# SATELLITE IMAGERY APPLICATIONS IN RESOURCE MANAGEMENT

*A Pilot Study to Test Potential Uses of Pre-Processed Thematic Mapper Data for Natural Resource Management in Minnesota*

**A Cooperative project between Bemidji State University, the Land Management Information Center and the Minnesota Department of Natural Resources**

**MARCH, 1990**



*Consultant's Report prepared for the Department of Natural Resources*

# INDEX

# SUMMARY

A coalition of state agencies (the State Planning Agency Land Management Information Center, Department of Natural Resources and Bemidji State University) initiated a pilot effort to explore applications of satellite imagery in resource management. Specifically, project participants sought to determine the extent to which a specific type of imagery could be used to identify land use and vegetative cover characteristics.

Imagery was acquired in a processed digital form from Ducks Unlimited, a waterfowl conservation organization which uses imagery to monitor waterfowl breeding areas and to develop waterfowl production models. Ducks Unlimited generates wetland maps of the prairie pothole region of the United States and Canada using the digital satellite imagery. Since, Ducks Unlimited is a regular user of imagery, it was hoped that cooperative arrangements to interpret the imagery would benefit all parties.

Satellite imagery provides extensive data on land use and land cover. The LANDSAT satellite sensors systematically record data for `pixels' (data recording units) that are about one quarter acre in size. The imagery data were processed by Ducks Unlimited and combined into 255 data classes. The challenge is to interpret what each data category indicates for land use and land cover.

The study concluded that the Ducks Unlimited imagery has considerable potential for a number of applications. It is especially suited to identification of hardwood species (red oak, aspen and birch) and some soft woods (red pines and occasionally lowland conifers and jack pines).

This particular imagery as processed by Ducks Unlimited does not seem to be well-suited for characterization of prairie types, wetlands, rivers or lakes as needed by DNR resource managers. In this pilot, a number of constraints were posed by the processing of imagery data, by equipment used to evaluate the data, by differences in resolution and by the date of the imagery.

Results from this limited pilot were promising; they suggest that imagery has a number of applications for resource managers. However, more work is needed to determine optimal use of the imagery. The DNR and the Land Management Information Center should continue to explore opportunities for expanded use and testing of satellite imagery.

# 1. INTRODUCTION

Since Sputnik, satellites have been gathering data about the earth and its resources. Resource managers long have hoped that imagery from satellites could provide extensive land cover detail at minimal cost. Each new generation of imagery has initiated new rounds of hopes. To date, those hopes have not been fully realized.

Despite growing skepticism, the new generation of imagery available from the LANDSAT satellite has held greater promise than in the past. This generation of imagery provides more detail and greater resolution. Project participants sought to test one product generated by this imagery for a number of specific resource management applications.

The project began with discussions between representatives from the Land Management Information Center (LMIC) of the State Planning Agency, the DNR Office of Planning, and DNR field staff from northern Minnesota, particularly out of the Detroit Lakes district office. These discussions produced a cooperative venture between LMIC, DNR and Bemidji State University. This report describes the project process and results.

A number of staff participated in the project at one time or another. Those who played the largest role are:

**Bill Befort,** *DNR Division of Forestry, Grand Rapids*
**Mark Carlstrom,** *DNR Division of Forestry, Park Rapids*
**Earl Johnson,** *DNR Division of Fish and Wildlife, Detroit Lakes*
**Les Maki,** *Land Management Information Center, State Planning Agency*
**Bob Merritt,** *DNR Division of Waters*
**Howard Mooney,** *DNR Division of Forestry, Detroit Lakes*
**Charles Parson,** *Department of Geography, Bemidji State University*
**Dan Reick,** *DNR Division of Forestry, Grand Rapids*
**Dick Rossman,** *DNR Division of Forestry, Bemidji*
**Joe Stinchfield,** *DNR Office of Planning*

Because of the dedication of these people and their contribution of time, thinking and in some cases dollars, an important project was undertaken and completed with minimal costs.

# I. STUDY OBJECTIVES

The overall project objective was to evaluate use of pre-classified satellite* imagery generated by Ducks Unlimited for several resource management applications. The project sought to identify hands-on applications for satellite imagery data useful in routine field operations on equipment and software accessible to regional DNR personnel.

More specific objectives were to determine if the satellite imagery pre-processed by Ducks Unlimited could be used to:

1) *generate data comparable to the Phase II timber inventory for all public and private land,*

2) *assist in mapping wetlands, particularly calcareous fens,*

3) *determine water resource characteristics (e.g. depth, clarity, etc.),*

4) *identify natural prairie resources.*

As the project progressed, objectives were fine-tuned and more specific objectives were developed.

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* Pre-classified satellite imagery data has been created with the use of specialized software that groups data into homogeneous classes. This project sought to further combine those classes and to determine if those classes indicated land use or vegetative cover types.

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# II. SATELLITE IMAGERY DEFINED

Imagery used in this project was produced by the Landsat Satellite Thematic Mapper imaging system. The satellite is in a near polar orbit at an altitude of nearly five hundred miles. It passes over earth every 16 days. Data from the satellite is beamed to a receiving station and formatted for users.

The imagery used in the pilot was generated from a May 6, 1987 pass over of Minnesota. On this day the sky over northern Minnesota was clear. The passover recorded reflected solar imagery from the ground along a path approximately 100 miles wide.

Because the earth spins as the satellite passes over, the original image is in the shape of a parallelogram. The data are resampled to re-position individual picture elements into a geographically correct projection with true north-south orientation. This allows users to overlay other Geographic Information System (GIS) data on the image with very little loss of positional accuracy.

The satellite records data for every 30 meter rectangular area (one quarter acre) on the ground. Each 30 meter area is regarded as one data 'pixel'. Seven different readings are recorded by the satellite for each thirty meter parcel ('pixel'). The 30 meter pixels are rectified into a geographically aligned image by EOSAT, a corporation with exclusive rights to produce and market Landsat satellite imagery.

Within each data pixel, the seven values which represent the intensity of reflected solar radiation in different wavelength bands, ranging from ultraviolet to near thermal infrared are recorded . Four of these bands were used in this analysis. The bands were processed and thus, a new classification created by Ducks Unlimited. Based on the Ducks Unlimited experience with imagery, bands 2, 3, 4, and 5 were used by them for monitoring wetlands. These bands include the colors green and red, and two bands of infrared which are sensitive to levels of chlorophyll. (Red also is sensitive to a number of other parameters including cell wall structure and leaf water content.)

# III. PILOT PROCESS

## A. Cooperator's Roles

Five groups cooperated on this project;

1) *regional DNR staff from Detroit Lakes,*

2) *Land Management Information Center (LMIC),*

3) *DNR Office of Planning,*

4) *Bemidji State University (BSU),*

5) *DNR Division of Forestry Phase II Forest Inventory and Geographic Information System (GIS) staff from Grand Rapids.*

### 1. Regional Staff Role:

DNR Detroit Lakes and other DNR regional staff contributed the following components:

1) *a list of potential applications for the satellite imagery. This yielded an extensive set of objectives which included applications from most resource managing disciplines. Each objective was evaluated either through a literature search or through experimental use of the Ducks Unlimited data.*

2) *selection of sample townships to pilot imagery testing. These townships are located in Becker County and have diverse vegetation and wetland types, including prairie and forest resources.*

3) *critique of products.*

4) *detailed ground truth.*

## 2. Bemidji State University Role

Charles Parson, professor of Geography at Bemidji State University (BSU), and students in the BSU Regional Studies and Mapping Center conducted the literature review and the experiments on the digital data. Equipment in the Regional Studies and Mapping Center provided the tools for the project. The University research librarian assisted the literature search through use of the computerized search with the Minnitex interlibrary loan program. Negotiations with Ducks Unlimited were handled by Dr. Parson.

The approach was one of working through the data and ground truth at the BSU Mapping Center, producing an output product for the Detroit Lakes DNR staff to evaluate, then repeating the process based on their insights.

The final stage in University involvement will be to train the Detroit Lakes staff to use the system for further resource management investigations. That training should be undertaken in early 1990.

## 3. LMIC/DNR Central Office Role

The DNR Office of Planning provided meeting arrangements, minutes, and overall logistical coordination for the project. Matching project funds were supplied by the Office of Planning and the DNR Division of Forestry.

LMIC provided computer time, generated overlays of forest inventory data used to produce the pilot data set for the seven townships in Becker County, reformatted the Ducks Unlimited data into township-size blocks, and provided technical support and advice throughout the project. LMIC retained the full Ducks Unlimited data set and have that data available for other applications and users. LMIC also provided contract and budget management.

## 4. Forest Inventory Staff Role

The Division of Forestry Forest Inventory GIS staff provided advice and assistance in designing the project and in guiding its progress. Their skills in aerial photography, use of satellite imagery and in forest cover interpretation were essential in developing correlations between satellite imagery and Phase II forest cover classes.

## B. Imagery Source and Pre-Processing

Ducks Unlimited purchases new imagery every three years. The volume of their monitoring effort requires them to use a standardized procedure to classify imagery. Their wetland classification produces three classes which are mostly related to the depth of water in the spring. Because of their regular use of imagery and interest in wetland mapping, it was thought that cooperation with Ducks Unlimited would provide a useful starting point for assessing imagery applications in resource management.

Six of the imagery's seven bands each have a possible range of values from zero to 255. Ducks Unlimited employs a statistical procedure to group the set of values for each pixel into clusters of pixels that are similar in reflectance patterns.

The data set produced by Ducks Unlimited for this study had 255 clusters of landcover type. Because of the large range of values for each band, there is very useful discrimination possible between the clusters. Theoretically, different vegetation types can have different reflectance patterns, called signatures. Signatures for distinct ground covers logically could be expected to exist among the 255 clusters of value groups in the imagery.

The project planned to evaluate use of the Ducks Unlimited pre-processed data to interpret other land uses and vegetative cover types. The original 255 signature clusters were grouped based on common values in the infrared spectrum (band 5). This tended to group vegetation types along a continuum. Vegetation at the lower end is water based (hydric) and non-hydric at the upper end.

A false color table was also supplied by Ducks Unlimited. The composite was generated using an intensified version of that color set. The image looked very much like a color infrared photograph, with dark lakes, tan marshes, and red forests. However, this image contained more information than typical color infrared photos. The imagery color composite presented a wider range of infrared values which measure tree age, moisture content and other conditions. This composite helped orient locations within sample townships.

## C. Evaluating the Satellite Imagery

The project plan was to use Phase II Forest Inventory data and U.S. Fish and Wildlife Service wetland maps to confirm or reject applicability of the Ducks Unlimited satellite imagery data for vegetation mapping purposes. Towards that end, the project team compared imagery and Phase II maps of the study townships.

A first step in the process was to overlay the Phase II forest inventory with the satellite imagery. (See Figure 1.) This was done on a VGA monitor screen since the geographic registration of the forest inventory through processing at LMIC was made to coincide with the geographic registration of the satellite imagery. Using EPPL7 software, the project team created a border around each Phase II timber stand and transferred that outline onto the satellite imagery data display. This high-lighted the diversity of satellite imagery classes contained in each Phase II stand.

Based on previous experience in Itasca County, (Dr. Charles Parson presentation at the **Association of the American Geographer** conference in Portland, 1988) several categories of Phase II timber type and size were combined. The satellite imagery and Phase II classes had numerous visual similarities and anomalies.

The project team cross-tabulated the two data sources. The cross tabulation compared clusters of satellite imagery signatures with Phase II timber classes. This yielded a matrix of 60 (Phase II) by 255 (satellite imagery) classes. The comparison again indicated many significant associations, but no clearly distinct pairings of satellite imagery classes with Phase II classes.

The project team tested several approaches for combining classes of data in the two data sets in order to identify all high correlations Initially, the cross-tabulations showed little consistency between satellite imagery clusters and Phase II primary timber type. The satellite image seemed to display much more variation and detail in forest cover than is displayed on forest inventory maps.

More striking differences existed between U. S. Fish and Wildlife wetland inventory maps and the satellite imagery information. Distinct patterns were present on both data sources, however, little correlation was found in the patterns. The two maps seemed to reflect totally different phenomena for the same areas.

The next step in the process was on-site investigation to confirm or refute relationships between satellite imagery and the two ground truth data sources. The project team generated paper copy maps of the satellite imagery data for the five study townships. DNR staff from the Divisions of Forestry and Fisheries and Wildlife took the maps on site to identify vegetation types displayed by the satellite imagery.

Several iterations of satellite mapping and DNR site investigation of timber type and wetland vegetation helped establish some basic relationship between imagery spectral response and vegetative cover. (See the conclusions section.)

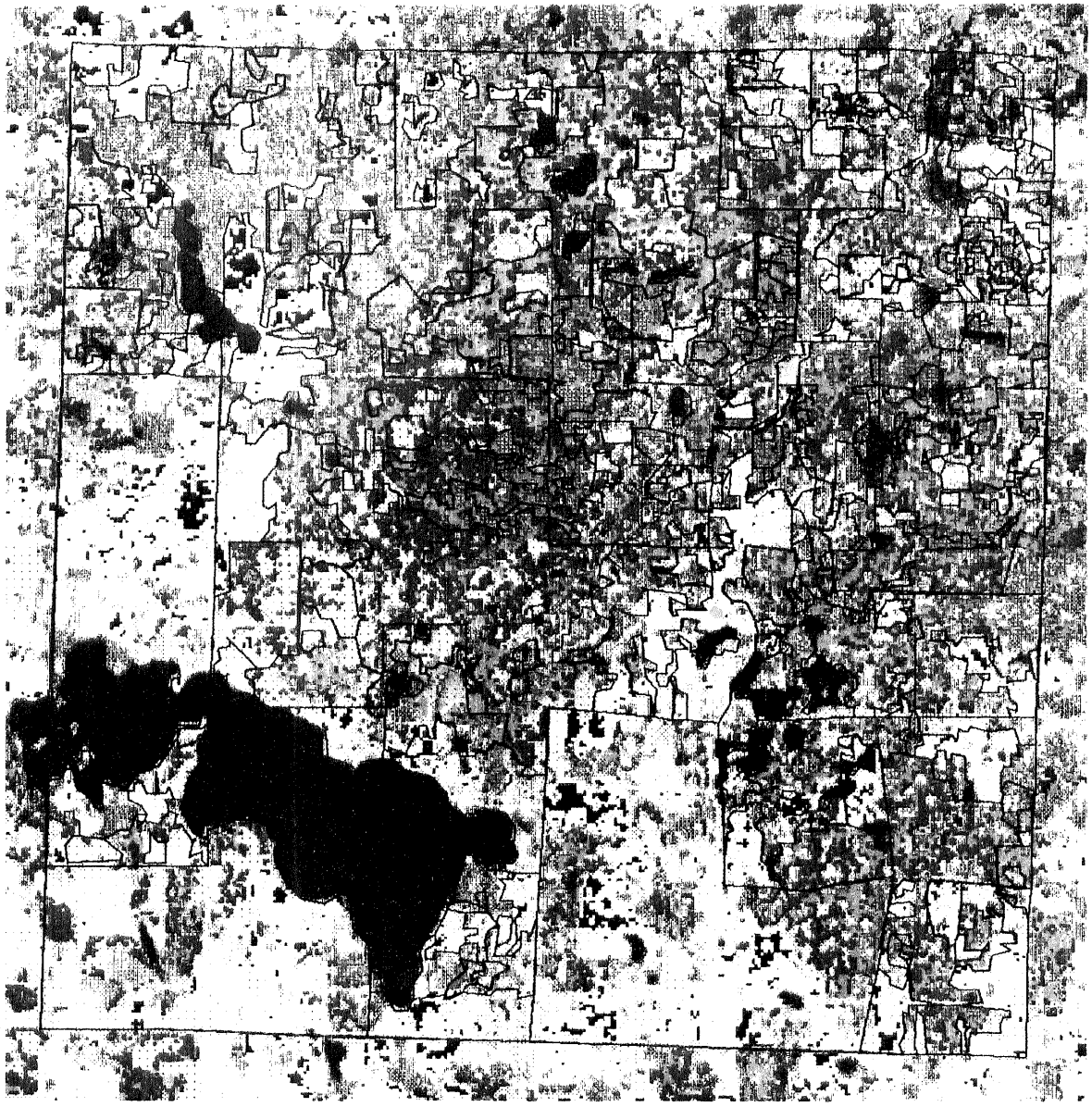

FIGURE 1

Township 139 N Range 37 W

FIELD IDENTIFIED TIMBER TYPES

WITH PHASE II INVENTORY STAND

BORDERS IN BLACK

- MATURE ASPEN
- REGENERATION
- JACKPINE
- ASH ALDER/LB
- RED PINE
- DIVERSE MIXED
- MAPLE--varies
- BIRCH
- RED OAK
- WATER

Polygon overlay represents Phase II stand boundaries.
Cover types were not determined for all signature classes.
More classes could have been developed with additional time.
Notice the transition in timber types from maple in the southwest of the township to birch aspen to the northeast.

Background colors from DU supplied Landsat Imagery

# IV HARDWARE AND SOFTWARE

Analysis of satellite imagery was undertaken using EPPL7 (version 7 of the Environmental Planning and Programming Language). EPPL7 is not an image-processing software package. However, it is appropriate for studying the information content of the pre-processed data.*

The frequencies (or the number of pixels with common satellite imagery signatures) were determined using the 'count' command, which provides a numerical total of pixels with each signature. A two-way frequency count was used to develop a cross tabulation of

*1) Phase II vegetation types*

- compared to -

*2) the number of satellite imagery pixels in clusters with similar signatures.*

Detroit Lakes DNR staff used a 35 mm slide projection system to match aerial photography to satellite imagery plots produced by BSU. The total image, from which the study set was extracted, is maintained on the LMIC central system. Several film recorder images were produced at LMIC using their equipment.

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* The Bemidji State University project staff used a standard VGA monitor on an IBM PS2/60 microcomputer, connected to an HP7475a plotter. Image analysis beyond sorting the 255 classes provided by Ducks Unlimited could not be done. The test, therefore was more of the Ducks Unlimited product than of the thematic mapper imaging system.

# V. CONSTRAINTS

## A. Process Constraints

The initial assumptions behind the process design proved to be incorrect. It was assumed that correlations could be statistically established between satellite imagery signatures and other data sources. When that assumption proved incorrect, the procedures were modified.

The revised process - that of repeat trips to pilot townships to match vegetation type with satellite signature - was time-consuming. With hindsight as a guide, future efforts would allocate ample time for on-site inspection and would identify pilot areas where detailed ground-truth information already exists.

## B. Imagery Constraints

The Satellite Imagery showed much more resolution than the Phase II data classes. The Ducks Unlimited data were occasionally mapping individual trees while Phase II classified entire stands usually of mixed species. In this case, the extreme amount of additional detail actually posed a constraint since interpretations of imagery signatures could not be confirmed without extensive site visits.

The satellite imagery posed two further constraints.

1) *The imagery was from the wrong time of the year for certain applications, and*

2) *Preclassification efforts by Ducks Unlimited resulted in data classifications not suited for some vegetative type identification.*

Satellite imagery literature suggests that more definitive results might have been achieved if unprocessed satellite imagery data had been used rather than data that had already been classified by Ducks Unlimited. (However, as noted earlier, the project objective was to 'test' the Ducks Unlimited imagery.) The Ducks Unlimited clusters were based on bands 2,3,4,5. In addition:

1) *Several studies in the literature search indicate that the band-1 satellite imagery data are useful in forestry identifications. Band-7 also has been very useful for some applications.*

2) *Thermal band-6 might better identify the cold upwelling spring water that distinguishes calcareous fens from normal bogs.*

The spring date of the imagery worked well for forest type identification, however new growth had not yet penetrated through the dead grass in wetlands. Wetland identification accordingly was weak. Imagery from later in the year might well have been more beneficial for wetland typing.

Ducks Unlimited imagery processing was designed for objectives different from those established for this pilot. Their use of satellite imagery is designed to identify duck habitat. Imagery processing optimal for identifying duck habitat could be useful for some of the pilot objectives (e.g. identifying wetland areas) and marginal for others (e.g. identifying tree types). Thus, the difficulty in using Ducks Unlimited imagery for some pilot objectives may be related more to the Ducks Unlimited data processing rather than to the suitability of the imagery itself.

## C. Equipment Constraints

The only limitation occurred in the plotter used to prepare a 'hard copy' (paper map). This mapping equipment was relatively inflexible and slow. A color dot matrix plotter would have yielded two benefits.

1) *It would have allowed preparation of more trial map plots for field personnel to evaluate.*

2) *Those trial plots would be of a higher quality and thus, would have been easier for field staff to assess.*

The following equipment/resources would have been beneficial on this project:

1. *A color dot matrix plotter would have reduced the time required to print maps (from 75 minutes to 10 minutes) and would have produced higher quality maps. Maps used in this report were printed on a high-resolution Hewlett Packard Paintjet plotter.*

2. *Color transparencies that could be overlain on the conventional aerial photographs would have been of great assistance in field work.*

3. *Larger format plotting capability might also have made interpretations easier. Plotting for this project was limited to 8 1/2 by 11 by the hardware.*

# VI. FINDINGS

## A. Imagery Use

**1. Hardwoods:** Digital satellite imagery as generated by Ducks Unlimited can help identify hardwood tree species. The analysis of accuracy and precision in species identification remain to be determined. The imagery seemed well-suited for identifying red oak, aspen, birch and maple stands. This could facilitate market research for locating a hardwood lumber industry in the area by identifying a more precise estimate of species acreage on private and public lands. (See Figure 2.)

**2. Softwoods:** Softwoods are clearly distinguishable using the satellite imagery, however the study area has an insufficient number and range of softwood species to provide a good test of the imagery potential. The imagery seemed to identify red pine stands with some consistency and jack pine and lowland conifer stands depending on the site.

**3. Wetlands:** The Ducks Unlimited satellite imagery may be useful for identifying wetlands for Ducks Unlimited objectives but was not ideally suited for DNR resource management efforts. The imagery classes oriented towards wetland identification tended to include larger areas than DNR inventory maps indicated to be appropriate. For example, some cultivated fields seemed to have the same imagery signature as wetlands. The project lacked the time to explore these signature relationships extensively.

Within wetland areas, the imagery showed some spatial organization, however the patterns could not be matched to mapped phenomena. It appeared that some land uses or covers were being identified in the satellite imagery that were not being mapped by conventional sources.

**4. Water Depth/Quality:** The Ducks Unlimited imagery was not useful for surface water penetration. The Ducks Unlimited pre-processing produced two classes which contained all surface waters. These could be used to estimate surface water areas, however, they did not allow discrimination between quality of the water, or submergent features.

**5. Prairie:** The Ducks Unlimited imagery was not well suited to identifying natural prairies. Resolution was the primary constraint. The Thematic Mapper records data for a pixel of about a quarter acre in size. Natural prairies tend to have considerable vegetative diversity within any quarter acre leading to difficulties in correlating spectral signature to prairie cover.

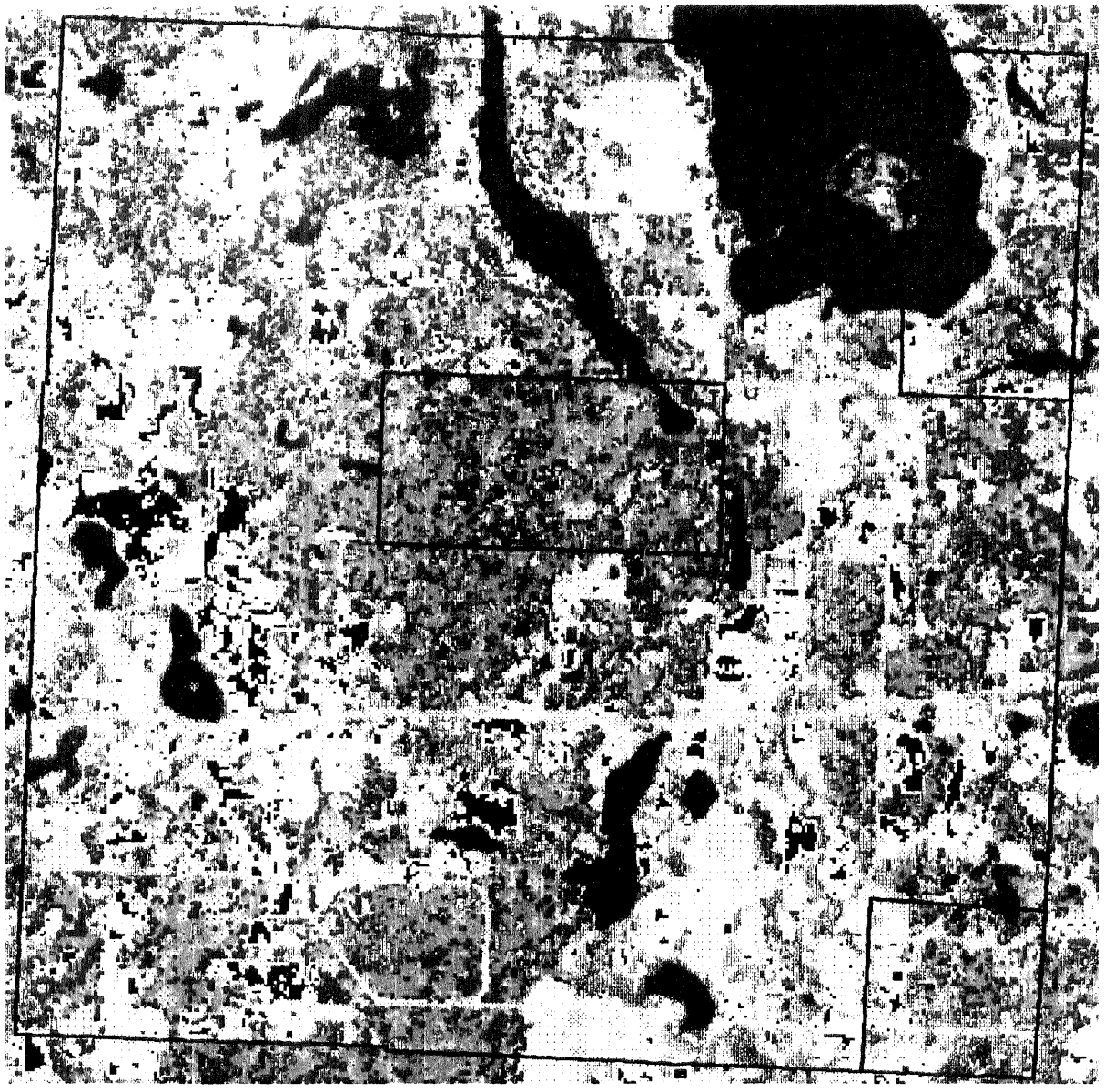

FIGURE 2

Township 139 N Range 40 W

FIELD IDENTIFIED TIMBER TYPES

With State Owned Parcel Boundaries

- MATURE ASPEN
- REGENERATION
- JACKPINE
- ASH ALDER/LB
- RED PINE
- DIVERSE MIXED
- MAPLE--varies
- BIRCH
- RED OAK
- WATER

Polygons enclose state-owned land.
Cover types were not determined for all signature classes.
More classes could have been developed with additional time.
Notice how effectively the imagery portrays tree species diversity
and the detail provided on private land.

Background colors from
DU supplied Landsat Imagery

**6. Streams:** Small streams were generally not identifiable for two reasons.

a. *Overhanging trees obscured water features from satellite sensors.*

b. *A small stream occupies only a part of each pixel. The remainder of the pixel was some form of vegetation. This mixed class of water and vegetation yielded nearly 70 of the 255 clusters of data.*

**7. Other Cover:** The imagery also may be well-suited for identifying other cover types such as timber cutover areas and agriculture. For example, a known timber trespass site of three acres was clearly identified. However, the project team made no systematic effort to validate these land cover interpretations.

The imagery can be used to generate maps of fairly large detail with significant applications even for site resource management and planning. Figure 3 indicates cover type for one section of land generated from Ducks Unlimited imagery. Each square in the section is slightly smaller than a quarter acre in size. Potential applications for data of such great detail are tremendously varied. Virtually every resource-managing discipline would benefit from development of an accurate data base with this level of detail

Development of such a data base is possible and feasible. However, much additional work is required to develop a better understanding of the strengths and limitations of satellite imagery.

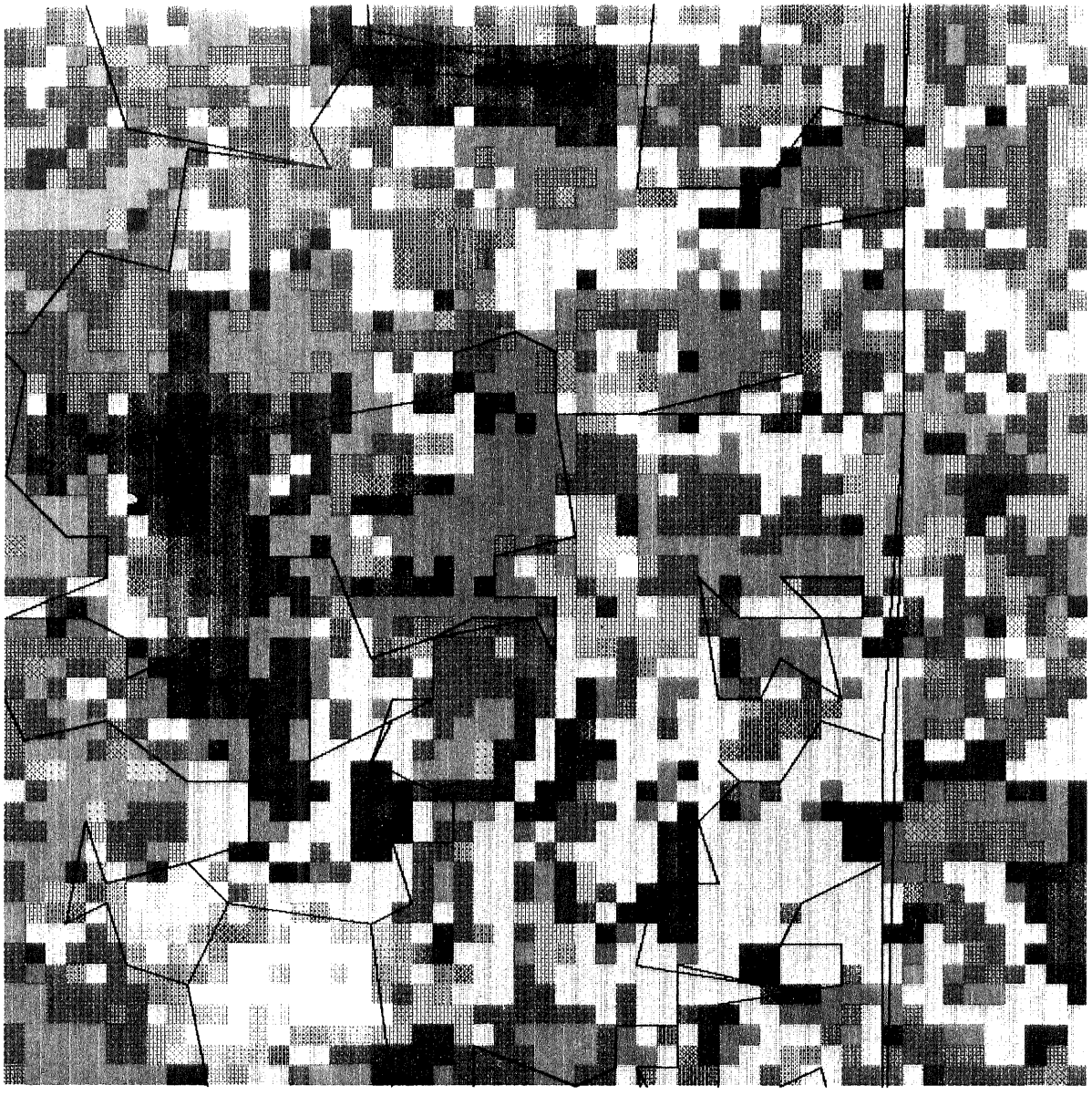

FIGURE 3

Township 139 N Range 37 W Section 13

FIELD IDENTIFIED TIMBER TYPES

WITH PHASE II INVENTORY STAND

BORDERS IN BLACK

- MATURE ASPEN
- REGENERATION
- JACKPINE
- ASH ALDER/LB
- RED PINE
- DIVERSE MIXED
- MAPLE--varies
- BIRCH
- RED OAK
- WATER

Polygon overlay represents Phase II stand boundaries.
Notice the diversity of stand types within phase II borders.
Notice how much data is provided by the satellite imagery
for a single section of land.

## B. Resource Management Applications

**1. Timber Management:** Timber species identification with the Ducks Unlimited imagery appears to hold promise as a way to quickly update some inventory data and to include private lands in the assessments. Several additional applications may be feasible but were not addressed by the work team. These include:

a. *assessing survival rates in plantations,*

b. *monitoring disease and insect infestations,*

c. *identifying areas of temporary flooding,*

d. *monitoring trespass logging.*

By combining imagery data with other computerized GIS (Geographic Information Systems) files, marketing applications may be feasible. For example, imagery-interpreted timber data combined with public ownership, transportation network and mill location might be capable of identifying opportunity areas for studying the location of new paper mill development.

**2. Wildlife Management:** Identifying forest openings and vegetative species diversity are ideal wildlife applications of satellite imagery. The satellite imagery is effective in locating small timber stands (one to five acres) which are overlooked in traditional inventories. Habitat improvements can be planned more effectively with the use of that information.

**3. Water Resource Management:** Satellite imagery provides a clear open water signature that has several applications, especially since imagery is available for several dates in any given year. For example, satellite imagery in combination with USGS hydrography information could be useful in local water planning efforts or in developing improved estimates of protected waters acreage. The interface of shoreland and water classes will limit some applications, however.

Wetland applications are uncertain. It should be possible to use imagery to identify vegetative patterns in bogs. However, this imagery application has not been explored to any great extent.

In summary, the project indicated that pre-classified satellite imagery data from Ducks Unlimited have potential for a variety of resource management applications. Even greater potential is likely if unclassified data are used. However, considerable additional exploratory efforts are needed to better determine appropriate uses of the imagery.

# VII. RECOMMENDATIONS

* The DNR should further explore the use of satellite imagery for resource management applications. It is especially useful to continue this effort now while the 1987 Ducks Unlimited imagery is current. The DNR should contact Ducks Unlimited to explore further cooperation in using their imagery.

* LMIC should develop a way to extract townships of data from the master image file with options for including overlays of information from other files. These files should be available to field personnel for their use in resource management. LMIC should work with DNR field staff to help explore appropriate applications of this data and to more fully evaluate their effectiveness.

* The DNR, in cooperation with LMIC and the Remote Sensing Lab, should develop a training program that educates regional staff to use EPPL7 and satellite imagery. Such education could be completed with two single-day training sessions. Data sets should be prepared to allow DNR regional staff an opportunity to work with real data from their region. Those training sessions should further explore and evaluate applications of the automated imagery data for resource management.

* The DNR should assess options for processing satellite imagery. Those options include further use of Ducks Unlimited processed data, use of the University of Minnesota Remote Sensing Laboratory to process data, or to establish cooperatively with LMIC, a state agency satellite imagery processing effort. The assessment should weigh findings developed in this study as well as information developed by two studies (*"Satellite Inventory of Minnesota Forest Resources"* and *"The Biological Inventory and Geographic Information Systems Development of Big Stone and Lac Qui Parle Counties, Minnesota"*) conducted by the Minnesota Remote Sensing Laboratory in cooperation with the DNR. This recommendation would require funding support.

* The DNR should establish a statewide network of plots for establishing ground truth to interpret satellite imagery. This could be accomplished through timber stand improvement. An alternative would be to use field staff to verify vegetative types identified by satellite imagery.