NUREG/CR-3583
S-762-R

Evaluation of Low-Altitude Remote Sensing Techniques for Obtaining Site Characteristic Information

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Prepared for
U.S. Nuclear Regulatory Commission

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Evaluation of Low-Altitude Remote Sensing Techniques for Obtaining Site Characteristic Information

Manuscript Completed: December 1983
Date Published: April 1984

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NRC FIN A1251

ABSTRACT

The Nuclear Regulatory Commission (NRC) contracted with EG&G/EM and the University of California, Santa Barbara to assess the potential of photographic remote sensing for demographic and environmental monitoring. Aerial infrared imagery and ground truth along with collateral data provided information on site area demographics and land use, land cover characteristics. The ability to determine transient populations from remotely sensed data was also evaluated. Both manual and machine-assisted techniques for extracting these data from reflectance infrared images were qualitatively assessed.

The National Aeronautics and Space Administration Aircraft Programs U-2 acquired color infrared imagery at scales of 1:65,000 and 1:130,000, and Keystone Aerial Surveys (of Philadelphia, Pennsylvania) used a Lear-Jet to acquire photography at scales of 1:36,000, 1:48,000, 1:60,000, and 1:80,000. Data on residence types and counts, industrial facilities types and location, transient facilities, transportation networks, and the location of water bodies were generated specifically for the study site surrounding the Limerick Power Station in Pottstown, Pennsylvania. Of the three different techniques of population estimations examined, the "Dwelling Unit" method was evaluated for respective utility and accuracy with NRC guidelines. Population in the study area was estimated by this method to be 129,763 while the applicant estimated the population at 156,354.

The level of spatial and classification accuracy of the derived products depended on both scale and image quality. Area-weighted thematic accuracy from manual analysis was 96%, while by-category accuracies ranged from 71% to 100%.

A limited test of machine-assisted processing of digitized photographic imagery was conducted. Results of the supervised classification were an average class accuracy of 59.6%, with separate class accuracies ranging from 11.6% to 100%.

Results of the analysis indicated that: 1) remote sensing can provide significant environmental and demographic information for selected site characterization; 2) at present, manual analysis of intermediate scale aerial photography is the most appropriate methodology from a cost versus accuracy standpoint; and 3) more analysis in the form of rigorous accuracy assessment and field verification programs is required to confirm accuracy of the demographic information generated in this study.

SUMMARY

Six different scales of aerial imagery were acquired and evaluated for use in providing selected environmental and demographic data for use in site characterization of nuclear power generation facilities. The 9" × 9" color infrared (CIR) imagery was acquired at scales of 1:36,000, 1:48,000, 1:60,000, 1:65,000, 1:30,000, and 1:130,000. The study site consisted of a circular area 10 miles in radius around the Limerick Nuclear Power Station near Pottstown, Pennsylvania.

A search was conducted through U.S. Government repositories for existing high-altitude aerial imagery that may have had possible utility in this study. No existing imagery was found to be available for this area.

Following an evaluation of the imagery acquired, the 1:36,000 scale imagery was used for mapping selected environmental and demographic characteristics of the study site in an overlay format. The area's population was estimated by sector in both tabular and graphic form. Total study area population was mapped in both choropleth and isarithmic manner. Water bodies were located and mapped. An overlay was produced locating industrial facilities in the study area, with special attention paid to those facilities which may handle hazardous materials. Transient facilities, including schools, churches, commercial centers, parks and campgrounds, and military and correctional institutions were also mapped. A map outlining and classifying the area's transportation network was produced. In addition to these specific characteristics, the general land use/land cover of the area was interpreted and mapped to Anderson Level II standards. A detailed statistical accuracy assessment of these land use/land cover maps was conducted and field-verified. Accuracy of these maps meets Anderson criteria with area weighted figures of 96% and by-category accuracies averaging 93%.

A limited test of machine-assisted processing of digitized photographic imagery was conducted for area land use/land cover. Results of the supervised classification were an average class accuracy of 59.6%, with separate class accuracies ranging from 11.6% to 100%.

Time and cost figures were compiled for each phase of the analysis. Image analysis and map production times were basically proportional to the complexity and difficulty of the tasks involved (as an example, estimating population for the study area was much more time consuming and costly than locating and mapping water bodies within the site).

Results of the study indicated that: 1) Remote sensing data and analysis techniques can provide environmental and demographic information which may be of value to the NRC's site characterization requirements; 2) Land use/land cover manual mapping to Anderson Level II standards can be done successfully using imagery of format and scale acquired for this study; 3) Population can be successfully estimated using a combination

of CIR photography and manual interpretation techniques; 4) Data and interpretation techniques used were appropriate for mapping transportation networks; 5) Water body mapping was successfully completed at the imagery scales utilized. It could have been completed using high-quality imagery of 1:80,000 scale and is amenable to machine-assisted analysis; 6) Industrial and transient facilities identification was also accomplished using techniques evaluated in this study; 7) Transient population estimation could not be accomplished from the data of this study; 8) Machine-assisted land use/land cover analysis could be accomplished but with reduced accuracy utilizing the available imagery.

Recommendations include: 1) an effort be initiated to validate the accuracy of the population estimation and the industrial and transient facility overlays; 2) future land use/land cover at Anderson Level II be performed using 1:24,000 scale imagery, and population estimations be performed using imagery of 1:10,000 scale or larger; 3) as a prelude to machine-assisted image analysis, a thorough evaluation of a number of classification procedures and algorithms be accomplished; and 4) the recommendation that NRC conduct a study for the potential of employing information systems technology for site inventory, monitoring, and modeling.

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EVALUATION OF LOW-ALTITUDE REMOTE SENSING TECHNIQUES FOR OBTAINING ENVIRONMENTAL INFORMATION

FINAL REPORT

1. INTRODUCTION

The demographic and environmental characteristics around various types of nuclear facilities has taken on greater importance recently. Increasing attention from industrial groups, government agencies, and the general public has been focused on the need for accurate up-to-date information. An outgrowth of this is realization of the need for refinement of population monitoring and mapping techniques for use in emergency preparedness planning. This project was undertaken to test the applicability of selected remotely sensed data for demographic and environmental monitoring.

Specifically, the research was designed to evaluate interpretation and analysis of a combination of 1) aerial photography on a variety of scales, 2) supporting ground data, and 3) site-specific scientific literature and United States census data to meet NRC requirements for a variety of demographic and environmental information.

The interpretability of high-altitude aerial photography (acquired by both NASA and a commercial firm) was evaluated in terms of resolution and utility for providing the following information:

1. A population estimation using residence types and counts (single family, apartments, etc.)
2. Vehicle counts
3. Industrial facilities (with emphasis on industries handling hazardous materials)
4. Location of water bodies within the study area
5. Transient facilities (commercial centers, parks, schools, etc.)
6. Transportation networks (including railroads, airports, and roadways)
7. Anderson Level II Land Use/Land Cover maps at 1:24,000 scale (to overlay standard USGS 7.5 minute topographic sheets)*

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*The Anderson land use/land cover classification system was developed for the Geography program of the United States Geological Survey. Two levels of classification which are generally applicable can be employed as a

Specific tasks for the research effort included:

1. Acquisition of color infrared (CIR) aerial photographs (by commercial Lear-Jet and NASA high-altitude U-2 aircraft) of an area 10 miles in radius around two test sites in Pennsylvania.
2. A search for and acquisition of any existing high-altitude aerial imagery for the test sites through the U.S. Geologic Survey's EROS Data Center.
3. Preparation of overlays ($\sim$30" × 30") showing desired demographic data to fit the NRC standard 1 inch = 0.5 mile Emergency Preparedness Map Series.
4. Preparation of Anderson Level II Land Use/Land Cover overlays at 1:24,000 scale.
5. Field verification efforts.
6. Assessment of accuracy for Anderson Land Use/Land Cover maps.
7. Documentation of time and costs involved in various analytic and cartographic tasks in the project.
8. Production of automated land use/land cover classification using selected digitized frames of aerial photography acquired for the project.

This report includes sections on: 1) the test site studied, 2) data acquisition procedures, and 3) data analysis and mapping techniques used in preparing the land use/land cover, population, transportation network, water bodies, industrial, and transient facilities overlays. A descriptive background is included of the statistical approach used to verify the accuracy of the land use/land cover maps produced for the study. The equipment, software and analysis techniques used in the automated land use/land cover phase of the study are described. Time and cost information is provided on the various phases of this site-specific, applications-oriented research project. Conclusions and recommendations are given from findings. Appendices A, B, and C outline Anderson Level II categories and software used in the digital analysis.

"front end" for higher order custom land cover classifications by users. Developed for use with image data, the system is described in Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer, 1976, "A Land Use/Land Cover Classification System for Use with Remote Sensor Data," U.S. Geological Survey Professional Paper 964, Washington, D.C., U.S. Government Printing Office, 28 p.

2. TEST SITES

The two test sites selected for acquisition of remotely sensed data, located in eastern Pennsylvania, were 10-mile-radius circles surrounding nuclear power generation facilities. The southernmost site was centered on the Limerick Nuclear Power Station near Pottstown, Pennsylvania, approximately 25 miles northwest of Philadelphia (see Figure 1). The northern site was centered on the Susquehanna Power Station near the town of Berwick, Pennsylvania, and is the same site studied earlier by EG&G/EM/UCSB researchers and documented in Borella, et al (1982).

The work described in this report relates only to the Limerick facility. Aerial imagery was acquired for both sites. Digitization of the Berwick imagery was accomplished for selected machine assisted land use/land cover analysis.

At the Limerick study site, the centroid* lies at 40°13'26" N latitude, 75°35'16" W longitude. The area's land cover is predominantly agricultural (mostly corn and pasture crops), in gently rolling hilly terrain. The predominant natural vegetation cover is deciduous forest. The study area is roughly bisected (northwest to southeast) by the Schuylkill River.

The city of Pottstown is the largest urban center nearby. Other significant cities in the study area include Royersford, Spring City, Phoenixville, and Boyertown.

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*The nuclear power generating station.

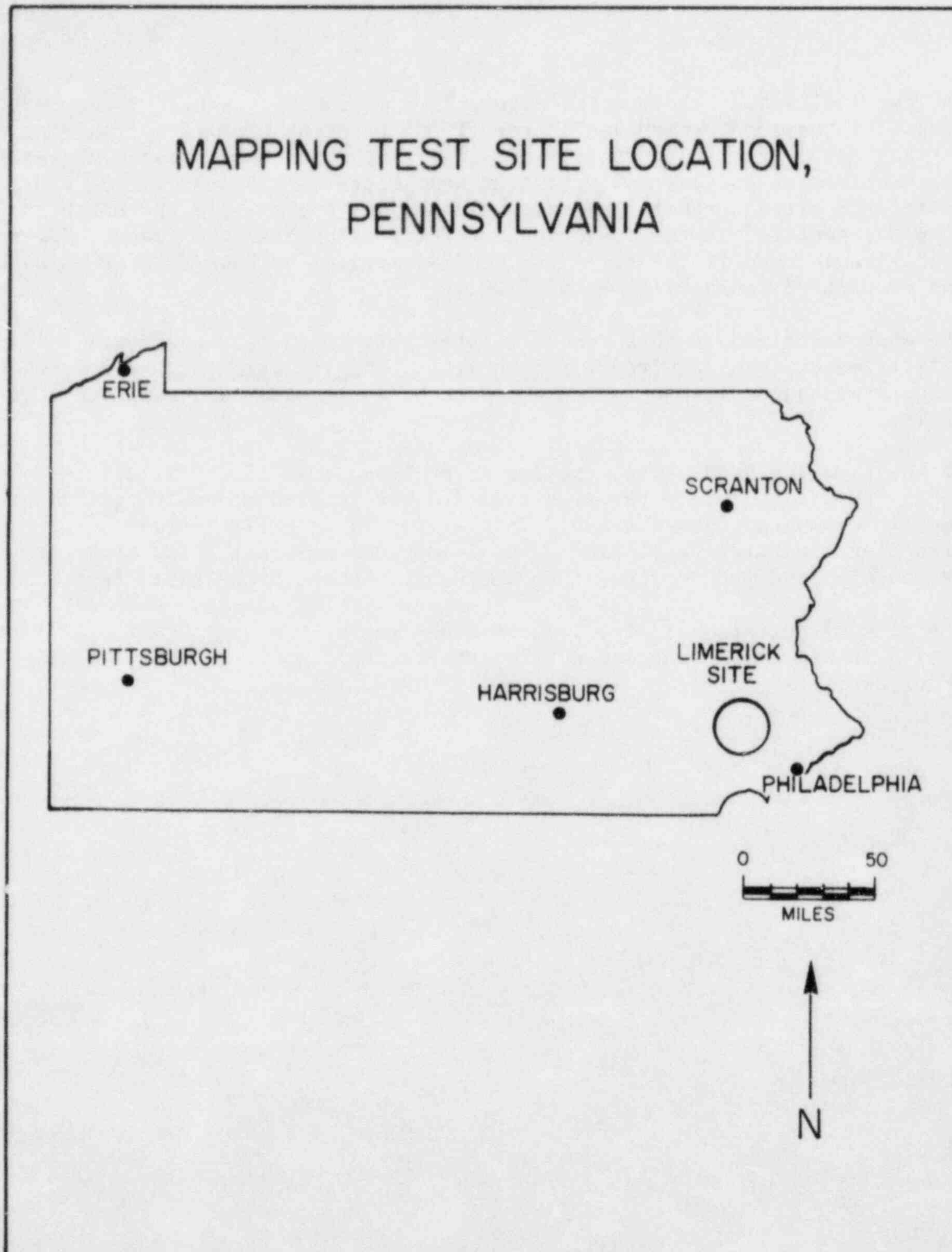

Figure 1. Study site location map

3. DATA ACQUISITION

Two sources were employed to obtain aerial photography of the study sites. On 16 November 1982, a NASA U-2 aircraft using a twin camera system flew at 65,000 ft above the terrain and obtained stereoscopic color infrared (CIR) transparencies with the following characteristics.

Camera	Lens (focal length)	Altitude (ft)	Scale of Imagery	9" × 9" Coverage (miles on a side)
Wild RC-10	6" (~150 mm)	65,000	1:130,000	18.5
Wild RC-10	12" (~300 mm)	65,000	1:65,000	9.2

On 7 December 1982, Keystone Aerial Surveys of Philadelphia, Pennsylvania, photographed the two test sites using a Lear-Jet aircraft. By flying at two different altitudes and using a twin camera system, four different scales of 9" × 9" stereoscopic color infrared transparencies were acquired. This imagery had the following characteristics.

Camera	Lens (focal length)	Altitude (ft)	Scale of Imagery	9" × 9" Coverage (miles on a side)
Wild RC-10	6" (~150 mm)	24,000	~1:48,000	6.8
Zeiss	8.25" (~210 mm)	24,000	~1:36,000	5.1
Wild RC-10	6" (~150 mm)	40,000	~1:80,000	11.4
Zeiss	8.25" (~210 mm)	40,000	~1:60,000	8.5

Figures 2 through 7 are examples of the CIR imagery acquired for use in this study.

Working in cooperation with Pacific Western Aerial Surveys of Santa Barbara, California, project personnel developed detailed specifications for the commercial imagery acquisition mission. Use of a local photogrammetric firm as contractor to another photogrammetric firm near the area of interest (which actually flies the photographic mission) is standard practice in the aerial survey field. EG&G/EM/UCSB used this method with excellent results in previous NRC sponsored research activity (Borella, et al, 1982).

Several factors were considered during the data acquisition mission planning stage of the project. It was determined that optimal imagery for demographic analysis and mapping would require that it be flown during the early winter season, after trees had shed their leaves but before snow cover. Bare tree and no snow conditions would minimize the chances that houses and automobiles would be hidden from image analysts under vegetative or snow cover.

Figure 2. Frame #206, commercially acquired imagery (Keystone Aerial Surveys, Philadelphia, Pennsylvania). Original scale 1:36,000 color infrared transparencies (12-7-82)

Figure 3. Frame #8686, commercially acquired imagery (Keystone Aerial Surveys, Philadelphia, Pennsylvania). Original scale 1:48,000 color infrared transparencies (12-7-82)

Figure 4. Frame #045, commercially acquired imagery (Keystone Aerial Surveys, Philadelphia, Pennsylvania). Original scale 1:60,000 color infrared transparencies (12-7-82)

Figure 5. Frame #8570, commercially acquired imagery (Keystone Aerial Surveys, Philadelphia, Pennsylvania). Original scale 1:80,000 color infrared aerial transparencies (12-7-82)

Figure 6. Frame #2113, NASA imagery. Original scale 1:65,000 color infrared transparencies (11-16-82)

Figure 7. Frame #1746, NASA imagery. Original scale 1:130,000 color infrared transparency (11-16-82)

The scale of imagery chosen were the result of several considerations.

1. The study site should be covered in as few images as possible for the demographic and environmental characteristics analysis.
2. The single image or "few frame" coverage might be amenable to accurate analysis for a few selected environmental parameters but not satisfy others of greater importance.
3. If the required analysis with a good accuracy was not technically feasible with single frame coverage, the next approach was to acquire five or more frames, with one frame always centered on the facility.

The requirement for the single-frame coverage was the motivating factor for contracting with the National Aeronautics and Space Administration (NASA) to photograph the study area with a U-2 aircraft flown at 65,000 ft (normal ceiling altitude for this type of aircraft) above datum. A 150-mm (6") focal length lens was used on a Wild RC-10 camera system to produce maximum areal coverage on the standard format 9" × 9" film frames. Even flying at the 65,000 ft maximum operational altitude of the U-2 and using the 150 mm lens format, the 1:130,000 scale imagery acquired does not satisfy the desire for 9" × 9" single-frame full site coverage. (This 1:130,000 imagery covers 18.5 miles on a side.)

The commercially flown 1:36,000 scale imagery was aquired to gain single-frame coverage of the center 2-mile-radius area of the study site. The 1:80,000 scale was selected to obtain single-frame coverage of the center 5-mile-radius portion of the study site and also provided coverage of the entire 10-mile-radius site in a relative few (9) frames. However, the 1:80,000 scale imagery proved not of sufficient resolution for analytical purposes. This is discussed in detail in Section 4.

The decision to obtain stereoscopic imagery of the study site resulted from two factors.

1. It was initially considered that the "3-dimensional" view afforded by stereoscopic photography might have aided in some instances in the demographic and land use/land cover interpretation tasks required for the project.
2. Since stereoscopic coverage is routinely acquired in this type of aerial photographic mission, the tasks of flight-line planning and photographic acquisition were made easier by following routine operational procedures.

In addition to the standard flight lines flown to obtain the stereoscopic coverage (60% overlap, 20% sidelap) of the study area, a single frame centered on the reactor station itself was obtained at each scale.

NASA processed the photography it had acquired, and delivered it to EG&G/EM. It was there evaluated in terms of coverage, exposure, scale, resolution, vignetting, and atmospheric clarity to determine its interpretability and usefulness in this study. It was obvious at first inspection that the imagery lacked sufficient clarity and resolution for the interpretation tasks required to meet certain of the project objectives. This was due to a high-level atmospheric haze layer present over the Limerick site area during photographic acquisition. Because NASA schedules were tight, photo windows were narrow due to weather, and aircraft were scheduled for routine maintenance, no reflying of the imagery was possible.

The commercial imagery flown by Keystone Aerial Surveys was processed and returned for inspection and evaluation. Specifically, the film quality was assessed, degree of vignetting examined, color balance and processing checked, actual flight lines plotted against the flight-line maps provided, photograph centers plotted, overlap and sidelap computed, and correctness of scale verified. The imagery met the contract specifications in all respects except that of flight line side-lap. A very small portion of the northeast corner of the study area was not imaged at the 1:36,000 scale. This area lies between flight lines 1 and 2 of the 1:36,000 scale photography (see Figure 8). It was determined that the very small non-imaged area would not significantly impact the study tasks and overall project objectives and that it would not be cause for rejection of the imagery. The imagery was of very high quality in all other respects and was accepted.

High-altitude aerial photography has been taken by various Federal Government agencies for research and applications-oriented purposes. Information concerning this coverage can be obtained from a number of Federal data banks (e.g., the U.S. Department of the Interior's Geological Survey, EROS Data Center, Sious Falls, South Dakota). A thorough search of the coverage acquired by all Federal Agencies was conducted through the UCSB Map and Imagery Collections Library (which has computer links to imagery collections and data centers around the U.S.) to determine the availability of existing aerial photographic coverage for the two test sites. This search indicated there was no previously acquired photography of the Limerick site in any of the repositories.

In addition, a variety of literature was collected to aid in analysis of the aerial photography. The 1:24,000 scale USGS 7.5 minute topographic sheets were obtained for use as base maps in the Anderson Level II Land Use/Land Cover mapping effort. Other types of thematic maps of the area acquired from various sources included 1:100,000 physiographic maps and road maps at various levels of detail. To complete the population estimation task, 1980 census data were acquired for the area.

UCSB researchers and image analysts made field site visits concurrent with both the NASA and commercial imagery acquisition missions. On-site field verification visits are often important in any image analysis project, particularly in those which the analysts interpret data acquired in areas about which they have limited knowledge. This type of visit is generally used to collect data and background materials to improve the researchers' and image analysts' familiarity with surface physical and cultural characteristics and to generally 'get the feel' of a particular area.

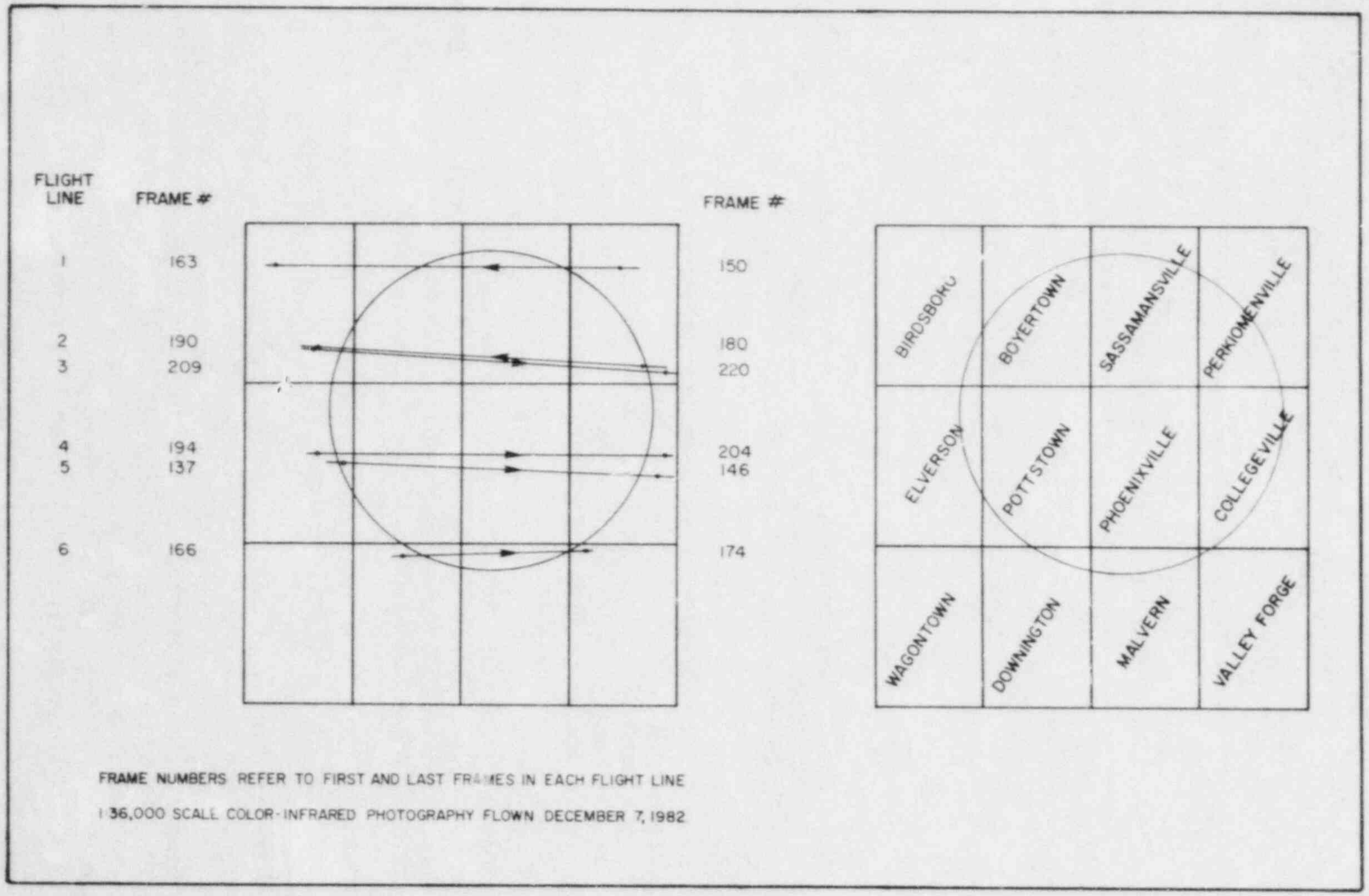

Figure 8. CIR photography and 7.5 minute quad index, Limerick site

4. DATA ANALYSIS, MAPPING AND PRESENTATION TECHNIQUES

At the beginning of the data analysis phase of this study, the various scales of CIR imagery acquired were qualitatively evaluated for use in the various interpretations required. Examples of each scale of imagery were examined in primarily terms of resolution, detail, vignetting, and atmospherics.

4.1 NASA IMAGERY EVALUATION

The smaller scale NASA imagery was evaluated first in an attempt to satisfy NRC desire for single-frame imagery coverage. The NASA 1:130,000* and 1:60,000 scale imagery proved to be of inadequate quality, both in terms of resolution required and the atmospheric degradation present for detailed interpretations needed for this study (see Figure 6 and 7). Even a very cursory examination clearly showed that this imagery was not useful for the tasks of vehicle counts, residence counts, thematic classifications, and population estimations within acceptable accuracy limits.

The imagery might have provided sufficient information for a land use/land cover classification, but only to Anderson Level I standards; it was determined that Anderson Level II classification criteria and accuracy levels could not be met. It was also determined that these data (particularly the 1:65,000 scale imagery) could have provided some useful information regarding industrial and transient facilities; yet, the detailed interpretation (i.e., classification as to <u>types</u> of industrial and transient facilities) desired for this study would have been impossible. The imagery was also judged to be of inadequate quality for transportation network classification and water bodies mapping.

4.2 COMMERCIAL IMAGERY

Personnel evaluated the commercial imagery in an attempt to determine the smallest scale imagery acquired that would provide required datail for the complex interpretations needed. This imagery would also have the virtue of covering the study area in the fewest number of frames.

Although of excellent quality overall, the smaller scales of this photography also proved to be less than optimal for most of the required interpretation tasks. Upon detailed examination of 1:80,000 and 1:60,000 scale imagery it was determined that:

1. This scale imagery was inappropriate for many of the required analysis tasks.

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*18.5 miles on a side coverage, which does not meet the criteria of 10-mile radius.

2. Land use/land cover at Anderson Level II most likely could have been accomplished and accuracy standards met using the 1:60,000 scale photography.

3. The population estimation, residence counts, thematic classification, and vehicle counts could not be carried out with an acceptable degree of accuracy using this scale imagery.

4. Water bodies could be mapped with a high degree of accuracy using the 1:60,000 or 1:80,000 scale imagery.

After examining the 1:48,000 and 1:36,000 scale photography, it was decided that:

1. While the 1:48,000 scale imagery covered the entire study site with fewer frames, the difference in coverage between the two scales of imagery was not significant. Mathematically, both scales of imagery could have covered the entire study site using four frames. The 1:48,000 scale 9" × 9" photographs cover 6.8 miles on a side. The 1:36,000 scale 9" × 9" photographs cover 5.1 miles on a side. However, due to the vignetting inherent on aerial photographs, more than four frames are needed to cover the study site with imagery suitable for accurate interpretation.

2. Because the 1:36,000 scale imagery had the highest resolution and the most visual detail, characteristics important to the detailed interpretations required by NRC, the image analysts concluded that the 1:36,000 scale photography was the only imagery that might come close to meeting NRC needs in terms of resolution and interpretability.

3. The 1:36,000 photography was also most closely matched in scale to the base maps used in the study.

4.3 ANDERSON LEVEL II LAND USE/LAND COVER MAPPING

It has been shown (Borella, et al, 1982) that land use/land cover mapping can be accomplished at Anderson Level II (see Table 1) standards using aerial photography at scales of about 1:36,000. This type of mapping was carried out for the Limerick site. The mapping was accomplished using manual photointerpretation procedures. The land use/land cover maps were drawn to 1:24,000 scale to overlay standard 7.5 minute USGS topographic maps.

To aid in feature location and discreet category delineation, black-and-white photographic enlargements were made to 1:24,000 scale from the 1:80,000 scale CIR imagery. In addition, to aid in the location and area referencing during the land use/land cover mapping, mylar overlays with roads and stable features copied from 1:24,000 USGS topographic quadrangle maps were made. These overlays were used as a mapping base; i.e., the mylar overlays to be used directly with the aerial image were annotated with roads and other stable features to make the interpreters' information transfer task more efficient.

Table 1. Anderson land use/land cover classification system

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
9 Perennial Snow or Ice	91 Perennial Snowfields 92 Glaciers

Trained image analysts interpreted the imagery and transferred the land use/ land cover classes to the base map, thereby producing pencil-line "working copy" maps (see Figure 9). Once these maps had been employed in the accuracy assessment and field verification process, final "archive copy" maps (Figure 10) were generated from them. Land use/land cover polygons were transferred from the pencil line working maps to the final archive maps in permanent ink. It should be emphasized that no corrections to the final archive copies were made as a result of field verification.

4.4 LAND USE/LAND COVER MAP ACCURACY ASSESSMENT

The statistical basis of the accuracy assessment procedures used in this study are essentially those presented in detail by Rosenfield, et al (1982), which describes a stratified systematic unaligned sampling technique. Sample points taken from the map as a whole, with additional random samples for under-represented thematic categories, are used to estimate the thematic accuracy of mapped categories. An application of this procedure is documented in Borella, et al (1982).

Prior to selection of sample points to be verified, the minimum sample size required to validate the accuracy for each category within specified confidence limits was estimated using a cumulative binomial distribution. A binomial distribution is proper in this case as verified points can be either "correct" or "incorrect." Anderson, et al (1976) state, "the minimum level of interpretation accuracy for identification of land use and land cover categories from remote sensor data should be at least 85 percent."

Following preliminary evaluation of the 1:36,000 scale commercial CIR photography of the site and a review of the Anderson Level II classification scheme (Table 1), the interpreters felt confident that the 85% accuracy level could be attained using these data.

Using the binomial distribution and imposing a 95% confidence requirement as described in Rosenfeld, et al (1982), a minimum sample size of 19 points per thematic category per site was calculated as needed to verify Anderson Level II classifications at 85% accuracy, with an allowable error of 10%.

Once this minimum sample size per category was determined, the sample selection procedure was implemented as follows:

1. The Limerick site was stratified using a 5-km grid network based upon Universal Transverse-Mercator (UTM) coordinates. These 5-km square "strata" provided the basis for subsequent sampling.
2. A systematic sample grid overlay was made for the 1:24,000 scale strata used. The overlay was partitioned into a 500-m sample grid covering the 5-km strata, thus resulting in a 10 by 10 sample grid of 100 sample points per strata coded by number, as shown in Figure 11.

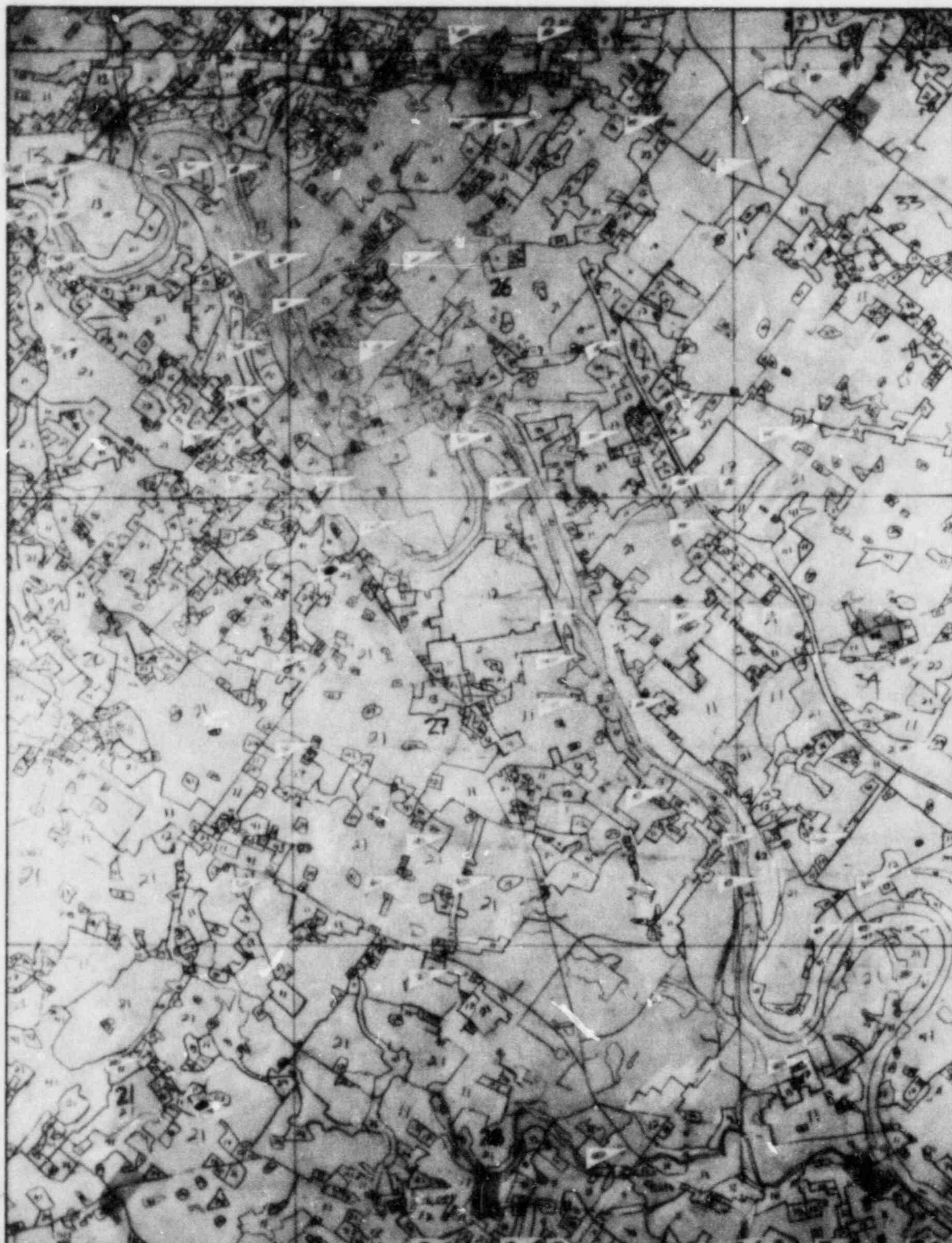

Figure 9. Working copy Anderson Level II land use/land cover map

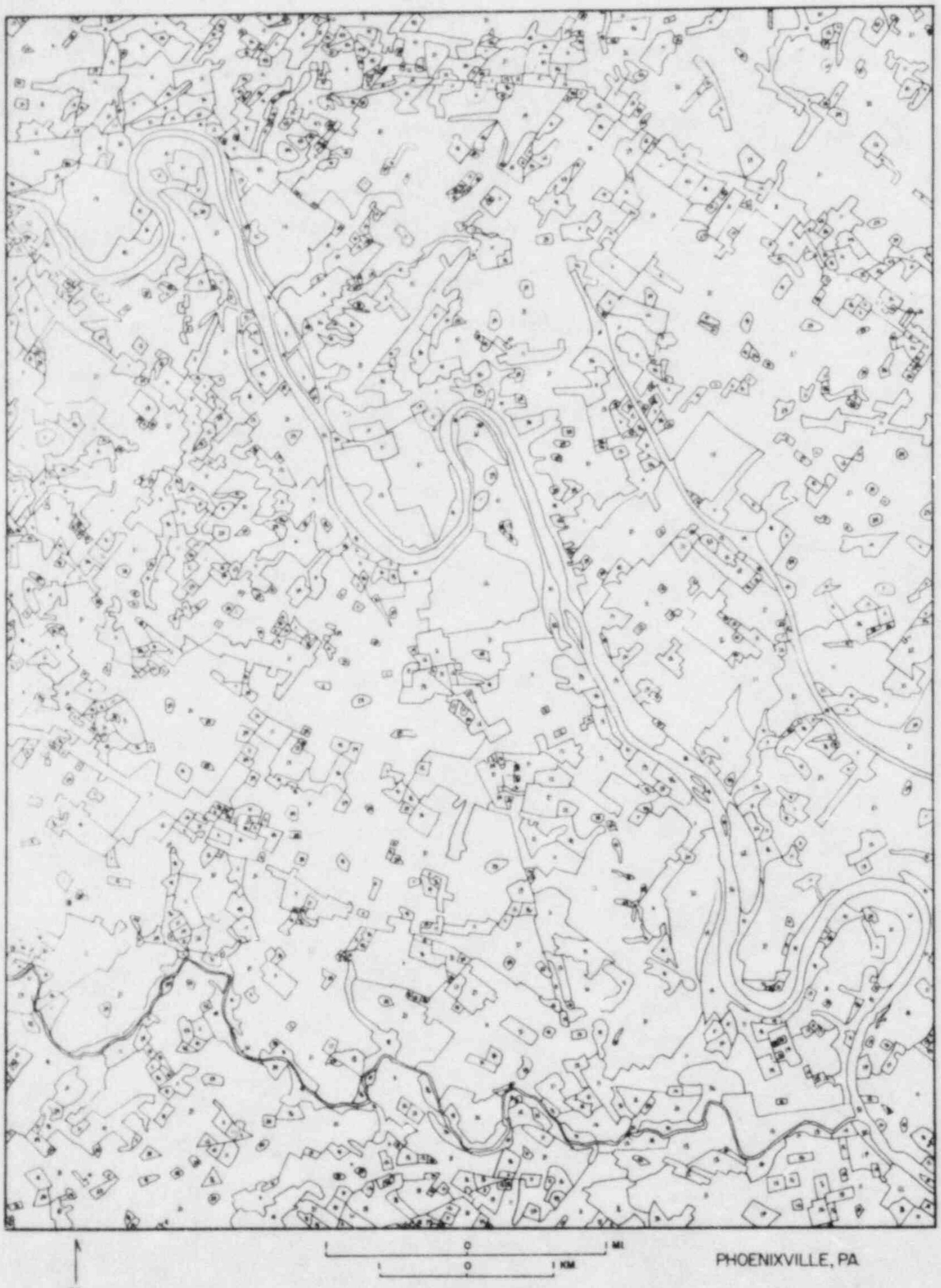

Figure 10. Archive land use/land cover map
(original scale 1:24,000)

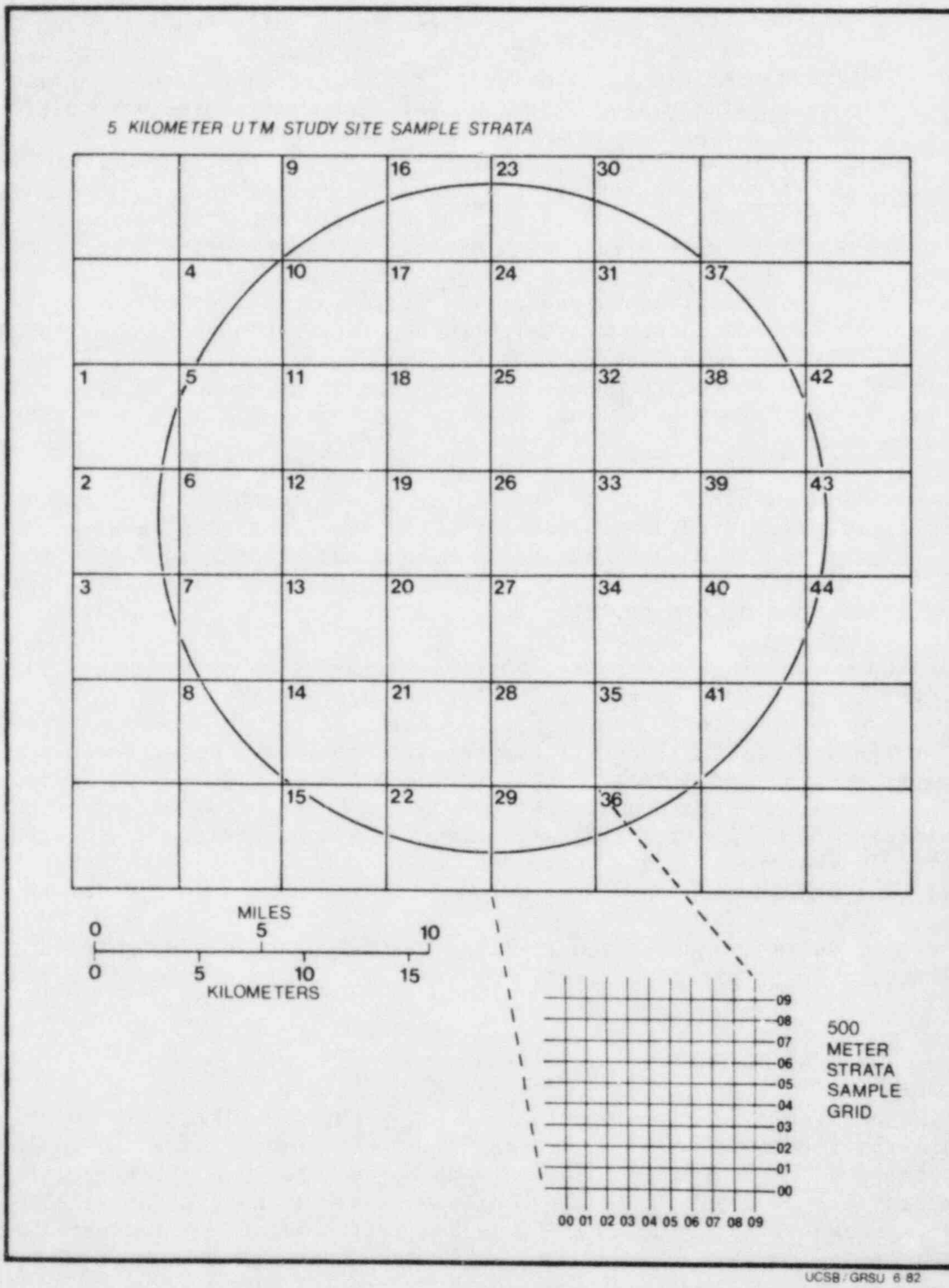

Figure 11. Test site stratification and sample point system

3. A computer program was employed to randomly order the 100 potential sample points within each strata. A separate random sample was provided for each strata thereby insuring an unaligned sample design since not all samples were used.

Two sets of points were generated for the study site in order to provide both area-weighted and category-specific estimates of accuracy.* An initial set of points was selected for verification by taking the first five random points within each 5-km strata, and marking their locations on the working map copies (these flagged sample points can be seen in Figure 9). This resulted in generation of approximately 160 points for the site to be used in an area-weighted accuracy estimate. After tabulating the land use/land cover category at each point, a second set of points was generated in an iterative manner whereby subsequent groups of five points per strata were examined for all strata, and points for any under-represented categories were added to the list to be verified and flagged as such on the working copy map overlays. This two-step approach provides both an accurate area-weighted sample and an efficient set of additional points needed for category-specific accuracy assessments. In some instances, however, it was not possible to adequately assess some class accuracies due to the low number of sites of these classes on the map, even after exhausting all 100 potential sample points per strata.

Following Rosenfeld's procedure, initial verification of mapping accuracy was done by an expert photo interpreter who had not participated in the original mapping effort. Any point which this interpreter was unsure of was designated for subsequent field verification; obvious agreements and outright errors were directly photo-verified and tabulated. This procedure is, of course, constrained by and dependent upon the level of expertise of the interpreter. Field verification involved approximately 20 specified samples in the study site. These samples were those points the photo expert was unsure of.

Accuracy results are presented in Table 2 and 3. An area-weighted accuracy estimate table is provided first, followed by per class accuracy estimates.

4.5 RESIDENT POPULATION ESTIMATION

A key characteristic estimated in this study was the resident population within the 10-mile radius study area. Remote sensing literature indicates that there are essentially three methods for obtaining population estimates from aerial photography: 1) the "built-up area" technique (Holz, et al, 1969; Ogrosky, 1975; Lo and Welch, 1977); 2) the "land use/land area density"

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*Area-weighted accuracy assessment tests accuracy of a map as a whole. This procedure yields an overall accuracy figure for the entire map without regard for map accuracies within individual classes. A "by class" sampling provides accuracy figures for each thematic category within the map.

Table 2. "Area weighted" accuracy figures land use/land cover mapping (Anderson Level II) manual interpretation

MAPPED CLASS

VERIFIED CLASS	11	12	13	14	15	16	17	21	22	23	24	41	42	43	51	52	53	61	62	75	76
11	27							1													
12		2																			
13			3																		
14				1																	
15					1																
16						0															
17							1														
21								64				1									
22									2												
23										0											
24											4										
41								1				33									
42													0								
43														3							
51															1						
52																0					
53																	1				
61																		0			
62																			0		
75																				1	
76																					8

TOTAL SAMPLES (AREA WEIGHTED): 158

ACCURACY (# OF CORRECT / TOTAL #): 152/158 = .962 (96.2%)

Table 3. "By class" accuracy figures land use/land cover mapping (Anderson Level II) manual interpretation

MAPPED CLASS

VERIFIED CLASS	11	12	13	14	15	16	17	21	22	23	24	41	42	43	51	52	53	61	62	75	76	CLASS ACCURACY
11	27		1			5	1	1		1	2											71%
12		17																				100%
13			19																			100%
14				16																		100%
15					3																	100%*
16	1					13																92%
17		1					18															95%
21	1	2						65	1			1										93%
22									12													100%
23					1					6	1											75%*
24		2									18											90%
41								1				34	3	3								83%
42													15									100%
43													2	20								91%
51															21							100%
52																2						100%*
53																1	3					75%*
61																		4				100%*
62																			4			100%*
75																				8		100%*
76																					19	90%

* inadequate sample for meaningful assessment

AVERAGE CLASS ACCURACY = 93%

technique (Collins and El-Beik, 1971; Kraus, et al, 1974; Thompson, 1975); and 3) the "dwelling unit" technique (Green, 1956; Hadfield, 1963; Binsell, 1967; Starsinic and Ziffer, 1968; Lingren, 1971; Lo and Chan, 1980).

Each of these techniques was evaluated for its utility in this application. The built-up area involves measuring the areal extent of an urban development and using average population/unit area data (determined by comparative calculations) to derive a total population figure for the area of interest. It was determined that this technique was inappropriate for use in this project for two reasons. First, the literature review indicated that the 'built-up area' technique is mostly a comparative technique dependent upon average population/unit area data derived for a number of other areas (or for the same area through time; Holz, et al, 1969). Second, indications are that this technique is applicable only to large urban areas (populations greater than 500,000) (Estes and Thorley, 1983).

The land use/land area density technique measures the areal extent of a variety of land uses with the area of interest and factors in average population densities for each category to arrive at a total population estimation. It was determined that the lack of detailed land use and housing type information required for this technique rendered it inappropriate for use on the Limerick study site.

After review and evaluation, the "dwelling unit" technique was determined most appropriate for this study. It offers the potential for highest accuracy in population estimation and is not dependent on surrogate areal or land use data for estimation.

Employing this technique and using the 1:36,000 scale imagery, the population of the study area was calculated by counting the number of residences and multiplying by an average number of inhabitants per residential unit. This number was generated from 1980 census data, in which residents per dwelling figures are compiled by county. The Limerick study site includes parts of three Pennsylvania counties: Montgomery, Chester, and Berks.

This technique for population estimation can be expressed as follows:

$$P_T = R_1 (i_1) + R_2 (i_2) + R_3 (i_3)$$

where:

P_T = Total population in study area

R_1 = Number of residences in study area in County #1

R_2 = Number of residences in study area in County #2

R_3 = Number of residences in study area in County #3

i_1 = Average number of inhabitants per residence, County #1

i_2 = Average number of inhabitants per residence, County #2

i_3 = Average number of inhabitants per residence, County #3

For this study, these values are as follows:

i_1 = 2.79 (average number of inhabitants per residence, Montgomery County)

i_2 = 2.90 (average number of inhabitants per residence, Chester County)

i_3 = 2.66 (average number of inhabitants per residence, Berks County)

Population figures were derived for the study area sectors as shown in Figure 12.

Figure 12 was compiled and drawn at a scale to overlay the standard NRC emergency planning map for the Limerick station. The scale is 1" = 0.5 mile (1:31,680). The chart is divided into 22.5° sectors (16 total for the entire area), it is also divided into a 5-mile radii from 0-2 miles and 1-mile radii for the 2- to 10-mile portion of the study area.

The population figures derived as discussed above were also used to generate two additional maps showing population density within the study area in a choropleth method (Figure 13) and an isarithmic method (Figure 14). For the choropleth population density map, existing house counts (from the population by sector mapping) were aggregated in 1/16- (¼ mile × ¼ mile) square-mile cells and population factors (by county) were integrated. The resulting population density figures were divided into six categories (according to NRC specifications) and mapped as gray values.

The isarithmic map was produced by plotting population density values averaged over a 4-square-mile grid. It should be recognized that these derived values do not occur at a point, yet must be plotted at selected intervals throughout the study area to create a statistical surface. It must also be noted that using the isarithmic mapping method, only the <u>average</u> value for a unit area can be derived, and the statistical surface created is dependent on these average values (i.e., it cannot be inferred that any single point within the unit area actually has such a value). Isarithmic mapping using this type of data (average population density) is likely to result in isopleths which exhibit a somewhat larger inherent error of position (Robinson and Sale, 1969). For these reasons the analysts believe the choropleth map gives a much more accurate and useful representation of population density within the study area, both in terms of grid size (grid cell resolution) and areal location.

In addition to the resident population estimate made for this project, resident population for the same area was estimated by the License applicant to NRC. A comparison shows that the population figure derived in this study for the entire area is 17.1% lower than that of the NRC applicant (129,763 to 156,354).

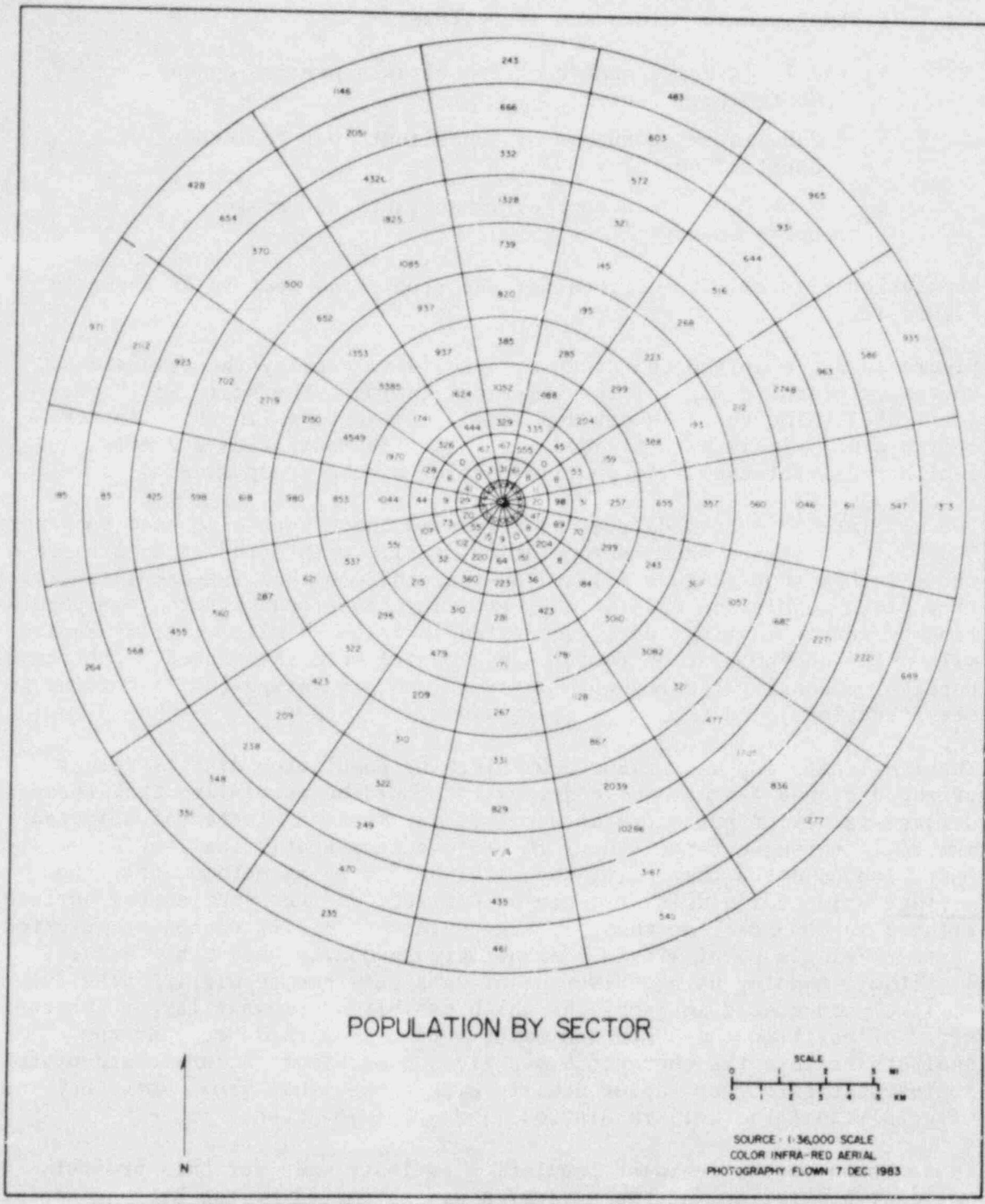

Figure 12. Population by sector. Total estimated population within 10-mile radius study area: 129,763

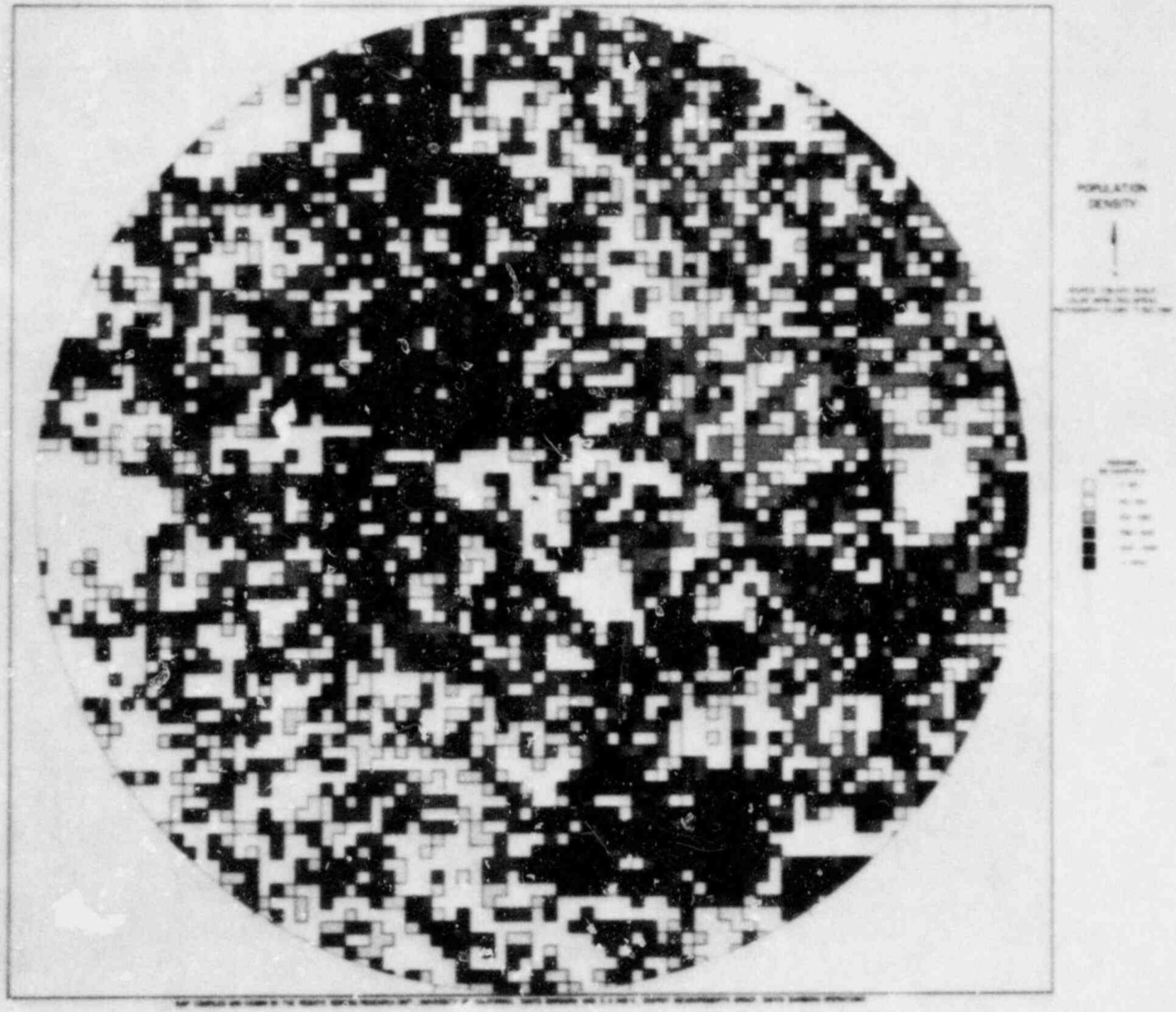

Figure 13. Choropleth map of population density within the Limerick study site. Data mapped in 1/16- (¼ mile × ¼ mile) square-mile units

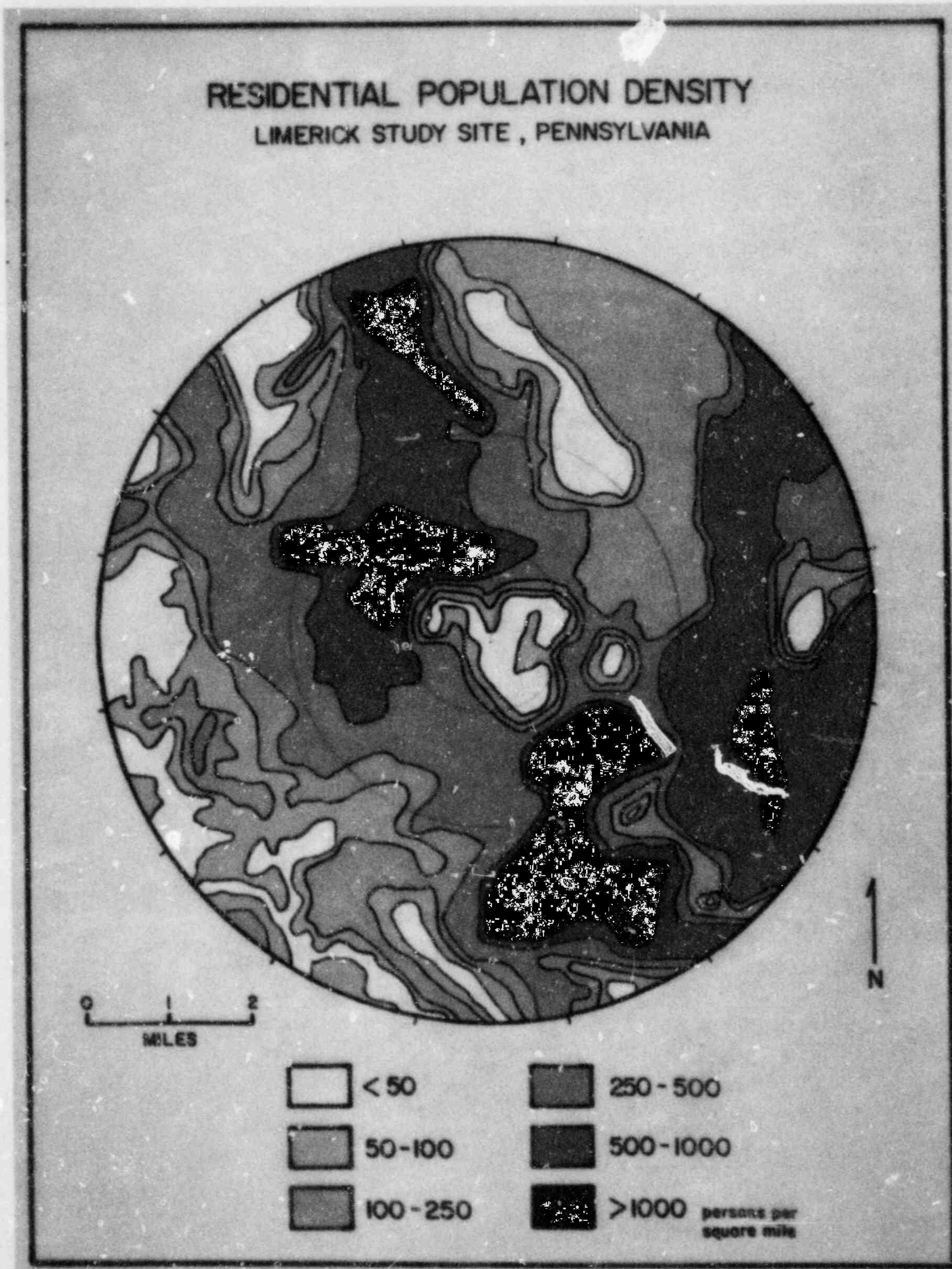

Figure 14. Isarithmic map of residential population density

4.6 TRANSPORTATION NETWORK MAPPING

An important cultural feature mapped for this study was the existing transportation network within the study area. NRC originally hoped that the aerial imagery acquired could be used to gather data on actual road lane sizes and improved shoulder widths, but this proved to be impossible due to the extremely small size of these features, as shown on the 1:36,000 CIR imagery. However, it was determined that a detailed usable transportation network classification could be produced using the 1:36,000 scale imagery. This analysis was accomplished and mapped in color overlay form (again at a scale to fit the NRC emergency planning maps (see Figure 15).*

The road network was classed into five types of roads, as follows:

1. Freeways — two or more lanes both directions, divided with controlled access
2. Multi-lane surface roads — two or more lanes each direction divided by lane markers, uncontrolled access
3. Single-lane surface roads — one lane each direction
4. Single-lane surface roads — undivided single lane
5. Unpaved (unimproved) roads — single lane width

The rail network within the study site was mapped to show single and multiple rail lines. Finally, the airports within the study area were also located and mapped; no distinctions were made as to size of airports or attendant facilities.

4.7 WATER BODIES MAPPING

A map was made (to overlay the NRC 1:31,680 scale emergency planning map) showing all water bodies within the study area (Figure 16). The water bodies shown include lakes, rivers, reservoirs, farm ponds, and other features such as settling ponds and water treatment facilities. The minimum mapping unit size used for this task was 0.1 inch (following the Anderson Land Use/Land Cover mapping standards). Using this unit, the smallest water bodies shown on the map are approximately 264 ft on a side (0.1" × 31,680).

Water body mapping is one task where a much smaller scale of imagery could have been used. Water bodies are readily identified on color infrared imagery, appearing as sharply bounded dark blue-black features. They exhibit a high degree of object-to-background contrast with the surrounding vegetated environment.

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*Figures 15 through 18 are extremely difficult to reproduce accurately in this document, since they are enlargements of 4" × 5" copies of 36" × 40" mylar overlays on the NRC emergency planning maps.

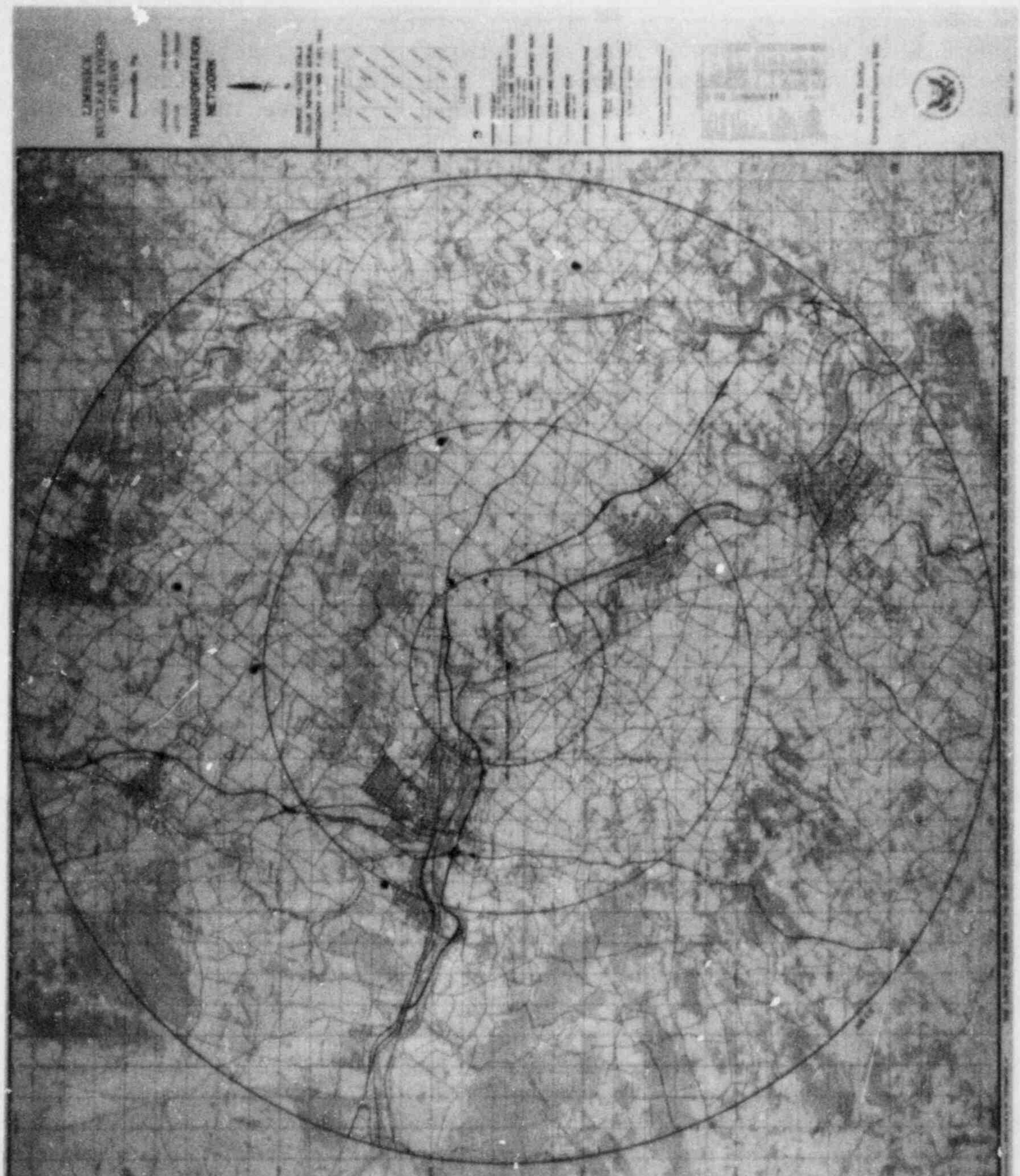

Figure 15. Transportation network within the Limerick study site

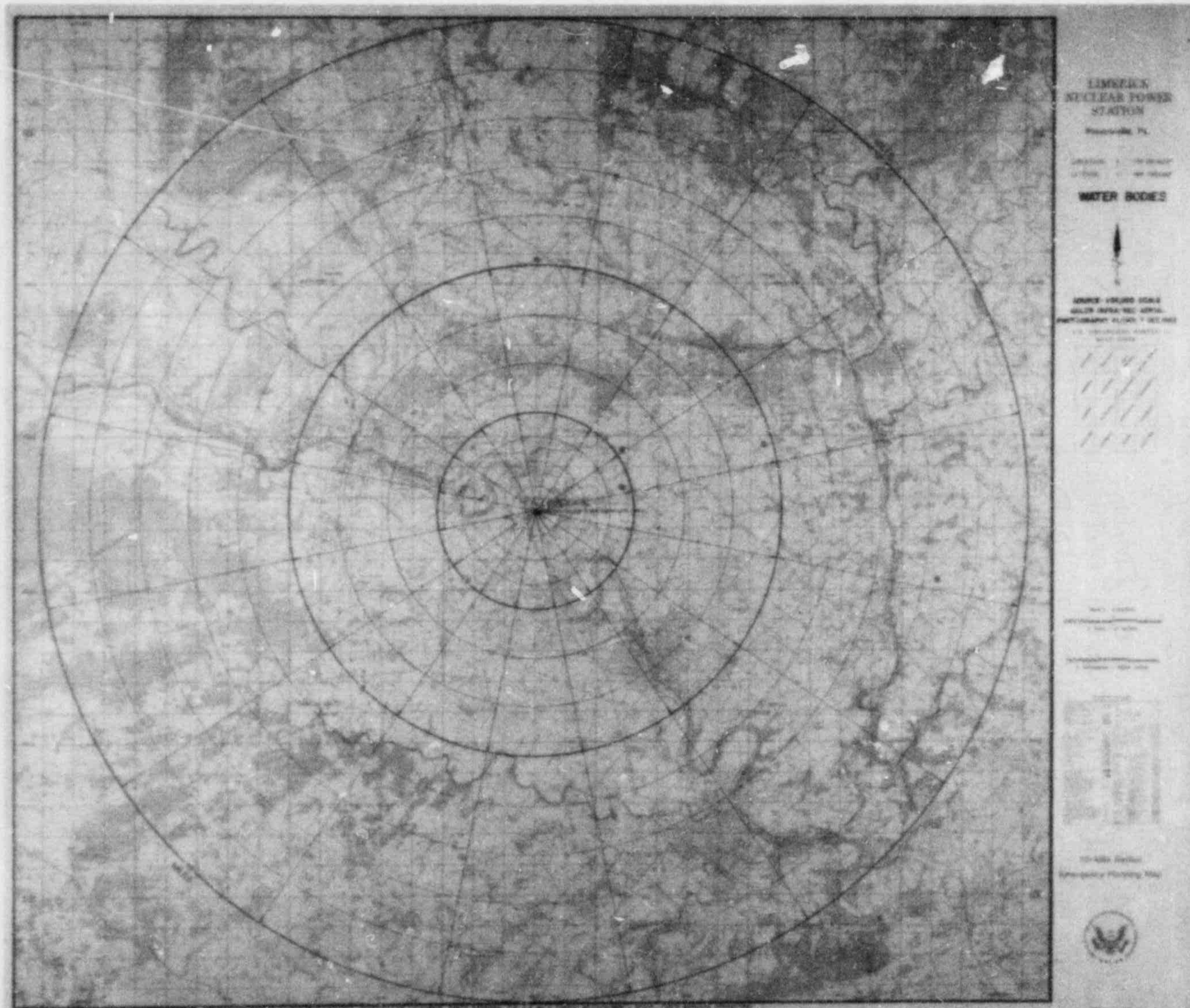

Figure 16. Water bodies mapped in Limerick site

Image analysts believe that water bodies could have been accurately mapped within the Limerick site using the 1:60,000 or 1:80,000 scale imagery acquired by Keystone Aerial Surveys. The atmospheric degradation present on the NASA imagery would preclude its use for this task.

4.8 INDUSTRIAL FACILITIES

NRC regulations require that the location of all industrial facilities within the 10-mile radius study site be known. An overlay showing these sites was produced by locating industrial facilities on the 1:36,000 photography and transferring those locations to the overlay (Figure 17). This overlay was also produced to fit the NRC 1:31,680 (1" = 0.5 mile) scale emergency planning map.

Many medium-to-large scale industrial facilities in the study area can be located by direct evidence such as the presence of raw materials, structures, equipment, end products, and wastes that typify industrial processes. Other smaller industries often have to be identified by inference, using locational or other contextual clues (Avery, 1977).

Medium- and large-scale industrial facilities were identifiable using the 1:36,000 scale imagery; the identification of smaller industrial facilities was more difficult however. No differentiation as to the size of the industrial facility is shown on the overlay.

Of particular interest to NRC was the identification of those industries within the study area which may handle hazardous materials. The basic interpretative strategy used to identify these types of facilities was to identify those industrial sites within the Limerick study area that are involved in processing type activities. These types of industrial locations usually have facilities for storage and handling of raw materials (piles, ponds, tanks, pipelines, etc.). Outdoor processing equipment (furnaces, cooling towers, chemical processing structures) are also often present. These facilities usually require an abundant energy supply, and this is often evidenced by oil storage tanks, coal piles, or transformer yards. Piles or ponds of waste and by-products are also present sometimes (Avery, 1977). After examining imagery of the study area for evidence of these types of indicators, those industries which may handle hazardous materials were located and highlighted on the overlay.

NRC had originally hoped the interpretative process could yield estimates as to the number of employees present at each industrial location mapped. A surrogate indicator of this might have been obtained by counting the number of vehicles parked at each industrial site located,* but the 1:36,000 scale imagery proved to be too small in scale to accomplish vehicle counting with acceptable accuracy.

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*Maximum transient population estimation accuracy would only be obtained by optimizing imaging resolution, acquisition date, and time.

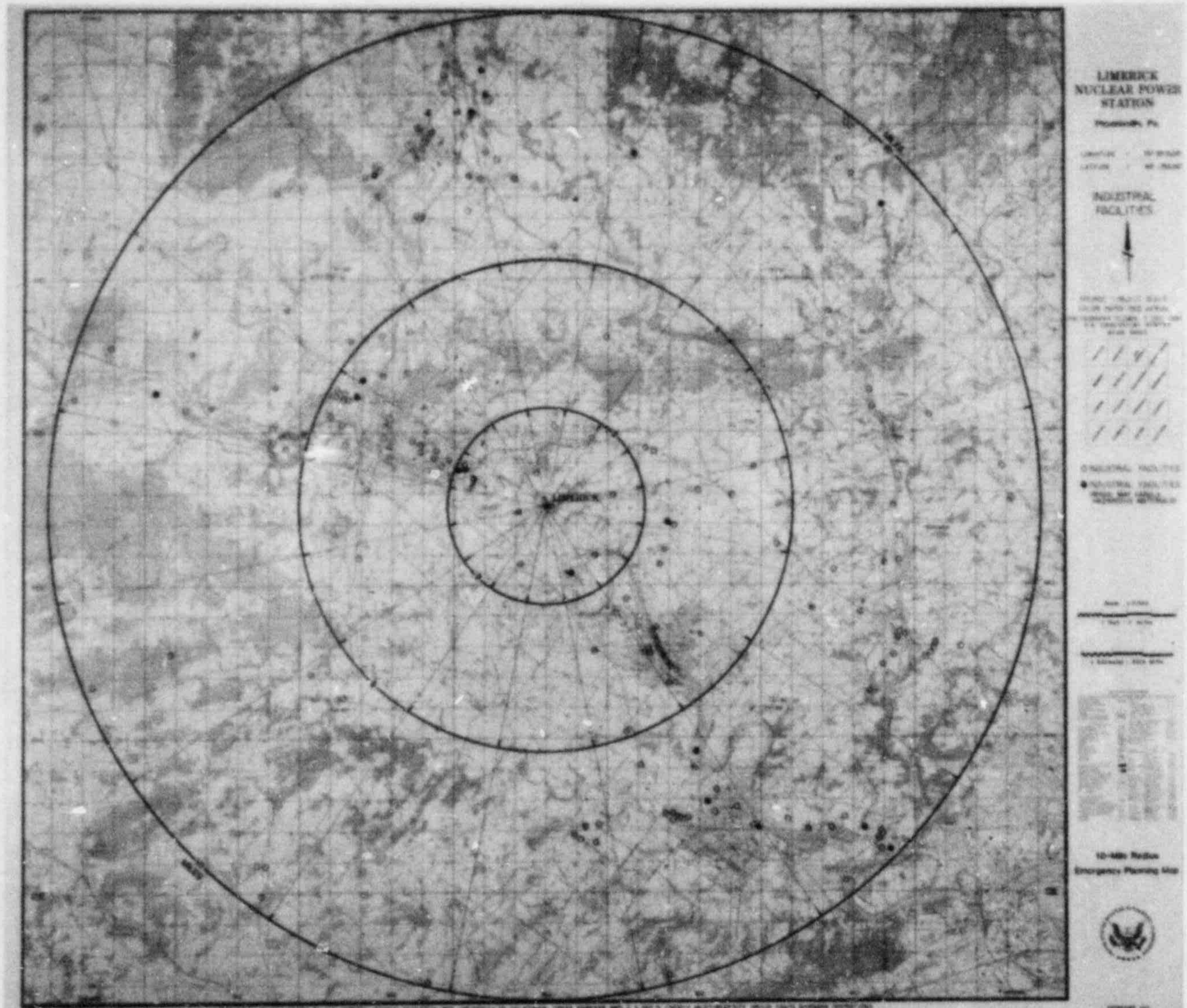

Figure 17. Industrial facilities mapped in Limerick study area

Another method of estimating employees at a facility might be to attempt a general identification of the type of facility and to acquire typical employee figures from field or ancillary data.

4.9 TRANSIENT FACILITIES MAPPING

Other facilities within the study area whose use or population is of a transient nature were also mapped. These consisted of schools, commercial establishments, hospitals, military and correctional facilities, recreational facilities (parks, campgrounds, sports fields, etc.), and churches. Each facility was coded and located on a mylar overlay fitting the 1" = 0.5 mile (1:31,680) scale NRC emergency planning map (Figure 18).

As with other interpretative tasks in this project, the 1:36,000 CIR photography acquired by Keystone Aerial Surveys was used for transient facility mapping. In addition, collateral data was of great value in identifying certain of the transient facilities within the study area and was used heavily in the identification and location of schools, churches, and parks.

As with the industrial facilities mapping task, NRC originally hoped that estimates could be made regarding maximum use levels at each transient facility located. The number of parking stalls in lots adjacent to each facility might have provided the basis for estimates, but the 1:36,000 scale imagery was not of sufficient resolution for these to be counted with any degree of accuracy.

4.10 TRANSIENT POPULATION ESTIMATION

During the planning stages of this study, it was desired to evaluate the use of remotely sensed data for estimating the transient population within the 10-mile radius study site. If the remotely sensed data acquired could be used to count accurately the number of motor vehicles present on the road network and in parking lots within the study site, estimates of transient population might be obtained.*

When the NASA imagery and commercially acquired photography were received, they were evaluated in terms of potential for use in this task. The photography was examined visually under high (15X) magnification to determine if it was of sufficient resolution for use in vehicle counts. Photomicrographs (shown in Figures 19-24) were taken of the central portions of selected images at each scale and both color slides and color prints were produced for evaluation.

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*Time of the day, week, weekend, and year are all variables that influence transient population accuracy from car counts. Optimized multiple imagery would be useful in improving accuracy.

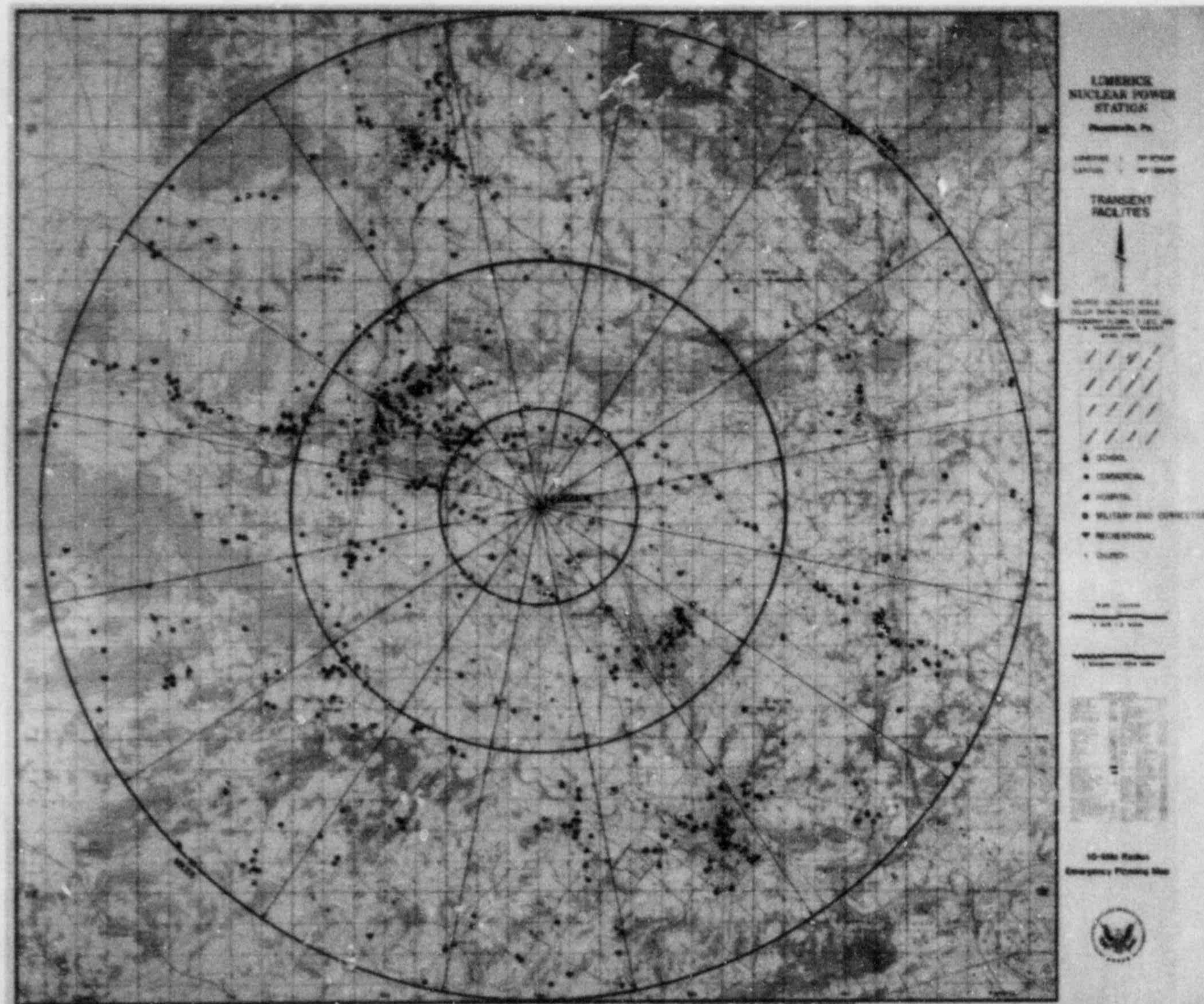

Figure 18. Transient facilities mapped in the Limerick study area

Figure 19. Photomicrograph of central portion of frame #206 (Limerick facility) acquired by Keystone Aerial Surveys 12-7-82. Original scale, 1:36,000

Figure 20. Photomicrograph of central portion of frame #8686 (Limerick facility) acquired by Keystone Aerial Surveys 12-7-82. Original scale, 1:48,000

Figure 21. Photomicrograph of central portion of frame #045 (Limerick facility) acquired by Keystone Aerial Surveys 12-7-82. Original scale, 1:60,000

Figure 22. Photomicrograph of central portion of frame #8569 (Limerick facility) acquired by Keystone Aerial Surveys 12-7-82. Original scale, 1:80,000

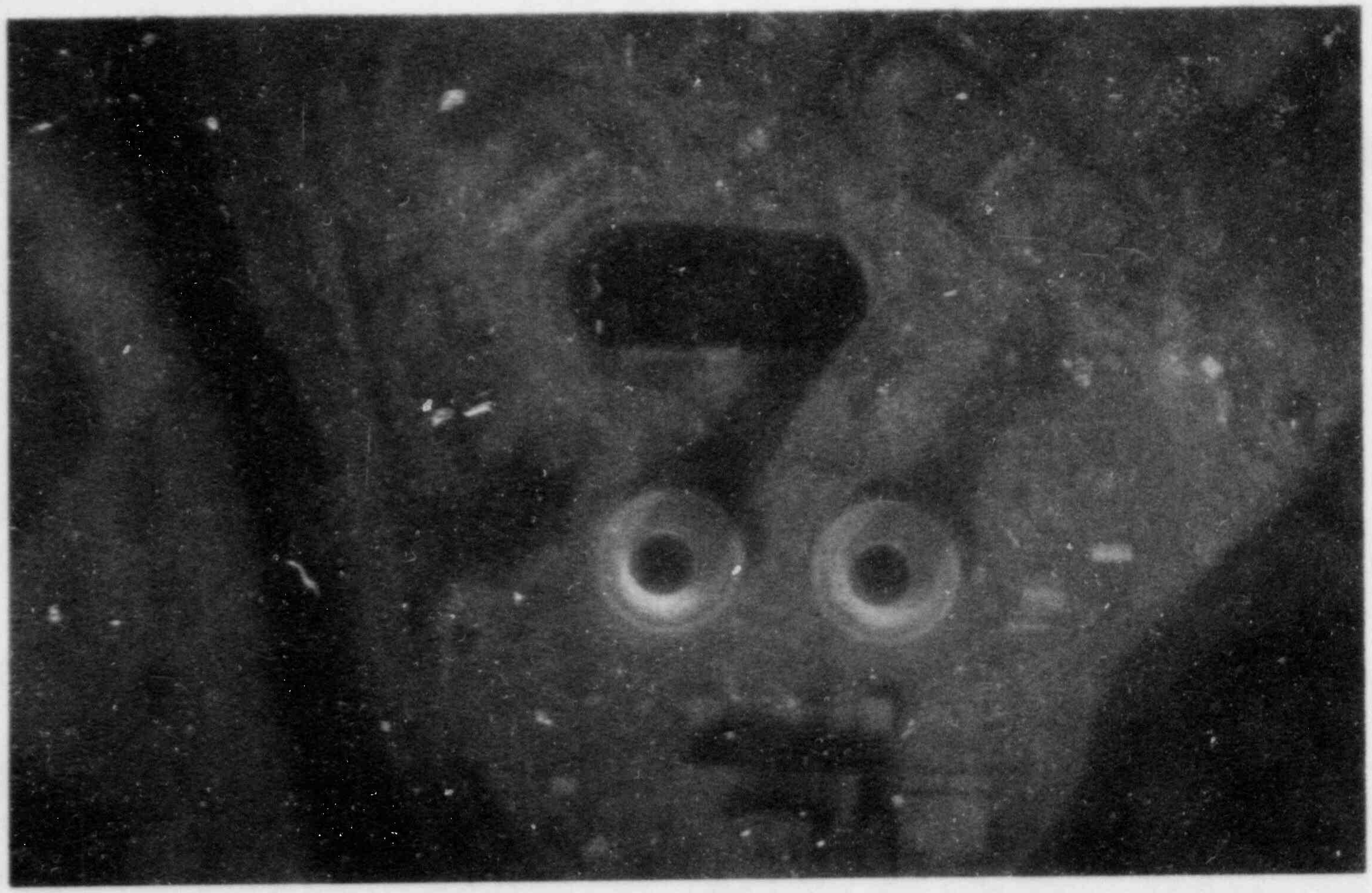

Figure 23. Photomicrograph of central portion of frame #2113 (Limerick facility) acquired by NASA 11-16-82. Original scale, 1:65,000

Figure 24. Photomicrograph of central portion of frame #1746 (Limerick facility) acquired by NASA 11-16-82. Original scale, 1:130,000

In addition, a review of state-of-the-art, machine-assisted and automated image analysis techniques was conducted to ascertain the potential of applying statistical and syntactic pattern recognition and symbolic reasoning to the identification of vehicles on aerial photography. This review included works such as: Rosenfeld and Kak, 1976; Swain and Davis, 1978; Fu, 1980; Nagao and Matsuyama, 1980; and Tinney, Sailer, and Estes, in press. The material from this review was presented to NRC personnel at a meeting in Silver Spring, Maryland, in April 1983.

All researchers and photoanalysts who viewed the imagery and the literature on machine processing were of the firm opinion that accurate vehicle counts could not be obtained using any of the imagery acquired for this study.

4.11 AUTOMATED IMAGE ANALYSIS TECHNIQUES

An automated land use/land cover classification of the Limerick site at Anderson Level II was performed at UCSB. This task was accomplished using a portion of frame #206 of the 1:36,000 scale CIR photography obtained by Keystone Aerial Surveys. Frame #206 is centered on the Limerick facility.

An analog-to-digital conversion of a portion of frame #206 was performed at the University of Southern California Institute of Physics using an optical/mechanical scan digitizer. The image portion (encompassing a 2-mile radius around the facility) was scanned at a 200-µm spot size (which corresponds to a ground resolution cell = 7 meters at 1:36,000 scale). The image was coded as three digital images corresponding to the complements of each of the three additive primary colors: red, blue, and green. Each of the three images contained a tonal scale of 256 (8 bits) levels and consisted of 1024 lines by 1024 samples. The image is recorded on a 9-track 1600 pbi magnetic tape in an 'unblocked' format.

Computer-assisted techniques for land use/land cover classification are well documented (Campbell, 1983; Estes, et al, author editor, 1983; Lillisand and Kieffer, 1979; Moik, 1980; and Swain and Davis, 1978).

Both supervised and unsupervised procedures have advantages and disadvantages, depending upon the applications. These procedures are discussed in greater detail in Estes, et al, 1983. Because the classification system employed in this project was predetermined (Anderson Level II), a supervised approach was taken. In the future it would be useful to test an unsupervised approach and an approach with aggregated categories. While these procedures might result in some combining of data classes, the information and accuracy improvement could be tested to see if NRC requirements can be better served using these techniques.

A supervised classification was performed using the Video Image Communication Analysis and Retrieval (VICAR) image processing software package at UCSB. The VICAR system is a set of computer programs developed at Cal Tech's Jet Propulsion Laboratory which facilitate processing and analysis of digital image data (Mertz, 1982; VICAR Documentation Manual, 1977). Image processing and classification tasks were performed using the UCSB Computer Center's NAS AS/6 computer. The processed images were interactively displayed using the UCSB Computer System Laboratory's VAX 11/780 computer system and I^2S Model 70 digital image display and manipulation system. The Computer Systems Laboratory (CSL) is an independent Organized Research Unit within the University of California.

A diagram outlining each of the steps in the image processing flow used for land use/land cover classification is shown in Figure 25. The image processing steps taken are described next.

The digital data on the 1600 bpi unblocked magnetic tape were read onto a mass storage disk using 'VSAR'.* This enables the 'F2' program to convert the original yellow, magenta, and cyan information into the primary colors blue, green, and red as follows:

Blue = 255 – yellow

Green = 255 – magneta

Red = 255 – cyan

In order to display the digitized image on the I^2S system, it was necessary to "smooth" tne image by reducing the number of picture elements (pixels) in the image. The program 'APAVG' was used for this purpose. "APAVG" created an image 256 lines by 256 samples by averaging a 4 × 4 array of pixels in the original image. This program also reduced noise in the image. A display and histogram of the digital images in each of the three bands was generated using 'DISPLAY' and 'LIST' respectively (see Figures 26 through 28 for gray map display images).

Representative training fields were identified using the CSL VAX/I^2S system. These fields permit the computer to recognize a particular combination of reflectance values which represent the spectral characteristics of the classes of interest. Both training and test sites were selected for each of the 17 Anderson Level II land use/land cover categories.

Test sites are used to assess accuracy within each category. Training and test sites were selected within each class and cover type within the study area in such a way as to characterize as thoroughly as possible all of the variations in spectral response throughout each class. Training and test site information was recorded by line and by sample and compiled in a polygonal format to be further processed.

Several data bases were utilized in the training/test site selection process. The oroginal 9" × 9" CIR image was used along with the manually derived land use/land cover maps produced previously in this study. Data from USGS 7.5 minute, 1:24,000 scale topographic maps was incorporated into the selection process. Visual analysis and identification of the digitized photo displayed on the VAX/I^2S system was also used.

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*For simplicity, all VICAR software programs will be capitalized and set in single quotation marks. Brief descriptions of each program are in Appendix C.

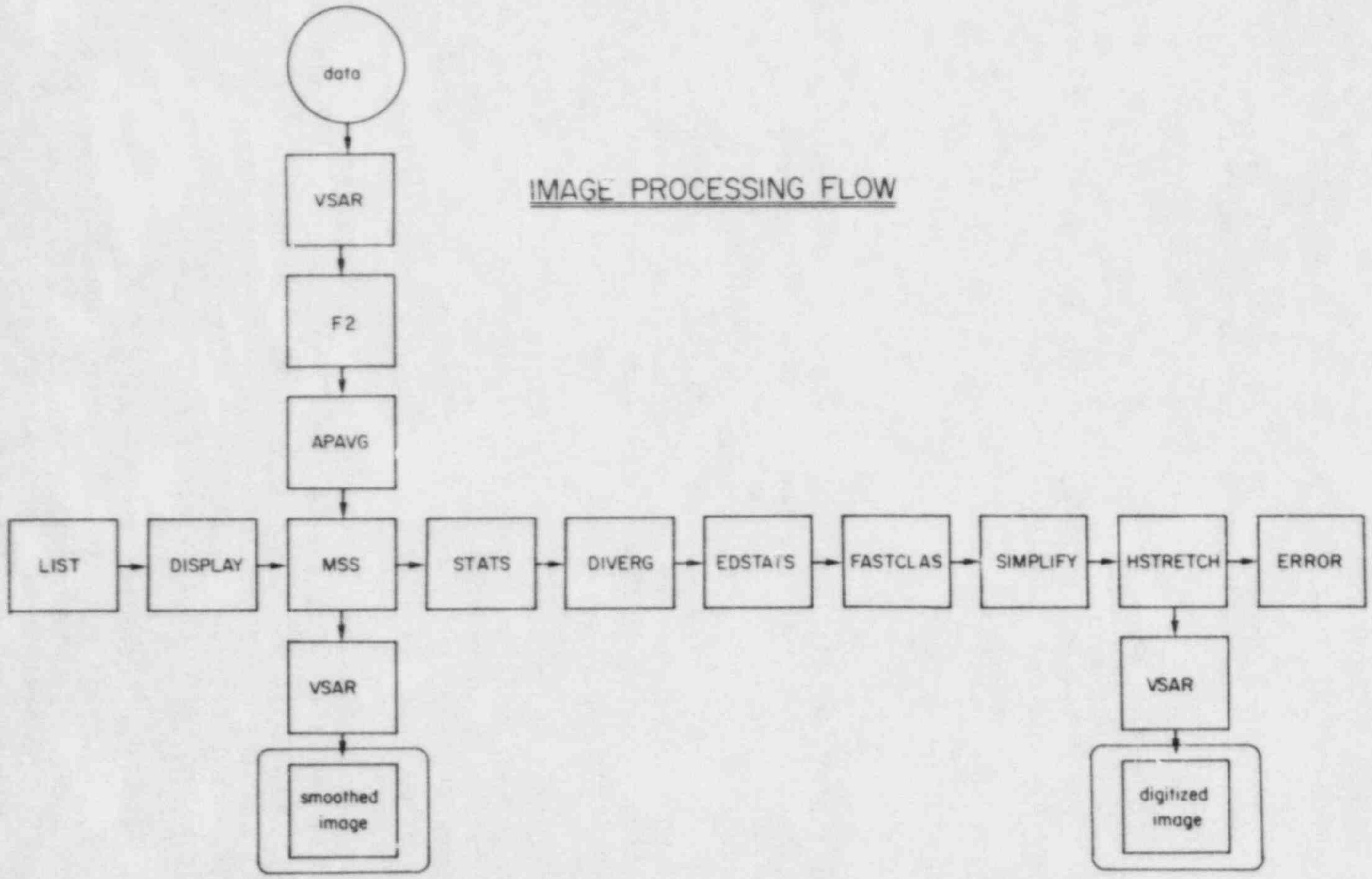

Figure 25. Flow chart of digital image processing for Anderson Level II land use/land cover classification, Limerick study site, Pennsylvania

Figure 26. Digital gray map of band 1 (blue) imag^ of portion of Limerick study area

Figure 27. Digital gray map of band 2 (green) image of portion of Limerick study site

Figure 28. Digital gray map of band 3 (red) image of portion of Limerick study site

The VICAR program 'MSS' was used to combine the three separate spectral data files into interleaved input data set for image analysis. Once this was accomplished and training and test sites selected, the program 'STATS' was used to generate multivariate statistics for the multichannel data. 'STATS' generates mean, standard deviation, covariance matrix, correlation matrix and histogram data for each of the 17 classes of interest in each of the three channels. A spectral data plot was also produced for the classes in each channel. Class separability matrices were calculated and divergence values were measured using 'DIVERG'.

An edited classification statistics file was created from the records in the statistics data set using the 'EDSTATS' program. The stored multivariate statistics file from 'EDSTATS' were used to classify the image using the program 'FASTCLAS', a multispectral classifier algorithm which combines the parallelepiped and Bayesian techniques.

High frequency information components were removed from the classified image by the VICAR applications program 'SIMPLIFY'. 'HSTRETCH' performed a linear contrast table stretch on the simplified image by assigning an intensity value for each class in each band (blue, red, and green).

'VSAR' was again used to copy the classified scene from mass storage disk to magnetic tape, then recorded on disk again at CSL, and the finished color classified land use/land cover image was displayed on video.

The final Anderson Level II land use/land cover classification image and its legend are shown in Figures 29 and 30. Error analysis of the data was calculated by sampling within each class using the program 'ERROR'. This program determines the percentage of correctly classified pixels within the test sites by comparing the test site to the training sites selected previously. The accuracy statistics for the image classification are shown in Table 4. Results of the supervised classification were an average class accuracy of 59.6%, with separate class accuracies ranging from 11.6% to 100%.

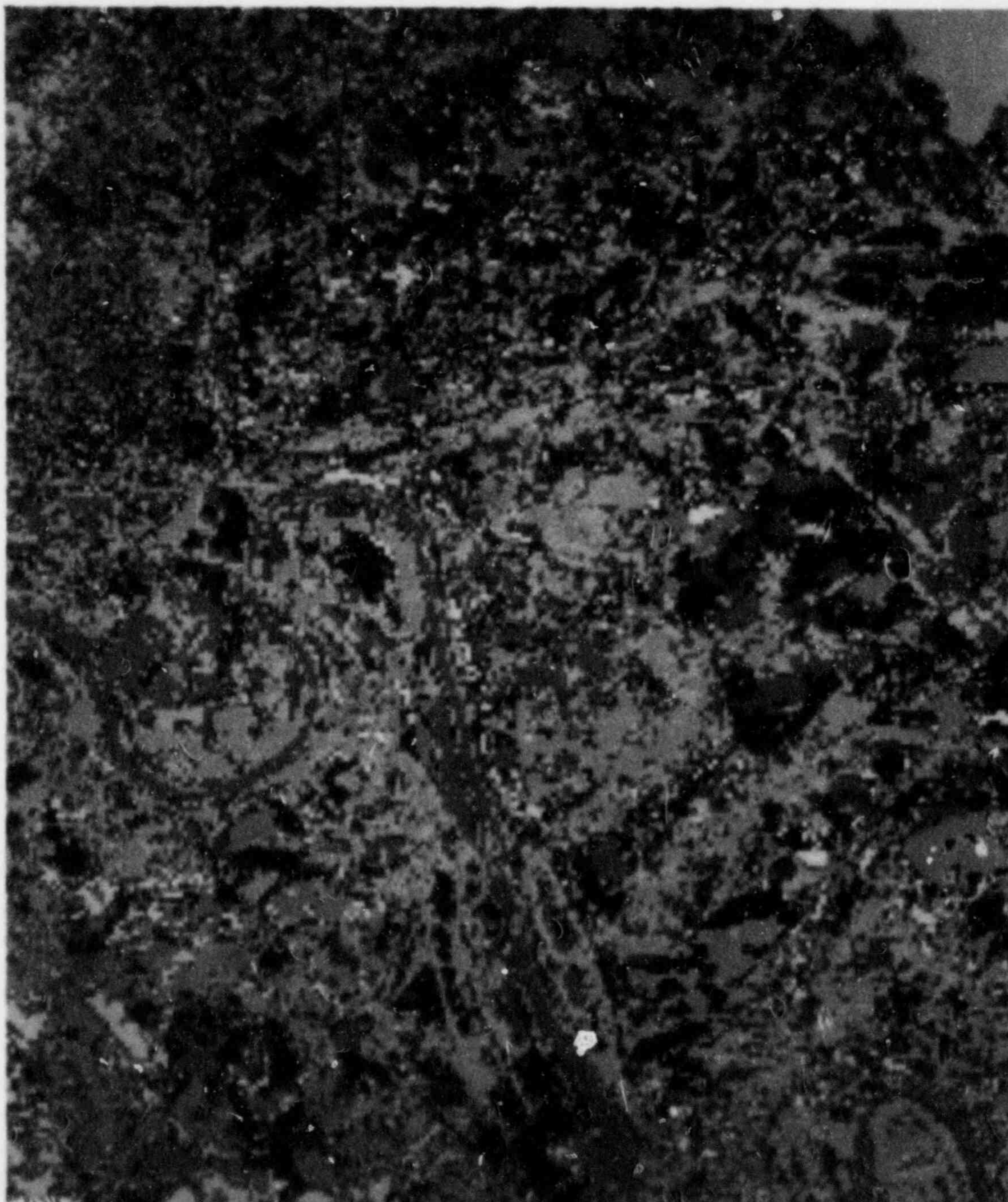

Figure 29. Digital land use/land cover classification, Limerick site, Anderson Level II

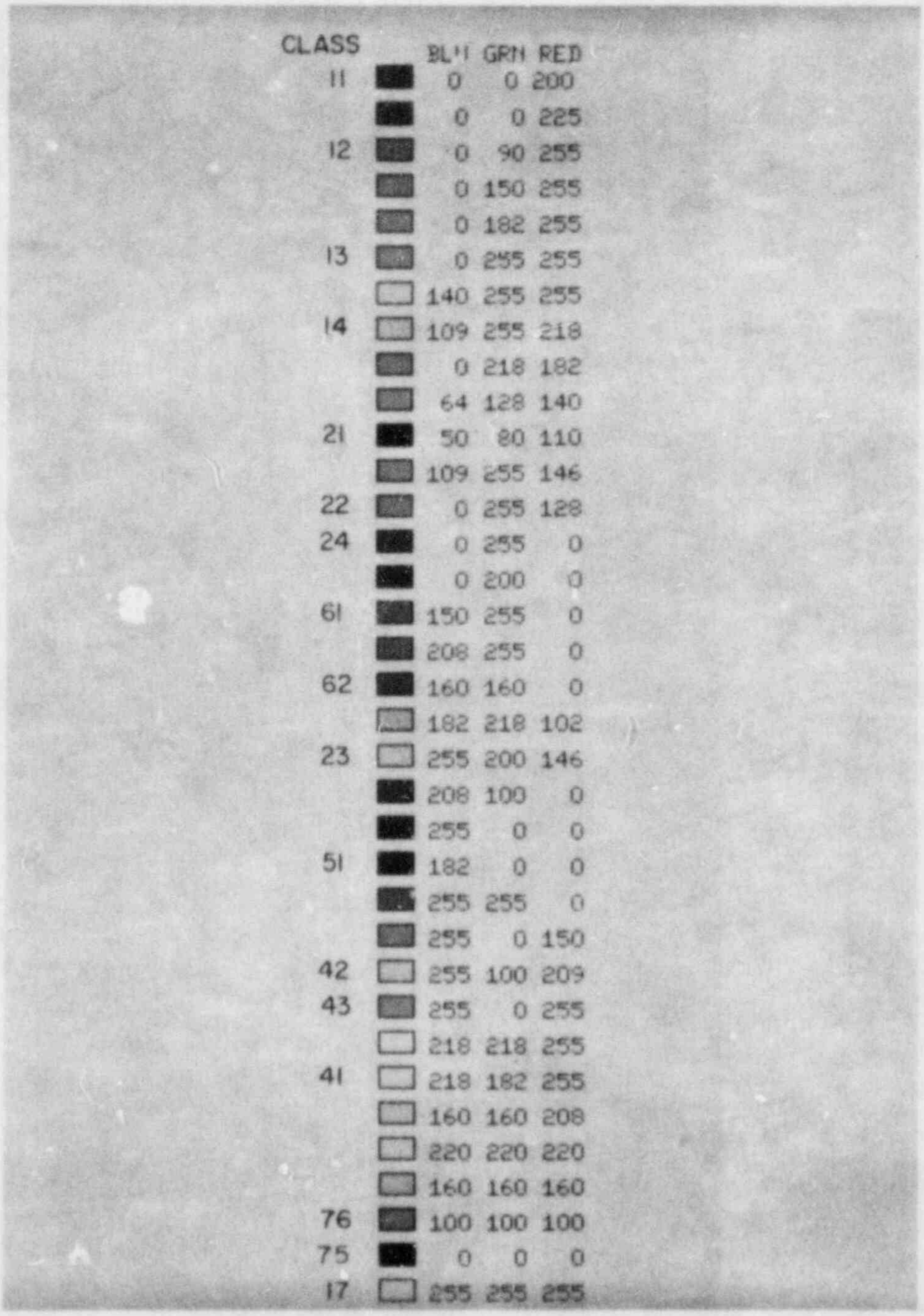

Figure 30. Color legend used to denote Anderson Level II land use/land cover categories in Figure 29, the digitially classified image. Digital number (DN) values shown were used to create discrete colors for each category

Table 4. By-class accuracies for digital Anderson Level II land use/land cover classification (see Appendix B for category designations)

Class	Percent Classified As																
	11	12	13	14	17	21	22	23	24	41	42	43	51	61	62	75	76
11	23.2	25.5	0.0	0.0	0.0	2.3	0.0	0.0	0.0	6.9	4.6	4.6	0.0	0.0	2.3	0.0	30.2
12	9.0	81.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	80.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	78.7	0.0	9.0	0.0	6.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	20.0	20.0	20.0	0.0	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	16.2	0.0	25.5	18.6	11.6	0.0	0.0	23.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6
22	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0
23	11.7	0.0	0.0	17.6	0.0	5.8	0.0	52.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.7
24	0.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	0.0	1.5	0.0	0.0	0.0	6.0	0.0	0.0	0.0	87.8	0.0	0.0	0.0	4.5	0.0	0.0	0.0
42	10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.8	21.4	0.0	0.0	0.0	0.0	0.0
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.5	71.4	0.0	0.0	0.0	0.0	0.0
51	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	96.8	0.0	0.0	0.0	0.0
61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0	0.0	75.0	0.0	0.0
75	0.0	0.0	0.0	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0
76	0.0	0.0	0.0	0.0	0.0	15.3	0.0	0.0	0.0	0.0	7.6	0.0	7.6	7.6	0.0	0.0	61.5

Average Class Accuracy: 59.8%

5. TIME AND COST FACTORS

Table 5 summarizes time and costs for the various planning, field verification, analysis, cartographic, etc., activities related to the Limerick site. Time for both experienced management personnel in planning and directing the effort and operational personnel doing the actual analysis, map making, etc., is covered.

It should be emphasized, however, that these costs cover dedicated labor associated with the tasks accomplished, and do not cover background research, literature surveys, preliminary evaluation of technical approaches from which decisions are made, learning exercises, and training/presentations at NRC. These are all the items that go to make up the initial activity of an applications research effort. The table also does not cover travel or per diem for project personnel.

The costs shown are derived from modified average 1983 labor salary surveys of the Merchants and Manufacturers Association (M&M) for the management personnel and from modified average 1983 Hughes wage and salary survey for the non-supervisory personnel.* These surveys cover industrial group salaries, but do not cover salaries of personnel in Universities, National Laboratories, or other government agencies. Overhead and Guidance and Administration (G&A) was calculated at 150%, with fee at 10%, probably low. Overheads and fees will be lower at universities and National Laboratories, with the salaries of selected operational personnel (graduate students) also lower.

These costs reflect 1983 salary levels. Personnel considered will have experience in acquiring and analyzing imagery, map making, accuracy assessment, and field verification. There is some small amount of learning exercise included, since many of the activities will be site-specific.

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*Salaries of management and planning personnel were based on employees with a PhD or M.S., supervisory, with at least 10 years experience. Support personnel salaries were based upon non-degreed, professional, non-supervisory category with appropriate training but limited experience.

Table 5. Time and cost for Limerick site activities

Work Effort	Management and Planning		Operational Support		Other
	Total Hours	Total Cost ($62/hour)	Total Hours	Total Cost ($34/hour)	Total Cost
DATA ACQUISITION					
<u>NASA Imagery</u>	12	744	6	204	
Mission Planning NASA Interaction Imagery Inspection					
<u>NASA Imagery Acq.</u>					$25,000
<u>Commercial Imagery</u>	18	1116	10	340	
Photo Engineering Contract Mission Planning					
Flight Lines Overlap Scales, Altitudes Film/Filter/Camera					
Image Evaluation					
<u>Commercial Imagery Acq.</u>					$30,000
<u>Existing Imagery Search</u>	1	62	4	136	
<u>Collateral Data Acq.</u>	10	620	30	1020	
DATA ANALYSIS TASKS AND MAPPING					
<u>Population Estimation</u>	60	3720	204	6936	
Base Map Preparation Work Copies Final Mapping					
Tabular Population Chart Population Density (choropleth) (isarithm)					
<u>Water Bodies</u>	2	124	8	272	
Archive Copy					

Table 5. Time and cost for Limerick site activities (continued)

Work Effort	Management and Planning		Operational Support		Other
	Total Hours	Total Cost ($62/hour)	Total Hours	Total Cost ($34/hour)	Total Cost
DATA ANALYSIS TASKS AND MAPPING (continued)					
Transportation Net	8	496	40	272	
Archive Copy					
Industrial Facilities	6	372	25	850	
Work Copies (interpretation) Archive Copies (final)					
Transient Facilities	6	372	40		
Work Copies (interpretation) Archive Copies (final)					
Land Use/Land Cover	60	3720	304	10,336	
Base Map Preparation Work Copies (interpretation) Archive Copies Accuracy Assessment					
Travel Field Verification					
DIGITAL CLASSIFICATION			160	5,440	
Digitizing					$ 480
Research Labor					
Computer Time					$ 1,000
PREPARATION OF PAPERS AND FINAL REPORT	22	1364	115	3,910	
Cerma Paper					
Final Report					
MATERIALS					
Cartographic					$ 650
Photographs, Slides					$ 600
Graphics					$ 100

6. CONCLUSIONS AND RECOMMENDATIONS

Remote sensing data and analysis techniques can provide physical and demographic information which may be of value to the NRC's site characterization and licensing process. Location and mapping of these types of information can be accomplished using color infrared (CIR) aerial imagery such as the type acquired for this and the previous study.

A fundamental consideration in this process, however, is acquiring imagery that is adequate (in terms of timing, scale, resolution, film type, format, and atmospherics) to provide data at the level of detail desired. The series of CIR images acquired for this study was not optimal for all the types of environmental analysis required. The photography ranged from a scale of 1:36,000 to 1:130,000. Imagery at these scales was acquired to attempt to satisfy study requirements for single frame coverage of 2-, 5-, and 10-mile distances from the Limerick facility.

In terms of the population estimation task, the 1:36,000 scale imagery used was not of large enough scale to resolve a number of key features necessary to unambigously identify the number of residences in multifamily structures (widespread in the study area). It was also extremely difficult to differentiate residences from commercial and other types of structures. This was an acute problem in the densely populated urban areas. Using the 1:36,000 scale imagery, the interpretation was also very slow and tedious, increasing the chances of interpretation error.

On a task by task basis, EG&G/EM/UCSB personnel conclude the following.

1. Land use/land cover mapping can successfully be carried out to Anderson Level II standards using imagery of the format and scales acquired for this study. We recommend, however, that future land use/land cover mapping at Level II should be performed using CIR photography at 1:24,000 scale. This recommendation is supported by the findings in Borella, et al (1982). If land use/land cover is to be mapped at Anderson Level III or IV, larger scale imagery (1:10,000 or larger) must be obtained.

2. Population estimation can also be successfully accomplished using a combination of CIR photography and manual interpretation techniques. The 'dwelling unit' method of population estimation is an inherently accurate technique, but is dependent upon optimal imagery for successful application. It is recommended that for future population estimation projects of this type, CIR imagery should be acquired at a scale of 1:10,000 or larger. Most importantly, we strongly recommend that a detailed accuracy assessment of the population figures derived in this or any other similar study be carried out. This would provide NRC with an improved level of confidence for any decisions to be made on the advisability of using this type of demographic analysis in the future.

An accuracy assessment of this type would address:

a. Design of a sampling scheme that would take into account the spatial distribution (density and pattern) of residences as well as the differences in residence type.

b. The product of a thorough field verification effort to verify the spatial and categoric accuracy of the derived population information.

c. A rigorous statistical assessment of the derived accuracies and establishing confidence limits within which the data can be evaluated.

3. The combination of data and techniques used in this research effort is very appropriate for mapping of transportation networks. If NRC wishes to obtain quantative data on lane and shoulder widths within an area's road network, we recommend that imagery of a scale 1:10,000 or larger should be obtained.

4. Water body mapping within a study site can be readily carried out using high quality CIR photography in scales of up to 1:80,000. Identification and mapping of water bodies is also a task amenable to digital/automated analysis techniques. Higher level information regarding water body conditions (high/low water levels, sedimentation, etc.) may be obtained with the use of larger scale photography. If such information is desired we recommend a mix of both color and CIR photography at scales of 1:24,000 or better.

5. Industrial and transient facilities analysis and location can also be accomplished using the techniques evaluated in this study. Again, the complexity of analysis obtainable is dependent upon the scale and quality of the imagery obtained. The discreet interpretation and location of these types of facilities is another process which would be aided by a thoroughly applied accuracy assessment and field verification effort. We recommend that such an effort be initiated to also validate the accuracy of the industrial and transient facility overlays generated in this research project.

6. Transient population estimation by vehicle count could not be accomplished in either a manual or machine-assisted mode employing the imagery acquired for this project. If such vehicle counts are an NRC requirement we would, at this time, recommend manual image analysis procedures using imagery of about 1:8,000 scale at carefully selected times of the day, week, and year. A project such as this will require detailed planning and must have adequate start-up time to insure optimal results.

7. Automated and machine-assisted analysis techniques for identifying and counting residences and automobiles, and for performing "general purpose" land use/land cover mapping of study areas containing a wide range of both physical and cultural features, are still very much state-of-the-art research using remotely sensed data. Accurate counts of residences and automobiles will continue to depend on manual interpretation for some time to come.

   Accurate land use/land cover classification is dependent upon the spatial, spectral, and temporal characteristics of the objects and phenomena in the area of interest and of the imagery obtained. It is our firm belief, based on considerable experience in this area, that automated and machine-assisted techniques for image analysis are not yet to a state where sufficiently accurate results can be achieved within reasonable time and cost constraints to meet operational NRC requirements.

   When NRC chooses to actively pursue the area of machine-assisted image analysis, we recommend that a number of classification procedures and algorithms be thoroughly evaluated. More specifically, tests of supervised and unsupervised procedures should be conducted employing both existing land use/land cover classification systems, e.g., Anderson and some form of special purpose classification system designed specifically to be employed with machine-assisted processing of remotely sensed data. This latter could represent some aggragate of use/cover class within an existing system or the design of a totally new land use/land cover classification system to suit NRC data requirements.

   Still, at this time and for the present type of studies, we recommend that NRC employ manual image analysis techniques. We <u>do</u> however recommend that NRC keep abreast of advances in automated and machine-assisted image analysis as well as research on artificial intelligence and geographic information systems. We believe the combination of research being accomplished in these three areas has significant long-range potential for certain NRC objectives.

8. Finally, we most strongly recommend that NRC conduct a study of the potential for employing information systems technology for site inventory, monitoring, and modeling. Such a study should examine both commercial systems and current research and development efforts. The ability of these systems to integrate point, tabular, graphic, and image data for interactive processing and improving the information potential from multiple layers of environmental data could represent a significant asset to NRC.

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APPENDIX A: ANDERSON LEVEL II CLASSIFICATION CRITERIA

According to the USGS, a land use/land cover classification system which can effectively employ orbital and high-altitude remote sensor data should meet the following criteria:

1. The minimum level of interpretation accuracy in the identification of land-use and land-cover categories from remote sensor data should be 85%.
2. The accuracy of interpretation for several categories should be about equal.
3. Repeatable or repetitive results should be obtainable from one interpreter to another and from one time of data acquisition to another.
4. The classification system should be applicable over extensive areas.
5. The categorization should permit vegetation and other types of land cover to be used as surrogates for activity.
6. The classification system should be suitable for use with remote sensor data obtained at different times of the year.
7. Effective use of subcategories that can be obtained from ground surveys or from the use of larger-scale or enhanced remote sensor data should be possible.
8. Aggregation of categories must be possible.
9. Comparison with future land-use data should be possible.
10. Multiple uses of land should be recognized when possible.

APPENDIX B: CATEGORIES OF ANDERSON LEVELS I AND II USED IN THIS STUDY

I II

1. URBAN OR BUILT-UP LAND

11. Residential

a. High density

b. Low density; houses on lots of more than one acre

12. Commercial and Services*

a. Predominantly for sale of products and services

Urban central business districts
Shopping centers
Commercial strip developments along major highways
Junkyards
Resorts
Etc.

b. Intensively developed portions of recreational areas would be #12, the extensive parts (golf courses) would be Other Urban or Built-Up Land, Category #17

c. Institutional land-uses

Educational
Religious
Health
Correctional
Military

13. Industrial

a. Light manufacturing

Design
Assembly
Finishing
Processing
Packaging

b. Heavy manufacturing

Steel mills
Pulp and lumber mills
Electric power generating stations
Oil refineries
Tank farms
Chemical plants
Surface structures associated with mining

*When non-commercial use exceeds 1/3, use Mixed Urban or Built-Up, Category #16.

14. Transportation, Communications, and Utilities

    a. Major transportation routes

        Freeways
        Railways (stations, parking lots, round-houses, switching yards)
        Airports
        Seaports

    b. Processing, treatment, and transporting of water, gas, oil, and electricity

        Pumping stations
        Electric substations

15. Industrial and Commercial Complexes

    a. Industrial parks — intentional development as discrete units of land-use

16. Mixed Urban and Built-Up

    a. When more than 1/3 intermixture of another use or uses occurs, developments along transportation routes, farmsteads intermixed with strip or cluster settlements

17. Other Urban or Built-Up Land

    a. Golf-driving ranges
    b. Zoos
    c. Urban parks
    d. Cemeteries
    e. Undeveloped land within an urban setting

2. <u>AGRICULTURAL LAND</u>

21. Cropland and Pasture

    a. Cropland harvested
    b. Cultivated summer fallow
    c. Cropland in soil improvement grasses
    d. Crop/pasture rotation land
    e. Pasture
    f. Idle cropland
    g. Crop failure land

22. Orchards, Groves, Vinelands, Nurseries, and Ornamental Horticultural Areas

23. Confined Feeding Operations

    a. Beef cattle feedlots

    b. Dairy farming with confined feeding

    c. Poultry farming

24. Other Agricultural Land

    a. Farmsteads

    b. Holding areas for livestock

    c. Small farm ponds

4. FOREST LAND

41. Deciduous Forest Land

    a. Predominance of trees that lose their leaves — oak, maple, hickory, aspen

42. Evergreen Forest Land

    a. Longleaf pine, spruce, balsam fir, hemlock, redwood

43. Mixed Forest Land

    a. Where neither predominates or when more than 1/3 mixture occurs

5. WATER

51. Streams and Canals

52. Lakes

53. Reservoirs

54. Bays and Estuaries

6. WETLAND

61. Forested Wetland

    a. Dominated by woody vegetation

62. Non-Forested Wetland

a. Dominated by wetland herbacious vegetation

7. <u>BARREN LANDS</u>

72. Beaches

75. Strip Mines, Quarrys, and Gravel Pits

a. Unused pits flooded with water are reservoirs

76. Transitional Areas

a. In transition from one land use to another

77. Mixed Barren Land

a. When a mixture of barren land features occurs and dominant land use occupies less than 2/3 of the area

APPENDIX C: VICAR SOFTWARE USED IN THIS STUDY

1. VICAR PROGRAM 'VSAR'

VSAR is a general purpose program for moving VICAR or non-VICAR data sets from tape to disk, disk to disk, or disk to tape. VSAR will generate a VICAR label or remove VICAR label records if desired.

2. VICAR PROGRAM 'F2'

F2 allows general arithmetic operations to be performed on one or two input images in either byte, halfword, or mixed byte-halfword input/output.

3. VICAR PROGRAM 'ADAVG'

This program reduces picture size and noise by averaging an N by M array of picture elements to produce one output pixel.

4. VICAR PROGRAM 'DISPLAY'

DISPLAY is a VICAR applications program which will display a picture or portions of a picture on the line printer. It can double print to achieve greater differences between gray levels. DISPLAY uses the high order six bits of each DN to determine which characters to print. Thus, there are 64 possible printing levels.

5. VICAR PROGRAM 'LIST'

LIST is a VICAR applications program which gives a decimal printout of a picture or portions of a picture, and produces histograms of the printed areas. Either the printout or histogram may be suppressed. Picture data may be six-bit, eight-bit, or halfword. Line and sample increments may be other than 1.

6. VICAR PROGRAM 'MSS'

MSS converts unleaved multispectral data to multispectral scanner format (MSS format). Unleaved multispectral data refers to data that has each channel as a separate VICAR data set. MSS combines this data into one VICAR data set. This format will save I/O time in programs that require several spectral bands concurrently. All spectral information about a line can be read into core with one read operation.

7. VICAR PROGRAM 'STATS'

STATS computes the statistics of specified training areas on multispectral data. The output consists of page printer output, a statistics data set compatible with multispectral classifiers BAYES and FASTCLAS, and (optionally) a picture containing the scribed training areas. Input multispectral data may be in separate VICAR data sets or in MSS format.

8. VICAR PROGRAM 'DIVERG'

DIVERG is a VICAR applications program which calculates the separability of class pairs, and the average, minimum, and maximum divergence values for single channels or multiple channel combinations. Comparison of the divergence values for specific channel(s) gives an indication of the relative information content of the data channel(s) under investigation. If certain channels do not add significant information they should be excluded from the classification/categorization procedure in order to reduce costs and improve accuracy performance. The separability matrix allows the user to locate confusion classes on a channel by channel, or channel combination basis. Separability and divergence values are scaled such that a divergence/separability index value of 180 appears as '100' on output. This value is merely a scaled indicator of the separability measure and has not yet been tested or linked to probabilities of correct classification.

9. VICAR PROGRAM 'EDSTATS'

EDSTATS allows a variety of editing functions to be performed on classification statistics records in statistics data sets which have been output from either STATS or USTATS. The output of EDSTATS is another classification statistics file identical in format to the original STATS/USTATS file, but modified in length and content by the parameter edit instructions used in EDSTATS. VICAR labels on the output file show the size changes and enable subsequent processing to take place normally. The output file is therefore suitable for subsequent input to multispectral classifiers BAYES and/or FASTCLAS or FSICLSPS. EDSTATS prints lists of all input file statistics, record for record, all instructions specified in parameters, all output file statistics, and error messages.

10. VICAR PROGRAM 'FASTCLAS'

FASTCLAS is a multispectral classifier using an algorithm which combines the parallelepiped and Bayesian techniques. Inputs are registered multispectral data and training statistics from VICAR program STATS. The inputed multispectral data can be in either separate VICAR data sets or in MSS format.

11. VICAR PROGRAM 'SIMPLIFY'

SIMPLIFY is a VICAR applications program used to remove high-frequency information (noise) components from classified or stratified images such as those images derived from the operation of VICAR programs FASTCLAS or UNCL. Through the use of a moving window, visually distracting detail is removed from a classified scene. The window size can be set to analyze either as 3 × 3 or a 5 × 5 neighborhood, checking the nearest eight or nearest 24 pixels, respectively.

12. VICAR PROGRAM 'HSTRETCH'

HSTRETCH is a VICAR applications program used for the production of binary masks and for modifying specific DN values of images. Operation of the program is similar to the table stretch option of STRETCH;

however, the parameter structure is often simplified. The major feature of HSTRETCH is that only those DN values which are to be modified need to be listed as parameters. Both halfword and byte data may be processed to yield either byte or halfword output data.

13. VICAR PROGRAM 'ERROR'

The purpose of ERROR is to determine the percentage of classified pixels within training site or test site areas. Use the RECT or VERT coordinates in STATS format for its calculations.

NRC FORM 335 (11-81)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC)
NUREG/CR-3583
S-762-R

4. TITLE AND SUBTITLE (Add Volume No., if appropriate)
Evaluation of Low-Altitude Remote Sensing Techniques for Obtaining Site Characteristic Information

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
J.E. Estes, J. Scepan, L. Ritter, and H.M. Borella

5. DATE REPORT COMPLETED

MONTH	YEAR
December	1983

DATE REPORT ISSUED

MONTH	YEAR
April	1984

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
University of California, Santa Barbara, Goleta, California 93106

EG&G/EM, Santa Barbara Operations, Box 98, Goleta, California 93116-0098

6. (Leave blank)

8. (Leave blank)

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Health, Siting, and Waste Management
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

10. PROJECT/TASK/WORK UNIT NO.

11. FIN NO.
NRC FIN A1251

13. TYPE OF REPORT
Final

PERIOD COVERED (Inclusive dates)

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less) The Nuclear Regulatory Commission contracted with EG&G/EM and the University of California, Santa Barbara to assess the potential of photographic remote sensing for demographic and environmental monitoring. Aerial infrared imagery and ground truth along with collateral data provided information on site area demographics and land use, land cover characteristics. The ability to determine transient populations from remotely sensed data was also evaluated. Both manual and machine-assisted techniques for extracting these data from reflectance infrared images were qualitatively assessed. The NASA Aircraft Programs 'U-2' acquired color infrared imagery at scales of 1:65,000 and 1:130,000, and Keystone Aerial Surveys (Philadelphia, Pennsylvania) using a Lear-Jet acquired color infrared imagery at scales of 1:36,000, 1:48,000, 1:60,000, and 1:80,000. Data on residence types and counts, industrial facilities types and location, transient facilities, transportation networks, and the location of water bodies were generated specifically for the study site surrounding the Limerick Power Station in Pottstown, Pennsylvania. Of the three techniques of population estimations examined, the "Dwelling Unit" method was evaluated for respective utility and accuracy within NRC guidelines. The level of spatial and classification accuracy of the derived products depended on both scale and image quality. Area weighted thematic accuracy from manual analysis was 96%, while by-category accuracies ranged from 71% to 100%.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

low altitude photography, remote sensing, demographic and environmental information, Anderson land use/land cover classification, color infrared, aerial imagery, aerial imagery digitization, machine-assisted analysis

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS (This report)
Unclassified

20. SECURITY CLASS (This page)
Unclassified

21. NO. OF PAGES

22. PRICE
$

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

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NUREG/CR-3583

EVALUATION OF LOW-ALTITUDE REMOTE SENSING TECHNIQUES FOR OBTAINING SITE CHARACTERISTIC INFORMATION

APRIL 1984