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REMOTE SENSING OF AQUATIC PLANTS

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ABSTRACT

To develop a means of rapidly assessing the extent and composition of aquatic plant infestations, a study including both computer simulation and field exercises was begun in 1975 to test various sensors in terms of their ability to detect and discriminate among noxious aquatic macrophytes. A survey survey of researchers currently studying the problem and a brief summary of their work is included. Results indicated that the sensor types best suited to assessment of the aquatic environment are color, color infrared, and black-and-white infrared film, which furnish consistently high contrasts between aquatic plants and their surroundings.

1. BACKGROUND

One major responsibility of the Corps of Engineers is to maintain the nation's navigable waterways. This maintenance depends partly on the control of noxious aquatic plants that threaten to choke the many channels. The ability to assess rapidly both the areal extent and the species composition of the various aquatic species greatly enhances the control efforts. Decisions concerning the type of control measure to be applied, the magnitude of the application, and the location for application require this information. Currently, an adequate means does not exist at the operational level for rapidly determining the position, extent, and character of aquatic plant infestations over large areas. In addition, the dynamic character of aquatic plant communities requires the ability to examine large areas repetitively, both to identify areas where rapid growth is occurring and to monitor the effectiveness of ongoing control measures.

The U. S. Army Engineer Waterways Experiment Station (WES) research efforts in aquatic plant control include developing an operational capability for mapping the distribution and character of aquatic plants with emphasis on ease of application, rapid execution, and use of available remote sensor systems and technology. The final product of the study will be guidelines for using remote sensors and rapidly extracting and portraying information on aquatic plants.

2. PROBLEM DEFINITION

Personnel of Corps of Engineers districts, divisions, and WES met at the WES in September 1975 to discuss the informational needs of Corps personnel actively engaged in aquatic plant control at the District level. Their needs included knowledge of areal extent and species composition at two scales and frequencies: yearly regional surveys and more frequent detailed surveys. Particular emphasis was placed on the following species: hydrilla (*Hydrilla verticillata* Royle), Eurasian watermilfoil (*Myriophyllum spicatum* L.), egeria (*Egeria densa* Planch.), waterlettuce (*Pistia stratiotes* L.), waterhyacinth [*Eichhornia crassipes* (Mart.) Solms.], duckweed (*Lemna* sp.), water chestnut (*Trapa natans* L.), and alligatorweed (*Alternanthera philoxeroides* Griseb.).

Acquisition of the data outlined above requires the ability to: (a) differentiate aquatic plants from their common surroundings, such as water or terrestrial plants, (b) differentiate from one another the various aquatic plant species, and (c) differentiate, for a given species, variations in plant biomass. Obviously, each successive differentiation is more difficult, especially for submersed aquatic plant species. It is also necessary that these differentiations be made by Corps of Engineers District personnel on a timely basis without additional manpower.

3. SCOPE AND PURPOSE OF STUDY

This paper will present a synopsis of the work that is being accomplished by the Corps Aquatic Plant Control Research Program on the remote sensing of aquatic plants. Work items planned for the future are also discussed.

The initial study efforts have been designed to determine the feasibility of acquiring the desired information for aquatic plants (i.e. location, species, and character) with existing sensor systems that would be available to the Corps districts. The follow-on work will involve formulation of guidelines for applying remote sensors for data acquisition, including setting forth criteria for mission planning, information extraction, and information portrayal.

4. ONGOING INVESTIGATIONS

The work to data has been to determine the feasibility of acquiring information concerning the extent and composition of aquatic plant assemblages by using currently available remote sensing procedures. The following discussion is divided into four sections: a literature review, a description of remote sensing systems, model studies, and field (imagery) investigations.

4.1 LITERATURE REVIEW

A literature review was conducted to identify current relevant work by other investigators. Scientists at the National Aeronautics and Space Administration (NASA) Kennedy Space Center, Florida, under contract to the Florida Department of Natural Resources, have been investigating the use of aerial photography and interactive image processing to monitor the status of hydrilla in small lakes where white amur fish (Ctenopharyngodon idella Val.) have been introduced (Vause and Davis, 1974). Their work has demonstrated the feasibility of accurately delineating and measuring the area of hydrilla infestations with low-altitude aerial photography. Dr. Charles Welby of North Carolina State University at Raleigh used Landsat data in a study for the Corps of Engineers Wilmington District that demonstrated the feasibility of delineating Eurasian watermilfoil infestations in certain North Carolina estuaries (Welby, 1974). Personnel at the Remote Sensing Center, Texas A&M University, College Station, under the sponsorship of NASA, Texas Water Quality Board, and the Corps of Engineers, have examined the use of aerial photography for detecting the presence of submersed and emergent aquatic plant infestations in selected locations in Texas (Benton and Newman, 1976). The results of these latter studies showed the feasibility of using color and color-infrared (IR) aerial photography to detect the presence of species such as hydrilla, waterhyacinth, and duckweed. The results obtained by these investigators are being used to support and guide the ongoing WES effort by providing basic data from which additional experiments are designed and to supplement the results of the WES studies.

4.2 DESCRIPTION OF REMOTE SENSING SYSTEMS

Remote sensing systems vary considerably in the types of information they provide. Airborne photographic sensors operate in the "visible" portion of the electromagnetic spectrum and record the energy reflected from the surface of ground features. The resulting photographs are normally the easiest of all remote sensing products to interpret because the films used have roughly the same sensitivity as the human eye. Thus, the human interpreter is accustomed to what he sees on the photographs. Other sensors, such as the multispectral scanner (MSS) system in Landsat, also record reflected energy and produce photo-like images of the terrain. The major difference is that, in the case of Landsat, the earth's surface is being viewed from space and the resulting resolution is much less than for photos acquired from an aircraft. Landsat provides the advantage of covering large areas in a single scene.

A second type of remote sensing concerns the thermal-IR portion of the electromagnetic spectrum. Thermal-IR systems record the energy radiated from terrain materials. The amount and spectral character of the energy is a function of the temperature and radiation characteristics of the materials. A third major type of remote sensing concerns radar or microwave systems. These systems (called side-looking radar) transmit a pulse of microwave energy (perpendicular to the airplane's flight path) and record the energy backscattered from the terrain surface. The amount of energy returned is a function of the surface roughness of the terrain surface. Side-looking radar systems also allow coverage of large areas in a short period of time.

Aerial photos and Landsat imagery, because of differences in reflectance characteristics of aquatic plants and their surroundings, are expected to be effective tools for delineating aquatic plant infestations.

Side-looking radar systems may provide a possible tool for regional-type surveys for emergent and floating aquatic plants because of their differences in roughness compared to relatively smooth water surfaces. Thermal-IR sensors are not expected to be very useful. Because of these basic assumptions, aerial photographic, Landsat MSS, and side-looking radar systems are considered to have the most potential for immediate application to the aquatic plant mapping problem, and are, therefore, the remote sensing techniques emphasized in this study.

4.3 MODEL STUDIES

A computerized mathematical model of the relations between photographic remote sensors and the environment has been developed by the WES (Link, 1974) to provide a capability for evaluating the performance of different film-filter combinations for acquiring specific types of data prior to the actual photography. The model was employed to determine the combinations that showed the most potential for allowing discrimination between aquatic plants and their surroundings and between aquatic plant species. The basic process for using the model is as follows: (a) the spectral reflectance characteristics of the feature (a noxious aquatic plant in this case) and its surroundings (other aquatic plants or water, etc.) are input to the program; (b) atmospheric conditions, sensor altitude, and other basic parameters are selected (from a spectrum of conditions available) and the model is run; (c) the output of the computer program is a table giving predicted optical density contrast values for the feature and background and for a variety of selected film-filter combinations. An example of the model output is presented in Figure 1. The rightmost column gives the contrast to be expected for the given feature and background for each film-filter combination listed. For single-emulsion films (e.g. film Nos. 2402, 2403, and 2424) the numerical value of the contrast must exceed 0.30 in order for the contrast to be readily detected by the human eye. The model considers each emulsion of multi-emulsion films (e.g. Nos. 2448 and 2443) individually. Therefore, the model output includes a contrast value for the cyan (C), yellow (Y), and magenta (M) emulsions of such films. The optical density values for individual emulsions do not give a true measure of the total contrast that occurs on these films for a feature and background. Thus, some combination of values is necessary. For the purposes of this study, a simple sum of the three (for the three emulsions) predicted optical density values was considered as an approximate value for the total optical density contrast that would occur for the multi-emulsion films. The sum of the predicted contrast values was compared to the 0.30 threshold previously mentioned to assess the capability of multi-emulsion films for discrimination of specific feature-background combinations.

Spectral reflectance curves (for features and backgrounds) are the only input required for execution of the model. For this study spectral reflectance curves of common aquatic plant species and water bodies were obtained in selected locations in New York, Florida, Louisiana, and Texas during the late summer of 1975. Some additional data were obtained in Louisiana, South Carolina, and Mississippi during the summer of 1976. A list of those aquatic plant species and other features associated with them (e.g. water) for which reflectance data have been collected is given in Table I. Species were compared to every other prominent species associated with it, as well as to the surrounding water.

The specific objective of the model studies was to make an initial assessment of the ability of available photographic film-filter combinations for discriminating (a) areas with submersed aquatic plant infestations from areas with no submersed aquatic plants, (b) areas with emergent aquatic plants from surrounding water, (c) specific submersed aquatic plant species from one another, and (d) specific emergent aquatic plant species from one another. It must be recognized at this point that the ability to detect the presence of submersed plant infestations is very dependent on water clarity. It is logical to assume that in very turbid water, it would be difficult to detect the presence of plants only a few centimetres below the water surface; whereas in clear water, it may be possible to detect infestations at much greater depths. The data represent relatively clear water conditions and, as such, should not be assumed to represent turbid water where the adequacy of specific film-filter combinations to detect submersed plants could decrease significantly. Table II presents a comprehensive tabular summary of the results of the model study.

The results of the model studies suggest that in almost all instances (in clear water conditions), it appears feasible to detect the presence of both submersed and emergent aquatic plant infestations with readily available film-filter combinations. In some instances specific comparisons of certain species do not appear to create an optical density contrast of sufficient magnitude to allow discrimination of one species from another. However, there are also instances when available film-filter combinations appear to be quite capable of allowing discrimination among certain aquatic plant species, especially emergent or floating ones.

The ability to discriminate among plant species based on image tone does not necessarily imply the ability to identify a specific plant species without some additional information, such as a prior knowledge of possible species for a given waterbody or growth patterns of a particular plant. Clearly, attributes of plants other than spectral properties must be considered, namely pattern and associative properties. These properties are more difficult to quantify than spectral properties since they are more a subjective impression than an easily measurable entity.

4.4 FIELD STUDIES

To confirm the model predictions and to establish further the capability to acquire information on aquatic plant species extent and composition with aerial photography, a number of field studies were initiated. The field studies consisted of acquiring ground truth data and aerial photographs of selected water bodies having infestations of a variety of aquatic plant species. The field studies were initiated with the acquisition of ground truth and aerial photography at Lake Boeuf, Louisiana, in May 1976; Lake Theriot, Louisiana, in May 1976; and Ross Barnett Reservoir, Mississippi, in April 1976, as shown in Table III. Ground truth data and photographs were obtained at Santee-Cooper Reservoir (Lake Marion), South Carolina, in July 1976. The aerial photographs were obtained from light aircraft with hand-held 35-mm and 70-mm cameras. A second ground truth and air-photo survey was accomplished at Lake Boeuf, Louisiana, Lake Theriot, Louisiana, and Ross Barnett Reservoir, Mississippi, in September 1976 to examine late-season or mature-growth-stage conditions.

In addition to the detailed work conducted at the three test water-bodies, high-altitude (acquired at a scale of 1:120,000 with a U-2 aircraft) aerial photographs and Landsat imagery have also been acquired. These images are being used to determine the relative quantity of information available on high-altitude imagery with respect to the information available on the low-altitude, detailed photos.

Figure 2 shows examples of the low-altitude aerial photographs of Lake Theriot, Louisiana, obtained in the field studies. Features evident on the photos are a canal entering the lake (near the top of each photo), an area of marsh vegetation (upper half of each photo), and an area of water heavily infested with hydrilla with some local infestation of waterhyacinths (lower portion of each photo).

Examination of the photographs in Figure 2 shows that the color-IR film with yellow filter (Figure 2a) produced the best discrimination of the submersed hydrilla from areas with no hydrilla (mainly the canal and its extension into the lake) and the rafts of waterhyacinth. The color film (Figure 2b) shows the rafts and fringe areas of waterhyacinths very well, but does not produce much contrast between the hydrilla-infested areas and the open-water areas, although the hydrilla is detectable. The black-and-white infrared film (Figure 2c) was underexposed but did produce good contrast between the hydrilla-infested areas and open water. The waterhyacinth rafts are detectable on the image but not as well as on the color-IR and color images (Figures 2b and 2c, respectively). The panchromatic film with red filter (2d) shows little contrast between the hydrilla-infested areas and the open-water areas; the areas of waterhyacinth were readily apparent. Of the four film-filter combinations shown, optical densities of (a) 1.04, (b) 0.81, (c) 0.85, and (d) 0.46, respectively, were predicted for hydrilla versus waterhyacinth. These relative values are not inconsistent with subjective evaluation of photographs, except for the relative ranking of the black-and-white infrared (c) and the Plus-X panchromatic film (d). The optical density contrast predicted for each film-filter combination shown for hydrilla and its surrounding water was (a) 0.41, (b) 0.16, (c) 0.68, and (d) 0.05, Again, the relative order of contrast agrees with predictions with respect to the color infrared and color films.

The results of the low-altitude aerial photo examinations are consistent with the results of the model studies and demonstrate the ability of commonly available photographic systems to obtain information concerning the extent and composition of aquatic plant infestations. For example, the results of the model studies summarized in Table II show that each of the organisms for which spectral reflectance characteristics were analyzed could be distinguished from its surrounding water by one or more of the film-filter combinations considered. Field exercises supported this prediction. Similarly, waterhyacinths when photographed with duckweed contrasted markedly in tone, whereas tone discrimination between waterhyacinth and spatterdock was not nearly as distinct. The field results, in summary, essentially agreed with model results in relative intensity of contrast.

Figure 3 shows an enlargement of a portion of color-IR high-altitude aerial photograph of Lake Boeuf, Louisiana. The photograph represents conditions in October 1974, when significant infestations of numerous species (egeria, waterhyacinth, and duckweed) had occurred. The presence of aquatic plants is easily detected on this image. Cursory examination of high-altitude aerial photos for Lake Theriot revealed an ability to detect Eurasian watermilfoil infestations, and imagery of Ross Barnett Reservoir showed the ability to detect watershield (Brasenia Schreberi Gmel.) infestations in September 1975.

Figure 4 shows a photographic enlargement of a band-7 (near-IR) Landsat image of the upper portion or Ross Barnett Reservoir in April 1976. Comparison of this image to ground truth data for the same time reveals that areas of watershield appear to be evident on the image. Landsat band-7 imagery of Lake Boeuf, Louisiana, shows obvious evidence of aquatic plant infestations exhibiting many image tones, indicating a possible ability to obtain additional information. Additional work is planned with the Landsat images in digital format to define the information available on Landsat imagery.

5. FUTURE STUDY EFFORTS

Presently, much emphasis is being placed on detailed interpretation and analyses of the different types of imagery acquired from the field studies. A careful comparison will be made among the spectral, spatial, and associative properties of the individual images and the associated ground truth information. The results of this effort will be a definition of the information gathering capability of each sensor type (i.e. to obtain information concerning the composition and extent of aquatic plant infestations) both for detailed and regional scale information.

Side-looking radar will be further investigated as a potential regional survey tool. A radar imaging mission of the Withlacoochee River Basin, Florida and the area from Lake Apopka to Orlando, Florida, has been executed by the 363rd Tactical Reconnaissance Wing, U. S. Air Force Tactical Air Command, Shaw Air Force Base, South Carolina. The side-looking radar imagery was obtained with the AN/APQ 102 synthetic aperture system that covers a ground swath of approximately 32 km for each flight path and has a resolution of approximately 15 m. A previous study conducted for NASA by the Environmental Research Institute of Michigan demonstrated the feasibility of observing large areas of floating aquatic plants using a very sophisticated and experimental radar system. The U. S. Air Force System is a more operations-oriented system in that it has been used for many years as the standard radar imaging system for Air Force reconnaissance missions. High-altitude aerial photographs of the study areas will be obtained to aid in evaluation of the aquatic plant information available on the side-looking radar imagery. Figure 5 shows the enlarged radar image of Lake Tohopekaliga, Florida, with the known aquatic plants labelled by personnel of the Florida Game and Freshwater Fish Commission. Tall plants can be seen quite vividly on the shoreline contrasted against the water surface. Anomalous patterns on the water surface also appear in areas known to be infested with submerged hydrilla and *Vallisneria*.

The aerial photography obtained for the Santee-Cooper Reservoir System will be used as an example of a large-scale field test for using aerial photos to determine the extent and composition of aquatic plant infestations in a large water body (930 sq km). The photos will be interpreted to delineate areas inhabited by individual (major) plant species and the results field checked for verification. A second aerial-photo mission over the Santee-Cooper complex is scheduled for the spring of 1977.

The follow-on work involves the design, fabrication, and implementation of an effective procedure for Corps district personnel rapidly to acquire needed information concerning the extent and composition of aquatic plant infestations via available remote sensor technology. This may involve development of some automated interpretation procedures for use with high-altitude and satellite imagery for rapid surveillance of very large areas and detection of potential problem areas. In addition, the relative costs of the available procedures and the resources necessary for their implementation will be examined. It is envisioned that several large-scale field programs, such as that described for the Santee-Cooper complex, will be planned and implemented to gain practical insight into effectiveness of the techniques, to identify items requiring additional development, and to effect a technology transfer to potential users.

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TABLE I. AQUATIC PLANTS FROM WHICH SPECTRAL REFLECTANCE DATA WERE COLLECTED

Date	Location	Organism/Feature
Sep 75	Florida	Waterhyacinth, alligatorweed, frogbit, waterfern, tapegrass, pickerelweed, hydrilla, water pennywort, green algae, cattails, water paspalum, Eurasian watermilfoil, salvinia, spatterdock, water lettuce, egeria, associated water
Sep 75	New York	Water chestnut, associated water
Sep 75	Louisiana	Waterhyacinth, coontail, cabomba, hydrilla, associated water
Oct 75	Texas	Waterhyacinth, alligatorweed, associated water
Jul 76	South Carolina	Egeria, waterprimrose, waterlily, associated water
Sep 76	Louisiana	Waterhyacinth (living and dead), American lotus, egeria, frogbit, duckweed, Eurasian watermilfoil, panicum, associated water

TABLE II. TABULAR SUMMARY OF RESULTS OF MODEL STUDIES

	Water	Waterhyacinth	Frogbit	Waterfern	Vallisneria	Hydrilla	Coontail	Egeria	Pickerelweed	Waterlettuce	Salvinia with duckweed	Alligatorweed	Spatterdock	Duckweed	American lotus	Panicum	Naiad	Waterprimrose	Cabomba
Water		□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
Waterhyacinth			□	□	□	□		□	△	□		□	□	□	□	□			
Frogbit			△										△	□	□	△			
Waterfern													○						
Vallisneria																			
Hydrilla							△	○											
Coontail																			△
Egeria																	□	□	△
Pickerelweed																			
Waterlettuce											○	△							
Salvinia with duckweed												△							
Alligatorweed																			
Spatterdock														□	○	△	□	□	
Duckweed														□	○	△	□	□	
American lotus																○			
Panicum																			
Naiad																		□	
Waterprimrose																			
Cabomba																			

Legend

□- Discrimination possible with at least one of the film types considered.
○- Discrimination not possible
△- Discrimination marginal
Blank - Comparison not made

TABLE III. FIELD STUDY SITES

Location	Mean Depth m	Area km^2	Important Aquatic Macrophytes
Lake Boeuf, Louisiana	1-1.5	7.0	Waterhyacinth, *Egeria*, duckweed, watermeal, American lotus, white waterlily, yellow waterlily, frogbit, *Panicum*
Lake Theriot, Louisiana	1-1.5	5.2	*Hydrilla*, waterhyacinth, Eurasian watermilfoil, yellow waterlily
Ross Barnett Reservoir, Mississippi	3.7	121.5	Naiad, pondweed, watershield, American lotus, coontail
Lake Marion, South Carolina	6.7	447.6	*Egeria*, waterprimrose, naiad

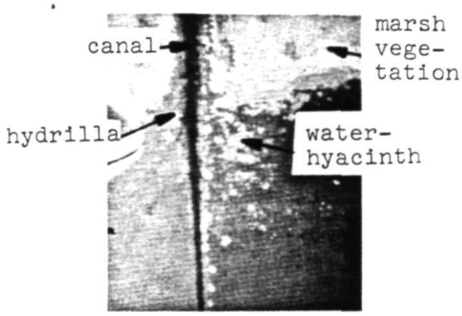
Film	Filter	Optical Density Contrast
2402 Plus-X Panchromatic	12 Yellow	0.017221
2403 Tri-X Panchromatic	12	0.013127
2402	47B Blue	0.178659
2403	47B	0.164144
2402	58 Green	0.079427
2403	58	0.079427
2402	25A Red	0.032514
2403	25A	0.014665
2402	3 Haze	0.063758
2403	3	0.043076
2448C Color*	3	0.000578
2448Y	3	0.270419
2448M	3	0.104692
2443C Color-infrared*	3	0.069592
2443Y	3	0.117260
2443M	3	0.010083
2443C	12	0.146050
2443Y	12	0.067922
2443M	12	0.004641
2424 Black-and-white infrared	12	0.194452
2424	25A	0.202076
2424	87C Infrared	0.173644
2424	87B Infrared	0.213561

Legend

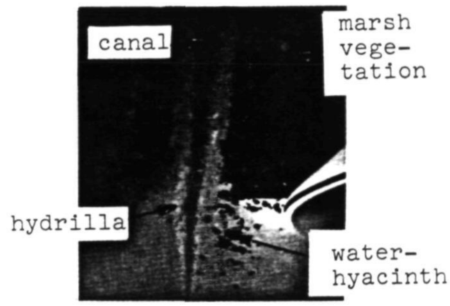
Feature: waterhyacinth, Black Creek, Fla.
Background: spatterdock, Black Creek, Fla.
Atmosphere midlatitude summer haze: 23 km
Zenith angle: 30 deg
Distance to sensor: 1.50 km

* C, Y, and M represent the cyan, yellow, and magenta emulsions, respectively, for multiple-emulsion color and color-infrared film.

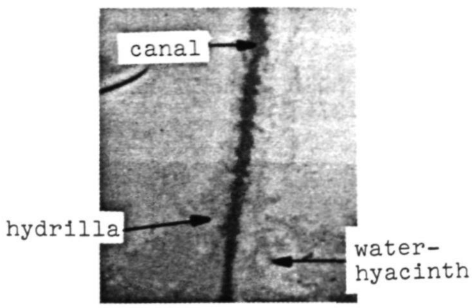
FIGURE 1. TYPICAL MODEL OUTPUT



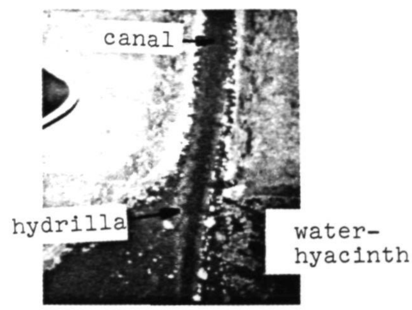
a. Color infrared with yellow (Wratten 12) filter.



b. Color.



c. Black-and-white infrared.



d. Panchromatic with red (Wratten 25) filter.

FIGURE 2. LOW-ALTITUDE (c. 300 m) AERIAL PHOTOGRAPHS OF A PORTION OF LAKE THERIOT, LOUISIANA.

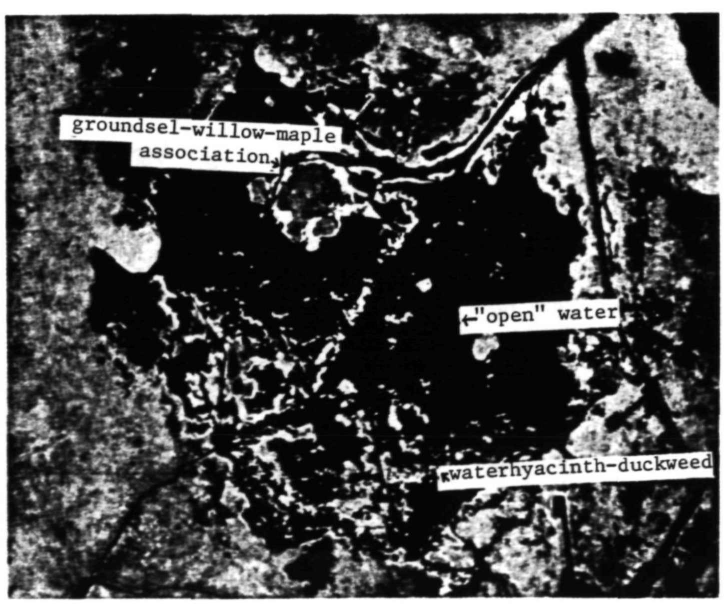


FIGURE 3. COLOR INFRARED HIGH-ALTITUDE (c. 18,000 m) PHOTOGRAPHS OF LAKE BOEUF, LOUISIANA.

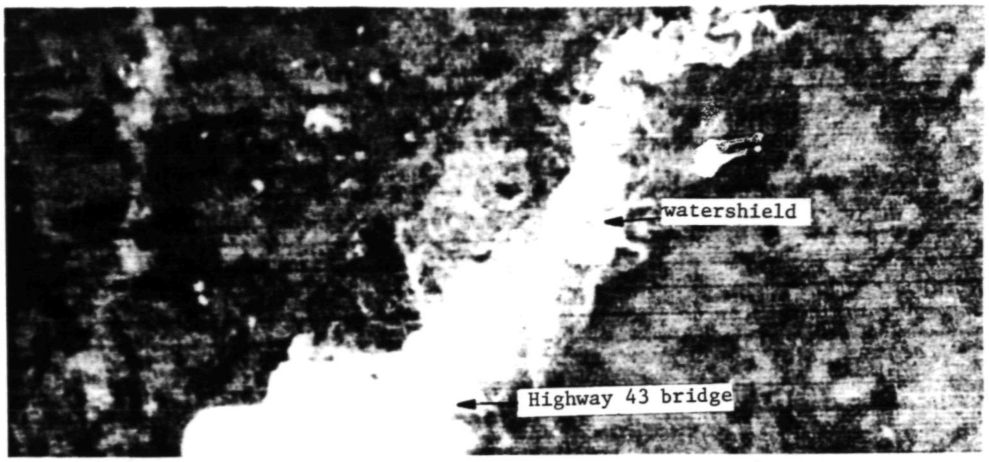


FIGURE 4. PORTION OF LANDSAT BAND-7 IMAGE OF ROSS BARNETT RESERVOIR, MISSISSIPPI (10 APRIL 1976).

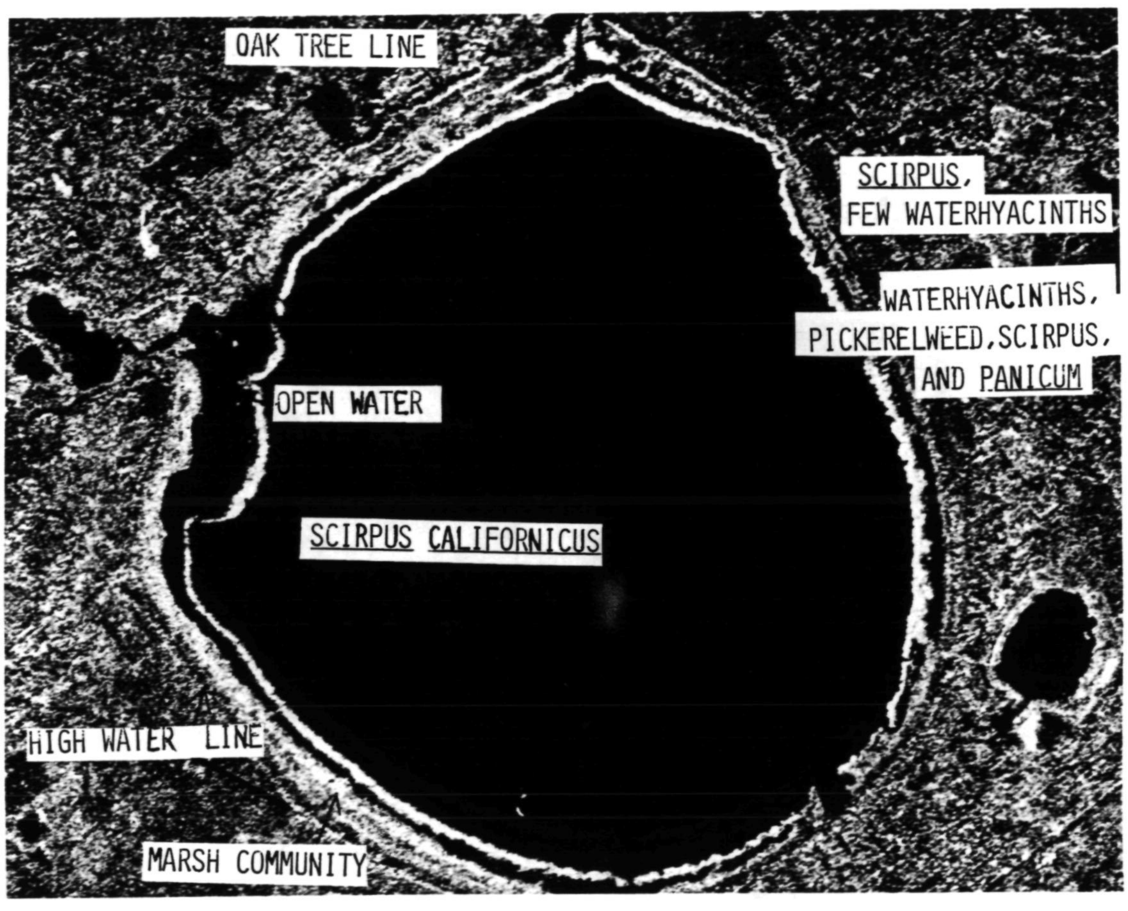


FIGURE 5. RADAR IMAGERY OF LAKE TOHOPEKALIGA, FLORIDA (SEPTEMBER 1976)

PRODUCTION OF A MAP OF LAND-USE IN IOWA THROUGH MANUAL INTERPRETATION OF LANDSAT IMAGERY

by

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ABSTRACT

The staff of the Iowa Geological Survey Remote Sensing Lab (IGSRSL) recently completed a land-use map of Iowa based on manual photo interpretation of LANDSAT I images. The map, the first of its kind for Iowa, was prepared at a scale of 1:250,000 and printed at a 1:500,000 scale. It displays nine categories of land-use; they are urban residential, urban commercial/industrial, urban open, transportation network, extractive land, agricultural land, forest land, water, and reservoir flood pool. Interpretations were verified through the use of Skylab and high altitude aircraft photography. Information from various maps produced by the U.S. Geological Survey, Iowa Department of Transportation, Federal Aviation Administration, and the Iowa Geological Survey also aided in production of the map. Preliminary copies of the map were reviewed by each of Iowa's 17 Regional Planning Agencies as well as the Iowa Conservation Commission and the Iowa Office of Planning and Programming. These agencies corrected interpretation or handling errors and insured inclusion of major land-use changes that occurred subsequent to LANDSAT image acquisition. A total of 6½ man-months was needed to produce the map at a total cost, from image acquisition through printing, of 18¢ per square mile. The map can provide useful information that may be used in conjunction with other resource data in defining some management goals or policies .

INTRODUCTION

Private citizens, public interest groups, and governmental boards and agencies have expressed an ever increasing desire for information about Iowa's natural resources. In part, this desire has been generated by an increased awareness of the complex nature of the problems relative to management of these resources. Such problems as water pollution, flood protection, highway construction, and shortages of energy and food have recently become increasingly insignificant. The search for the solutions to these problems has lead to the introduction of comprehensive land-use and single resource legislation at both the federal and state governmental levels and to the consideration of more restrictive rules and ordinances at the county and city levels of government.

Land-Use in Iowa, 1976 was produced to provide generalized information on the present utilization of land in Iowa. As the first such map produced in the state, it is intended to provide a synoptic view of the distribution of several categories of land-use within the state.

SOURCES OF DATA

Imagery from the LANDSAT Satellite was the primary source of information used in production of the map *Land-Use in Iowa: 1976*. LANDSAT was chosen because it represented the only available source of imagery that provided statewide coverage which was both current and at a uniform, small scale. These attributes allowed production of an up-to-date map at a workable scale, 1:500,000, using a reasonably small number of images and thus making manual photographic interpretation efficient.

For production of the map nine LANDSAT color infrared composite images were obtained from the EROS Data Center at a scale of 1:250,000 (Figure 1). This working scale allowed direct comparison with the U.S. Geological Survey 1 x 2 degree NK series maps. The complete state coverage of the NK series maps provided a valuable base for the LANDSAT land-use interpretations. Use of this scale for map production allowed a 50% reduction to a scale of 1:500,000 for the completed, printed version of the map. Such reduction enhances the appearance of drafted maps.

Uniformity of information across all designated images and the land-use information desired were the criteria used in choosing the land-use categories to be mapped. The images were acquired with zero or minimal cloud cover between August, 1972 and August, 1973. Where available, summer images were used because they were determined to provide the most satisfactory land-use data.

For the southernmost counties in central and western Iowa suitable LANDSAT imagery was not available. To map land-use in these areas 1:80,000 scale color infrared aircraft photography was used. This photography was obtained by the Iowa Geological Survey in cooperation with the U.S. Soil Conservation Service during the spring of 1975. Other photographic and non-photographic sources of land-use information were utilized to verify LANDSAT interpretations. All of these sources, their uses and references are listed in Table 1.

LAND-USE CATEGORIES

Nine land-use categories were designated to be identified and mapped. They were (1) Urban Residential, (2) Urban Commercial/Industrial, (3) Urban Open, (4) Transportation Network, (5) Extractive Land, (6) Agricultural Land, (7) Forest Land, (8) Water, and (9) Reservoir Flood Pools. With few exceptions the categories chosen were those which were readily identifiable on all the LANDSAT images used. One exception was the location of flood pools associated with Iowa's four major reservoirs. These areas were not identifiable on the imagery because the pools were not full when the images were produced. The maximum pool locations were determined using information supplied by the U.S. Army Corps of Engineers at Rock Island and the U.S.G.S. N.K. series maps.

PRODUCTION OF THE MAP

The actual production of *Land-Use in Iowa, 1976* was accomplished by manual interpretation of the 76cm x 76cm LANDSAT color infrared images followed by repetitively cross-checking interpretations against various other data sources, including data provided by regional planning agencies. Mapping was done in ink on overlays of K & E 44 1035 Stabilene ink-surface film. The first step in this process was to map county lines on the overlay within the limits of the image being interpreted. This was accomplished by locating key roads and intersections near county lines on Iowa Highway Commission *General Highway and Transportation Maps* and on images. Then using these landmarks the county lines were mapped on the overlay. The presence of the county lines assisted photo interpreters in locating particular land-use areas to be verified from other maps.

All federal highways and selected state highways were then added to the overlay. They were located by using the U.S.G.S. 1:250,000 scale NK series maps as a base. These locations were then verified from the LANDSAT images. Where disagreements occurred the LANDSAT locations were used. Normal pool and flood pool levels of Iowa's four major reservoirs were also added to the overlay at this time. Information from both LANDSAT and the NK series maps were used for this purpose.

Interpretation and mapping of the remaining land-use categories (forest, extractive facilities, water, airports, and urban residential, commercial and industrial, and urban open) were then completed from each LANDSAT image.

To facilitate mapping land-use from LANDSAT images, the interpreters began with the areas with which they were somewhat familiar. This allowed each interpreter to gain skill at identifying the spectral reflectance characteristics of each of the various land-use categories

Features mapped as towns and rivers were verified from the *General Highway and Transportation Maps* and NK series maps, with the latter being used to locate rivers where they become unidentifiable on the images. Airports were checked against the *Sectional Aeronautical Charts* to verify location, runway composition, and size. Features identified as extractive facilities were verified from the *General Highway and Transportation Maps*, NK series maps, and the map of *Mineral Resources of Iowa*. A final in-house check was accomplished by examining all available high altitude and Skylab photography to verify the interpretations from the LANDSAT imagery. Railroads were added later using the *Current Inventory and Transportation Map of Iowa* and the NK series maps for location.

The next step in the production of the map of *Land-Use in Iowa, 1976* was the transfer of interpretations from the overlays to a 1:250,000 scale base. The base consisted of 12 individual maps. Each map included a grouping of counties chosen so the areas of each map were nearly equal and their physical size would allow easy duplication by the Geological Survey's Diazojet Mark III Whiteprinter. The transfer of information to the base maps was done township by township in order to correct for minor variations between the scales of the LANDSAT images and the base maps.

The area of southwest and south central Iowa not covered by good quality LANDSAT color composites was mapped by interpreting land-use information on the 1:30,000 scale, 1975 IGS-SCS color infrared photgraphy. This information was transferred directly from the photography to the ozalid copies of the base maps, using available U.S.G.S. topographic maps for control. The IGS-SCS imagery provided increased resolution and therefore greater land-use information than the LANDSAT imagery. For uniformity, the data was generalized to match the level of detail obtained by LANDSAT interpretation.

After transfer of the information to base maps, black-line ozalid copies of each map were produced, with the various land-uses color coded with Prismacolor pencils. The colored ozalid prints were then regrouped by counties to correspond with the areas included in Iowa's multi-county regional planning agencies, and a copy of the land-use interpretation was mailed to each agency for additions, corrections, and comments. Of the 17 agencies, 14 returned the maps with corrections and suggested changes. Those suggestions consistent with the purpose and limitations of the map were adopted and the appropriate changes were made. The finished maps were then drafted to produce camera-ready copy, i.e. registered overlays from which the printer could directly burn negatives without the costly process of photographically producing color separations. These were then forwarded to the printer for production of the final map.

IDENTIFICATION OF LAND-USE FROM LANDSAT IMAGES

Because none of the eight land-use classifications interpreted from the LANDSAT imagery produced a unique, visual spectral response on the color infrared composites, a number of factors had to be considered in identifying the land-use of any given area. Some of the factors considered were color (hue and saturation), shape, size, and association with other features. The following section describes many of the parameters used to identify each land use as well as some of the possible problems in interpretation associated with each.

1. Urban Residential. Three classes of urban land-use are differentiated on the map of *Land-Use in Iowa: 1976*. These are residential, commercial/industrial, and open land. On the LANDSAT color infrared images developed, urban areas appear in flesh-colored tones, with white and/or soft blue mottling present in larger cities. Their identification is often aided by their location at the hub of a radiating road network.

Urban residential areas dominated by single famly dwellings produce a flesh to pink coloration on the LANDSAT imagery, resulting from the integration of white tones produced by such high reflectance objects as houses,roads and driveways, and red tones produced by the high reflectance of infrared EMR by trees, lawns and other vegetation. The classification of a particular reflectance as a residential area is a generalization because such areas may contain small businesses and even light industry. However, they are predominantly residential.

The August imagery has proved to be the best for differentiating urban residential areas. They can be easily mapped at this time of year due to their contrast with the more uniformly red colors produced by surrounding croplands and other heavily vegetated areas. Much of the urban vegetation is stressed by lack of moisture, mowing and other urban influences. This stress conbined with the integration of white light from the previously mentioned highly reflective objects reduces the intensity of the red tones of urban vegetation as compared to most rural vegetation. The only features which may be confused with urban areas at this time are large areas of sparsely vegetated, well-drained (usually sandy) soils. Such areas are generally found only near major rivers.

Identifying urban areas on the May and June images has proven to be more difficult. At this time the vegetation within urban areas is especially vigorous, reflecting highly in the near infrared. This produces a bright red and white mottled appearance on the LANDSAT prints which is very similar to the response produced by the combination of forestlands, grasslands, and well-trained soils often found in drainages near urban areas.

Low density urban residential areas may be erroneously omitted from this classification. This omission is the result of large green spaces and associated high reflectance of EMR in the infrared wavelengths. Such areas can be easily misidentified as forest or urban open.

2. Urban Commercial and Industrial. Once an urban area has been identified commercial and industrial areas can be differentiated based on their responses on the color infrared print. Two types of responses are common. Older commercial or industrial areas appear as bluish colors often ringed by a white aureole. The blue colorations are produced by the limited reflectance from the asphalt roofs of older buildings, with the tone of blue dependent upon the amount of white contributed by high reflectance features such as streets, parking lots, etc. between the buildings. The more white present, the lighter the blue tones. The white aureole is produced by the high reflectance features surrounding the complexes.

Newer industrial complexes and commercial facilities commonly use more modern roofing practices and are almost always associated with large parking lots. These produce a bright white response within the urban areas on the LANDSAT prints due to their high levels of non-selective reflection of incident EMR.

These high reflectance industrial and commercial areas may be confused with other large features with similar high reflectance characteristics. Such land-uses as sand and gravel pits, quarries, and certain large, well-drained, bare soil areas as well as such urban features as high density residential areas, large apartment complexes, and institutions may be misinterpreted as commercial and industrial. Other industrial or commercial facilities of smaller size, dispersed among other land-uses or well landscaped with vegetation, may be misidentified as urban residential.

3. Urban Open. The final urban classification, urban open, includes extensively vegetated areas, such as parks, within urban areas. The more natural settings of these parklands tend to promote healthier vegetation than is found in other urban situations. Some reduction of urban stress and much less highly reflective material create a brighter red response, similar to that produced by non-urban vegetation. There is little chance of confusing this land-use with others. In some cases, however, low density, heavily-wooded residential land may be confused with urban open. Agricultural land surrounded by urban areas could also be confused with urban open land use, but these are rare situations.

4. Transportation Network. Three major transportation systems were included on the land-use map: highways, railroads, and airports. All three are represented on the map by only a selected portion of the facilities actually present.

All federal highways and selected state highways were mapped. Although the transportation network in Iowa represents a significant land-use in Iowa (over 3% of Iowa land is utilized as roads or rights of way)[1], only a portion was included on this small scale map, primarily as an aid in the location of specific areas on the map. The decision to map all federal highways, and only key state highways in areas not served by the federal roads, allows a relatively uniform distribution of roads across the state without de-emphasizing other land-uses.

Identifying selected highways can be difficult. The August images proved optimal in identificaiton of the road network in Iowa. The responses produced on August LANDSAT images by this network were off-white to yellow linear features. The large number of section line roads in Iowa create a striking, square, grid-like geometric pattern over the majority of the state. Only in the high relief areas of southern and northeastern Iowa is this grid absent. Because of this large network of roads, and the difficulty in differentiating between concrete, asphalt, and gravelled roads it was necessary to work closely with the U.S.G.S. 1:250,000 scale maps, state highway maps and regional planning agencies in order to assure that the proper roads were mapped. The road network is much less distinct on the spring images. However, at this time paved roads display a slightly greater reflectance than the gravel roads. Even so, it was necessary to use supplementary highway maps when interpreting spring imagery.

At the request of many of the state's Regional Planning Commissions, prinpal railroad routes as chosen by the Iowa Department of Transportation were also included. Although the actual railroad right-of-ways can only rarely be seen on the LANDSAT images, their diagonal trend breaks up the rectangular pattern of agricultural land. This effect leads to relative ease in mapping railroads in the state. The U.S.G.S. 1:250,000 scale maps were used to aid in locating the railroads where the routes were not identifiable on the imgery.

Paved airport runways were readily identifiable on all LANDSAT imagery used for this project. They, like the roads, are excellent reflectors of visible and near infrared EMR and therefore, have an off-white appearance on the imagery. They are relatively short in length and often oriented in a northwesterly or northeasterly direction. Because of the relative abundance of aircraft landing strips around the state, both public and private, it was decided to include only public airports with hard-surfaced runways of at least 457.2 meters in length. This decision allowed use of Federal Aviation Administration Sectional Aeronautical Charts to confirm the locations of airport as interpreted from the imagery.

5. Extractive Land. Extractive facilities, including quarries, sand and gravel pits, and recent borrow pits, are characterized by a high reflectance of incident electromagnetic radiation. On the LANDSAT images these facilities have a very bright white response because of the highly reflective and non-selective nature of the interaction of such materials with EMR. Once the interpreter becomes familiar with this response, they can usually be differentiated from other land-uses. There are, however, other responses which may be confused with these extractive facilities. Very dry, and well-drained soils which have not been recently disturbed often produce a similar white response on the imagery. Urban commercial and industrial areas with newer buildings and large parking lots also produce this white response as do new housing developments and trailer courts. Generally the white produced on the image is seldom as intense as that produced by an extractive facility.

Perhaps the land-use most easily confused with extractive land is large cattle feed lots. The many buildings, use of concrete surfaces, and compaction of bare soil by the cattle create a high reflectance situation very similar to an extractive facility.

Several features of extractive land aid in its identification. Sand and gravel pits are commonly found in association with streams. High reflectance in such locations, especially when vegetation is vigorous, may be mapped as extractive land with a high degree of certainty. Recent borrow pits, areas where materials have been removed for construction, are most frequently found along major highways, particularly interstate highways. Thus high reflectance areas directly associated with such highways, and not associated with urban areas, have a high probability of being borrow pits. In identifying quarries, the presence of a flooded portion and its associated blue (highly turbid) water reflectance may provide a helpful clue.

Coal strip mines, also mapped as extractive, have a much different response. On the LANDSAT images they have a grayish-blue coloration very similar to the older commercial and industrial areas discussed. The tones of the strip-mined areas range from almost black to light blue and often display a white aureole. The grayish-blue tones are produced by the black shale and other rock materials which are devoid of vegetation. Strip mines are very easily confused with bare, poorly drained soils. Thus they are often impossible to identify on spring or fall imagery where bare fields are common. On the August imagery, however, the strip-mined areas may be easily spotted and identified because of the high contrast between the vegetated fields and unvegetated mining areas.

6. Agricultural Land. The vast majority of the area mapped as agricultural land is utilized in agricultural related endeavors, such as row crops, cover crops, pasture land, and farmsteads. Many other land uses, however, also exist in these areas. These include such uses as non-pasture grasslands, scrub land, roads and right-of-ways, very small or low density residential areas, and small ponds and wooded areas. The failure to display these land-uses is not an attempt to minimize their importance. They have not been differentiated on the map because of the inability to accurately interpret them with uniform accuracy over all of the LANDSAT images studied, and the difficulty in displaying them on the small-scale final map.

Row crops, primarily corn and soybeans, are planted in the spring, usually in middle and late May, respectively, and cover over 70%[2] of Iowa's agricultural land. Areas devoted to row crops can be identified on the May and June images as colors of dark to light grayish blue-green. These areas are bare ground, plowed either in the spring or the previous fall. The more recently plowed fields usually appear darker than those plowed earlier because of greater surface roughness and greater surface soil moisture. Rough ground scatters sunlight, reflecting a lower percentage back to the detectors on the LANDSAT. Rain, wind, and other erosive forces act to smooth these fields with time, increasing their reflectance and changing their appearance on the color infrared composite to lighter tones of grayish blue-green. The amount of soil moisture present also affects the tones of bare soil areas. Water, whether as standing water or soil moisture, absorbs a very large percentage of the incident infrared EMR. This makes poorly drained areas with higher soil moisture appear as darker tones. Conversely, better drained areas have lower soil moisture and reflect a greater percentage of incident EMR to the satellite. This produces lighter tones on the images.

The grayish blue-green color is attributable to the general brown to black color of Iowa soils. Brown is produced by combining reflection of EMR of red light wave-lengths with a lesser amount of green wavelengths. When the green reflectance is colored blue and the red is colored green as they are in producing color infrared images, blue to green-blue color is produced. The intensity of the reflectance of these colors and the amount of infrared light reflected controls the tone of the response.

On the July image those row crops planted early in the growing season have germinated and grown to the extent that they can no longer be differentiated from cover crops by a human interpreter. This is also true in August although the Purdue University Laboratory for Application of Remote Sensing has successfully used computer analysis to differentiate corn, beans, and other crops using early August LANDSAT imagery.[3] Such computer manipulation of imagery requires sophisticated equipment and technology and was not considered necessary for a general land-use analysis.

Cover crops, primarily winter wheat, oats and hay crops, constitute about 10.5%[4] of Iowa's agriculture land. Winter wheat is planted in the fall and is not easily differentiated from hay crops, pastures, and non-pasture grasses on spring imagery.

Some differentiation of these agricultural land-uses is possible under ideal conditions. For example, heavily grazed pastureland can sometimes be identified, especially in times of drought, by the lower infrared reflectance of the grazing-stressed grasses. Similarly, for a few weeks subsequent to mowing, hay crops can be differentiated by their lower infrared reflectances. Both of these conditions occur at random times, therefore, no single image is adequate for mapping either land-use without serious omission errors.

7. Forest Lands. The classification of forest land includes all identifiable wooded areas except those within urban areas or reservoir flood pools. Generally wooded areas of 10 acres or larger could be identified; however, this varied with forest location, season, and image quality. Forested areas, like other concentrations of vegetation, reflect very highly in the infrared portion of the electromagnetic spectrum giving them a red appearance on the LANDSAT color infrared composite images. The red of these forests is a darker red than that produced by crops, pasture or non-pasture grasslands. In some instances, however, particularly on the springtime images, patches of forested land can easily be confused with individual vegetated fields. Also, the ability to differentiate between forest and non-forest vegetation is reduced as image quality deteriorates towards the edges of some images. Midsummer and snow-covered winter scenes provide the best definition of these forested areas.

In Iowa the location and shape of many forested areas assist in their interpretation. They usually occur as irregularly shaped patches and frequently border drainage-ways. However, many of the thin gallery forests along drainages were not mapped because of difficulties in identifying or mapping them at the small map scale used.

8. Water. Reservoirs, lakes, ponds, and rivers have been classified as water on the land-use map. Iowa has four major reservoirs: Coralville, Rathbun, Red Rock, and Saylorville. The areas of these reservoirs mapped as water are the recreational pool level of each as determined from information obtained in part from the Corps of Engineers and the 1:250,000 NK series maps. It was necessary to use this supplemental data because on the August 1972 image of southeastern Iowa, both the Coralville and Rathbun Reservoirs are at abnormally high levels, as is the Red Rock Reservoir on the May 1973 image of central Iowa. The new Saylorville Reservoir was not yet filled when the map was published but was also mapped at its designed recreational pool level.

All lakes and larger ponds which could be identified on the LANDSAT images have been mapped. The minimum resolvable size varies from image to image depending on season and pond location. Five acre and larger ponds can be identified on the August imagery, but few ponds or lakes smaller than 50 acres can be identified on the May and June images.

This inability to distinguish water in the spring-time images is primarily due to the similar responses of water and moist, bare soil. Clear water absorbs a very large percentage of the incident near infrared EMR. This, combined with water's low reflectance of red and green EMR, creates a black response on infrared images. The response goes from black to blue with increased turbidity. Bare soil, especially if it is moist or freshly plowed, also produces a black to dark blue response. Therefore, smaller water bodies surrounded by moist, bare soils are difficult to identify because of the reduced contrast. However, smaller water bodies surrounded by materials with a higher reflectance can often be mapped because of increased contrast. Such situations occur where lakes are ringed with trees or grass or, in the case of quarries or gravel pits, where rock is exposed surrounding the open water.

Rivers were also often difficult to identify. Where there is no significant vegetative border in springtime images, the rivers are often not differentiable from bare soils. On the August images the canopy effect of trees growing along narrower rivers often obscures them. Because of these problems, locations of some sections of the rivers mapped on the land-use map were obtained from the U.S.G.S. 1:250,000 scale maps. All information derived in this manner was overlain on the images to correlate locations as closely as possible. Because of these interpretation difficulties it was arbitrarily decided to map *all streams identified as rivers on the U.S.G.S. maps and to exclude creeks* irregardless of their discharge.

9. Reservoir Flood Pools. Reservoir flood pools are those areas of land inundated when a reservoir is at maximum capacity.

The land included in these flood pools is owned by the Federal Government and controlled by the Corps of Engineers. It is intermittently flooded, sometimes for prolonged periods, but some areas are leased to farmers for raising crops when possible. These flood pool areas may also contain forests and are frequently used as recreation areas during times of lower water levels. However, since the flood pool represents the restricting factor in determining land-use in these areas, other possible uses have not been mapped. The boundaries of all four reservoir flood pools displayed on the map were determined from information provided by the Corps of Engineers and U.S.G.S. 1:250,000 NK series maps. This was necessary because none of the reservoirs were at their maximum pool levels when imaged by LANDSAT.

MAP LIMITATIONS

Even though many techniques were employed to reduce errors during the production of the map *Land-Use in Iowa: 1976* undoubtedly some mistakes or misinterpretations are present. However, the use of many sources of data to verify LANDSAT interpretation and the final inspection by the state's regional planning agencies has minimized these errors. Most of the possibilities for error or misinterpretation have been discussed in detail throughout this text. Some registration problems in printing have shifted geographic locations slightly on portions of the map, and a few outlined land-uses were left uncolored due to printer error. The lack of an accurate base of comparison hinders the determination of map accuracy.

To date only a minimal number of errors have been identified on the map. The staff of the Iowa Geological Survey Remote Sensing Laboratory feel that, as a regional interpretation, the map of *Land-Use in Iowa: 1976* represents an accurate portrayal of the utilization of land in Iowa.

CONCLUSION

The Land-Use Analysis Laboratory at Iowa State University in Ames, Iowa, has digitized the map of *Land-Use in Iowa: 1976* and subsequently analyzed the map to determine the area consumed by each land-use category and the percent of the total area of the state represented by each. The following are the results of their study.

Land-Use	Area Hectares x 1000	Square Kilometers	Percent of Total State
Urban Residential	157.1	1,570	1.1
Urban Commercial/Industrial	28.6	285	0.2
Urban Open	14.3	143	0.1
Transportation Network*	14.3	143	0.1
Extractive Land	14.3	143	0.1
Agricultural Land	12,999.7	129,997	91.0
Forest Land	914.2	9,413	6.4
Water**	128.6	1,285	0.9
Reservoir Flood Pool	42.9	427	0.3
Total State	14,314.0	143,136	100.2%

* Transportation Network figures include airports only
** Inland rivers are not included in Water figures.

Because of the difficulty in clearly portraying thin, linear features such as railroads, highways, and most rivers to scale on a small scale map such as the map of *Land-Use in Iowa: 1976* and the inaccuracies involved in digitizing such features, they were not included in the Land-Use Analysis Laboratory's area percentages. Information on the land area used by these features can be obtained from the Iowa Department of Transportation[5] and Iowa Conservation Commission.[6]

Land-Use in Iowa: 1976 was produced in a relatively short time and at a low cost. Map interpretation time, including actual interpretation and checking with other available imagery and maps, averaged about 5 man-days per area for each of the 12 multi-county groupings used for the map production. Another 2½ man-day per area was needed for transferring, corrections, and other changes; this totaled about 90 man-days of interpretation. The nine 76cm x 76cm enlargements of LANDSAT images used were obtained at a cost of $40.00 each from the EROS Data Center, and one roll of mylar and ozalid paper was used. The combined cost for producing the photointerpreted may was $4910.

An estimated 40 man-days was needed by the drafting department to produce camera-ready copies of each of the 12 area maps. Six rolls of mylar were used in the final drafting, and including the drafting pen points consumed, the total drafting costs were $1870.

The cost to print 2700 copies of *Land-Use in Iowa: 1976* totaled $3398. The total cost of production of the map was $10,178.

REFERENCES CITED

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2. - U.S. Department of Agriculture, Statistical Reporting Service, Jan. 1976, "Crop Production".

3. - Bauer, Marvin E. and Cipra, Jan E., 1973, "Identification of Agricultural Crops by Computer Processing of ERTS MSS Data", LARS Information Note 030173, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana, 9p.

4. - U.S. Department of Agriculture, Statistical Reporting Service, Jan. 1976, "Crop Production".

5. Iowa State Highway Commission, 1975, "The Highway Mode: Principal Routes as Proposed, June 1975": Iowa State Highway Commission, Ames, Iowa p. 15-17.

6. - Iowa Conservation Commission, 1975, "Land and Waters Under Jurisdiction of the Conservation Commission" Des Moines, Iowa.

FIGURE 1. LOCATIONS AND DATES OF LANDSAT COLOR COMPOSITES USED FOR MAPPING.

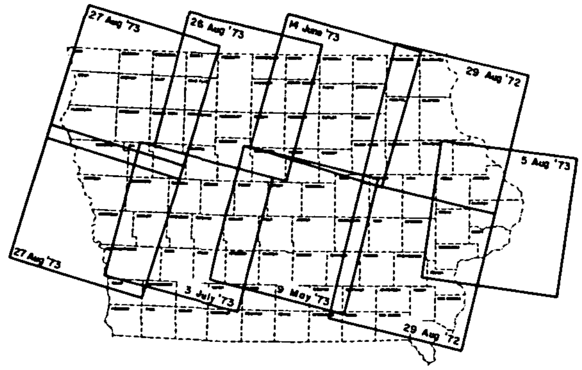

TABLE 1. DATA SOURCES USED FOR LAND-USE MAP PRODUCTION.

DATA	USE	SOURCE
Photography		
Landsat 76cm x 76cm color enlargements (1972-75 Scale: 1:250,000	general land-use mapping	EROS Data Center Sioux Falls, S.D.
NASA Skylab Photography (1973-74) Scales: 1:2,800,000 and 1:950,000	used to check LANDSAT interpretations	EROS Data Center Sioux Falls, S.D.
IGS-SCS High Altitude Southern Iowa River (1975) Basin Study Photography Scale: 1:80,000	mapping regions of Southern Iowa not mapped from LANDSAT-- also used to verify LANDSAT interpretations	Iowa Geological Survey Remote Sensing Lab Iowa City, Iowa
NASA Cornblight Photography Scale: 1:120,000 (1972)	used to check LANDSAT interpretations	EROS Data Center Sioux Falls, S.D.
NASA High Altitude Des Moines (1973) to Omaha Flight Scale: 1:120,000	used to check LANDSAT interpretations	EROS Data Center Sioux Falls, S.D.
Non-Photographic Data		
U.S.G.S. 1:250,000 scale N.K. Series Maps; NK 14-3 15-6, 14-9, and NK 15-1 through 15-12	used to prepare county outlines on base map; verify city, highway, river, railroad, and reservoir location	U.S.Geological Survey Iowa City, Iowa
1975 Official Highway Map of Iowa Scale: 1:825,000	used to verify city location and size and highway location	Iowa Department of Transportation Ames, Iowa
Current Inventory & Transportation Map of Iowa (1974) Scale: 1:1,580,000	used to identify and locate principal railroads & airports	Iowa Department of Transportation Ames, Iowa
Sectional Aeronautical Charts, Omaha and Chicago Scale: 1:500,000	used to locate and identify principal airports	Federal Aviation Administration Local Airports
Iowa Highway Commission County Highway & Transportation Maps, Scale: 1:250,000	used to locate and identify towns, roads, & extractive facilities	Iowa Department of Transportation Ames, Iowa
Mineral Resources of Iowa Scale: 1:500,000	used to check extractive facilities	Iowa Geological Survey Iowa City, Iowa