AGRICULTURE INFORMATION BULLETIN NO. 352

Land Use Classification with Simulated Satellite Photography

U.S. DEPARTMENT OF AGRICULTURE
ECONOMIC RESEARCH SERVICE

ABSTRACT

Imagery expected from the Earth Resources Technology Satellite (ERTS) was simulated by reduction of conventional black and white aerial photography (scale 1/20,000) to the small scales (e.g., 1/2,560,000) that would result from photographing large areas of the ground at satellite altitude. Small sections of the reduced negatives were then enlarged for land use interpretation tests. It was concluded that the classification system now used by Economic Research Service, USDA, in its inventory of major land uses would be compatible with satellite photography. Data for the following categories cannot be obtained from satellite photography: ownership; end-use for specific crops; some transitional vegetation and multiple-use areas.

Key Words: Land utilization, Classification, Photogrammetry, Inventories, Aerial photography, Simulation, Remote sensing, Earth Resources Technology Satellite.

PREFACE

Aerial photographs have long been used as an aid in studying the features of the earth. Now, new types of imagery, both photographic and nonphotographic, offer even greater opportunities for extending our understanding of the cultural and natural landscape. Earth-orbiting, unmanned, instrument-carrying vehicles now investigate the planet from new perspectives. In addition to conventional cameras, these space vehicles carry a wide array of devices--television cameras and sensing instruments which detect differences in heat radiation and light reflectance from the surface below.

Assuming continued successful development and use of these instruments, remote sensing from space vehicles will return vast quantities of information to the earth. It has therefore become necessary to (1) determine the potential agricultural applications of remote sensing, (2) anticipate the type of data to be obtained by remote sensing, and (3) plan for the use of these data.

A number of questions should be answered before the earth-orbiting remote-sensing systems come into general use in the United States: Will the new system eliminate the need for conventional land use data-gathering systems? Or will the new systems merely supplement the old systems, and, if so, to what extent? Will the data from the new remote-sensing systems be compatible with data series of earlier years? For example, will current USDA reports on major land uses have to be changed to take advantage of satellite data? Will definitions of major land use categories have to be modified? What are the limitations of expected satellite data in presenting a realistic picture of land use?

There is little justification for promoting agricultural applications of remote sensing from satellites if the data obtained are not as good as, or are no better than, data obtained by traditional methods--e.g., aerial photographs, ground surveys, questionnaires.

The Economic Research Service of the U. S. Department of Agriculture has been engaged in a comprehensive investigation of the potential economic benefits to agriculture of remote sensing from orbiting spacecraft. Research for this study, a part of the comprehensive program, was carried out for ERS by the Center for Aerial Photographic Studies at Cornell University from June 1968 to June 1969 under Contract No. 12-17-04-1-463. The present report constitutes a summary of data included in progress reports, a seminar presentation, the interim report, and the final report issued for the project, and was prepared for publication by the Economic Research Service.

The project was monitored by Simon Baker, formerly with the Natural Resource Economics Division, and Richard McArdle, Natural Resource Economics Division, ERS.

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SUMMARY AND CONCLUSIONS

Standard USDA black and white aerial photos were successfully used to simulate the imagery expected from Earth Resources Technology Satellites (ERTS). To do this, portions of photos of selected test areas, originally obtained at a scale of 1/20,000 by conventional aircraft, were photographically reduced to the smaller (e.g., 1/2,560,000) scales that would result from the photography of the larger surface area encompassed from the greater altitude of the satellite.

Small sections of the reduced negatives were then enlarged to permit interpretation of various categories of land use. Ground photography of selected sites within the test areas was used to check interpretation of the simulated imagery.

The following conclusions, based on the simulation of satellite-scale photography and an estimate of the quality of such photography, were reached:

1. The land use classification system currently in use by the U. S. Department of Agriculture will be compatible with satellite photography. Approximately 90 percent of the data now required for periodic land use reports can be obtained from satellite photography. An additional 5-8 percent of the required information can be inferentially derived from satellite photography and supplementary sources.

2. An estimated 2-5 percent of the data now included in the periodic reports cannot be obtained from satellite photography. Examples of agricultural information which satellite photography cannot provide include: land ownership; end-use for specific crops, e.g., for feed, seed, or human consumption; and transitional vegetation areas and some multiple-use areas, e.g., pastureland reverting to forest and cropland used as pasture.

3. Weather conditions are a serious inhibiting factor to the successful use of satellite photography of any type. This limitation would tend to be minimized if the Department continues to issue its periodic land use report at 5-year intervals. The span of time would provide opportunity for coverage in favorable weather of areas which are generally subject to a high degree of cloud cover. The use of high-altitude aircraft as a supplemental sensor vehicle would assure adequate coverage of land use within any 1 year.

4. The fact that specific land use data can be tied to specific geographic locations will greatly increase the value of the periodic report as well as other land use reports. Development of base map information from initial satellite flights will greatly simplify subsequent land use inventories.

LAND USE CLASSIFICATION WITH SIMULATED SATELLITE PHOTOGRAPHY

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INTRODUCTION

The study on satellite photography was undertaken to determine what categories of agricultural and nonagricultural land uses can be obtained by interpretation of imagery of the type expected from the NASA Earth Resources Technology Satellites (ERTS A and B).

The study was carried out in three major phases. First, study areas (four counties) were selected that presented a wide range of agricultural and nonagricultural land uses. Second, standard aerial photographic coverage of the study areas was used to simulate imagery of the type expected from ERTS. Third, categories of land use that could be determined from the simulated satellite imagery were evaluated and compared with land use categories currently used by the Economic Research Service in its inventory of major land uses. 1/

RESEARCH PROCEDURES

Conventional black-and white aerial photography was the only type of imagery considered in the project. Because of the vast amount of available experience in photographic interpretation, as well as the established reliability of material and equipment, this type of imagery provides the most realistic base for the projection of the quality, type, and quantity of

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1/ H. Thomas Frey, Orville E. Krause, and Clifford Dickason, "Major Uses of Land and Water in the United States with Special Reference to Agriculture: Summary for 1964." Agr. Econ. Report No. 149, Nov. 1968. pp. 67-68. Hereafter referred to as the "Land and Water Report." Reproductions of tables from the report, showing typical column headings and row stubs, are shown in figure 7a-d on pages 16-17.

information to be obtained from earth satellites in the near and mid-future periods. The fact that no final decision regarding instrumentation to be carried by ERTS had been made at the initiation of this study also influenced the decision to rely on conventional imagery as a basis for simulation.

Selection of Test Areas

To investigate the potential of satellite photography, four different areas representative of the country's principal agricultural regions were studied.

The northeastern agricultural region received primary attention because of its complexity. The wide variety of crops, topography, land use, and size of land parcels in this region called for far stricter criteria than those needed for the other agricultural regions studied. Cortland County, N. Y., was used as a type area for the Northeast (figure 1.).

Benton County, Ind., was selected as representative of the midwestern region. This area was visited once for field inspection, and typical ground features, buildings, and so on, were photographed to establish identity, dimensions, and use of the land. The county agent's knowledge of crops and farm practices expedited the field work.

Dallas County, Tex., was selected as representative of the southwestern region. The area studied consisted of urban land, a major protected watershed and reservoir, subhumid farmland, and pasture.

Adams County, Wash., was chosen as representative of the great grain fields of the Northwest and elsewhere. The area also included large portions of irrigated valley lands, with crops and irrigation structures typical of the West. No ground control was established in this test area, or in Dallas County, Tex.

Simulation of Satellite Imagery

In planning the research and design of the experimental system for this study, several definitions and basic assumptions were adopted.

(1) Type of Imagery

Three basic types of remote sensors can be used for various applications in agriculture.

These sensors--photographic, infrared, and microwave systems (including radar)--function fundamentally by recording reflected or emitted energy from physical objects or conditions. They differ primarily in that, as the names imply, each is sensitive to energy of a

Figure 1. Aerial photo mosaic of Cortland County, N. Y., showing test sites

limited and largely non-overlapping wavelength range within the electromagnetic spectrum 2/

Of the three sensor types,

> ...photographic cameras have been developed to the the highest state of perfection. In comparison with other sensor types, photographic systems possess higher resolution capabilities and superior metric qualities, and photographic interpretation techniques are relatively well developed. 3/

Black and white conventional aerial photography offers one method by which some of the newer sensing systems can be measured.

(2) Resolution

Identification of land use categories, and measurement of acreage within categories, is directly dependent on the quality of the imagery.

> The factors affecting the ability of remote sensors to record targets are complex but relatively well-known. For photographic sensors, this capability, commonly termed resolving power, is expressed in lines per millimeter (ground resolution is expressed in feet). Resolution has been defined as "the ability of a film or lens, or a combination of both to render barely distinguishable a standard pattern consisting of black and white lines." Roughly five times better ground resolution is required for object identification than for object detection. Among the variables on which resolving power depend are sensor optics, distance from target, type and format of recording medium, strength of energy source, contrast between target and background, atmospheric conditions, and recording medium processing techniques. 4/

For this study, the definition of resolution has been modified. Although resolution is expressed as and implies

2/ H. Thomas Frey, Agricultural Application of Remote Sensing--The Potential from Space Platforms. Agr. Info. Bulletin No. 328. Sept. 1967. p. 15.

3/ Frey, op. cit., p. 16.

4/ Ibid., p. 16.

a minimum linear measurement, research shows that many objects can be identified that are smaller in dimension than the "minimum" measurement determined by optical test. Therefore, image interpretation, not photogrammetric measurement, was defined as the basis of usefulness.

(3) Contact Prints Versus Positive Transparencies

Paper contact prints of the test areas were used as original ground imagery. Prints from aerial photography vary in quality, and will resolve from 10 to 40 lines per millimeter. These prints were the basic material for the "degradation process" that ultimately reduced the quality of the end product of this simulation to a fraction of that ideally obtainable from the satellite. Positive transparencies were considered for use in place of contact prints because of their better resolution and scale of tones. However, because of other and more significant steps in the degradation process, this alternative was discarded.

(4) Simulation Procedures

Briefly summarized, the simulation process was based on the assumption that photographic imagery would be obtained from the satellite. The first step in simulation was the reduction of standard aerial photographic prints to a scale similar to that expected from satellite photography. The second step was the enlargement of the reduced negatives to a size readable by interpreters. Aerial photographs, ground photographs, and field inspections of the test area were used to check the interpretation of the simulated imagery.

Specific steps in the simulation sequence are outlined in the text below and in the diagram (figure 2).

(a) Mosaics: Using USDA photography, mosaics of parts of the four study counties (Cortland Co., N. Y.; Dallas Co., Tex.; Benton Co., Ind.; and Adams Co., Wash.) were prepared. These areas represent a wide range of land uses, including the more complex, smaller farm operation patterns of the East, irrigated crop areas of the West, urban development penetration areas, and forestry patterns.

(b) Ground Truth: Primary emphasis was given to the Cortland County area. Several test sites were chosen to provide unique as well as typical farm features for field checking. Two hillside sites in particular were selected because of their advantageous locations for developing ground truth photographic material.

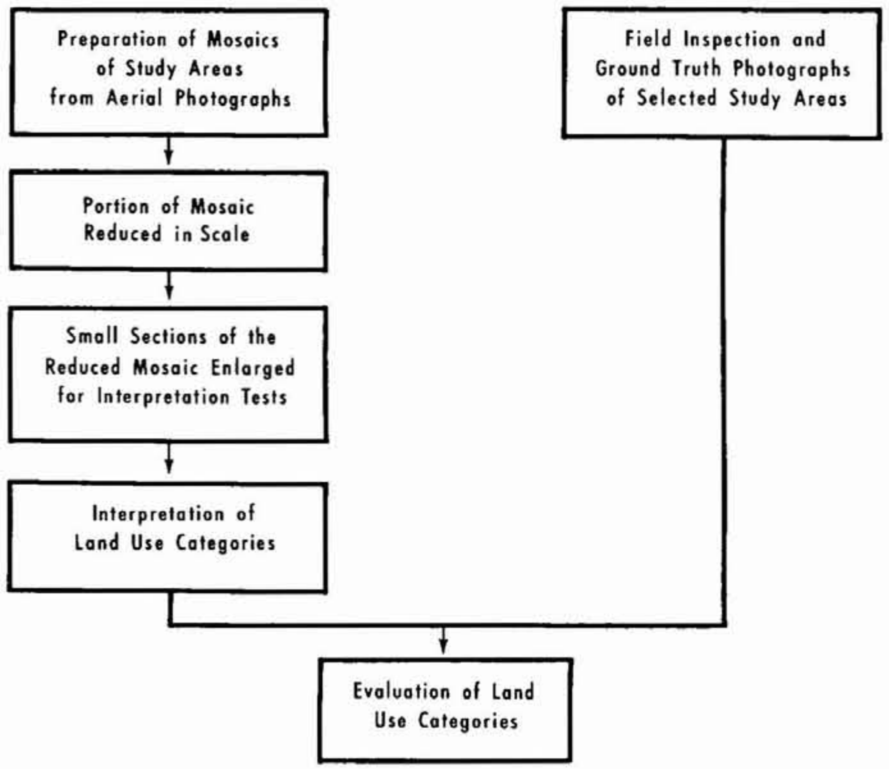

Figure 2. --Diagram of simulation process

A series of panoramic pictures were taken of two selected sites. Center points of the photos were identified, and the location of the camera was permanently established. Seasonal coverage at these two sites was continued to establish a basis for comparison of seasonal changes in land use responses. The photo subjects included woodland, river valley soils, valley farms, hilltop farms, pasture, inactive farmland, and other categories covered by the USDA land use inventory (figure 3, center spread, pp. 10-11).

Included among the many other points selected were farm buildings of different sizes and shapes, showing various degrees of response on the original aerial photographs. The buildings were used to establish the point at which typical farm images fall below the threshold of recognition as the photographic scales are reduced.

(c) Reduction: The mosaics, with selected test areas included, were from standard black and white aerial photography contact prints (scale 1/20,000) made under contract with the Agricultural Stablization and Conservation Service, U. S. Department of Agriculture. These prints were reduced in scale by photographing the mounted mosaic

from successively greater distances. The mosaics were placed on a vertical mount with standard resolution patterns for comparison (figures 4 and 5).

The process of copying the mosaics of the test areas was the first direct process over which control could be exercised. Quality cameras, lenses, lights, and processing equipment were used. 5/

Camera vibration was the primary problem in this step. To reduce this effect to a minimum in some cases, exposures were made by controlling lights in a darkened studio, rather than by using shutters. Building vibrations, even at night, remained a source of camera movement. Negatives with the following scale ratios were obtained:

1:640,000	(1" = 10.1 miles)
1:1,280,000	(1" = 20.2 miles)
1:1,920,000	(1" = 30.3 miles)
1:2,560,000	(1" = 40.4 miles)

(d) Enlargement: Small (5/8-inch square) sections of the negatives of the reduced mosaics were then enlarged. 5/ Prints made from these negatives showed a large amount of degradation had occurred in the reduction and enlargement process.

In the process, enlargements were made to a standard size based on 5 times for the first negative in the series (5 times, 10 times, etc.). By the fourth enlargement, it became obvious that the enlarger could not resolve all the details included on the negatives. Through the use of an integrated photomicrographic system with Kohler lighting, the same negative (no. 4) was printed again, and 4 more stages of enlargement were reproduced. The last enlargement was more than 200 times the size of the original image, and definitely exceeded the system's possibilities for usable data (figure 6).

The enlarging process is similar to the one that might be used for satellite-acquired photography. (The assumption is that photographic imagery obtained from

5/ See appendix A for a description of film and equipment used in reduction and enlargement.

the satellite will be of very small scale--cover large areas on the ground--and will have to be enlarged to a scale which would allow a human interpreter to take off the data desired.)

(e) Results: The purpose of the reduction/enlargement tests of the mosaic was to determine the points at which various levels of delineation/resolution become restrictive. Stated another way, the tests determined how much ground a negative can cover and still provide an image that can be interpreted when enlarged.

When small sections of the negatives were enlarged back to original sizes (as described above), relatively little ground resolution was lost on the print except for the 1/2,560,000-scale enlargement, which was quite fuzzy. The film used was capable of registering imagery well above 1/1,000,000 with very little loss of land use category interpretability. A scale of 1/2,560,000 has apparent limitations, however.

To test interpretability at various scales, a picture was taken of the Cortland County, N. Y., test mosaic, obtaining a scale approximating 1/900,000. A 5/8-inch square, covering one of the test sites, was taken from the reduced negative and enlarged sufficiently for photo interpretation. In relatively little time, members of the Cornell photo interpretation staff easily identified five major categories of land use.

Ground truth was determined by field visit, plus photos of the test area taken at ground level. Based on this and other tests, a qualified interpreter could obtain satisfactory information for a modified land use classification from imagery that has been reduced to 1/2,500,000, despite the lack of image clarity.

Regarding ground resolution, it should be noted that with successively greater enlargement, spot recognition--the usual index of ground resolution--drops out before linear recognition. In land use classification interpretation, the various categories have linear boundaries, so that a large-scale print might be valueless for spot identification (such as houses) but still be interpretable for categories with linear resolution characteristics, such as land use boundaries.

LAND USE INFORMATION FROM SIMULATED SATELLITE IMAGERY

Land use categories given in the "Land and Water Report," prepared at 5-year intervals by the Economic Research Service, were used as a guide for a classification based on satellite imagery.

Figure 7a-d illustrates land use categories shown in column headings and row tabs in representative tables from the "Land and Water Report."

Assuming that the imagery received from the satellite would have a final scale ranging from 1:1,000,000 to 1:2,000,000, testing under this program, conducted by reasonably well-trained photo interpreters, indicates that land use identification parallel to the information categories found in these land inventory reports can be accomplished.

The required imagery and the limitations on interpretations are discussed below under each major land use category. 6/ The major categories under discussion are linked to the categories shown in figure 7a-d by means of the numbers in brackets. A summary of the interpretability of each category is given at the conclusion of the section.

Agricultural Land Use [1]

With the image scale specified and under the conditions and constraints outlined, the acreage in the agricultural land category, which includes cropland, pasture and range, grazed forest land, and farmsteads and farm roads, should be identifiable in all test areas. Some error can be expected in identifying forested pasture and range, however. This is a borderline category that may be identified as either agricultural or nonagricultural land, depending on the intensity and consistency of grazing. The degree of error in categorizing the forested pasture may reach 50 percent because of such factors as atmospheric conditions at time of photography, and/or the capability of the interpreter, and the time available for making a decision.

Probably, all cropland and most productive pasture can be specifically identified in all agricultural regions. Forest land *per se*, even when associated with farm operations, can be identified as such and classified as desired if the area is 25 acres or more. Stands smaller than this are hard to distinguish. Dense woodlots found in the Northeast and Midwest cannot be classified as grazed or ungrazed, but a forest brush (second growth on abandoned agricultural land) may show evidence of use as part-time pasture.

The criteria that place these lands in the proper category are largely inferential in nature. Fence lines in the grazing areas are quite prominent, and the grey values of various fields reflect the intensity of

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6/ See appendix B for a discussion of factors other than photographic operations which influence interpretability.

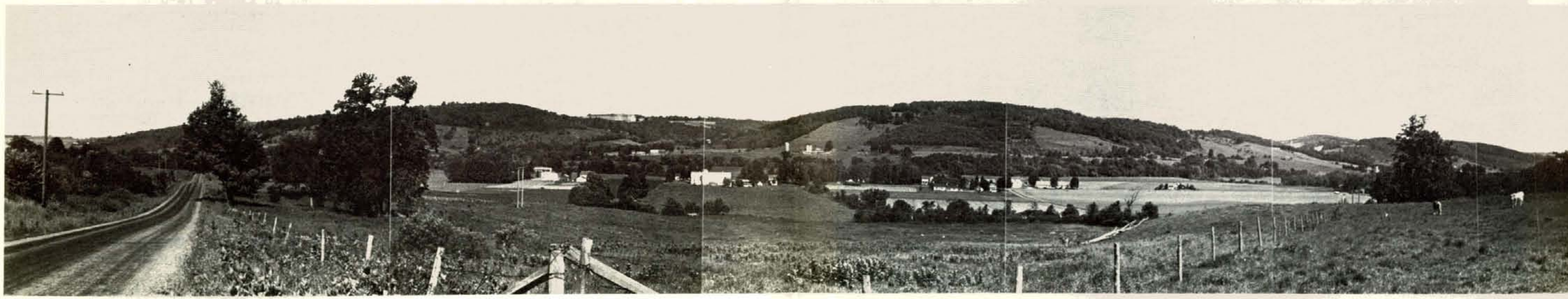


Figure 3. Comparison of aerial and ground imagery at Test Site 2 within the Cortland County, N.Y., study area

(arrow indicates position of camera)

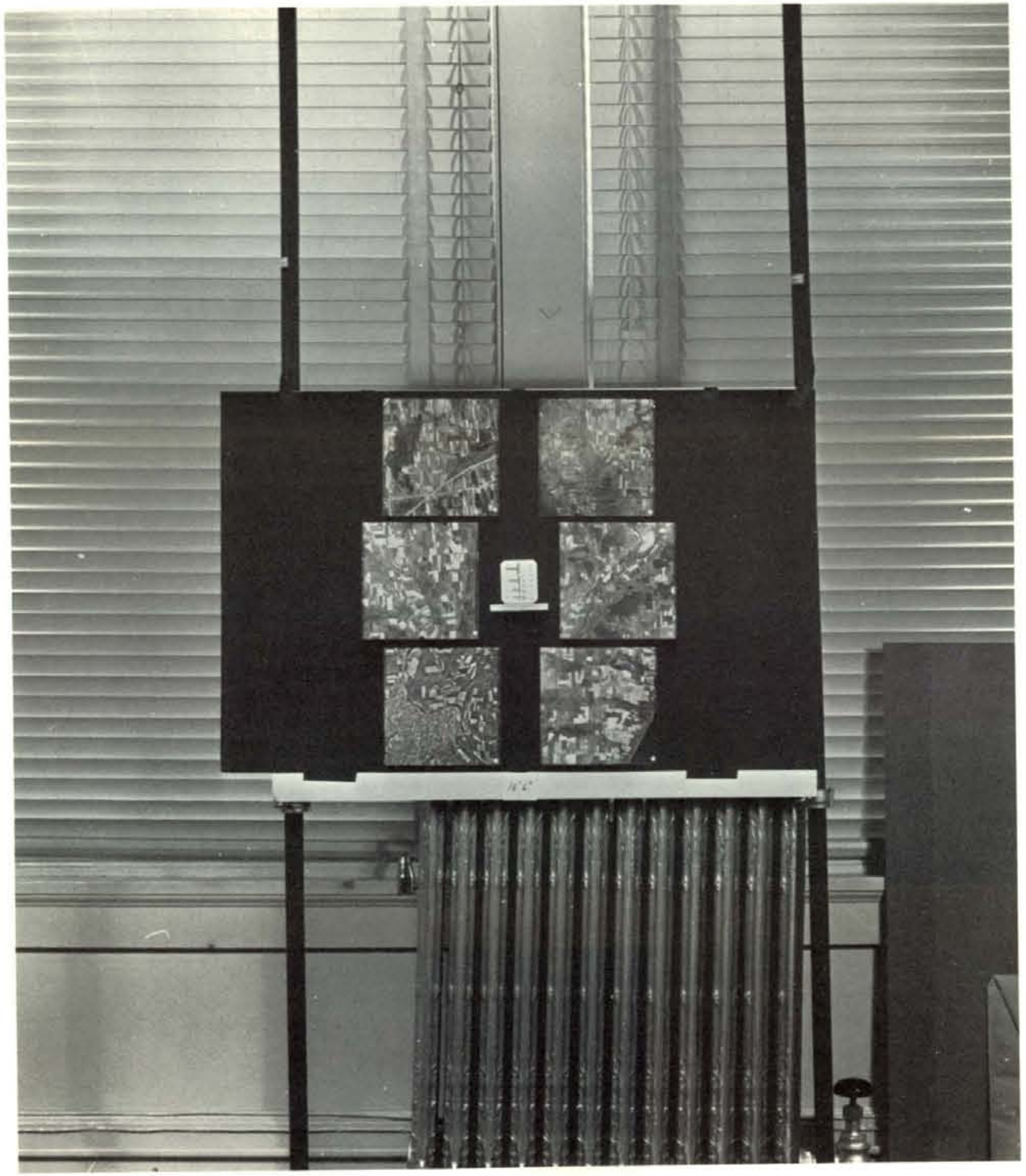


Figure 4. Aerial photo mosaics of study areas photographically reduced in scale (Note resolution pattern in center. Radiator was not heated at time of photography)

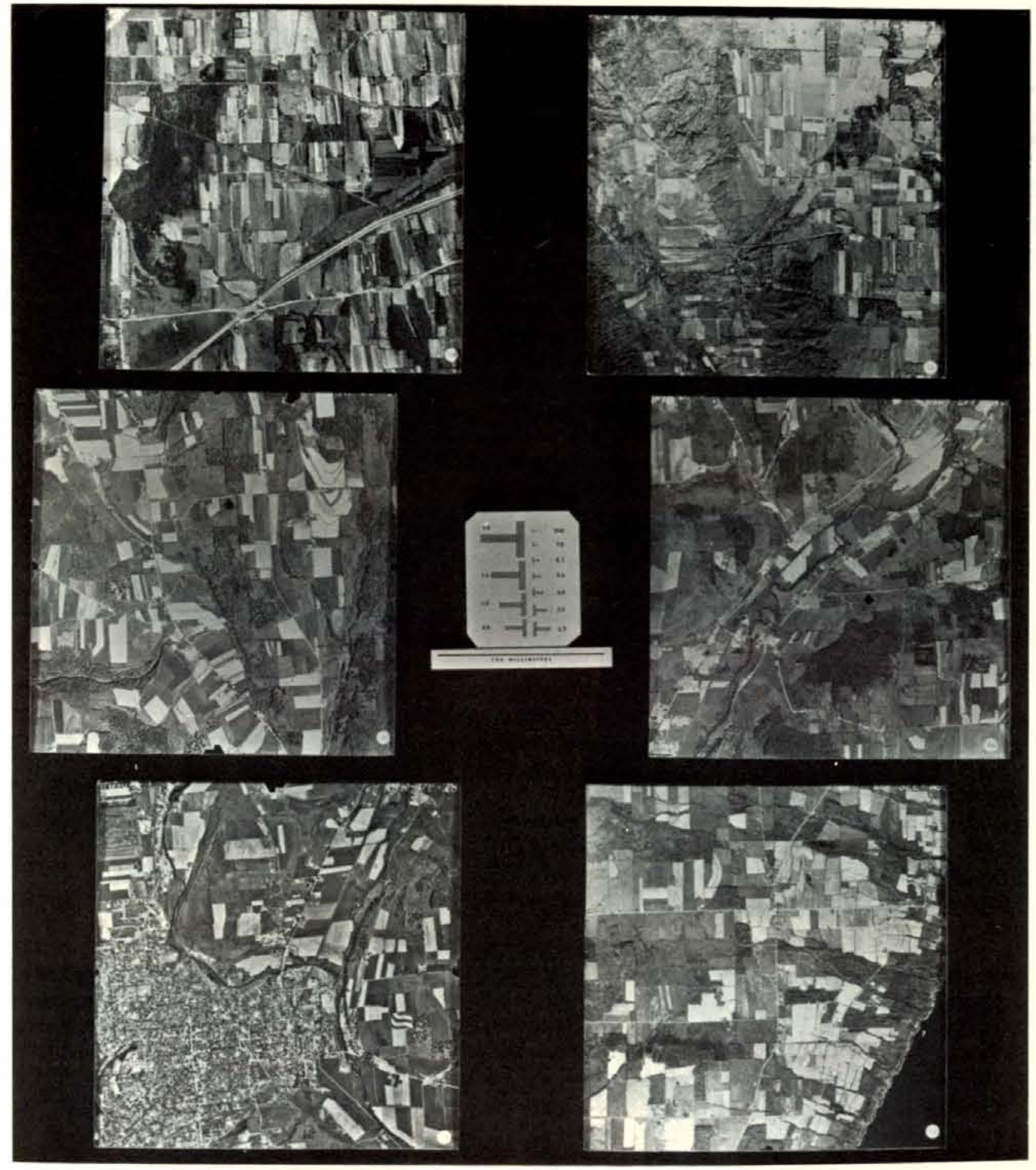
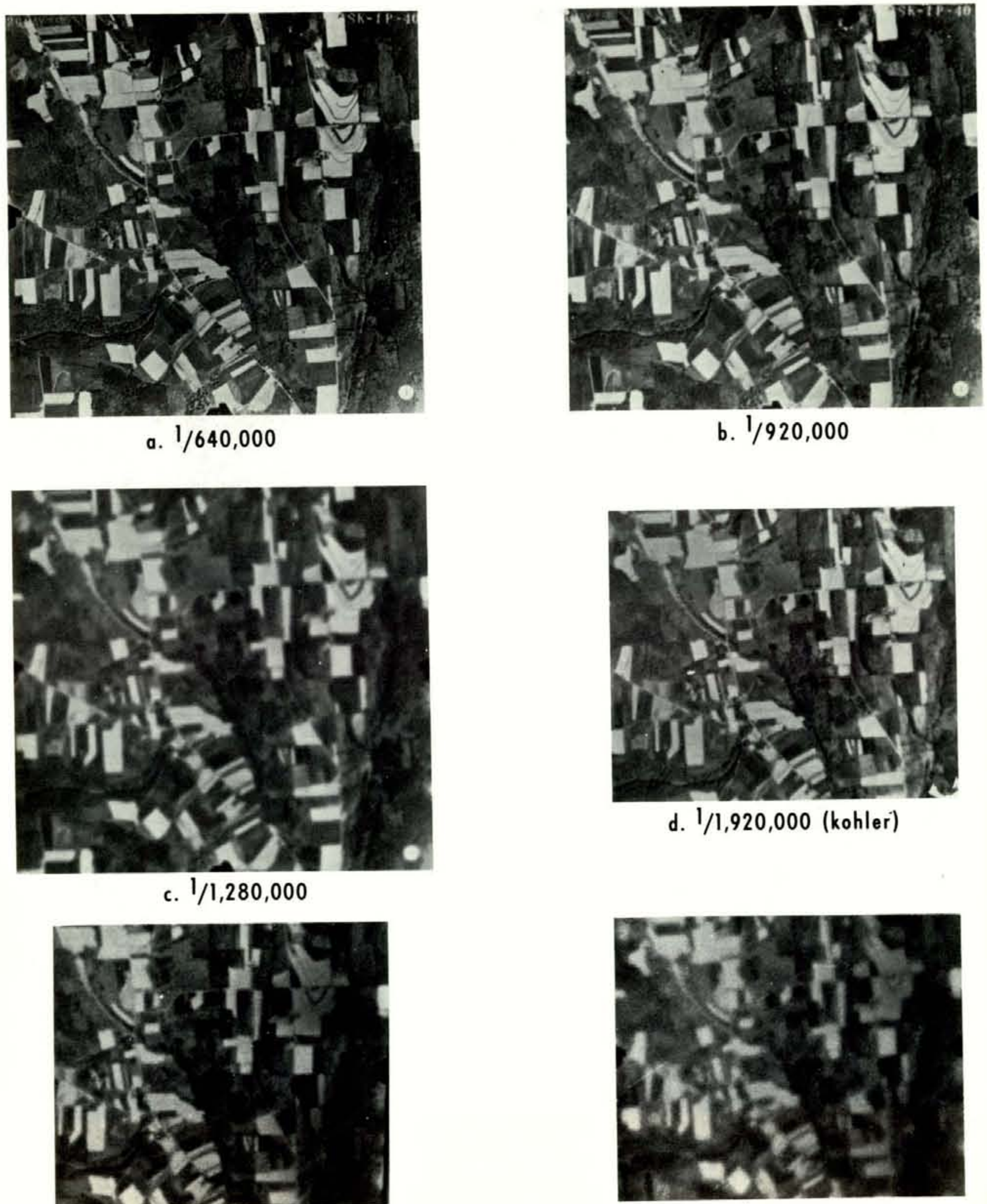


Figure 5. Aerial photographs (scale 1/20,000) reduced to 1/32nd of original contact print, with a resulting scale of 1/640,000 (overground)



a. 1/640,000 b. 1/920,000 c. 1/1,280,000 d. 1/1,920,000 (kohler) e. 1/2,560,000 f. 1/3,840,000

Figure 6. Test Site 1, Cortland County, N.Y. Enlargements from reduced scale air photo negatives showing loss of detail as scale becomes smaller (Indicated scales are those of the negatives from which prints were made)

grazing. High-quality photographic coverage can reveal whether a forest tract is grazed. However, the specific area within the tract which is grazed is not easily identified. Essentially, wherever cattle funnel through natural or artificial constrictions (e.g., between rock outcrops or through fence gates) the evidence of grazing can be identified. Dispersal of grazing areas through the forest results in subtleties too minute to record in ultra small-scale photography.

Cropland [2]

The use of satellite coverage will permit the identification of cropland as such. The uniformity of tone and the "clean" lines of the cultivated areas assure the identification of cultivated lands. However, the inventory of harvested cropland will be time-dependent. Even assuming appropriate timing for photographing one crop in one region, it would be unrealistic to expect area coverage and satisfactory timing for more than 20 percent of the important harvested areas. Only supplemental photography by high-altitude aircraft or multiple satellite programs will fill this gap.

Acreages of nonharvested cropland must be obtained by subtraction of harvested acreage from total cropland after harvest. This determination requires two observations of satisfactory coverage: one during the early growing season and one after harvest. Lacking the evidence that a specific field was planted to a current crop, it does not appear feasible to differentiate between mature, nonharvested crops and soil improvement or idle cropland.

Cultivated summer fallow [3] is land plowed but left unseeded; it is found mainly in the 17 Western States. This land can be identified by photographic coverage late in the growing season.

Total cropland used for crops [6] can be determined from photos of the scales obtained from simulated satellite coverage, but the three component categories, cropland harvested [4], crop failed [5], and summer fallow [3], cannot be distinguished separately.

Cropland used only for soil improvement crops [7] is not harvested or pastured; it is combined with idle cropland [8] in the inventory. In general, this category is poorly defined in the simulated photographic coverage and identification is of questionable accuracy even when using conventional photography unless the time for photography is well chosen. Part-time or occasional use of land as pasture spills over into this category and the distinction, although present, is too subtle to recognize at workable photo scales.

Cropland used only for pasture [9] cannot be identified accurately, even in conventional aerial photography. This land appears on the photo as cultivated cropland, and until it is definitely committed to pasture, either intensively used or used for a long period of time, it cannot be distinguished from other cropland.

Table 2.--Agricultural and nonagricultural uses of land, United States, 1964

Major land use	Acreage	Percentage of total
[1]Agricultural:		
[2]Cropland:		
[6]Cropland used for crops		
[7] [8]Soil improvement crops and idle cropland		
[9]Cropland used only for pasture		
[11]Grassland pasture and range		
[12]Forest land grazed		
[16]Farmsteads, farm roads		
Total agricultural land		
[13]Nonagricultural:		
[12]Forest land not grazed		
Special uses:		
[14] [15]Urban and other built-up areas		
[17]Primarily for recreation parks and wildlife		
[18]Public installations and facilities		
[19]Miscellaneous land		
Total nonagricultural land		
Total land area		

Table 3.--Major uses of land in farms and not in farms, United States, 1964

Major use	Land in farms		Land not in farms		Total
	Acreage	Percent-age of total	Acreage	Percent-age of total	Acreage
[1]Agricultural uses of land:					
[2]Cropland					
[11]Grassland pasture and range					
[12]Woodland grazed					
[16]Farmsteads, farm roads					
Total agricultural land					
[13]Nonagricultural land:					
[12]Forest land not grazed					
[13]Special uses					
[19]Other land					
Total nonagricultural land					
Total land area					

Figure 7a-d. Land use categories in tables of "Land and Water Report"

Table 6.--Major uses of cropland, 48 States, selected years

Cropland use	1954	1959	1964	1965	1966	1967
[4]Harvested						
[5]Crop failure						
[3]Cultivated summer fallow						
[6]Total used for crops						
[7][8]Soil improvement and idle cropland						
[9]Cropland used for pasture						
[2]Total cropland						

Table 7.--Cropland uses by regions, United States, 1964

[10]Region	[6]Cropland used for crops	[7][8]Cropland in soil improvement crops or idle	[9]Cropland pasture	[2]Total cropland
Northeast				
Lake States				
Corn Belt				
Northern Plains				
Appalachian				
Southeast				
Delta States				
Southern States				
Mountain				
Pacific				
48 States				
Alaska				
Hawaii				
United States total				

One characteristic inherent in a photographic system will perhaps greatly improve the inventory of these various land uses. The "Land and Water Report" points out that the "use" distribution of diverted cropland is not known. The continuance of a satellite and/or aircraft surveillance program would, after 2 years, provide clear patterns and trends in land use. The distinction must be made between "instant recognition"--a one-pass attempt--and the perspective acquired by repeated coverage, both seasonally and annually. Repeated coverage largely compensates for the present inadequacies of scale, resolution, and other factors.

Cropland Uses by Regions [10]

Regional characteristics play an important part in this breakdown of land use. Knowledge of regional practices contributes to the recognition of various land uses. Basically, the feasibility of determining land use patterns is limited, as previously explained.

Trends in Major Uses of Cropland (National and Regional)

Trends in land use are established over a period of time, and major improvements in statistics can be made by use of photography. Satellite coverage offers perspective on geographic location and associated influences, such as urban-transition-rural, and provides a focus on trends that cannot be duplicated otherwise.

Types of Crops Harvested Annually

Annual crops are difficult to identify at present on the basis of instant photo recognition. It is also questionable whether current research will provide a means in the near future. Nevertheless, crop types can be identified by means of sequential photography. As has been pointed out in this report, planting and harvesting times and cultivation practices, together with other physical aspects of various crops, do permit identification.

Pasture and Range Resources [11]

The pasture and range categories are difficult to identify, particularly when they are associated with other land uses. Without supporting data, these categories would be marginal, difficult, or impossible to identify, depending on the final quality of the sensor image.

Permanent grassland can be most readily identified by relating it to the fence lines and gradations in tone between adjacent fields. Other land uses can be excluded by competent interpreters familiar with regional practices, and in all probability a reasonable degree of accuracy can be achieved with high-quality coverage. Climatic conditions in the region of the country where grassland predominates tend to favor consistently good resolution by photo coverage.

Cropland used only for pasture is most difficult to distinguish in all regions because of its close association with and resemblance to cropland used otherwise.

Forest pasture and range is an extensive use of land, and is therefore difficult to define areally and to classify.

Pasture and Range Productivity

Forage production per acre varies widely among the different types and qualities of pasture and rangeland. For example, an acre of cropland pasture is, on the average, 25 times as productive as an acre of nonfarm pasture and range. The productivity of forest pasture is strongly influenced by the species composition of the stand, its density, and underlying physical factors.

Forage production per acre appears to be an area in which considerable improvement can be expected. Repeated coverage by satellite will not only give seasonal and annual variations related to climatic conditions, but the improved perspective of variations in forage quality (as reflected in stand density and color tone) related to soils and alkali conditions will also provide valuable information for range management and research.

Forage yield from forest pasture can, with some supporting information, be determined from photo coverage since the tree density, contrasted against the light tones of the grassy ground cover, can be clearly distinguished. The gradation of color tone from dense forest to open savannah can be scaled to indicate the quality of the forage.

Changes in Pasture and Range Acreages

Based on the analysis of the difficulties associated with photo recognition of cropland pasture, trends in this category of land use will be difficult to determine. A high degree of error in recognizing cropland pasture will be accompanied by a time lag of several years in recognizing the abandonment of forest pasture. The detection of new grassland pasture may also involve the perspective of several years' time. The 5-year interval of reporting on land use seems to offer sufficient perspective. The subtlety of changes in grassland improvement--brush clearing, fertilization, reseeding, and shifting of cropland to pasture use--will influence the possibility of error. Small parcels which are improved gradually will probably escape notice while the quality is being upgraded.

Forest Land [12]

Experience has shown that forest land can be identified in aerial photography. Other categories of land with forest cover can also be mapped as, for example, plantations down to 50- to 25-acre stands. Many areas in the humid States have several classes of forest land. A reasonably skilled interpreter can distinguish the following categories, especially if regional characteristics are provided as supplemental information.

(1) Forest brushland and brush pasture--regenerating lands with visible brush cover, up to and including pole stands (6-inch diameter) less than 30 feet in height and 40-50 years of age.

This type is an approximate age-class category. It results from the forest regenerative process that takes place on lands formerly cleared for agricultural use, or on older forested areas which have been clear-cut or completely burned by fire.

When cultivated land is abandoned, the regenerative process may be rapid; deciduous and coniferous seedlings take hold, resulting in fully stocked pole stands, up to approximately 30 feet in height, within 40 to 50 years.

When land has been pastured during the regenerative process, species such as thornapple, wild berry bushes, and firecherry become partially established; the better hardwood species do not because of grazing competition which impedes forest regeneration and delays complete regeneration for many years. As a result, the land remains in the brushland category for long periods of time.

Intermittent grazing frequently occurs on this type of pasture, particularly if the land is near water and farm buildings. However, once land has reverted to forest brushland, is not used regularly for grazing, and is not accessible to water and barns, it should be classified as brushland rather than permanent pasture.

When old field lines and fences are still plainly visible on the aerial photo, the forest stand is probably still in the brush pasture category unless the average height of the stand is well over 30 feet.

(2) Forest lands--natural stands, at least 50 percent or more stocked with deciduous or coniferous trees over 50 years of age and more than 30 feet in height.

Generally, these stands mark the residual forest lands which were never cleared for agriculture or completely clear-cut for forest products. However, some cleared lands which were abandoned over 50 years ago will have become forest stands; the average height of the stand will exceed 30 feet.

Some forest lands are commonly included with permanent pasture.

(3) Plantations--artifically stocked; any species, age,class, or size.

<u>Nonagricultural Land Uses</u> [13]

Among the special land uses, urban areas [14] are most readily defined. Strip development of housing along rural highways can be readily identified if the houses are reasonably contiguous for a length of 1,000 feet or more. Transportation areas [15] down to and including town and country highways

are identifiable. Farm roads and lanes [16] are not consistently evident and therefore are not classified separately in the "Land and Water Report."

Parks and wildlife refuges [17], national defense installations [18], and most other extensive uses of land are not easily delineated. The problem is one of ownership; use may be known but the areal extent is often indefinite. In these instances, simple supplementary sources must be used to support data obtained even with conventional aerial photography.

The land area in marsh, rock, true desert, and tundra [19] is readily identifiable, and since change in these categories is rare, a rather precise mapping can be obtained when aerial coverage is available. Because of contrast generated against a broad and generally uniform background, changes can be detected as they occur in subsequent flights.

<u>Irrigation and Drainage</u>

Irrigation and drainage in all of their principal forms provide a distinctive signature of sufficient size to be readily recognized in aerial photography.

Land uses on flood plains can be clearly identified as to area and extent. The detailing and assigning of degrees of protection from floods of various frequency cannot be done regardless of scale or quality of the photo. This type of information is obtained directly from other sources, Federal and State.

Areas under irrigation as practiced in most of the Western States can be precisely identified in photos because of the strong contrast between wet and dry soils. Identification of land with overhead irrigation as now used in the more humid areas is less feasible because of the transient nature of the installations and the low contrast in tones between the irrigated and nonirrigated adjacent lands.

While small structures for retaining or supplying water on farms (farm ponds, reservoirs, and pit tanks) can usually be identified in aerial photos, these objects may not be recognized in satellite photography. Small ponds in the South may be lost in forest pasture; elsewhere, size and/or contrast with the background would indicate their presence.

<u>Use of Irrigated Land in the West</u>

In terms of acreage, hay and pasture are the most important uses of irrigated land in the West. Uses of irrigated land, as in other cropland, can be identified with reasonable accuracy if repetitive photo coverage is available. One view, or several views at random times throughout the year, may not suffice. Periodic coverage during the planting-growing-harvesting cycle, depending on the complexity of the cropping pattern, will produce identification of crop type. Hayland and pasture, including the number of hay crops per season and even the fertilizing or treatment of these areas, can be obtained from 30-day interval coverage, if the image quality is excellent. It is expected that repetitive coverage by ERTS will be at 18-day intervals.

Crop quality in irrigated lands can be clearly observed, and can be evaluated with supporting information. This is especially true of alkali damage in irrigated lands.

Trends in Irrigated Acreage

Trends in irrigation--increases and decreases in acreage--can be precisely ascertained because of the strong photographic contrast related to the amount of water applied to a field. Alkali conditions are a major reason for a decrease in irrigated area. Satellite coverage, which will give a precise geographic "fix" on these trends and changes, will be a significant improvement over the present system of basin irrigation use on a sample design.

Sources of Irrigation Water

Only major sources of surface water can be directly related to the irrigated land via photo recognition of canals and similar features. Lacking the physical evidence, inferences supplemented when possible by secondary source information will indicate ground water sources.

Overhead irrigation supplied by ground water or by intermittent use of surface water would probably pass unnoticed and unrecorded by the photo interpreter.

Drainage

As in the irrigation category, established physical drainage structures on the land surface are sufficiently large and continuous to be readily observed, identified, and reported by photo mapping. The drainage ditches of Indiana, Iowa, Missouri, and the Delta country, for example, are clearly visible in the ultra small-scale negatives and the enlargements used in this study. The extensive subsurface drainage of Wood County, Ohio, and Kern County, Calif., are detectable only in conventional photography, and then only at specific times when the subsurface system differentially dries the soil above the tile.

SUMMARY OF INTERPRETABILITY

Agricultural land, as characterized in the "Land and Water Report," can be identified with varying degrees of success from aerial photographs. According to the research performed for this study, black and white simulated satellite imagery of specific scale and quality would provide the following information on land use.

(1) Cropland: All can be identified.

(2) Harvested cropland: All generally identifiable, especially if plants are destroyed during harvest and if photos are obtained at the proper season.

(3) Orchards and vineyards: Identifiable, and assumed to be harvested if maintenance activity level of the planting is satisfactory.

(4) Crop failures: Would demand timely specialized coverage, which might not be economically feasible.

(5) Cropland used only for soil improvement: Generally cannot be identified.

(6) Cultivated summer fallow areas: Generally can be identified in areas where it is the common practice.

(7) Idle cropland: Identification generally good.

(8) Cropland pasture: Identification is of questionable accuracy.

(9) Double cropping: Can be identified only with time-lapse photography (not a scale problem).

(10) Crops for feed vs. human consumption: No basis for decision available.

(11) Cropland uses by regions: Uses can be summarized on any area basis requested.

(12) Pasture and range: Readily identifiable; but determination of intensity of grazing questionable.

(13) Forest areas that are pastured: Cut areas can be identified; forest range can be identified if generally grazed. Small areas are more difficult to identify. Forest lands that are in plantations, have been cut over, or are in natural growth transition can be identified.

(14) Changes in land use: If it is possible to identify the land use, then changes in that use can be obtained by sequential coverage.

(15) Commercial forest areas: Generally identifiable.

(16) Noncommercial forest areas: A value judgment, but one that can be developed.

(17) Special uses: Photo interpretation is particularly well adapted to identifying intensive special uses, such as built-up or urban areas and highways. Boundaries of parks and public installations in rural areas are not easily identified.

(18) Irrigated land areas: Areas with permanent irrigation installations are quite easily identified; those with portable sprinkler systems are not.

Certain applications of aerial photography to land use classification do not appear to be feasible. Most of these applications center around determination of ownership patterns, specialized land use, or the end use of crop planted. For example, it is not possible to identify soybeans that are produced for oil as opposed to other uses.

Photo Reduction

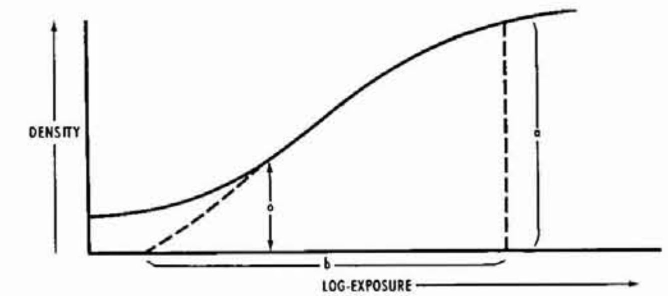
The film ultimately adopted for use in simulating satellite photography was S-243, a slow-speed high-definition panchromatic emulsion with an extended red sensitivity used for high-altitude reconnaissance. Normal development is 8 minutes in D-19. With this development, the film reaches a gamma 7/ of 2.3 to 2.4. The film has an Aerial Exposure Index of 1.6 (the reciprocal of twice the exposure--in meter-candle-seconds--at the point on the toe of the characteristic curve where the slope = 0.6). Its granularity is indexed at 7.4. (The root-mean-square granularity value indicates the impression of graininess that would be produced if the samples were examined visually at a magnification of 12 times when the film has a net destiny of 1.0, excluding the density of the support.)

Because the contact prints used in the study had already been filtered for aerial haze and the effects of ultraviolet rays, they represented a contrast ratio in excess of the natural field objects; thus, alterations in exposure and development were necessary. Sensitormetric tests indicated that exposures based on the use of ASA 2 and short development in D-76 would be adequate. Actually, most of the film was handled in D-76, diluted 1 to 1 with water, at 68° for 2.25 to 2.50 minutes. A gamma of 0.8 to 0.9 resulted.

Photo Enlargements

Enlargements for this study (unless otherwise stated) were made with a Precision "A" enlarger, using a no. 211 enlarging bulb and a modified condenser system. The paper used was Polycontrast Rapid, corrected by gelatin filters and developed in Dektol film 1.5 to 2.0 minutes. Enlargements from these ultra small-scale negatives introduce a large amount of degradation in the process.

7/ Gamma is conventionally described as a numerical means of measuring the degree of development of a specific film under controlled conditions. Gamma is the tangent of the angle resulting when the straight line portion of the characteristic curve is projected to the log E axis. Thus, gamma is easily measured by comparing the ratio of a/b.



Most of today's enlargers compromise with quality for a variety of reasons:

(1) Enlargers must work under a wide range of conditions and often with several lenses.

(2) High-quality instruments are prohibitively costly.

(3) Enlarging lenses vary in quality. (Even those that are corrected for normal projection distances must necessarily cover a range from 4 to 10 times their focal length, unless they are designed for a limited function.)

(4) Multiple problems are encountered in holding the film negative in the desired plane.

(5) Evenness of the illumination of the film plane is accomplished by either diffusers or a condenser system. Condenser enlargers normally give better definition and contrast. However, even here the matter of the range of enlargeability often dictates optical compromises.

(6) Light is usually supplied by a diffuse bulb. Some enlargers offer, as an option, a point source of light; however, this requires additional precision focusing of the light source to approximate or duplicate Kohler illumination.

Degradation

The aerial photography used as a control in this study was taken under near-optimum conditions. The contractor waited until atmospheric conditions were favorable. Under these circumstances, the quality of this test photography (used for the ground image) may well be equal to or of higher quality than much of the satellite coverage. On the other hand, each step of the simulation process contains an element of degradation that to some degree reduces the quality of the final product, compared with a "standard" photographic image obtained from a satellite. This evaluation is largely subjective, however. The standard image is not yet finally defined. It was assumed for the study that the satellite imagery would be electronically relayed by a Return Beam Vidicon (RBV) system, 8/ whose resolution would likely be limited to 20 meters. 9/ This resolution would provide high-quality imagery, both wide-scan panoramic and nonstereo. Interpretation is also expected to be made easier because coverage will be timed to provide exposures at higher sun angles.

8/ A system similar in many respects to television imagery.
9/ Ground resolution for the RBV system to be carried by ERTS was later set at 100-200 feet. The first ERTS-RBV imagery will probably have a ground resolution in excess of 100 meters.

Evaluation of the degradation has been based on optics, films, processing, and other photographic operations. The simulation process described in the study results in a degradation factor of 0.65, or roughly a quality of 65 percent of expected satellite coverage. This scale is largely based on accumulated (negative) values of resolution.

APPENDIX B. LIMITATIONS ON SATELLITE PHOTOGRAPHY

The present study emphasizes the photographic aspects, such as scale or resolution of land use classification from satellites. Photographic operations, however, do not include all of the factors which influence interpretability. The value of satellite reconnaissance in land use studies will depend in large measure on the time of year (season) and weather conditions.

To be useful as a means of supplementing or eliminating other sources of land use data, the coverage must be obtained in a critical time period (season). For example, 2 weeks in mid-July give optimum conditions for the proper development of crops, diseases, and so on, in Northeastern United States. Earlier coverage in this region will result in imagery of lower interpretive value, particularly if wet spring weather has caused crops to mature slowly or has caused a delay in committing cropland to a specific use. On the other hand, earlier coverage of the South and Southwest, where the growing seasons are more advanced, might provide imagery of significant value.

Weather conditions will determine the ultimate limitation on satellite coverage. Of the sensors now available, only radar will record through cloud cover. Unfortunately, imagery now available from these radar sensors is of marginal value for land use classification. Only people directly concerned with aerial photography can fully appreciate the relatively few "photographic days" available for flying specification photography.

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