Detailed Urban Land-Use and Land-Cover Mapping Using Large Format Camera Photographs: An Evaluation

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ABSTRACT: The usefulness of space shuttle Large Format Camera (LFC) photographs for urban land-use and land-cover mapping at 1:50,000 scale was evaluated using the Boston Metropolitan Area as the test site. Black-and-white panchromatic National High Altitude Photographs (NHAP), which are usually employed by Federal and State agencies for land-use and land-cover mapping, were also evaluated for the same test site so that a comparison could be made with LFC photographs. Visual interpretation of urban land-use and land-cover types at Level III as a detailed categorization of Level II of the USGS classification scheme was carried out for both sets of photographs. Ground-truth data were also obtained from a land-use and land-cover map of Boston produced by the Department of Forestry and Wildlife Management, University of Massachusetts at Amherst at 1:25,000 scale, to which the maps produced from LFC photographs and NHAP were compared. It was found that an overall accuracy of 65 percent was achieved for the map from LFC data and 70 percent for the map from NHAP data, thus demonstrating that LFC photography was comparable in performance to NHAP data as an urban land-use and land-cover mapping tool by virtue of its excellent geometric accuracy, favorable base-height ratio, and high spatial resolution. It was also noted that object-to-ground contrast and the distinctiveness of image element characteristics determined the success of discriminating complex urban land-use/land-cover classes using LFC photographs, which resulted in high variations in accuracy among Level III categories. It was concluded that LFC photographs should best be employed to produce urban land-use and land-cover maps at the more generalized Level II categories at 1:50,000 scale.

INTRODUCTION

AFTER THE ACQUISITION of Large Format Camera (LFC) photographs by Space Shuttle Challenger on 5 October 1984, there was a flurry of interest among photogrammetrists to evaluate the capabilities of LFC photography in photogrammetric control extension and topographic mapping (Derenyi and Newton, 1986; Gruen and Speiss, 1986; Togliatti and Moriondo, 1986; Murai, 1986; Buchroithner *et al.*, 1987; Fritz and Malhotra, 1987). They generally agreed that LFC photographs were metrically accurate and could achieve root mean square errors (RMSE) in planimetry in the region of 5 to 20 m and in height in the region of 10 to 15 m by employing an analytical approach. It was concluded that topographic maps at scales of 1:50,000 or smaller with contour intervals of 50 m or larger could be produced from LFC photography. It was also observed that the large format (23 by 46 cm), the 80 percent forward overlap mode, the high resolution from the use of forward motion compensation (FMC), and the use of a reseau for film distortion corrections provided advantages over conventional photogrammetric camera systems.

While the geometric accuracy of LFC photographs is well established, little research has been conducted in evaluating its non-topographic applications, particularly in land-use and land-cover mapping. Only some preliminary work on evaluating the thematic contents of the LFC photography has been carried out (Togliotti and Moriondi, 1986; Lo, 1988), and it was generally agreed that LFC photographs, when suitably enlarged, could allow individual buildings larger than 10 m per side to be detected under good object-to-ground contrast. Linear features, such as roads and streams, with widths of less than 5 m, could normally be identified under good object-to-ground contrast. Thus, Togliatti and Moriondo (1986) concluded that LFC photographs contained sufficient detail to meet the thematic content requirements for 1:50,000-scale mapping. More thorough evaluations of LFC photographs for land-use and land-cover mapping were conducted by Dietz (1986) for the Black Hills region of South Dakota and by Gierloff-emden (1986) for the Noale-Musone region of North Italy. It was found that individual buildings in small urban areas could be identified and that, because of the use of Forward Motion Compensation (FMC) in the camera, 16× enlargement of LFC photographs was quite suitable in maintaining the edge acuteness of features for the interpretation of land use and land cover. It was concluded that feature identification was greatly dependent on the photographic quality, specifically the object-to-ground contrast, and that land-use and land-cover maps at scales of 1:50,000 and smaller could be compiled from LFC photography.

These evaluations on land-use and land-cover mapping using LFC photographs have dealt only with broad Level I categories of land use and land cover according to the U.S. Geological Survey scheme (Anderson *et al.*, 1976). In view of the predicted average area weighted resolution (AWAR) of 92 lines per mm of Kodak film type 3414 (Schardt and Mollberg, 1985) and the empirically determined spatial resolution of 50 lines per mm (Gierloff-emden, 1986) for LFC photographs, more detailed urban land-use and land-cover mapping at Level II and even Level III should be possible, noting also that the *minimum* mapping unit for urban or built-up uses is 4 ha for 1:250,0000 scale mapping by USGS (original compilation scale at 1:125,000) (Place, 1977). Both the long focal length (f = 30.5 cm) and the forward motion compensation (FMC) employed enabled LFC photography to be focused more sharply on the urban environment from a space perspective than NHAP, which was the principal data source for Level II land-use and land-cover mapping employed by the USGS. Despite the small photographic scale of NHAP, the final map products generally have scales ranging from 1:24,000 to 1:250,000 (Anderson *et al.*, 1976). The Level II categories are not the ultimate limit of the USGS land-use and land-cover classification scheme, and with the availability of supplemental information, Level III categorization from Level II is possible and indeed desirable because Level II categories can be created by aggregating Level III categories (Anderson *et al.*, 1976). It is obvious that the amount of details interpretable from a photograph is related to its spatial resolution. Anderson *et al.* (1976) suggested

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 56, No. 2, February 1990, pp. 197-206.

0099-1112/90/5601-197$02.25/0

TABLE 1. MODIFIED LEVEL III LAND-USE AND LAND-COVER CLASSIFICATION SYSTEM EMPLOYED FOR THE MAPPING

111.	Single family residential
112.	Multifamily residential
121.	Retail commercial
122.	Institutional
131.	Processing industry
132.	Fabrication industry
141.	Transportation: Airport
142.	Transportation: Dockyard
143.	Transportation: Railroad
144.	Transportation: Major Highway
171.	Open land: Parkland
173.	Open land: Golf Course
174.	Open land: Cemetery
410.	Forest
510.	Rivers and streams
520.	Lakes and ponds
530.	Bays and estuaries
620.	Tidal wetlands
621.	Marshes
720.	Beaches
750.	Quarries and gravel pits

that Level III categories could only be interpreted with medium-altitude photographs from 1:20,000 to 1:80,000 scale. In this evaluation of the LFC photographs as an urban land-use and land-cover mapping tool, the LFC photographs were enlarged to a scale of 1:50,000 to meet the primary requirement for Level III interpretation. By doing so, the spatial resolution of the LFC photographs was stretched to its limit.

In order to provide a control for the evaluation, NHAP data were employed in parallel for interpreting Level III categories of urban land-use and land-cover and the accuracy of the interpretation determined, thus making such an evaluation of LFC photographs more meaningful in practical terms. This paper reports on the results of such an evaluation and examines the implications arising from it.

DATA AND METHODOLOGY

In this evaluation of LFC photography for its capability in detailed urban land-use and land-cover mapping, the best quality LFC data, National High Altitude Photographs (NHAP), and ground truth data in the form of a detailed urban land-use and land-cover map at 1:25,000 scale were employed. The study area is the city of Boston, Massachusetts. It was selected for two important reasons. First, excellent LFC photographs of the study area, which constitutes only a small portion of the frame covering Cape Code, Massachusetts, Connecticut, Rhode Island, New Hampshire, and Vermont, are available (Figure 1). NHAP data of the study area in black-and-white panchromatic and color infrared films acquired about six months after the LFC photography on 17 April 1985 are also available (Figure 2). Second, because Boston is a large metropolitan port of approximately 3 million residents, it contains a wide variety of urban land use and land cover. Many of the urban land-use and land-cover categories are distributed close to each other and thus serve as excellent test sites. The ground truth data consist of 1:25,000 scale land-use and land-cover maps for each community in the metropolitan Boston study area for the year 1985 (Figure 3). These maps were produced in an on-going land-use mapping program started in 1951 by the Remote Sensing Unit, Department of Forestry and Wildlife Management, University of Massachusetts at Amherst and were kept updated using large-scale aerial photographs (MacConnell *et al.*, 1974; Goodwin, 1988). These land-use maps featured 20 categories of land use and land cover based on which a new 21-category urban land-use/land-cover key at Level III of the U.S. Geological Survey scheme (Anderson *et al.*, 1976) was designed (Table 1). This new scheme which subdivided Level II categories into as much detail as possible, provided the basis for the land-use and land-cover interpretation which was carried out manually with the aid of a mirror stereoscope equipped with 3X and 6X binocular attachments.

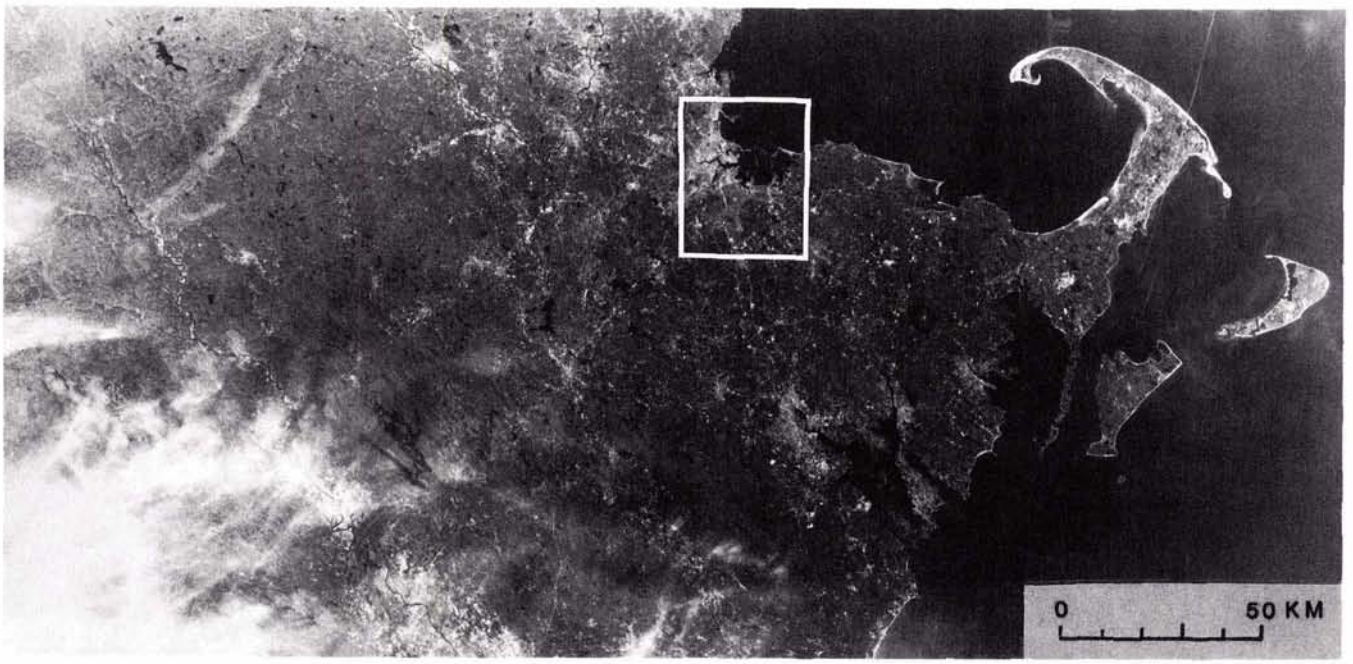

FIG. 1. Large Format Camera (LFC) frame number 663 showing the Boston study area.

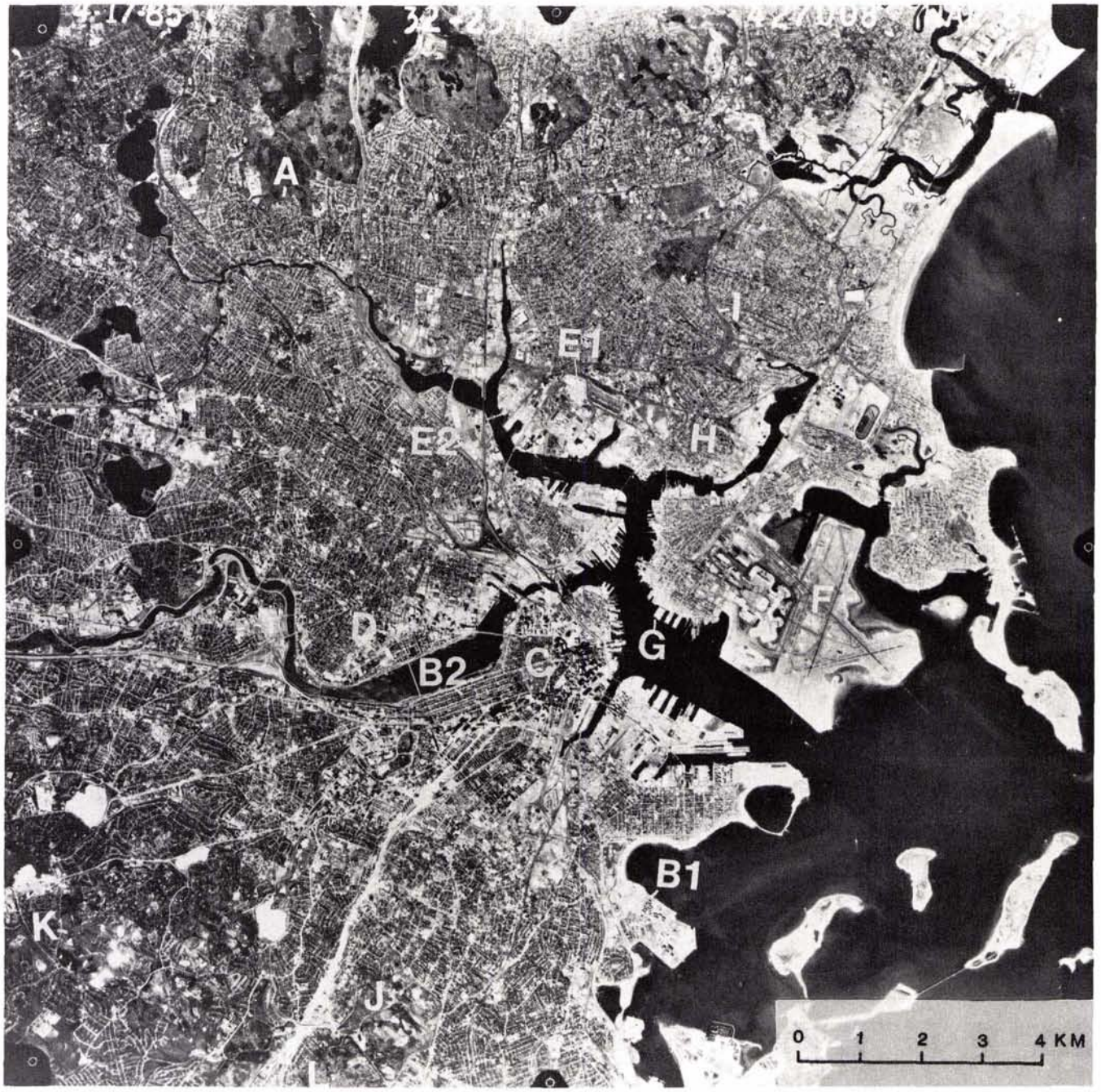

FIG. 2. National High Altitude Photography (NHAP) frame number 466 showing Boston Harbor and airport. Letters refer to urban land-use and land-cover classes: A = single family residential, B1 = apartment complex, B2 = row houses, C = retail commercial and warehouse, D = institution, E1 = processing industry, E2 = fabrication industry, F = airport, G = dockyard, H = railroad, I = highway, J = parkland, K = golf course, and L = cemetery.

LFC photograph frames 663 and 665 of the study area (nominal scale 1:780,000) were employed in this evaluation. These two frames had an endlap of 60 percent and a corresponding base to height (*B/H*) ratio of 0.60. The Boston study area was photographically enlarged 15.6 times to produce 1:50,000-scale paper prints of the two frames (Figure 4) and covers an area of 454.4 km.^{2}

The NHAP data of the Boston area employed in this study consisted of a strip of five black-and-white pannchromatic photographs (frames 463 through 467 inclusive) at a nominal scale of 1:80,000. Each photograph in the strip has an endlap of 60 percent which resulted in a *B/H* ratio of about 0.57, thus making it compatible with that for the LFC photography used. The NHAP black-and-white panchromatic film is Kodak Type 2402 with a resolution of 50 lines per mm at 1.6:1 contrast ratio. In this respect, NHAP is also compatible with the LFC photography. The only incompatibility between the two photographic data sets is the time of photography: the LFC photographs were acquired in early Fall and the NHAP in Spring, thus giving rise to a difference in tone and textures of the vegetation cover. In order to provide supplemental information to aid the interpretation of the black-and-white panchromatic NHAP data, color-infrared

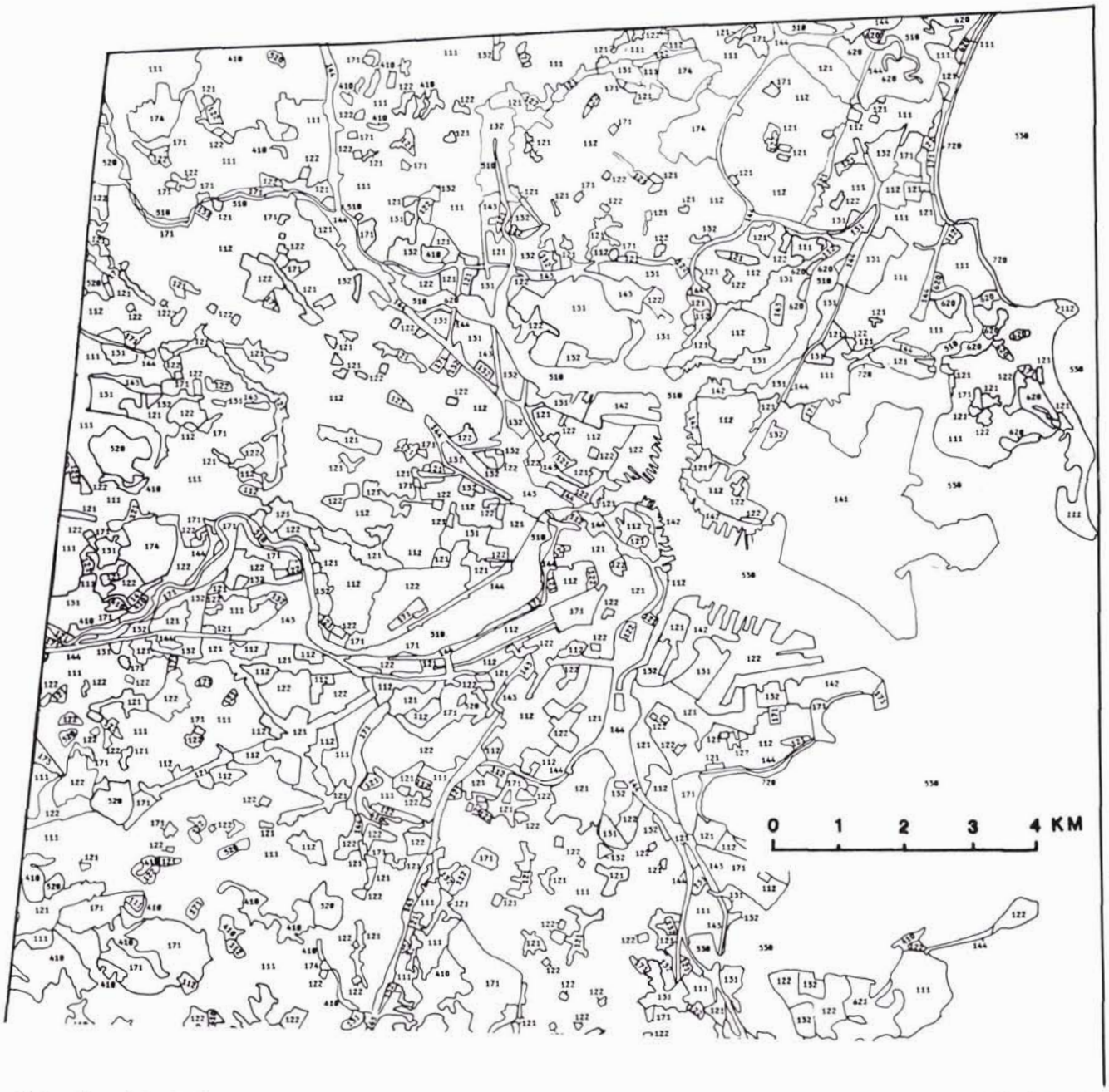

FIG. 3. A portion of the detailed urban land-use and land-cover map of Boston originally compiled at 1:25,000 scale produced by the Department of Forestry and Wildlife Management, University of Massachusetts at Amherst, serving as ground truth for accuracy evaluation.

NHAP data at a nominal scale of 1:58,000 acquired at the same time as the black-and-white panchromatic NHAP were also used.

RESULTS OF INTERPRETATION

LARGE FORMAT CAMERA (LFC) PHOTOGRAPHS

The LFC photographs of the Boston area were visually interpreted using both monoscopic and stereoscopic methods. The favorable *B/H* ratio and the 15.6× enlargement of the photographs resulted in an excellent stereomodel which could be comfortably viewed with 3× magnification or no magnification at all with the mirror stereoscope. The detailed urban land-use/land-cover polygons were mapped directly onto a Mylar overlay of the right hand photograph. Monoscopic viewing using a 4× power 4-inch diameter lens magnifier permitted quick delineation of single-family residential use and urban highways. Stereoscopic viewing was most useful in delineating the Central Business District (CBD), multifamily residential units, and high-rise building structures. The final result of the interpretation is a map at the scale of 1:50,000 (Figure 5).

In the course of interpretation, the image characteristics that helped to distinguish different land-use and land-cover classes were noted. Observations for the more complex urban land-use and land-cover classes are given below

- *Single-family residential (class 111).* This class was characterized generally by a coarse texture and light gray tone as shown at A in

FIG. 4. The Boston study area in LFC frame 663 enlarged to 1:50,000 scale. Letters refer to urban land-use and land-cover classes: A = single family residential, B1 = apartment complex, B2 = row houses, C = institutional and retail commercial, E1 = processing industry, E2 = fabrication industry, F = airport, G = dockyard, H = railroad, I = highway, J = parkland, K = golf course, and L = cemetery.

Figure 4. Large homes were detectable against the darker background. This land use exhibited a linear or gridded pattern toward the urban core and changed to a curvilinear pattern with increasing distance from the central city. In less dense residential areas, the individual home lots could be recognized easily.

- *Multifamily residential (class 112).* This class consisted mainly of two forms: (1) apartment complexes and (b) row houses (B1 and B2 in Figure 6). Apartment complexes were characterized by a light-to-medium gray tone and coarse texture. Row houses appeared as closely packed multifamily residences near the urban core. The tone of the row houses was generally light-to-medium gray, and the texture of this class appeared coarse to medium. As the distance increased from the central city, the discrimination between single-family residential use and row houses became difficult if the two types of land use were mixed together.
- *Institutional (class 122).* This exhibited a white to gray tone and coarse texture (an institution marked by C in Figure 4). This category appeared as large individual structures or small groups of buildings, some of which were mixed with residential land use. Shape and size were important discriminating criteria. Government buildings were difficult to identify in areas of high building density such as the central city and the nodes of urban use occurring at major street intersections.
- *Retail commercial and warehouse (class 121).* This class exhibited a white to gray tone and coarse to medium texture (the area surrounding C in Figure 4). Often, retail land use was associated with major highway intersections and characterized by large buildings with large parking areas. Strip commercial land use followed major streets, sometimes leading to nodes at major intersections. Warehouses appeared as large structures with small parking areas located on or near major transportation routes and industry.
- *Industrial (class 130).* This class was characterized by a white to dark gray tone and coarse texture (E1 and E2 in Figure 4). In some cases processing industry (E1) identified by the presence of tank forms for oil or chemical storage could be distinguished from fabrication industry (E2). Fabrication industry, which appeared similar to warehousing both in pattern and association with major transportation routes, was identified more readily by its location on the perimeter defined by major highways away from the urban core.

It was clear from the above that there had been a heavy reliance on such image elements as tone, texture, shape, and situation (or association) in mapping detailed urban land use and land cover from the LFC photographs. This observation indicated that the spatial resolution of the enlarged LFC photographs was in-

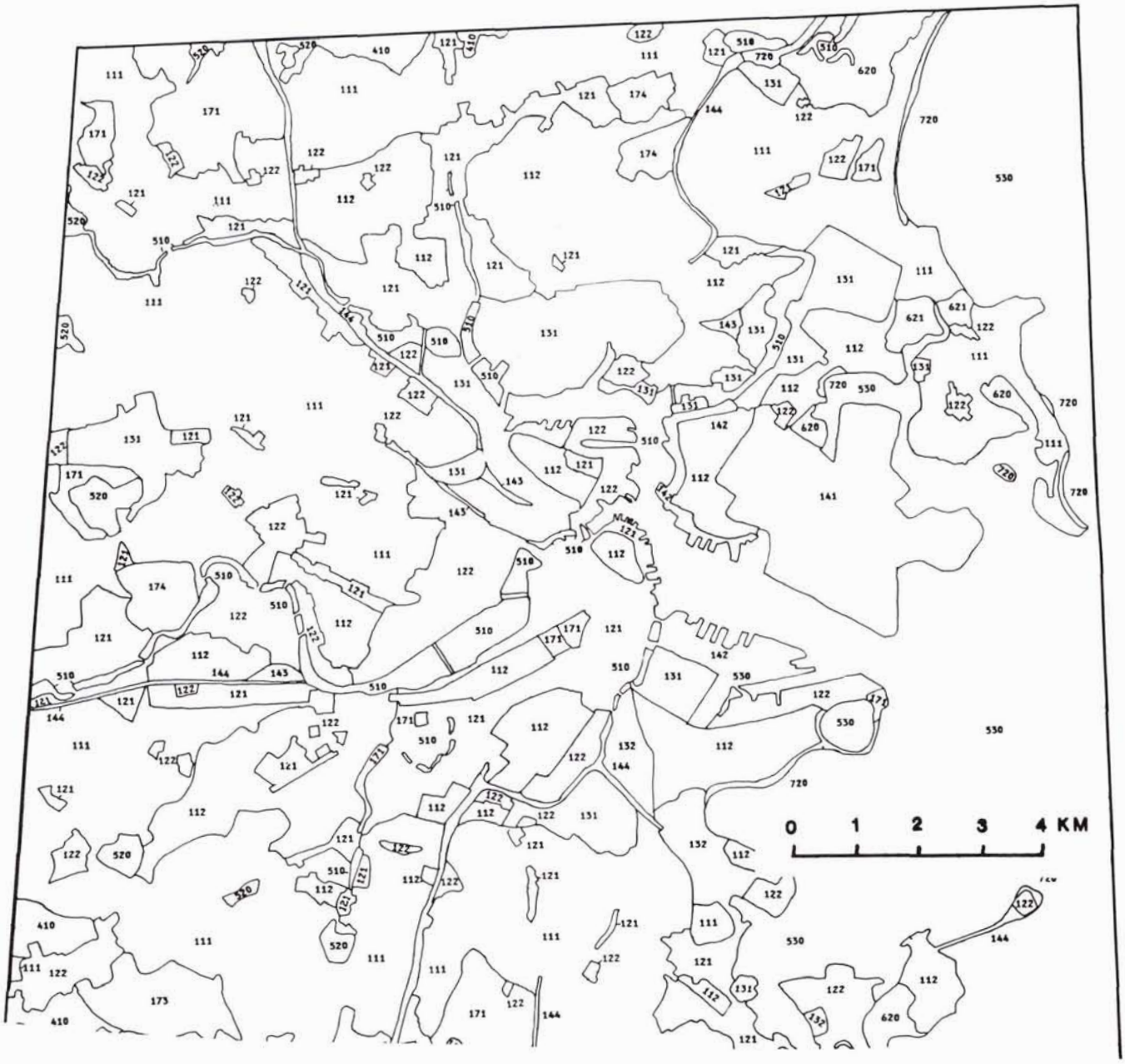

FIG. 5. A portion of the detailed (Level III) urban land use and land cover map of Boston produced from a visual interpretation of the enlarged LFC photograph in Figure 4.

sufficient to allow positive identification of industrial types and some forms of residential uses.

NATIONAL HIGH ALTITUDE PHOTOGRAPHY (NHAP)

Although stereoscopic viewing with 6× magnification was found useful in identifying small point features and some specific land-use categories such as schools, hospitals, office buildings, and the Central Business District based on height information, much of the interpretation could be done monoscopically.

Land-use and land-cover data were mapped at the scale of the photographs (1:80,000) and subsequently changed to 1:50,000 scale with the aid of a Bausch and Lomb Zoom Transferscope so that the final map was compatible in scale to that produced from the LFC photography (Figure 6).

The following image element characteristics, employed to aid in the identification of the more complex urban land-use and land-cover classes in the NHAP data, were noted for comparison with those observed in LFC photography described above:

- *Single-family residential (class 111).* This category exhibited a medium to light gray tone and a coarse texture (A in Figure 2). The linear patterns of streets in older urban sections and the curvilinear street pattern of newer developments were readily evident with individual homes recognizable on the photograph.
- *Multifamily residential (class 112).* This class comprised both apartment complexes and row houses as shown at B1 and B2, respectively, in Figure 2. The apartment complexes ranged in tone from white to very dark gray and were characterized by a coarse texture. The repetition of similarly shaped structures of equal size was the chief cue in the identification of these features. Row houses appeared

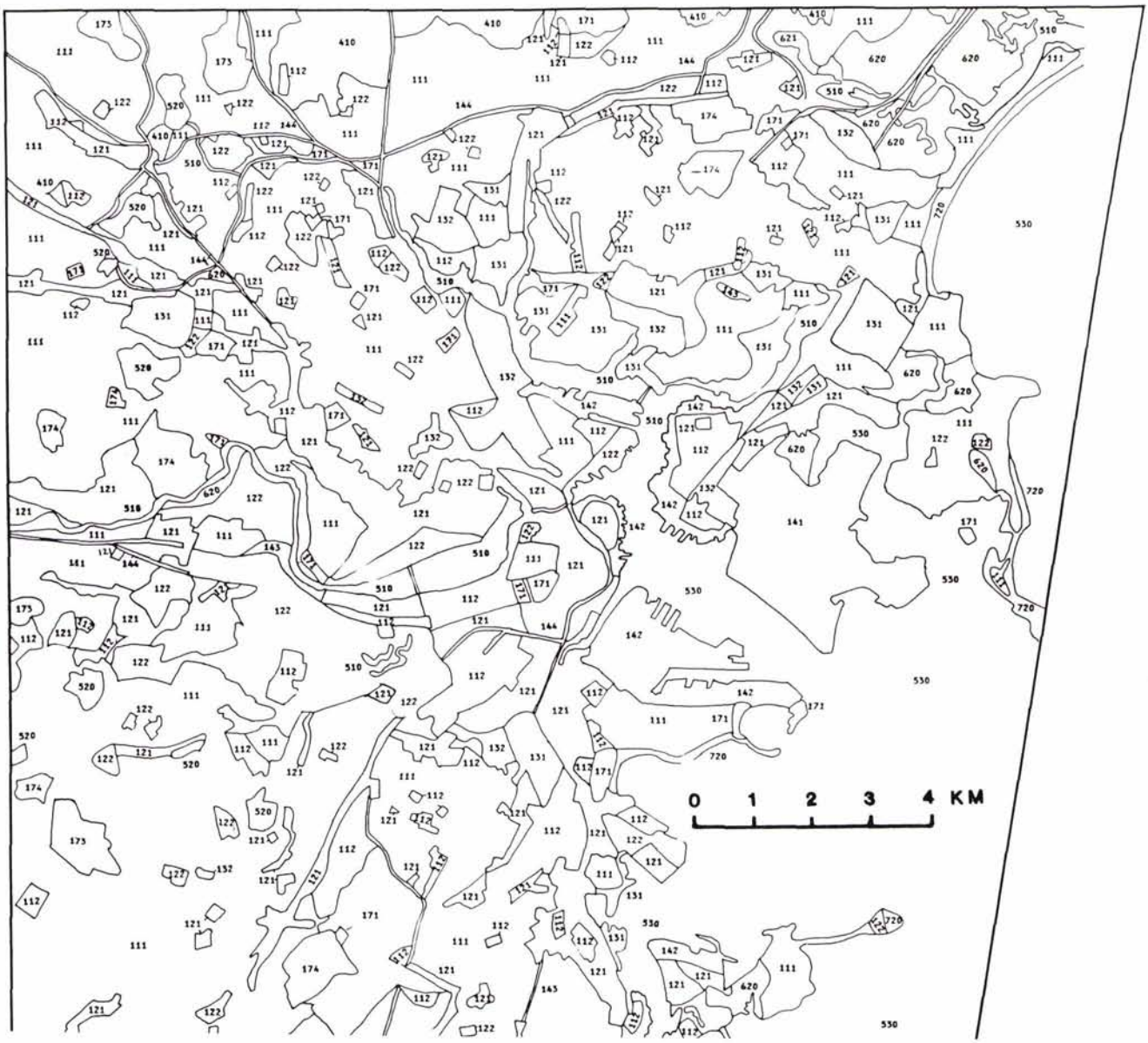

FIG. 6. A portion of the detailed urban land use and land cover map of Boston produced from a visual interpretation of NHAP data shown in Figure 2.

as closely arranged single-family residences, and identification was based primarily on association with the urban core and industrial complexes. In some cases, differences in height could be detected, which aided in the identification of this class. However, identifying a distinct boundary between land-use classes 111 and 112 proved difficult with decreasing distance from the central city.

- *Retail commercial and warehouse (class 121).* This class was characterized by a very white to very dark gray tone and a coarse to medium texture (C in Figure 2). Retail land use is often associated with major highway routes and intersections and with the central city complex. Strip commercial land use was often found to have a coarser texture than the surrounding residential land use, although in many cases it was of the same tone. Shopping malls had the appearance of several large buildings surrounded by large parking lots. The automobiles of mall patrons were visible in the parking lots. Warehouses appeared similar to malls with the exception of having much smaller parking areas. Warehouses were often associated in proximity to industrial land use and major transportation classes of all types.
- *Institutional (class 122).* This class was characterized by a very white to medium gray tone and a medium to fine texture (D in Figure 2). This land use consisted of large structures in close association with one another with little parking areas evident. Positive identification of this class was possible only with reference to the topographic maps which named the structure in question.
- *Industrial (class 130).* This class exhibited a white to very dark gray tone and a coarse texture (E1 and E2 in Figure 2). Processing industry, i.e., steelmaking, refineries, etc., was differentiated from fabrication industry such as shipbuilding in many cases. Processing industry was identified by the presence of tank farms, piping, and smoke stacks. The smoke stacks were evident by the shadows they cast. The dumping of water from one processing industry (E1 and Figure 2) provided a cue in identifying that particular feature. Fabrication industry appeared to be very similar to warehousing and was generally of a lighter tone than processing industry. Both types of industry were associated with major transportation land uses. However, fabrication industry was most often found near major highways and the airport.

The interpretation of detailed urban land use and land cover from NHAP data also relied heavily on tone, texture, and association, but the better ground resolution of NHAP data seemed to display the characteristics of tone and texture more distinctly than in the case of LFC data. Also, individual buildings were more clearly visible.

ACCURACY EVALUATIONS

Determining the classification errors in the two land-use and land-cover maps (Figures 5 and 6), both at the scale of 1:50,000, derived from the interpretation of NHAP and LFC photographs was accomplished by checking sample land use at point locations on these maps against that at corresponding point locations on the 1:25,000-scale ground truth map of the Boston study area (Figure 3). The bias-free stratified systematic unaligned sampling method was adopted to select the sample points on the maps (Berry and Baker, 1968; Fitzpatrick-Lins, 1981). A transparent grid with a minimum of 1175 sampling dots was arrived at in this way and laid on top of the two test maps. In order to maintain a statistically significant conclusion on the degree of accuracy for each class of land use, a minimum of 30 samples for each class is necessary (Van Genderen and Lock, 1977; Hay, 1979). In the case where a land-use class with less than 30 samples occurred after the initial stratified systematic unaligned sampling, further samples were selected from that class by random sampling until the minimum requirement of 30 samples per class was met. The total number of sample points actually used in each map was 1295 for LFC and 1298 for NHAP. Based on the comparison with the ground truth map, an error matrix in the manner specified by Story and Congalton (1986) was compiled for each test map, from which both the omission and commission errors made in the photographic interpretation could be analyzed and explained in terms of the "producer's" and the "user's" accuracies, respectively. The following evaluations focus only on the "user's" accuracy because it is more logical to judge these maps from the user's concern for their reliability.

Large Format Camera (LFC) Photography Classification Accuracy

An examination of the error matrix (Table 2) reveals an overall classification accuracy of 65 percent for the land-use and land-cover map produced from LFC photography. In obtaining the "user's accuracy" or the errors of commission for individual categories of land/use land cover interpreted, the number of correctly classified point samples of a certain category of land use was divided by the total number of point samples that were classified in that same category (i.e., the row total). It was observed that the land-use classes of highest accuracy were 530 (Bays and Estuaries, 100 percent), 510 (Rivers and Streams, 97 percent), 750 (Quarries and Gravel Pits, 94 percent), 141 (Airport, 94 percent), 410 (Forest, 89 percent), 520 (Lakes and Ponds, 83 percent), and 720 (Beaches, 81 percent). All these categories were large area features (with the exception of Quarries and Gravel Pits) and exhibited distinctive image element characteristics in tone, texture, and shape that rendered them easily identifiable.

The more complex urban land-use and land-cover classes that could be identified with moderate accuracy were classes 111 (Single-Family Residential, 71 percent), 142 (Dockyard, 78 percent), and 144 (Major Highways, 71 percent). Obviously, some difficulties were experienced in interpreting classes 112 (Multifamily Residential, 44 percent), 121 (Retail Commercial, 45 percent), 131 (Processing Industry, 47 percent), and 122 (Institutional, 33 percent). In the urban categories, classes 112, 121, and 122 were often misclassified among themselves and with class 111 (Single Family Residential). All of these classes occurred in areas of very intensive land use and required a very high spatial resolution to detect individually distinguishable image elements. The spatial resolution of LFC photographs continued to be inadequate to meet this requirement.

The accuracy of interpretation was also partly affected by the lack of complete compatibility between the land-use scheme employed for the photographic interpretation and that employed by the University of Massachusetts-Amherst ground truth map where residential use was differentiated according to building density (dense, medium, and sparse) along with a Multifamily Residential Category which was not adopted in the USGS classification scheme.

National High Altitude Photography (NHAP) Classification Accuracy

The error matrix (Table 3) showed an overall classification accuracy of 70 percent for the land-use and land-cover map produced from NHAP data. Judging on the "user's accuracy" of individual land-use and land-cover categories, one found the highest accuracy of interpretation in land-use classes 510 (Rivers and Streams, 100 percent), 520 (Lakes and Ponds, 100 percent), 410 (Forest, 99 percent), 530 (Bays and Estuaries, 98 percent), 144 (Major Highways, 97 percent), 620 (Tidal Wetlands, 91 percent), 750 (Quarries and Gravel Pits, 91 percent), and 141 (Airport, 88 percent). Again, these are large area features with distinctive image characteristics in terms of tone, texture, and shape.

As for the more complex urban land-use and land-cover types, notably, classes 111 (Single-Family Residential, 63 percent), 112 (Multifamily Residential, 60 percent), and 131 (Processing Industry, 63 percent), NHAP data seemed to have resolved them much better than in the case of LFC photography, as revealed by the very consistent though moderate performance in each class. On the other hand, land-use classes 121 (Retail Commercial, 41 percent) and 122 (Institutional, 33 percent) remained difficult to be identified, probably because the only image element cue that could be used was situation (or association). Hence, the results of interpretation for these two land-use categories were very similar in both the NHAP and the LFC cases.

DISCUSSION AND CONCLUSION

The accuracy evaluation presented above seems to suggest that the land-use and land-cover map produced from the NHAP data (with 70 percent accuracy) is slightly better than that produced from the LFC photography (with 65 percent accuracy). If we are to define detailed urban land use and land cover as the six classes of complex urban uses, namely, Single-Family Residential (111), Multifamily Residential (112), Retail Commercial (121), Institutional (122), Processing Industry (131), and Fabrication Industry (132), we can recompute the overall accuracy figure for each map by simply taking the mean of the "user's accuracy" percentages of these six land-use classes in each map. It becomes clear that the overall accuracy for the LFC map is 45 percent and that for the NHAP map is 51 percent. Thus, the LFC photographs give slightly poorer results than those for the NHAP data in mapping complex urban land use. In both cases, however, the accuracy lags far behind the minimum 85 percent stipulated by the U.S. Geological Survey land-use and land-classification scheme for Level II categorization (Anderson *et al.*, 1976). On the other hand, the comparison of performance between the use of LFC and NHAP data indicates the similarity in accuracy between these two forms of photography. The LFC photography has an advantage that it occupies only a very small portion of the original 23 by 46-cm format frame (Figure 1). The fact that one stereomodel covers the whole study area compared with four in the case of NHAP makes the LFC photographs an economical tool for urban land-use and land-cover mapping. Thus, LFC photographs are suitable substitutes for NHAP photographs for land-use and land-cover mapping.

TABLE 2. ERROR MATRIX FOR LAND-USE AND LAND-COVER MAPPING FROM LFC PHOTOGRAPHS VERIFIED INTERPRETATION

Land Use Class*	Verified Interpretation																					Row Total	Percent Correct
	111	112	121	122	131	132	141	142	143	144	171	173	174	410	510	520	530	620	621	720	750		
111	268	45	28	5	2	1				3	1	1		22					1			377	71
112	20	35	16	6		1				1	1											80	44
121	9	3	30	6	3	9			3	3												66	45
122	8	4	8	21	1	8		2	1	3	2		2	1				3				64	33
131	4		8	4	24	4		1	3	2				1								51	47
132			2	1	17	9			3	1	1											31	29
141						1	30										1					32	94
142				3	3			25			1											32	78
143			2		10	5			10	4												31	32
144	2		5						3	25												35	71
171	4	1							3		13		1	10								32	41
173	3										12	9		8								32	28
174											12	4	14									30	47
410	3			2						1			1	65	1							73	89
510														1	30							31	97
520														6		29						35	83
530																	129					129	100
620				13						2								15	4			34	44
621		5		11										1				17	3			37	8
720											6									25		31	81
750														2							30	32	94
																			Overall Accuracy: 839/1295				65

* For key to the land-use classes, see Table 1.

TABLE 3. ERROR MATRIX FOR LAND-USE AND LAND-COVER MAPPING FROM NHAP DATA VERIFIED INTERPRETATION

Land Use Class*	Verified Interpretation																					Row Total	Percent Correct
	111	112	121	122	131	132	141	142	143	144	171	173	174	410	510	520	530	620	621	720	750		
111	268	71	26	10	2	5			1	4	4		1	34				1				427	63
112	9	18	2	1																		30	60
121	8	5	35	11	6	8			3	5	2			1							1	85	41
122	1	3	14	16		6				1	2		3	3								49	63
131			4	1	22	3			3	2												35	
132			3	1	9	14			2													29	48
141	1					3	28															32	88
142		2	3	3		1		30														39	77
143					12	13			5													30	17
144	1									31												32	97
171	7	2		2							13			8								32	41
173											5	23	2	1								31	74
174	2		1	2							7		22	6								40	55
410													1	74								75	99
510															30							30	100
520																30						30	100
530																	131		2			133	98
620	2										1							30				33	91
621													1	6			3		28			38	74
720											5									31		36	86
750	1													2							29	32	91
																			Overall Accuracy: 908/1298				70

* For key to the land-use classes, see Table 1.

The manual interpretation of Level III urban land use and land cover from LFC photographs is still handicapped by the spatial resolution limitation of the camera-film system. Successful discrimination among land-use and land-cover classes depends on good object-to-ground contrast as well as distinctive image elements typified by tone, texture, shape, and situation. The LFC photographs taken in space at an altitude of 238 km suffered from a poorer target-ground contrast than that for the black-and-white panchromatic NHAP data taken at an altitude of 12 km. But the LFC photographs still possess a great potential for land-use and land-cover mapping at Level II of the USGS classification scheme, because by aggregating such Level III categories as Single-family Residential (111) and Multifamily Residential (112) into the Residential category (11) and Retail Commercial and Warehouse (121) and Institutional (122) into the Commercial and Services category (12), the accuracy of interpretation for each category will be greatly improved and the overall accuracy of the map reaches 76.7 percent (as compared with 80 percent for NHAP data). Thus, the LFC photographs after enlargement can perform just as well as the NHAP data in Level II land-use and land-cover mapping at the national level.

Despite the mediocre accuracy of LFC photographs for detailed urban land-use and land-cover mapping at Level III, considerable potential remains for improved interpretation of detailed urban land-use and land-cover information by enhancing object-ground contrast using the true color and/or color infrared film supplemented by better quality collateral data. On the other hand, given a good level of reference for the human photointerpreter, LFC photographs with the combination of high metric accuracy and excellent resolving power will be an effective tool for land-use and land-cover mapping and revision with Level II categorization at 1:50,000 scale or smaller at the national level.

ACKNOWLEDGMENT

The authors wish to acknowledge the University of Georgia Research Foundation and the Department of Geography, University of Georgia for financial support that made this research possible. The comments of the reviewers of this paper, which lead to its improvement, are also gratefully acknowledged.

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(Received 29 November 1988; revised and accepted 3 May 1989)