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E75-10188

CR142337

Utilization of ERTS-1 for Appraising Changes in Continental Migratory Bird Habitat (SR 255)

Type III Final Report

December 1, 1974

(E75-10188) UTILIZATION OF ERTS-1 FOR APPRAISING CHANGES IN CONTINENTAL MIGRATORY BIRD HABITAT Final Report, 15 Jul. 1972 - 30 Apr. 1974 (Northern Prairie Wildlife Research Center) 101 p HC $5.25 CSCL 06H G3/43

N75-20791

Unclas 00188

1255A

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
NORTHERN PRAIRIE WILDLIFE RESEARCH CENTER
JAMESTOWN, NORTH DAKOTA 58401

REMS 8.30.4

April 4, 1975

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland 20771
Attn: Scientific Investigation Support Code 902.6

RE: Review of final report for contract S-70243AG, Task #37 (MMC #255).

Dear Sir:

Mr. Harvey K. Nelson, the addressee of Mr. James Higgins' letter of March 4, 1975 was transferred to a new assignment in Washington, D. C. I have been assigned the task of handling this correspondence.

We are pleased that our final report is in compliance with applicable government specifications. In response to Mr. Higgins' recommendations and questions the following is provided.

Recommendation: In general, NASA would like more details on the methods and procedures used in the thresholding technique mentioned throughout your report.

Response: Signal level thresholding works because in the near-infrared wavebands the apparent radiance of water is uniform and lower than the radiance of other terrain objects. Pages 14 thru 21 of the report describe in detail why the apparent radiance of water is low. Pages 21 thru 24 describe the actual techniques employed for selecting a threshold boundary (i.e., the decision boundary for separating water from non-water features). The threshold boundaries used for the three sets of data processed during this investigation were based on empirical observations. The derivation of a thresholding boundary based upon the scene irradiance and solar altitude parameters was not within the scope of this investigations.

Question: Figures 11 and 12 refer to "Radiance Data Value". What are these values and what is the scale used?

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Response: Radiance data value refers to the voltages (digital counts) read directly from the computer compatiable data tapes. These voltages could have been converted to radiance levels as received at the scanner but such calibration of the data was not necessary for the accomplishment of this task. We chose to refer to the digital counts as "radiance data values" so as not to infer such a calibration of the data. In Figure 11, the tick marks on the abscissa scale occur every 5 digital counts beginning with zero. The decision boundary was placed between the ninth and tenth voltage level.

Question: What accuracy was used in measuring the acreage of the ponds studied? How were the pond sizes determined?

Response: In the threshold recognition made, each ERTS-1 pixel was examined and determined to be either totally water or non-water (in spite of the fact that a fraction of the pixel may have contained water). The computer algorithm assumed each ERTS pixel to be 0.45 hectares (1.11 acres) in areal extent. For any grouping of pixels classified as a pond or lake, the number of pixels in that pond or lake was multiplied by this area factor to obtain the apparent total area of the water feature. Many pixels lying on the perimeters of ponds and lakes undoubtedly contained some unrecognized and untabulated water. This caused the surface areas of virtually all water features to be underestimated. Percentage-wise, the errors were greater for the smaller ponds and for those of irregular shape (i.e., those having a high ratio of perimeter length to area). The very small ponds, of course, would not be recognized at all. Whether or not certain small ponds and peripheral features of larger ponds and lakes were recognized or not was also the result of the sensor's line scanning and pixel sampling geometry and the random occurrence of surface water with respect to the sampled pixel. Generally in this study, we have not tried to derive a percent error factor which could have been used to correct the tabulated pond size to a true pond size. Rather we have been interested in noting changes in pond size frequency and total pond numbers over certain time

UTILIZATION OF ERTS-1 FOR APPRAISING CHANGES IN CONTINENTAL MIGRATORY BIRD HABITAT

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December 1, 1974

Type III Final Report for Period 15 July 1972 - 30 April 1974

Prepared for:

Goddard Space Flight Center
Greenbelt, Maryland 20771

Publication authorized by the Director, U.S. Fish and Wildlife Service

periods. Since the ponds were observed using the same sensor at these time intervals, trends in water conditions have been observable in spite of the fact that the data were not in absolute units.

I hope you have found the above explanations adequate for your needs. Please let me know if I can be of any further assistance. Ten copies of the final report are enclosed as requested.

Sincerely yours,

David S. Gilmer
Wildlife Biologist

Enclosures

cc: Richard Williams
Priscilla Woll

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
Utilization of ERTS-1 for Appraising Changes in Continental Migratory Bird Habitat (SR-255)

5. Report Date
1 December 1974

6. Performing Organization Code

7. Author(s) (IN 051)
Edgar A. Work, Jr., David S. Gilmer, A. T. Klett

8. Performing Organization Report No.

9. Performing Organization Name and Address
Environmental Research Institute of Michigan
P. O. Box 618
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Northern Prairie Wildlife Research Center
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10. Work Unit No.

11. Contract or Grant No.
S-70243-AG

13. Type of Report and Period Covered
Type III Progress Report
15 Jul 72 - 30 April 1974

12. Sponsoring Agency Name and Address
G. Richard Stonesifer, Technical Monitor
Goddard Space Flight Center
Greenbelt, Maryland 20771

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Information on numbers, distribution, and quality of wetlands in the breeding range of migratory waterfowl is important for the management of this wildlife resource. Using computer processing of data gathered by the ERTS-1 multispectral scanner, techniques for obtaining indices of annual waterfowl recruitment and habitat quality are examined.

As a primary task, thematic maps and statistics relating to open surface water were produced. Discrimination of water was based upon water's low apparent radiance in a single, near-infrared waveband. An advanced technique using multispectral information for discerning open water at a level of detail finer than the virtual resolution of the data was also successfully tested. In another related task, vegetation indicators were used for detecting conditions of latent or occluded water and upland habitat characteristics.

17. Key Words
Wetlands
Migratory Bird Habitat

18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Not Applicable	86	

SUMMARY

Objective and Scope of the Study

Aerial surveys of waterfowl and their breeding habitat in parts of the United States and Canada were first begun as a pilot program in 1947 and operationally implemented on an annual basis in 1955. Since then aerial crews have flown more than 500,000 transect miles conducting these surveys. Currently the aerial observations are supplemented by limited ground observations along certain transects; together they constitute a double sampling procedure. The data obtained from these surveys represent the single most important input to management decisions concerning waterfowl hunting regulations (Bowden, 1974). Information derived from the surveys includes an estimate of the size of the waterfowl breeding population (by species), an estimate of probable annual recruitment rates, and an appraisal of habitat quantity and quality. Most of this information is not available from any other source, and, in addition to providing for management needs, certain research needs are also dependent upon the data.

Some aspects of the survey must be implemented through visual observations by many trained biologists. In particular this would include the sighting, identification, and tabulation of birds and their habitat relationships. Information on habitat quantity and quality are, however, potentially accessible through the utilization of remote sensing/computer aided techniques. As a result, an opportunity is provided for broadening the areal extent of the survey and for increasing the management and research data base.

The emphasis of the current study was placed on developing techniques for acquiring new indices of habitat quality thereby increasing the opportunities for making sound and timely management decisions using remote sensing methods. A primary task was the detection of open surface water. Other related tasks included the examination of latent or occluded standing water and soil moisture as manifested through the form and aspect of vegetation. The study was directed primarily toward those habitat features which are characteristic of a glaciated prairie area in southcentral Canada and northcentral United States, an area frequently referred to as the "prairie pothole" region. Duck populations proliferate or decline almost in direct proportion to the abundance of surface water in this region -- a region which makes up only 10 percent of the total waterfowl breeding area of the continent, yet produces 50 percent of the duck crop in an average year (Smith, et al., 1964).

Results and Conclusions

Data from the annual breeding and production surveys currently con-

ducted by the U.S. Fish and Wildlife Service are used to estimate waterfowl production by means of mathematical models. Counts of May and July ponds are some of the variables used in this model. Computer analysis of multispectral scanner data collected by the Earth Resources Technology Satellite-1 (ERTS-1) has indicated that a unique potential exists for complementing and enhancing the current survey programs. The research results presented here lay the ground work for the future development and operational implementation of high altitude remote sensing techniques for synoptically surveying the prime waterfowl breeding areas of North America.

The salient results and conclusions of the study follow:

1. A simply implemented technique, requiring a single near-infrared waveband of data, exists for accurately mapping and tabulating ponds and lakes. As a result, development of an operational system utilizing satellite sensors as a primary source of data appears to be a realistic goal for the future.

2. This same technique also provides statistical information of relative water body size -- a potential index of waterfowl productivity (Crissey, 1969) not available using current aerial survey procedures. The capability to determine the perimeter and the shape complexity of water bodies also exists. However, because shorelines often vary widely in length at scales finer than the present resolution limit of the sensor, data on these peripheral characteristics were thought not to be precise enough for comparing the habitat quality of at least the smaller ponds and lakes.

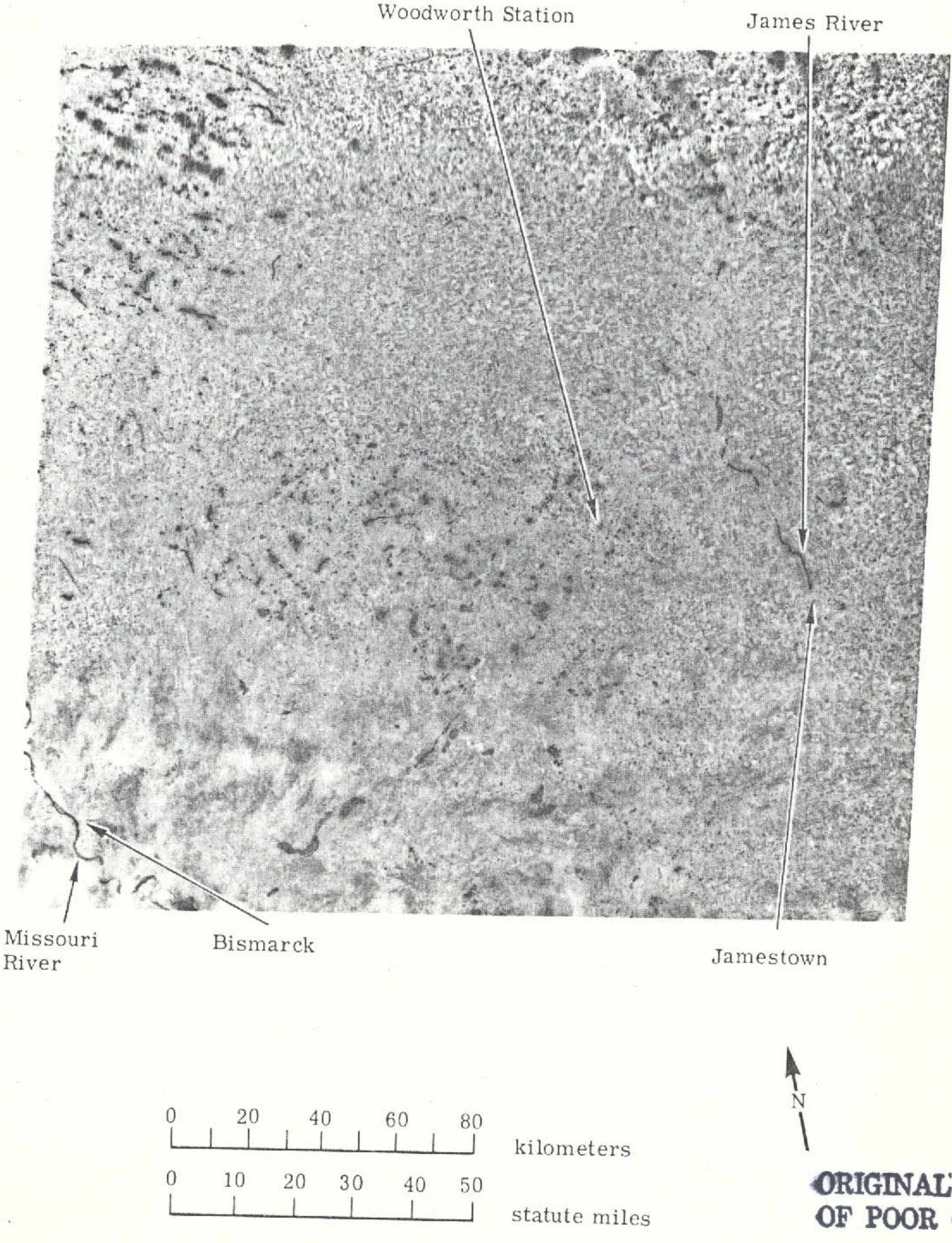
3. The minimum size pond that was consistently discerned from ERTS-1 data by the single-waveband recognition technique was about 1.6 hectares (4 acres). As a consequence, efforts of the present study have resulted in an identification of between 14 and 18.5 percent of the ponds and lakes estimated with conventional low altitude aerial survey methods. This disparity in estimates was the result of the proportionately large number of ponds smaller than the minimum resolution capabilities of the ERTS-1 multispectral scanner.

4. In spite of this inability to recognize the smaller ponds, the measurement of relative changes in pond and lake numbers using ERTS data has been positively correlated with those relative changes monitored using conventional aerial survey techniques. Nevertheless, the rate of both seasonal and annual change indicated from the ERTS data lagged the relative changes noted from the conventional aerial survey data. These lags in pond number changes were attributed to a faster rate of decline in size and numbers of the smaller ponds, many of which were not discernible in the

ERTS data. It appears that the rate of water loss from prairie ponds is proportional to the length of shoreline per unit of area; this suggests that water loss from a small pond should progress at a faster rate than for a large pond.

5. The proportion estimation technique allowed for the recognition of a greater number of small ponds not previously identified and also greatly improved the area and peripheral shape definition of the larger ponds and lakes. This technique, which utilizes the increased information content of multiple spectral bands, was employed for estimating the amount of open surface water which may be within a sensor's resolution cell in fractional amounts (i.e., the cell may contain a mixture of materials). Use of this technique improved the apparent spatial resolution of the data by a factor of three in comparison to the single-waveband technique mentioned above. In future operational systems for mapping open water, a combination of the single waveband and the proportion estimation techniques is likely to be employed for the sake of accuracy and efficiency.

6. The differentiation of prairie vegetation classes (deep marsh, shallow marsh, small grains, row crops, and range) cannot be consistently realized using ERTS data collected in early or mid July. Such an analysis was attempted using ERTS multispectral scanner data collected on 7 July 1973. The classification results were only partially correct because of a general similarity of spectral signatures for various classes of green herbaceous vegetation. It is conjectured that data gathered in a different phenological period would be more satisfactory for delineating types of prairie vegetation, especially for differentiating between wetland and upland vegetation features.



ERTS-1 MULTISPECTRAL SCANNER IMAGE OF EAST-CENTRAL NORTH DAKOTA COLLECTED AT 1659 GMT ON 31 JULY 1972. The upper right half of the frame generally lies in a drift plane of the Central Lowland while the remainder of the frame lies in the Missouri Plateau section of the Great Plains province. Many of the numerous ponds and lakes which are present in the scene are clearly visible. This photo product is an MSS-7 (0.8 to 1.1 μm) video reproduction from the electronic signal telemetered from the spacecraft.

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LIST OF ABBREVIATIONS

ERIM - Environmental Research Institute of Michigan

ERTS - Earth Resources Technology Satellite (ERTS-1 is frequently referenced in the text. It refers to the first generation ERTS sensor package launched on 23 July 1972.)

IFOV - instantaneous field of view

km - kilometers

MSS - multispectral scanner

NASA - National Aeronautics and Space Administration

NPWRC - Northern Prairie Wildlife Research Center

pixel - picture element, a term used to describe a digitized sample of an image with which a specific ground area can be associated

USF&WS - United States Fish and Wildlife Service

μm - micrometers

BACKGROUND AND HISTORY OF THE STUDY

Because of their free movement between states and nations, migrating waterfowl, including wild ducks, brant, geese, and swans, are protected in accordance with treaties between the United States and Canada, Mexico, and Japan. The U.S. agency responsible for the coordinated management of this wildlife resource is the U.S. Fish and Wildlife Service (USF&WS) of the Department of the Interior. Population management including the establishment and administration of hunting regulations, and habitat management and preservation are the current approaches to management of waterfowl populations. Management of populations by the administration of hunting regulations is a direct approach, has a rapid impact, and occurs on an annual basis. In order to be effective, it requires a rapid assimilation of data on populations and habitat. Management of habitat is effective over the long term and includes preservation through acquisition and lease arrangements, the regulation of land use, and the manipulation or treatment of certain features to enhance habitat quality. In this context, remote sensing offers a tool for monitoring changes in land-use and habitat quality and for evaluating land areas for acquisition.

Annual waterfowl hunting regulations are established to allow for a reasonable level of harvest by hunters while insuring the survival of an adequate number of birds to sustain a viable breeding population the following year. In order to establish annual hunting regulations, the magnitude of the fall flight of birds must be predicted. Figure 1 indicates the sequence of events currently followed in making this prediction. Additive and subtractive factors affecting the fall flight, as well as the timeliness of the events, are indicated. Adjustments, based on ecological assessment of wetland abundance and quality and trends associated with long- and short-term land use, may be possible prior to regulation formulation.

From Figure 1, it becomes apparent that estimating the fall flight of waterfowl is critically dependent upon appraisals made of the magnitude of the breeding population and annual production of young. Of these two factors, changes in production influence the size of the fall flight more than do changes in breeding population (Crissey, 1957). Waterfowl biologists have suggested that a reliable production index could be derived independently of the size of the breeding population from an estimate of the number of ponds existing in mid-July (Crissey, 1969). Current waterfowl breeding ground surveys evolved from an experimental survey first conducted in 1947. Crissey (1957), Stewart et al. (1958), and, more recently, Henny et al. (1972) and Pospahala et al. (in prep.) discuss the operational aspects of the breeding ground surveys.

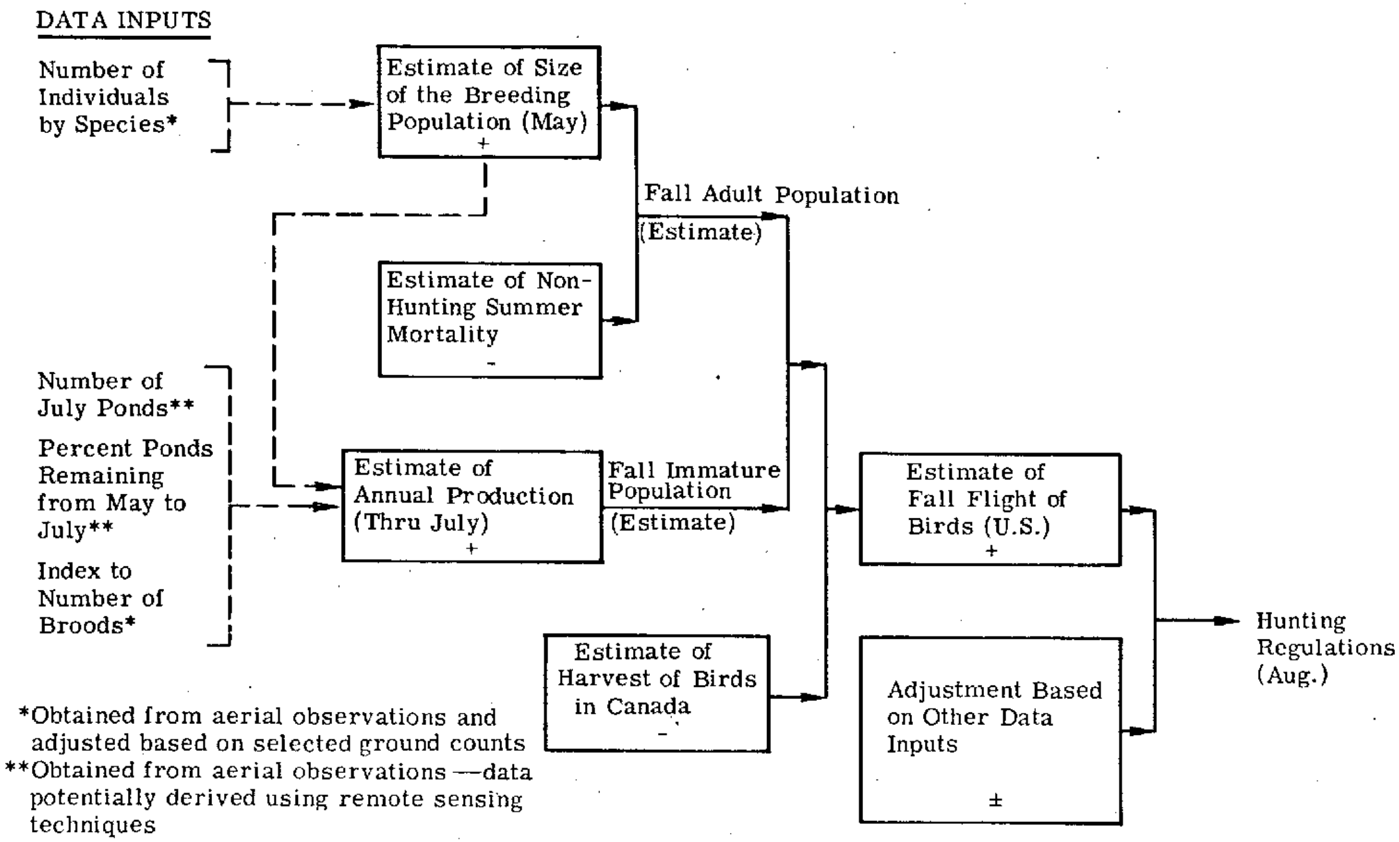

FIGURE 1. DETERMINING HUNTING REGULATIONS BASED UPON THE ESTIMATED MAGNITUDE OF THE FALL FLIGHT OF MIGRATORY WATERFOWL

Average continental distribution of breeding and wintering ducks is illustrated in Figure 2. The wintering range is widespread, extending beyond the North American continent into parts of Central and South America. Most of the primary duck breeding habitat in North America are located in northwestern Canada, the southern portions of the prairie provinces, the Dakotas, and parts of Alaska. Habitat conditions in these areas greatly influence the annual continental waterfowl population.

Estimates of waterfowl breeding population and production are obtained using a double sampling approach. The first sample consists of a series of transects which are flown by light aircraft in May and July of each year. Sampling transects and strata are illustrated in Figure 3. Strata were delineated on the basis of expected waterfowl population density, habitat type, and expected variability of the estimates. Over 2.2 million square kilometers of the breeding range are sampled during each survey. Approximately 80,000 transect kilometers are flown at an altitude of 30 to 45 meters. The survey crew normally consists of a pilot and observer. Together they count and, when possible, identify ducks by species over a 400-meter wide strip in May and a 200-meter wide strip in July. Ponds are counted over a 200-meter wide strip in both May and July (Henny et al., 1972; Pospahala et al., in prep.). Each crew member records his count on a tape recorder and later the same day transcribes this information onto summary sheets.

The second sample consists of air/ground transects that serve to adjust for biases encountered in the aerial survey. Specifically, these biases are the result of the inability of the aerial crew to see and count all birds present on the ground, identify all birds with equal ability, and identify and classify all wetlands. The results of the aerial survey plus appropriate corrections are converted to estimates of birds or broods per square mile; these numbers are then expanded according to the number of square miles in the sampling unit. The May survey yields an estimate of the size of the breeding population. This population component must be adjusted to account for normal summer mortality (predation, disease, and accidents) when estimating the size of the fall flight (Geis et al., 1969).

In estimating that portion of the fall flight which is made up of the current year's production, additional analyses are required. Geis et al. (1969) described a mathematical model (Figure 4) for estimating mallard (*Anas platyrhynchos*) production. The mallard was chosen because: (1) it is the most abundant and widespread waterfowl species in North America and is nearly always killed in greater numbers than any other species (Anderson and Henny, 1972); (2) a large amount of ecological data is available for the species; and (3) populations of several other dabbling duck species are affected by many of the same factors as the mallard.

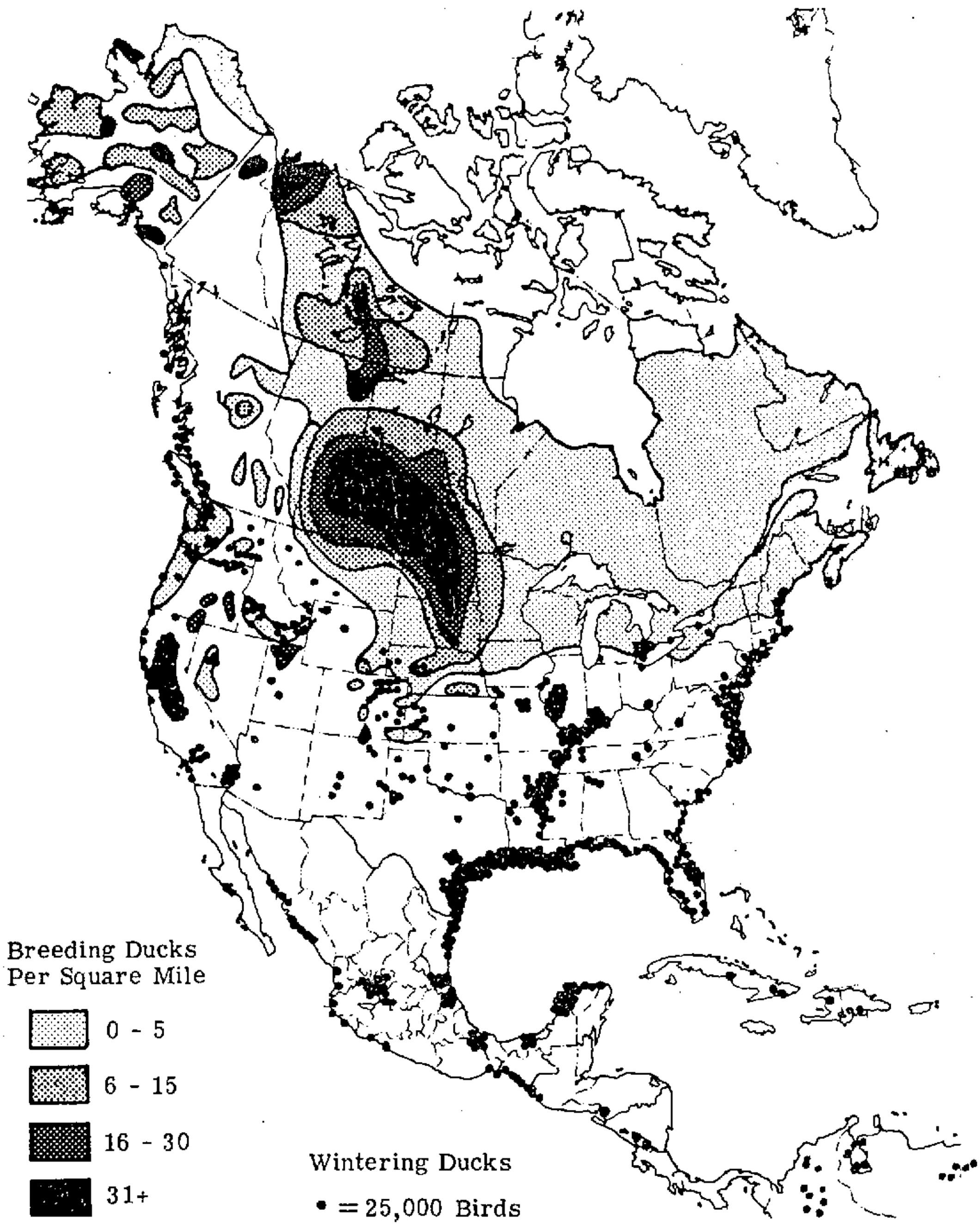

FIGURE 2. AVERAGE DISTRIBUTION OF NORTH AMERICAN BREEDING AND WINTERING WATERFOWL

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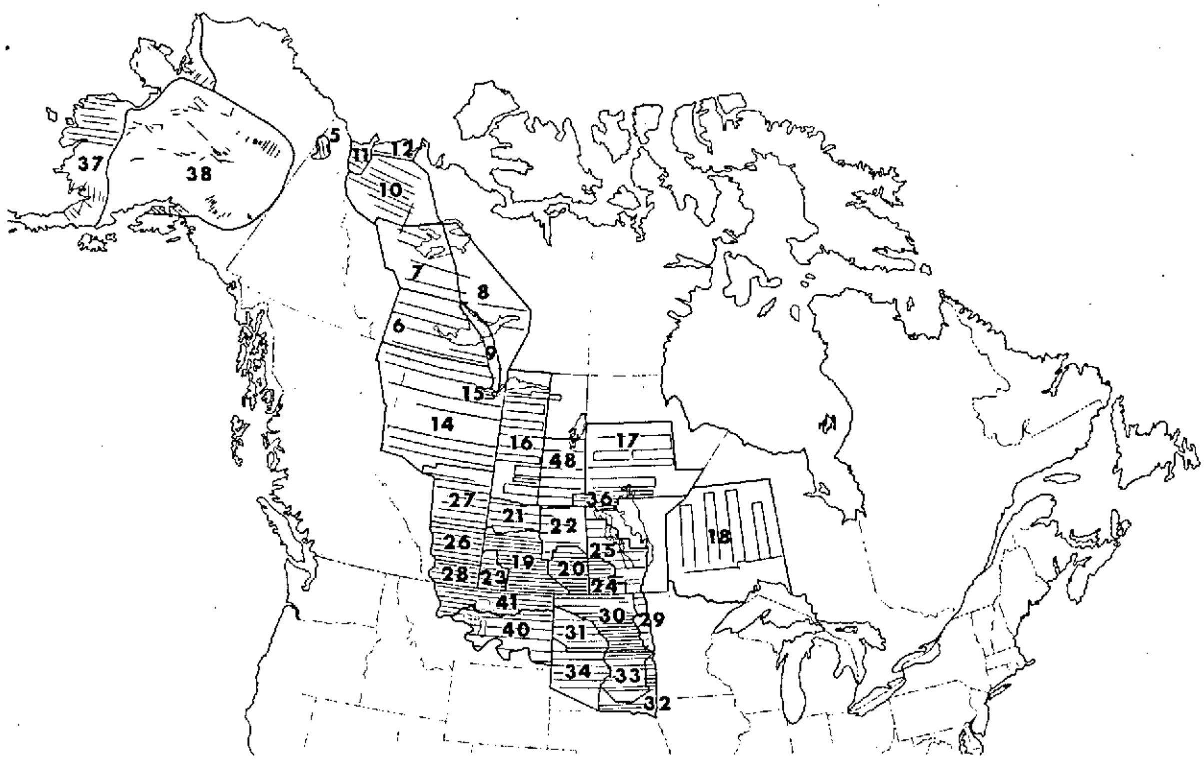

FIGURE 3. TRANSECTS AND STRATA FOR AERIAL WATERFOWL BREEDING AND PRODUCTION SURVEYS. Due to continued evaluation of survey procedures, the sampling frame and units are occasionally modified. The above transects and strata were the units most recently in effect during 1973.

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U. S. Dept. of the Interior

$$\hat{Y} = 7.926 + 1.468\,X_1 - 0.624X_2 - 0.028X_3 + 0.016\,X_4$$

where $\hat{Y}$ = Predicted number of mallard young (millions)

X_1 = July ponds (millions)

X_2 = continental mallard breeding population (millions)

X_3 = percent of ponds remaining from May to July

X_4 = index to number of broods (thousands) unadjusted

FIGURE 4. EXAMPLE OF A MODEL FOR PREDICTING ANNUAL PRODUCTION OF YOUNG MALLARDS. (After Geis, A. D., R. K. Martinson, and D. R. Anderson, 1969.)

The Geis et al. (1969) prediction model was developed from a multiple regression analysis based upon 13 years of data. Data from both the May and July surveys are utilized in this model. Referring to Figure 4, the quantities, X_1 and X_3, potentially may be obtained by remote sensing methods and computer aided analysis techniques. The term X_2 can only be obtained from visual observations made during the May survey, while X_4 is derived from visual observations made in July.

More recent analysis has indicated that it may be possible to redesign the model and eliminate use of the brood index (X_4) (private conversations 29 October and 10 December 1973 with D. R. Anderson, Migratory Bird and Habitat Research Laboratory, U.S. Fish and Wildlife Service, Laurel, Maryland). If this is possible, greater emphasis will be placed on the July pond counts; this enumeration could be effectively accomplished with remote sensing/computer aided processing techniques.

Applications of these techniques will improve the accuracy of pond counts, and other factors such as pond area and perimeter could be incorporated into a model that could further improve production estimates. The July survey usually lasts until late in the month; however, the results of this survey must be available in early August for use in establishing hunting regulations. Computer processing of remotely sensed data is appropriate for insuring rapid availability of survey information. For satisfying longer term survey requirements, the utilization of remote sensing for recognizing vegetation will establish a basis for a wetland classification system and provide additional factors for estimating waterfowl habitat quality.

To date, the joint studies carried out by the Northern Prairie Wildlife Research Center (NPWRC), USF&WS and the Environmental Research Institute of Michigan (ERIM) have emphasized the utilization of automated electronic techniques for acquiring, processing, and analyzing multispectral scanner (MSS) data. The intent here has not been to reduce the importance of the human observer or the photointerpreter. In fact, the human's ability to perceive relative differences in the characteristics of observed materials and to use contextual and ancillary information and experiences to interpret imagery makes his replacement by computers in the foreseeable future a very remote possibility (Malila, 1974). The nature of wide-area survey programs, however, makes computer aided analysis techniques a valuable tool because of the computer's capability for accurately and consistently performing certain programmed functions on large amounts of data at high throughput rates. For this reason the present study has emphasized the use of electronically recorded remote sensing data and its subsequent machine processing.

Remote sensing of waterfowl habitat using multispectral scanners and related machine processing techniques began in 1968 as a joint effort between NPWRC and ERIM. The goals were to evaluate existing methodology and to investigate new processing techniques for mapping selected components of a waterfowl breeding habitat based on their spectral signatures. Major emphasis was placed on recognizing and delineating water from a terrain background. This was done on both a special purpose analog computer and on a large general purpose digital computer both utilizing a multispectral data input. Subsequently, it became apparent that there was an additional need for quantifying the recognition maps. As a result, in 1969, efforts began which were to culminate in digital software programs capable of generating numerical statistics on wetland characteristics.

That period also saw the application of vegetation mapping techniques to assist in wetland classification. Through the use of aircraft MSS data, general recognition categories such as matted and standing aquatic vegetation, grazed and idle pasture, cultivated land, and bare soil areas were delineated.

By 1970, it had become apparent that multiband data were not necessary for water recognition, but, instead, optimum recognition could be achieved by the thresholding or voltage level slicing of data gathered in a single near-infrared* waveband. Previously water recognition had been done with a four or six channel subset of visible channels. The new single waveband technique proved to be more effective and faster. Also by this time digital computer programs had evolved that would not only achieve a pictorial representation or map but also generate statistical summaries of the output data. Specifically these summaries tabulated numbers, areas, perimeters, and shape factors of ponds for each data-line mile. Thus, in May and July of 1970, a sequence of aircraft transects were flown to provide data with which to detect changes in wetness between the two observations. Besides water recognition, a substantial emphasis was placed on extracting vegetation maps from this data. The availability of July data enhanced data analysis opportunities considerably because the May data had provided only moderate differentiation of vegetation types. With analog and digital processing techniques, both wetland and upland vegetation mapping was accomplished.

Much of the work described above has been documented by Burge and Brown (1970) and Nelson et al. (1970) for the period 1968-69 and by Work and Thomson (1974) for the period 1970-72. Preliminary work associated with the present study was described by Work et al. (1973, 1974).

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*The term "near-infrared" is rather arbitrary. For these discussions, the range 0.7 to 2.0 um will be considered the near-infrared.

The text which follows includes a discussion of the ERTS-1 survey program as it has related to this study (Section 2), a description of the methods and results for the three subtasks which comprised the study (Section 3), and finally a summary discussion of the results (Section 4).

2

THE ERTS-1 SURVEY PROGRAM

The prime objective of this investigation was to extract synoptic information on changes in waterfowl habitat conditions. Generally, the study was limited to a consideration of habitat conditions related to open surface water (i.e., ponds and lakes)* and other conditions of soil and surface wetness varying from open surface water situations to dry upland situations. The study was a natural extension of the earlier aircraft programs described in Section 1. The goals were to both modify techniques which evolved from those earlier programs as well as to institute new techniques which would be suitable for very high altitude, wide area (synoptic) surveys.

The original plan for the study was to work with two sets of data collected by the ERTS-1 multispectral scanner (MSS) over an identical site in May and again in July of 1972. Data were to be used principally to document the amount of surface water present during each observation and to indicate changes in surface water between May and July. Because the launch date for the ERTS-1 satellite was delayed until mid-summer 1972, it became necessary to defer the bulk of the investigation until a May/July sequence of data was available from the 1973 season. However, during the satellite's first pass over the site on 31 July 1972, cloud-free conditions prevailed and acquisition of a good data set resulted. Consequently, data were available with which to document changes in surface water over not only a single season (May to July) but also over an annual period (July to July).

The areal extent of the selected study site was roughly equivalent to one-eighth of an ERTS data frame. The site is approximately centered on the Woodworth Station, a USF&WS research facility operated by the Northern Prairie Wildlife Research Center, Jamestown, North Dakota. Portions of three frames of ERTS data collected on 31 July 1972, 14 May 1973, and 7 July 1973 were processed and analyzed. The locations of these data frames within the state of North Dakota are shown in Figure 5. Figure 6 shows the locations of certain landform and habitat features in North Dakota and delimits the site which constituted the study area for this investigation.

The study area overlapped two distinctly different groups of glacial landforms -- the drift plain and the Coteau du Missouri. The drift plain was formed by Pleistocene glaciation that possessed a margin which retreated in an orderly manner and which occasionally halted

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*In this study, nonfluvial water bodies less than 20 hectares (50 acres) are arbitrarily defined as ponds. Lakes are larger than 20 hectares.

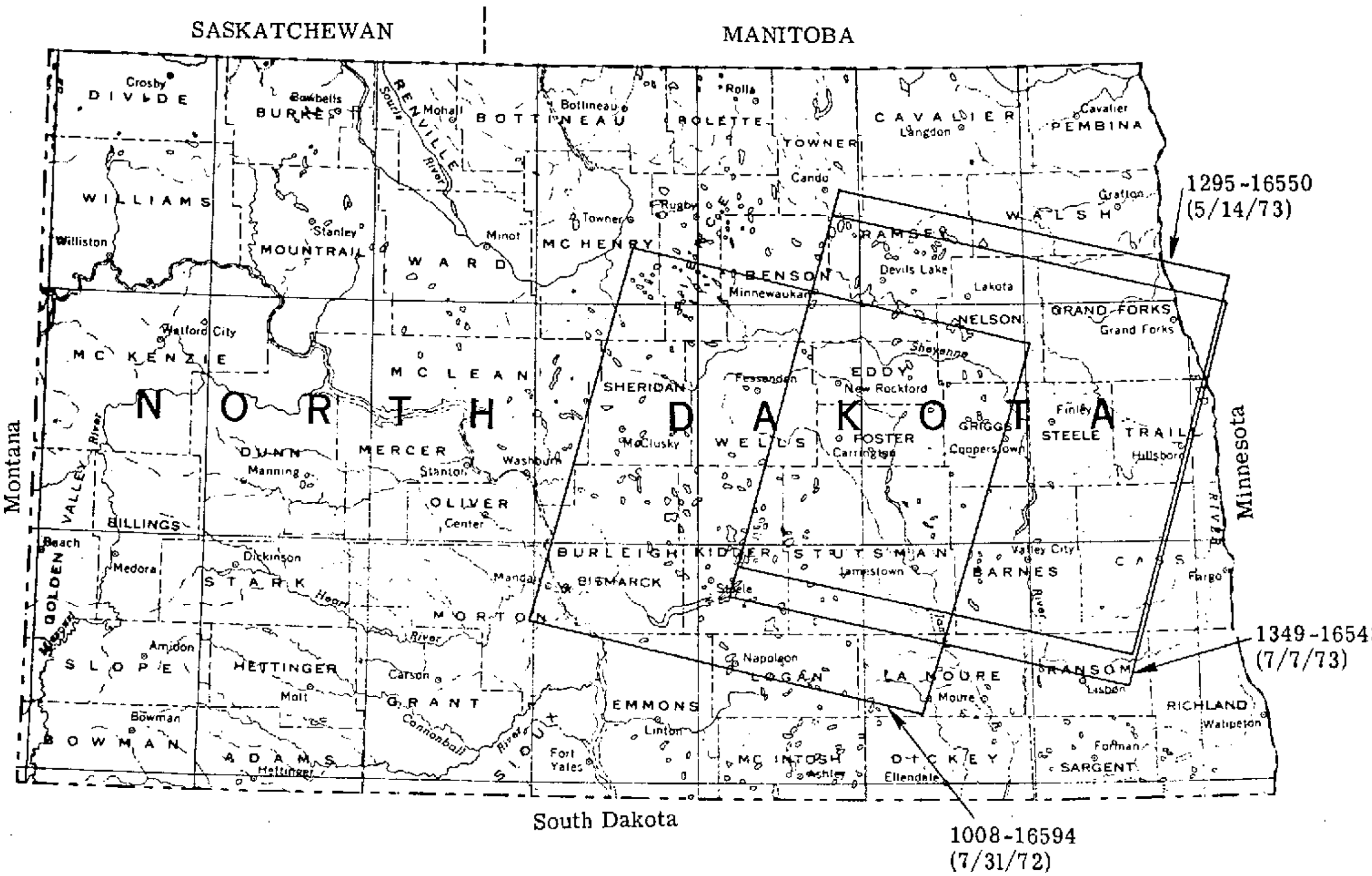

FIGURE 5. LOCATIONS AND IDENTIFICATION NUMBERS OF ERTS-1 OBSERVATIONS UTILIZED IN THIS INVESTIGATION. The larger lakes and major streamcourses within the state of North Dakota are indicated.

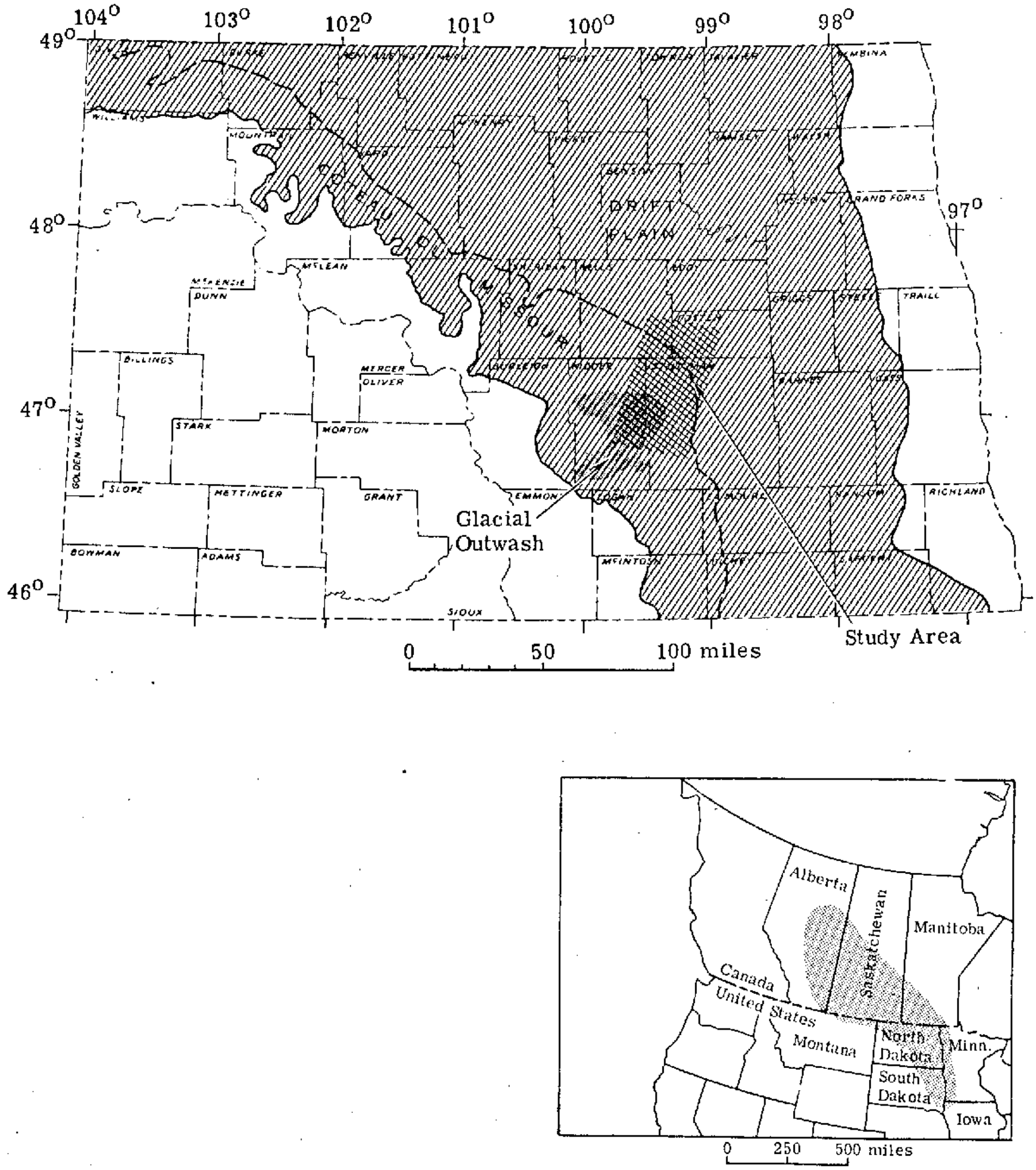

FIGURE 6. MAJOR DUCK-PRODUCTION AREAS OF THE PRAIRIE POTHOLE REGION OF NORTH DAKOTA. Boundaries of two physiographic features, the drift plain and Coteau du Missouri, and a glacial outwash feature referred to in the text are indicated. The location of the study area selected for this investigation is shown. The inset shows the continental extent of the prairie pothole region.

or readvanced. Drainage in the plain is integrated only along the edges of large meltwater channels. Numerous shallow, marshy depressions are present between these former channels. Permanent lakes are uncommon and usually shallow. The other physiographic feature, the Coteau du Missouri, is characterized by the prominence of high underlying bedrock which has acted to buttress advancing ice sheets causing extensive glacial stagnation. In addition, the ice had become overlain with large quantities of superglacial till which caused protracted and irregular melting of the underlying ice. The resultant topography is hummocky, drainage is non-integrated, and lakes and sloughs are abundant as is characteristic of an area of collapsed ice topography. The Coteau contains some of the best waterfowl breeding areas in the contiguous 48 states (Clayton, 1967).

3

STUDY METHODS AND RESULTS

The approach to this study was to divide the effort into three subtasks. Section 3.1 describes the recognition of open surface water using a single near-infrared band of data. This approach utilized techniques developed earlier in aircraft programs, was simple to execute, and in the future could be readily implemented on an operational basis. Section 3.2 describes the utilization of multispectral data and advanced processing techniques for improving the apparent spatial resolution of discriminated water features; an important aspect of the satellite survey program because many ponds are smaller than the sensor's instantaneous-field-of-view (IFOV). Finally, Section 3.3 discusses the application of multispectral processing for vegetation recognition such that vegetation types are used as an indicator of latent water conditions and general habitat quality.

3.1 SURFACE WATER MAPPING USING A SINGLE WAVEBAND OF NEAR-INFRARED DATA

3.1.1 METHODS

Previously, investigators had tested several techniques for mapping open water. These included: (1) pattern recognition using multispectral data channels in the visible range (Burge and Brown, 1970), (2) thermal contrast between water and a terrain background (Work and Thomson, 1974), and (3) signal level thresholding of radiation received in a single near-infrared band (Malila and Wagner, 1972; Work and Thomson, 1974). Of these techniques, signal level thresholding has proven the most easily implemented and the most accurate. Thresholding works because at near-infrared wavelengths the reflectance of water is relatively uniform and lower than for other terrain objects. Thus, with an appropriate near-infrared waveband of data, water may be delineated by accepting scene points with low radiance values (classified as water) while rejecting all values above a certain threshold (nonwater). In the text, this form of water recognition is termed "thresholding."

To appreciate the effectiveness of thresholding, it is helpful to have an understanding of the interaction of incident radiation" with

*This discussion excludes consideration of thermal or self-emitted infrared radiation and is therefore limited to radiation in the visible and near-infrared at wavelengths somewhat less than 4 μm.

water. When ambient radiation impinges upon any object, the radiation is reflected, transmitted, absorbed, or a combination of these. In particular, the apparent radiance of open water (i.e., ponds, lakes, rivers, etc.) is the result of: (1) reflections at the air-water interface, (2) reflections from particulate matter suspended in the water volume, and (3) reflections from the bottom. In the near-infrared, that fraction of radiation which penetrates the air-water interface is almost totally absorbed if the water has any significant depth. Consequently, an infrared sensor viewing a water body receives virtually no radiation that may have been reflected by the bottom or reflected by particulates suspended in the water volume. This situation is shown quantitatively in Figure 7 which illustrates the increasing near-infrared absorptivity of water and in Figure 8, which illustrates the spectral transmission of pure water for a variety of path lengths. As a result, an infrared sensor viewing water detects radiation that has been directed to that sensor by reflections occurring primarily at the air-water interface.

In considering reflections at the surface interface, two factors must be taken into account: (1) the ERTS multispectral scanner views scene objects at angles close to the nadir (nominally within 5.78 degrees), and (2) reflections at a water surface are specular in character. The source of radiation must also be considered. Basically, scene reflected radiation will have emanated either directly from the sun or from diffuse solar skylight. In relative magnitude, direct solar radiation predominates, especially in the near-infrared and especially under clear sky conditions when optimal satellite viewing occurs. Figure 9 compares the magnitudes of direct solar and skylight radiation for clear day conditions.

Because the field-of-view of the ERTS scanner is limited to near normal observations and because a water surface exhibits specular reflecting characteristics, radiation reflected by water to the scanner must have emanated from a sky position near the zenith. Given the northerly latitudes which characterize the prime breeding grounds of North American waterfowl, the ERTS scanner does not view water-reflected direct solar radiation (i.e., the ground level specular point is a considerable distance outside the field-of-view

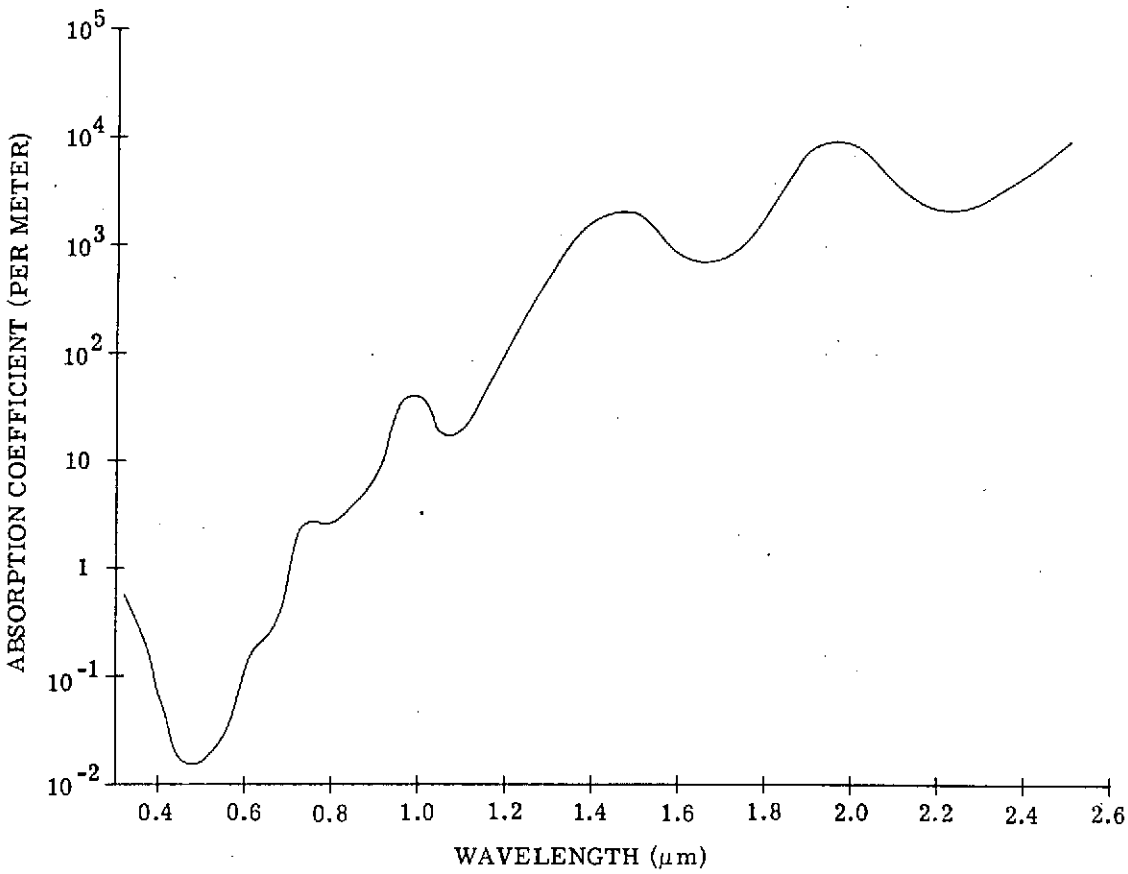

FIGURE 7. ABSORPTION COEFFICIENT OF PURE WATER AS A FUNCTION OF WAVELENGTH. (Plotted after data from Sverdrup et al., 1942.)

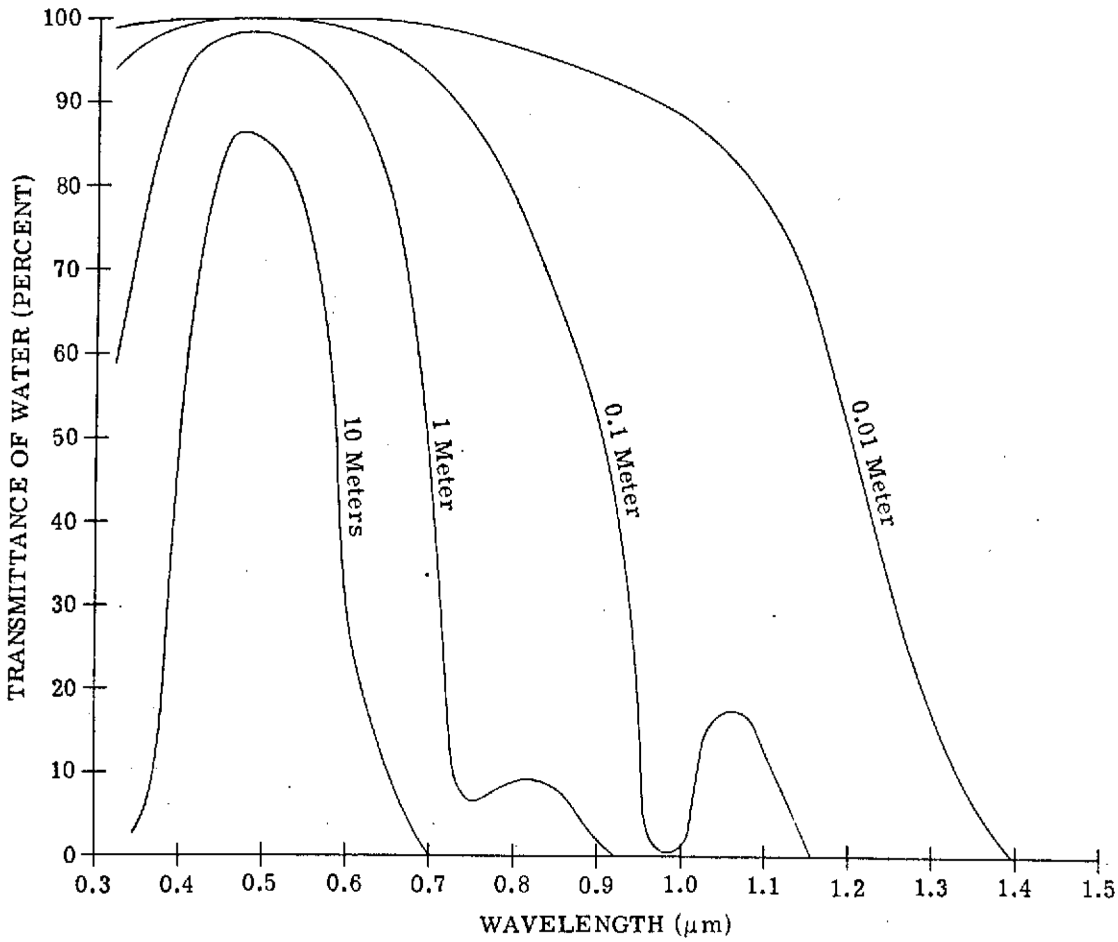

FIGURE 8. SPECTRAL TRANSMITTANCE OF PURE WATER FOR DIFFERENT PATH LENGTHS. (Plotted after data from Sverdrup et al., 1942.)

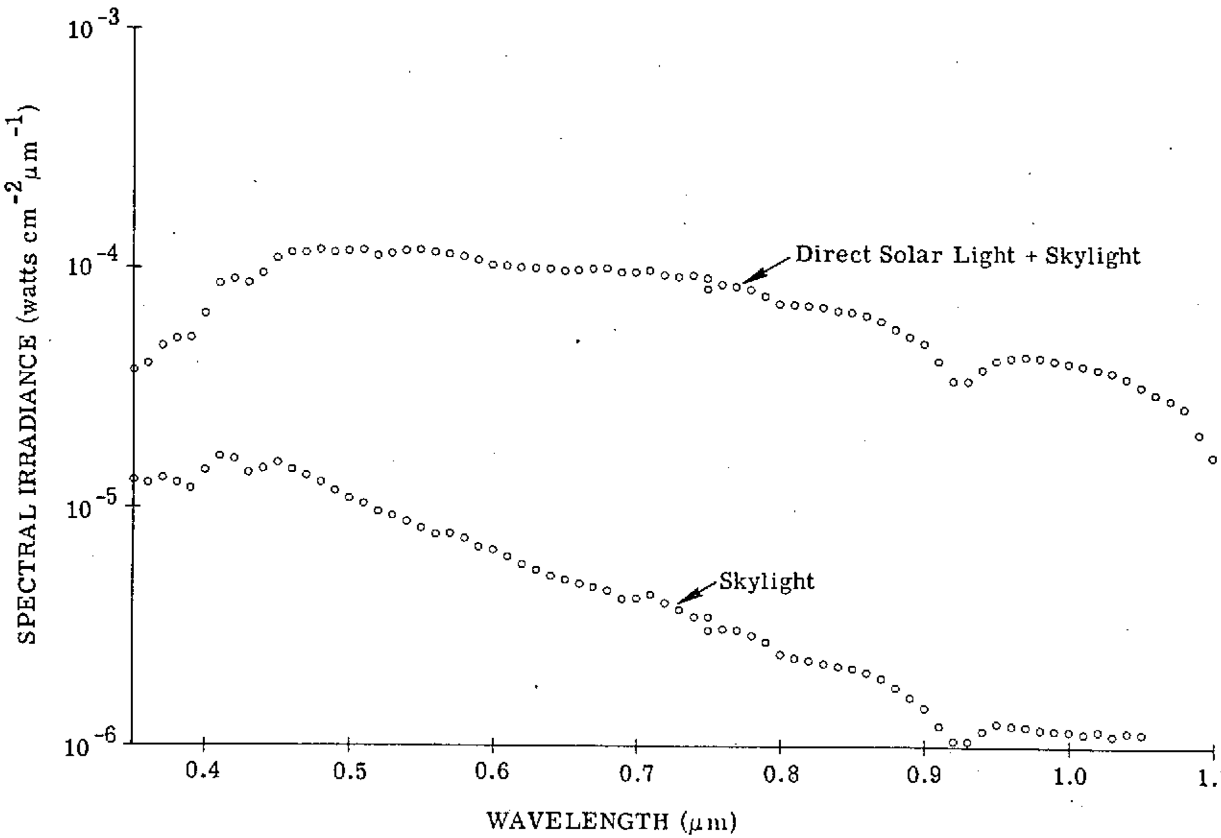

FIGURE 9. SCENE IRRADIANCE COMPONENTS FOR A CLEAR DAY. (After McDowell, 1974.) Spectral irradiance levels attributable to skylight alone may be significantly different and variable with wavelength due to variations in atmospheric haze. The conditions shown were recorded on an exceptionally clear day in New Mexico on 30 October 1970 at a sun elevation angle of 43 degrees.

of the scanner).* This leaves only that fraction of diffuse skylight, which emanates from a near-zenith sky location, to impinge upon a water surface at angles near the normal and thence to be reflected to the scanner. However, even this component is greatly diminished because water is a weak reflector of radiation, which impinges upon its surface at any but very oblique angles. This latter condition is illustrated in Figure 10. In the final analysis, it may be said that water exhibits a consistently low apparent radiance in the near-infrared because of a variety of phenomena including volume absorptivity, specular reflectivity, irradiant spectral quality, and illumination and viewing geometry. Most other terrain features are relatively strong diffuse reflectors, and as a result achieve somewhat higher magnitude, near-infrared signatures because their Lambertian (i.e., diffuse) reflectance of both direct solar and skylight irradiance.

The ERTS-1 MSS possesses two near-infrared channels which could have been used for surface water discrimination -- MSS-6 (0.7 to 0.8 μm) and MSS-7 (0.8 to 1.1 μm). In an earlier study which utilized aircraft data, Work and Thomson (1974) evaluated the relative merits of various near-infrared bands for mapping surface water. They compared bands in the 0.73- to 0.92-μm, 1.0- to 1.4-μm, and 1.5- to 1.8 μm ranges and concluded that all produced reasonably good results. Given a choice, however, the longer wavelength bands did provide some margin of improvement. The longest wavelength bandpass available (i.e., MSS Band 7 -- 0.8 to 1.1 μm) was used in this study. As will be seen, this channel provides good mapping results with only minor problems occasioned by very shallow water, water carrying high sediment loads, or water overlain with floating vegetation.

Implementation of the thresholding technique was accomplished by observing radiance values for selected water features within a scene

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*Strong (1973), through the combined use of imagery collected over ocean surfaces from ERTS-1 and NOAA-2 satellites, found that when the sun elevation exceeds 55 degrees, the ERTS-1 imagery is subject to considerable contamination by sunlight even though the specular point has been nearly 550 km from nadir. Strumpf and Strong (1974) have termed this condition "diffuse glitter." The condition is a result of the sea state or the slope of wind driven surface waves. In North Dakota the maximum solar elevation angle during the time of the ERTS-1 overflight (approximately 1015 local sun time) is 59.5 degrees along the southern boundary of the state at the summer solstice. This would indicate that water bodies at these latitudes are capable of producing diffuse glitter for a limited period of time centered on 22 June. However, surface conditions on even the largest water bodies found in the North Dakota prairies are considerably smoother than those found in the oceans. Considering the imagery handled during the course of this study, no evidence of diffuse glitter was observed.

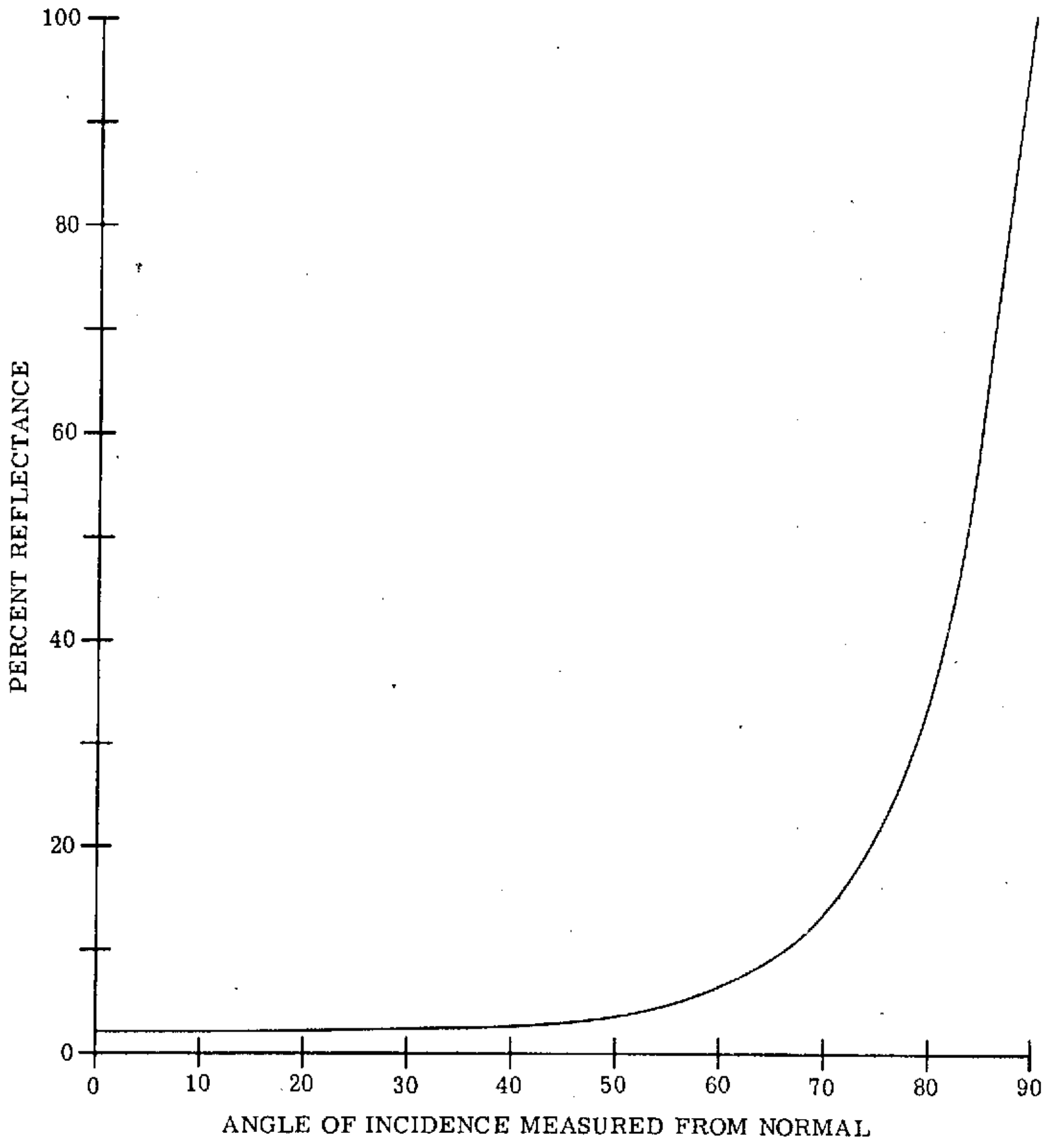

FIGURE 10. PERCENT REFLECTANCE OF THE AIR-WATER INTERFACE AS A FUNCTION OF THE ANGLE OF INCIDENCE. Reflectance is measured from the normal direction. These values are for unpolarized light only. (After Piech and Walker, 1972.)

and comparing these values with those for other terrain features also known to exhibit relatively low radiance characteristics. A decision boundary or threshold was then selected which effectively separated surface water from all other scene objects on the basis of their apparent radiances. Experience has shown that various scene objects exhibit radiances that may or may not be close to the low radiance of water depending on (1) the specific near-infrared band under consideration, (2) the geographic locale, and (3) the phenologic state of some scene objects. Mollisoil (chernozem) soils are present over much of eastern North Dakota (Wisconsin Agricultural Experiment Station, 1960). These soils are dark and have consistently approached the low radiance characteristics of water in the near-infrared. For the North Dakota locale, the practice has been to train the computer to differentiate between water and these bare soil features.

As an example of the thresholding technique, histograms of reflectance values used to establish the locations of decision boundaries between water and other scene features are shown for satellite data in Figure 11 and for aircraft data in Figure 12. Note that in these data water and soil had density distributions displaced from each other. In the case of the aircraft data, several additional scene features were considered -- specifically marsh vegetation and shallow water. The marsh vegetation had a density distribution similar to and overlapping that of soil. The distribution for shallow water indicated an apparent continuum between deep water and soil. In the case of the satellite data, locating the decision boundary nearer to the soil's density peak was justified in order that shallow water not be excluded from the recognition of total standing water.

The accuracy of the histogram method of differentiating between water and nonwater was further tested by the analysis of several lakes for which aerial photos nearly concurrent with the ERTS data were available. Figure 13 is a tabulation of ERTS MSS-7 data values of less than a certain threshold. These values have been plotted on a grid corresponding in geometry and aspect to an ERTS pixel (picture element) array at an original scale of 1:10,000. This plot was then compared with aerial photography collected by supporting aircraft at that scale. With this procedure, it was possible to accurately delineate the correct lake boundaries on the ERTS imagery and validate the selection of a threshold level. In Figure 13, data values of "8" and "9" are seen to lie predominantly on the lake margin indicating that those pixels may have contained mixtures of both water and nonwater materials. However, a few 8's (data values) were scattered within interior lake areas implying that a data value of 8 could legitimately represent a constituency of 100 percent water. In this instance, an independent histogram analysis had been used to select a threshold level of 8 (i.e., data values of 8 or less were counted as water pixels while all other pixels were considered nonwater). The particular lake plotted in Figure 13 is

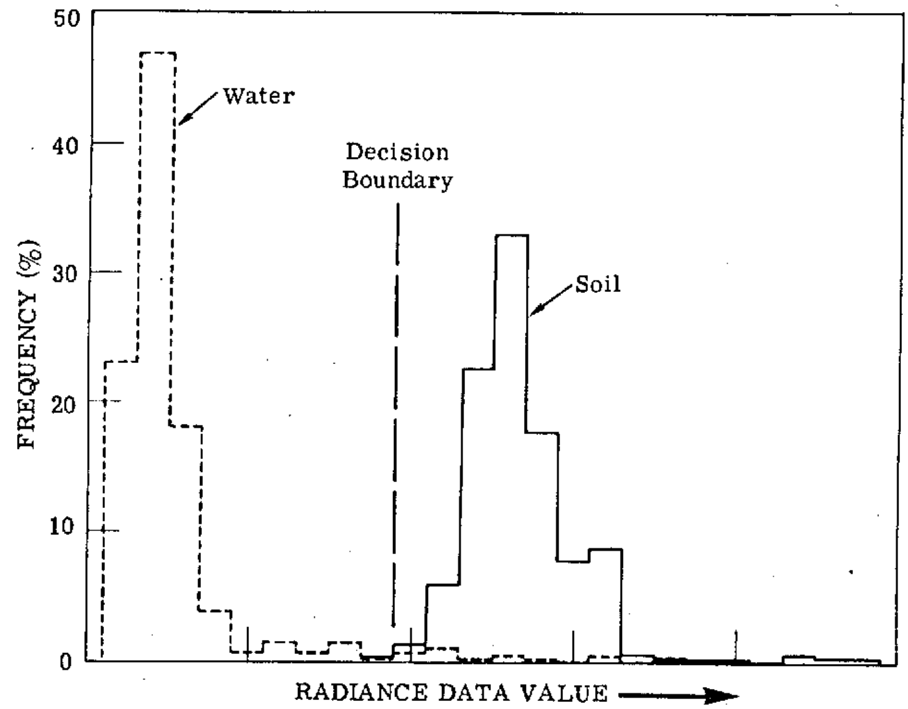

FIGURE 11. HISTOGRAMS OF REFLECTANCE VALUES FOR WATER AND SOIL FROM ERTS-1, MSS-7 DATA. Data collected near Woodworth, North Dakota at 1659 GMT, 31 July 1972.

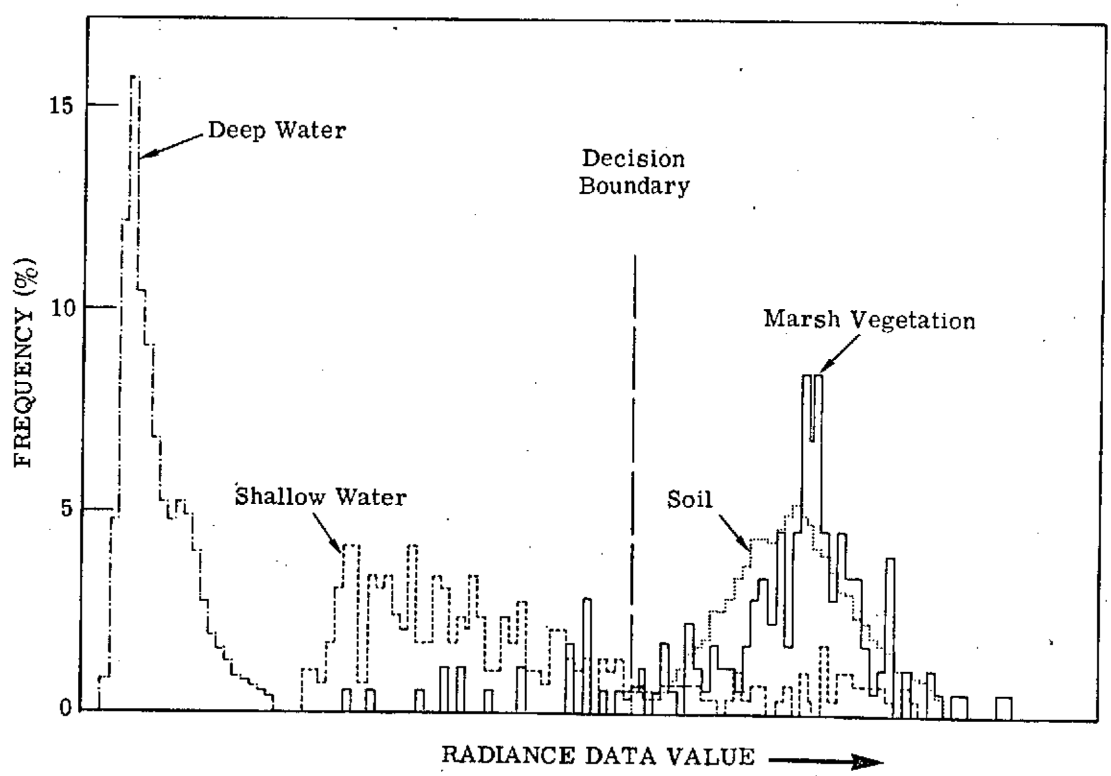

FIGURE 12. HISTOGRAMS OF REFLECTANCE VALUES FOR WATER, MARSH VEGETATION, AND SOIL FROM AIRCRAFT MSS (1.0 TO 1.4 μm) DATA. Data collected near Woodworth, North Dakota on 28 July 1972, from 4500 ft altitude.

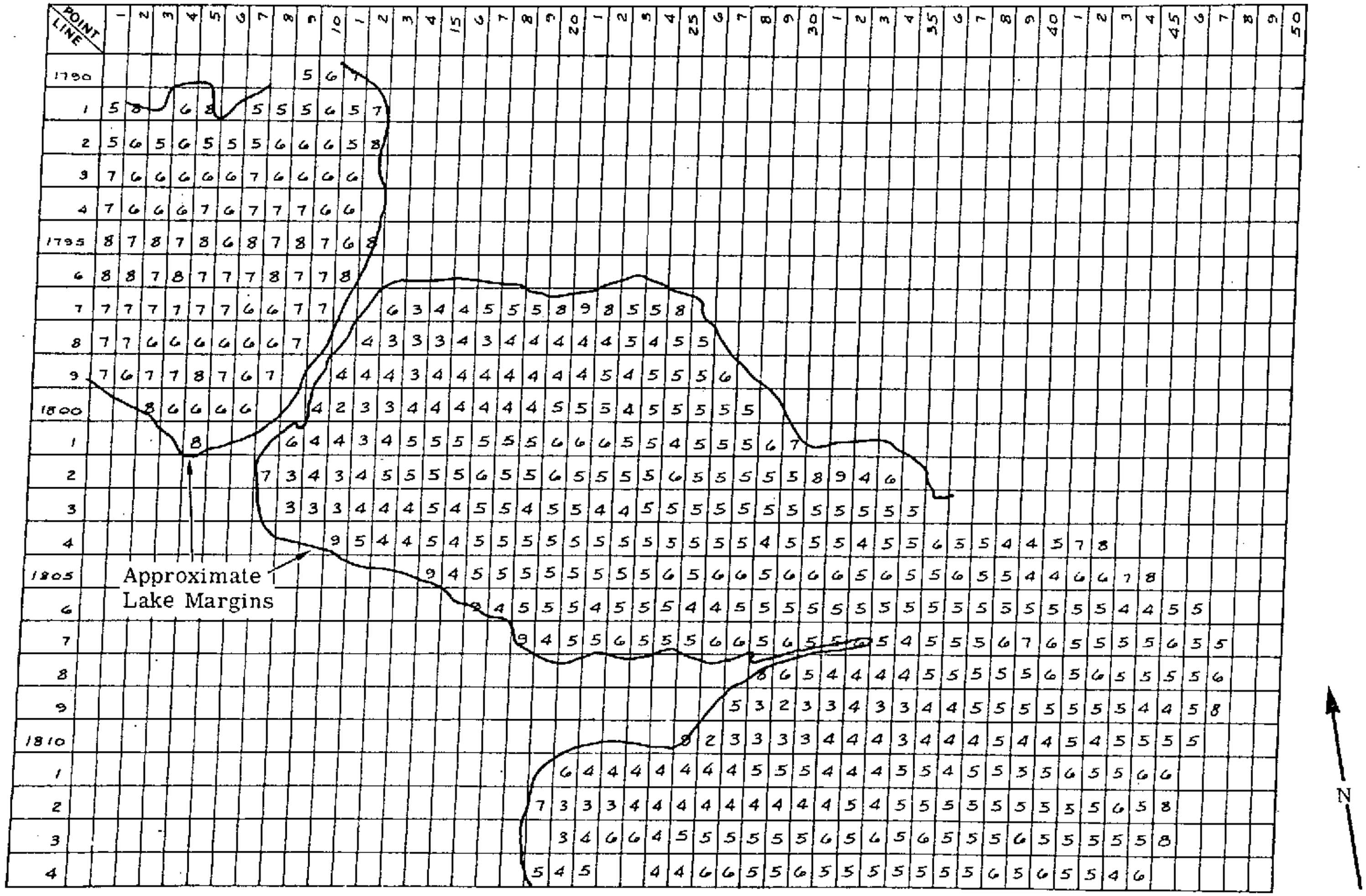

FIGURE 13. ERTS CHANNEL MSS-7 DATA VALUES FOR DES MOINES LAKE. Data values of 8 and less were determined to represent pixels consisting wholly of water. Higher values were deleted from the final map. Original scale of the pixel grid was 1:10,000.

Des Moines Lake, situated 16 miles due west of the village of Woodworth, North Dakota. The lake is divided by a narrow earthern causeway surmounted by a two-lane highway. The waters of both halves but particularly of the northern half are alkaline and high in suspended solids. In the spectral band MSS-7 (0.8 to 1.1 μm), Des Moines Lake exhibited slightly higher reflectance values than many of the other lakes which contained fewer suspended particulates.

3.1.2 RESULTS

Thematic water mapping using the thresholding technique described above was accomplished for data collected on three different dates. The intent was to monitor both a seasonal as well as an annual change. For the three observations, data were processed and analyzed for the same tract which comprised 3317 km^2 (1278 square miles). The tract shown in Figure 6, partially overlapped both the Coteau du Missouri and the drift plain physiographic regions.

Observations which took place on 31 July 1972, 14 May 1973, and 7 July 1973 occurred during periods of radically different moisture regimes. In July 1972, moisture conditions were near average for that time of year. Some of the seasonal* ponds and lakes had diminished or disappeared completely but many others remained. Snow accumulation during the winter of 1972-73 was abnormally low, and, as a result, there was little recharge of prairie depressions during the spring melt. Many of the ephemeral and temporary ponds never experienced standing water during the spring of 1973 and by mid-May some seasonal ponds had dried-up.** Drought conditions persisted, and, by mid-July 1973, virtually all seasonal ponds had become dry and many semipermanent ponds and lakes had radically diminished in area.

Figures 14 through 16 are computer-generated water recognition maps for each of the three observation dates. Each map comprises approximately 1520 km^2 (590 square miles) and in each case represents nearly the identical scene. The large clearly discernible prairie lakes include Des Moines, Barnes, and Chase Lakes. Probably the most dramatic change in these maps is the complete disappearance of Sink and Kunkel Lakes, which were only recognized on the observation of 31 July 1972. Note, also, the numerous small lakes particu-

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*The classification designations used in this text follow the classification system of Stewart and Kantrud (1971).

**Shjeflo (1968) has mentioned the importance of the spring snowmelt. In a study of 10 prairie potholes he noted that only 31 percent of the annual recharge was attributable to snowmelt, but that this fraction was vital because it was available in the spring when waterfowl were nesting.

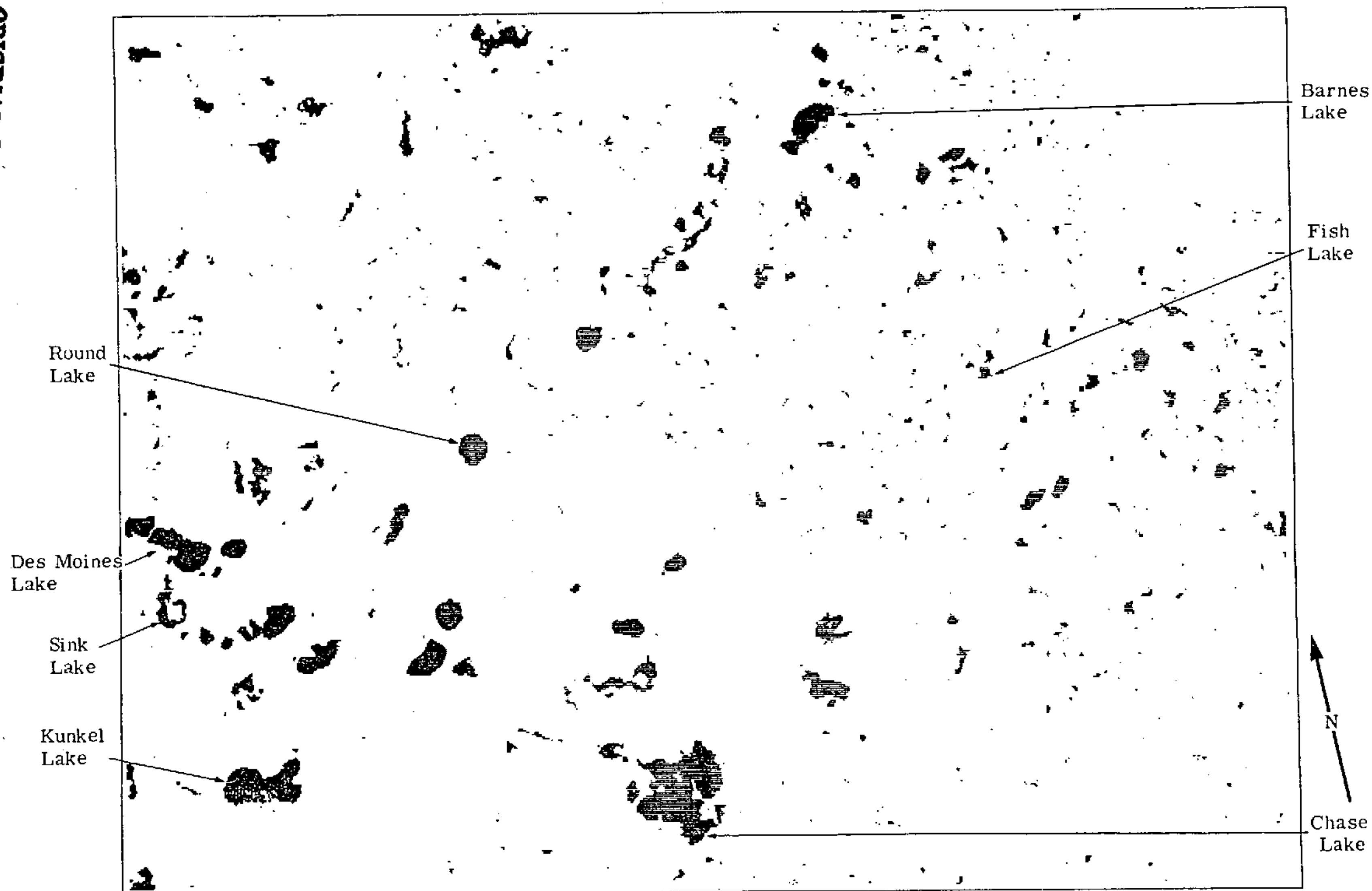

FIGURE 14. DIGITAL WATER RECOGNITION MAP FROM ERTS OBSERVATION 1008-16594 OF 31 JULY 1972.
The map, obtained by thresholding channel MSS-7, encompasses approximately 1520 km^2.

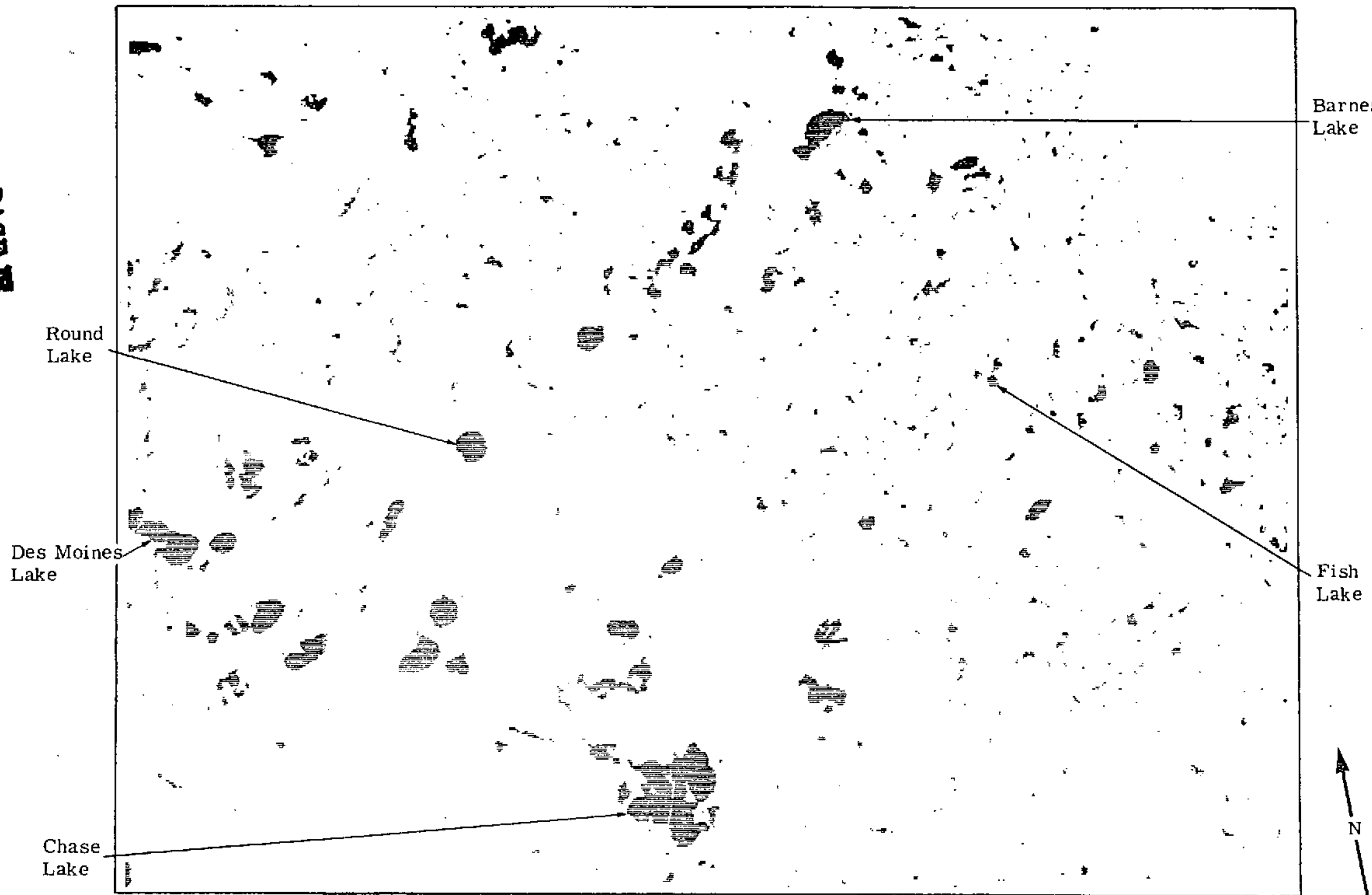

FIGURE 15. DIGITAL WATER RECOGNITION MAP FROM ERTS OBSERVATION 1295-16550 OF 14 MAY 1973.
The map, obtained by thresholding channel MSS-7, encompasses approximately 1520 km^2.

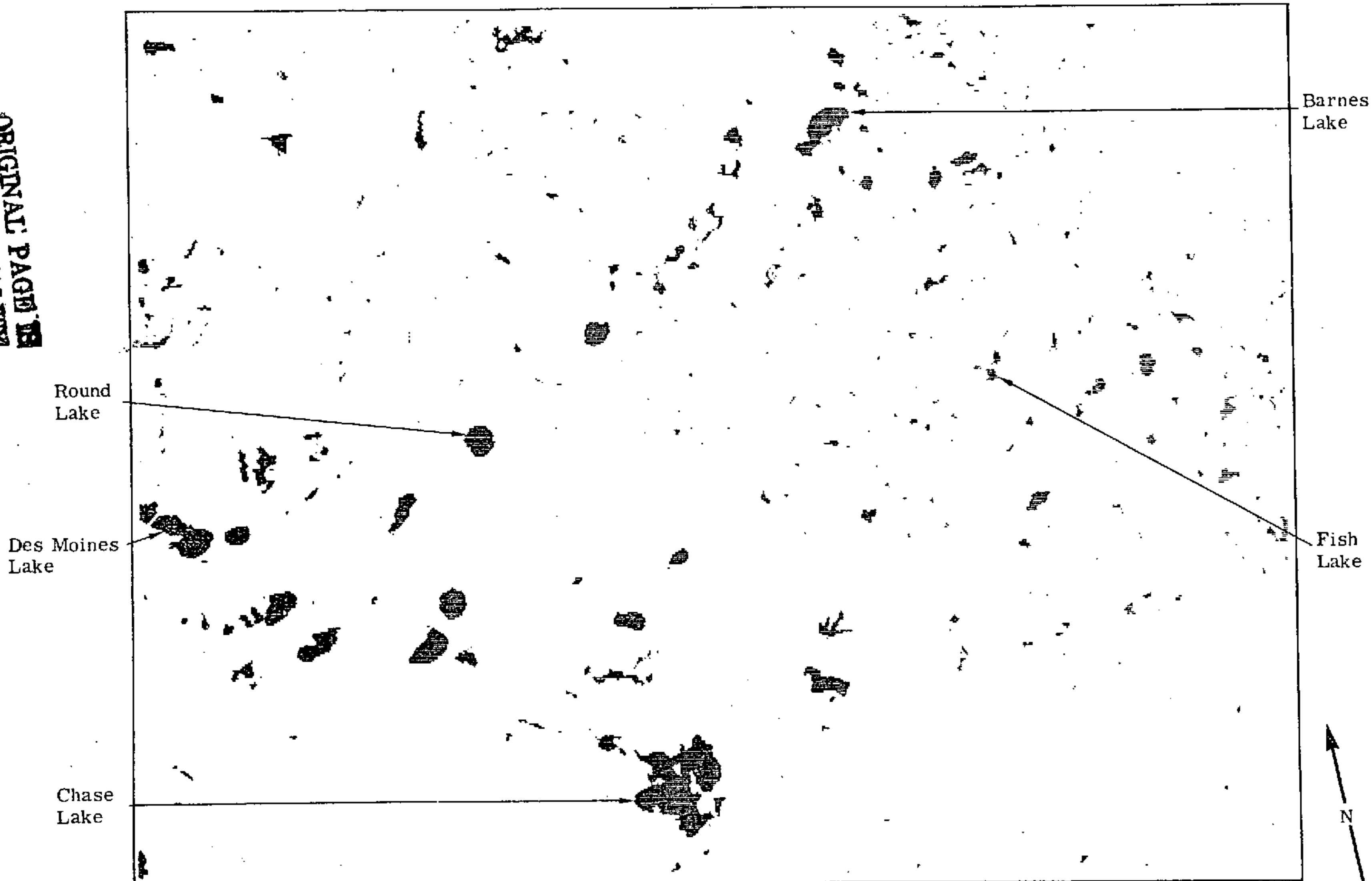

FIGURE 16. DIGITAL WATER RECOGNITION MAP FROM ERTS OBSERVATION 1349-16543 OF 7 JULY 1973. The map, obtained by thresholding channel MSS-7, encompasses approximately 1520 km^2.

larly in the upper left corner of the scene. In consonance with the moisture conditions noted above, many of these small lakes showed a steady decrease in area and numbers over the consecutive time periods spanned by the three observations. Many additional changes will be apparent to the reader upon further study.

In examining the foregoing imagery, the reader should be aware that a scanner image is created by the scanner painting out a series of contiguous swaths on the ground in a direction orthogonal to the satellite's ground track. The cellular structure of the digital data is created when digital sampling subsequently occurs along each scan line. The scan and the sampling rates are such as to create a cell or pixel having a nominal ground area size of 79 meters by 57 meters. The computer maps, reproduced as Figures 14 through 16, very nearly duplicated this rectangular aspect by printing out the digital characters at a line spacing of eight per inch and a point spacing of ten per inch. (The map was subsequently photo-reduced for publication.) An ERTS MSS image-frame consists of 2340 scan lines and 3240 points along each of the scan lines for a total of 7,581,600 pixels or data points per frame.

The maps of Figures 14 through 16 have been assembled from several computer output strips each having the standard 132-column-wide format. Digital maps as such do not represent an efficient form of data management. When generated with a general purpose computer, this type of information display is both time consuming to assemble and unwieldy to handle if the scene is larger than a small fraction of an ERTS frame. (The area encompassed by each of Figures 14 through 16 amounts to only 4.5 percent of an ERTS frame.) The map display and the required manual interpretation are not amenable to a wide area survey on a routine basis. For purposes of analysis, the data have generally greater value if presented in terms of statistical tables. Figure 17 illustrates a statistical tabulation of ponds and lakes observed on 7 July 1973 in that portion of the study area common to the Coteau du Missouri physiographic region. (The boundary between landforms was used to stratify the study area. A similar tabulation was produced for the drift plain stratum.) The upper listing in the tabulation is an enumeration of all surface water features recognized in the stratum and a summary of the pond size frequency for the stratum is presented in the lower tabulation.

The statistical enumeration of water features was produced by a computer program designed for use with satellite data. Its function has been to utilize a threshold decision criterion for classifying a grouping of pixels as a water body and then to compute the area of each specific water feature. Perimeter calculations are also possible. Because of the small size of many of the ponds and the potential that the shorelines of larger ponds and lakes could vary widely in length at scales finer than the resolution limit of the data, perimeter calculations were not likely to be meaningful. Consequently, determinations of pond perimeters were not made using the data of this study.

07JUL73 C N47-22/W098-22 N N47-21/W098-07 1349-16543- SUN EL57 AZ131 192-4866-N 0-1-0-1 H ERIM (ERTS DATA)

TABULATION OF RECOGNIZED WATER BODIES

LAT	LONG	SCAN LINE	POINT	AREA (ACRES)	AREA (HECTARES)
47.3710	99.4194	1439	194	20.867	8.445
47.3909	99.5535	1440	13	1.098	.444
47.3733	99.4483	1442	156	1.098	.444
47.3637	99.4051	1446	216.	7.688	3.111
47.3668	99.4399	1449	170	1.098	.444
47.3320	99.2560	1458	422	1.098	.444
47.3288	99.2353	1458	450	1.098	.444
47.3281	99.2403	1460	444	4.393	1.778
47.3489	99.3953	1464	236	2.196	.889
47.3282	99.2599	1464	419	2.196	.889
47.3190	99.2149	1467	481	3.295	1.333
47.3176	99.2053	1467	494	2.196	.889
47.3268	99.2699	1468	407	4.393	1.778
47.3532	99.4564	1471	156	1.098	.444
47.3194	99.2509	1474	435	2.196	.889
47.3164	99.2458	1477	443	1.098	.444
47.3270	99.3193	1478	344	3.295	1.333
46.8232	99.2766	2154	655	76.677	31.112
46.8153	99.2397	2157	706	2.196	.889
46.8163	99.2510	2158	691	27.456	11.111
46.8419	99.4221	2159	460	1.098	.444
46.8324	99.3655	2160	537	83.466	33.779
46.8122	99.2338	2160	715	1.098	.444
46.8208	99.3163	2166	603	46.126	18.667
46.8418	99.4842	2172	381	2.196	.889
46.8051	99.2446	2172	705	19.768	8.000
46.8024	99.2417	2175	710	4.393	1.778

SCENE N.D. COTEAU

LINES 1386 THRU 1428 POINTS 3 THRU 250
LINES 1429 THRU 1452 POINTS 3 THRU 374
LINES 1453 THRU 1499 POINTS 3 THRU 498
LINES 1500 THRU 1571 POINTS 3 THRU 622
LINES 1572 THRU 2175 POINTS 3 THRU 747

SCENE AREA= 922 SQ. MI.
= 2389 SQ. KM.

PIXEL LENGTH = 79.00 METERS PIXEL WIDTH = 56.26 METERS

MODE = NORMAL
POINTS COUNTED IF VOLTAGE IS .GE. 0.0 AND .LE. 8.0 VOLTS

DISTRIBUTION OF LAKES IN THE SCENE

BY AREA

AREA (ACRES)	AREA (HECTARES)	FREQUENCY
.25 TO .50	.10 TO .20	0
.50 TO 1.00	.20 TO .40	0
1.00 TO 2.00	.40 TO .81	149
2.00 TO 3.00	.81 TO 1.21	60
3.00 TO 4.00	1.21 TO 1.62	47
4.00 TO 6.00	1.62 TO 2.43	65
6.00 TO 8.00	2.43 TO 3.24	29
8.00 TO 10.00	3.24 TO 4.05	21
10.00 TO 15.00	4.05 TO 6.07	38
15.00 TO 20.00	6.07 TO 8.09	28
20.00 TO 25.00	8.09 TO 10.12	10
25.00 TO 30.00	10.12 TO 12.14	18
30.00 TO 40.00	12.14 TO 16.19	14
40.00 TO 50.00	16.19 TO 20.23	11
50.00 TO 75.00	20.23 TO 30.35	18
75.00 TO 100.00	30.35 TO 40.47	16
100.00 TO 150.00	40.47 TO 60.70	13
150.00 TO 200.00	60.70 TO 80.94	7
OVER 200.00	OVER 80.94	13

FIGURE 17. EXAMPLE OF COMPUTER PRINTOUT OF POND AND LAKE STATISTICS FOR AN AREA WITHIN THE COTEAU du MISSOURI PHYSIOGRAPHIC REGION OF NORTH DAKOTA. Data collected by ERTS-1 at 1654 GMT on 7 July 1973.

ORIGINAL PAGE IS OF POOR QUALITY

In the tabulations which were produced, each pond and lake has been identified and its position defined using each of two coordinate systems based on a scan line and point number scheme and a more conventional latitude and longitude system. The scan line and point number information has inherently been available from the ERTS data. Conversion to latitude and longitude coordinates was accomplished by a regression analysis using several control points located within the scene. The convention used to reference each water body has been to identify the body by the number of the last (most southerly) scan line with at least one pixel in the water body and the point number of the greatest (most easterly) numbered water pixel of that scan line.

Graphical summaries of pond numbers for the two observed strata and the three observation dates are shown in Figures 18 through 21. These have been normalized so that comparisons between the different sized strata are possible. From the graphs, it is evident that very dramatic seasonal and annual changes in surface water have occurred and that differences did exist between strata. Ponds and lakes in all size classes are less numerous in the drift plain than on the Coteau. Note that the ordinate or density scales for the two strata are different by an order of magnitude. On the other hand, annual and seasonal change patterns for the two strata tend to be similar. The moisture regime relating to the dry conditions prevalent throughout the period is strongly correlated in the annual and seasonal change patterns shown. In fact, the annual and seasonal changes for both strata tend to be similar and generally of the same order of magnitude. Implicit in this statement is the fact that pond numbers and size distributions were approximately the same in May 1973 as they were the previous July. This, of course, was because of the lack of sufficient snowmelt to recharge the ponds to their usual spring repletion. For the period from May to July 1973 the effects of further or perhaps increased desiccation can be seen. Surface water features in nearly all size class have decreased and, on the average, were lower in July 1973 than during any of the previous two observations.

In examining these data the reader should remember that as the ponds and lakes in one size class diminished in area they eventually reverted to a lower size class. Unless that lower size class has had its own attrition of water features the smaller ponds could potentially have shown an increase in numbers.

It is also important to stress one other point. The pond sizes listed by the computer must in practice be termed "apparent size." This is because each pixel of data has been examined and been determined to be either totally water or not water. Many pixels lying on the perimeters of ponds and lakes undoubtedly contained some unrecognized and untabulated water. This caused the surface areas of virtually all water features to be underestimated. Percentage wise, the errors were greater for the smaller ponds and for

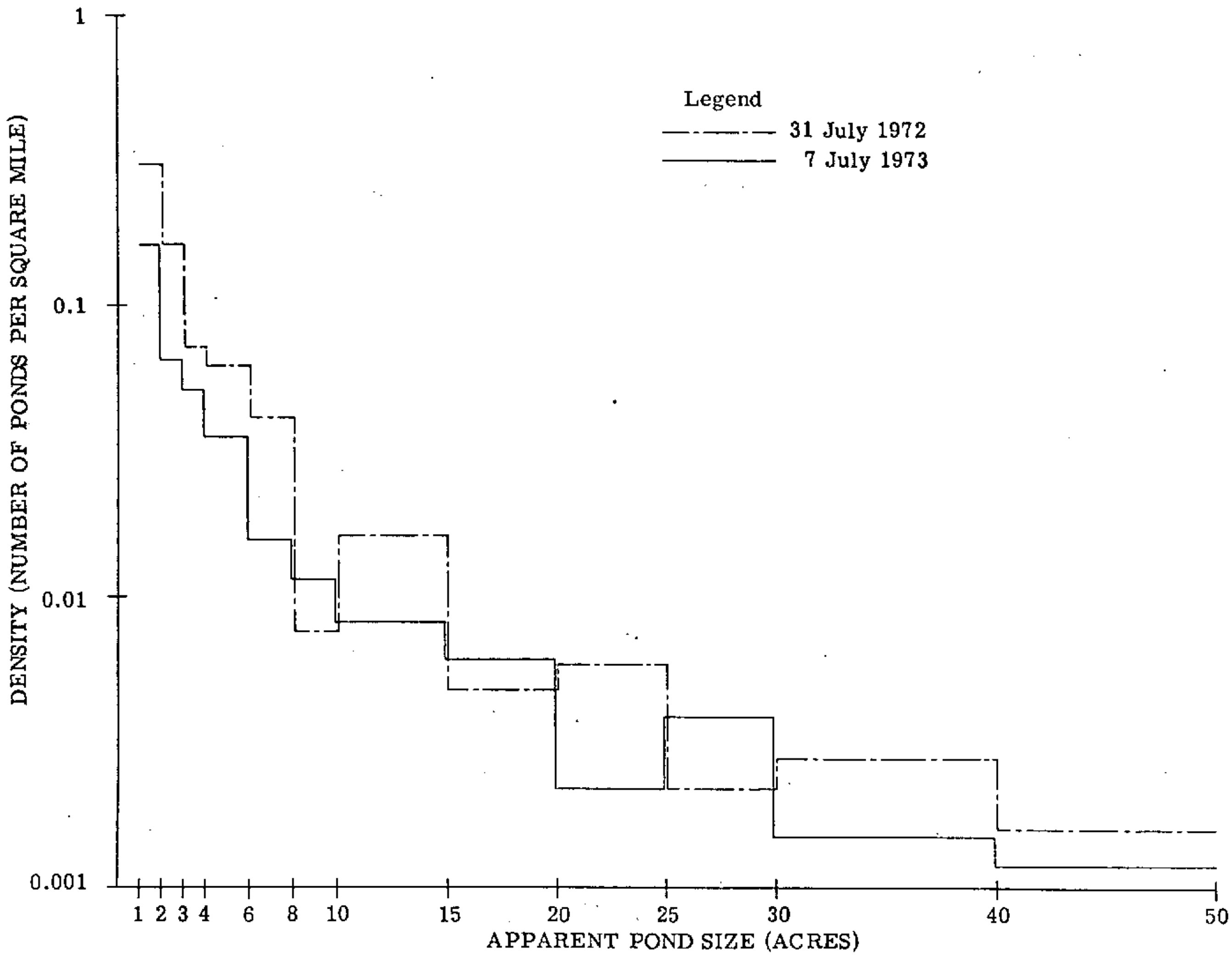

FIGURE 18. SUMMARY OF SIZE DISTRIBUTION OF PONDS IN THE COTEAU STRATUM FOR AN ANNUAL PERIOD. Where the pond size increments are greater than one-acre, the data have been averaged over the increment.

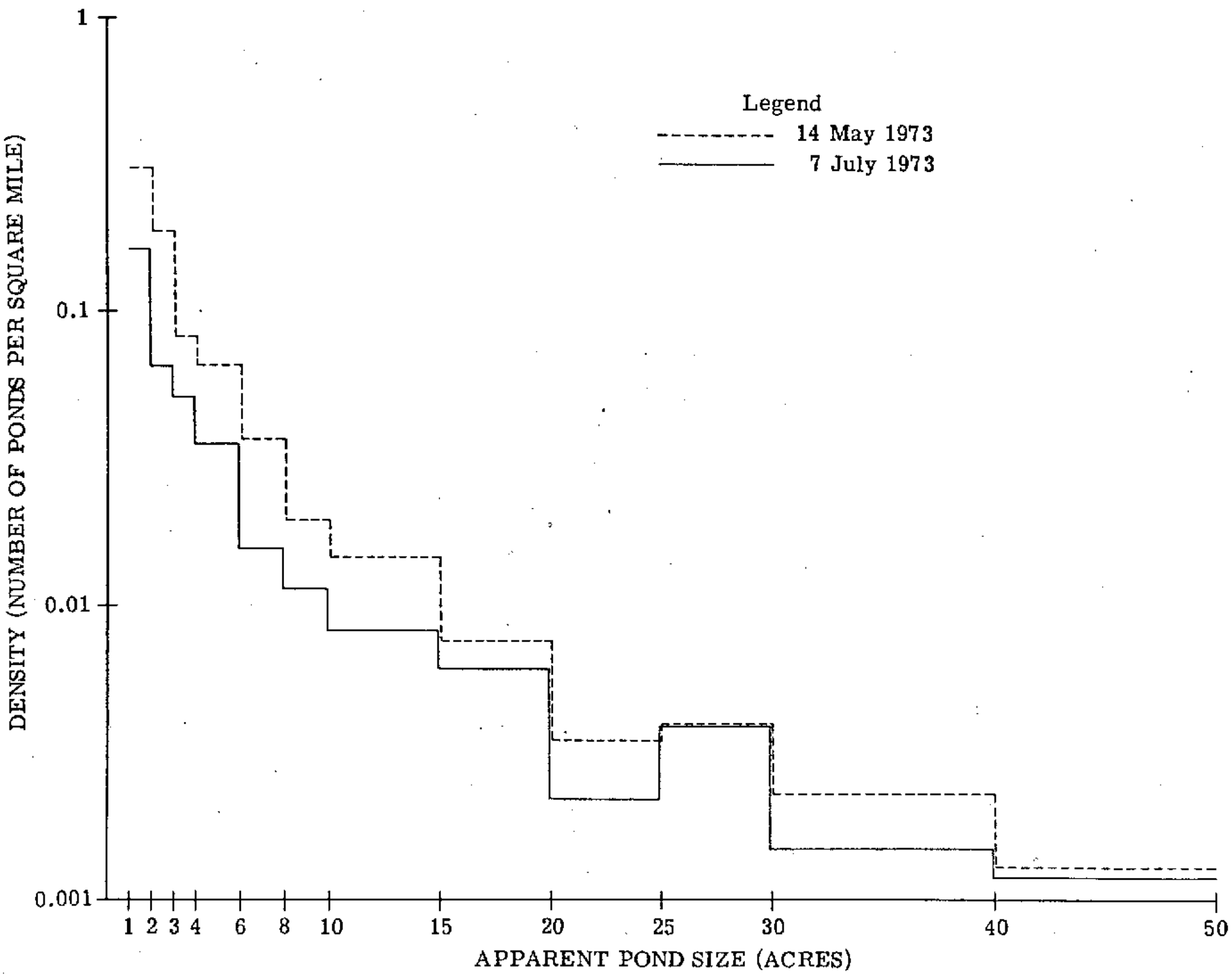

FIGURE 19. SUMMARY OF SIZE DISTRIBUTION OF PONDS IN THE COTEAU STRATUM FOR A SEASONAL PERIOD. Where the pond size increments are greater than one-acre, the data have been averaged over the increment.

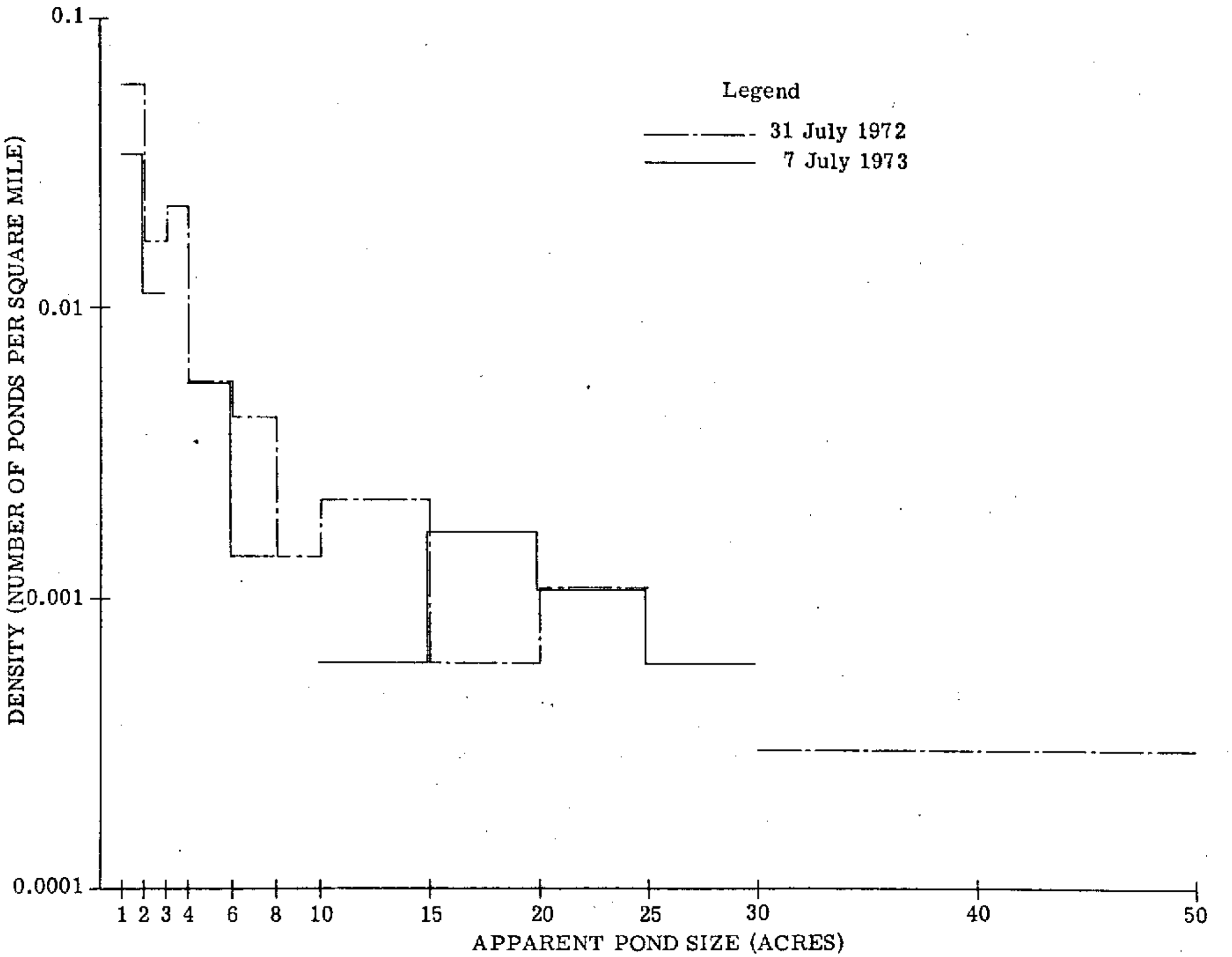

FIGURE 20. SUMMARY OF SIZE DISTRIBUTION OF PONDS IN THE DRIFT PLAIN STRATUM FOR AN ANNUAL PERIOD. Where the pond size increments are greater than one-acre, the data have been averaged over the increment. Discontinuities in a curve indicate an interval where no ponds were tabulated.

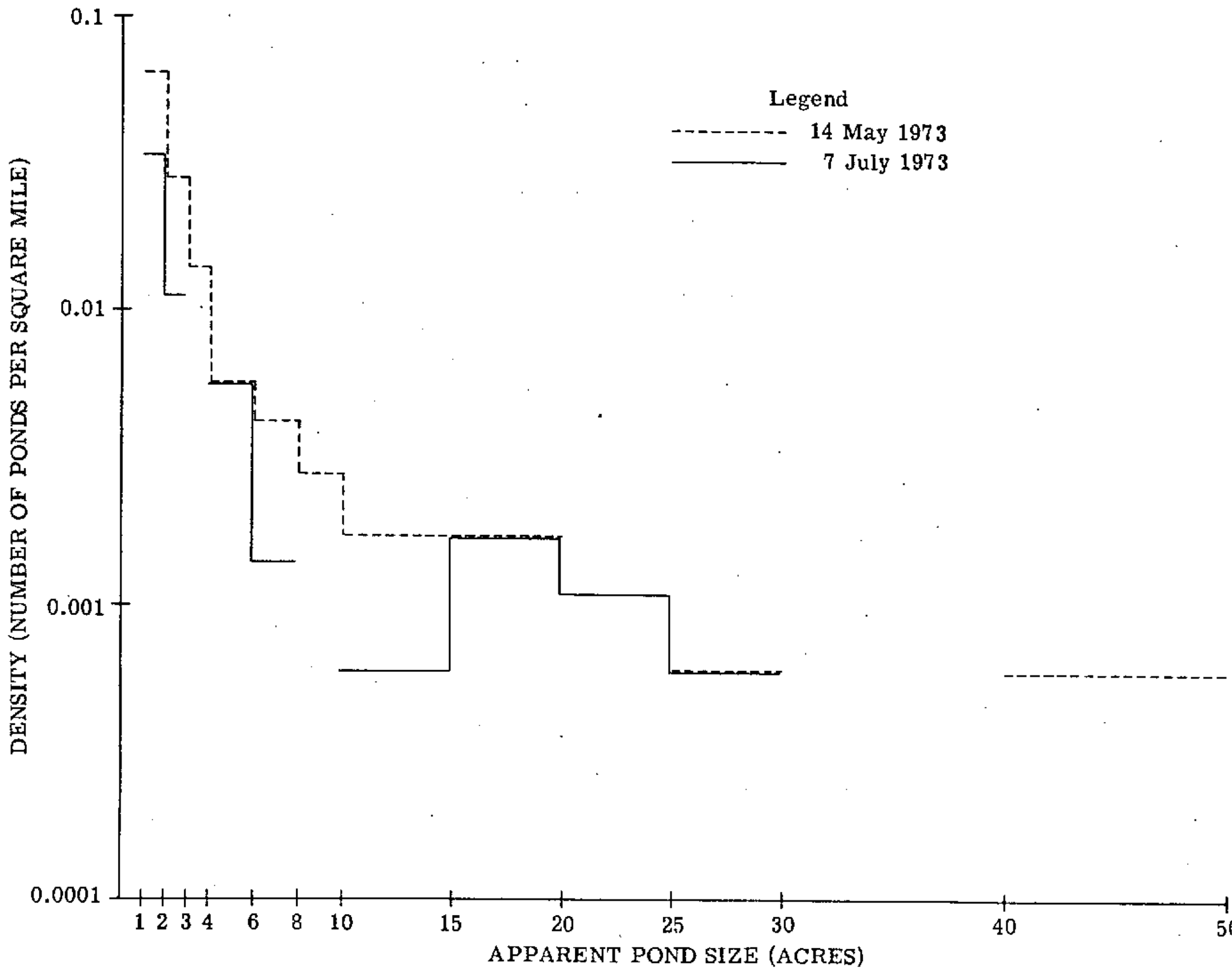

FIGURE 21. SUMMARY OF SIZE DISTRIBUTION OF PONDS IN THE DRIFT PLAIN STRATUM FOR A SEASONAL PERIOD. Where the pond size increments are greater than one-acre, the data have been averaged over the increment. Discontinuities in a curve indicate an interval where no ponds were tabulated.

those of irregular shape (i.e., those having a high ratio of perimeter length to area). The very small ponds, of course, would not be recognized at all. Generally a pond must have been at least 0.4 hectare (1.0 acre) in size to be recognized. Recognition of a 0.4 hectare pond was dependent upon whether the pond was wholly included in one digital sample (i.e., within a pixel) or fractionally distributed over several pixels. In general, it is problematic whether ponds in the 0.4- to 1.6-hectare (1.0- to 4-acre) size class were recognized. Above 1.6 hectares, ponds were nearly always recognized but not necessarily recognized at their full areal extent. The next section will consider the problem of sensor resolution and will utilize a radically different approach for improving the apparent resolution of the data.

3.2 SURFACE WATER MAPPING USING AN ADVANCED TECHNIQUE FOR IMPROVING APPARENT SPATIAL RESOLUTION

With the advent of satellite programs many workers in the field of remote sensing have been uncomfortable with the diminished resolving capabilities inherent in the operation of sensors, particularly scanners, at high altitudes. One method of circumventing this difficulty while simultaneously exploiting the synoptic coverage provided by satellites has been multistage sampling (Langley, 1969). An alternative approach, which will be described, does not depend upon multiple sampling at increasingly higher resolution. Instead, the approach takes advantage of the added information content of multiple spectral channels to estimate the proportions of materials present within a scanner's instantaneous field-of-view (IFOV)*. The technique termed "proportion estimation" or "mixtures estimation" was first outlined by Horwitz et al. (1971) and further described by Nalepka et al. (1972). Before this study, the application of this technique was largely developmental in nature, and its use in this study must be considered to be among the first attempts to test its applicability in an operational context.

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*The terms "IFOV" and "pixel" are often used interchangeably. However, in the case of ERTS data the terms are not synonymous. The ERTS-1 MSS optics provide an IFOV of approximately 79 x 79 meters while the data are sampled and digitized at a rate which equates a pixel to an area of approximately 79 x 57 meters. In the strictest sense, a description of the proportion estimation approach must make reference to the sensor's optical IFOV. In the actual processing and display of output data, however, reference will be made to the pixel or digitized sample.

The proportion estimation approach has been developed by ERIM under separate funding by the National Aeronautics and Space Administration (Contract NAS9-9784). The following sections will describe and evaluate the results of a test of this technique on ERTS-1 MSS data gathered on 7 July 1973.

3.2.1 METHODS

When the IFOV of a multispectral scanner is large with respect to the scene objects being scanned, a single resolution cell may contain a number of different material classes (i.e., the IFOV may be composed of a mixture of materials). The proportion estimation algorithm when applied to such data provides an estimate of the proportion of objects present within each of the scanner's IFOV's.

Approaches to the proportion estimation problem are heavily steeped in theory, an understanding of which is not necessary to appreciate its operation. The essence of the technique can, however, be illustrated in geometric terms. Assume that a data set comprised of two spectral channels, λ_1 and λ_2, contains three pure and unique materials -- A, B, and C. This situation can be depicted as in Figure 22 where the signature means for the three materials are shown in two-dimensional signal space. The signature simplex is the geometric figure formed by the lines connecting each pair of signature means. In the nondegenerate case, each pure signature is a distinct vertex of this simplex. If an unknown scene element (IFOV) consists of a mixture of all three materials, the signature of this material, X, lies within the simplex. An estimate of the pairwise proportion of pure materials constituting the unknown element is obtained by drawing a line from a vertex through the unknown signature to the opposite leg of the simplex. The ratio into which each leg is divided defines the pairwise proportional composition of the unknown. For the case illustrated in Figure 22, the unknown happens to lie at the centroid of the triangle and its composition would be in the ratio of 1/3, 1/3, and 1/3 of materials A, B, and C, respectively. Cases requiring special geometric interpretation are shown in Figure 23. Figure 23a illustrates the occurrence of an unknown, Y, on the edge of the signature simplex. In this case the unknown would be comprised of only materials A and C. Figure 23b shows an unknown, Z, which lies completely outside the simplex. In this case, the unknown is comprised of materials A and C in the proportion determined by drawing an orthogonal line (i.e., the shortest distance) to the nearest edge of the simplex or, in the case illustrated, to leg A-C of the simplex triangle. If the unknown, Z, were quite distant from the signature simplex (described in terms of a χ^2 distance), the present algorithm will designate the unknown as an alien object or, in other words, an object composed of none of the simplex materials.

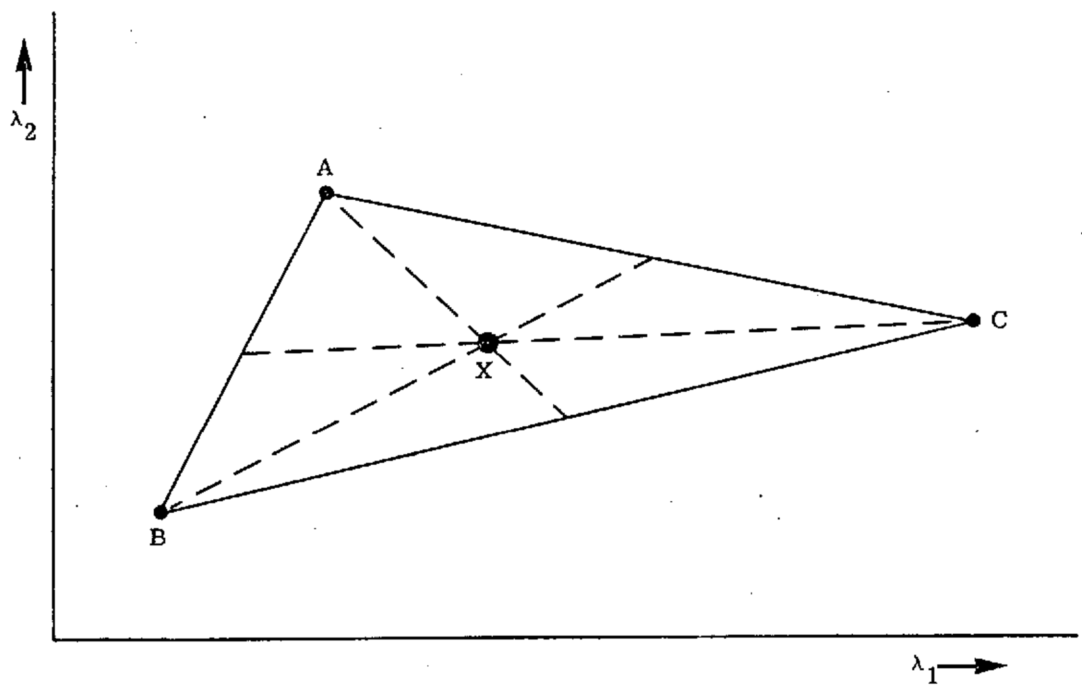
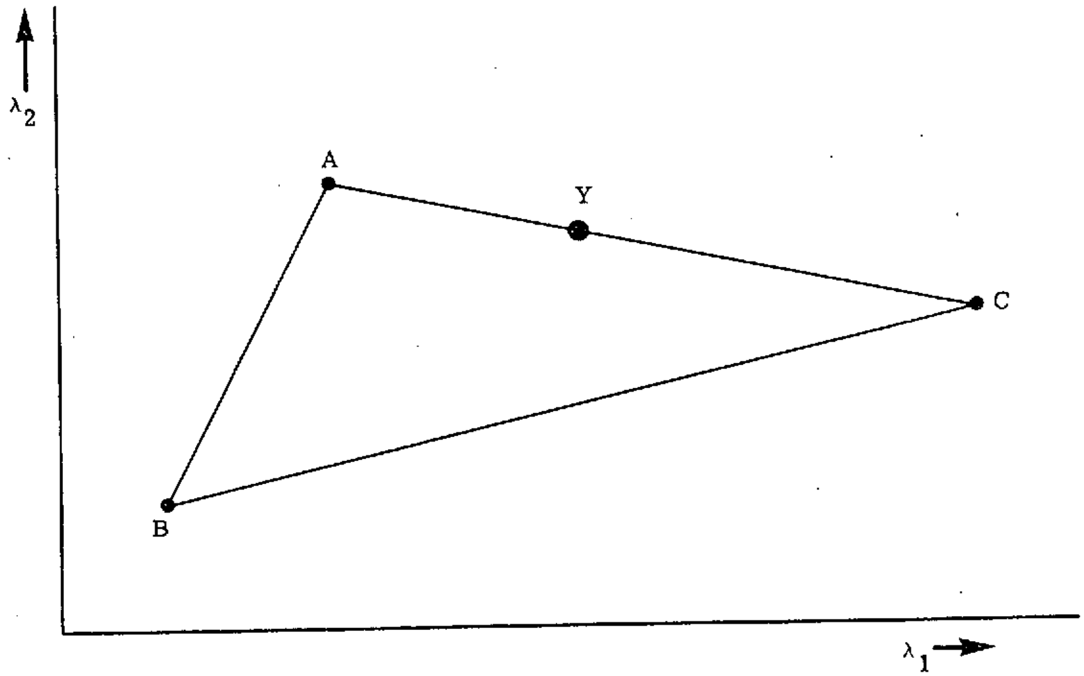
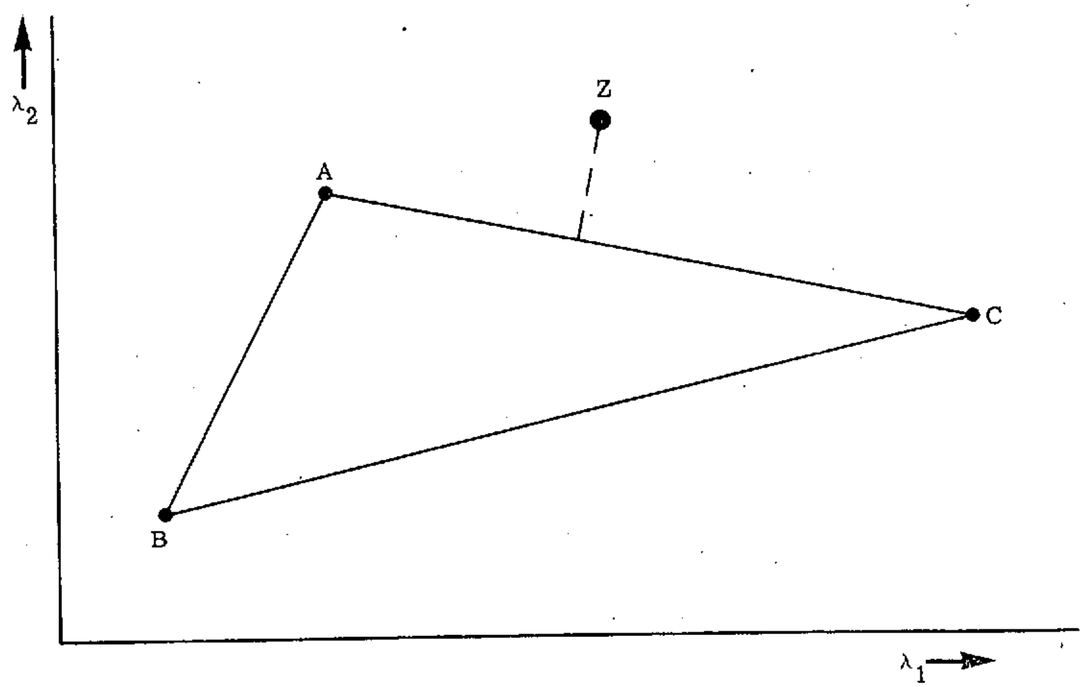


FIGURE 22. GEOMETRIC INTERPRETATION OF MEANS OF SIGNATURE MIXTURES. In the case illustrated, the unknown, X, is a mixture of three pure materials—A, B, and C—which form the vertices of the signature simplex.



(a) The Unknown, Y, Lying On the Margin of the Signature Simplex Is a Mixture of Materials A and C



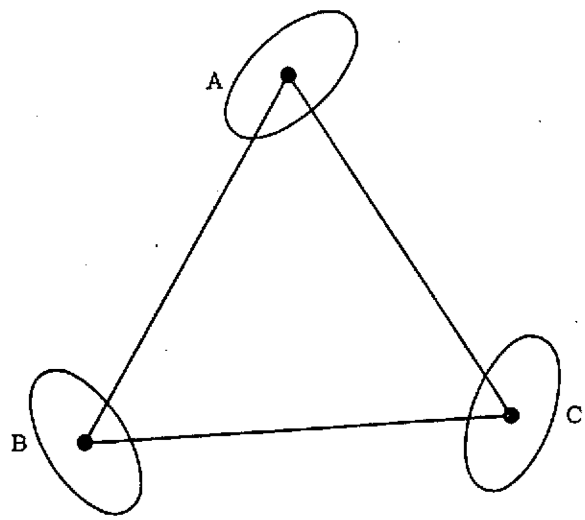
(b) The Unknown, Z, Lying Outside the Signature Simplex Is a Mixture of Materials A and C. If Z were too distant from the simplex, it would be declared an alien object.

FIGURE 23. GEOMETRIC INTERPRETATION OF ESTIMATE (SPECIAL CASES)

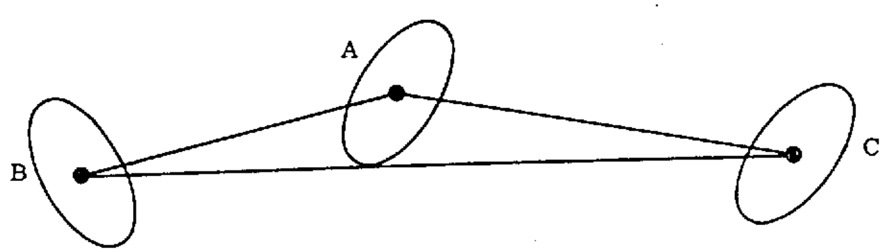
Although the above description has been limited to three pure and unique materials in two-dimensional signal space, the concept is easily expanded to situations where many object materials exist in spectral hyperspace. In applying the algorithm, however, it is necessary to observe two operational constraints. Firstly, at least n-1 spectral channels of information are required to satisfactorily estimate mixtures of n-object materials. Secondly, if the signatures for the materials in a mixture are similar or if one of them comes too close to a weighted average of the others, the estimates of the proportions may be poor. The latter condition is illustrated by Figure 24. Figure 24a shows a valid signal simplex for three signatures and two channels of data. Here covariance matrices interpretable in terms of loci of constant probability are shown. Figure 24b is a nearly degenerate signature simplex in which the vertex of one signature has come close to the weighted average of the other two signatures. A measure of what is "too close" is dependent upon the size and shape of the unit contour ellipsoid about the vertex or more specifically upon the covariance matrix.

In the present study, the intent was to delineate only water in a mixture of several scene materials. This should then have made it possible to both improve the size estimates of larger ponds and to detect small ponds which otherwise would have been undetected. Figure 25 illustrates the mixtures problem in the case of water recognition achieved by use of the single-channel thresholding algorithm. The dashes represent pixels with low reflectance values (in channel MSS-7) which nevertheless were not low enough to be classified as water. Some of these boundary elements may be attributed to marsh vegetation and/or mud flat margins because both of these exhibit low reflectance characteristics in the near-infrared. However, these boundary elements probably also contained some water. This caused the acreage of the lake to be underestimated because, in the thresholding mode, pixels were classified as either totally water or not water.

Besides improved areal perception, the proportion estimation approach is even more significant in that it offers the possibility for discerning very small water features less than a resolution cell in size. Prairie ponds or lakes frequently range from a fraction of an acre to several square miles in size. Although the larger ponds account for the greatest proportion of surface water present, the smaller ponds far exceed the larger in numbers. At a study area in northeastern South Dakota, Drewien and Springer (1969) observed that 73 percent of the wetland depressions were less than 1 acre in size. Similarly, Millar (1969) working at three widely scattered sites in Saskatchewan noted that between 82.0 and 87.5 percent of the basins were 1 acre or less in size but that these constituted only 29.2 to 44.1 percent of the total water acreage. The smaller pothole ponds are more susceptible to impressive changes in surface area and in total numbers. The depressions creating them are



(a) Signature Simplex with Unit Contour Ellipsoids



(b) Nearly Degenerate Signature Configuration

FIGURE 24. GEOMETRIC CONFIGURATIONS FOR THREE SIGNATURES AND TWO CHANNELS

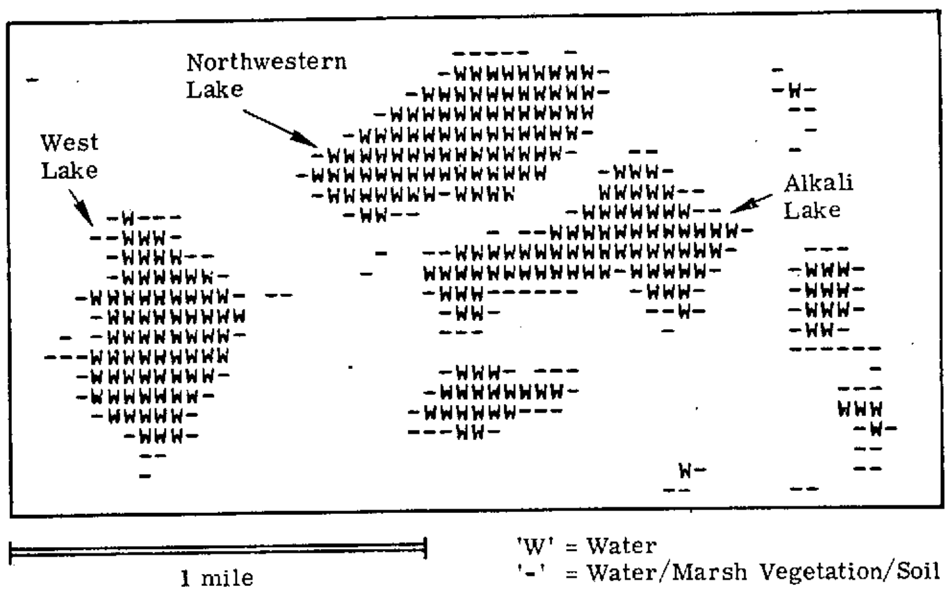


FIGURE 25. EXAMPLE OF BOUNDARY EFFECT ASSOCIATED WITH RECOGNITION MAP OF LAKES NEAR WOODWORTH, NORTH DAKOTA USING ERTS-1 DATA COLLECTED AT 1659 GMT ON 31 JULY 1972

generally very shallow and saucer shaped. As a result, slight changes in water depth can lead to a disproportionately greater change in areal extent.

Because this study was concerned with habitat changes particularly on a seasonal scale and the current waterfowl production models deal with sheer wetland numbers, the application of the proportion estimation algorithm was directed more towards recognizing numbers of water features than towards describing their areal extent.

3.2.2 RESULTS

The application of the proportion estimation algorithm involved, as a first step, the securing of spectral signatures for object materials occurring in the observation scene. Multispectral signatures extracted from actual scene elements (training sets) for the ERTS observation of 7 July 1973 are shown in Figure 26. In selecting the training sets, care was taken to pick resolution elements which were pure in their constituency. In order to obtain representative samples, however, the signatures were obtained by combining several training sets which consisted of like materials. For example, the water signature represents a combination of several ponds and lakes which ranged in water quality from the relatively clear to the moderately turbid. As a result, the signature for water in this instance has a very large standard deviation particularly in the shorter wavelength channels. Similarly, other signatures represent a variety of field and marsh situations but with significantly less variance.

Because of the restrictions inherent in the use of the algorithm, it was necessary to limit the signatures utilized to five as a maximum. In order to reduce the number to five, the row crop and shallow marsh signatures were eliminated from further consideration. Row crops, chiefly corn and sunflower, were eliminated because they were not widely abundant, and shallow marsh because its signature was similar to the small grain signature. (Morphologically, many shallow-marsh grasses and forbs are similar to the cereal grains -- all members of the grass family.)

The proportion estimation algorithm was applied to the remaining five signatures, water, deep marsh, bare soil, small grains, and range. The initial test failed as a result of the existence of a nearly degenerate signature simplex. In fact, each of the signatures for deep marsh, small grains, and range were independently found to be within one-half standard deviation value of the simplex of the other four signatures. This suggested that there was little difference between these three signatures which together represented nearly the entire green vegetation content of the observation scene. It appeared, therefore, that one representative class could be substituted for the three material classes. The small

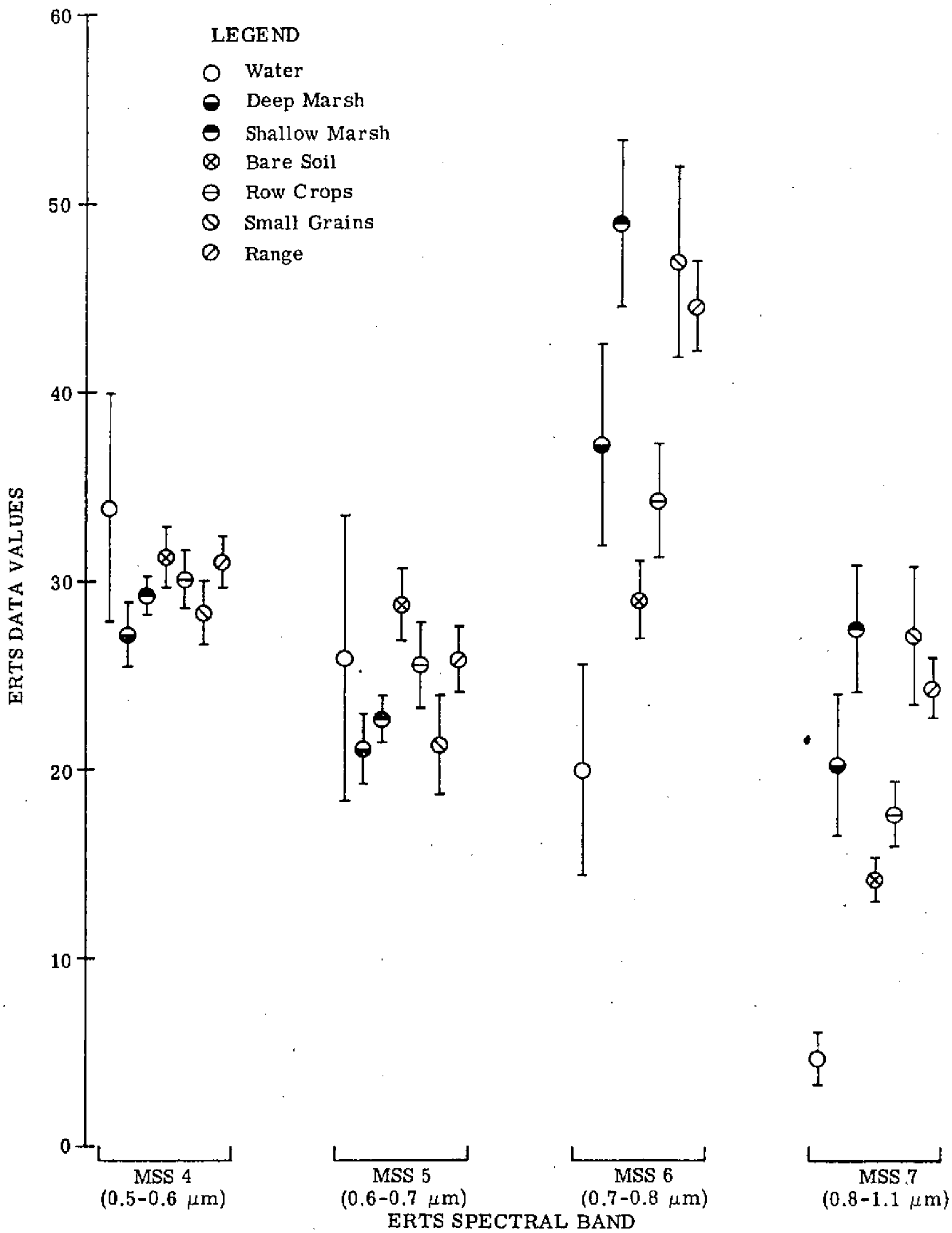


FIGURE 26. SPECTRAL SIGNATURES USED IN THE MULTISPECTRAL PROCESSING OF ERTS-1 DATA OF 7 JULY 1973, SCENE OBSERVATION 1349-16543. The signature mean and plus and minus one standard deviation are shown.

grain signature was selected because it was already a stand-in for shallow marsh and was most likely to be a pure signature. (Deep marsh conditions may have included some water, and the range signature may have contained some bare soil and stubble, particularly in heavily grazed areas.)

After reducing the problem to the use of three signatures, the algorithm was again applied but without marked improvement. Many water features were still only partially recognized while many water false alarms occurred in nonwater areas. The problem seemed to be the result of the extremely large variance associated with the water signature. Note in Figure 26 that the statistical spread of the water signature in MSS channels 4 and 5 very nearly overlapped all other signatures because of the variety of water quality conditions included in the signature. The water signatures appeared to be highly influenced by the amount of dissolved and/or suspended solids present in some lakes. Specifically, many of the lakes in outwash areas of the Coteau tend to be more saline than water features resting atop glacial till in other parts of the Coteau (Sloan, 1972). It appeared to be signature contributions from these outwash lakes that caused the gross variability in the general water signature heretofore utilized. Many of the more saline lakes in the outwash areas exhibited unusual visual coloration. This ranged from a pale chocolate color to a lime-white color in the extreme. This extreme coloration seemed to occur for partially evaporated lakes. In such instances, it appeared that many salts had precipitated out and that these were being kept in partial suspension because of wind and wave action. In the dry year of 1973, a much greater number of lakes were observed to fit this description than had been observed in the previous year.

Although a large glacial outwash is a major feature in the present study site, glacial outwash conditions cover only a small part of the Coteau du Missouri as a whole (Sloan, 1972). Consequently, it seemed reasonable to use a modified water signature which was not all inclusive of these saline conditions but which would be more universally applicable to the proportion estimation problem. Figure 27 shows the signatures for three individual lakes located near Woodworth, North Dakota. Additionally their combined signature is shown, and, for comparison, the original general signature inclusive of the outwash lakes is included. It is obvious that the signature means and standard deviations for the three Woodworth lakes are uniquely different from the general water signature.

At this juncture, one additional modification was made. The original set of object signatures (Figure 26) had seemed redundant in two of the four spectral channels (i.e., although displaced in scale, channel 5 appeared to echo channel 4, and channel 7 appeared to be a repetition of channel 6). This suggested that for the scene materials under consideration the total information content was present within two channels, the other two for the most part being

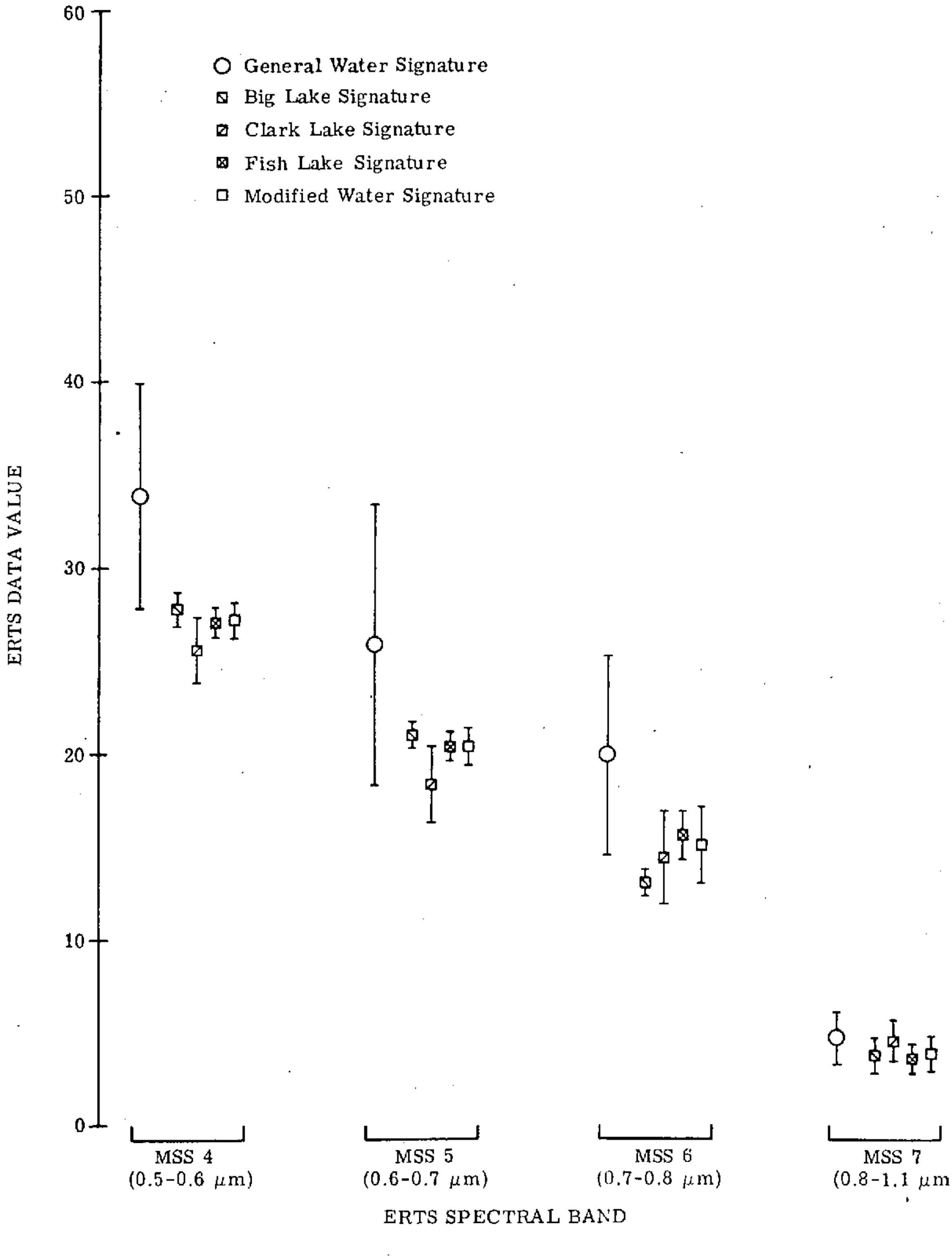


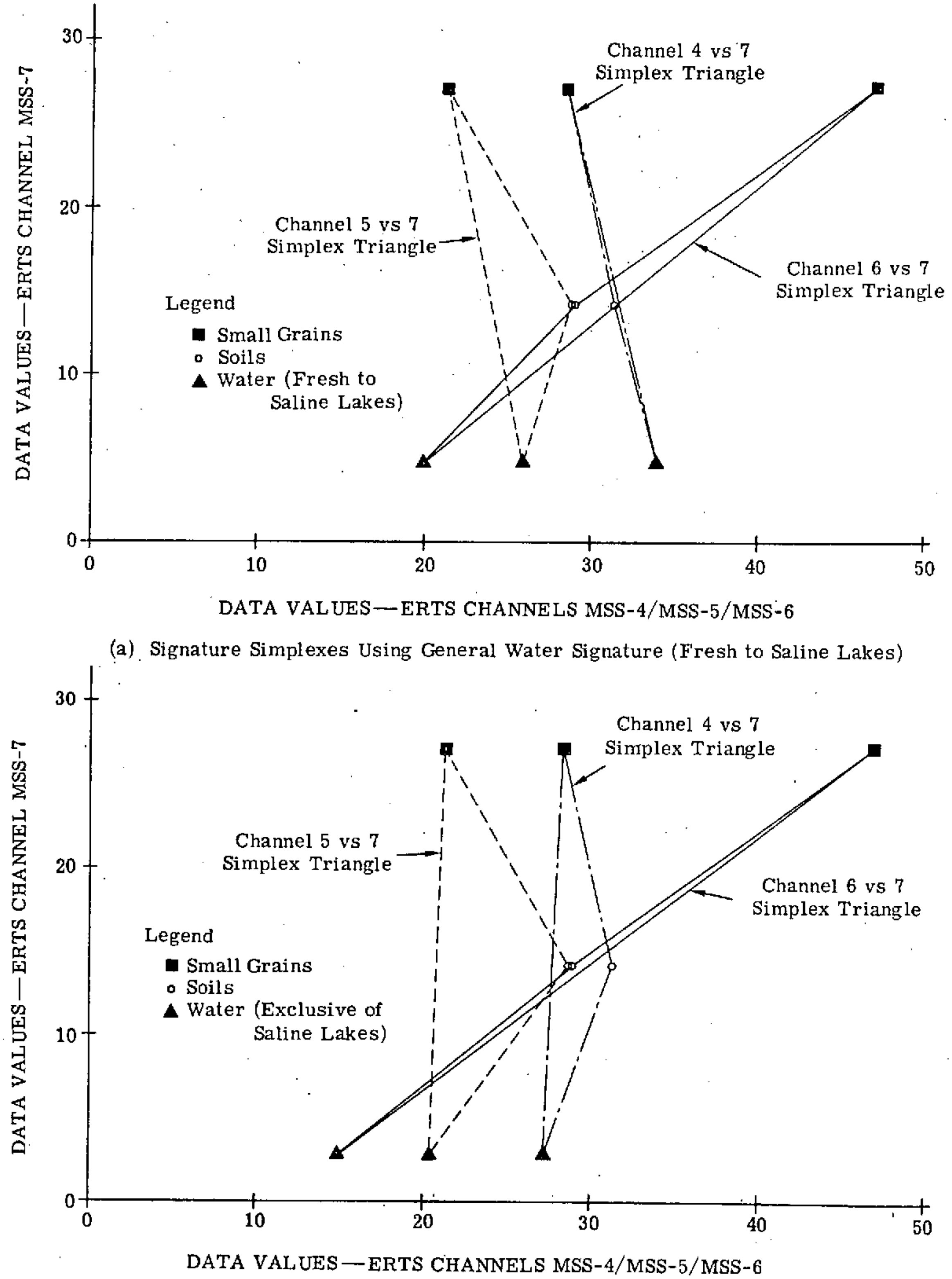
FIGURE 27. COMPARISON OF SEVERAL DIFFERING WATER SIGNATURES. The general water signature was inclusive of fresh, brackish, and saline lakes. The modified water signature was used for proportion estimation processing. It was a composite signature compounded of Big, Clark, and Fish Lakes—all fresh to slightly brackish lakes. The signature means and plus and minus one standard deviation are shown.

redundant. If this was the case, earlier attempts to operate the algorithm with five signatures were headed for failure from the onset. In any instance, it now seemed desirable to limit the number of spectral channels to two if for no other reason than to reduce computational time. Channel MSS-7 was one channel selected because of the obviously good separation of signatures in that channel. The choice of the second channel was predicated upon which channel when paired with MSS-7 provided the best nondegenerate signature simplex. Figure 28a illustrates possible simplex combinations using the composite water (inclusive of fresh and saline lakes) signature. Only one combination, MSS-7 and MSS-5, offered even a modest separation of signatures. Figure 28b shows considerable improvement with the use of the fresh to brackish water (exclusive of saline lakes) signature, but again the pair, MSS-7 and MSS-5, offered a clear choice.

By refining the problem to include only three signatures and two spectral channels, the computational algorithm was applied to an area of 287 km^2 (110 square miles). For this algorithm, the computer output was a set of proportions for each pixel. A water recognition map generated from this output is shown in Figure 29, and, for comparison, a map generated with the single-waveband thresholding algorithm is shown in Figure 30. In the proportion estimation map, the symbol density is related to the proportion of water estimated for that pixel. In order for the map to accurately portray the scene, certain percentage or acceptance limits were determined for the output of the algorithm. For example, it seemed appropriate to count pixel values of 0.86 and above as totally water. This procedure tended to account for the likelihood that a value close to a signature mean (i.e., close in terms of the probability contours) may in fact have been a pure sample related to that mean. Similarly, pixels showing less than 0.30 water were assumed to be false alarms (i.e., nonwater pixels classified as water), and they were excluded from any consideration as surface water. These limits were established after an examination of a small portion of the processed data and a comparison with multispectral scanner data and photography collected by supporting aircraft.

In general, a detailed comparison of the classification maps and related imagery indicated that proportion estimation significantly improved both pond shape definition and the recognition of smaller water features which otherwise would not have been detected.

The most striking of the few deficiencies noted in the proportion estimation recognition map was the rendering of Alkali Lake. From Figures 29 and 30, it is apparent that this lake was not fully delimited in the proportion estimation case. As implied by its name, the lake is probably high in dissolved and perhaps precipitated solids and as such was a lacustrine feature for which the water signature utilized was not representative. An inspection of this same lake in



(a) Signature Simplexes Using General Water Signature (Fresh to Saline Lakes)

(b) Signature Simplexes Using Modified Water Signature (Exclusive of Saline Lakes)

FIGURE 28. GEOMETRIC CONFIGURATIONS OF SIGNATURE SIMPLEXES CONSIDERED FOR THREE SIGNATURE, PROPORTION ESTIMATION PROCESSING

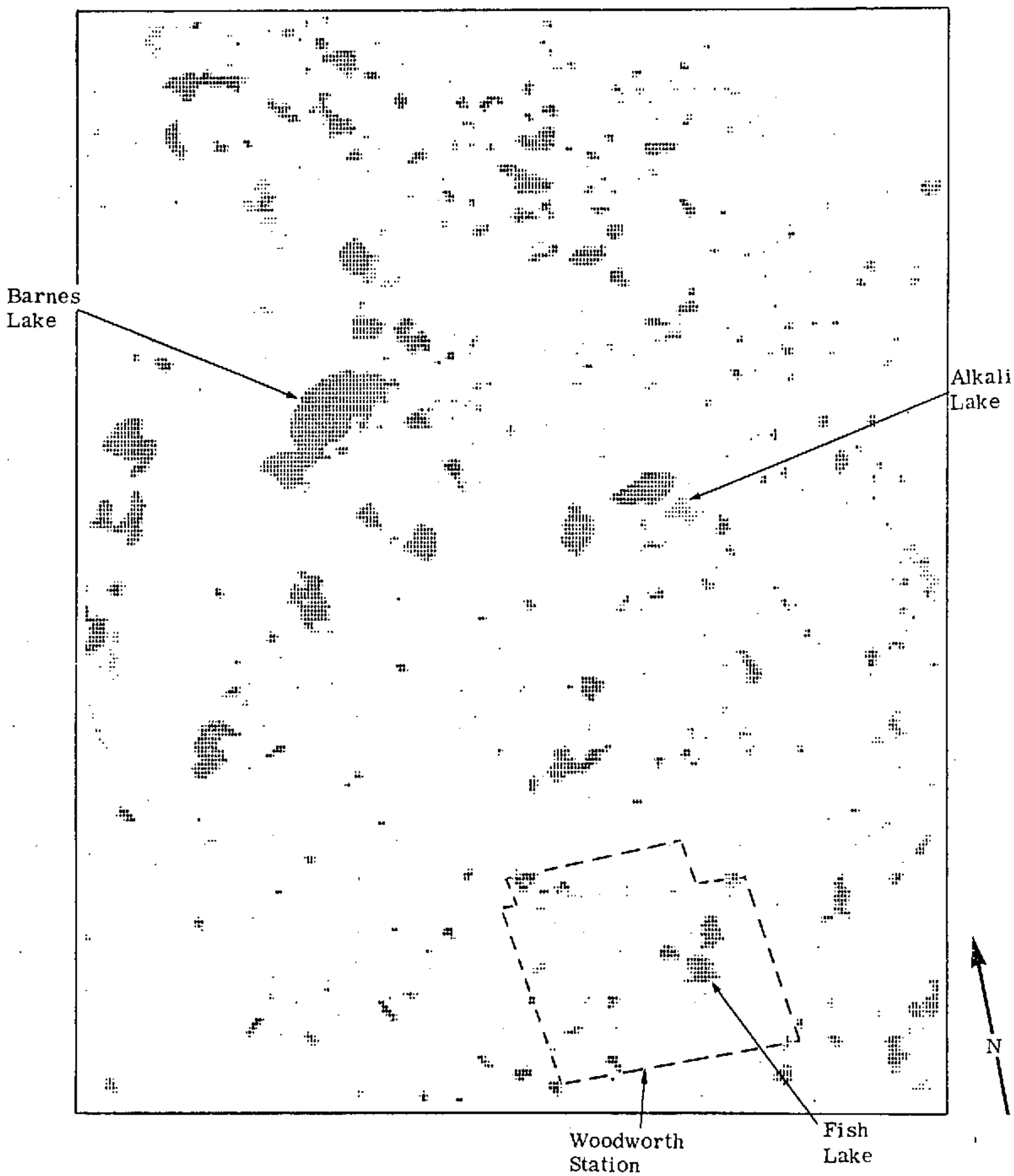


FIGURE 29. WATER RECOGNITION OBTAINED BY USE OF THE PROPORTION ESTIMATION ALGORITHM. The symbol density is related to the proportion of water estimated for that pixel.

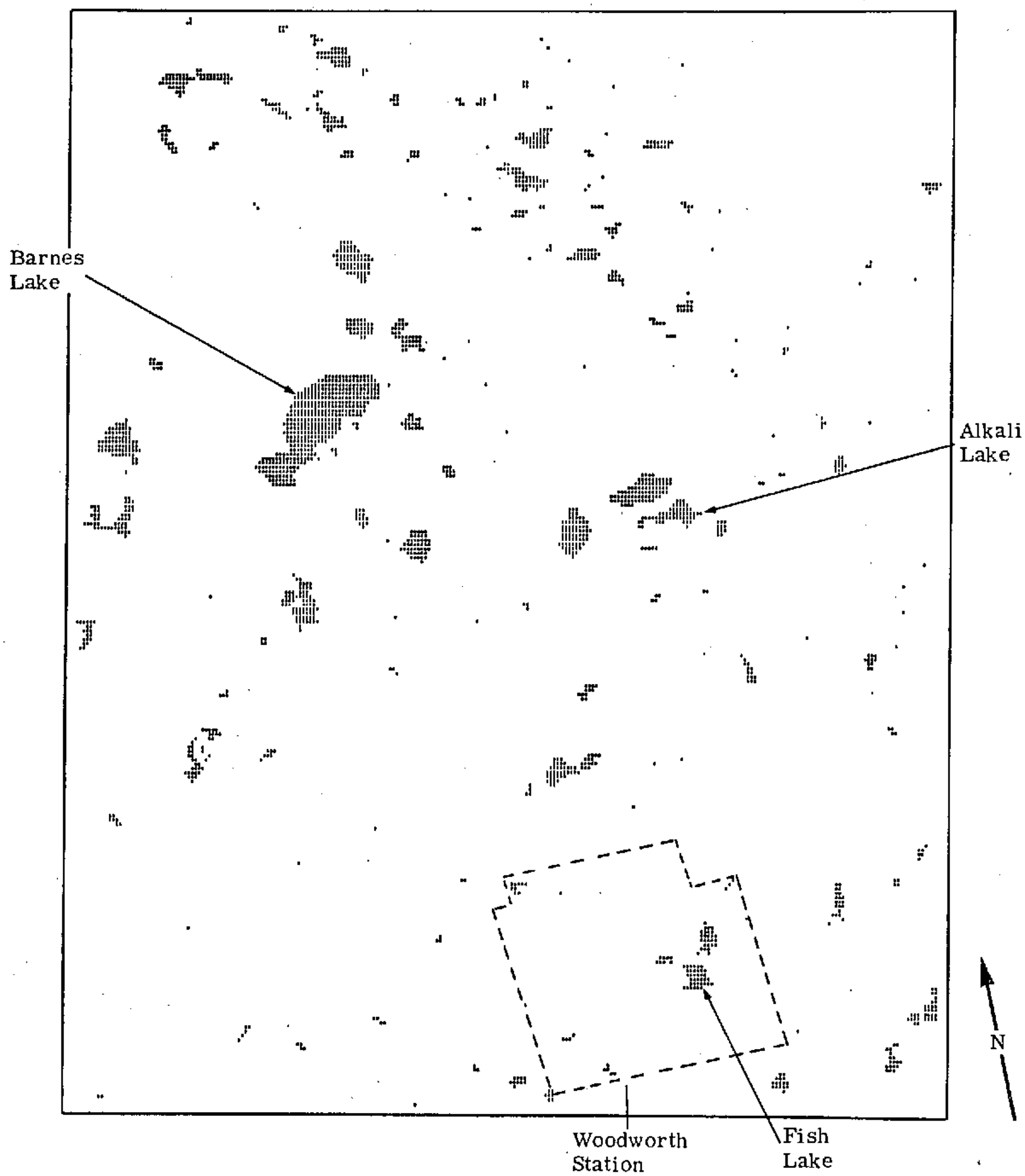


FIGURE 30. WATER RECOGNITION OBTAINED BY THRESHOLDING CHANNEL MSS-7. The decision criteria is such that each pixel has been classified as either totally water or not water.

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aerial photography indicated a color hue similar to many of the highly saline (c.f., alkaline) lakes found farther west in the Coteau outwash. Even if not faithfully represented it is significant to note that the lake was at least partially recognized.

Enlarged water recognition maps obtained from both the single-waveband thresholding and the proportion estimation algorithms are shown in Figure 31. These include portions of the area seen previously in Figures 29 and 30. For comparison, a strip of scanner video collected by an aircraft 36 days later is also included. Many small ponds and marshes had dried up in the interim between the ERTS and aircraft observations. These would include those wet areas shown at "a," "b," "c," "d," and "e" as detected only with proportion estimation. The very small pond at "f" was present on both dates, but only proportion estimation processing has been able to delineate the feature. The water features at "g" were small open water areas within a marsh complex that was actually an extension of the large lake located slightly to the southwest. A few false alarms or commission errors are also present. The feature at "h" was actually a patch of moist bare soil. At "j" there were no areas of open water either. The false alarms at "h" and "j" occurred for pixels allegedly containing 30 and 31 percent water, which suggested that a slightly higher false alarm threshold would have eliminated them.* The classification as water of the remaining features shown in Figure 31 has been corroborated.

As mentioned above, this test sought to emphasize the enumeration of bodies of water, with the accurate delineation of area as a secondary goal. The several maps presented clearly indicate that proportion estimation detected many features not otherwise detectable. Not only were many small ponds recognized but the area and shape definition of many of the larger lakes and ponds were improved. Table 1 presents a comparison of numerical and area tabulation for the 287-km^2 test area using both the thresholding and proportion estimation algorithms.

Some water features for which both aircraft and ERTS data have been available were examined in detail. Although this analysis showed a marked improvement in area determination, the enhancement on the average did not improve area enumeration to better than 85 percent of actual surface coverage. This statement is based upon a comparison of lakes in the 10- to 50-acre size range. On the other hand it appears that all ponds larger than 1.3 acres have consistently been recognized and that many smaller ponds to 0.33 acre as a

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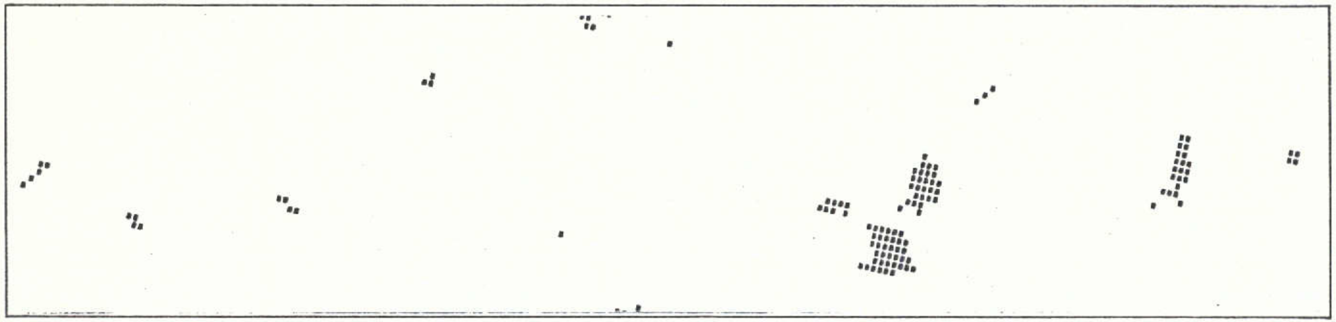
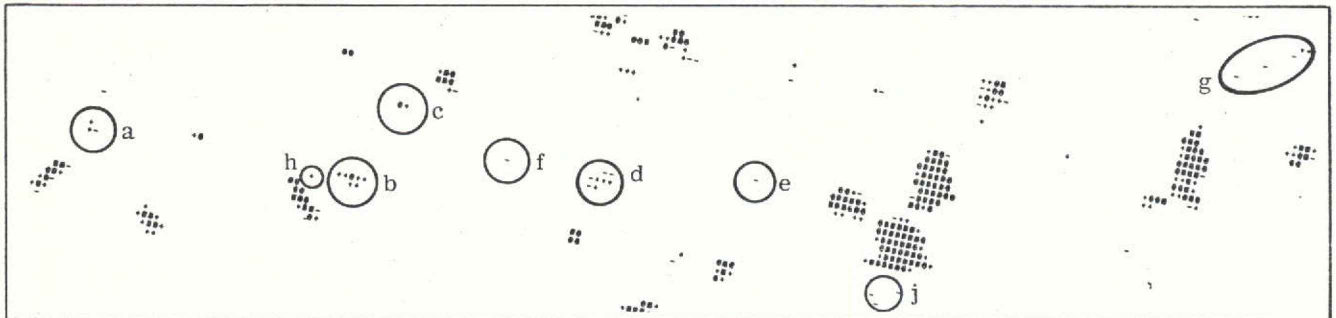
*The false alarms at "j" occurred in a meadow which had previously been burned and undoubtedly some bare soil areas were visible when viewed from above. Earlier work (Work and Thomson, 1974) has indicated that burned or blackened stubble on a soil background can under some conditions be confused with water.



Water Recognition by Thresholding — ERTS MSS-7 Data of 7 July 1973, 1654 GMT



Water Recognition by Proportion Estimation — ERTS Multispectral Data of 7 July 1973, 1654 GMT

Aircraft Scanner Imagery — 1.0 to 1.4μm Video, 4500 ft Altitude, 12 Aug 1973, 1633 GMT Bare Soil

FIGURE 31. WATER RECOGNITION IN VICINITY OF WOODWORTH STATION, NORTH DAKOTA. Many ponds and marshes have dried up in the interim between the ERTS and aircraft data collection. The callouts are referenced in the text.

TABLE 1. COMPARISON OF TABULATIONS OF PONDS AND LAKES

USING THE PROPORTION ESTIMATION ALGORITHM		USING THE THRESHOLD ALGORITHM	
AREA (ACRES)	FREQUENCY	AREA (ACRES)	FREQUENCY
0.25 to 0.50	72	0.25 to 0.50	
0.51 to 1.00	71	0.51 to 1.00	
1.01 to 2.00	62	1.01 to 2.00	47
2.01 to 3.00	31	2.01 to 3.00	15
3.01 to 4.00	19	3.01 to 4.00	14
4.01 to 6.00	21	4.01 to 6.00	22
6.01 to 8.00	20	6.01 to 8.00	11
8.01 to 10.00	11	8.01 to 10.00	5
10.01 to 15.00	15	10.01 to 15.00	10
15.01 to 20.00	7	15.01 to 20.00	7
20.01 to 25.00	5	20.01 to 25.00	2
25.01 to 30.00	3	25.01 to 30.00	4
30.01 to 40.00	4	30.01 to 40.00	3
40.01 to 50.00	6	40.01 to 50.00	3
OVER 50.00	14	OVER 50.00	13
TOTAL	361	TOTAL	156

minimum have been recorded. This is a threefold improvement relative to the single-waveband thresholding technique. For the 287-km^2 area studied, an increase of 131 percent in the number of water bodies tabulated has been observed relative to the number tabulated using the thresholding algorithm.

Immediately before the present study, Malila and Nalepka (1973 and in press) had conducted a similar test for water recognition with the proportion estimation algorithm and ERTS data gathered over a Michigan site of 18 km^2 (7 square miles). In that study, they were able to realize a water area count that came to within 96 percent of actual surface coverage. In the present study such accuracies were not achievable partially because of the wide variations in water signatures over the extended area studied. Subsequent modifications to the procedure should, however, improve mapping accuracies. These are discussed in Section 4.

3.3 VEGETATION MAPPING FOR THE DETERMINATION OF LATENT WETNESS AND OTHER HABITAT CONDITIONS

The above sections of this report were concerned with mapping and detecting changes in open surface water. This section will expand the study to include an incipient consideration of ERTS data for mapping surface water and areas of high soil moisture which have been concealed or occluded by a vegetation canopy. In achieving this end, the differentiation of vegetation types was used to indicate the degree of latent surface wetness. At the same time it was operationally convenient to map upland vegetation. As opposed to changes in open surface water, changes in vegetation tend to be a protracted environmental phenomena. Nevertheless, the observation of these phenomena are important in assaying conditions of long term habitat quality and waterfowl carrying capacity.

Assessment of habitat quality is important for the formulation, enactment, and enforcement of legislation designed to control the alteration of wetlands. Many states have or currently are adopting such legislation. Wetland assessment is particularly important to the U.S. Fish and Wildlife Service in their wetland lease and purchase programs which must consider waterfowl needs on a regional or continental basis. Consistent with these needs Martin et al. (1953) produced a nationwide classification system which provided the basis for the first Federal wetland inventory related to waterfowl use (Shaw and Fredine, 1956). Other wetland classification systems have preceded and succeeded the Martin et al. system and in some cases are designed for specific regions (Nord et al., 1951; Evans and Black, 1956; Stewart and Kantrud, 1971; Cowardin and Johnson, 1973; and Golet and Larsen, 1974). All of these systems rely heavily on indices provided by vegetational lineation.

In addition, the delineation of vegetation serves as a useful indicator of land-use. Land-use in and adjacent to wetlands may have direct and indirect effects on breeding waterfowl. In the prairies where upland areas are interspersed with wetlands, many species of breeding ducks utilize upland nesting sites. Sowls (1955) has characterized the nesting terrain to include "the nesting meadows" and "the nesting and feeding waters which were nearby." He has documented that ducks will nest relatively distant from water -- the distance varying with species. In his study, he noted that nesting cover more than 100 yards from water accommodated only 10 percent of the nests of northern shoveler (Anas clypeata), but had 24 percent of the mallard, 31 percent of the pintail (Anas acuta), and 29 percent of the gadwall (Anas strepera) nests. Evans and Black (1956) and Drewien and Springer (1969) emphasized the importance of dispersal for nesting pairs and particularly the influence of land-use on the availability of quality nesting cover at the dispersed sites. Drewien and Springer (1969) in their study showed that ponds located in soil bank fields, idle areas, and hayfields received considerably higher use than ponds located in cultivated or plowed fields and pastures.

Active agriculture does, of course, depreciate both the quality and extent of waterfowl breeding habitat. With burgeoning world demands for food, the agricultural community is being looked upon for ever increasing production. To the waterfowl manager, these agricultural demands are pressures to which he must react either by becoming more efficient in selecting and managing waterfowl production areas or by adjusting the annual waterfowl harvest accordingly.

Although not a prime task of this study, the mapping of wetland and associated upland vegetation was undertaken in order to obtain background information on technique and phenological character. For budgetary reasons, this phase of the study was kept to modest proportions. It was carried out using data and processing investments already utilized for surface water mapping.

3.3.1 METHODS

The data set of 7 July 1973 along with the associated signatures previously extracted from that set were again utilized for this study subtask. Those signatures are repeated here as Figure 32. Use of the data set of 14 May 1973 was rejected because vegetation at that phenological stage is generally a nondescript residue of dead herbaceous vegetation remaining from the previous year. This dead vegetation masks new growth and is spectrally indistinguishable for both upland and wetland areas (Burge and Brown, 1970). The several signature categories of Figure 32 were selected because they are potentially separable using multispectral techniques and are subjective relative to waterfowl ecology. For example, it would have been

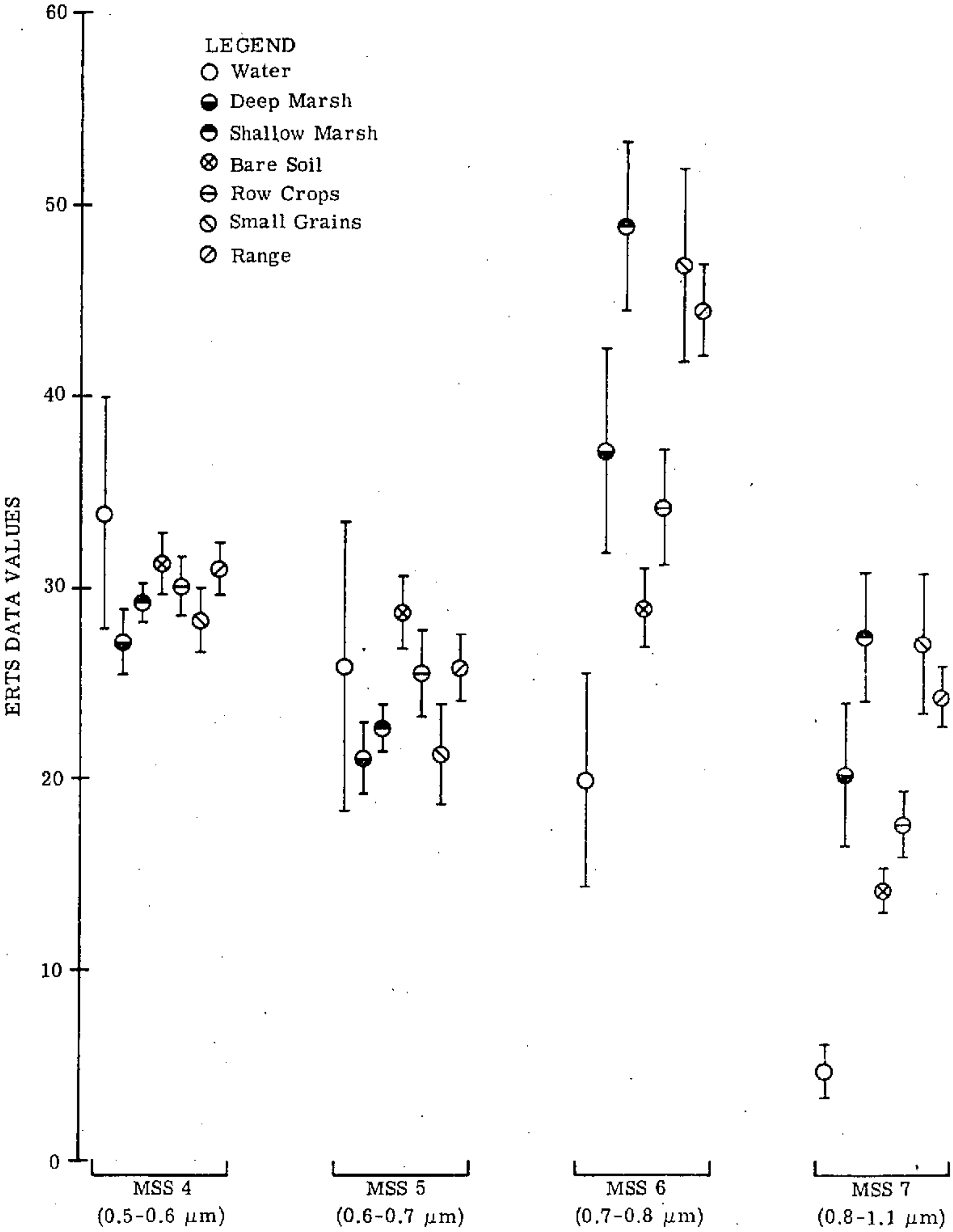


FIGURE 32. SPECTRAL SIGNATURES USED IN THE MULTISPECTRAL PROCESSING OF ERTS-1 DATA OF 7 JULY 1973, SCENE OBSERVATION 1349-16543. The signature mean and plus and minus one standard deviation are shown. This figure appeared earlier in the text. It is repeated here for the convenience of the reader.

difficult at best to differentiate between types of cultivated small grain, and in the context of habitat quality, a differentiation would not have been significant.

In North Dakota, small grains planted include hard red wheat, durum wheat, barley, oats, flaxseed, and, to a lesser extent, rye (U.S. Bureau of the Census, 1967). With the exception of rye, these are all spring planted, cereal grains. An analysis of data of 7 July 1973 would indicate that there was perhaps more variability of signatures between fields of one grain type than between several grain types. Variability seemed to be the result of planting date and site characteristics. Figure 33 shows the signatures for some of the more dominant small grains. These signatures were obtained from an aggregation of fields. The composite small grain signature is also shown.

Row crops represent another upland cover type. In this study the term "row crops" refers to corn and sunflower. In addition, pasture and open prairie situations were examined. As used here, the term "pasture" refers to fenced, usually small, and often intensively grazed areas of grasses and forbs. The term "prairie" denotes more open grassland situations which may also include low woody shrubs and may be subjected to varying grazing intensities. A similarity was observed between pasture and prairie signatures in all channels. This similarity, it appeared, justified incorporating the two signatures into one. The composite signature was termed "range."

The mapping of wetland vegetation proved difficult in several respects. In the prairies, certain wetland plant species are numerous and often have morphological characteristics that are similar to other wetland and upland species. In addition, zones of relatively uniform vegetation are not always the rule nor are these zones frequently extensive in area. This is a situation unlike many coastal wetland areas (Klemas et al., 1974). For these reasons low prairie and wet meadow vegetational types were not considered in this study. However, the recognition of vegetational classes representative of more permanent wetland conditions was attempted. These conditions included deep and shallow marsh situations. Signatures for the shallow-marsh class were obtained from plant associations of whitetop (*Scolochloa festucacea*) and sedges (*Carex* spp.). Whitetop is a tall, lush marsh grass that grows in solid stands and, in drier years, is cut for hay. In particular, mowing for hay favors increased growth allowing the species in the long term to become dominant over the sedges. On the other hand, pasturing tends to cull out the whitetop and allows sedges to become dominant. The deep-marsh class was represented by coarser plants, specifically, bulrush (*Scirpus* spp.) and cattail (*Typha* spp.). Bulrushes commonly occur in solid stands and frequently in association with cattails. Cattails occur less frequently in solid stands and consequently were not as dominant in the deep-marsh composite signature as were the

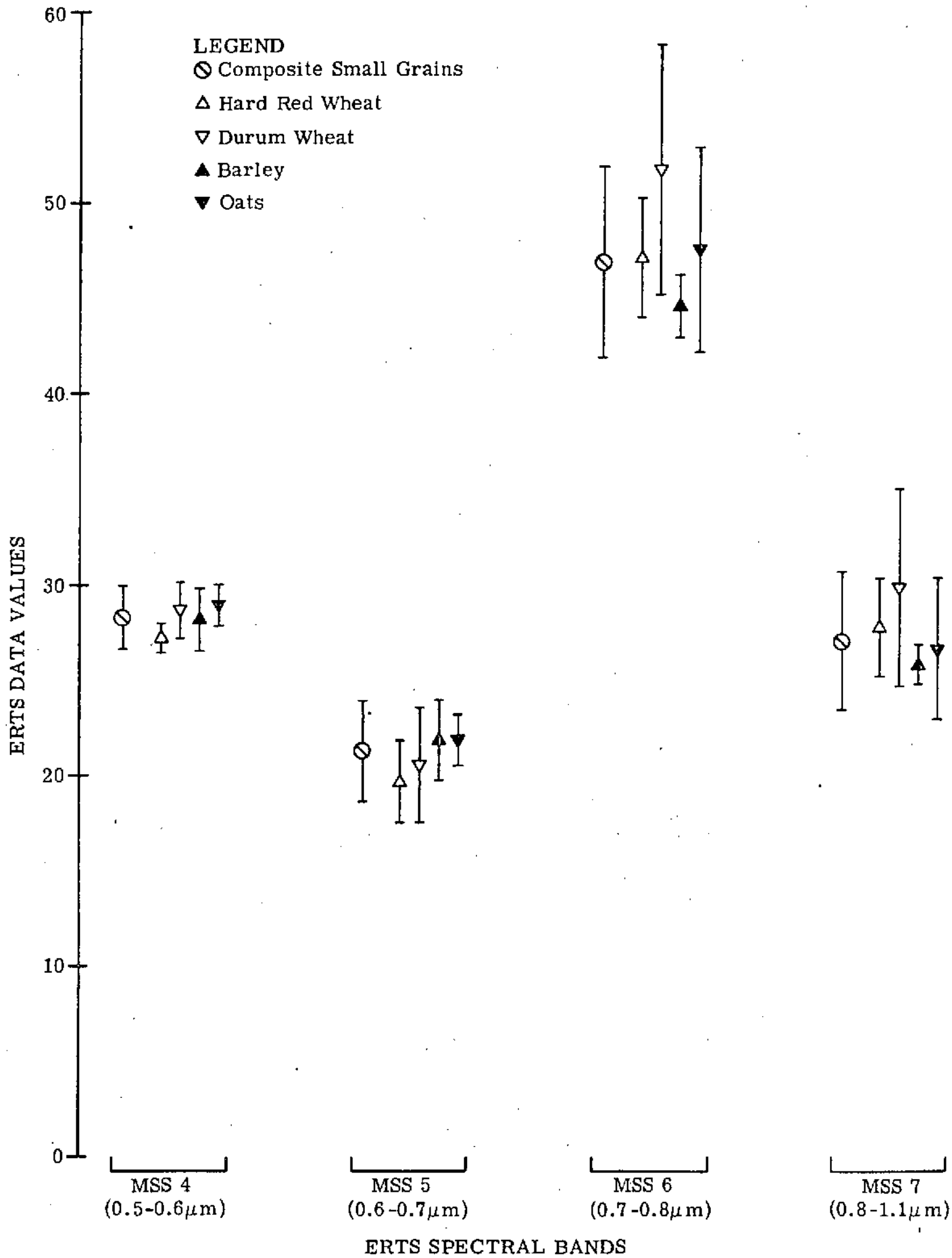


FIGURE 33. SPECTRAL SIGNATURES OF THE DOMINANT SMALL GRAINS GROWN IN NORTH DAKOTA. These signatures were extracted from ERTS-1 scene observation 1349-16543 of 7 July 1973. The signature mean and plus and minus one standard deviation are indicated. A composite small grains signature compounded from the individual signatures and used in the multispectral processing is shown. Note that the variability of any one grain type is generally greater than between grain types.

bulrushes. Relative to agricultural fields the marsh signatures were more difficult to acquire and train on. Figure 34 shows a relatively large marsh situation, but note that relatively few pure pixels could be obtained from the scene to represent the deep- and shallow-marsh signatures. As a result, several marshes had to be examined in order to acquire enough data points for a statistically representative sample.

The production of a recognition map was accomplished with pattern recognition and machine (computer) processing techniques. The concept of pattern recognition may be expressed in terms of the partitioning of multispectral hyperspace. Earlier (Figure 24), it was illustrated that signatures may be depicted in multispectral space by signature means and probability density functions. In the present case, a maximum likelihood criterion with statistical pattern recognition techniques was used to partition the signal hyperspace. Essentially the partition boundaries were located such that the sum of the type I and type II errors* between every possible combination of signature pairs was minimized. Maximum likelihood processing as applied to earth resources surveys has been described previously by Nalepka (1970). Pattern recognition techniques in general have been described by Fukunaga (1972), Meisel (1972), and Duda and Hart (1973) among others.

In applying this form of processing, two types of decision rules may be used -- a so-called linear decision rule and a quadratic decision rule. The linear rule refers to the partitioning of spectral hyperspace using first-order lines or surfaces and the quadratic rule refers to the use of second order lines or surfaces. In terms of computation time, the linear rule is faster running and consequently cheaper to implement. In an independent analysis, J. Reyer (unpublished memo, 1974), using data extracted from the ERTS North Dakota observation of 7 July 1973, indicated that recognition accuracy was as good with the linear rule as with the quadratic rule (83.3 percent). This may not always be the case, but it does confirm past experiences. One other factor should be remembered; the partitioning of signal space has been performed based strictly on the signatures. If the signatures are not statistically representative of the scene elements as a whole, some inaccuracies in recognition classification can be expected. This has been the reason for using composite signatures based upon a variety of field or marsh situations. Also, because the water signature demonstrated such wide variance in three of four ERTS channels, it seemed desirable not to allow pattern recognition processing of water features in the scene. Instead all water pixels

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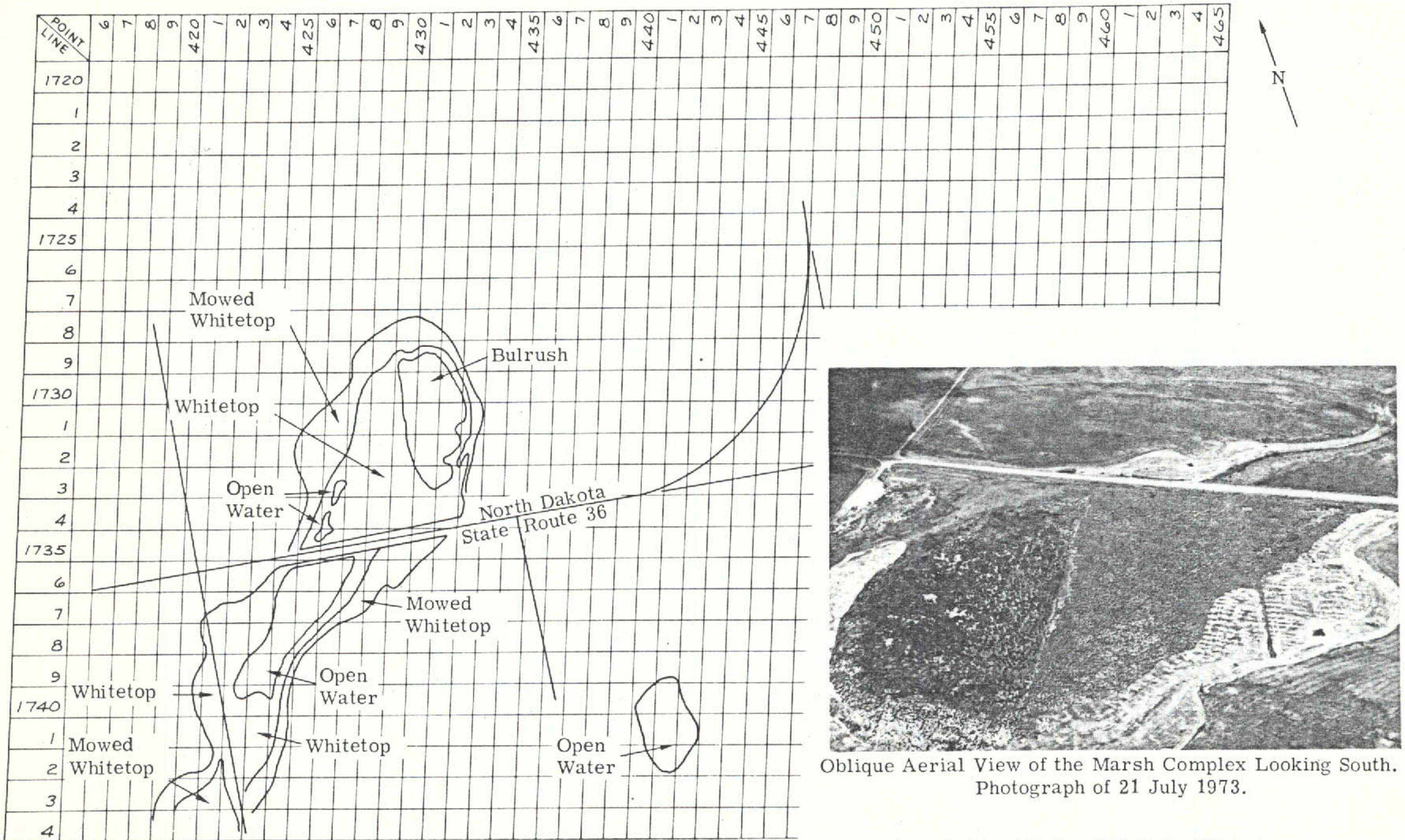
*Type I and II errors are terms used in statistics. When it happens that a null hypothesis is true and we conclude that it is false, the mistake is called a type I error. When it happens that the null hypothesis is false and we fail to reject it, the mistake is called a type II error.



Oblique Aerial View of the Marsh Complex Looking South. Photograph of 21 July 1973.

FIGURE 34. TYPE MAP OF MARSH COMPLEX NEAR THE VILLAGE OF WOODWORTH, NORTH DAKOTA. Type map was made using vertical aerial photograph at an original scale of 1:10,000 and was overlain on an ERTS pixel grid of the same scale. A fence bisecting the northern half of the marsh has created an abrupt boundary between the shallow marsh (Whitetop) and deep marsh (bulrush) zones. Note that relatively few pixels lie wholly within each marsh zone.

were separated from the data set at the onset of processing with the single-waveband thresholding algorithm (Section 3.1). As a result, pattern recognition processing was applied only to nonwater pixels and the water and nonwater classification maps were then superimposed at the final juncture.

3.3.2 RESULTS

Before a recognition map was produced, an analysis was performed to predict classification accuracy and to foretell which signature pairs may have been so alike as to be the source of substantial classification errors. Table 2 presents the pairwise separation of signature means in ERTS four-channel spectral hyperspace. Separability is given in terms of standard deviation units. In deriving these values, the simplifying assumption of an average covariance matrix was made for each signature in a paired set. Thus, the standard deviation separation was the same in each direction and the table as a result is diagonally symmetrical. A small standard deviation indicated that the paired signatures did not have good separability and a high incidence of type I and type II classification errors were to be anticipated. From the table it was apparent that a considerable number of errors were to be expected for the shallow marsh and small grains pair. Similarly, but to a lesser extent, classification difficulties were anticipated in the case of the deep marsh/small grains, range/small grains, and the range/shallow marsh paired combinations. These problems of separability were a further manifestation of the situation noted earlier for proportion estimation processing (Section 3.2), specifically that the differences between green herbaceous vegetation present in the scene were relatively subtle for the phenological period considered.

Results of a further analysis of signature pairs are presented in Table 3. Here the prime function has been to rank order the spectral channels on the basis of their ability to separate and classify the various signature pairs. On the basis of this criterion, the best channel was selected; then the channel which, along with the one chosen, was best and so on. For the present study, channel MSS-7 was picked first, then MSS-5, MSS-6, and finally MSS-4. These results, indicated in the table, show that the probability of pairwise misclassification decreased as additional channels were selected. Again the simplifying assumption of an average covariance matrix has been made for each signature in a paired set. A separate study has shown this to be a satisfactory and reasonable first approximation.

It is of interest to note in Table 3 that after two channels (MSS-7 and MSS-5) were selected, there was substantially less improvement in classification as additional channels were added. This indicated that for the circumstances of this test, the power to classify was

TABLE 2. LISTING OF THE PAIRWISE DISPLACEMENT OF SIGNATURES IN FOUR CHANNEL SPECTRAL HYPERSPACE. Signatures are from ERTS observation 1349-16543 of 7 July 1973 over east-central North Dakota. Displacements are in terms of standard deviations. The analysis has made the simplifying assumption that paired signatures have equal covariance matrices.

	Bare Soil	Deep Marsh	Shallow Marsh	Small Grains	Row Crops	Range
Bare Soil						
Deep Marsh	6.35					
Shallow Marsh	7.25	2.65				
Small Grains	5.21	1.98	1.14			
Row Crops	2.68	2.74	3.95	3.41		
Range	8.40	3.23	2.37	2.15	4.86	

TABLE 3. SUMMARY OF THE PAIRWISE PROBABILITY OF MISCLASSIFICATION OF ERTS MSS SIGNATURES. Signatures are from ERTS observation 1349-16543 of 7 July 1973 over east-central North Dakota. The probabilities are the summed average of Type I and Type II errors and are ranked for:

Single-channel processing (1)
utilizing channel MSS-7

Two-channel processing (2)
utilizing channels MSS-7 & MSS-5

Three-channel processing (3)
utilizing channels MSS-7, MSS-5, & MSS-6

Four-channel processing (4)
utilizing channels MSS-7, MSS-5, MSS-6, & MSS-4

	Bare Soil	Deep Marsh	Shallow Marsh	Small Grains	Row Crops	Range
Bare Soil						
Deep Marsh	(1) 13.66% (2) 0.14% (3) 0.14% (4) 0.08%					
Shallow Marsh	(1) 0.42% (2) 0.10% (3) 0.02% (4) 0.01%	(1) 15.62% (2) 13.09% (3) 9.30% (4) 9.30%				
Small Grains	(1) 0.83% (2) 0.64% (3) 0.49% (4) 0.46%	(1) 17.64% (2) 16.58% (3) 16.19% (4) 16.14%	(1) 48.06% (2) 31.56% (3) 28.44% (4) 28.40%			
Row Crops	(1) 12.05% (2) 9.18% (3) 9.04% (4) 9.04%	(1) 32.43% (2) 11.59% (3) 10.47% (4) 8.55%	(1) 3.29% (2) 3.27% (3) 2.43% (4) 2.41%	(1) 4.72% (2) 4.51% (3) 4.51% (4) 4.40%		
Range	(1) 0.01% (2) 0.00% (3) 0.00% (4) 0.00%	(1) 23.99% (2) 7.73% (3) 5.75% (4) 5.29%	(1) 27.45% (2) 14.31% (3) 13.56% (4) 11.76%	(1) 30.77% (2) 15.19% (3) 14.96% (4) 14.07%	(1) 2.01% (2) 0.93% (3) 0.83% (4) 0.75%	

vested largely in two spectral wavebands. Had the processing of data for a large scene area been under consideration it would have been reasonable to limit the classification process to the use of two channels for the sake of economy at the expense of only slightly diminished recognition accuracies.

Because this test of recognition was limited in areal scope, classification processing was performed with all four ERTS MSS bands. The resultant recognition map is shown in Figure 35. As shown, the map has been photo-reduced from the original computer product and for ease of reproduction is presented here as a black and white, gray-scale coded figure. Viewed as a whole the map provides a good rendition of land-use patterns. Many roads including the lesser section survey roads are clearly evident as are many of the agricultural fields, especially those in summer fallow (bare soils). A major highway (U.S. 52/281) paralleled by a railroad may be seen cutting diagonally across the upper right map quadrant. Also, in this quadrant, the demarcation between the Coteau du Missouri and the drift plain to the northeast is very evident as the grasslands of the Coteau escarpment suddenly give way to areas of more numerous agricultural fields. The occurrence of grassland or range elements (light toned symbols) is even more pronounced toward the lower left quadrant.

Many of the lakes previously mentioned in the text are also major landmarks in this map; these would include Barnes Lake (the fish-shaped lake at the map center) and Des Moines Lake in the lower left corner. The outlines of several lakes are also apparent although the lakes themselves remain unclassified; these would include Sink and East Fischer Lakes both of which have completely dried up leaving a bed of highly reflective salt. The computer algorithm has been unable to specifically identify these flats and has included them in the "other" recognition category. Several smaller dry lacustrine salt beds are present elsewhere on the map.

Several very large marsh areas also conspicuously stand out on the map. At "a" a large moisture seep occurs between Round Lake and another similarly shaped lake several miles to the southwest. An enlargement of this feature is shown in Figure 36. This seep has created an extensive marsh. Nearer the southern-most lake the vegetation was predominantly whitetop, a shallow marsh species. Midway between the two lakes was an area of deep marsh which was also correctly classified. Some elements around this deep marsh have been classified as small grains but in fact were areas of shallow marsh or possibly wet meadow.

At "b" in Figure 35, a large deep marsh several miles north of Barnes Lake was identified. An enlargement of this feature is shown in Figure 37. In this instance, the deep marsh was bisected by an east-west road and several pixels of open water occurred within the marsh

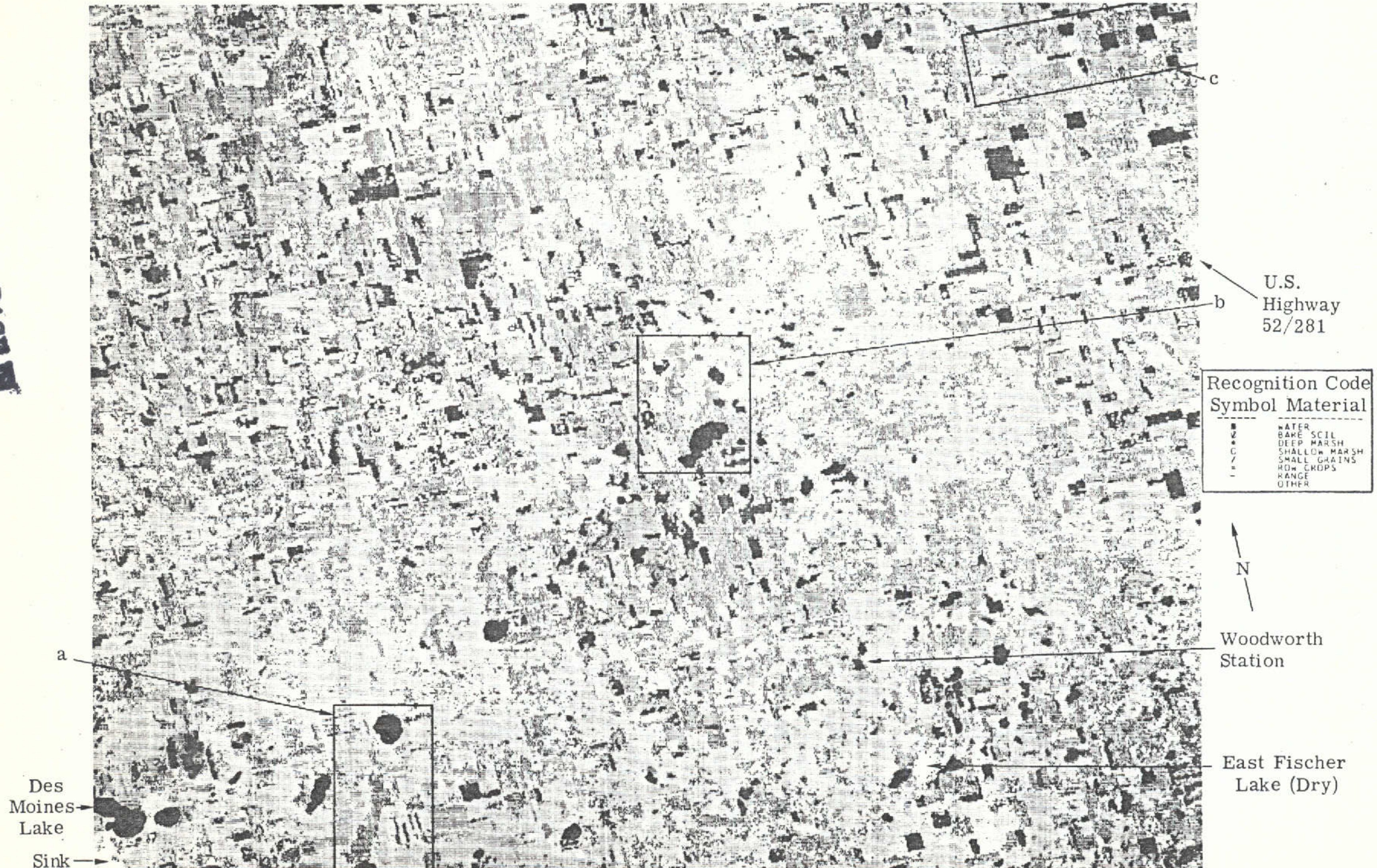
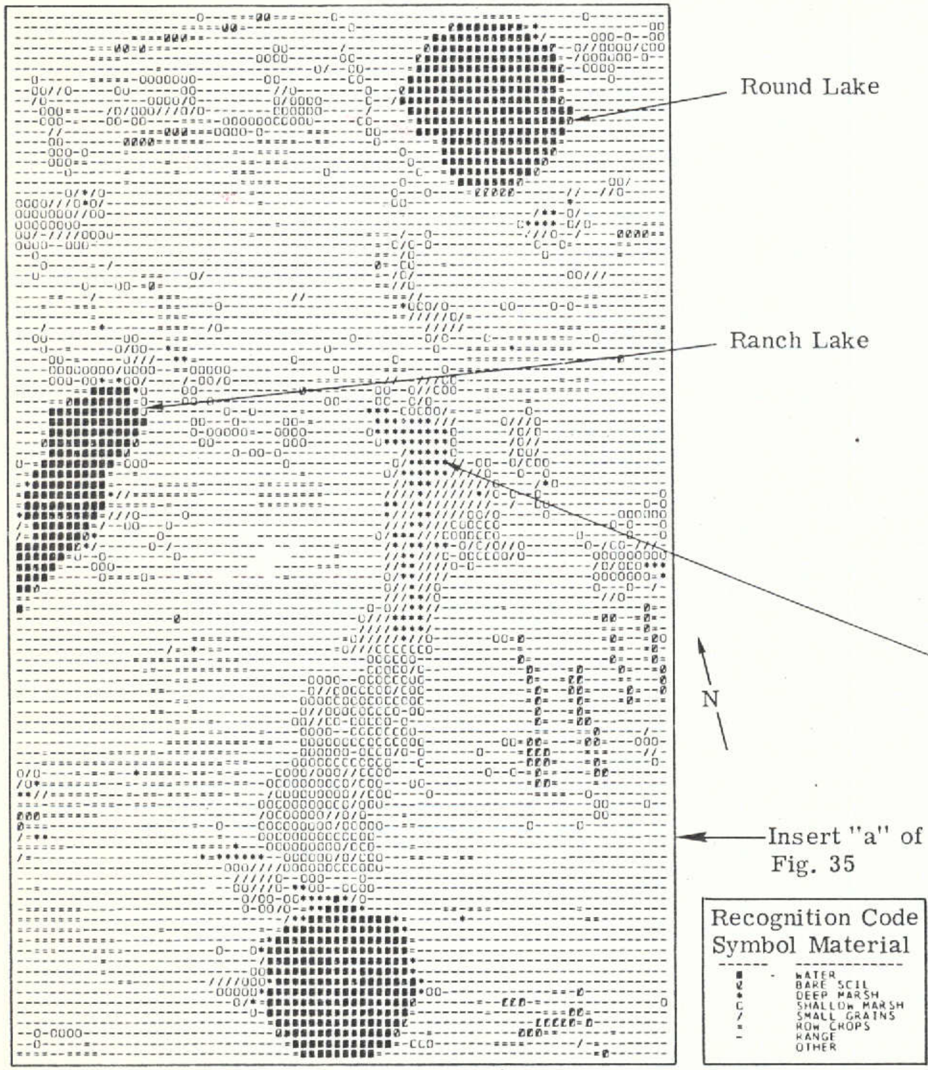
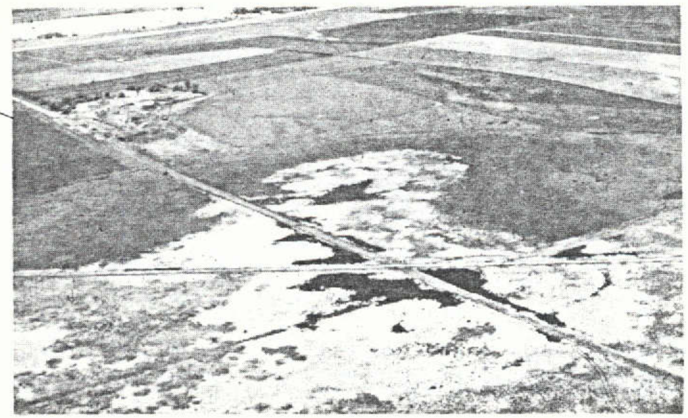


FIGURE 35. DIGITAL CLASSIFICATION MAP FROM ERTS DATA OF 7 JULY 1973 FOR AN AREA ENCOMPASSING 1800 km^2 IN EAST-CENTRAL NORTH DAKOTA. The callouts are referenced in the text.

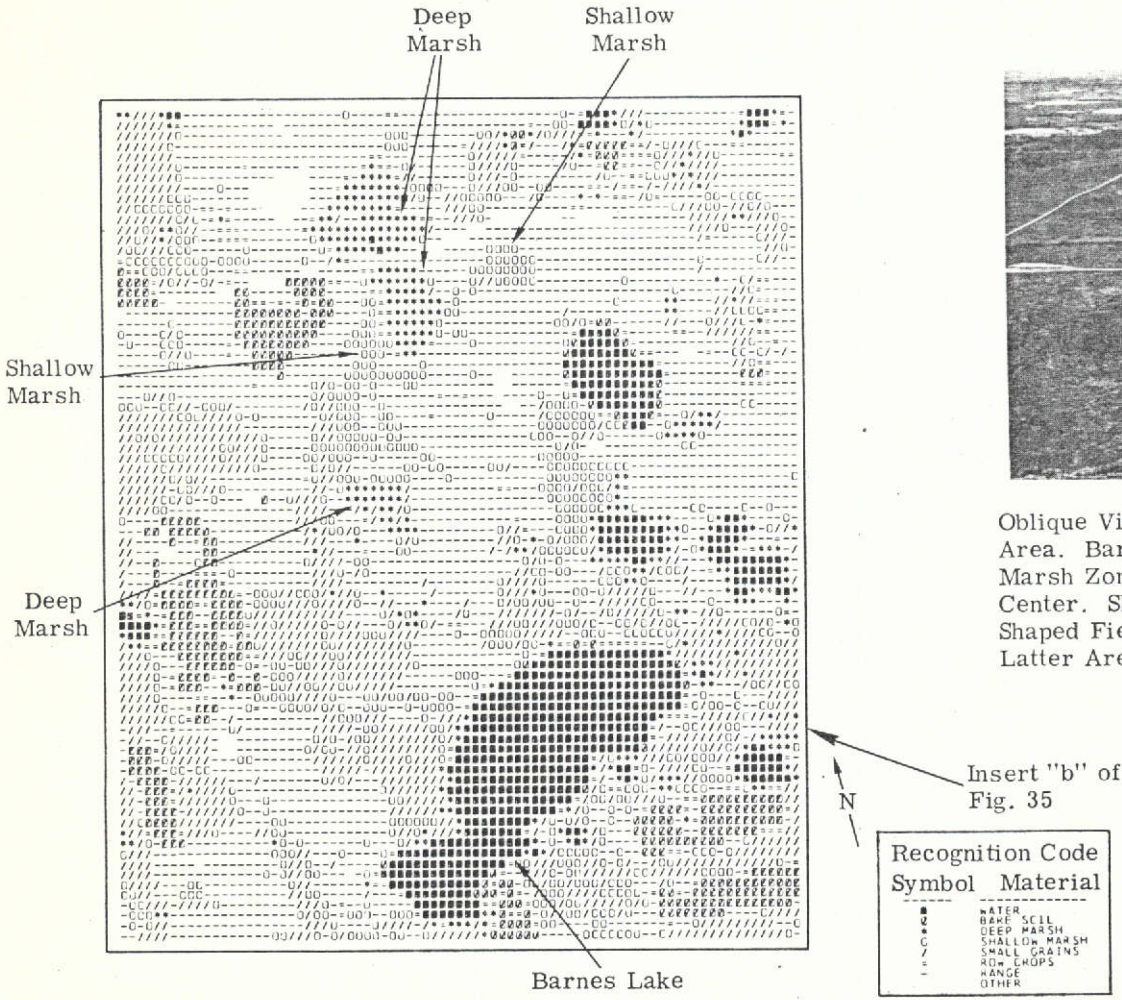


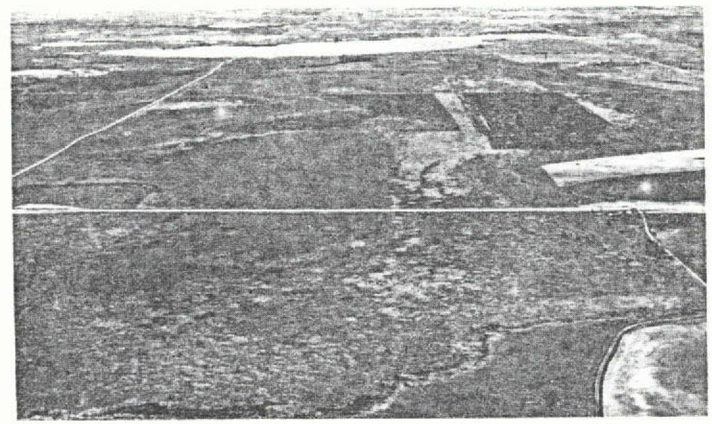
Panorama of Marsh Complex Looking Northwest Toward Round Lake. Photograph of 3 June 1974.



Deep Marsh Area Looking Northwest. Ranch Lake Is at Upper Left.

FIGURE 36. DIGITAL RECOGNITION OF EXTENSIVE MARSH COMPLEX EXTENDING SOUTHWESTWARD FROM VICINITY OF ROUND LAKE. The complex was recognized in processed ERTS data collected on 7 July 1973.





Oblique View Looking South Across Extensive Marsh Area. Barnes Lake Is in the Background. Deep Marsh Zones Are the Mottled Features at Photograph Center. Shallow Marsh Zones Include the Regularly Shaped Fields at Upper Right. Apparently These Latter Areas Have Been in Hay Production. Photograph of 3 June 1974.

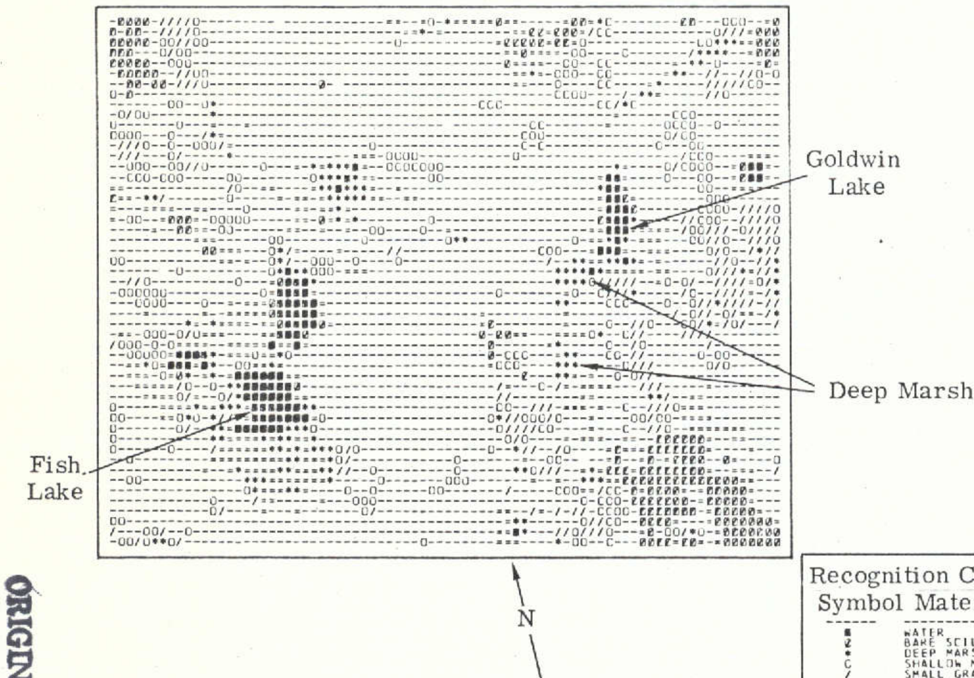
FIGURE 37. DIGITAL RECOGNITION OF A MARSH COMPLEX LOCATED NORTH OF BARNES LAKE. The complex was recognized in processed ERTS data collected on 7 July 1973.

north of the road. To the southwest and to the east, extensive shallow marsh areas occur. The occurrence of these several features was confirmed subsequent to production of the map. However, note that there was a scattering of small grain elements in association with the marsh elements. These were not corroborated, but it is unlikely that any small grains were present in this area.

Figures 38 and 39 show several smaller marshes in the vicinity of Woodworth, North Dakota, the elements of which have not been faithfully recognized. This situation was the result of the limited areal extent and the irregular shapes of these marshes as well as the problem of spectrally-similar vegetation components. In this instance, proportion estimation processing would have been useful for improving the definition of shape and area of these features. Unfortunately, the marsh signatures have not been unique or separable enough from other vegetation types to justify the use of that technique with this data set. Note that the leftmost marsh illustrated in Figure 39 is the same marsh previously shown in Figure 34. Some of the elements of this marsh have been recognized but its delineation is poor because many of the surrounding features have been similarly classified. In this case, many of the marsh features simply were not distinguishable from the surrounding upland features.

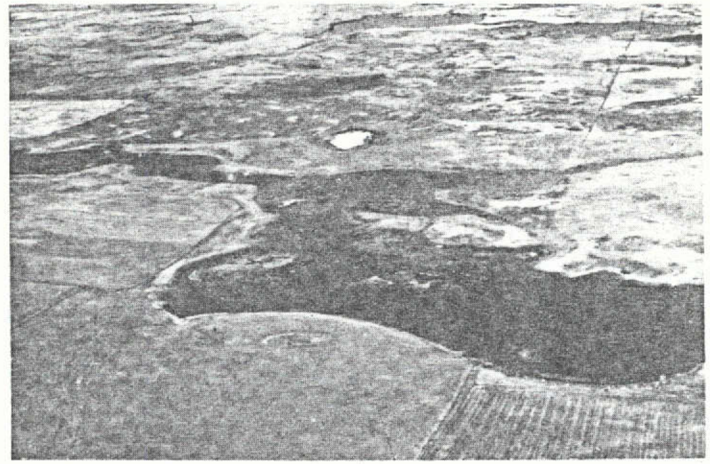
An enlarged classification map principally illustrating crop recognition is shown in Figure 40. These data constitute the area labeled "c" in the small scale recognition map of Figure 35. The bare soil (summer fallow) fields have been accurately and consistently classified while field patterns for crops and pastures are present but much less distinct. The errors that occur in the pastures and cropped fields are again a manifestation of the general similarity of signatures for the various green, herbaceous vegetation types. At the left end of the diagram, a clustering of elements classified as "range" may be seen. In fact, this area included an extensive growth of whitetop which had been cut for hay. The remaining stubble evidently was mistaken for an upland pasture or range situation. The deep marsh area surrounded by this stand of whitetop has been partially delimited from its surroundings but is for the most part incorrectly classified as a row crop. Apparently some confusion exists between these two categories because of a dark soil background visible through a row crop canopy and a similarly dark water background frequently visible through a marsh canopy.

The net result of these recognition map analyses is that many large features and patterns have been delimited and that a general land-use condition is discernible. Area measurements of agricultural land allocation, except for summer fallow, would not have been possible with this data set because green herbaceous vegetation at that phenological stage exhibited similar spectral characteristics regardless of species or type. For the same reasons, as well as small size



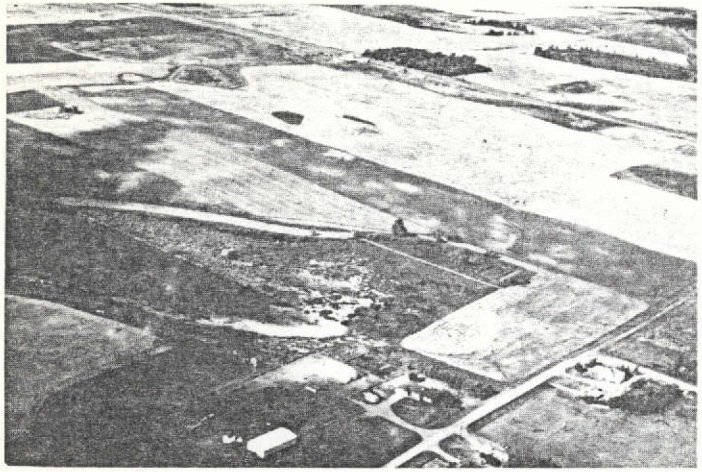
Recognition Code

Symbol	Material
■	WATER
Ø	BARE SOIL
*	DEEP MARSH
C	SHALLOW MARSH
/	SMALL GRAINS
=	ROW CROPS
-	RANGE
	OTHER



The Deep Marsh Is Seen at the Center and Left Center of This Oblique Photograph of 21 July 1973. Fish Lake Is Seen at the Top Center.

FIGURE 38. DIGITAL RECOGNITION OF AN ELONGATED DEEP MARSH NEAR THE WOODWORTH RESEARCH STATION. Note that the narrow width of the marsh has caused it to be mapped only intermittently. The recognition map was created from data collected on 7 July 1973.



View of a Marsh Looking Southwestward. Note the Presence of Deep and Shallow Marsh Zones. A Portion of the Marsh Consisting of Whitetop on the Northern Side of the Complex Had Been Cut for Hay. Photograph of 21 July 1973.

A Deep Marsh Containing a Solid Stand of Hardstem Bulrush (Scirpus acutus). Photograph of 21 July 1973.

Marsh Shown in Type Map of Fig. 34

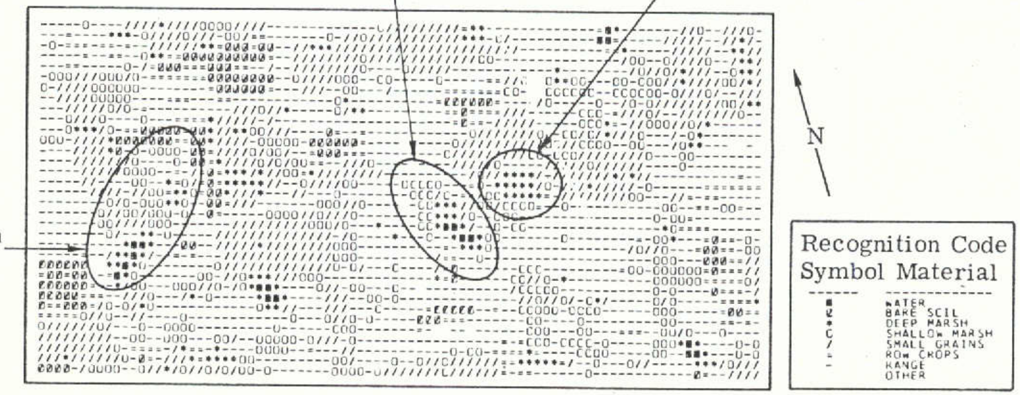


FIGURE 39. DIGITAL RECOGNITION OF SEVERAL MODERATE SIZED MARSHES NEAR THE VILLAGE OF WOODWORTH, NORTH DAKOTA. The recognition map was created from ERTS data collected on 7 July 1973.

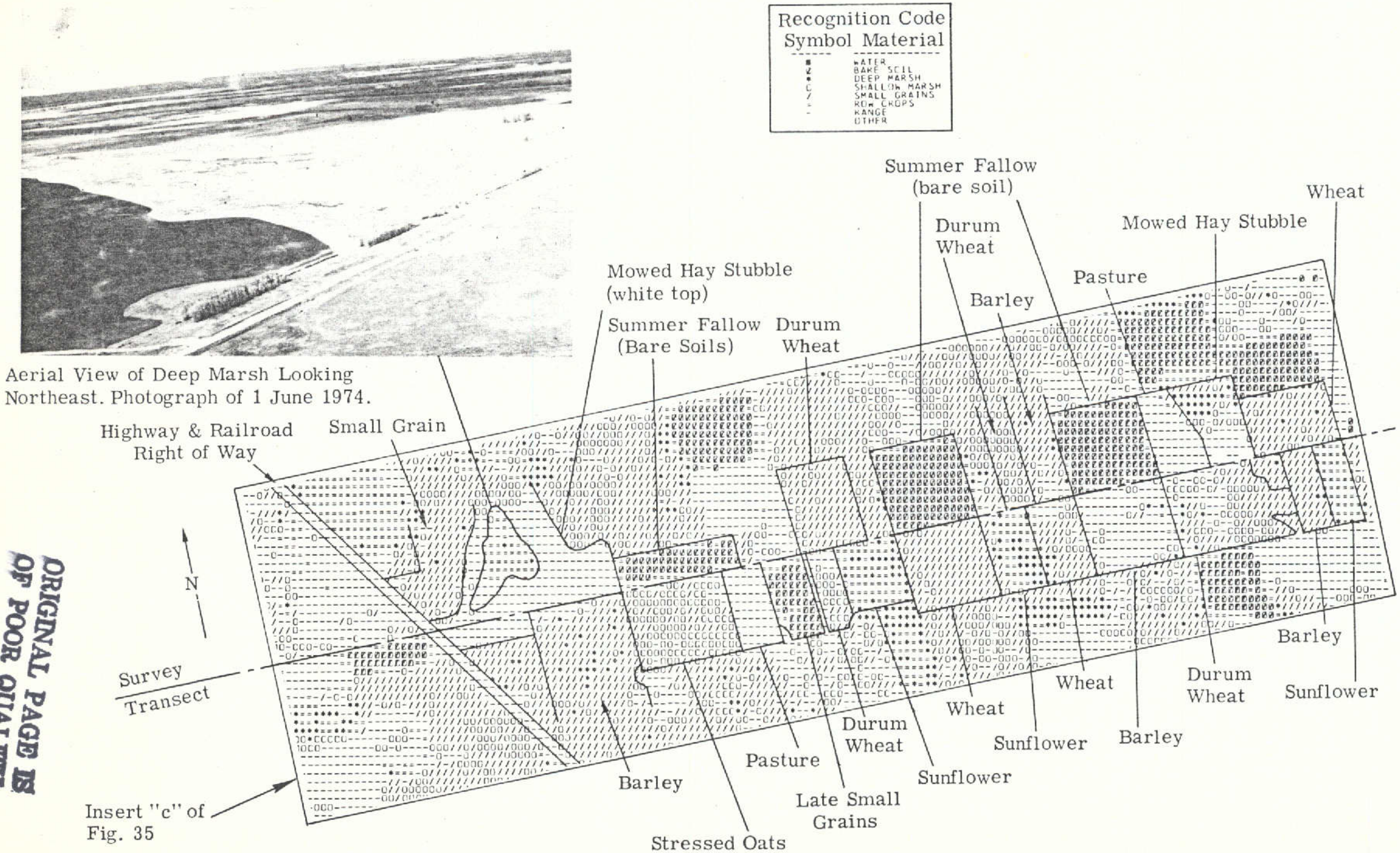


FIGURE 40. DIGITAL RECOGNITION OF AN AGRICULTURAL AREA. The map was generated from ERTS data collected on 7 July 1973. Actual land-use patterns along a survey transect of 17 July 1973 are indicated.

and irregular shape, many marsh areas were not accurately delimited. Exceptions included some large marsh areas and some that exhibited relatively uniform, dense stands of emergent vegetation. In particular, there seems to have been a high number of errors for range, row crop, and marsh elements because of varying degrees of canopy cover and the biasing effects of the underlying soil and water.

It is emphasized again that this recognition experience has utilized data from only one observation date. A choice of data gathered at a different time or joint use of several data sets which would have been spatially registered (multitemporal recognition) would in all likelihood have yielded more accurate results. For example, it is quite conceivable that data gathered later in the season would have allowed an improved delineation of wetland from upland vegetation. This should be possible because, as the season progresses, upland communities become more and more desiccated in the subhumid prairies while many wetland communities retain their vigor as the result of greater residual soil moisture. These differences of senescence or vigor should be most pronounced in channel MSS-5 (0.6 to 0.7 μm). In addition, it should be noted that as wetland and upland vegetation signatures become more separable and unique the opportunities for utilizing proportion estimation techniques are enhanced. It is possible that this technique could improve the mapping of wetland vegetation as it has improved the mapping of open surface water.

4

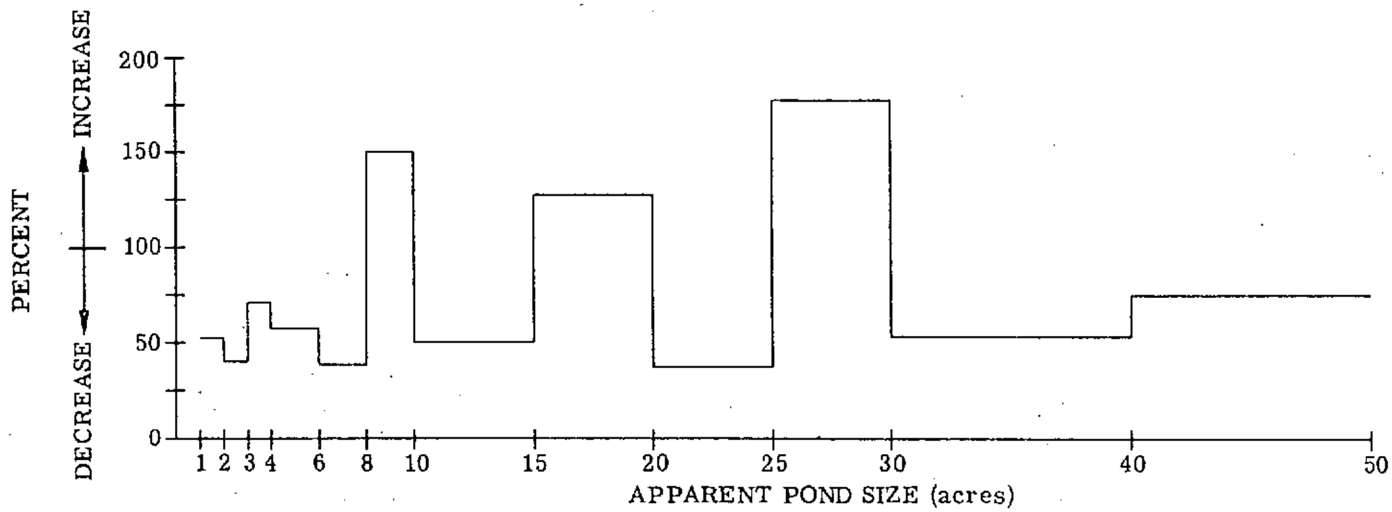
SUMMARY DISCUSSION

In the foregoing sections, opportunities and techniques have been developed for using ERTS data to assess the breeding habitat of migratory waterfowl. This section will summarize and discuss the applicability of these techniques to the survey of habitat conditions found typically in the glaciated prairie region of North America.

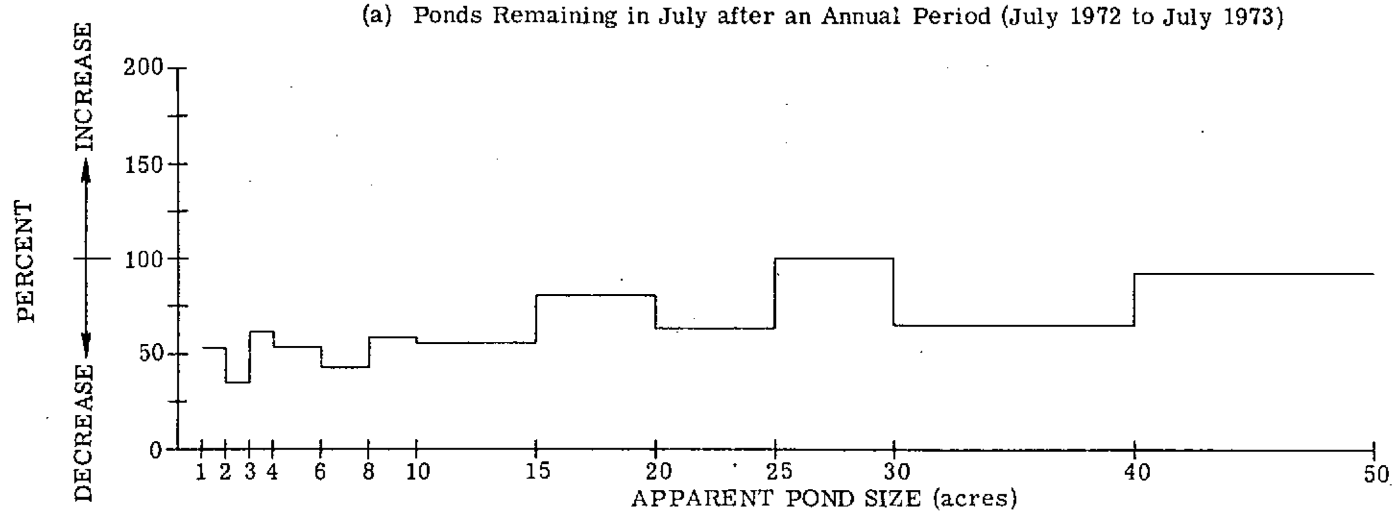
4.1 OBSERVATIONS OF OPEN SURFACE WATER

The mapping of open water has been carried out using two radically different techniques, a single-channel approach and a multiple-channel approach termed "proportion estimation." Single-channel processing has proven simple to implement. Operationally the computer algorithm was rapid and accurately recognized lakes and large ponds. An analysis of the water recognition maps generated using this algorithm indicated that generally lakes and ponds larger than 1.6 hectares (4 acres) were consistently recognized while those in the range 0.4 to 1.6 hectares were recognized only randomly. Ponds of less than 0.4 hectare were not recognized. These resolution anomalies were a result of the sensor's optical resolving power, the sensor's line scanning and pixel sampling geometry, and the random occurrence of surface water with respect to the position of each data pixel.

The resultant products of single-channel processing have been thematic maps and statistical tabulations relative to open surface water. The maps served to visually portray the location and frequency of surface water bodies, but, because of their large scale, these computer-generated maps were inconvenient to handle. The statistical tabulations provided a useful collation and data summary which has been comprehensive for an area 3311 km^2 (1278 square miles) in size. This same area was observed on three sequential dates in order to provide an index to change in surface water conditions through a single breeding season and over an annual period. The study area included portions of two different physiographic regions, a coteau or moraine feature created by stagnation ice and a drift plain or low relief feature of numerous ground moraines. The drift plain inherently has fewer pothole or basin features and because of its low relief has been subjected to wetland drainage projects in the past. The differences in frequency of wetlands warranted a stratification of the statistical results based on these physiographic terrain features. Figure 41 summarizes the relative change in numbers of ponds of several size classes observed in that portion of the study area lying in the coteau physiographic region.



(a) Ponds Remaining in July after an Annual Period (July 1972 to July 1973)



(b) Ponds Remaining in July after a Seasonal Period (May 1973 to July 1973)

FIGURE 41. RELATIVE CHANGES IN NUMBERS OF RECOGNIZED PONDS AND LAKES AFTER AN ANNUAL AND A SEASONAL PERIOD. The numbers were tabulated from ERTS data collected over a 2389 km^2 site in the Coteau du Missouri physiographic region of North Dakota. Where the pond size increments are greater than one-acre, the data have been averaged over the increment.

These data reflect the effects of a dry period which was prevalent and became more severe throughout the data collection phase of this study. Similar data were obtained for that portion of the study area extending into the drift plain. As a result of the less frequent occurrence of water bodies and the smaller area sampled in the drift plain, it was felt that any inferences made of conditions for the plain as a whole would be less reliable.

The central question may be posed: How do changes in water conditions as monitored by ERTS compare with those changes as monitored by more conventional aerial survey methods? As a basis of comparison, data pertaining to the USF&WS survey Stratum 46* which encompassed the present study area were considered. Stratum 46 is 36,876 km^2 (14,238 square miles) in extent and is divided between the coteau (43 percent) and drift plain (57 percent). Allocating the data of the present study in this ratio and extrapolating to an area equivalent to the size of Stratum 46, the estimates of Table 4 were obtained. From these estimates it appears that between 14 and 18.5 percent of the lakes and ponds estimated from standard USF&WS survey data were recognized from the ERTS data. This disparity is probably consistent with the proportionately large number of ponds which were smaller than the resolution capability of the ERTS scanner. Comparisons, however, between the ERTS and the USF&WS survey data must be made rather cautiously because the standard survey procedures were to sample throughout the entire stratum, whereas the ERTS data analyzed were for only a fragment of the stratum, and the data may not have been representative of the stratum as a whole.

Figure 42 illustrates annual and seasonal changes in lake and pond numbers as estimated from both the standard USF&WS survey data and from ERTS data. A strong positive correlation will be noted in comparing these two estimates; however, those changes or declines in pond numbers attributable to the ERTS data consistently lagged the changes observed in the USF&WS survey data. This may indicate that the smaller ponds, many of which were not detected with ERTS, diminished in both size and numbers at a greater rate than did the larger ponds. This supposition appears to be borne out by the data of Table 4 from which it is evident that the ratio of ERTS tabulated ponds to USF&WS tabulated ponds was greater in July 1973 (18.5 per-

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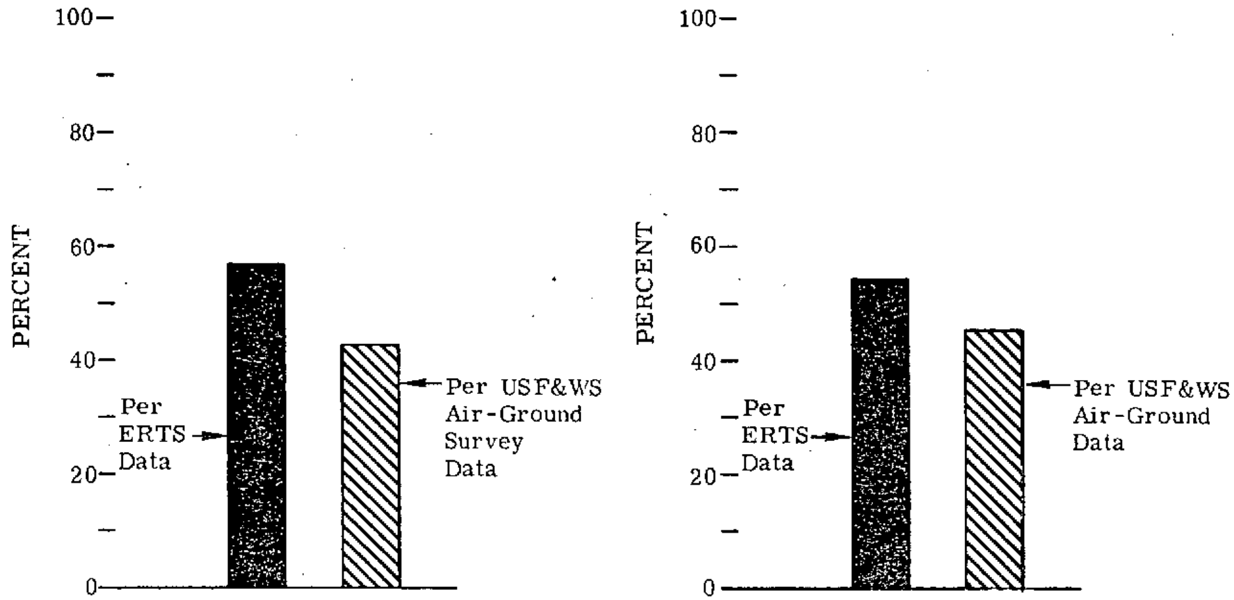
*Stratum 46 is a newly designated USF&WS survey unit which has resulted from a revision of those strata boundaries shown in Figure 3. The revision was implemented and first used in the waterfowl breeding and production surveys of 1974. The new Stratum 46 consists of that portion of old Stratum 30 lying south of latitude 47°22'N. Data from earlier surveys have been modified so that they represent an appropriate allocation to the revised strata boundaries.

TABLE 4. COMPARISON OF ESTIMATES OF SURFACE WATER

	Pond Numbers For Stratum 46 Per Estimate From U.S. Fish & Wildlife Service (USF&WS) Survey Data	Pond Numbers Obtained From ERTS Survey Data and After Extrapolation To An Area Equivalent to Stratum 46*
July 1972	57,480	7993
May 1973	54,000	8375
July 1973	24,468	4545
May 1974	96,600	

*Estimates based upon ERTS survey data are inclusive of only those lakes and large ponds which have been identified using single-channel processing techniques. The disparities in the estimates are due to the proportionately large number of water features which were present within the scene but which were smaller than the resolution capabilities of the ERTS sensor. Note, however, that relative temporal changes in pond numbers are positively correlated for the USF&WS survey data (as illustrated in Figure 42).



(a) Ponds Remaining after an Annual Period (July 1972 to July 1973)

(b) Ponds Remaining after a Seasonal Period (May 1973 to July 1973)

FIGURE 42. CHANGE DETECTION OF NUMBERS OF PONDS AND LAKES AS MONITORED FROM ERTS DATA AND FROM DATA COLLECTED DURING AIR-GROUND WATERFOWL BREEDING AND PRODUCTION SURVEYS. The breeding and production surveys are conducted in May and July respectively by the U.S. Fish and Wildlife Service (USF&WS). The data shown apply to a survey stratum in east-central North Dakota.

cent) than in July 1972 (14 percent), (i.e., total pond numbers were less in July 1973 than in July 1972 with the probable result that proportionately more of the ponds present in July 1973 were larger and more readily recognized in the ERTS data of that date). It might be assumed that the larger ponds and lakes were to a degree stabilized by the regional water table and the smaller ponds were perched or isolated from ground water. Hydrological investigations do not support this, however. Sloan (1972) determined that shallow-water flow systems dominate the ground water hydrology of prairie potholes. Eisenlohr (1972) summarized Sloan's study by stating that "the water table is at a shallow depth and that the water table is continuous with the surface of pothole ponds that are at least seasonal* in permanence."

It would seem that smaller ponds diminish at higher rates for other reasons. Millar (1969, 1971) in studies in southern Saskatchewan observed that ponds in small basins lost water at a faster rate and on the average survived a shorter time than did those in larger basins. This phenomenon suggested to Millar that the rate of water loss was proportional to the ratio of shoreline length per pond area. He believed that ponds lost water at greater rates in their peripheral belts than in their central areas because of greater evaporation in the warmer, shallow water of the peripheral areas and due to transpiration losses by plants growing in these areas and on adjacent onshore locations. These water depletion mechanisms are consistent with the causative factors also advanced by Shjeflo (1968), Sloan (1972), and Eisenlohr (1972).

The above discussion has sought to explain the disparity in the rate of decrease of pond numbers as observed from conventional survey data versus the rate observed from the ERTS data of this study. It is suggested that corrective factors could be applied to the ERTS data in order that the data would better reflect actual changes in water conditions. A statistical method based upon double sampling might be appropriate. In addition, further analysis of the hydrological situations for a variety of regional conditions would be useful. The basic problem, however, could be resolved more effectively if data of finer spatial resolution were available.

In this study, the limited testing of a unique technique for improving the apparent spatial resolution of multispectral data was undertaken. The technique, termed "proportion estimation," involved the use of a computational algorithm for estimating the fractions of

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*The reader is reminded that references to wetland types in this text are based on the classification system of Stewart and Kantrud (1971). In that classification system, a seasonal pond or lake has been designated as a Class III wetland. Generally in the USF&WS survey only ponds and lakes of Class III permanence and above are tabulated.

pure materials present within the resolution cell of a multispectral sensor. Results obtained from proportion estimation indicated that the minimum discernible size of ponds was one-third the minimum size discerned from the single-waveband water-recognition algorithm. In the course of the test, 231 percent as many ponds and lakes were recognized as were recognized with the single-waveband processing algorithm; however, the technique has been applied to a test site of limited size (287 km^2) and for one scene observation date. As a result, valid comparisons could not be made with standard USF&WS survey data.

Proportion estimation processing requires the utilization of multispectral data. Furthermore, the number of scene materials or categories that can be considered must, as a maximum, be no more than one greater than the number of channels utilized in the processing. For the 7 July 1973 data utilized in this test, characteristics of the scene materials were such that only two of the four ERTS channels were unique in their information content, the other two channels being redundant. During this phenological period, then, the sensor was effectively a two channel system. As a result, the test was limited to a consideration of only three scene materials -- water, bare soil, and green vegetation. The general nature and nonspecificity of these materials meant that signature extraction was easily implemented.

One facter that initially precluded the successful application of the algorithm was the use of a water signature which typified an extreme cross section of water conditions ranging from fresh to very saline. The variability of this signature was very great, and, in the final analysis, it was found necessary to reduce signature variance by considering only conditions which ranged from fresh to moderately brackish. In mitigating this decision, it should be noted that saline lakes tended to occur most frequently in areas of glacial outwash. Although an outwash feature was a prominent part of the study area of this study, such features constitute only a small areal fraction of the Coteau and drift plain of North Dakota taken as a whole. Furthermore, the anomalous appearance of many of the saline lakes was the result of the unusually dry conditions which prevailed at the time. As the water levels in these lakes decreased, dissolved salts became more concentrated. Salt crystals appeared to precipitate out as concentrations increased and either settle to the bottom or remain in suspension because of wind agitation of the water surface. At this stage, the lakes assumed a very turbid appearance which was manifested as a spectral anomaly in the visible channels of the ERTS data (spectral channels MSS-4 and MSS-5).

It has been noted that the salinity of a lake can often be correlated with the size and permanance of that lake -- lakes with a greater inflow than outflow seepage tending to be more saline and generally larger and more permanent (Mitten, 1965; Sloan, 1972). This has been a fortunate circumstance because proportion estimation processing was employed primarily to recognize the smaller and heretofore unresolved ponds. In the future, it is probable that water recognition will be most optimally implemented with a combination of the single-waveband and proportion estimation processing techniques. Specifically, those data pixels comprised wholly of water would be recognized as such and edited from subsequent consideration by the single-waveband processing technique, a technique which is generally insensitive to varying conditions of water quality. The remaining data pixels would then be examined with proportion estimation processing to delimit pixels fractionally containing water thus recognizing the smaller, previously unresolved ponds and the peripheral parts of the larger ponds and lakes. Such an approach would also be desirable for the sake of economy because the proportion estimation algorithm requires lengthy computation times and preferably should not be applied to the whole body of data.

With the increased use of the proportion estimation algorithm in this and other studies, accumulated evidence indicates that certain modifications to the present algorithm could produce significant improvements in performance. Currently the algorithm operates by assuming that the number of object classes or materials that can occur simultaneously in a resolution cell is the number represented in the set of pure signatures. In essence, the current algorithm tends to force a mixtures estimate on each cell examined whether that cell contains a mixture or not. In a proposed modification to this procedure, the algorithm would first examine a resolution cell and determine if it was composed of one object class (i.e., material). If it did not pass this test, the resolution cell would then be examined on the assumption that it contained two materials and so on to the consideration of a maximum number of classes pre-programmed into the algorithm. Generally, it is not probable that any resolution cell would contain more than three or four object classes (e.g., as at the intersection of four agricultural fields). Another but related problem inherent with the current algorithm is its tendency to generate small estimates of proportions for each object material in the signature set. In the past, this has occurred even when some of the materials have not been actually present in the resolution cell. The employment of a minimum acceptable limit for any one scene material which, for each resolution cell, would have the effect of setting small proportion estimates equal to zero and then normalizing the others could effectively alleviate this problem.

In summary, the proportion estimation technique has significantly enhanced the apparent spatial resolution limits of the data. However, the computational algorithm is still being refined and increased success is anticipated with subsequent development. In the future, it seems probable that a combination of the single-waveband processing algorithm and a proportion estimation algorithm will provide for both improved performance and efficient operation.

4.2 OBSERVATIONS OF VEGETATION AS AN INDICATOR OF LATENT WETNESS AND UPLAND HABITAT CONDITIONS

This phase of the study was intended to compliment the work described above, specifically the mapping of open water. Previously described techniques have not been appropriate for mapping surface water or areas of high soil moisture concealed by a vegetation canopy. The mapping of wetland vegetation types in order to discern areas of occluded water and conditions of potential wetland productivity was therefore undertaken. During the course of mapping wetlands, it was operationally convenient to also map associated upland vegetation as an indicator of land-use and its suitability for waterfowl nesting. This study phase was limited to a consideration of one data set, ERTS observation 1349-16543 collected on 7 July 1973. Multispectral signatures had already been obtained from that observation for use with the proportion estimation water mapping algorithm.

A classification or recognition algorithm based upon a maximum likelihood criterion was applied to an 1800 km^2 area of the data set to produce a seven category recognition map. These categories were water, deep marsh, shallow marsh, small grains, row crops, range (inclusive of pasture, grassland, and prairie conditions), and an "other" or unclassified grouping. In the resultant map, open water and bare soil features (frequently fields in summer fallow) were easily and accurately delimited. Some of the larger marsh situations were also clearly identified; however, the marsh zones peripheral to open water in many of the smaller wetlands were not discerned partially because of the narrowness of these zones. Moreover, marsh recognition and, in fact, the classification of all green vegetation was inexact because of the general similarity of vegetation signatures. Virtually all the vegetation types present in the scene were grasses and forbs which, at the time of observation, were in a nearly identical phenological stage. Analyses of signatures of the various vegetation types showed that a high incidence of misclassification was unavoidable. In spite of this, the resultant recognition map was synoptically indicative of general land-use patterns. However, when examined pixel by pixel, numerous errors of commission were observed. At the pixel level of detail the present computer-generated map could achieve its greatest potential if it were to serve as a working base for further interpretation. In this capacity, the computer map would provide a unique data base because it is a product much closer to the resolution limits of the ERTS-1 multispectral data than other image products available from that sensor. On the other hand, an interpreter's ability to perceive relative differences in observed scene elements and to use ancillary information and experiences could be used to improve the quality of the computer generated map. Such a procedure might be termed "interpreter enhanced classification recognition."

The basic problem with the classification map generated in this study was an inherent inability to delineate various categories of green vegetation and a lack of sufficient resolution to adequately delimit marsh zones within small wetland basins. It is suggested that an observation made at a different season or phenological period would have allowed for greater separability of wetland and upland vegetation types. Late summer or early fall, when upland vegetation has been subjected to a greater degree of moisture stress and upland plant senescence had become more prevalent, would probably be a more satisfactory period. At such a time as the multispectral signatures of vegetation become more separable, proportion estimation processing could then be applied to marsh situations in order to improve their apparent resolvability. The improvements to be realized should approach those that have been noted in the proportion estimation mapping of water.

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