< $.01	< $.01	Based on the actual costs to compile collars for CARETS maps at 1:100,000 and assumed to be the same per map at each scale
Reproduction	($18/sheet) $.01	($18/sheet) $.01	USGS cost to produce positive film transparencies at scale
Publication Cost	$.06	$.06	Cost of publication by the USGS (interview with Bernard Kelley, USGS Topographic Div., 4/11/75
TOTAL	$.48	$.13	

*1975 dollars
**conforming to the USGS 1:250,000 map series

do not vary depending on the source and costs that are dependent on the source material. As in table 13, the costs per hour are based on a standardized 1975 cost of $20.00 per hour. The time for compilation and cartography are based on the experience of the CARETS project. And the costs of reproduction and publication are the costs of the work within the USGS. Table 14 indicates that the costs to produce a Level I map at 1:250,000 from ERTS imagery are $.13 per km^2. The cost to produce a Level I land use map from aircraft photography is 4 times the cost to produce a land use map from the lower resolution ERTS imagery.

CONCLUSIONS

From the above results we can now address the questions asked at the beginning of the paper. The first question concerns whether the proposed classes can be validly discriminated using the high-altitude aircraft and ERTS sources. Both linear traverse and point sampling techniques of field verification reveal that three of the four major Level II categories--cropland and pasture, heavy crown cover forest, and bays and estuaries--are mapped with a high degree of accuracy, using high-altitude aircraft photography. In the rural areas, however, certain land use categories are frequently mapped incorrectly from the aircraft photography, most notably commercial land (12), and light crown cover forest (42). We will not discuss the insufficiencies of the classification system, however; because criticism from evaluators of the scheme resulted in the revision of category 42 before the publication of U.S. Geological Survey Circular 671 (Anderson and others, 1972), and the revision of category 12 after the circular's publication.

Category 12 has been revised to include institutional land use within the limitation of commercial and services, and a separate land use category was created for commercial and industrial complexes. Category 42, originally intended to represent light crown cover forest, was removed from the classification scheme after the CARETS program had completed its mapping. Even as the mapping was in progress, the definition of light crown cover forest was being modified. Category 42, therefore, cannot be considered a reliable land use category as compiled on the CARETS maps.

Category 61, vegetated nonforested wetland, did not show as high a percentage of accuracy as the other non-urban land use categories. This could result from the inability of the sensor to distinguish consistently the signature of wetland, or, more likely, from seasonal fluctuations in the water level that differed from the time of aerial coverage to the time of field verification.

In general, the accuracy of the land use maps increases as mapping scale increases. At the smaller scales much of the inaccuracy results from aggregation of areas below the minimum mapping size into the surrounding land use. At the scale of 1:100,000, the accuracy as determined by the linear traverse was 91 percent, whereas accuracy as determined by the low-aircraft point sample was 77.4 percent. The discrepancy in these two measures of accuracy is partially the result of the method of field verification. The point sample, drawn from a larger field than the linear traverse, represented the land use at a point even if below minimum mapping size; the linear traverse represented land use along a line, with linear resolution of 200 metres (the minimum mapping element at 1:100,000).

The generalization due to aggregating the land use parcels within a single uniform code at the minimum mapping size accounts for approximately 4.6 percent of the error at 1:100,000 scale and 5.4 percent of the error at 1:250,000 scale. The adjusted accuracy of the land would increase by these percentages at each respective scale, so that the adjusted accuracy at 1:100,000 would be increased from 77.4 percent to 82.0 percent. An upward adjustment of the accuracy is also possible by having category 42, light crown cover forest, deleted from the land use classification. Category 42 was almost never mapped correctly, and resulted in 3 percent of the total experiment error at 1:100,000 Likewise, category 42 resulted in 3 percent of the total experiment error at both 1:24,000 and 1:250,000 scales. By mapping light crown cover forest as either pasture land or forest land the accuracy would be increased by about 3 percent at each scale.

The unadjusted accuracy of the maps at a scale of 1:24,000 and 1:250,000 was 84.9 percent and 73.0 percent respectively as determined by the point sample technique of field verification. A comparison of these accuracy percentages with the costs of producing the maps, reveals that the range in accuracy is relatively small. The high cost of producing a land use map at 1:24,000 (\$11.93 per km^2) is not offset by the increased accuracy. Mapping at a scale of 1:100,000 in the non-urban areas is about twice as expensive as mapping at 1:250,000, and the accuracy for the larger scale is only slightly improved over the accuracy at the smaller scale. The decision to map at either 1:100,000 or 1:250,000 should be dependent on the intended utilization of the maps. For areas including urban land categories it would be most accurate to map at the scale of 1:100,000 in order to have a consistent accuracy level for the three main land use categories: urban and built-up land agricultural land, and forest land.

This study found that the accuracy of Level I maps interpreted from both high-altitude photography and ERTS imagery, at a scale of 1:250,000, was similar in all categories except for urban and built-up land. ERTS interpreters detected less built-up land than did the interpreters of high-altitude photography when mapping at 1:250,000. Of the 760 points sampled there were 24 points of built-up land identified on the maps from ERTS imagery and 49 identified on the maps from high-altitude photography, compared to 71 points identified as urban and built-up land in the field. Much of the difference from field data is due to the larger ground mapping unit at 1:250,000.

The advantage of compiling Level I land use maps from enlarged color composites of ERTS imagery is that the accuracy approaches that of mapping from high-altitude photography while the costs are about one-fourth. Costly photogrammetric manipulation of the imagery is not required, and accuracy could be improved with the use of low cost auxiliary data. The conclusion thus would be that for Level I mapping, ERTS is the most cost effective. For areas where urban land uses are mixed with agricultural land or forest land, a combination of ERTS data and high-altitude photography would provide the best overview.

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APPENDIX A

Land-use categories in CARETS data base

Level I Categories	Level II Categories and Map Notation Used
URBAN & BUILT-UP	11-Residential 12-Commercial and services 13-Industrial 14-Extractive 15-Transportation, communications, and utilities 16-Institutional 17-Strip and clustered settlement 18-Mixed 19-Open and other
AGRICULTURAL	21-Cropland and pasture 22-Orchards, groves, bush fruits, vineyards, and horticultural areas 23-Feeding operations 24-Other
FOREST LAND	41-Heavy crown cover (40% & over) 42-Light crown cover (10% to 40%)
WATER	51-Streams and waterways 52-Lakes 53-Reservoirs 54-Bays and estuaries 55-Other
NONFORESTED WETLAND	61-Vegetated 62-Bare
BARREN LAND	72-Sand other than beaches 73-Bare exposed rock 74-Beaches 75-Other

APPENDIX B

Land-Use Classification System for Use With Remote Sensor Data*

Level I	Level II
01. Urban and Built-up Land	01. Residential
	02. Commercial and Services
	03. Industrial
	04. Extractive
	05. Transportation, Communications, and Utilities
	06. Institutional
	07. Strip and Clustered Settlement
	08. Mixed
	09. Open and Other
02. Agricultural Land	01. Cropland and Pasture
	02. Orchards, Groves, Bush Fruits, Vineyards, and Horticultural Areas
	03. Feeding Operations
	04. Other
03. Rangeland	01. Grass
	02. Savannas (Palmetto Prairies)
	03. Chaparral
	04. Desert Shrub
04. Forest Land	01. Deciduous
	02. Evergreen (Coniferous and Other)
	03. Mixed
05. Water	01. Streams and Waterways
	02. Lakes
	03. Reservoirs
	04. Bays and Estuaries
	05. Other
06. Nonforested Wetland	01. Vegetated
	02. Bare
07. Barren Land	01. Salt Flats
	02. Beaches
	03. Sand Other Than Beaches
	04. Bare Exposed Rock
	05. Other
08. Tundra	01. Tundra
09. Permanent Snow and Icefields	01. Permanent Snow and Icefields

*Source: U.S. Geological Survey Circular 671, p. 6.

APPENDIX C

U.S. GEOLOGICAL SURVEY
LAND USE AND LAND COVER CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA*

Level I		LEVEL II	
1	Urban or Built-up Land	11	Residential
		12	Commercial and Services
		13	Industrial
		14	Transportation, Communications and Utilities
		15	Industrial and Commercial Complexes
		16	Mixed Urban or Built-up Land
		17	Other Urban or Built-up Land
2	Agricultural Land	21	Cropland and Pasture
		22	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
		23	Confined Feeding Operations
		24	Other Agricultural Land
3	Rangeland	31	Herbaceous Rangeland
		32	Shrub and Brush Rangeland
		33	Mixed Rangeland
4	Forest Land	41	Deciduous Forest Land
		42	Evergreen Forest Land
		43	Mixed Forest Land
5	Water	51	Streams and Canals
		52	Lakes
		53	Reservoirs
		54	Bays and Estuaries
6	Wetland	61	Forested Wetland
		62	Nonforested Wetland
7	Barren Land	71	Dry Salt Flats
		72	Beaches
		73	Sandy Areas Other than Beaches
		74	Bare Exposed Rock
		75	Strip Mines, Quarries, and Gravel Pits
		76	Transitional Areas
		77	Mixed Barren Land
8	Tundra	81	Shrub and Brush Tundra
		82	Herbaceous Tundra
		83	Bare Ground Tundra
		84	Wet Tundra
		85	Mixed Tundra
		86	
9	Perennial Snow or Ice	91	Perennial Snowfields
		92	Glaciers

*Source: U.S. Geological Survey Professional Paper 964 (in press)