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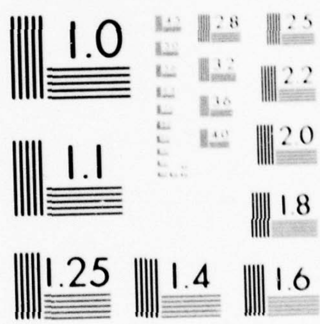

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STUDY IN REMOTE SENSING FOR LAND USE

LEVEL II

R.D. SHINN
F.V. WESTERLUND
UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON

JUNE 79

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This research tested three methods of obtaining land use information by remote sensing for United States Air Force (USAF) land use planning. The three methods tested were: (1) photo interpretation of aircraft photography; (2) equidensitometric processing of aircraft or Landsat imagery; and (3) statistical analysis of Landsat digital data. The two sites tested were McChord AFB and Fairchild AFB in Washington State. Using test scenarios of mission realignments it was found that photo interpretation was an accurate and ready means to obtain land use information.

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PREFACE

This report summarizes efforts by the Remote Sensing Applications Laboratory, University of Washington, to comparatively evaluate three methods of remote sensing for application to U.S. Air Force Air Installation Compatible Use Zone (AICUZ) land use planning. The report was prepared by Drs Richard Shinn and Frank Westerlund under JON 21039P40.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

The purpose of this research was to test three methods of obtaining land use information by remote sensing for United States Air Force (USAF) realignment decision. The three methods tested were: (1) photo interpretation of aircraft photography; (2) equidensitometric processing of aircraft or Landsat imagery, and (3) statistical analysis of Landsat digital data. The two sites tested were McChord AFB and Fairchild AFB in Washington State. The test scenarios were simulated mission realignments of a 40 percent increase of aircraft operations at McChord AFB and a 40 percent reduction at Fairchild AFB.

For each site, land use maps were prepared using each remote sensing method. Land use was summarized by the compatible use districts (CUD's) at each AFB. The Air Installation Compatible Use Zone (AICUZ) studies prepared for each AFB were used to determine the compatibility of the land use with respect to realignment CUD's. Overlays showing all incompatible areas were prepared for each land use map.

Sets of base maps with overlays were prepared to display the results. A typical set includes : (1) a base map at 1:24,000 scale; (2) an overlay with CUD's delineated; (3) an overlay with land use polygons; and (4) an overlay with incompatible areas cross-hatched.

Equipment configurations, time requirements, and budget costs are all included in the overall evaluation. The degree to which the procedures could be automated was evaluated with turn-around time a consideration.

Photo interpretation (PI) was found to be an accurate and ready means to obtain land use information. It depends upon high altitude aircraft photography, but neither of the other two modes could be done effectively without the same photography and some PI. The results from PI were used as a control in comparing land use information.

Equidensitometric analysis of various forms of remotely sensed images is rapid but not effective for more than Level I land use classifications, and it is difficult to achieve consistent, replicable results.

The digital analysis of Landsat data was done two different ways. At McChord AFB the use of a previously prepared spectral classification allowed quick land use associations and manual data summaries. At Fairchild AFB, a complete analysis was done with Editor software on ARPANET's ILLIAC-IV and TENEX computers.

SECTION II

CONVENTIONAL METHODS OF OBTAINING LAND USE INFORMATION

The USAF has not been systematically taking inventories of the base environments for its AICUZ studies or for its environmental narrative. The conventional method has amounted to collecting secondary land use information from the local planning agencies in the vicinity of the base under study. This approach has not been significant in its costs of acquisition or of reporting. Nor has the information provided the Air Force with its own assessment of the surrounding communities' land use problems. This discussion will focus on two types of land use reports the USAF prepares and on two Air Force bases used in this study.

1. AIR INSTALLATION COMPATIBLE USE ZONES

The AICUZ program has not included a land use map of the Air Force Base (AFB) vicinity in all cases. When a land use map is included, it is usually generalized to give only a cursory orientation to the vicinity and is not specified to a level of detail commensurate with the land use guidelines of the CUDs. The 2 digit level has been increasingly more common in AICUZ studies since the inception of the program. Earlier studies often used some four-digit classes and mixed levels freely.

AICUZ was conceived as an advisory program for the mitigation of problems associated with the encroachment of incompatible land use to AFB's. As such, a detailed land use inventory was not required. The tables could be interpreted for most land used to determine the compatibility given certain noise level and accident potentials associated with USAF operations at an AFB. Although the advice is usually well received it is not always heeded, as is the case for the clear zone north of McChord AFB, Washington.

Land use inventories would be a help to the AICUZ program. The availability of an independent assessment of the land use would undoubtedly add to the persuasiveness of the USAF position on land use in base environments.

It is necessary to remind the reader at this point that the specific purpose of this study is to find means of assessing community impact with mission realignment decisions. Thus, it is not necessary to be as detailed as one would want to be in a land use zoning case. However, the utility of the study can be extended to the AICUZ and environmental narratives where an independent source of land use information is valuable.

2. ENVIRONMENTAL NARRATIVES

The National Environmental Policy Act of 1969 requires the preparation of Environmental Impact Statements (EIS) when there is a major change of operations or construction of facilities. The environmental narrative (base line) is a step toward the preparation of EIS's. Generalized land use from the local planning agencies is derived from acitivities and only begins to cover the needs of land assessment. Land cover classifications reveal more of the natural environment's features than is the case with most land use records. Thus, it may be a significant gain in information to have a remote sensing derived land cover classification for the AFB vicinity.

SECTION III

PROJECT TEST SITES

1. FAIRCHILD AFB, WASHINGTON

The area impacted by noise at Fairchild AFB is large, an area extending 12 miles from the ends of the runways. An AICUZ study was done in 1975, and more recently an Environmental Narrative has been completed. Fairchild AFB is west of Spokane and Spokane International Airport. The 13 CUDs of the AICUZ lie within Spokane County. The western portion of the study area is largely wheatlands and rangelands. There are three small settlements west of Fairchild AFB, and Medical Lake is to the southwest. The latter is the small town where Eastern Washington State Hospital is located, a mental health facility.

The AICUZ report did not contain a land use map, but the environmental narrative did contain a map and a summary of land use by local planning jurisdictions.

The vicinity of Fairchild AFB was inspected and photographed at ground level in August 1977. The inspection team also visited with personnel at Fairchild AFB to discuss the study and to collect reports and maps.

Immediately to the east of Fairchild AFB are new sets of industrial developments in the accident potential zones (APZ's). To the northeast is a community called Airways Heights that will open a new school in 1978 in CUD 6. These developments suggest that the AICUZ guidelines have not been heeded by Spokane County in its land use decisions.

The northwestern districts of the City of Spokane are also in the study area with large areas in the 70L_{dn} contours. The area near Spokane Falls Community College and Shadle Park High School are two of the important study areas. The field study in this area did not reveal any visible evidence of land use decisions affected by the noise from aircraft.

2. MCCHORD AFB, WASHINGTON

The area within the 65 L_{dn} contours at McChord AFB is about 6 miles from the end of each runway. The north area is in the Tacoma planning area, and it extends into intensely developed portions of the City of Tacoma. Tacoma is north of McChord AFB, and the entire area between the two can be described as developed.

A negative effect from aircraft noise on the value of development may exist, but evidence of new development raised the question of the effectiveness of the land use controls in Pierce County.

The AICUZ report prepared in 1976 contained a land use map that had been prepared from the land use information available in the local planning agencies.

The area to the south of McChord AFB is in the Fort Lewis Military Reservation and is largely a field training range. To the east is the Parkland community and Pacific Lutheran University. On the west is the Lakewood area and the McChord AFB military family housing area.

SECTION IV

DESCRIPTION OF REMOTE SENSING METHODS TESTED

The three alternative remote sensing methods tested for land use inventory in this study are: (1) photo interpretation of aircraft imagery, (2) equidensitometric processing of aircraft or Landsat imagery, and (3) statistical analysis of Landsat digital data. For each method, the procedures followed are outlined, and characteristics of information products are described. Also documented are the resources needed for implementing each method, including required data resources, equipment/facilities and associated costs, technical skills of analysts, labor consumption, and other costs. These parameters, along with performance measures applied to the information products, are incorporated in the comparative evaluation of the three methods which follows.

1. PHOTO INTERPRETATION OF AIRCRAFT IMAGERY

a. General

Photo interpretation (PI) involves the visual inspection (usually with optical aids) of aerial photographic images by a human interpreter and the manual recording of information on image overlays or, preferably, directly on a map base.

Although aerial photography has been employed for military intelligence since World War I and for civilian uses since the 1930's, its use for systematic, area-continuous land use or land cover inventories over extensive areas has been a more recent development, resulting from the availability since the 1960's of high-altitude, color-infrared photography and improved optical and mapping aids such as the zoom transfer scope (discussed later). Several specific methods are documented by Westerlund (1977) (Reference 1), including both polygon methods, where the interpreter delineates on the map base the boundaries of each area of homogeneous land use or cover as defined by the classification scheme, and grid methods, where the interpreter assigns a single classification to each cell in a uniform, orthogonal, coordinate grid system constructed on the map base. In the latter case, each cell's classification represents an aggregate of the land use or cover observed within the land area corresponding to that cell.

Grid methods have been shown to be somewhat faster than polygon methods because manual effort is greatly reduced. Spatial information detail can be high, depending on cell size, and grid methods generally produce more consistent results among different interpreters, provided that decision rules governing cell classification are formulated. Finally, grid methods are advantageous for repeat analyses aimed at change detection, since the geographic recording units are constant. These advantages of grid PI methods are documented by Hartlmueller (Reference 2) in an airport environs land use change study, and by Bryan (Reference 3) in an application to McChord AFB.

This past experience has shown that skilled PI of modern, high-resolution, high-altitude aircraft photography can produce accurate land use/cover information at a level of detail generally corresponding to that used in AICUZ CUD designations, i.e., two-digit Standard Land Use Coding Manual (SLUCM) classes (Reference 4). However, PI is a labor-intensive method with relatively little possibility of future improvement in speed or efficiency. Therefore, in this study, PI is viewed primarily as a control or standard against which the other two, more automated types of remote sensing methods, are compared.

b. Procedure

The procedure followed in this study for the PI method, for each scenario, was as follows:

(1) Prepare a base map enclosing the AICUZ area. Mosaic United States Geological Survey (USGS) 7½-minute quadrangle maps (1:24,000). Photograph and reproduce this mosaic at the scale on opaque, stable base material. (This step was common to all three remote sensing methods and was done once in the project for each study area.)

(2) Formulate a land use/cover classification scheme appropriate to the information content of high-altitude aircraft photography and the characteristics of study areas. Define each class in terms of its correspondence to the SLUCM classes and its compatibility or incompatibility to the 13 CUD's as defined in the AICUZ Program. Assign a numerical code to each class, corresponding to SLUCM codes. In this study, a classification scheme was developed that should be generally applicable, with possibly some modifications, to most Air Force installations (see Table 1).

(3) Prepare a 4-hectare (ha.) transparent grid at 1:24,000 for base map overlay with alignment to the Universal Transverse Mercator (UTM) coordinate system. Trace 1-km grid intersection points from base map, transfer them to scribe film, interpolate 4-ha grid intersection points, and scribe grid lines connecting these points. Make a contact film positive from the scribe film using a high-contrast photographic film. The grid overlay does not have to be as large as the base map since it can be progressively moved during interpretation. It should be large enough to register on the 1-km tick marks on opposite sides of an individual quad sheet, so its minimum size is about 12 inches by 18 inches.

(4) Accomplish PI by using a zoom transfer scope. An aircraft photographic image on an easel is optically superimposed on a "sandwich" consisting of the base map (or individual quad sheets from the base map) overlaid by the grid overlay, overlaid by a working overlay (polyester drafting film with a matte surface on one side that accepts pencil). Information is recorded by numerically coding each 4-ha cell on the working overlay, according to its interpreted land use/cover class. In this study, the interpretation was limited to the area of the AICUZ, i.e., the $65L_{dn}$ contours before and after realignment, which were traced on the working overlay. Because of the limited working space under the zoom

TABLE 1. LAND USE/COVER CLASSES FOR MANUAL PI

Designation	Standard Land Use Coding Manual (SLUCM) Classification
	Residential
11	11. single and two family
12	12. multi family
14	14. mobile homes
15	15. transient lodging
19	19. rural residential (low density untracted)
	Industrial and Manufacturing
20A	21, 23, 25, 27, 34, 35 (light industry)*
20B	22, 24, 26, 32, 33 (heavy industry)*
	28, 29, 31 (special, petrochemical and refining)*
	Transportation and Utilities
41	41. RR
43	43. airport, AFB
45	45. highway and street ROW
48	48. utilities
	Commercial and Professional Services
50A	53-64 (shopping center)*
50B	53-63 (strip commercial)
50C	53-64 (CBD)*
	Other Services
65	65. medical/hospital
68	68. educational
69	69. church
624	624. cemetery
675	675. military base development (excluding housing)
	Public Recreation
72	73. public assembly -spectator sports, concerts, theater, civic center
741	741. golf course, riding stable, skating rink, tennis, bowling, skiing
743	743-44. water based rec., beach, marina
75	75. resorts and group camps
761	761. playgrounds and local parks
762	762. regional parks (scenic)

TABLE 1. LAND USE/COVER CLASSES FOR MANUAL PI (CONCLUDED)

Designation	SLUCM Classification	
	Resource Production and Open Space	
81A	811-814.	crop land .
81B	815-816.	livestock, pasture, grazing land
83A	83.	mature conifer forest
83B	83	clear cut and conifer regrowth
83C	83	mixed and deciduous forest
85	85.	mining
91	91.	idle land (non-forested)
93	93.	water and wetland
95	95.	under construction
99	99.	undeveloped land, other uses: e.g. Fort Lewis training ground, which also could be class 6759

* These distinctions and terms are not used by SLUCM.

transfer scope, it was more convenient to use individual quad sheets as a temporary map base (rather than the entire base map), with working overlays of the same size, from which information could be transferred later to the full-size final overlay.

(5) Conduct a ground truth field check of the AICUZ area to verify interpretation and resolve problems or questions encountered. Document field check with ground photography. (See Section IV, Paragraph 1j, Ground Truth Requirements.)

(6) Prepare the final land use overlay on stable, transparent drafting film. Outline (delineate) homogeneous land use/cover areas identified on the working overlays, i.e., the boundaries of individual grid cells or contiguous groups of grid cells assigned the same classification.

(7) Superimpose final land use and L_{dn} contours and APZs, before and after realignment. Using an electronic planimeter, measure the area of each land use/cover class within each CUD as defined by the L_{dn} contours and APZ's (before and after realignment). Referring to the definition adopted for each land use/cover class in Paragraph 1.b.(2) of this section, determine its compatibility or incompatibility within each CUD.

(8) Prepare a tabulation, before and after realignment, of the area in hectares of each land use/cover class within each CUD and its percentage of the CUD area, indicating its compatibility or incompatibility.

(9) Prepare an impact overlay showing incompatible land use areas. Use a press-on pattern with transparent backing applied to the transparent overlay sheet.

c. Information Products

(1) Product Formats

Information products from the PI method for each scenario consisted of the base map, the final land use overlay, the impact overlay, and the tabulations of land use/cover hectarages and percentages within each CUD.

(2) Classification Characteristics and Detail

The tabulations are also indicative of the level of detail of land use/cover classification achieved by the PI method, an important criterion of performance. For the McChord AFB AICUZ, 25 classes were observed; for the Fairchild AFB AICUZ, 29 classes.

The same classification scheme was employed in both cases. This scheme, shown in Table 1, was formulated prior to either interpretation, based on known capabilities of manual PI using high-altitude aircraft photography. The scheme contains a total of 35 classes, which can be related to SLUCM classes at the two-digit level, and in some cases at the three-digit level. It should be noted, however, that many individual two-digit SLUCM classes are not uniquely represented by PI classes. For example, SLUCM classes, 21, 23, 25, 27, 34 and 35 cannot be individually distinguished and are interpreted as one class, light industry (20A). The light versus heavy industry distinction is not made by SLUCM. Similarly, commercial retail trade classes and services, classes 53 through 64, are not interpretable in terms of the product or service-related distinctions used by SLUCM; however, they can be distinguished in terms of physical or morphological distinctions denoted by "shopping center" (50A), "strip commercial" (50B), and "CBD" (50C), characteristics not observed by SLUCM. Thus, those two-digit SLUCM classes which are not distinguished by PI are in almost every case identical in compatibility according to AICUZ guidelines. The new distinctions provided, although not now incorporated in AICUZ guidelines, may in some cases have value for defining differences in land use compatibility.

Where two or more SLUCM classes were subsumed by a PI land use/cover class, incompatibility was assumed to occur if any one of the SLUCM classes was incompatible according to AICUZ guidelines. Compatibilities of the 35 P.I. classes are shown in Table 2. This assumption, coupled with the 4-hectare aggregation, tends to raise the computed area of incompatibility above that which would be the case for an exact SLUCM classification on, say an ownership level. The extent of this difference is not known since a SLUCM classification is not available, and the comparison is probably moot since the latter is not a viable alternative because of the time and labor required. For the purpose of realignment evaluation, incompatibility estimates produced by PI are not expected to be excessively exaggerated, and the error is on the side of safety from an environmental planning standpoint.

d. Data Source Requirements

Many studies, including those cited above, have shown that color-infrared (CIR) aerial photography is superior to other types for interpretation of general land use and land cover because of its ability to clearly distinguish man-made and natural surface materials such as pavements, roof surfaces, vegetation, bare soil, and water, and to penetrate haze and air pollution.

For areas of typical AICUZ size, efficient manual PI requires image scales of at least 1:24,000, and preferably smaller. NASA high-altitude research aircraft photography at scales ranging from about 1:50,000 to 1:130,000 in 9.0-inch (22.9-cm) film positive format is ideal for most purposes. This photography, available from the USGS EROS Data Center, covers approximately half of the land area of the U.S., including most urban areas. However, this is not a dependable data source because the photography is not flown on a regular basis but in response to specific requests. Most existing coverage dates from 1970. Image quality is variable, especially prior to 1974. Where recent NASA aircraft coverage happens to exist for an AICUZ, it can be a suitable source. CIR and natural color photography flown in 1975 by a NASA Ames Research Center U-2 aircraft at 65,000 feet, with a Wild RC-10 camera, 6-inch (152-mm) lens, image scale 1:130,000, was used for the two scenarios tested in this study, (Reference 5).

TABLE 2. LAND USE/COVER COMPATIBILITY FOR PI METHOD

X-Compatible
Blank - Incompatible

LAND USE/ COVER	CZ	C. U. D. 1	2	3	4	5	6	7	8	9	10	11	12	13
11														
12														
14														
15														
19														
20A												X		X
20B												X		X
41		X	X	X	X	X	X	X	X	X	X	X	X	X
43	X	X	X	X	X	X	X	X	X	X	X	X	X	X
48		X	X	X	X	X	X	X	X	X	X	X	X	X
50A												X		X
50B												X		X
50C												X		X
65														
68														
69														
624		X	X	X	X	X	X	X	X	X	X	X	X	X
675												X		X
72														X
741						X						X		X
743						X						X		X
75													X	X
761											X	X	X	X
762											X	X	X	X
81A		X	X	X	X	X	X	X	X	X	X	X	X	X
81B				X	X	X		X		X	X	X	X	X
83A		X	X	X	X	X	X	X	X	X	X	X	X	X
83B		X	X	X	X	X	X	X	X	X	X	X	X	X
83C		X	X	X	X	X	X	X	X	X	X	X	X	X
85		X	X	X	X	X	X	X	X	X	X	X	X	X
91	X	X	X	X	X	X	X	X	X	X	X	X	X	X
93	X	X	X	X	X	X	X	X	X	X	X	X	X	X
95		X	X	X	X	X	X	X	X	X	X	X	X	X
99		X	X	X	X	X	X	X	X	X	X	X	X	X

The USGS EROS Data Center (EDC) at Sioux Falls, South Dakota, is the repository and outlet for NASA aircraft photography and USGS aerial mapping photography. EDC provides a computerized data search service which reports existing coverage for any specified geographic area. Other Federal agencies also acquire, archive, and disseminate aerial photography. These include the U.S. Department of Agriculture's Agricultural Stabilization and Conservation Service (ASCS) and Forest Service, the National Oceanic and Atmospheric Administration's Coastal Mapping Division, and branches of the Department of Defense such as the Defense Intelligence Agency and the Army Corps of Engineers. Some states acquire periodic air photo coverage in support of orthographic mapping programs. Current information about these data sources is provided by Kroeck (1976), (Reference 6).

A few private aerial photographic contractors have capability for obtaining high-altitude aerial photography in the scale range of 1:45,000 to 1:90,000 (obtainable by commercial Learjet with 12-inch or 6-inch cameras at service ceiling of 45,000 feet). These firms produce some of the photography for the Federal and state agencies mentioned.

Although all of the above are potential sources of data for mission realignment application, it is recommended that the Air Force consider internal means of providing aerial photographic source data on a timely basis and to uniform specifications optimally suited to this purpose.

Because of weather, low winter sun angle, and other operational constraints, it is difficult to obtain high quality air photo coverage on short notice, even if dedicated equipment is available. Therefore, the best approach might be a continuous photo mission program providing coverage of all Air Force installations at 1 to 2 year intervals, thereby maintaining a file of current data.

Whether or not the source is internal to the Air Force, it is essential that the necessary data be identified, acquired, and maintained in a file prior to any use for mission realignment evaluation. Ordering reproductions of existing coverage from another source or location can involve considerable delay (for example, turn-around time on regular priority orders of imagery from the EDC averages 3 to 4 weeks; "rush" orders at twice the cost are about twice as fast).

Finally, it should be noted that high-altitude aerial photographic coverage is a requirement for all three remote sensing methods tested in this study.

e. Data Costs

The cost of aerial photographic coverage could vary considerably depending on its source, whether that source was internal or external to the Air Force, and most importantly, whether new data is acquired from flights flown for this purpose (either contracted or flown by the Air Force) or whether existing coverage is obtained at the unit cost of reproduction.

This study provides a cost estimate only on the basis of the last type of data acquisition, purchase of image reproductions of existing NASA aircraft photography from EDC. EDC's unit price for first-generation duplicate, color film positives in 9.0-inch (22.9-cm) format is $15.00 (i.e., for one frame). This price is comparable to that of other Federal agencies for the same product. State and private commercial sources usually charge somewhat more for similar reproduction of existing photography.

Data costs for the aerial photography used in the PI method for each scenario were as follows:

Scenario	No. of Frames	Type	Cost
McChord AFB	2	9.0-inch color film positive	$30
Fairchild AFB	4	9.0-inch color film positive	$60

This coverage, at a scale of 1:130,000, required a minimum number of frames to cover the AICUZ in each case, with 60 percent forward overlap between frames. If only larger scale photography were available, the number of frames required would be proportionately greater.

Costs of supplementary, non-remote-sensor data, such as maps and ground photography are not considered here but are discussed later.

f. Equipment and Facilities

Essential equipment for efficient photo interpretive land use/cover includes an optical transfer device for image-to-map transfer of information. The sketchmaster devices used in the past for this purpose have been replaced by the zoom transfer scope which, through the use of a light beam splitter and zoom optics, optically superimposes any image and base map within a scale range of 1:10 or greater and in some cases also removes distortion in the image ("zoom transfer scope" has become a generic term for this type of instrument; however, this is the trade name of instruments produced by the Bausch and Lomb Company; similar instruments are produced by other manufacturers).

Also available now are stereoscopic models of the zoom transfer scope which allow superimposition of a stereo pair and a base map. This configuration may offer some advantage for PI; however, this would be slight in the case of general land use/cover interpretation from high-altitude aerial photography. Distortion-removal features, such as the optional anamorphic (image stretch) correction on the Bausch and Lomb Zoom Transfer Scope® are worthwhile for quickly achieving an accurate image-to-map fit. The instrument used in this study was Bausch and Lomb Model

ZT4 (Catalog No. 53-05-04-03), monoscopic with anamorphic correction and wide base, (Reference 7).

Other necessary equipment includes hand magnifiers in the range of 3X-20X, and one or more light tables. A light table with spool mounts is useful for initial inspection of film; however, this is not essential for most uses, since the zoom transfer scope requires cut-film imagery. A desirable but optional equipment item is a mirror stereoscope, preferably with zoom occulars, mounted on a light table. This can be useful in resolving occasional interpretation problems (such as distinguishing shadow from surface features) but not essential for this application. A stereoscopic zoom transfer scope would remove any need for a separate stereoscope.

An additional piece of equipment used in this study for all three remote sensing methods is an electronic planimeter-digitizer for measuring areas of compatible and incompatible land use in the CUDs from the final land use overlays. This measurement could be made with a dot grid or a simple mechanical planimeter; however, the electronic device was faster and more convenient to use. Its digitizing capabilities were not used for the PI method; less elaborate electronic planimeters without these capabilities are available.

Facilities should include a dedicated space with controlled lighting that could house this equipment, provide necessary work space for map production, insure secure storage of imagery in spooled and cut form, and provide for storage of maps and materials. A windowless room of 300 to 500 square feet, or more, would be ideal.

g. Capital, Maintenance, and Operational Costs of Equipment and Facilities

Estimated capital costs of the equipment described above are as follows:

(1)	monoscopic zoom transfer scope with recommended accessories	$ 6,370
(2)	stereoscopic zoom transfer scope, with recommended accessories	8,730
(3)	zoom stereoscope, light-table mounted with scanning stage (not required with stereoscopic zoom transfer scope)	2,085
(4)	light table, 36 inches by 48 inches by 34 inches high	560
(5)	hand magnifiers: 5x, 9x, 12x (two each)	84
(6)	4-drawer steel filing cabinet for storage of cut-film imagery	100

(7) electronic planimeter $ 4,500

Other items such as a horizontal file for storage of base maps, shelf storage for spooled imagery, storage for materials, drafting and work tables for map production are assumed to be already available and are not costed.

Totals:	Minimum system - (1), (4), (5), (6), (7)	$11,614
	Desirable system - (1), (3), (4), (5), (6), (7)	$13,699
	or (2), (4), (5), (6), (7)	$13,964

The above represents equipment for one PI unit. Depending on the type of inventory program adopted, the workload level could require one, two, or three of these units. If land use inventories are conducted for all Air Force installations on a periodic basis (say 50 or more installations per year), at least two PI units would be required for simultaneous work. If inventories are made only in response to specific realignment proposals, one unit would probably be sufficient.

Maintenance costs for this equipment would be minimal, consisting of an adjustment and cleaning of the zoom transfer scope every 3 years at a cost of perhaps $200. Adjustment and cleaning of a stereoscope would be required at longer intervals, if at all. Operational costs for the equipment itself would also be minimal, consisting mainly of electrical power for the lighting systems in the zoom transfer scope and light tables.

Captial or lease costs and maintenance costs for the physical space required to house PI facilities have not been estimated. It is assumed that this space would be available.

h. Materials and Production Costs

Both expendable and nonexpendable materials were required for the PI method. Some of these materials were common to all three methods since they related to the production of map products in the common format selected for the project (base map plus overlays).

Nonexpendable materials included drafting instruments and scribe pens used to prepare the base map grid, overlay mechanical pencils used to record information on the working overlays, and Rapidograph pens used to make the final land use overlays. Total cost of these nonexpendable materials was less than $100.

Expendable materials included scribe film and photographic film sheets used to make the base map grid overlays, matte polyester film for the working overlays, and transparent, stable base drafting film for final overlays, along with leads, ink, transfer lettering, and other materials.

USGS maps used for working purposes may also be considered materials, and although their reuse is possible, at least one working set is likely to be expended for each land use inventory effort for an AICUZ. In this study, the original intention was to acquire map separations of selected planimetric data from the USGS 7½-minute quandrangles covering each study area and then to mosaic these and have them reproduced on opaque stable base material to provide base maps for use with overlays produced by all three remote sensing methods, for both working and presentation purposes. However, since the separations could not be obtained from the Geological Survey in time for the project, standard paper quad sheets were used for mosaics and reproduced in this manner. For PI and recording of information on the zoom transfer scope, individual quad sheets were used as a temporary base, along with the movable grid overlay and working overlay.

The following are cost estimates for expendable materials that can be broken down for the two scenarios.

Item	McChord Quantity	McChord Cost	Fairchild Quantity	Fairchild Cost
USGS quandrangle maps - for base map production*(common to all three remote sensing methods)	4	$7.	14	$24
USGS quadrangle maps, individual quad sheets for PI	4	7	12	21
Scribe flim sheets, 12 inches by 18 inches**	1	1.	1	1.
Photographic film sheets, 12 inches by 18 inches***	1	2.	1	2.
Matte polyester film 36 inch width ****	4ft	6.	8ft	12.
Transparent drafting film, stable base 36 inch width *****	12ft	20.	24ft	40.
35-mm photographic film for ground truth photography (common to all three remote sensing methods) *****	2 36-frame rolls	8.	2 36-frame rolls	8.
TOTAL EXPENDABLE MATERIALS		$51.		$104.

* USGS quadrangles were mosaiced to form three base maps, as follows: McChord AFB: Steilacoom, Tacoma South, Ft Lewis, Spanaway; Fairchild AFB West: Rearday West, Readan East, Depp Creek, Edwall, Waukon, Medical Lake; Fairchild AFB East: Deep Creek, Airway Heights, Spokane Northwest, Medical Lake, Four Lakes, Spokane Southwest, Clayton, Deer Park. All are 7½-miniquads except for Clayton and Deer Park, 15 foot quads that were enlarged to 1:20,000 and mosaiced to the NE corner of Fairchild AFB East in commercial production of the base map (no 7½-minute quads were avail able for that area). All maps were ordered without vegetation overprint.

** Keuffel and Esser Scribe-Coat.

*** Graphic Arts high-contrast film (similar to Kodak Kodalith).

**** Keuffel and Esser Herculene matte film, 5 mil (matte on one surface).

***** Keufell and Esser Stabilene ink surface film, 3 mil.

****** Kodak Kodachrome 40, KPA 135-36.

Other expendable materials used which were not readily divisible between the two scenarios included transfer lettering, symbols, press-on patterns, registration pins and registration hole reinforcers, spray fixative, mechanical pencil lead, ink, drafting tape, erasers, cleaning fluid, cotton, and cloth gloves. Total cost of these materials was approximately $60 and would not have been substantially less had the work been done for only one scenario.

Production costs, as follows, consisted of expenditures for commercial services in connection with base map production and photoprocessing of the ground truth photography. Photo processing for preparation of the grid overlay was performed by the project staff; however, an estimated cost is shown.

Item	McChord	Fairchild
Base map production - photographic reproduction of USGS quad map mosaics on opaque stable base (common to all three remote sensing methods)	$65.	$130.
Developing film positives from scribe film for grid overlay	3.	3.
Photo processing of ground truth photography - mounted 35-mm slides	7.	7.
TOTAL PRODUCTION COSTS	$ 75.	$140.

i. **Analyst Skills**

Efficient and reliable PI requires an experienced interpreter who is familiar with patterns of land use/cover typically found in urban and regional settings throughout the United States and with their appearance or "signatures" on high-altitude, CIR photography. Some formal PI training as well as instruction in the theory and operation of photographic remote sensor systems is highly recommended background. Formal training specific to land use application is not widely available, except for a few specialized University programs such as that at the University of Washington, Department of Urban Planning. Such training might have to be provided internally. This should not be a formidable requirement, however, since these interpretive skills are largely self-learned. Following some training, a period of apprenticeship under an experienced interpreter would be desirable (see Organizational Requirements, Paragraph m).

j. Ground Truth Requirements

All methods of remote sensing analysis require ground verification in the form of field checks or surveys of some type. In some applications, the major purpose of field checks is to provide a basis for making accurate statements about the classification, usually through a randomized sample of ground observations that is used for statistical computation of classification accuracy. There are many complications involved in this approach, not the least of which is defining accuracy in the context of area-continuous, spatially-aggregated land use classification. No generally agreed upon definition or method exists.

More importantly, such an approach contributes nothing to improvement of the accuracy of the classification and hence, in many cases, is not a cost-effective expenditure of resources. Previous experience has shown that if like effort is devoted to investigating specific problems and uncertainties encountered in the classification, the benefits derived in terms of a corrected and improved classification can be substantial. This approach was followed in the study. A single "windshield" reconnaissance of 6 to 8 hours duration was made at each site following PI. These visits provided a qualitative verification of the general accuracy of the interpretations and resolved a small number of interpretation problems which in each case, were subsequently corrected in the classifications. Ground photography documented both the general site conditions observed within each AICUZ and the specific interpretation problems investigated.

Resources permitting, probably more effort should be devoted to ground truth data collection than was done in this study. A site visit prior to as well as following the interpretation can be helpful in acquainting the interpreter with characteristics of the study area, particularly if he has no prior familiarity. (In this study, the interpreter had visited and was somewhat familiar with the two sites.) Also, more ground photography than the 72 frames obtained for each site might be advantageous, although no strict rule can apply to this.

The field checks also provided the ground truth verification for the other two remote sensing methods except that, in this study, the verification for those methods was provided indirectly through the use of the PI as a control.

k. Labor Consumption

Labor consumption, in manhours, of each procedural task of the PI method is shown in Table 3. These figures are broken down by scenario and also by the professional level of the persons involved. Total labor consumption is estimated at 68 manhours for the McChord AFB scenario and 109 manhours for the Fairfield AFB scenario.

l. Turn Around Time

Table 3 also indicates the number of calendar days required for each activity. Because of the consecutive nature of most of these activities, the total time requirement was 49 and 55 days for the two scenarios. This represents the time from data request to completion of information products, including the time to process an EDC order through the investigator's organization and EDC under conditions of regular priority. If data are assumed to be already on file, and other preparatory tasks have been completed, turn around time drops to as low as 7 to 13 days.

m. Organizational Requirements

There are no special institutional requirements. However, it would be essential that some means be employed to maintain photo interpretive competence over time, that is, not upset by staff turnover. Since the substantial workload implied by PI application to all Air Force installations could require 3 to 4 full-time interpreters, or proportionately more staff members with partial assignment to this task, a designated PI unit maintained by periodic training and apprenticeship of new interpreters would probably be necessary.

2. EQUIDENSITOMETRIC PROCESSING OF AIRCRAFT OR LANDSAT IMAGERY

a. General

Equidensitometric image processing, also known as density slicing, is a technique for machine-aided interpretation of remote sensing data in hardcopy image form, such as aircraft photography or satellite imagery. Equidensitometric processing operates on the principle of level slicing, whereby the continuous light intensity range in an image, represented inversely by film emulsion density, is divided into a number of discrete intervals (often referred to as "levels," but actually interval ranges of intensity), and the image is reconstructed so that areas within each interval are depicted by a single density, symbol, or color. The reconstruction has the purpose of enhancing certain land cover features or "theme," to facilitate visual interpretation, or, with more effort, of delineating a series of themes in terms of intensity intervals which together consitute a land cover classification for the whole imaged area.

Equidensitometric processing systems now available and in use, including the system tested, do not analyze images spectrally. A vidicon camera or a microdensitometer is used to record intensity levels from a single image, whether black-and-white or color, across the entire spectral bandpass to which that image responds. The resulting signal, in either video or digital form, is processed according to photometric parameters defining the intensity intervals set by the analyst, and re-imaged on a cathode ray tube (CRT), lineprinter, electrostatic plotter, or other raster output device. Because the spectral data contained in a color image, or a set of multiband black-and-white images, cannot be utilized, land cover classification is possible only within certain limits. In most instances, there are some differing land cover types which cannot be distinguished by intensity alone, and if these land covers are spatially associated, they may not be individually identifiable.

The major advantage of these systems, apart from their use of common image data sources, is their rapid processing time (instantaneous with CRT display) which allows the analyst to freely interact with and manipulate the image until it represents desired information. Future systems, including some now under development, should have the capability for interactive processing of spectral data from image inputs, for example, by recording the separate intensity levels of each layer of color film, allowing the analyst to establish spectral signatures for land cover types, and producing rapidly displayed classifications (such systems now exist for interactive processing of Landsat digital data). Developments in this area may warrant attention.

b. Calspan EPIC/Spatial Data Systems Datacolor® System

The system used in this test was the most common type, a video system with color display. This commercially manufactured system, the Spatial Data Systems Inc. Datacolor® 703-32, is one component of the Experimental Photometric Interpretation Console (EPIC) developed by Calspan Corporation of Buffalo, New York, for the Rome Air Development Center, Griffis AFB. EPIC combines conventional PI hardware with photometric equipment designed to calibrate and measure intensity levels in film images. The latter equipment includes a stereoscope-mounted microdensitometer, digital photometer, and the Datacolor system, which can be calibrated to provide precise quantification of density ranges and intervals. EPIC has some capabilities for analyzing intensity differences among the layers of a color film and computing spectral signatures; however these techniques are designed primarily for target detection. There is no present capability for spectral classification of area-continuous land cover. Hence, the Datacolor® system was used for conventional equidensitometric image processing, independent of other EPIC components. Quantification of density ranges was useful mainly for documenting the displays produced.

The Datacolor® 703-32 system consists of the following components and functions:

(1) Light box and diffuser, providing a constant illumination of 1000 foot-candles, so that transmitted light is a true indication of film density.

TABLE 3. LABOR CONSUMPTION, PHOTO INTERPRETATION METHOD

Tasks	McChord AFB Man-Hours Principal Investigator	McChord AFB Man-Hours Research Associate	McChord AFB Man-Hours Cartographer	McChord AFB Calendar Days	Fairchild AFB Man-Hours Principal Investigator	Fairchild AFB Man-Hours Research Associate	Fairchild AFB Man-Hours Cartographer	Fairchild AFB Calendar Days
1. Selecting, ordering aircraft photography from EROS Data Center*	1	2		42**	1	2		42
2. Development of land use/cover classification scheme	3***	4***		1****	3***	4***		1**
3. Base map preparation and production*	1	1	5	6****	1	1	5	6**
4. Grid overlay preparation*			3	1****			3	1**
5. Photo Interpretation		12		2		25		4
6. Ground truth field checks	6*****	6*****		1	8*****	8*****		2

TABLE 3. LABOR CONSUMPTION, PHOTO INTERPRETATION METHOD (CONCLUDED)

Tasks	McChord AFB Man-Hours Principal Investigator	McChord AFB Man-Hours Research Associate	McChord AFB Man-Hours Cartographer	McChord AFB Calendar Days	Fairchild AFB Man-Hours Principal Investigator	Fairchild AFB Man-Hours Research Associate	Fairchild AFB Man-Hours Cartographer	Fairchild AFB Calendar Days
7. Preparation of final land use overlay			11	2			19	3
8. Planimeter measurement of land use areas		8		1		20		3
9. Tabulation of land use areas		2				2		
10. Preparation of impact overlays			3	1			7	1
TOTALS	11	35	22	49 (max) 7 (min)	13	62	34	55 (max) 13 (min)

* These tasks could all be performed prior to a request for mission realignment evaluation (basis for min. calendar-day estimate).

** Typical data acquisition from EDC should be less than the 42 days required in this study (see Paragraph 1d).

*** These figures are duplicated for the two scenarios, however only 7 manhours were expended to develop one classification used for both scenarios.

**** If prior ordering of data has not been done, these calendar day requirements are subsumed in the time required for data acquisition, because these tasks can be performed during that period.

***** Does not include travel time as labor.

(2) Monochrome TV camera mounted above light box, distance adjustable to suit images ranging from 35 mm to 12 inches by 16 inches.

(3) Color analyzer. Logarithmic amplifier converts the camera signal to a signal that is proportional to density (Density, D, is related to the transmittance (0 to 1) of the film by $D = \log \frac{1}{T}$; thus a transmittance of 1/100 corresponds to a density of 2). A high-speed analog-digital converter digitizes the density signal into from 1 to 32 levels, representing equal density intervals within each of four preset density ranges. A color generator generates a fixed proportion of red, green, and blue video signals for each of the 32 levels.

(4) Color TV display monitor. Displays the image, either in direct, black-and-white video, or in terms of color-assigned density intervals. The colors are produced by trios of red, green, and blue phosphor dots on the picture tube face, excited by beams from three electron guns, which are controlled by the red, green, and blue video signals from the color analyzer.

(5) Control console and color keyboard

(a) "D min" and "D max" controls for selecting the total density range of the analysis, from 1 to 2.25, and controls for calibrating these settings (using a step density tablet on the light box).

(b) "COLOR" selection keys for the 32 levels (intervals) of density. The colors representing these levels are assigned in a fixed order: four shades each of yellow, cyan, green, orange, magenta, violet, red, and blue (from low to high density, or from bright to dark portions of the image). The levels selected (any or all) equally divide the total density range, so the width of the levels depends on the number selected.

(c) "B/W" keys for each of the 32 levels, for display of the black-and-white video image instead of color for the portion of the display representing each level.

(d) "BLACK" keys for blacking out the portion of the display for any level.

(e) "AREA" keys for activating readout of the percentage of image area (display screen area) represented by any level.

(f) Digital readout. When not being used to indicate area, the digital readout indicates the density interval represented by each color level.

(g) Gamma Control Option. This feature, incorporated into the Color Analyzer Console, permits the total density range selected by the Dmin and Dmax controls to be divided into two, three, or four subranges of unequal width. The D_1, D_2, and D_3 controls are used to preset the limiting densities for these subranges within the total range set by Dmin and Dmax. Eight color levels, in sequence, are assigned to each subrange; those levels selected equally divide the subrange. The gamma controls non-linearize the density versus color curve, which would otherwise have constant slope over the total density range because of the equal width of color levels (density intervals). When the subranges are activated, the curve is segmented into two, three, or four linear curves of differing slopes.* The color levels can thus be made unequal. They can also be made unequal by assigning a different number of levels to each subrange. This provides increased capability for isolating land cover classes that may have wide or narrow reflectance ranges.

The Datacolor® system is similar to two other video equidensitometric systems previously used by the investigators.** Its advantages, compared to these other systems, are a more precise quantification of density levels (useful for documentation purposes), a larger number of density levels, and perhaps more importantly, a larger color selection which the latter provides. However, in common with the other systems, the Datacolor® lacks capability for random assignment of specified colors to density levels, which limits capability for map-like representation of land cover types. (The fixed color sequence can be altered by using patch cord plugs, but this is not an interactive capability.) A disadvantage of Datacolor® is its relatively inconvenient method of adjusting level widths using the gamma controls. It is difficult to alter the width of a single level, unless that level is assigned to an entire subrange. Also, it is difficult to visualize the color sequence and relative widths of the levels. The ISI-130 system allows unlimited adjustment of the width of any level, and provides a color bar on the display screen for visualization.

c. Procedure

The procedure followed for the equidensitometric method, for each scenario, was as follows:

(1) Prepare base map, as described under photo interpretation method, Section IV, Paragraph 1.b.(1).

(2) Select and acquire image data sources to be tested. These include multi-band and color aircraft (U-2) imagery: Vinten 70-mm, green, red, and IR bands (in black-and-white) and CIR, and RC-10 9.0-inch CIR

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* The slope of the color-density curve is analogous to the slope of the photographic density-log exposure curve, denoted by "gamma". Because the gamma of a photograph is not linear except near the center of the range, one state purpose of the gamma control option is to change the slope of the density-color curve to compensate for a photograph's non-linearity. This relates to precise photometric uses of the Datacolor® system not applicable to this study.

** The ISI - System 130, Interpretation Systems Incorporated, Lawrence , Kansas 66044, and the I^{2}S Digicol, International Imaging Systems Division, Stanford Technology Corporation, Sunnyvale, California 94086.

(For McChord) and natrual color (Fairchild); and Landsat imagery: 70-mm, bands 4, 5, 6, 7, and 7.3-inch color composites. (See "Data Source Requirements," Section IV, Paragraph e.)

(3) Prepare a transparent, distortion-compensated, 10-km UTM grid overlay for each image to be tested, as a means of geographically locating land cover features appearing in the Datacolor® density level displays on the color monitor screen. Delineate control points consisting of 10-km UTM grid line intersections on a base map overlay. Identify these points on each image and delineate them on an image overlay. Transfer points to scribe film, scribe grid lines connecting points, and make film positive to use as a grid overlay for each image.

(4) Equidensitometric process on Datacolor® 703-32 system. Each type of imagery in the set selected for a scenario was tested on the system, starting with Landsat 70-mm separate bands, Landsat color composite, U-2 Vinten separate bands, Vinten CIR, and RC-10 CIR or natural color. Aircraft coverage required use of two or more frames to cover the study areas; however extension of the analysis to adjacent frames was done only for imagery that showed promising results.

The general procedure for processing an image is as follows:

(a) Set-up, involving alignment of the image on the light box, with reference to direct video display on the monitor, to frame desired area of image for analysis. Focusing of the f-stop on the TV camera lens; adjustment of display monitor brightness and contrast.

(b) Determine the total density range of the image, by introducing one color (one level or density interval) for the entire range, and manipulating the Dmin and Dmax controls. This can be done in several ways. Dmin can be set at 0, and Dmax turned from 0 toward 2.25, stopping at indents for each density interval of 0.15. The point at which color first appears on the screen, and the point at which the screen is filled in with color, indicate the limits of the range. The same can be accomplished by working backward, with Dmax set at 2.25 and Dmin stepped back from 2.25 toward 0, or the two controls can be moved in unison, with Dmax set 0.15 ahead of Dmin. In this case, the screen never fills with color, but areas of color appear corresponding to each density interval.

(c) When the total density range is established, with Dmin and Dmax set accordingly, introduce more color levels to increasingly divide the range. This gives an indication of how much density-related information exists in the image; beyond a certain number of levels, no useful information is added. Also, as levels are added, the analyst watches for desired distinctions between land cover features. It is usually not possible with any number of equal levels to achieve all the desired distinctions at the same time, with color boundaries falling at correct locations. However, most of the distinctions that can be achieved will appear, and disappear, as levels are added.

(d) Then use gamma controls to widen or narrow certain levels or groups of levels to distinguish as many land cover types of interest as possible and to delineate their boundaries as accurately as possible. Attention may focus on one cover type or distinction at a time, but as each new distinction is addressed, care must be taken to preserve information already delineated.

At this point, the method cannot be set forth in precise terms. It is largely a trial and error process, with a deliberate, but not entirely fixed objective. It was not possible to apply a specific land use classification and obtain this as the result. In each case, the best possible representation of general land use/cover types was sought, in terms of detail (number of types) and location of boundaries, but the result varied considerably form image to image.

Also, it is important to remember that this process cannot really be described as automated data processing or classification. Rather, it is machine-aided interpretation and representation. PI, of the video display, the density display, and of hardcopy imagery inspected off the system, guides the maniulation of color-assigned density levels. Although the level slicing to some degree aids interpretation through a form of image enhancement, the objective is largely to replicate, or illustrate, what has already been photo interpreted, and thereby produce an "instant", map-like information product.

(e) Refine the display representation concentrating on the selection of colors to legibly and logically "paint" land cover types. Since random color assignment is not possible with the Datacolor®, this coloring step is not entirely separable from the level manipulation. However, once a desired level configuration is achieved, some capability remains to change colors, or shades of colors, or to black out colors, and thereby improve the representation without drastically affecting the configuration.

(f) Document the best result achievable for each image. Record the settings of the TV camera f-stop, the Dmin and Dmax controls, the calibration controls, and the gamma controls (if activated). Record the color levels used, by number. Photograph the display from the monitor screen on 35-mm color slide film; record camera settings.

All of the above steps require anywhere from 15 minutes to 1½ hours per image. If it should be decided to extend an analysis to an adjacent frame of aircraft coverage of the same type, all settings would be left alone until that image was in place and aligned. Adjustments would then be made as necessary, to produce a representation consistent with the previous one.

(5) Select preferred equidensitometric products, i.e., photographs of selected level displays, based on comparison with the manual PI and ground truth.

(6) Obtain 8 inch by 10 inch color print enlargements of selected products.

(7) Align each color print to base map on zoom transfer scope using the 10-km grid lines appearing in the display. Transfer boundaries of density levels to working overlay and assign symbols for land cover classes. In most cases this involved tracing all the density levels represented by colors in the display. In a few cases, certain density levels were combined or deleted. (These decisions, and the land cover class assignment, were made largely during the image processing, and recorded in a log). For some of the data transfer, it was found easier to hang the base map and overlay on a wall and project the original color slide of the display on to it, using a slide projector with zoom lens. By adjusting the projection angle, it was possible to obtain an adequate superimposition in most cases. This method permitted work over the whole map surface at one time, avoiding the several realignments necessary with the zoom transfer scope. A few of the displays, however, exhibited marked scale difference in x versus y directions, which could only be adequately corrected using the anamorphic correction on the zoom transfer scope.

(8) Prepare final land use overlay on stable, transparent drafting film.

(9) Superimpose final land use and L_{dn} contours and APZ's, after realignment. Planimeter areas of land use/cover classes within each CUD, and determine compatibility or incompatibility.

(10) Prepare tabulation of area in hectares of each land use/ cover class within each CUD and percentage of CUD area, indicating its compatibility or incompatibility. Total these areas for each CUD and for entire AICUZ.

(11) Prepare impact overlay showing incompatible land use areas.

d. Information Products

(1) Product Formats

Information products, for the McChord scenario, consisted of the base map, the final land use overlay, the impact overlay, and the tabulation of land use areas, by CUD, for the after realignment case. For the Fairchild scenario, the selected density displays did not cover the entire AICUZ, so a land use overlay was prepared only for two 10-km-square grids within the AICUZ, on the Fairchild West base map. Consequently, no area measurement or tabulation was prepared for the Fairchild scenario.

The colored density displays may also be considered an intermediate information product. The selected displays are listed in Table 4.

(2) Classification Characteristics and Detail

TABLE 4. SELECTED EQUIDENSITOMETRIC PRODUCTS (DENSITY LEVEL DISPLAYS)

McChord AFB*

	Area Covered	Image Source	D Min	D Max	D_1	D_2	D_3	No. Levels	Colors
1.	McChord & North	U-2 Vinten Red Band, 1975	0.3	2.1	0.6	1.5	off	23	2-16, 25-32
2.	McChord & South	U-2 Vinten Red Band, 1975	0.3	2.1	0.6	1.5	off	23	2-16, 25-32
3.	McChord & North	Landsat 70 mm Band 5, 1974	0.15	1.65	off	0.75	0.75	22	2-17, 27-32
4.	McChord & South		0.15	1.2	off	0.75		24	2-17, 25-31

Fairchild AFB

	Area Covered	Image Source	D Min	D Max	D_1	D_2	D_3	No. Levels	Colors
1.	Fairchild AFB East to Spokane Int'l	U-2 Vinten CIR, 1975	0.3	1.65	off	0.45	off	23	3-10,17-19,2 32,11-16(B/W 20,22(B/W)
2.	Fairchild AFB West to Medical Lake-Reardon	U-2 Vinten CIR, 1975	0.3	1.65	0.6	off	off	7	4,7,12,16,20 28, 29
3.	West of Medical Lake-Reardon	U-2 Vinten CIR, 1975	0.3	1.05	0.6	off	off	7	4,7,12,16,20 28,29

*Note: The U-2 Vinten and Landsat derived products for McChord were very similar in land cover representation. The Landsat products were originally selected for land use mapping in preference to the U-2 products because of some level distortion caused by vignetting in the latter. It was then found that the greater width of the grid lines in the Landsat products (the result of greater enlargement) obscured important detail, because of unfortunate coincidence with the McChord runway alignment. For this reason, the U-2 Vinten products were finally used to prepare the land use overlay.

Table 5 shows the land use/cover classification achieved with the equidensitometric products for McChord and the CUD compatibility defined for each class. Although 23 density levels and colors were used, only five land use/cover groups useful for AICUZ compatibility analysis were distinguished and mapped on the land use overlay.

The boundaries of these broad land use/cover classes appear to be reasonably accurate, based on comparison with manual PI. Major distinctions are made between land uses representing daytime and night time population and between areas of high and low residential density. However, several land uses of differing compatibility as defined in AICUZ guidelines are subsumed within each class. Since the incompatible uses are governing, the definitions of compatibility or incompatibility that must be adopted for these broad classes necessarily produce a significant overestimation of incompatible area, as seen by comparing the McChord tabulations for the equidensitometric and PI methods.

Although the McChord product would conceivably have some value for realignment application, it should be noted that this was the best product achieved out of 28 displays produced for the two scenarios. Although the test produced findings useful for obtaining optimum results, it is uncertain whether even this level of classification could be consistently produced for many Air Force installations. Regional environmental characteristics appear to be a critical factor in some instances for identification of key land uses. For example, when surrounded by dry-land grain fields, residential land use in the vicinity of Fairchild AFB was poorly distinguished, and in some cases not at all, due to similar total reflectance. This was not a problem in the McChord area, where residen tial land use was surrounded by forest, pasture, or more intensive land uses of lower or higher reflectance.

e. Data Source Requirements

The test did not produce definitive results with respect to the comparative effectiveness of aircraft and Landsat imagery for equidensito metric analysis. Aircraft imagery, because of higher resolution, in most cases did produce land use/cover information that was more detailed spatially. However, this difference was less than expected from the difference in image resolution. There was little observable difference in image resolution. There was little observable difference in density-related information detail (i.e., number of density levels relatable to land use/ cover types). The band 5 (red band) image of McChord produced almost exactly the same classification as the red band U-2 Vinten image of similar contrast.

Spectral type appeared to be a more decisive factor than platform. Whether aircraft or Landsat, imagery with greater contrast and dynamic range, such as red band and CIR, produced better results than blue band, IR bands, or natural color.

TABLE 5. LAND USE/COVER CLASSES AND COMPATIBILITY FOR EQUIDENSITOMETRIC METHOD, MCCHORD AFB

Density Levels/ Colors	Major Color Group	Land Use/Cover Class	Map Designation (corresponding SLUCM codes)	CUD Compatibility
2	(blacked out)	AFB structures	675	11, 13
3, 4	yellow	commercial, industrial pavement	20-50	11, 13
5-8	cyan	residential	10	none
9-10	green	pasture, rural residential	19	none
13-17	orange	forest	83	all except CZ
25-28	-	-	-	all
29-32	blue	water	-	all

* Negligible area appeared in these levels.
** Water class (SLUCM 93) appeared in image but was not present within ATCUZ area, and hence was not mapped.

There were disadvantages to aircraft imagery not shared by Landsat. Chief among these was the density level distortion caused by edge fall-off (vignetting). Another major disadvantage was the need to use more than one frame of aircraft imagery to cover an AICUZ, with consequent differences in density displays from which information had to be combined. Neither scenario required more than one frame of Landsat coverage (the north and south Landsat displays for McChord were taken from the same image).

Some of these problems with aircraft imagery could probably be removed if flights were tailored specifically to this application, e.g., use of cameras with antivignetting filters and aligning flight lines and timing exposures so as to cover the AICUZ with a minimum number of frames. However, in view of the information deficiencies observed in the equidensitometric products, it is doubtful that any investment by the Air Force in aerial photographic data collection could be justified on the basis of this method alone. If equidensitometric processing is only an adjunct to PI, then some consideration might be given to these requirements in specifying air photo coverage.

Non-Air Force sources of aerial photography were covered in Section IV, Paragraph 1.d. The sole source for Landsat imagery is the EROS Data Center.

f. Data Costs

Table 6 lists the imagery used in this study for the equidensitometric method and its cost, purchased from EDC. Of course this was a comparative test of different types of imagery, so much more coverage was used than would be needed operationally. The imagery required to produce the selected equidensitometric products consisted of the following:

McChord AFB

Type	No. Frames	Cost ea.	Total
U-2 Vinten 70-mm, b/w film positive	2	$ 5.00	$10.00
Landsat 70-mm, b/w film positive	1	8.00	8.00

Fairchild AFB

Type	No. Frames	Cost ea.	Total
U-2 Vinten 50-mm, CIR film positive	4	$10.00	$40.00

TABLE 6. IMAGERY TESTED FOR THE EQUIDENSITOMETRIC METHOD

Aircraft Photography (NASA-ARC Research)

Site	Date	Flight	Accession	Camera/Type	Scale	Frames	Quan	Unit	Tot
Fairchild AFB	9/9/75	75-155	022114	Vinten 70mm B/W Green Band	1:450,000	0044-0049	6	$ 3.	$ 1
Fairchild AFB	9/9/75	75-155	02215	Vinten 70mm B/W red Band	1:450,000	0044-0049	6	3.	1
Fairchild AFB	9/9/75	75-155	02216	Vinten 70mm B/W IR Band	1:450,000	0044-0049	6	3.	1
Fairchild AFB	9/9/75	75-155	02217	Vinten 70mm CIR	1:450,000	0044-0049	6	10.	6
Fairchild AFB	9/9/75	75-155	02218	RC-10 9.0-inch CIR*	1:130,000	4184,4185, 4187,4189	4	15.	6
McChord AFB	9/4/75	75-153	02209	Vinten 70mm B/W Green Band	1:450,000	0072-0075	4	3.	1
McChord AFB	9/4/75	75-153	02210	Vinten 70mm B/W Red Band	1:450,000	0072-0075	4	3.	1
McChord AFB	9/4/75	75-153	02211	Vinten 70mm B/W IR Band	1:450,000	0072-0075	4	3.	1
McChord AFB	9/4/75	75-153	02212	Vinten 70mm CIR	1:450,000	0072-0075	4	10.	4
McChord AFB	9/4/75	75-153	02213	RC-10 9.0-inch CIR	1:130,000	4089,4090	2	15.	3

Landsat Imagery

Site	Date	Scene ID	Type	Bands	Scale	Quan	Unit	Tot
Fairchild AFB	7/31/76	8255617495	70-mm B/W Pos.	4,5,6,7	1:30,369,000	4	$ 8.	$ 3
Fairchild AFB	7/31/76	8255617495	70-mm B/W Neg.	4,5,6,7	1:3,369,000	4	10.	4
Fairchild AFB	7/31/76	8255617495	9.0-inch CIR	Color Composite	1:1,000,000	1	15.	1
McChord AFB	9/6/75	8514018050	70-mm B/W Ps.	4,5,6,7	1:3,369,000	4	8.	3
McChord AFB	9/6/75	8514018050	70-mm B/W Neg.	4,5,6,7	1:3,369,000	4	10.	4
McChord AFB	9/6/75	8514018050	9.0-inch CR	Color Composite	1:1,000,000	4	15.	1
McChord AFB	6/13/74	8169018245	70-mm B/W Pos	4,5,6,7	1:3,369,000	4	8.	3
								$48

* Note, because this imagery was purchased on a priority service basis to allow an early start on photo interpretations, the actual price paid was three times this.

g. Equipment and Facilities, Costs

The equidensitometric method requires the full set of PI equipment described in Section IV, Paragraph 1.f, and the electronic planimeter, in addition to an equidensitometric image processing system. Several types and models of systems are commercially available, some with optional packages that offer additional functions not used in this study, e.g., point densitometers, density profilers with XYZ display, movable area framers. The cost estimation below assumes a basic video system with capabilities similar to the Datacolor® 703-32.

Photo interpretation unit, including planimeter ("minimum system" as costed in Section IV, Paragraph 1.g)	$11,614
Basic video equidensitometric system including TV camera and mount, bellows lens assembly, light box, image analyzer module, color display* monitor, on-site installation.	$21,000
TOTAL CAPITAL COST	$32,614

Operational cost of an equidensitometric system is limited to power consumption. No figure is available for maintenance costs, possibly as high as a few hundred dollars per year.

h. Materials and Production Costs

Nonexpendable and expendable materials required are approximately the same as for the PI method. Materials for base maps, working and final land use overlays, and impact overlays are the same. In lieu of materials for a base map grid overlay, scribe film and photographic film sheets are required for the image grid overlays. Thirty-five milimeter film is required for photographing the density displays, in addition to ground truth photography.

i. Analyst Skills

The same PI skills required for the PI method are required for the equidensitometric method. Expertise in interactive equidensitometric image processing builds on photo interpretive skills and would be acquired mainly through practice. Basic instruction in the use of the equipment

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* Reference: ISI System 130, less XYZ display monitor, Interpretation Systems Incorporated, Lawrence, Kansas 66044, February 1975 price list.

Item	McChord Quantity	McChord Cost	Fairchild Quantity	Fairchild Cost
USGS quadrangle maps for base map production (common to all three remote sensing methods)	4	$ 7.	14	$ 24.
Scribe film sheets, 12 inches by 18 inches	2	2.	4	4.
Photographic film sheets, 12 inches by 18 inches	4	8.	8	16.
Matte polyester film, 36 inch width	4 ft	6.	8 ft	12.
Transparent drafting film, stable base, 36 inch width	12 ft	20.	24 ft	40.
35-mm photographic film for photographing density displays. 36-frame rolls	1	8.	2	8.
35-mm photographic film for ground truth photography (common to all three methods)	2	8	2	8.
TOTAL EXPENDABLE MATERIALS		$ 55.		$112.

Production costs for commercial services were as follows:

Item	McChord	Fairchild
Base map production (common to all three methods)	$65.	$130
Developing film positives from scribe film for image grid overlays	6.	12.
Photo processing of 35-mm slides of density displays	4.	8.
Color prints, 8 inches by 10 inches, from slides of density displays	15.	22.
Photo processing of ground truth photography - 35mm slides	7.	7.
TOTAL PRODUCTION COSTS (COMMERCIAL SERVICES)	$97.	$179.

and observation of its use by an experienced analyst are probably the only specific training that a prospective analyst could receive; however, this could be part of a broader training program in PI as discussed in Section IV, Paragraphs 1i and 1m.

j. Ground Truth Requirements

Same as for PI method.

k. Labor Consumption

Labor consumption, in manhours, of each procedural task of the equidensitometric method is shown in Table 7. Total labor consumption was estimated at 72 manhours for the McChord scenario and 83 manhours for the Fairchild scenario.

l. Turn Around Time

Table 7 also estimates calendar days for activities. A total time requirement of 50 to 52 days was observed for turn around from data request to completion of information products, including the time to process a regular-priority EDC order. If data are assumed to be already on file, and other preparatory tasks have been completed, turn around time drops to as low as 8 to 10 days.

m. Organizational Requirements

No special institutional requirements. Comments for PI method, Section IV, Paragraph 1m, apply.

3. STATISTICAL ANALYSIS OF LANDSAT DIGITAL DATA

a. General

This relatively new method of remote sensing analysis is based on computer processing of Landsat Multispectral Scanner (MSS) data in digital form. These data consist of numerical reflectance values in four spectral bands (green, red, and two IR bands) for picture elements, or pixels which correspond to 56- by 79-meter (0.44-hectare) areas on the ground. As a Landsat satellite circles the earth, it scans a 185-km-wide swath every 0.07 second, collecting data for six rows of 3,240 pixels. Of these rows, 2,340 make up a Landsat "scene," 185-km square and containing 7.6 million pixels. The reflectance data for each band for each pixel are encoded as a six-bit digital word representing a reflectance value from 0 to 127, except for the fourth band (band 7), where the range is 0 to 63.

TABLE 7. LABOR CONSUMPTION, EQUIDENSITOMETRIC METHOD

McChord AFB

Tasks	Manhours: Principal Investigator	Associate Investigator	Research Associate	Cartographer	Calendar Days
1. Selecting, ordering aircraft photography from EROS Data Center*	1		2		42
2. Base map preparation and production*	1		1	5	6**
3. Image grid overlay preparation*				20	3
4. Equidensitometric processing	7	7			2***
5. Transfer land use to working overlay		1	3		1
6. Ground truth field checks	6****		6****		
7. Prepare final land use overlay				4	1
8. Planimeter measurement of land use areas			4		1
9. Tabulation of land use areas			2		
10. Preparation of impact overlays				2	1
TOTALS	15	8	18	31	52(max) 10(min)

* These tasks could all be performed prior to a request for mission evaluation (basis for minimum calendar-day estimate).

** If prior ordering of data has not been done, this calendar day requirement is subsumed in the time required for data acquisition, because this task can be performed during that period.

*** Travel time (to Calspan, Buffalo) is not included in calendar time.

**** Does not include travel time as labor.

TABLE 7. LABOR CONSUMPTION, EQUIDENSITOMETRIC METHOD (CONCLUDED)

Fairchild AFB

Tasks	Manhours: Principal Investigator	Associate Investigator	Research Associate	Cartographer	Calendar Days
1. Selecting, ordering aircraft photography from EROS Data Center*	1		2		42
2. Base map preparation and production*	1		1	5	6**
3. Image grid overlay preparation*				30	1
4. Equidensitometric processing	10	10			
5. Transfer land use to working overlay		1	3		
6. Ground truth field checks	8****		8****		2
7. Prepare final land use overlay				3	1
8. Planimeter measurement of land use areas					
9. Tabulation of land use areas					
10. Preparation of impact overlays					
TOTALS	20	11	14	38	50(max) 8(min)

The digital data for a Landsat scene are obtained from the USGS EDC on a computer compatible tape (CCT), which, with appropriate software for reformatting and geographic referencing or geometrically correcting the data, can be input to commonly used digital computers for analysis and display. In recent years, major emphasis has been given by NASA, universities, and private industry to the development of hardware and software for Landsat digital analysis; this includes both dedicated hardware/software systems and software packages for use on existing computer systems.

The simplest product from processing a Landsat CCT is a map-like print-out of pixel reflectance values in any one band, using over-struck lineprinter symbols to represent, perhaps 10 gray-scale levels (reflectance intervals), i.e., an equidensitometric display. If printed at eight lines per inch, this "gray-scale map" approximately overlays a USGS 1:24,000 quadrangle map.

More involved computer analysis is concerned with automated classification of pixel data into specified information categories. Classification is based on establishment of spectral signatures or clusters that can be related to categories of land cover or land use. These clusters may be visualized as regions in four-dimensional space corresponding to sets of pixel values in the four MSS spectral bands. Unsupervised-classification uses statistical logic to produce a set of distinct clusters from a random sample of pixels. In supervised classification, clusters are established by providing sets of pixel data known to represent desired cover categories based on ground truth (in fact, provided predominantly by interpretation of aircraft photography), a process known as training. Once established, the spectral clusters, as defined by their means and variances with respect to each spectral band, can be used to classify any or all of the pixels in a Landsat scene, though accurate classification may be limited to a locality for which the training data is valid--usually a specified "window" in a scene. This classification is based on a decision rule that determines unique category assignment; this algorithm, of which there are several types, is known as a classifier. Such classification of large amounts of pixel data is referred to as bulk processing, and is far more demanding of central processing unit (CPU) time than is the prior computational process of developing clusters and cluster statistics.

The results of classification are displayed in map form on output devices such as a lineprinter, an electrostatic plotter, or an electronic beam printer/film recorder. Tabular outputs can also be produced, for summarizing the pixel count or area of each class, within specified geographic areas. Map or tabular products may report each of the spectral classes in the classification, but more often, these are aggregated to produce a smaller number of information classes which are assigned land cover or land use designations.

Hardware/software systems for Landsat data processing differ primarily in the way an analyst interacts with the data in establishing the statistical basis for classification, through training and development of spectral clusters. Some of the early software programs designed for use with conventional computers used basically one input of training data, with no feedback for evaluation or other participation of the analyst until a bulk-classified product was produced. Contemporary systems are more interactive. The analyst is fed scattergrams of raw data, statistics and graphic plots for clusters, and test classifications of small areas. All this enables the analyst to constantly evaluate and intervene in the process of classification development, to achieve a more satisfactory result.

The basis for interactive processing is two-way communication via a terminal, with either lineprinter or CRT display of information. The most highly interactive systems (often with specially-programmed, dedicated mini-computers) employ color displays capable of representing the multispectral Landsat data in raw or classified image form and of representing the windows, or "masks," used to extract selected data for training, classification, or data summary.

All methods of Landsat digital analysis require that Landsat data be put into a geographic framework so that it can be interfaced with ground truth for training purposes and so that classified data output is locationally defined. An initial correction of CCT's performed prior to or as part of most software programs is designed to remove displacement of data lines caused by the earth's rotation beneath the satellite and skew caused by the satellite's advance during each scan sweep and to rotate the data to a north orientation (which it lacks because the sun-synchronous orbit is not a true polar orbit). With this correction, gray-scale line-printer can be produced that approximates a USGS map projection. However, a much better geographic reference is required, a transformation whereby each pixel can be associated with map coordinates, such as lat./long. or UTM coordinates. This requires the construction of a calibration file based on a set of control points where pixels can be identified with known coordinate locations.

Programs that employ an accurate calibration file allow the analyst to relate at all times to a map base, and to digitize from maps the boundaries of training areas, for input of ground truth, or windows, for extracting sets of raw data, or masks, for summary of classified data, and also to have the best possible fit of lineprinter and other output to the map base.

b. The ARPANET/EDITOR Program

Landsat-derived land use/cover classifications used for the McChord and Fairchild scenarios were produced with the use of several multiuser hardware systems via lineprinter terminals connected to the Advanced Research Projects Agency national computer network (ARPANET) of the U. S. Department of Defense. ARPANET is accessed at Terminal Input Point (TIP's) or by telephone lines connecting to a TIP.

The software package used was EDITOR, a multipurpose Landsat classification program developed at the University of Illinois at Urbana, Center for Advanced Computation (CAC).

During 1976-77, EDITOR was used to produce two land use/cover classifications of the Puget Sound region, from 1974 and 1975 Landsat-1 data, as part of the Central Puget Sound Urban Demonstration of the Pacific Northwest Land Resources Inventory Demonstration Project (LRIDP). The LRIDP is a joint effort of the Pacific Northwest Regional Commission, NASA-Ames Research Center, the U.S. Geological Survey and state and local governments. The Puget Sound EDITOR classifications were produced at NASA-Ames under the direction of USGS Geography Program staff assigned to provide technical support to LRIDP demonstrations. Representatives of 11 state and local agencies in the Puget Sound area also participated, along with the University of Washington Remote Sensing Applications Laboratory.

The 1975 classification was used as the source of Landsat-derived land use/cover information for the McChord scenario, as a test of the use of a previously-produced classification covering a large area and designed for multiple use, a type of information that may be widely available in the near future.

At the same time, the Puget Sound demonstration provided the inspiration for attempting a new EDITOR classification directed specifically at an AICUZ-mission realignment application. Support for this effort came from the NASA User Applications Program at Ames, in the form of a demonstration of ARPANET/EDITOR remote-access capabilities. Under this arrangement, the University of Washington Remote Sensing Applications Laboratory was able to produce an EDITOR classification of the Fairchild AFB area, using a terminal in the College of Architecture and Urban Planning's Computer Center to access ARPANET at the NASA-Ames TIP.

The use of ARPANET for EDITOR classification involves a number of processing steps and facilities. For the 1975 Puget Sound classification used for McChord AFB, the overall processing sequence was as follows:

(1) Reformatting a Landsat CCT at CAC, including removal of skew and rotation to north heading.

(2) Shipping the transformed tape to Bolt, Beranek and Newman (BBN), a commercial vendor of computer services in Boston, where it was mounted and run with the EDITOR software on a PDP-Tenex computer on command from the Ames terminal, for interactive processing leading to the development of classification statistics.

(3) On-line use of these statistics for bulk classification on the Ames Illiac IV/14-Tenex computer system, or off-line on a CDC-7600, to produce a classified data tape.

(4) Off-line use of the classified data tape to produce hardcopy output products such as lineprinter symbol maps. Dicomed film-recorder color codec maps, and tabular summaries.

(5) Other processing of the classified tape to geometrically correct the data to a UTM projection was done on ARPANET using an IBM 360-91 at the University of California at Los Angeles, for subsequent

production of precision color-coded maps on an Optronics laser-beam film recorder at the Jet Propulsion Laboratory (JPL) in Pasedena, California.

For the remote ARPANET demonstration used for Fairchild AFB, a different configuration was used. A transformed Landsat CCT was mounted at NASA-Ames and run with the EDITOR software on the Ames 14-Tenex, commanded by the University of Washington terminal. The 14-Tenex was also used to set up bulk jobs on the Illiac IV. Lineprinter maps and Dicomeds were produced off-line using these peripherals at Ames, and products were mailed to the University of Washington. As in the case of the Puget Sound classification at Ames, a digitizer was used in conjunction with the lineprinter terminal. The University digitizer, a Numonics 1224 volatile planimeter-digitizer, was of a different type than had been used previously with EDITOR; new software was written at CAC to allow direct data entry using this digitizer.

EDITOR itself is a highly flexible and interactive program incorporating a simple user language. The program includes a geographic calibration procedure, followed by an iterative process of training and cluster development by land cover groups, which incorporates elements of both supervised and unsupervised classification. Although EDITOR has not been adapted for use with a color display, it does provide many forms of graphic and statistical feedback to the analyst.

EDITOR has been used extensively by the U.S. Department of Agriculture for multi-state crop inventories, as well as by the USGS Geography Program for experimental application to the Land Use and Data Analysis (LUDA) program for national land use mapping. To serve these different purposes, there have been many changes and additions to the program, including alternate versions of several parts. The EDITOR software at Ames (known as AMESPNW EDITOR) differed in certain respects from the software at BBN (known as RAY EDITOR) which was used for the Puget Sound classification.

c. Procedure

Procedures followed for the digital analysis method differed at certain points for the two scenarios, because of the different ways the data were provided. Differing procedures for certain steps are noted.

(1) Prepare base map, as described under photo interpretation method, Section IV, 1.b.(1).

(2) Acquire aircraft and Landsat imagery from EDC.

(3) Acquire Landsat digital data (raw or pre-classified).

(a) For McChord: Acquire 1:24,000 lineprinter output from 1975 Puget Sound classification for McChord AFB window. This includes lineprinter showing all spectral classes and a specified grouping as land cover classes with printer symbols chosen for maximum legibility of homogenous units.

(b) For Fairchild: Identify suitable Lansat CCT. A suitable transformed tape was located at NASA-Ames, (AMESPNW Project). If it had not been available, a CCT would have to have been purchased at EDC and sent to the University of Illinois (CAC) for transformation.

(4) Data processing

(a) For McChord:

1. Outline polygons defining homogenous land use/ cover (four or more contiguous pixels) on lineprinter map with grouped classes.

2. Prepare final land use overlay on stable, transparent film by tracing polygons.

(b) For Fairchild:

1. Clip data from transformed tape, create data file.

2. Calibrate data file by selecting control points from 1:250,000 map; construct global calibration file.

3. Clip window corresponding to study area.

4. Print gray-scale maps of raw data from window.

5. Print histograms of raw data.

6. Print scattergrams of raw data.

7. Precise calibration of data, selecting precise control points from 1:24,000 map; create precise calibration file.

8. Select training fields, verify with aircraft imagery, transfer to maps.

9. Digitize training fields.

10. Pack files.

11. Cluster analysis, construct categorized files.

12. Statistical review of clusters.

13. Print scattergrams of categorized files.

14. Interpret and check with photos and maps.

15. Reiterate (j) through (n) or (h) through (n) as necessary.

16. Write final statistics file.

17. Submit bulk classification job.

18. Accomplish reclassification for smoothing.

19. Print land cover map (Lineprinter).

20. Produce color-coded maps (Dicomed color negatives, enlarged to produce color prints, 1:100,000, 1:24,000).

(5) Data Summary

(a) For McChord:

1. Superimpose final land use and L_{dn} contours and APZ's after realignment. Planimeter areas of land use/cover classes within each CUD, and determine compatibility or incompatibility.

2. Prepare tabulation of area in hectares of each land use/cover class within each CUD, and percentage of CUD area, indicating its compatibility or incompatibility. Total these areas for each CUD and for AICUZ.

(b) For Fairchild:

1. Digitize CUD's from 1:24,000 quadrangle maps. Each quad map is calibrated, the CUD polygons are digitized, a mask file and aggregation file are generated, separately for each map.

2. Display aggregation files. Printout tabulation of area in hectares of each land use/cover class within each CUD or portion of a CUD on each map.

3. Manually prepare a tabulation which presents areas and percentages for each CUD, indicating compatibility or incompatibility. Total these areas for each CUD and for AICUZ.

(6) Prepare impact overlay showing incompatible land use areas (McChord only).

(7) Prepare color-coded land use map, 1:24,000, with overlaid noise contours after realignment (Fairchild only).

d. Information Products

(1) Product Formats

Information products, for the McChord scenario, consisted of the base map, the final land use overlay, the impact overlay, and the tabulation of land use areas, by CUD, for the after realignment case. The lineprinter map with grouped, symbolized land cover classes (on which manual delineation of homogenous polygons was done) may be considered an intermediate information product.

Products for Fairchild consisted of the two-part base map, lineprinter map of the classification, and color-coded maps, 1:100,000 and 1:24,000, the latter with overlayed noise contours after realignment; also the tabulation of land use areas based on digitized mask files and aggregation files for CUD's.

(2) Classification Characteristics and Detail

Tables 7 and 8 show the land use/cover classes (grouped spectral classes) for McChord and Fairchild, their correspondence with SLUCM classes, and the CUD compatibility defined for each class.

The two classifications are very similar, despite the difference in environmental conditions. Thirteen land use/cover classes are distinguished for McChord, eleven for Fairchild. In each case, about half the classes represent open space categories that are compatible with all the CUD's, except for the incompatibility of crops and forest with the Clear Zone. Grass and pasture or range are classes that are compatible with several CUDs but not all. The remaining four or five general urban classes have to be defined as almost entirely incompatible.

Overall, these classifications achieve significantly greater differentiation of cover types than the equidensitometric products, but the advantage is mainly in the highly-compatible non-urban categories. Except for the addition of mobile homes, and wooded residential in the case of McChord, there is little more urban detail than in the best equidensitometric products.

Table 9 further illustrates the discrepancy between AICUZ classes and the Landsat-derived classes for McChord. The inability to distinguish commercial, industrial, and most institutional uses, or any of the two-digit SLUCM classes within these groups, limits assessment of compatibility to a broad level and produces overestimation of incompatible area compared to the PI method-43 percent of the McChord AICUZ, classified incompatible compared to 22 percent for PI. This overestimation is almost as large as that obvserved for the equidensitometric product (49 percent). The fine grain, or high level of spatial detail of the digital products compared to the other methods (0.44-ha pixels compared to 4-ha cells for PI) does not seem to counteract the overestimation of incompatibility.

None of this necessarily implies that the digital classifications are inaccurate. An accuracy test of the 1975 Puget Sound classification based on PI of a random sample of pixels yeilded a figure of 73 percent correct, which is fairly high for any type of land use map. The imprecision in compatibility measurement arises from the generality of the classification.

TABLE 8. LAND USE/COVER CLASSES AND COMPATIBILITY FOR DIGITAL ANALYSIS, MCCHORD AFB

Land Use/Cover Class	Map Designation (Corresponding to SLUCM codes)	CUD Compatibility
Water	93	all
Idle, barren	90	all
Scrub, clear cut	83B	all except CZ
Grass	741* 90**	5, 11, 13* all**
Pasture	81B	3,4,5,7,9-13
Crops	81A	all
Conifer	83A	all
Mixed deciduous	83C	all
Pavement	40	all
Mobile home	14	none
Residential	11	none
Wooded residential	19	none
Commercial/ industrial	20-50	11,13

*Northern half of AICUZ, grass designated golf course.
**Southern half of AICUZ, grass designated undeveloped.

TABLE 8. LAND USE/COVER CLASSES AND COMPATIBILITY FOR DIGITAL ANALYSIS, FAIRCHILD AFB (CONCLUDED)

Land Use/Cover Class	Corresponding SLUCM Code	CUD Compatibility
Residential	11	none
Mobile homes	14	none
Commercial/industrial	20-50	11,13
Pavement	40	all
Grass	70	4,5,10,11,12,13
Irrigation	81A	all except CZ
Crops	81A	all except CZ
Range	81B	3,4,5,7,9-13
Conifer/deciduous	83	all except CZ
Idle	90	all
Water	93	all

TABLE 9. ASSOCIATION OF AICUZ/SLUCM LAND USE CLASSES AND ARPANET/EDITOR LAND USE/COVER, MCCHORD AFB

General Land-Use	2-Digit	SLUCM* Description	1975 Land Cover Description	1975 Spectral Classes Number
Residential	11	Single and two family	Residential	9,15,16,18
	12	Multi-family	Residential	9,15,16,18
	14	Mobile homes	Mobile homes	30
	15	Transient lodging	Residential	9,15,16,18
	19	Rural residential(untracted)	Wooded Residential	19,35
Industrial and Manufacturing	21,23,25 27,34,35	Light industry	Commercial and Bright Commercial	4,8,12 17,23,25,38,43,44
	22,24,26 32,33,28	Heavy industry Special: petrochemical and refining	Commercial and Bright commercial	
Commercial and Professional Services	53-64	Shopping center	Commercial and Bright Commercial	4,8,12 17,23,25,38,43,44
	53-64	Strip commercial	Commercial and Bright Commercial	
	53-64	CBD		
Transportation and Utilities	41	Railroad		
	43	Airport, AFB	Pavement	13,41,42
	45	Highways and streets	Pavement	
	48	Utilities	None	
Other Services	65	Medical-hospital	None	
	68	Educational	None	
	69	Church	None	
	624	Cemetary	Grass	24,32
	625	Military base develop. (excluding housing)	None	

TABLE 9. ASSOCIATION AICUZ/SLUCM LAND USE CLASSES AND ARPANET/EDITOR LAND USE/COVER, MCCHORD AFB (CONCLUDED)

General Land-Use	2-Digit	SLUCM* Description	1975 Land Cover Description	1975 Spectral Classes Number
Public Recreation	72	Public assembly (Spectator sports, concerts, theater, civic center)	None	
	741	Golf course, riding stable, skating rink, tennis, bowling, skiing	None	
	743-4	Water based recreation (beach, marina)	None	
	75	Resorts and group camps	None	
	761	Playgrounds and local parks	Grass	
	762	Regional Parks (scenic)	Grass	24,32
Resource Production and Open Space	811-814	Cropland	Cropland	29,31,33,34
	815,816	Livestock, pasture, grazing land	Pasture	28
	83	Mature conifer forest	Old conifer	36,37
	83	Mixed and deciduous	Mixed forest	14,21
	83	Clear-cut and conifer regrowth	Clear-cut	47
			Regrowth	48
	85	Mining	Dark ground	5
			Barren ground	39
			Rock	49
	91	Idle land (nonforested)	None	
	93	Water and Wetland	Water, sed. water	1,2,3,6
			Wetlands	7,27
	95	Under construction	None	
	99	Undeveloped land-other uses		

*Standard Land Use Classification Manual

If the distinctions that are made in the Landsat digital classification, such as day versus night population, high versus low population density, grain fields, and others, are sufficient to make it a useful product for realignment evaluation, then there is indication that it can also be a reliable product. The similarity of the McChord and Fairchild classifications and the consistency of the 1974 and 1975 Puget Sound classifications indicate that digital analysis can produce consistent results, repeatedly, which was not the case with equidensitometric processing.

e. Data Source Requirements, Costs

The basic data requirement for digital analysis is the Landsat computer compatible tape (CCT). Landsat CCT's are produced by NASA at the Goddard Space Flight Center in Maryland, however Goddard is not the normal outlet. The primary distribution point is the USGS EDC. CCT's are also available through NOAA*. Direct purchase arrangements between NASA and USAF may be possible and could have the advantage of shortening the time from Landsat overflight to data availability for purchase, which is on the order fo 2 to 4 months for EDC.

A Landsat CCT covers an entire Landsat scene in four strips running north-south, of 810 columns by 2340 rows (lines)**. Under present rules, EDC will only sell CCT's covering whole scenes. The cost is $200 per CCT on a regular priority order, $600 on a rush order. Delivery time on a regular order is at least 6 weeks, or up to twice that required for imagery orders.

With the two present Landsat satellites, the average interval of possible coverage of any location is 9 days. However, depending on regional climatic conditions, CCT's may be available for anywhere from two to 25 cloud-free scenes per year for a given nominal scene area. The EDC geographic search service can be used to identify scenes within stated limits of cloud cover and quality level as they are received. Browse facilities at most USGS and NOAA offices provide viewing of 16-mm microfilms of band 5 images for all Landsat coverage for identifying suitable scenes. The Air Force may wish to acquire its own browse facility and be furnished with current microfilms and catalogs.

Options for CCT acquisition and usage via ARPANET are discussed under organizational requirements, Section IV, Paragraph 3.b.

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* National Oceanic and Atmospheric Administration, Satellite Data Services Branch, Suitland, Maryland 20233.

** CCT's are availabble in 7- and 9-track formats, with bit rates of 800 and 1600 b.p.i. ARPANET/EDITOR demonstrations have used 9-track, 1600 b.p.i.

Landsat digital analysis also requires high-altitude aircraft photography for training and verification. Although this is a secondary data source, requirements should be considered the same as for the PI method. In one respect they are more stringent, that being the date of air photo coverage, which should approximate as closely as possible the date of the Landsat data. A difference of a few months can produce errors in training data due to seasonal changes or rapid land use changes. This more stringent temporal requirement is less likely to be satisfied by existing aircraft coverage and may further necessitate securing special-purpose flights.

f. Equipment and Facilities, Costs

Digital analysis via ARPANET/EDITOR requires two basic, dedicated equipment items, a lineprinter terminal and a digitizer that can be used on-line with the terminal. Additional hardware not needed on a full-time basis includes output devices such as a high-speed, wide carriage line-printer, a flatbed plotter or an electrostatic printer-plotter, and a film recorder. Purchase of these peripherals is optional; their use is available on a service basis through ARPANET facilities or may be available within the Air Force.

The digital method also requires the full set of PI equipment described in Section IV, Paragraph 1f. Depending on the instrument, the on-line digitizer may incorporate the electronic planimeter functions (as was the case with the Numonics digitizer used in this study).*

The following are capital costs estimates for the basic equipment used in this study:

Lineprinter terminal**	$ 1,200
Digitizer-planimeter, volatile type, with rigid cursor assembly, keyboard, calculator module with digital readout.	4,500
Photo interpretation unit ("minimum system as in Section IV, Paragraph 1.g. less planimeter")	7,114
TOTAL CAPITAL COST	$12,814

* Reference: Numonics 1224 planimeter-digitizer. Numonics Corporation, North Wales, Pennsylvania 19454.

** Reference: General Electric Terminet 300. One of the faster, "silent" ink-jet terminals now available would be preferable.

This is the capital cost for one equipment set. As for the other remote sensing methods, two or three complete and functionally independent equipment sets may be required, depending on the workload and nature of the program.

Operational costs of this equipment, apart from power consumption, relate to the costs of using ARPANET, including the cost of a TIP, or of telephone data communication to a TIP (telephone charges or lease of a line) and any direct user charges for ARPANET use. The nature and amount of these costs would depend largely on the institutional arrangement for use of ARPANET. This study provides an estimate of the cost of commercial data communication via telephone line, which came to $696 (40 hours of connect time @ $0.29/minute, for two Fairchild AFB classifications and one smoothing reclassification). The project was charged $375 for 9 minutes of ARPANET sequence time, charged as a bundle cost of $2500/hour. There was no charge for ARPANET connect time itself nor for CPU time; these are not presently subject to user charges and were covered by the demonstration arrangement with NASA. A substantial additional cost was for voice telephone communication with individuals at NASA-Ames and CAC who provided guidance on the use of EDITOR. Most of this cost, as well as 4 hours of connect time in addition to the 40 hours mentioned above, were attributed to first-time learning by the investigators.

Maintenance costs for the terminal, digitizer, and photo interpretive equipment would be small, possibly $100 to 200 per year.

g. Materials and Production Costs

Nonexpendable and expendable materials required are similar to the other two remote sensing methods, and few of these materials are employed in the digital processing itself. Expendable materials were as follows:

Item	McChord Quantity	McChord Cost	Fairchild Quantity	Fairchild Cost
USGS quadrangle maps for base map production (common to all three remote sensing methods)	4	$ 7.	14	$24.
Additional set of USGS quad sheets for delineating and digitizing training fields	4	7.	14	21.
Transparent drafting film stable base, 36 inch width: For land use and impact overlays	12 ft	20.	-	-
For noise contour overlay	-	-	10 ft	18.

Item	McChord Quantity	McChord Cost	Fairchild Quantity	Fairchild Cost
Lineprinter paper, 12 inch width (for terminal)	-	-	100 yds	10.
Lineprinter paper, 18 inch width (for map output)	20 yds	3.	40 yds	6.
35-mm photographic film for ground truth photography (common to all three remote sensing methods). 36-frame rolls	2	8.	2	8.
TOTAL EXPENDABLE MATERIALS		$45.		$87.

Production costs for commercial services were as follows:

Item	McChord	Fairchild
Base map production (common to all three methods)	$65.	$130.
Production of print enlargements of color-coded maps, 1:250,000 and 1:100,000 (2 each)	-	300.
Photo processing of ground truth photography - 35-mm slides	7.	7.
TOTAL PRODUCTION COSTS (COMMERCIAL SERVICES)	$72.	$437.

h. Analyst Skills

In addition to photo interpretive skills equivalent to those required for the PI method, digital analysis requires both a conceptual understanding of the theory and process of Landsat computer-based spectral classification and specific working knowledge of the ARPANET system and EDITOR language/functions. Although on-the-job experience is ultimately important, this knowledge and these skills are not self-learned to the same extent as the partly intuitive skills involved in equidensitometric processing or PI They require intensive formal training of a magnitude probably inconvenient for the Air Force to handle internally, involving, for example, equipment dedicated to training purposes. A university might be well-suited for such a task, carried out through a specific training program probably a few weeks in duration, including both classroom instruction and "hands-on" laboratory experience. Photo interpretation and other required skills could also be incorporated. Although such a training program would presumably require direct support from USAF, it could be developed as part of a broader, University-based remote sensing training program such as that envisioned (and to be supported) by NASA under its Regional Apprlications Program.

i. Ground Truth Requirements

As emphasized earlier, interpretation of aircraft photography is considered the major form of ground truth for support of Landsat digital analysis; however, this PI should also be supported by some conventional field reconnaissance and checking. The orientation of ground observations may be slightly different from that employed in the PI method, since the object is not to verify or correct and area-continuous PI but rather to check some of the interpretation done for selection training areas and to gain a sense of whether these areas are representative of land use and cover over the study area.

j. Labor Consumption

Labor consumption, for the McChord AFB and Fairchild AFB scenarios, is shown in Table 10. Note how the tasks and time figures reflect the entirely different approaches taken with respect to these scenarios, i.e., the McChord study working with an existing EDITOR classification; the Fairchild study developing a new classification from scratch. The total labor requirement of 100 manhours estimated for the Fairchild effort compares to only 48 manhours for McChord.

For Fairchild, the labor consumed by on-line EDITOR data processing (work at the terminal, while connected) is an estimate of ample times for performing each task correctly the first time.

k. Turn Around Time

Table 10 also shows turn around times for the two scenarios, as a total of calendar days required for each task. As in the case of the other remote sensing methods, turn around time is reduced by more than half if data acquisition and other preliminary tasks are completed prior to analysis (the maximum and minimum figures for total calendar days).

An even greater difference in turn around times is observed between the approaches taken in the two scenarios. Where a basic Landsat classification has already been done, as in the case of McChord, turn around time is reduced to about one eighth of the time required for a new classification--as little as 5 days if the classified data (lineprinter map) have already been acquired and base map preparation has been completed.

TABLE 10. LABOR CONSUMPTION, DIGITAL ANALYSIS METHOD

McChord AFB

Tasks	Manhours Principal Investigator	Research Associate	Cartographer	Calendar Days
Acquire classified data, lineprinter; determine and specify land use/cover class groupings and line printer symbols (McChord only)*	2		2	7
Base map preparation and production*	1	1	5	6**
Delineation of polygons of homogeneous land use/cover on lineprinter map (McChord only)	1		20	3
Prepare final land use overlay (McChord only)			11	2
Tabulate land use areas (McChord)		2		
Prepare impact overlay (McChord)			3	
TOTALS	4	3	41	12(max) 5(min)

* These tasks could be performed prior to a request for mission realignment evaluation (basis for minimum calendar-day estimate).

** If data has not bee previously acquired, this calendar-day requirement is subsumed in the time required for data acquisition, since this task can be completed during that period.

TABLE 10. LABOR CONSUMPTION, DIGITAL ANALYSIS METHOD (CONCLUDED)

Fairchild AFB

Tasks	Manhours Principal Investigator	Research Associate	Cartographer	Calendar Days
Select and acquire computer compatible tapes (CCT's) (Fairchild only)*	1	2		42
Transform CCT's (Fairchild)*		1		14
Base map preparation and production*	1	1	5	6**
On-line EDITOR data processing (Fairchild only) to produce classification	16	10		14
Laboratory tasks associated with EDITOR processing, e.g., *training field selection* (Fairchild)***		48		7
Print land cover maps, lineprinter (Fairchild)				7
Prepare color-coded maps and enlargements (Fairchild)		1		14
Digitize CUDs, generate mask, aggregate, display aggregation files tabulating land use areas (Fairchild)	7	7		
TOTALS	25	50	5	98(max) 42(min)

1. Organizational Requirements

Implementation by the USAF of the digital analysis methods tested in this study would impose certain organizational requirements not attendant to the PI or equidensitometric methods. These requirements are in two areas: (1) external institutional and organizational requirements for utilizing the ARPANET system and EDITOR program, and (2) internal organization for conducting Landsat digital analysis to support mission realignment evaluation or other applications to AICUZ planning or environmental assessment.

There are several options for ARPANET use. For example, the Air Force could acquire its own Landsat CCT's from EDC (or possibly NASA-Goddard), send them to the University of Illinois (CAC) for transformation, and then send them to BBN or another point in the network to be run with the EDITOR software package. (This location might eventually be a USAF computational facility; in this case the main advantage in using the network would be for the bulk processing on Illiac.) BBN or another vendor might assume all these tasks, and the USAF would only conduct the interactive data processing from its terminal.

Internal organization would concern mainly the relationship between the Air Force command and the environmental planning office. As in the case of the other two remote sensing methods, it is assumed that a designated Air Force laboratory would have responsibility for the digital data processing and analysis leading to the production of a land use classification product for each AFB.

In the case of the PI and equidensitometric methods, the land use product took the form of a line-drawn map overlaying the base map of the AFB environs. Area measurements by CUD, tabulation of areas of compatible and incompatible land uses by CUD, and preparation of an impact overlay were also assumed to be performed by the designated laboratory. However, given capability for planimetric measurement, this work could also be done by the base command. In either case, the data analysts would have to visit the site to perform ground truth data collection.

With the digital methods there would be more options for dividing tasks between the designated laboratory and the base commands, if this were desirable for any reason (there is no technical reason for dividing the work, other than reducing the workload at the designated laboratory). The two major options are as follows:

(1) The designated laboratory would do the entire job. It would produce the classification, in the form of a classified tape, which would be stored until needed for a realignment evaluation. At that time, line-printer maps and 1:24,000 color-coded maps of the classification would be produced, and CUD's would be digitized to generate a mask for production of tabular data summaries. These materials, as prepared in this study for Fairchild AFB, would then constitute a completed set of products.

(2) The designated laboratory would produce the classification in the form of a classified tape, which would be stored until needed for a realignment evaluation. At that time, a lineprinter map (with spectral classes grouped to represent land use/cover classes) would be produced and sent to the AFB (this task could also have been done previously). Then the base command staff would delineate polygons from the lineprinter to make a land use overlay, combine this with the base map and L_{dn}/APZ's overlays, compute areas, summarize the data, and prepare and impact overlay, i.e., do what was done in this study for the McChord scenario, where an existing land use/cover classification was used. This option would require that each base command acquire an electronic planimeter.

Both of the above options still require that the designated laboratory collect on-site ground truth necessary for training to produce the original classification.

Given prior production of the basic classification, either option would have the potential for turn around times of less than one week from the time of request. Option (1) is probably somewhat faster and more efficient, since all the work is done at one point and since it incorporates automated data summary (following a manual digitizing step). However, the availability of option (2) could provide greater flexibility in operations.

Other organizational requirements relate to provisions for analyst training that have been covered in Sections IV 3.h. and IV 1.m.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS BASED ON COMPARISON OF THE THREE REMOTE SENSING METHODS

a. Comparison Table

Table 11 shows a comparison of the three remote sensing methods for land use inventory tested for each of the two Air Force base mission realignment scenarios. The comparison incorporates both quantitative measures of cost and effectiveness and qualitative factors related to personnel training requirements and potential for improved efficiency.

Quantitative measures of effectiveness include three measures of classification detail and suitability: (1) the number of land use/cover classes, (2) the number of urban land use/cover classes, and (3) the number of two- or three-digit SLUCM classes uniquely distinguished. The last of these indicates the degree of direct relationship to classes presently used in AICUZ compatibility guidelines; however, this should not be viewed as a rigid standard of effectiveness. As has been noted, the PI classification, and also the digital classification, makes some distinctions in land use/cover not made by SLUCM which may be useful for environmental planning.

Data resolution refers to the minimum mapping unit of the final map products resulting from each method. Only in the case of the digital method is this resolution equal to the resolution of the raw sensor data. More spatially detailed information could have been produced by the PI method, for example, but with greater cost and time consumption.

An accuracy measure is provided by the figures for "Difference in Percentage of Incompatible AICUZ Area After Realignment Compared to PI Method," in Table 11. As stated at the outset, the PI method was used as a control or standard in this study, in lieu of any absolute standard of accuracy. These figures are the differences, in percentage points, between the percentage of incompatible AICUZ area computed for each method, and the percentage of incompatible area computed for the PI method, for each scenario after realignment.

Turn around time indicates maximum and minimum estimates for the time in days from information request to completion of products. Maximum figures are approximately those which were obtained in this study for each method/scenario, including time required to process data orders from EDC. Minimum figures assume prior acquisition of data and in some cases preliminary work. These assumptions and contingencies are explained in Tables 3, 7, and 10.

Cost figures indicate actual expenditures in this study, with the exception of capital costs of equipment/facilities, which are current estimates for equipment like that used in the study. Cost of overhead is

TABLE 11. COMPARISON OF REMOTE SENSING METHODS

QUANTITATIVE FACTORS		METHOD: Manual Photo Interpretation of Aircraft Imagery	METHOD: Equidensitometric Processing of Aircraft or Landsat Imagery	METHOD: Statistical Analysis of Landsat Digital Data Utilizing ARPANET/EDITOR
EFFECTIVENESS				
1. No. of Land Use/ Cover Classes	McChord AFB	35	6	13
	Fairchild AFB	35	6	11
2. No. of Urban Land Use/Cover Classes	McChord AFB	25	3	6
	Fairchild AFB	25	3	4-5
3. No. of 2- or 3-Digit SLUCM Classes Uniquely Distinguished	McChord AFB	26	5	10
	Fairchild AFB	26	5	8
4. Data Resolution (Hectares)	McChord AFB	4	4	0.44
	Fairchild AFB	4	4	0.44
5. Difference in Percentage of Incompatible AICUZ Area After Realignment Compared to PI Method	McChord AFB	0%	+27.2%	+21.3%
	Fairchild AFB	0%	Not Computed	+5.2%
6. Turn around Time (Days)*	McChord AFB	49/7	52/10	12/5
	Fairchild AFB	55/13	50/8	98/42

* Max./Min. turn around times from Tables 3, 7, and 10.

** Each figure includes $60.00 worth of miscellaneous working materials that were not purchased separately for each method/scenario, but which would be required for any one application.

*** Fairchild AFB production costs include $696 for UWATSYSTEM telephone charges and $375 for 9 minutes of ARPANET sequence time (charges as a bundle cost of $2500/hr.). Similar costs were incurred at NASA-Ames to produce the Puget Sound classification used for McChord AFB; however, these are not counted as costs for this project.

**** Salaries and benefits for project personnel computed as follows: Principal investigator, $18./hr., Associate Investigator, $13./hr., Research Associate, $8./hr., Cartographer, $6./hr. Manhour estimates for these personnel are from Tables 3,7, and 10. No overhead is included in any of the cost figures in this table.

TABLE 11. COMPARISON OF REMOTE SENSING METHODS (CONCLUDED)

		METHOD		
QUANTITATIVE FACTORS		Manual Photo Interpretation of Aircraft Imagery	Equidensitometric Processing of Aircraft or Landsat Imagery	Statistical Analysis of Landsat Digital Data Utilizing ARPANET/EDITOR
COSTS ($'s)				
1. Data Cost	McChord AFB	30.	18.	200
	Fairchild AFB	60.	40.	200.
2. Materials and Production Costs**	McChord AFB	186.	212.	177.
	Fairchild AFB	304.	351.	1655.***
3. Labor Costs****	McChord AFB	610.	704.	342.
	Fairchild AFB	934.	843.	1040.
4. Total of Above (non-Captial Costs)	McChord AFB	826.	934.	719.
	Fairchild AFB	1298.	1234.	2895.
5. Capital Cost of Equipment/Facilities (Minimum Estimate)	McChord AFB	12000.	33000.	13000.
	Fairchild AFB	12000.	33000.	13000.
QUALITATIVE FACTORS				
1. Analyst Training Required	McChord Fairchild	Moderate Basic PI Skills	Moderate Basic PI skills plus experience with system.	Extensive PI skills statistical & computer skills, experience w. software
2. Level of Automation	McChord Fairchild	Low (Labor intensive)	Intermediate	High
3. Potential for Improvement in Efficiency	McChord Fairchild	Low	Some Depends on system development, esp. capability for multiband imagery	High Depends on both hardware and software development

not included. These project costs may differ considerably from costs encountered under operational conditions because of different circumstances, such as different institutional arrangements, labor rates, and possible economies of scale if many analyses are carried out simultaneously. Rather than try to estimate possible operational costs, it was decided to document costs for this project as carefully as possible and to use this documentation as a basis for comparison.

The three qualitative factors related to concerns that provided the basis for this study: a method for land use inventory be found that would not require a large number of trained personnel for its implementation, that would utilize the best available technology, and that would be as efficient as possible in producing needed information, or that would present the greatest potential for improvement in efficiency.

The first qualitative factor, level of analyst training required, should be interpreted in relation to the other two factors. The more technologically advanced methods require more analyst expertise, not less. Basic PI skills are required for all three methods, and as one proceeds from PI to digital analysis, more skills and knowledge must be added. Most of these skills are not separable to different individuals. However, this increased requirement for training and expertise is offset by a possible reduction in the number of trained personnel required, a tradeoff that would presumedly be considered desirable.

No estimates are given for the number of analysts required since this would depend on workload factors. The manhour figures for the four participants in this study shown in Tables 3, 7, and 10 (from which labor costs were derived) provide some basis for estimating the number of analysts required for a given workload.

"Level of Automation" is a qualitative statement of the level of technology involved in each method and, hence, the capability or potential capability of each method for replacing human effort with machine effort. The word "potential" is important here, because the more automated methods, particularly digital analysis, are at an early stage of development with respect to land use inventory application. Like all hardware/software systems under development, they require substantial initial investments of human effort, which was demonstrated in this study. Thus, while manual PI represents a low level of automation and is permanently labor intensive, digital analysis, which is highly automated, presents an as yet unrealized potential for reduction in labor requirements. This potential for improvement in efficiency, which includes speed and overall economy as well as minimization of labor, is explicitly stated as the third qualitative factor.

b. Summary Comparison of Methods

(1) Classification Detail

From the standpoint of effectiveness, it is evident that PI still holds a clear advantage over the other two methods in terms of classification detail and capability for producing many of the two-and three-digit SLUCM classes now incorporated in AICUZ compatibility guidelines. Equidensitometric processing is markedly inferior in this respect, and appears capable of producing only what would be termed a "Level I" classification (less than 10 classes total). Digital analysis as performed in this study via ARPANET/EDITOR is also significantly inferior to PI with respect to the number of urban land use classes distinguished; however, it does make urban versus non-urban and residential versus commercial/industrial (livlihood) distinctions reliably, given careful training for these type of land cover in all parts of the study area. For classification of natural and vegetative surface, digital analysis results more closely approached PI results, readily distinguishing crops from fallow fields and pasture, forest from brush and clear cuts, and wetlands, water and other features.

The importance of the difference in urban classification detail between the PI and digital methods will be determined by the importance of applying the AICUZ guidelines at the SLUCM level of land use classification detail. If a somewhat more aggregate conception of land use is determined to be adequate or appropriate for realignment evaluation, or other environmental planning purposes, then a digital classification similar to that produced in this study may be sufficient.

(2) Data Resolution

Data resolution is one factor where digital analysis has a clear advantage. In spite of the lower spatial resolution of Landsat as compared to aircraft sensor data, computerized digital processing is able to capture all of this resolution on the final information product. This advantage will be still greater with the recently launched Landsat-3 and future remote sensing satellites carrying higher resolution sensors.*

Data resolution may or may not be important for AICUZ and related planning. Size of the minimum data unit does not appear to strongly affect the overall percentage of compatible or incompatible land use determined for an AICUZ, but it does become important in identifying localized instances of incompatible use. At this level, the accuracy of classification of individual data units becomes a concern. Recent experience with several ARPANET/EDITOR classifications performed by the USGS Geography Program at NASA-Ames has shown that it is difficult to achieve accuracies of more than 80 to 85 percent, based on a check of randomly-sampled individual pixels, although area summaries by land use or cover class may be considerably more accurate. Accuracy of individual pixel classifications can be improved somewhat through a smoothing routine designed to remove anomalies, such as that employed for the Fairchild AFB classification.

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* Landsat-3 pixel size is 56 meters square or 0.31 ha, compared to 0.44 ha for the 56 by 79-meter pixels of Landsat-1 and-2. The Thematic Mapper aboard the future Landsat-O will have a pixel size of approximately 30 meters square or 0.09 ha.

(3) Incompatible Area Percentage Differences

These differences are large for equidensitometric processing and variable, but smaller, for digital analysis. In part the differences can be explained by the application of the existing AICUZ guidelines to land use classifications that are more aggregate than SLUCM. Decisions about the compatibility of any given class took account of all possible SLUCM classes that might be subsumed under that class, and if any of these were incompatible with a given CUD, the entire class would be designated incompatible. However, if the AICUZ guidelines were modified specifically to accomodate more aggregate land use data, overestimation of incompatible area might be reduced, especially in the case of digital classification. Such modified guidelines would not replace the present detailed guidelines but would complement them for use in broad overviews based on aggregate data.

(4) Turn Around Time

The minimum figures in Table 11 for turn around time for all three methods are in the neighborhood of one week. The shortest turn around time (5 days) is for digital analysis for which the basic classification had already been performed (McChord AFB). However, the turn around time for performing the Fairchild AFB digital classification was 42 days, after subtracting time for data acquisition. The length of this period is attributable, in part, to the mode of ARPANET/EDITOR use, whereby such peripherals as a wide-bed lineprinter and Dicomed film recorder were located at a distance (at NASA-Ames), requiring mailing of output products. It is also attributable to learning time for the investigators.

The minimum turn around times for PI and equidensitometric processing probably could not be reduced much from the figures shown. The minimum turn around for digital analysis could be reduced from the 5-day figure shown for McChord AFB if the manual mapping process of polygonization from lineprinter output were automated, e.g., using a plotter program to draw these lines, or producing a film-based map product such as the Fairchild AFB color-coded map. It appears, therefore, that digital analysis, with prior basic classification, is the only method that could achieve a turn around time from request to product in the neighborhood of 2 to 3 days, although the prior time period required for the basic classification (in elapsed days, not necessarily manhours of labor) may be somewhat longer than for the other methods.

(5) Costs

Cost figures established in this study are not highly conclusive in favoring one method over the others. Non-capital costs are similar for PI and equidensitometric processing, and significantly higher for digital, when the cost of basic classification is included, as for Fairchild AFB. Again, part of the Fairchild AFB digital cost figure must be attributed to learning by the investigators; this is reflected in the telephone charges and labor costs. Also, production of the color map products was a major expense. High non-capital costs for digital analysis via ARPANET/EDITOR are balanced by low capital costs--only slightly higher than for manual PI and much less than for equidensitometric processing, where complete hardware must be acquired.

(6) Qualitative Factors

The implications of the "Qualitative Factors" section of Table 11 were discussed in the introductory discussion of the Table.

Manual PI represents a low level of automation, has little potential for improvement in efficiency, and will always be labor intensive. However, it has reached a level of development where it is effective and reasonably efficient (by present standards). Hence, PI will always serve as a back up for automated methods, and, for the forseeable future, some PI will be incorporated in automated approaches, such as the training required for digital analysis.

Equidensitometric image processing is partly automated and possesses some potential for improvement if systems based on simultaneous analysis of multiband images or individual color film layers become available. However, development in this area appears to be limited, and no systems are readily available at present. In view of the inferior performance of the equidensitometric method utilizing a typical, currently-available system, it is recommended that this method not be given further consideration at this time.

Statistical analysis of Landsat digital data is the only one of the three methods of land use inventory that is highly automated, highly receptive to further technological developments, and has major potential for improvement in efficiency in terms of speed, economies of scale, and reduced human labor. Digital analysis should provide the U.S. Air Force with a method that minimizes the number of trained personnel, although skill requirements of these personnel would be high.

It should be stressed that the potential for improvement in the digital method is very real and immediate. Several types of new Landsat data processing systems have recently become available, and major development continues on others. These include integral (self-contained) or "turnkey" hardware/software systems, software packages for use on existing main-frame computers, and remote-access-configured systems such as ARPANET/EDITOR. In many of the newer systems, emphasis is given to simplified user languages and interactive procedures employing a color video display for more efficient analysis/machine interface.

Although the investigators conclude that statistical analysis of Landsat digital data, as a generic method, has the greatest potential for satisfying the needs of the U.S. Air Force for land use inventory, it has not been determined that ARPANET/EDITOR is necessarily the optimum digital method. Several different options for Landsat digital analysis exist, which provide the basis for the following recommendations.

2. RECOMMENDATIONS

It is recommended that the U.S. Air Force conduct a follow-on study to evaluate the comparative utility and cost-effectiveness of three options for statistical analysis of Landsat digital data, in comparison with the ARPANET/EDITOR option evaluated in the present study. Evaluation criteria and study documentation should be consistent with the present study.

The three options are: (1) purchase of services from a private industry contractor employing its own hardware/software system, (2) acquisition and use of an integral hardware/software system including an interactive color display, and (3) acquisition of a software package for use on an existing main frame computer.

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