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USE OF LANDSAT DATA TO ASSESS WATERFOWL HABITAT QUALITY

JOHN E. COLWELL, DAVID S. GILMER, EDGAR A. WORK, Jr.,
DIANA L. REBEL and NORMAN E. G. ROLLER

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USE OF LANDSAT DATA TO ASSESS WATERFOWL HABITAT QUALITY

by

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16. Abstract

This report is a discussion of the feasibility of using Landsat data to generate information of value for effective management of migratory waterfowl. Effective management of waterfowl includes regulating waterfowl populations through hunting regulations and habitat management. This report examines the ability to analyze annual production by monitoring the number of breeding and brood ponds that are present, and the ability to assess waterfowl habitat based on the various relationships between ponds and the surrounding upland terrain types. The basic conclusions of this report are that: 1) Landsat data can be used to improve estimates of pond numbers which may be correlated with duck production; and 2) Landsat data can be used to generate information on terrain types which subsequently can be used to assess relative waterfowl habitat quality.

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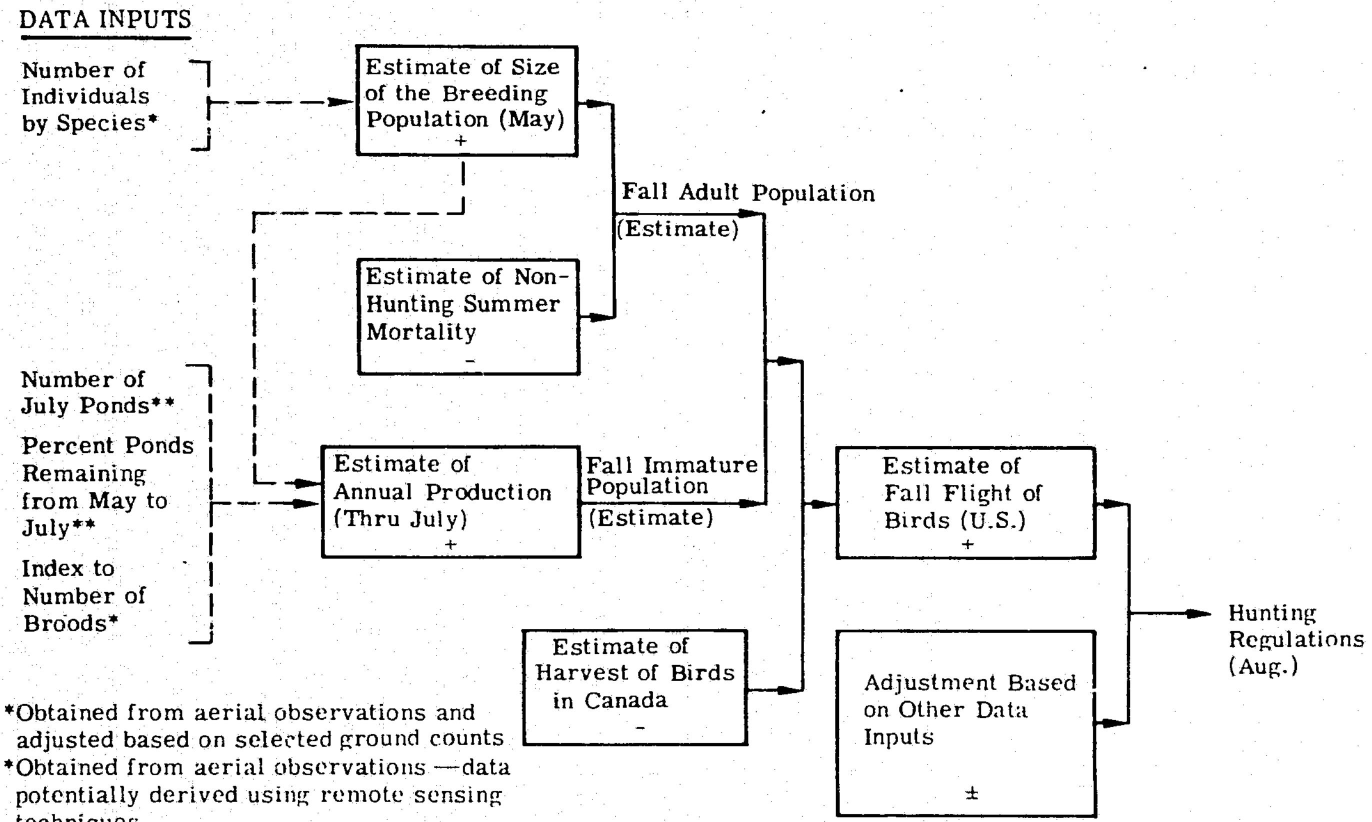
1
INTRODUCTION

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 Fish and Wildlife Service (FWS) 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 acquistion and lease arrangements, the regulation of land use, and the manipulation or treatment of certain features to enhance habitat quality.

This report deals with the potential of remote sensing inventory techniques to furnish FWS personnel with data that will improve their capabilities to manage migratory waterfowl. Present FWS objectives and procedures will be described before we discuss the findings obtained in this study.

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 generally the sequence of events 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



*Obtained from aerial observations and adjusted based on selected ground counts

**Obtained from aerial observations —data potentially derived using remote sensing techniques

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

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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 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).

Several studies by waterfowl biologists (e.g., Crissey, 1969; Geis, et al., 1969) have indicated the importance of pond number and condition to annual duck production. Emphasis has generally been placed on pond counts in May (breeding season) and in July (brood season). In addition, other terrain characteristics are known to be important to short and long term habitat quality and duck production.

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 is 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 currently obtained by FWS 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 km^2 of the breeding range are sampled during each survey. Approximately 80,000 transect kilometers are flown at an altitude of 30 to 45 meters. Ponds are counted over a 200-meter wide strip during the aerial transect in both May and July (Henney et al., 1972).

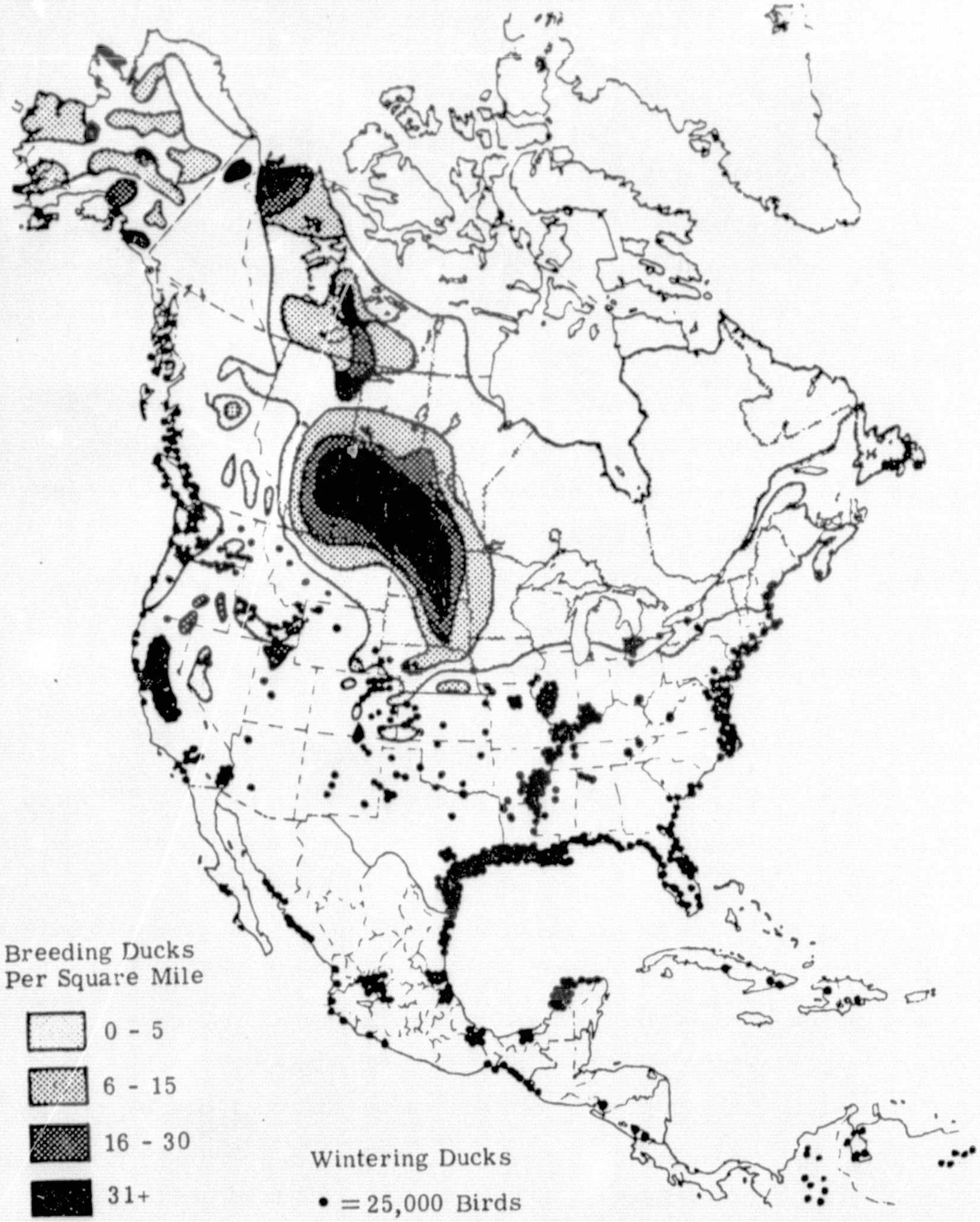

FIGURE 2. AVERAGE DISTRIBUTION OF NORTH AMERICAN BREEDING AND WINTERING WATERFOWL

Fish & Wildlife Service
U. S. Dept. of the Interior

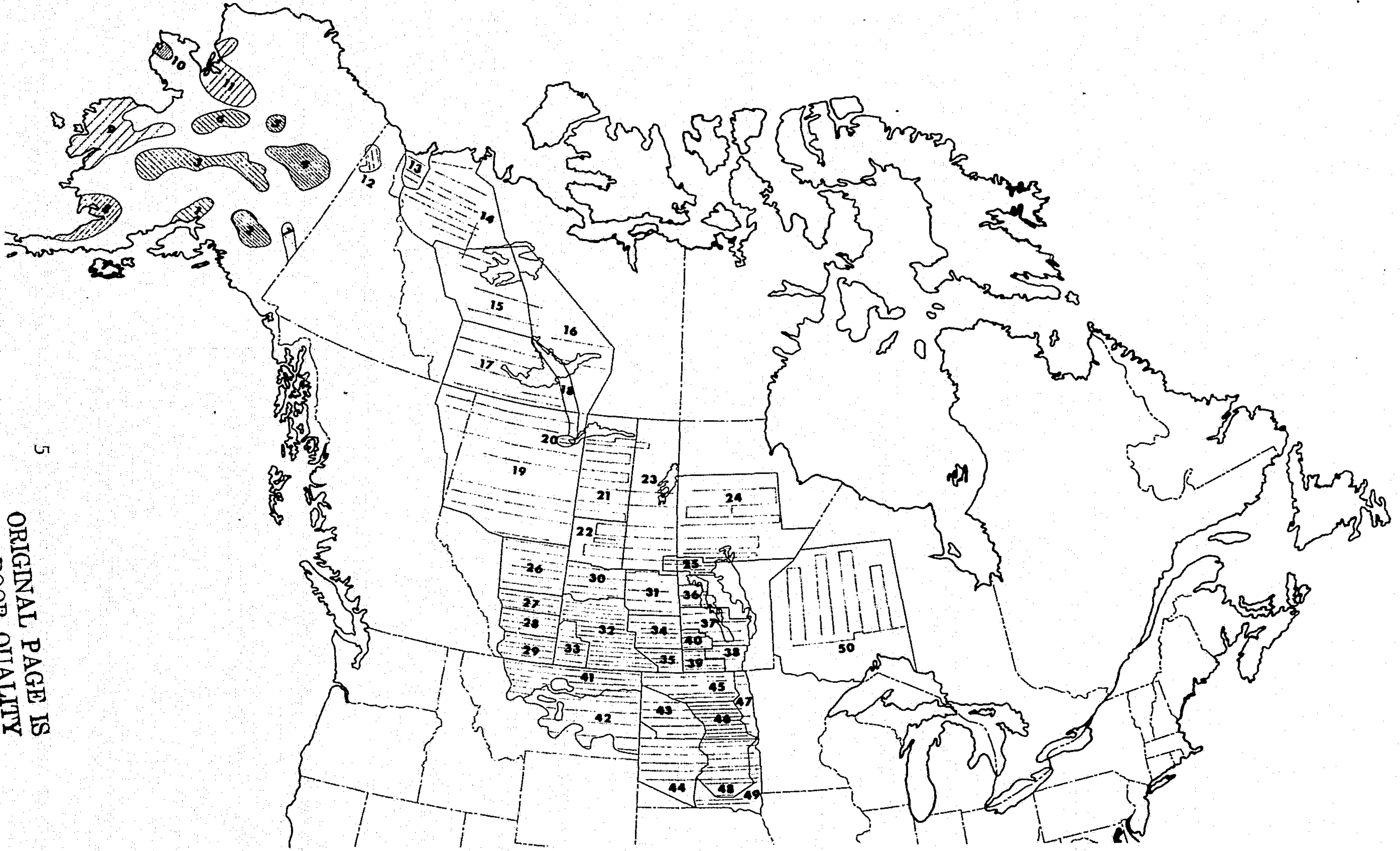

FIGURE 3. TRANSECTS AND STRATA FOR AERIAL WATERFOWL BREEDING AND PRODUCTION SURVEYS. Due to continued evaluation of survey procedures, the sampling frame and units are occasionally modified. The above transects and strata were the units most recently in effect during 1973. In 1974, part of Stratum 30 became Stratum 46. Fish & Wildlife Service
U.S. Department of the Interior

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The second sample in the present design of the FWS Survey 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.

Given the very large area that must be surveyed by the FWS and the requirement for timeliness in establishing hunting regulations, remote sensing techniques offer the potential to make improvements in the present FWS survey. Investigating the potential of remote sensing has been the primary purpose of this and previous related projects, described in the next section.

Applications of remote sensing techniques may 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 present FWS 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 may be appropriate for insuring rapid availability of survey information. For satisfying longer term survey requirements, the utilization of remote sensing for recognizing vegetation will establish baseline terrain conditions and provide additional factors for estimating waterfowl habitat quality.

1.1 BACKGROUND

Remote sensing of waterfowl habitat by use of multispectral scanners and related machine processing techniques began in 1968 as a joint effort between Northern Prairie Wildlife Research Center (NPWRC) and the Environmental Research Institute of Michigan (ERIM). The goals were to investigate new processing techniques for mapping selected components of 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 water recognition maps. As a result, in 1969, efforts began which were to culminate in digital software programs capable of generating numerical statistics on characteristics of water bodies.

That period also saw the application of vegetation mapping techniques to assist in wetland classification. Through the use of aircraft multispectral scanner (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, recognition of water 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 cost-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 1.6 linear km (1.0 mile) of scanner data. 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 these 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.

With the advent of instrumented satellites designed primarily for earth resource observations, opportunities became available for synoptically inventorying very large areas with respect to wildlife habitat conditions. This era began in July 1972 with the launch of the first Earth Resources Technology Satellite (ERTS-1, later renamed Landsat-1) by the National Aeronautics and Space Administration (NASA). In addition to building and launching the satellite, NASA selected and funded over 300 investigations to utilize data accumulated by the satellite's sensors. The U.S. Fish and Wildlife Service in association with the Environmental Research Institute of Michigan conducted one of these investigations.

Specifically, that investigation developed techniques for monitoring waterfowl breeding habitat in the prairie pothole region of North Dakota. An important outcome of that investigation was the development of computer aided techniques for discriminating open surface water and for generating relevant statistics on these features. Resultant products were sets of statistics on numbers, size, and distribution of ponds and lakes identified within the study area during each of the different observations. The area studied overlapped portions of two biotic subregions (physiographic provinces) in North Dakota, the Missouri Coteau and Southern Drift Plain, indicated in Figure 4. A comparison with Figure 5 indicates that Stratum 46 covers portions of both physiographic provinces.

An additional Landsat processing effort was begun in 1974. It was basically a continuation of previous efforts. As a result of the above efforts the total Landsat data that have been analyzed to date includes: July/August 1972; May 1973; July 1973; June 1974; and August 1974. Much of the work described above has been documented by Burge and Brown (1970) and Nelson et al. (1970) for the period 1968-69; by Work and Thomson (1974) for the period 1970-72; and for the period 1972-present, by Work (1974), Work et al. (1974), Work and Gilmer (1975), and Work and Rebel (1976).*

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*An additional investigation in which 1976 pond data are analyzed is reported in Rebel and Work (1977).

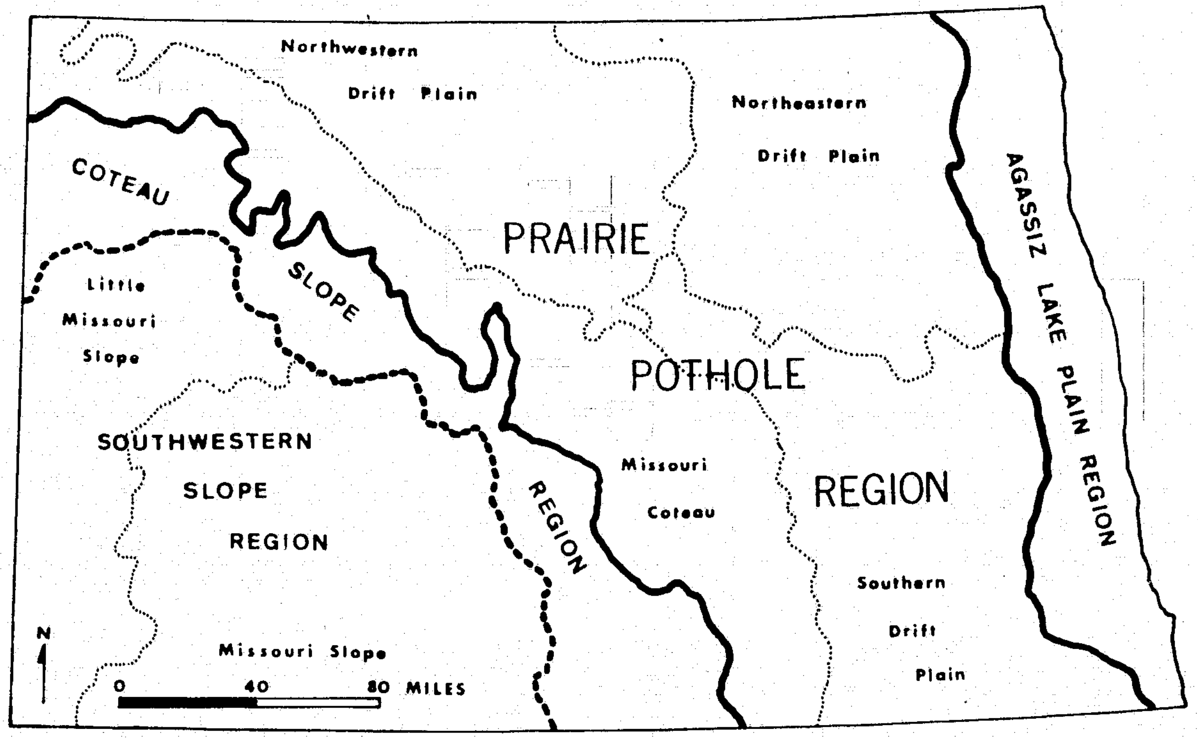

FIGURE 4. THE BIOTIC REGIONS OF NORTH DAKOTA
(After Stewart and Kantrud 1973)

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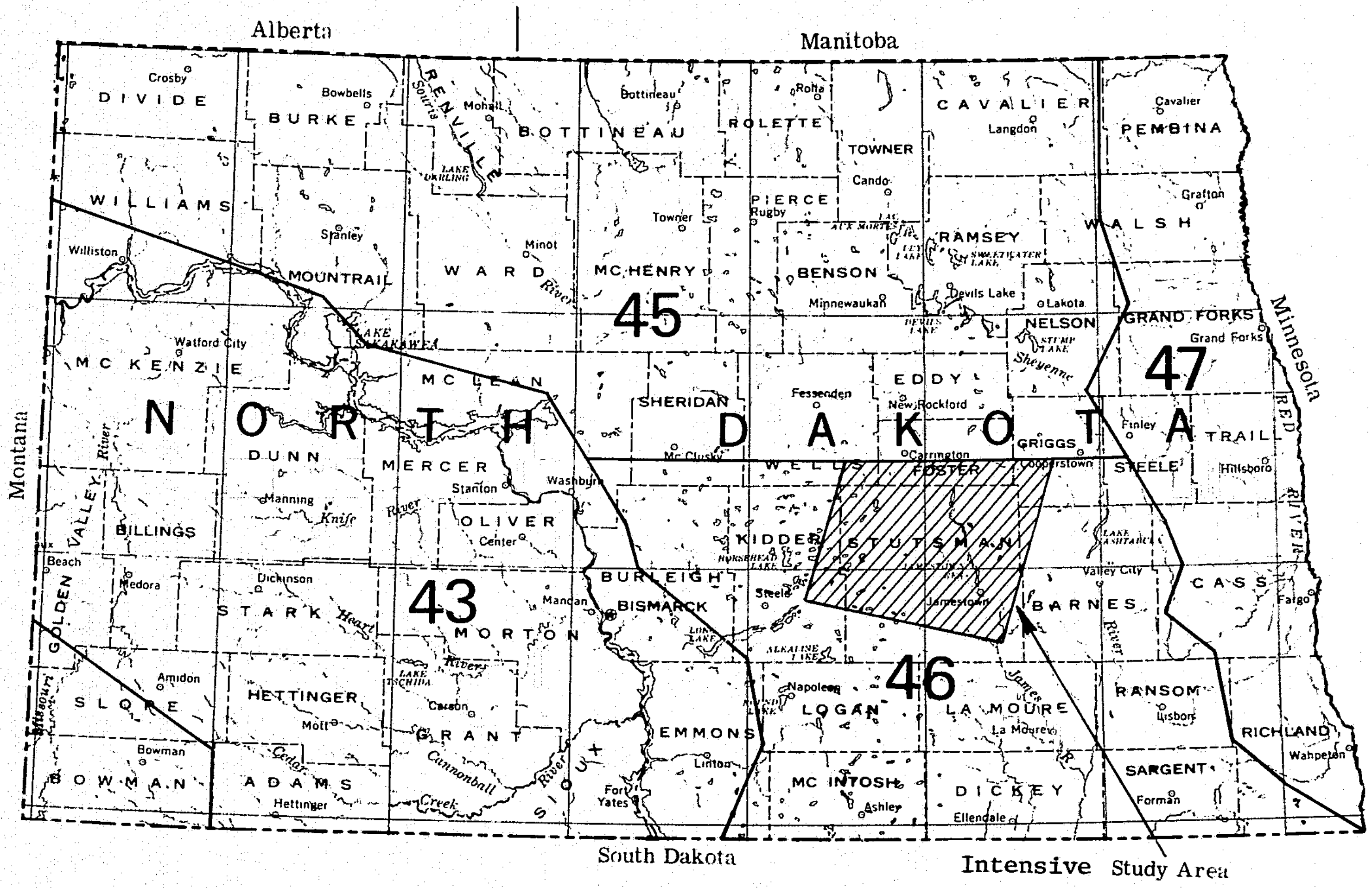

FIGURE 5. GEOGRAPHIC LOCATION OF THE INTENSIVE STUDY AREA WITHIN THE STATE OF NORTH DAKOTA. The limits and designations of waterfowl breeding and production survey strata utilized routinely by the U.S. Fish and Wildlife Service are also indicated.
Scale - 1:3,000,000

1.2 APPROACH

The previous investigations in this program have shown what kinds of information can be generated with remote sensing (particularly Landsat) data. The purposes of the current investigation reported on here were: 1) to demonstrate the capabilities of Landsat data for large area survey (all of FWS Stratum 46); 2) to improve on Landsat capabilities by using Landsat data in conjunction with aircraft data in a census and double sampling procedure; 3) to demonstrate improved terrain classification with multitemporal Landsat data; and 4) to demonstrate the concepts of using remotely determined pond and terrain data to assess duck production and waterfowl habitat quality.

This report is organized in the following fashion. First, water mapping with Landsat and aircraft data is discussed, and the results are analyzed. Next, terrain mapping with multitemporal Landsat data is described. We then discuss the potential utility of the water and terrain information as follows: 1) describe and demonstrate the concept of the use of water data for estimating annual duck production; and 2) describe and demonstrate the use of terrain classification data, in conjunction with pond data, for assessing waterfowl habitat quality.

A discussion of Landsat determination of pond area is included in an appendix. Some of the effects of size and shape are indicated in that appendix.

Throughout the body of the report, we include brief summaries of data or comparisons with results achieved in our previous investigations, in an attempt to put this present study into perspective. For those desiring more detailed information on previous results or previously developed procedures, the original references should be consulted.

The work reported here was conducted jointly by the Northern Prairie Wildlife Research Center (NPWRC), U.S. Fish and Wildlife Service, and by the Environmental Research Institute of Michigan (ERIM). The work was funded by FWS, through a NASA Grant. Dr. David S. Gilmer of NPWRC was the Principal Investigator, and Mr. Edgar A.

Work, Jr. and Dr. John E. Colwell of ERIM were co-investigators. Significant contributions to the project were made by Ms. Diana L. Rebel and Mr. Norman E.G. Roller of ERIM. Assistance in collecting field data was provided by Tom Klett and Phillip M. Arnold, USFWS. Mr. Harold Oseroff, NASA Technical Officer, provided helpful administrative guidance and assistance during this investigation.

2
SURFACE WATER MAPPING

A primary emphasis of this investigation was to refine previous techniques for surface water mapping in order to make them more nearly operational, with the hope that the techniques might ultimately be implemented directly by FWS personnel. The two surface water mapping problems on which we concentrated most were: 1) the routine, efficient handling of very large amounts of Landsat data, including geographic registration of multiple frames and multiple dates of Landsat data, and 2) an efficient sampling strategy, in which large amounts of Landsat data would furnish a coarse estimate (census) of ponds which would subsequently be corrected (adjusted) by a small double sample so as to obtain a final estimate with precision. The philosophy behind these two efforts is described in the next two sections, which are followed by a discussion of the implementation and results of these efforts.

2.1 APPROACH

2.1.1 LANDSAT DATA HANDLING

Our previous experience in processing Landsat data for determination of surface water dealt with relatively small areas (one-eighth Landsat frame or less). One of the major goals of this project was to extend the small area techniques to larger areas, in order to make them more applicable to the large scale problems associated with management of migratory waterfowl over the major North American breeding areas. The large volumes of data involved required that new procedures for data handling be developed. A substantial amount of effort went into the development of software for this purpose. Though this effort was very important in bringing Landsat data closer to operational use, the details of the effort are complex, and for the purpose of this report they are discussed in general terms.

2.1.2 SAMPLING PROCEDURE FOR SURFACE WATER MAPPING

Previous studies have indicated that the relatively coarse resolution of Landsat data precludes Landsat from detecting very small

(<0.4 ha) ponds.* Nevertheless, small ponds may be quite numerous, and may be quite important to habitat quality and waterfowl production. For this reason, a primary objective of this investigation has been an analysis of fine resolution aircraft data in conjunction with Landsat data as a part of a double sampling procedure (design) for estimating the total number of water bodies in the sampled universe. Specifically, this universe has been the FWS breeding ground survey Stratum 46, encompassing 36,876 km^2 in the southeastern quarter of North Dakota.

2.1.3 CENSUS AND DOUBLE SAMPLING

Double sampling techniques have previously been shown to be useful when employing Landsat data to estimate characteristics of features over large areas (e.g., Hay, 1974). In this study, our double sample consisted of aircraft-derived estimates of ponds from flightlines flown as nearly coincidental with FWS survey transects as possible. The density of this sample was chosen to be approximately 1 percent of the total area of Stratum 46. The aircraft estimates were compared with corresponding Landsat estimates, sample-unit by sample-unit, in order to develop a regression relation that could be used to adjust a large area Landsat estimate made on a nearly complete enumeration (census) of the stratum.

In practice, the desired size of the double sample should be established on the basis of the variances of the primary (Landsat) and secondary (aircraft) estimates, the unit cost of making the respective estimates, and the desired precision of the stratum estimate. Due to lack of prior information of this kind, those issues have not been specifically examined in this study.

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*The exact figure may be larger or smaller than this, depending on adjacent terrain classes, location of the pond with respect to the Landsat pixel, and the sophistication of the processing technique used (e.g., see Section 2.2).

2.2 BASIS FOR IDENTIFYING SURFACE WATER

In previous investigations we analyzed several ways of utilizing multispectral scanner data to identify surface water. The fundamental basis for differentiation of water is its unique absorptance and reflectance characteristics. Figure 6 shows the spectral transmittance for different lengths of columns of pure water. Note that in the near infrared (>0.7 μm), the fraction of radiation which penetrates the air-water interface is largely absorbed. Consequently, a sensor viewing a body of water in a near infrared band receives very little reflected radiation from the bottom or from suspended particulates.

In previous studies, level thresholding of the signal in a near infrared waveband has been shown to be a reliable and simple techinque for delineating surface water (e.g., Work et al., 1974). Studies with aircraft multispectral scanner data have shown that an excellent waveband for delineating surface water is the 1.5-1.8 μm spectral interval (Work and Thomson, 1974). However, this spectral interval is not available on Landsat data. The closest approximation to the ideal waveband is MSS7 (0.8-1.1 μm). Level slicing of this waveband has been used with success in previous studies (e.g., Work, et al. 1974).

Because many prairie ponds are frequently smaller than 0.4 ha (the virtual resolution of Landsat data), a technique called proportion estimation (Horwitz, et al., 1971) was investigated previously to see if small ponds and margins of ponds could be better differentiated (Work, 1974). The tests of proportion estimation showed some improvement in differentiation of water bodies. However, the technique was considered too costly and too developmental to be used for the quasi-operational large area demonstration.

Some investigators have indicated that somewhat better separation between water and non-water classes could be achieved by using two Landsat channels than when using only one channel (NASA, 1973). We have previously investigated the relative utility of two channels vs one channel on 1973 Landsat data (E. Work, personal communication). The results did not show increased discriminability of water with two

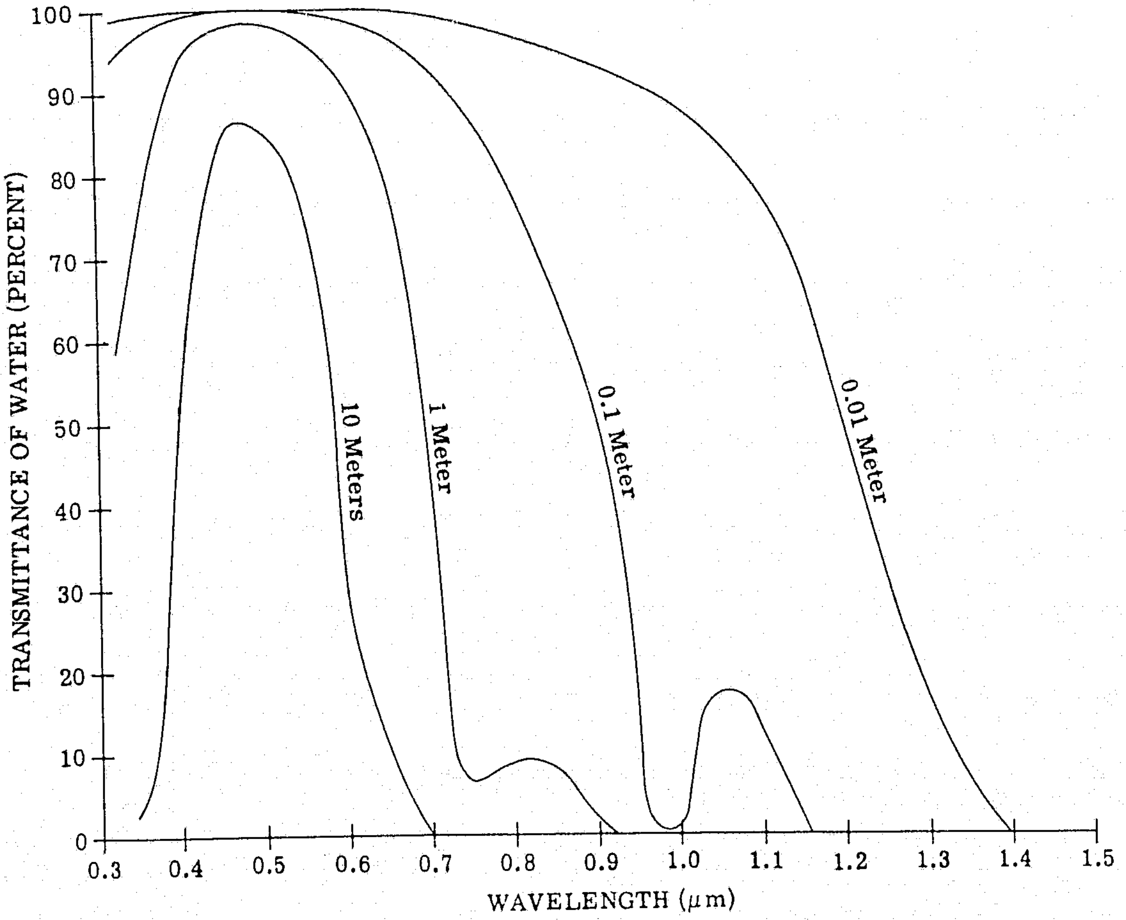

FIGURE 6. SPECTRAL TRANSMITTANCE OF PURE WATER FOR DIFFERENT PATH LENGTHS. (Plotted after data from Sverdrup et al., 1942.)

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channels of data. However, in view of our desire to optimally differentiate ponds from other targets we decided to do an additional analysis of another data set, as a part of this project. The results of this analysis are discussed in the following paragraphs.

For 15 July 1975 Landsat data, a total of 40 signatures representing most of the terrain classes and spectral variability present in the scene were determined. Mean values of these signatures were plotted in two combinations of two-channel data space, namely MSS4 vs MSS7, and MSS5 vs MSS7. The results are presented in Figures 7 and 8, and indicated that all water could be separated from non-water with a MSS7 level slice. Based on these results we see little or no additional value for using any data other than MSS7 to differentiate water from non-water.

However, there may be other advantages to two channel data processing. One of the serious limitations of a single channel approach is that the optimal "slicing level" may change from time to time, from frame to frame, or even within a frame, as external factors such as atmospheric conditions or solar zenith angle change. For example, for one set of data we processed as part of this project, an MSS7 level slice at a digital count of 7 was used on one frame (May 4), but a level slice of 9 had to be used on an adjacent day (May 5) frame in order to get comparable results in the overlap region. The apparent reason for this change was hazy atmospheric contions on May 5. Without a change in level slice there would have been substantial errors in the results. For example, a single lake which had an indicated contiguous area of 88 ha with the May 4 data and with a level slice of seven, was indicated as 7 discrete groups of points (pseudo-lakes) totaling 42 ha with the same level slice on the May 5 data.

One possible two channel processing approach, ratioing the two channels, is generally effective at normalizing some of the multiplicative part of external effects. Therefore, we briefly investigated the utility of ratioing in normalizing the slicing level for differentiating ponds.

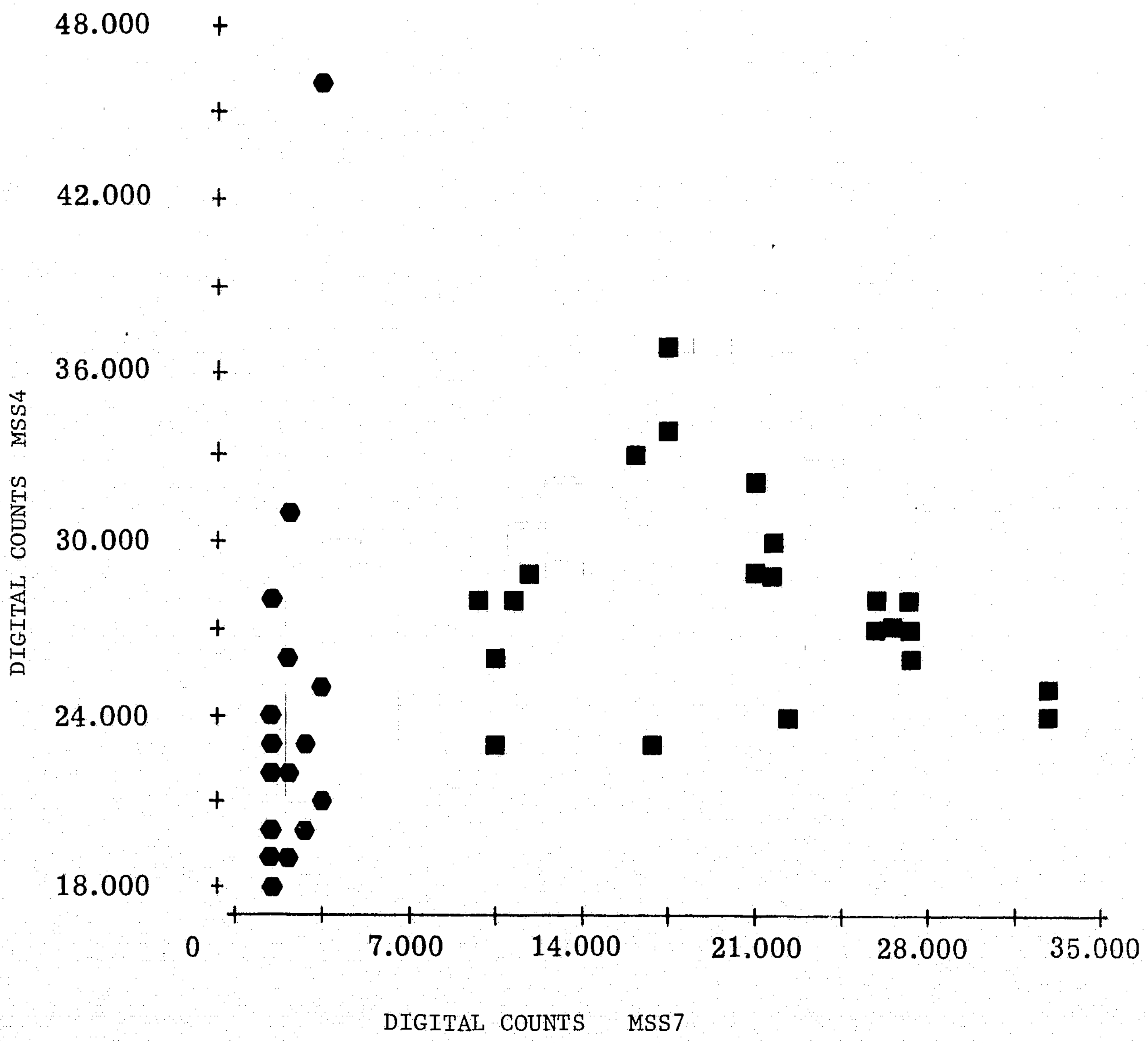

FIGURE 7. SCATTER PLOT OF MSS4 VS MSS7 OF MEAN DIGITAL VALUES FOR WATER (⬢) AND NON-WATER (■)CATEGORIES FROM 15 JULY 1975 LANDSAT DATA.

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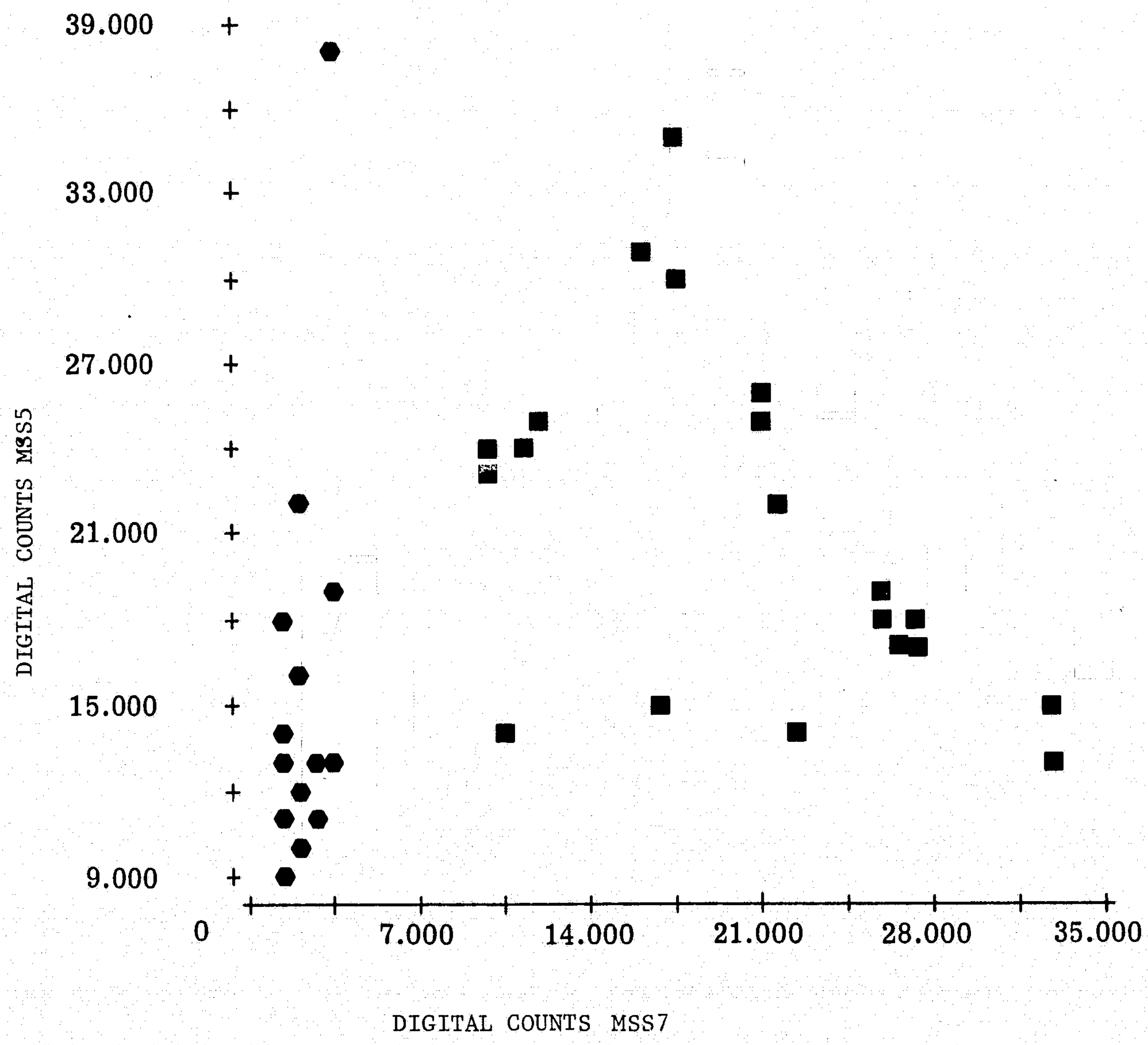

FIGURE 8. SCATTER PLOT OF MSS5 VS MSS7 OF MEAN DIGITAL VALUES FOR WATER (⬢) AND NON-WATER (■) CATEGORIES FROM 15 JULY 1975 LANDSAT DATA.

For the same data described above which gave us unacceptable results using a single MSS7 level slice for two dates, we implemented a level slice of the ratio MSS4/MSS7. The slicing level used was based on an analysis of previously processed Landsat data. It was picked subjectively so as to differentiate water from non-water. A ratio value of approximately 4 for MSS4/MSS7 (or MSS7/MSS4 = .25) seemed acceptable.

When the two dates of Landsat data (4, 5 May 1975) were processed, a single MSS4/MSS7 ratio was found to give nearly comparable pond data for both dates when a ratio level slice of 4 was used. For example, the lake discussed above was indicated as 1 pond with 96.8 ha on 4 May and 1 pond with 90.0 ha on 5 May. (Table 1)

TABLE 1. COMPARISON OF CONSISTENCY OF LANDSAT SINGLE BAND AND RATIO LEVEL SLICE FOR DIFFERENTIATION OF ONE POND

	SINGLE BAND THRESHOLD (MSS7=7)		TWO BAND THRESHOLD (MSS4/MSS7=4)	
DATE	NO. OF PONDS INDICATED	AREA INDICATED (ha)	NO. OF PONDS INDICATED	AREA INDICATED (ha)
4 May	1	94.5	1	96.8
5 May	7	46.4	1	90.0

Our preliminary conclusion based on this very limited test is that, although it is not a panacea, a ratio of two channels may give more consistent slicing levels than a single channel. A linear combination of two channels* may be even more useful, because it can have a non-zero intercept and is not as sensitive to noise as a ratio is.

We believe that the utility of a two-band decision rule for differentiation of water bodies should be further investigated, especially if large amounts of Landsat data are to be processed over large areas and/or at several points in time. Such an investigation was

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*e.g., an equation of the form $aX_1 + bX_2 = k$, where X_1 and X_2 are digital values in two MSS bands, and a, b, and k are constants.

beyond the scope of this project. Therefore, we have chosen to use the previously used approach of MSS7 threshold level slicing for differentiation of water bodies in this study. One advantage of doing so is to make 1975 results "comparable" with results from 1972, 1973, and 1974 Landsat data, generated in previous studies.

2.3 LANDSAT WATER MAPPING

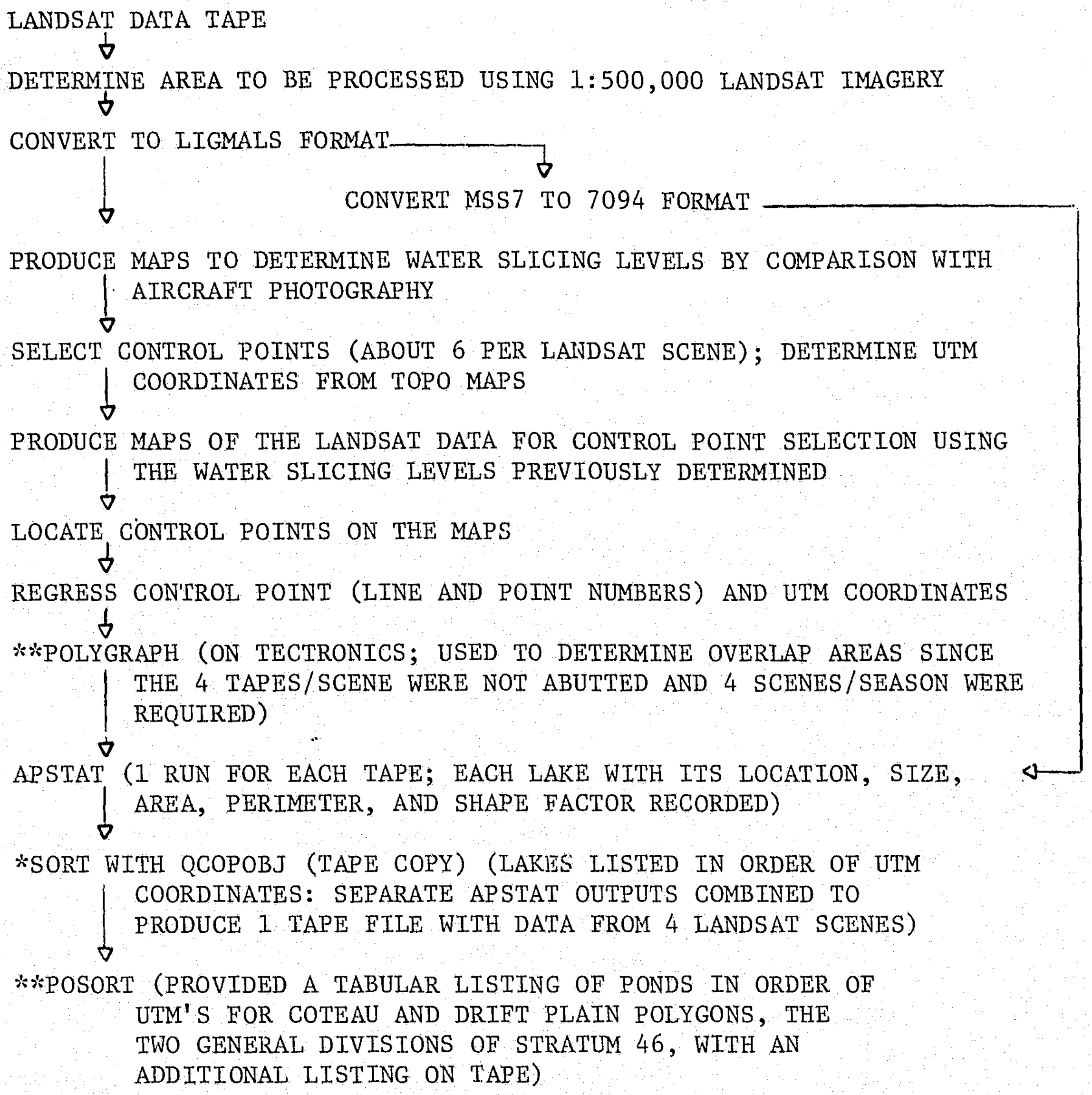
2.3.1 STUDY AREA

The data processed comprised observations made during May and again during July 1975 throughout a 36,876 km^2 area in southeastern North Dakota designated by the FWS as Survey Stratum 46 (See Figure 5). For the purpose of this study FWS Survey Stratum 46 was subdivided into two parts. These parts, specified as the "Drift Plain" and "Coteau", were delineated on the basis of physiographic differences which frequently cause the frequency of occurrence and type of wetland to vary between the two substrata. The two physiographic provinces are labeled in Figure 4. The Coteau is characterized by hummocky topography and abundant potholes. The Drift Plain has fewer potholes, and because of its low relief and rich soils, it has been subjected to intensive agriculture and accompanying wetland drainage projects. Some cloud cover was present during May and limited our survey to approximately 87 percent (32083 km^2) of the stratum. Nearly 100 percent (36855 km^2) of the stratum was monitored during July.

2.3.2 PROCESSING PROCEDURE

Water mapping with Landsat data was implemented by using the procedures shown in Figure 9. The MSS7 threshold was determined as before. Briefly, this consisted of establishing several candidate levels, making trial maps of a portion of the region, and comparing the results with aerial photos to decide on the optimum level.

In order to relate line and points to Universal Transverse Mercator (UTM) coordinates for absolute location of ponds it was necessary to establish ground control points. These points were selected such that they were easily locatable on both the topographic



LANDSAT DATA TAPE

DETERMINE AREA TO BE PROCESSED USING 1:500,000 LANDSAT IMAGERY

CONVERT TO LIGMALS FORMAT

CONVERT MSS7 TO 7094 FORMAT

PRODUCE MAPS TO DETERMINE WATER SLICING LEVELS BY COMPARISON WITH AIRCRAFT PHOTOGRAPHY

SELECT CONTROL POINTS (ABOUT 6 PER LANDSAT SCENE); DETERMINE UTM COORDINATES FROM TOPO MAPS

PRODUCE MAPS OF THE LANDSAT DATA FOR CONTROL POINT SELECTION USING THE WATER SLICING LEVELS PREVIOUSLY DETERMINED

LOCATE CONTROL POINTS ON THE MAPS

REGRESS CONTROL POINT (LINE AND POINT NUMBERS) AND UTM COORDINATES

**POLYGRAPH (ON TECTRONICS; USED TO DETERMINE OVERLAP AREAS SINCE THE 4 TAPES/SCENE WERE NOT ABUTTED AND 4 SCENES/SEASON WERE REQUIRED)

APSTAT (1 RUN FOR EACH TAPE; EACH LAKE WITH ITS LOCATION, SIZE, AREA, PERIMETER, AND SHAPE FACTOR RECORDED)

*SORT WITH QCOPOBJ (TAPE COPY) (LAKES LISTED IN ORDER OF UTM COORDINATES: SEPARATE APSTAT OUTPUTS COMBINED TO PRODUCE 1 TAPE FILE WITH DATA FROM 4 LANDSAT SCENES)

**POSORT (PROVIDED A TABULAR LISTING OF PONDS IN ORDER OF UTM'S FOR COTEAU AND DRIFT PLAIN POLYGONS, THE TWO GENERAL DIVISIONS OF STRATUM 46, WITH AN ADDITIONAL LISTING ON TAPE)

FIGURE 9.

PROCESSING FLOW CHART
NORTH DAKOTA STRATUM 46 - 1975 DATA

maps and the Landsat data. The UTM coordinates of the points were determined from the topographic maps, or by conversion of latitude and longitude to UTM's. The same points were then located on the Landsat data, and their respective line and point numbers were determined. Multiple linear regressions relating the UTM and Landsat coordinates were then determined and applied to the Landsat data.

In carrying out the processing efforts, the location in a data set of certain geographic areas of interest has been facilitated by use of a newly developed software program which permits an accurate solution of the intersection of a polygonal test site with a rectangular Landsat image. A graphics display terminal was used to provide a direct visual presentation of the situation. The operator then entered and stored points of interest through the use of the screen cursor. The program also permits entry of points in either UTM or line/point coordinate systems. Conversion is accomplished on a point by point basis permitting the mixing of input modes. Subsequent to the reformatting of data and recognition training, we utilized sequentially three software programs, APSTAT, SORT, and POSORT.

Program APSTAT (Area, Perimeter Statistics) examined the reformatted Landsat Computer Compatible Tape (CCT) and used a decision criterion to classify each pixel as being either water or nonwater in content. In the current instance, the decision criterion for open surface water was based on water's uniquely low apparent radiance in a near-infrared waveband (MSS7, 0.8 to 1.1 μm). The program then recognized individual water pixels as small ponds and clusters of water pixels as larger ponds and lakes. Subsequently, the geographic position (in UTM coordinates), the area, and the perimeter (land/water edge) of each water feature were computed. The results of these computations, with the data for each pond appearing as a separate record, were then repeated in the computer's output stream on cards and/or magnetic tape.

The pond data records derived from APSTAT occurred as a series of data files and within a file in a sequence by increasing scan line count and increasing pixel count along any scan line. As a convenience for subsequent data editing or information extraction we felt it essential to order the pond data records in a logical sequence. Consequently, we utilized a software program known as SORT. This utility program was available through the University of Michigan Terminal System for arranging records from one or more data sets to form a single data set ordered on one or more attributes of the data. In the present situation the program permitted the merging of multiple data sets (the result of the utilization of multiple Landsat files and CCT's) and the ordering of pond data records in a north to south progression based upon the UTM coordinate system. The ordered output records were stored on magnetic tape.

Program POSORT (Post-Sort) was then utilized to: (1) edit the pond data records based upon specified spatial bounds; (2) compute the area of the bounded space (i.e., the study area); (3) list the ponds occurring within the bounded space; and (4) summarize the frequency of pond occurrence based upon certain size and perimeter criteria. The program was especially written to handle the type of data which resulted from the SORT program and which were unique to this study effort. Basically program POSORT allowed the editing of data so that only information relative to ponds occurring within FWS Survey Stratum 46 were analyzed, and it further permitted the substratification of these data. In this context, the program was able to handle a geographic space defined by a closed polygonal figure having as many as 50 vertices. The polygon was specified to the computer in terms of UTM coordinates corresponding to these vertices.

2.3.3 RESULTS

A result of the processing described above has been thematic maps of surface water for a portion of FWS Stratum 46. These maps, in photoreduced form, are shown here in Figures 10 and 11.

Summaries of pond data for the May (breeding season) and July (brood season) surveys were obtained from the POSORT program. These summaries included: 1) pond frequency by size class; and 2) shape

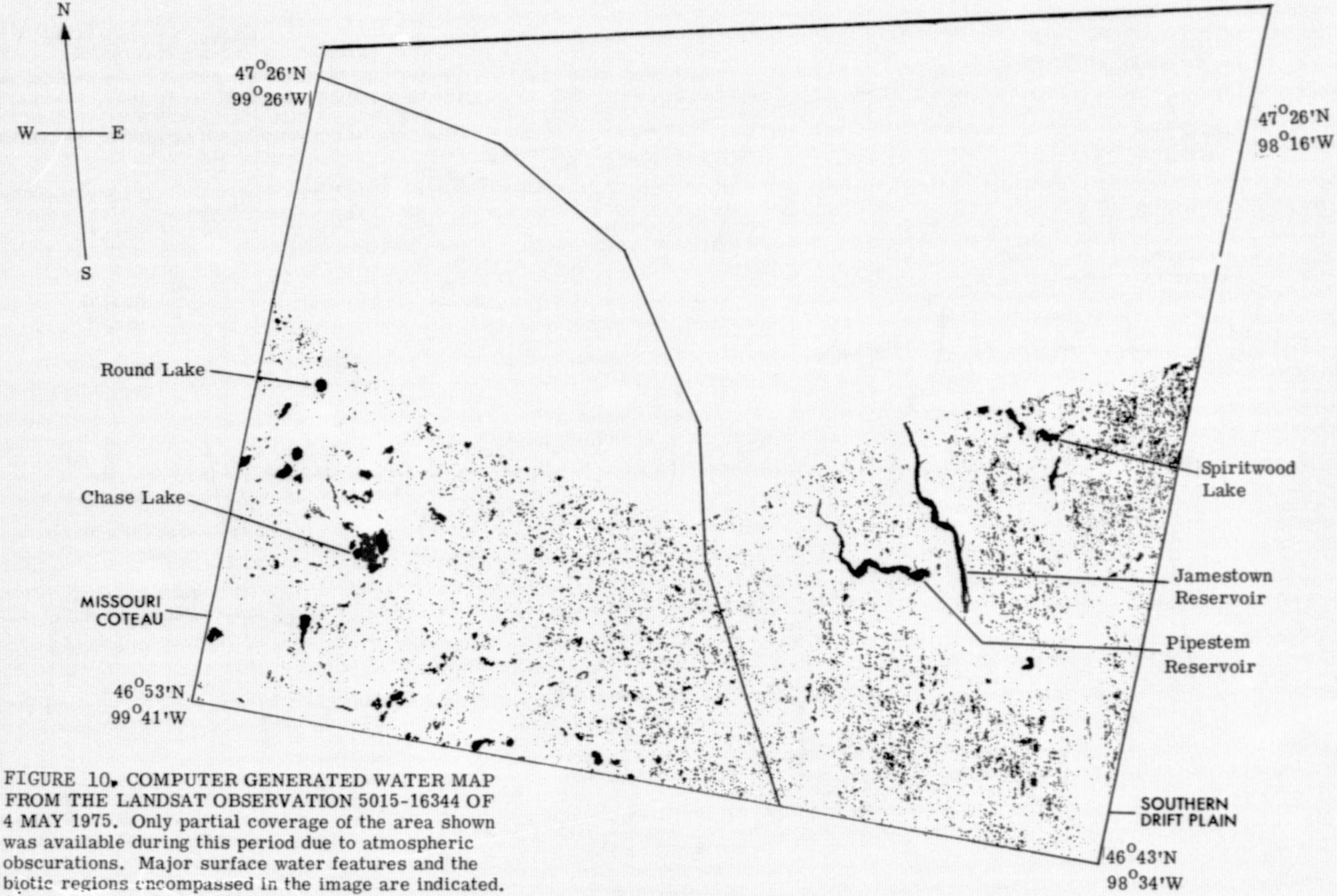


FIGURE 10. COMPUTER GENERATED WATER MAP FROM THE LANDSAT OBSERVATION 5015-16344 OF 4 MAY 1975. Only partial coverage of the area shown was available during this period due to atmospheric obscurations. Major surface water features and the biotic regions encompassed in the image are indicated. Approximate scale - 1:500,000.

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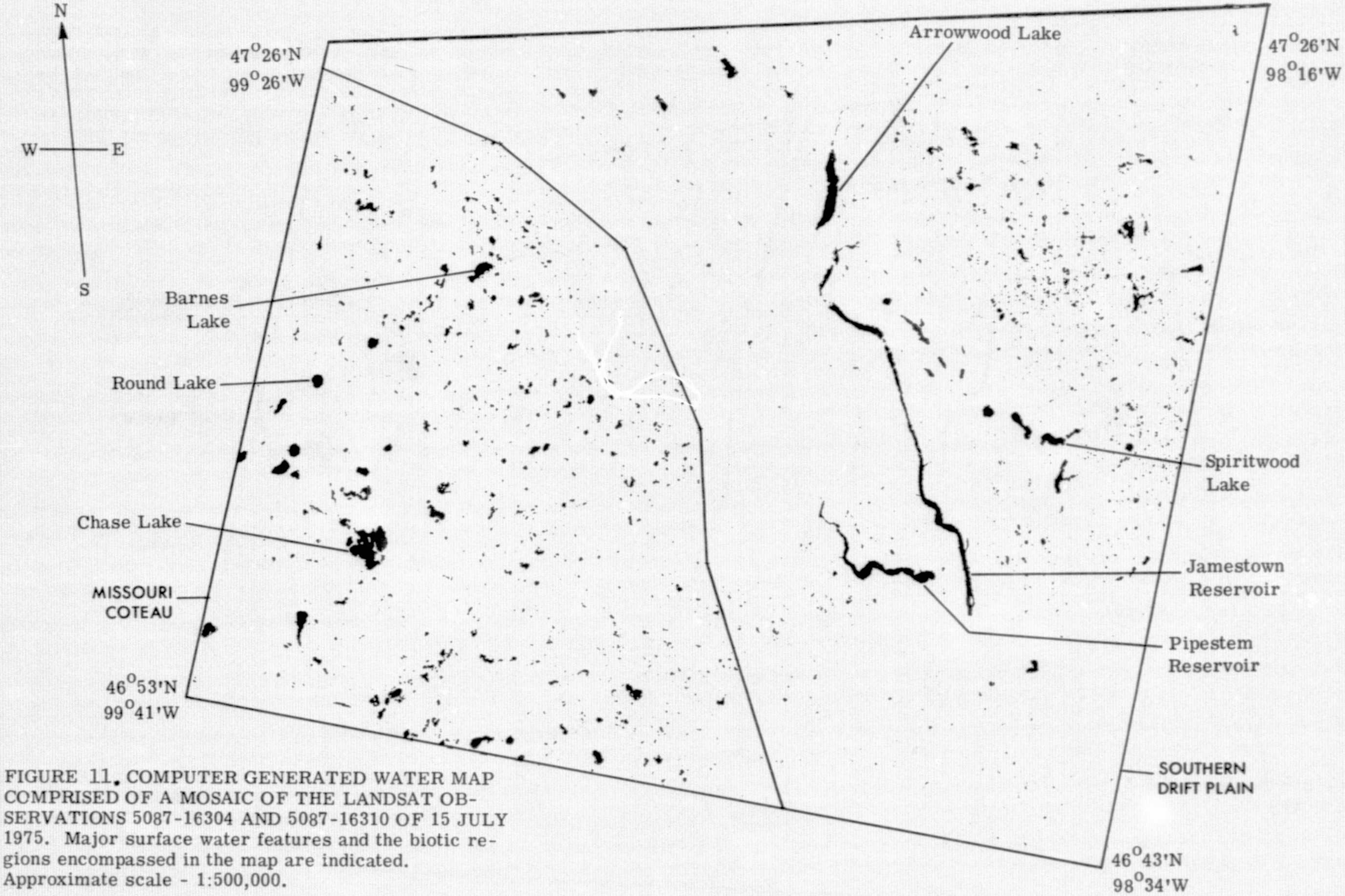

FIGURE 11. COMPUTER GENERATED WATER MAP COMPRISED OF A MOSAIC OF THE LANDSAT OBSERVATIONS 5087-16304 AND 5087-16310 OF 15 JULY 1975. Major surface water features and the biotic regions encompassed in the map are indicated. Approximate scale - 1:500,000.

factor frequency. Totals of 58,650 and 18,213 water features respectively, were observed for each of these surveys. Figure 12, derived from the POSORT output, illustrates pond size frequency and the seasonal (i.e., May to July) change in pond numbers for Stratum 46 as a whole.

2.3.3.1 ANALYSIS OF POND DATA (1972-1975)

One of the principal potential advantages of data collected by earth-orbiting satellites is that the data are collected repetitively. Such data furnish the possibility of monitoring trends that occur over time. Since we have processed Landsat data over the period from 1972 through 1975, we will now take the opportunity to briefly review and compare that information.

Figures 13 through 18 are photo-reduced reproductions of computer-generated water recognition maps for each of 6 Landsat observations which have been analyzed prior to this study (see Figures 10 and 11 for 1975 observations). Each map is presented at an approximate scale of 1:500,000. The fact that the north-south map direction is not orthogonal to the east-west direction is a manifestation of the earth's rotation during the period the satellite was scanning the scene. As noted previously, we have not precisely scaled nor skew corrected the data for presentation in map form. Had map overlays been necessary for the end analysis, it would have been practicable to have incorporated these geometric adjustments. In the case of Figures 10, 11 and 15 through 18, the surveyed area was identical in each instance. The substrata areas of Figures 13 and 14 were reduced in size due to limited availability of usable data.

Marked variations in pond and lake numbers and distributions are apparent in the maps. In particular, the observation of 14 June 1974 (Figure 17) shows an abundance of surface water throughout both the Coteau and Drift Plain substrata, as discussed in a previous report (Work and Rebel, 1976). At the other extreme, the observation of 7 July 1973 (Figure 16) depicts a low level in the number of surface water features for the period covered by this study. Dramatic changes

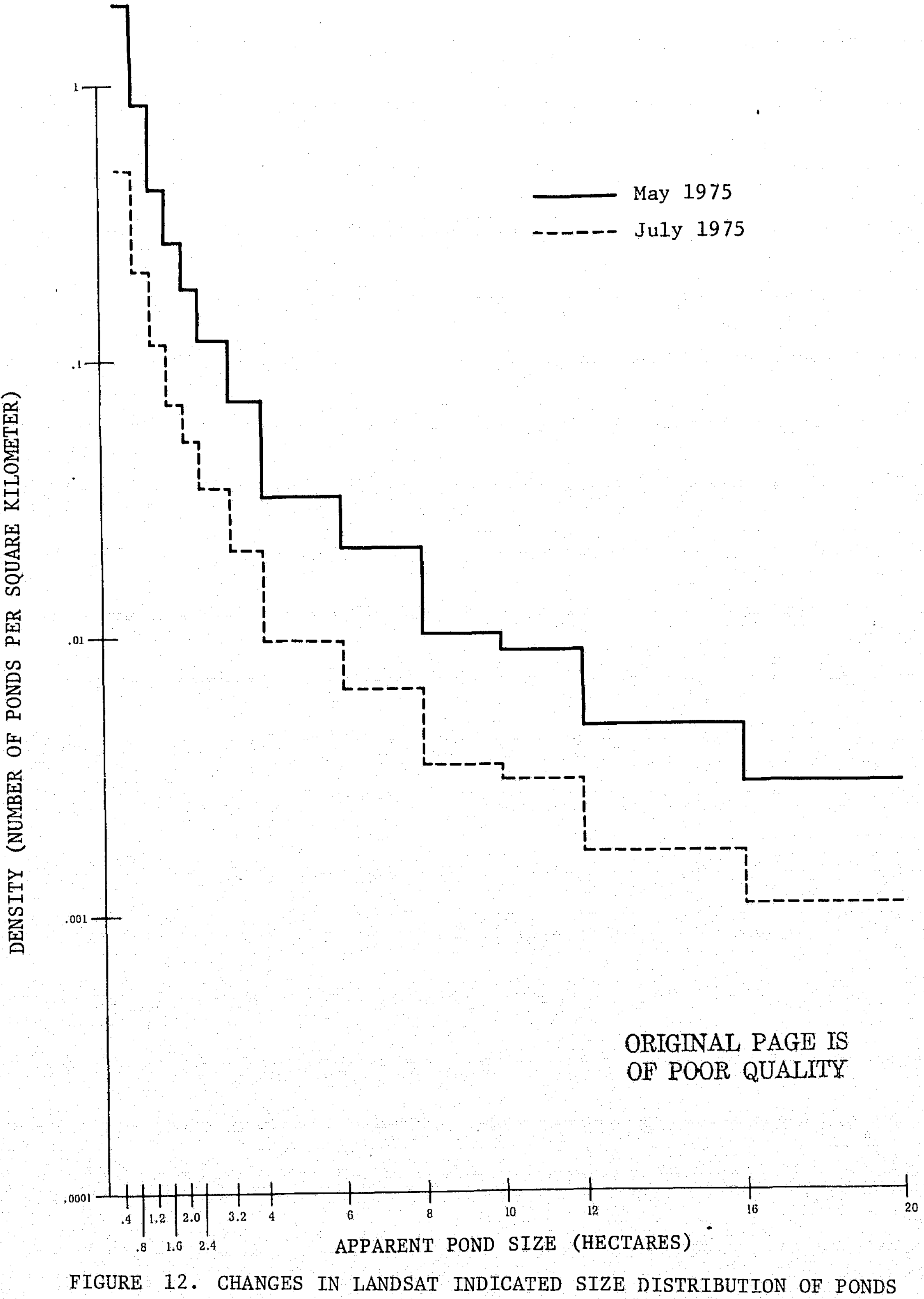

FIGURE 12. CHANGES IN LANDSAT INDICATED SIZE DISTRIBUTION OF PONDS IN USFWS STRATUM NUMBER 46 AS OBSERVED BETWEEN THE BREEDING AND BROOD SEASONS OF 1975. Data within the various pond size increments have each been normalized to a nominal one-hectare increment.

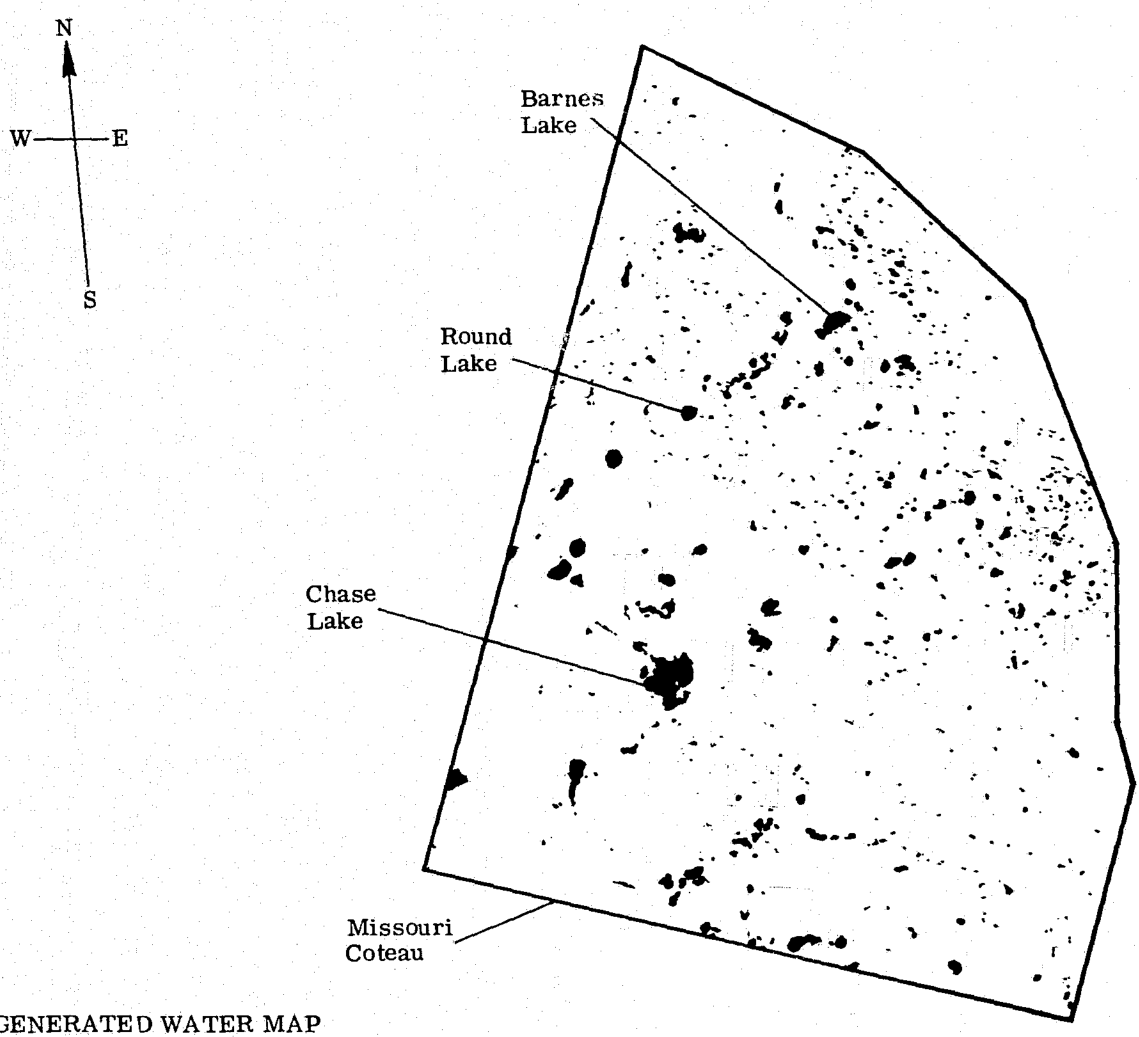

Figure 13. COMPUTER GENERATED WATER MAP FROM LANDSAT OBSERVATION 1008-16594 OF 31 JULY 1972. Major surface water features and the biotic region encompassed in the map are indicated. Approximate scale — 1:500,000

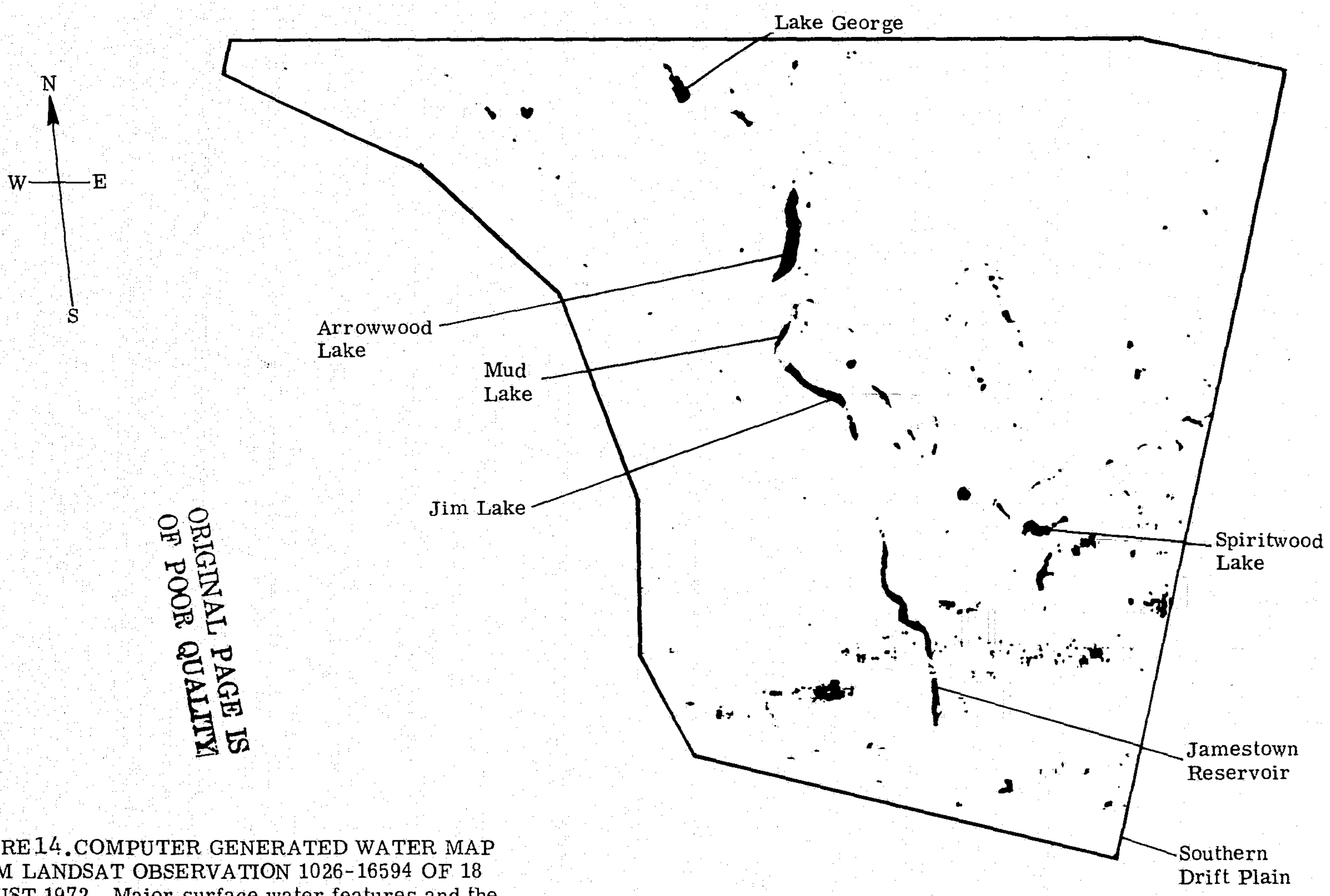

FIGURE 14. COMPUTER GENERATED WATER MAP FROM LANDSAT OBSERVATION 1026-16594 OF 18 AUGUST 1972. Major surface water features and the biotic region encompassed in the map are indicated. Approximate scale—1:500,000

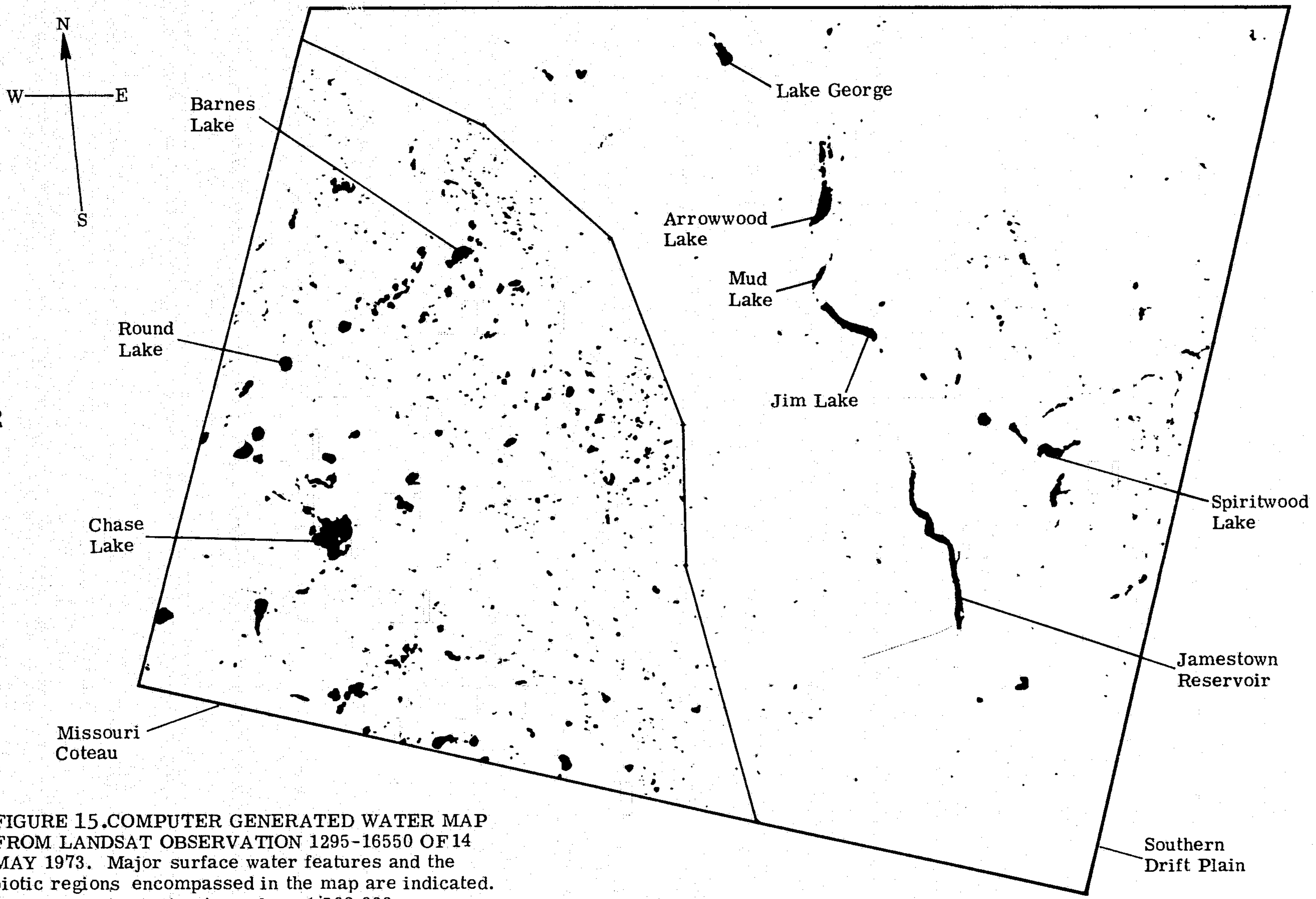

FIGURE 15.COMPUTER GENERATED WATER MAP FROM LANDSAT OBSERVATION 1295-16550 OF 14 MAY 1973. Major surface water features and the biotic regions encompassed in the map are indicated. Approximate scale — 1:500,000

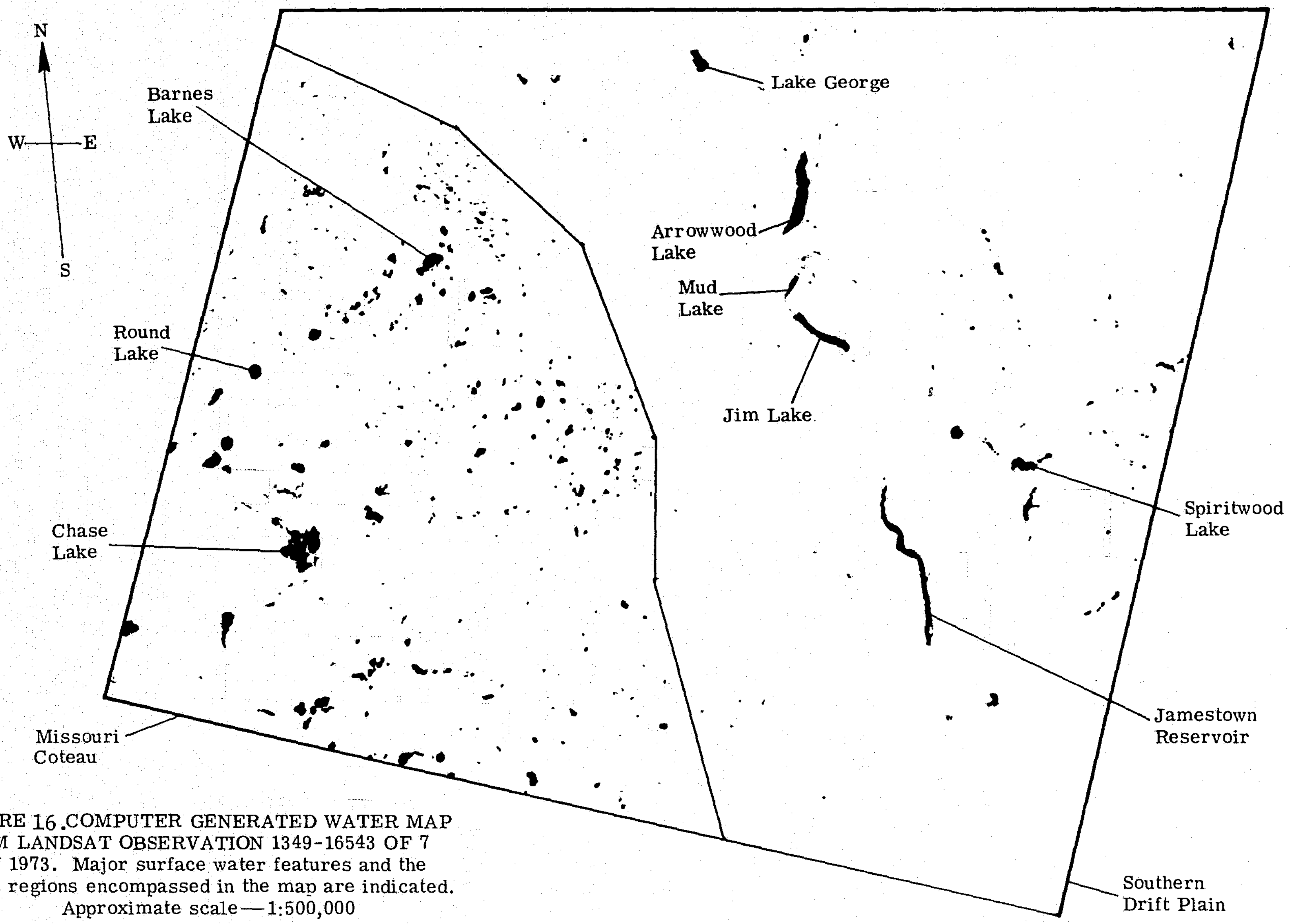

FIGURE 16. COMPUTER GENERATED WATER MAP FROM LANDSAT OBSERVATION 1349-16543 OF 7 JULY 1973. Major surface water features and the biotic regions encompassed in the map are indicated. Approximate scale — 1:500,000

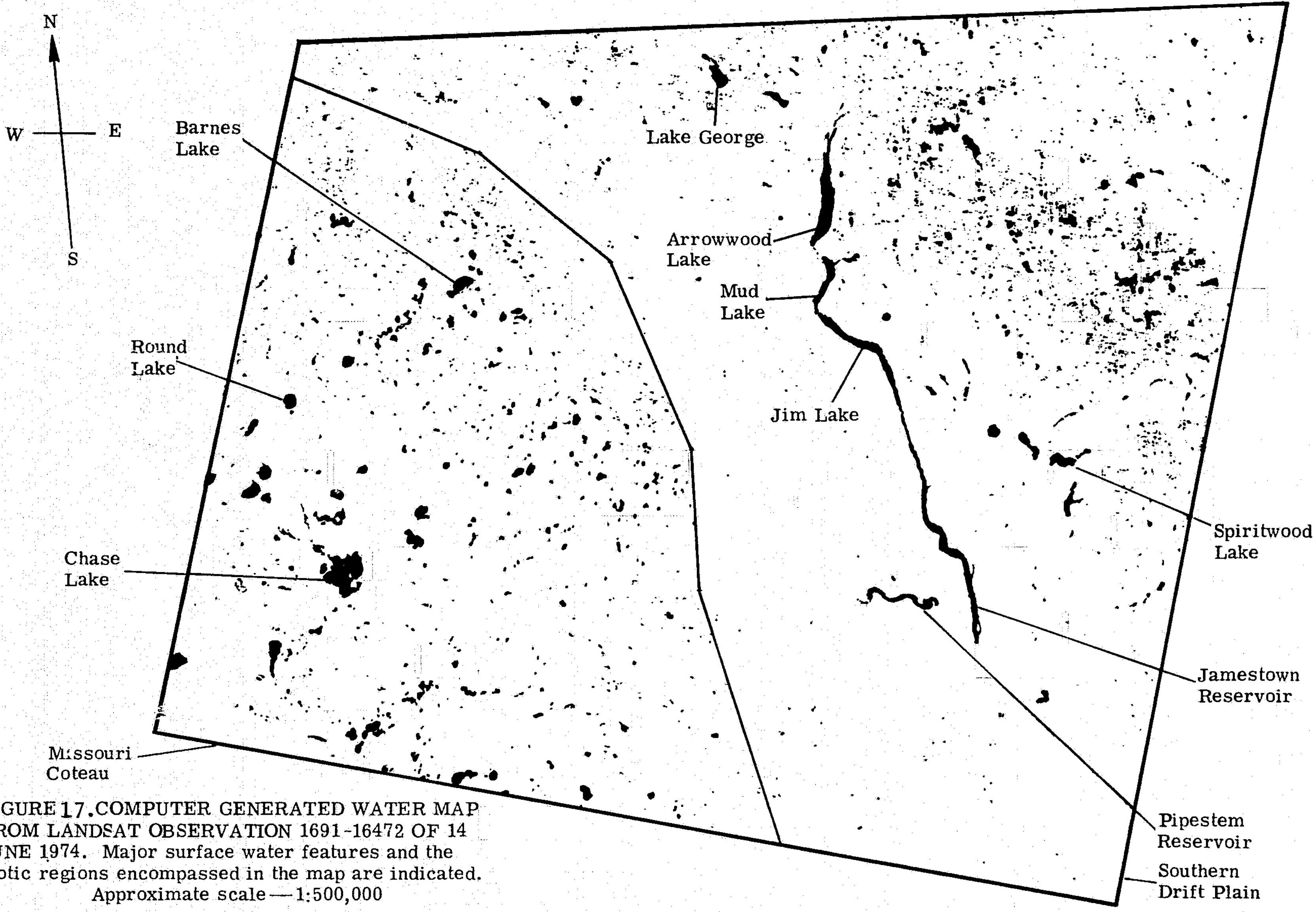

FIGURE 17. COMPUTER GENERATED WATER MAP FROM LANDSAT OBSERVATION 1691-16472 OF 14 JUNE 1974. Major surface water features and the biotic regions encompassed in the map are indicated. Approximate scale — 1:500,000

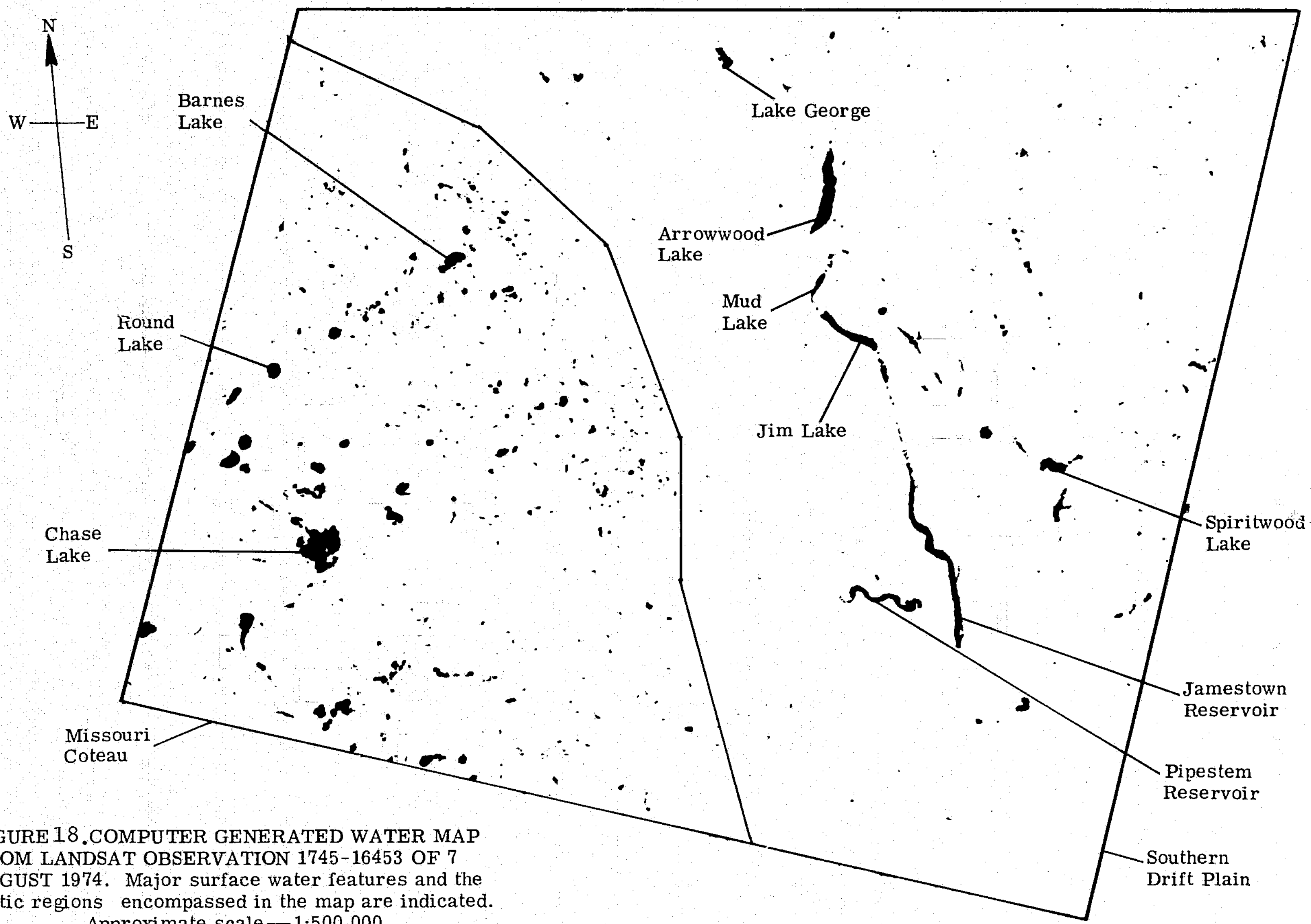

FIGURE 18. COMPUTER GENERATED WATER MAP FROM LANDSAT OBSERVATION 1745-16453 OF 7 AUGUST 1974. Major surface water features and the biotic regions encompassed in the map are indicated. Approximate scale — 1:500,000

in certain large water bodies are also readily apparent from the maps. For example, Pipestem Reservoir (Figures 17 and 18) is an impoundment which was completed in early 1974 and thus does not appear on earlier maps. Arrowwood Lake is also a controlled impoundment which apparently was partially drained during the observation of 14 May 1973 (Figure 15).

Precipitation is one of the main factors affecting surface water conditions. Figure 19 presents a 4-year summary of rainfall patterns as observed at a research station operated by the Northern Prairie Wildlife Research Center near Woodworth, North Dakota. Certain precipitation patterns of this figure are manifested in the surface water maps just presented and in the statistics tabulated from this study. Generally, the spring and summer of 1973 were relatively dry, and consequently pond numbers during this period were small. The heavy rains of September 1973 came too late to affect the observations of that year. In 1974, the spring and summer rains were heavy, producing the increased prevalence of the water during the 14 June 1974 observation.

In 1975, March blizzards deposited up to 51+ cm (20+ inches) of snow over parts of the state (Pospichal, 1975a). This, in addition to April rains, caused flooding in many areas of North Dakota. In Stratum 46, there was abundant sheet water present in May. In late June, there was greater than average precipitation, which led to an inordinately large number of water bodies remaining in July (up 60% from the average).

Neither the thematic maps of surface water (ponds) nor an analysis of precipitation patterns can provide a truly quantitative description of habitat conditions. Such a characterization is feasible, however, by use of scanner data in a tape recorded format which can be analyzed by a digital computer. Figure 20 summarizes changes in the size distribution of ponds in the Coteau as observed in the interval between the waterfowl breeding seasons of 1972-1975, based on information available from computerized analyses.

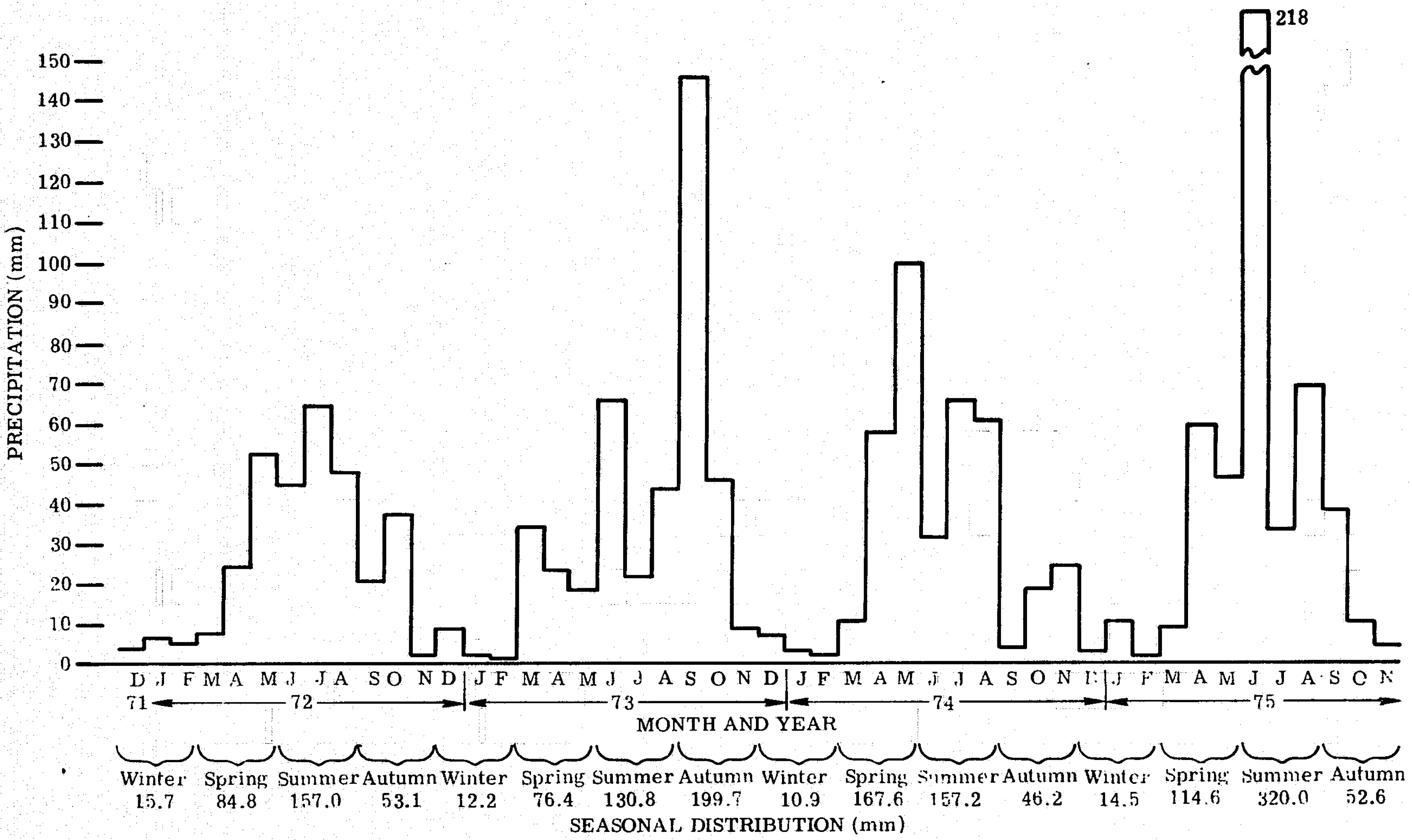

FIGURE 19 . MONTHLY AND SEASONAL PRECIPITATION AT WOODWORTH, NORTH DAKOTA FOR THE PERIOD DECEMBER 1971 THRU NOVEMBER 1975. (Plotted from unpublished data, U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center.)

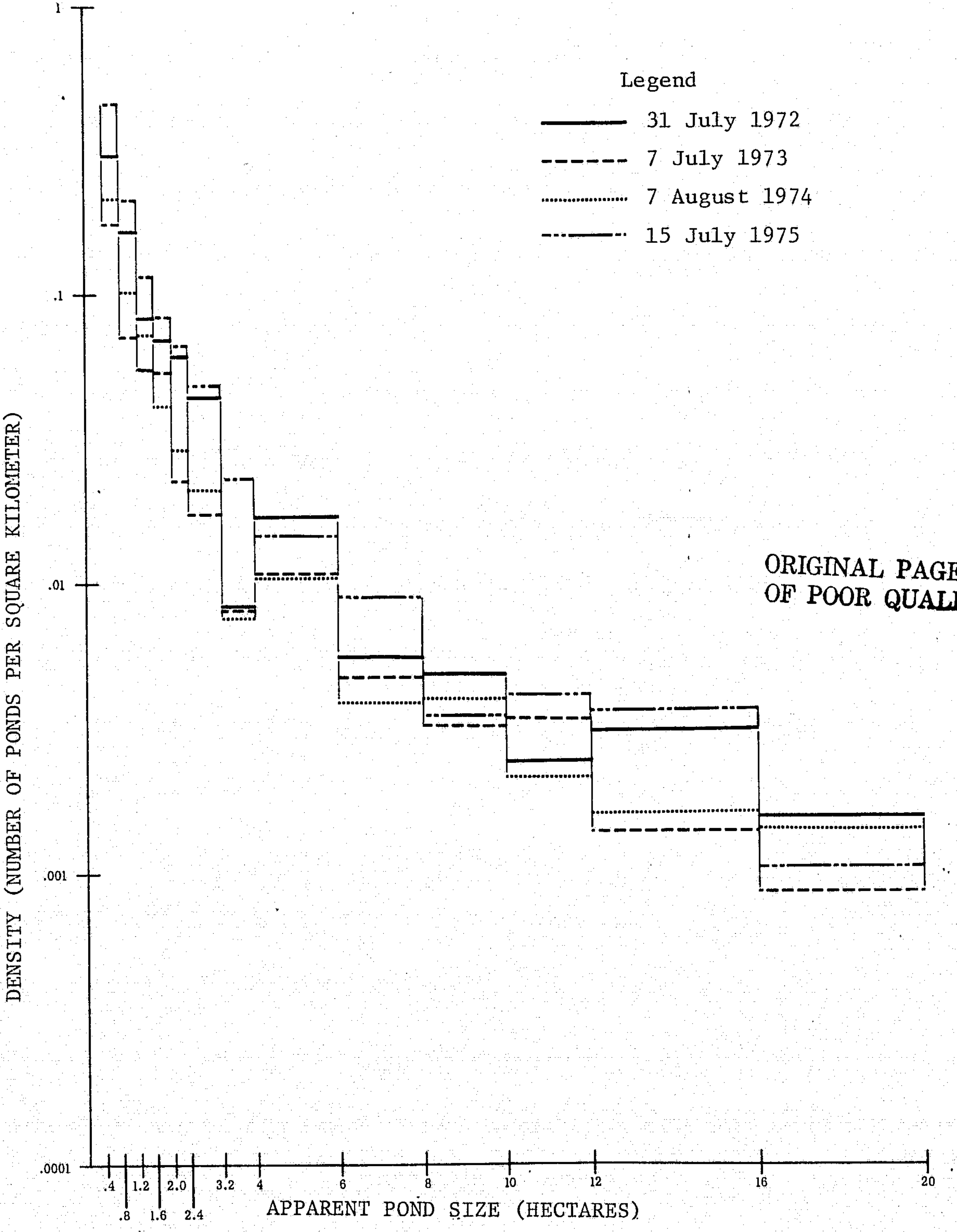

FIGURE 20. CHANGES IN LANDSAT INDICIATED SIZE DISTRIBUTION OF PONDS IN THE COTEAU SUBSTRATUM AS OBSERVED ANNUALLY DURING THE WATERFOWL BROOD SEASON, 1972-1975. Data within the various pond size increments have each been normalized to a nominal one-hectare increment.

2.3.3.2 COMPARISON OF LANDSAT AND FWS POND ESTIMATES (1972-1975)

We have compared our Landsat pond estimates to pond estimates derived from the annual waterfowl breeding population and production surveys conducted by the U.S. Fish and Wildlife Service for the period 1972-1975. As a basis of comparison, data pertaining to FWS Survey Stratum 46 which includes the intensive study area examined in previous investigations were considered. As can be seen in Figures 21 and 22, the Landsat estimates tend to track the FWS estimates, but are considerably lower. Stratum 46 (36,876 km^2) overlaps both the Coteau (43 percent) and the Drift Plain (57 percent). Pond densities obtained from the two substrata within our 6200 km^2 study area* were multiplied by appropriate area weighting expansion factors in order to approximate the number of ponds LANDSAT sensors would detect in an area equivalent to FWS Survey Stratum 46. These results (a substantial Landsat underestimate) suggest that a great number of prairie ponds are less than 0.4 hectare (1 acre) in size, the spatial resolution of Landsat data. The predominance of small ponds in the prairie pothole region is well known. For example, based upon observations in northeastern South Dakota, Drewien and Springer (1969) noted that 73 percent of the wetland depressions were less than 0.4 hectare, and Millar (1969) working at three widely scattered sites in Saskatchewan found that between 82.0 and 87.5 percent of the basins were 0.4 hectare or less in size.

Table 2 presents the FWS and Landsat pond estimates for Stratum 46 for the years 1972-1975. Note that the percent of FWS counts represented by Landsat counts remained fairly constant over the period from 1972-1974, having an average value of 18.8 percent. During the 1972-1974 period, an average expansion factor of approximately 5.3 would be necessary to make Landsat pond counts equivalent to FWS pond estimates. If such an expansion factor had been applied, the corrected Landsat estimates would have been within -5, -8, +6, +22, and -18 percent,

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*The Intensive Study Area occupies about 17 percent of Stratum 46. It is an area for which complete coverage was obtained for 1972-1975 data.

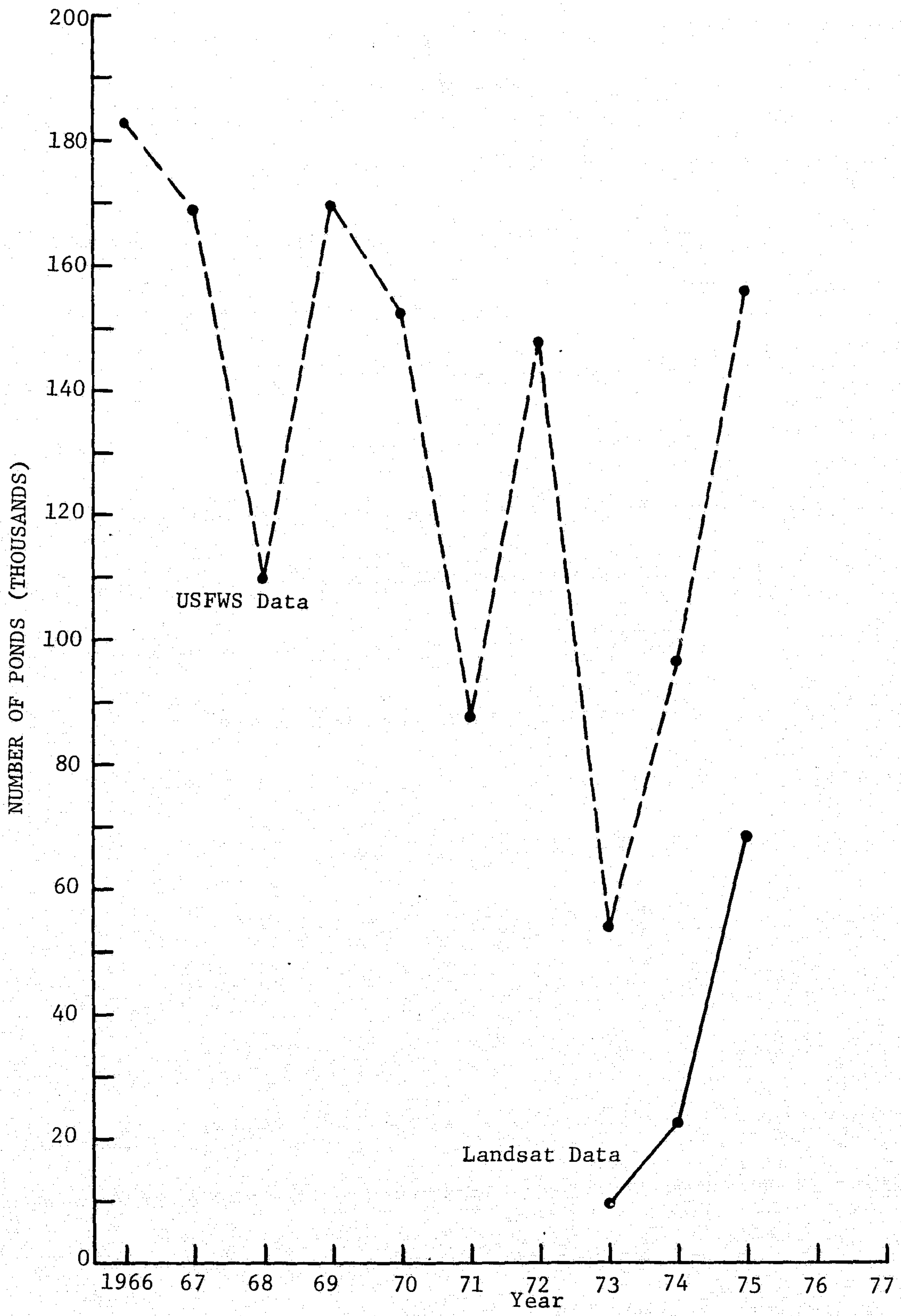

FIGURE 21 . NUMBER OF MAY (BREEDING SEASON) PONDS ESTIMATED FOR STRATUM 46 AS DERIVED FROM AERIAL SURVEY DATA OF THE U.S. FISH AND WILDLIFE SERVICE AND FROM LANDSAT DATA.

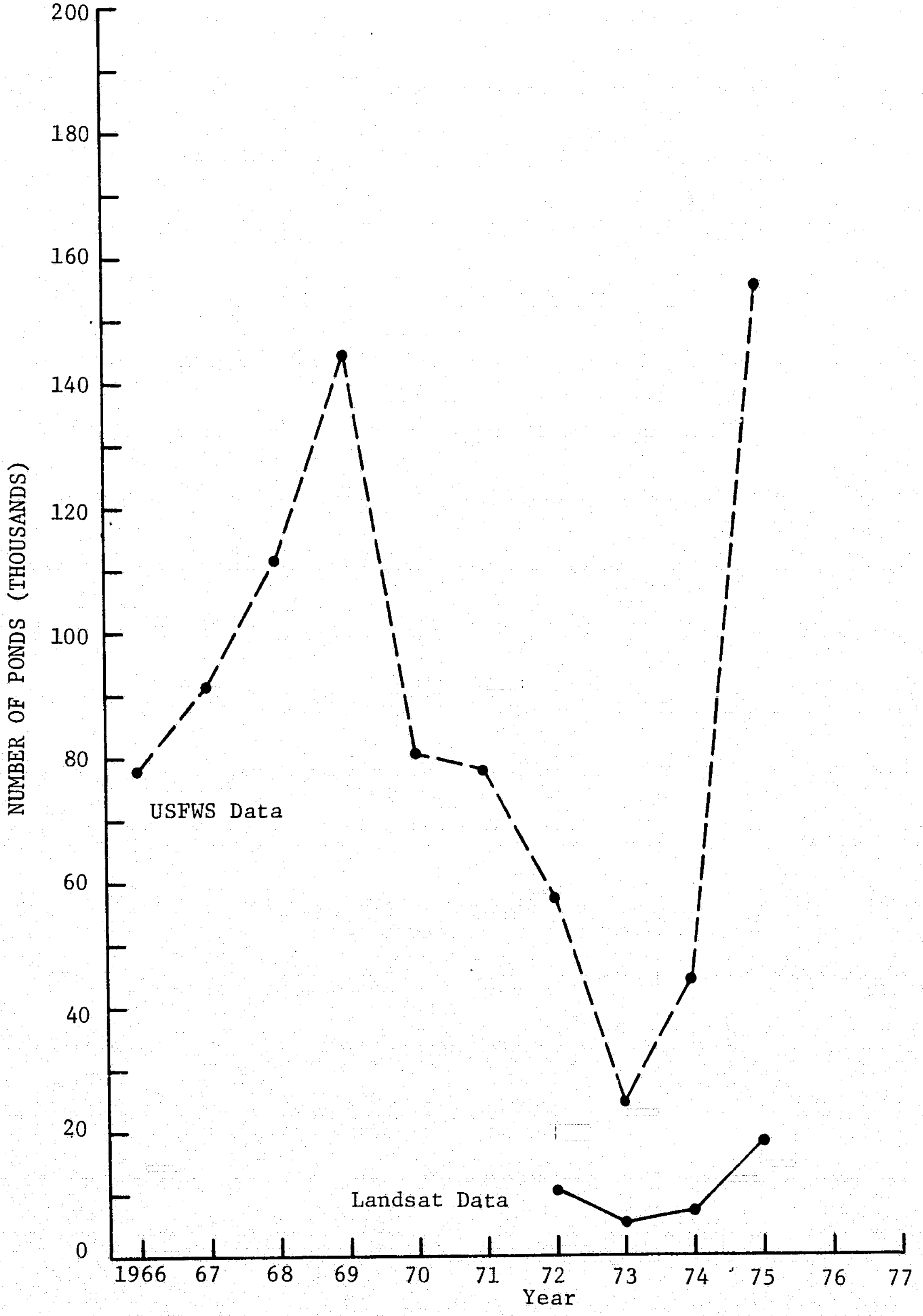

FIGURE 22. NUMBER OF JULY (BROOD SEASON) PONDS ESTIMATED FOR STRATUM 46 AS DERIVED FROM AERIAL SURVEY DATA OF THE U.S. FISH AND WILDLIFE SERVICE AND FROM LANDSAT DATA.

TABLE 2. COMPARISON OF LANDSAT DERIVED AND FISH AND WILDLIFE SERVICE ESTIMATES OF SURFACE WATER FOR STRATUM 46, NORTH DAKOTA, 1972-1975.

Survey Period	Pond Numbers for Stratum 46 per Estimate from U.S. Fish & Wildlife Service (FWS) Survey Data	Pond Numbers Obtained from Landsat Survey Data and After Extrapolation to an Area Equivalent to Stratum 46*	Percent Pond Numbers (Landsat Data Relative to FWS Data)
Brood Season 1972	57,500	10,300	18
Breeding Season 1973	54,000	9,400	17
Brood Season 1973	24,500	4,900	20
Breeding Season 1974	96,600	22,200	23
Brood Season 1974	44,500	6,900	16
Breeding Season 1975	155,800	68,600	44
Brood Season 1975	155,500	18,500	12

*New information has been used to normalize and correct these numbers. Consequently, there are slight differences between these figures and those reported in Work and Rebel, 1976.

respectively (an average of 11.8%, sign ignored) compared to the FWS survey estimates.

However, 1975 Landsat pond estimates are quite anomalous in terms of the proportion of the corresponding FWS estimates they represent. The percentages of 44% (May) and 12% (July) were checked by comparing them with the ratio of the Landsat and aircraft pond counts from the double sample. The Landsat double sample estimates were 45% and 13%, respectively, of the aircraft counts, which are assumed to be without error. This result adds credibility to the validity of the proportions of FWS counts represented by Landsat counts.

The reason for the anomalous nature of the 1975 Landsat estimates is not clear at this time. There are several possibilities. During May, a vast amount of sheet water was present throughout the stratum. This sheet water in many instances was enumerated by Landsat, but typically such ephemeral wetlands are not tabulated by the FWS observers. During July 1975, many wetland basins which would not normally contain water at this time of year did in fact contain water because of the late June rains. Many of these basins would not have been tabulated by Landsat because of their small size and/or because of emergent vegetation which would have developed by this date and which occluded the water to the view of the Landsat sensor.

Another possibility for the anomalous nature of the 1975 Landsat pond counts is the fact that the absolute timing of the Landsat data, and its timing relative to the FWS estimates varies from year to year and season to season. In addition, the 1975 Landsat counts were made on a larger area than the previous counts, thereby possibly representing different overall conditions.

These explanations of the anomalous nature of the 1975 Landsat pond counts may or may not be correct. However, the important conclusion is that Landsat counts cannot be assumed to be the same proportion of FWS counts under all conditions. In other words, the correct proportion may have to be determined for each estimate, perhaps by double sampling.

2.4 AIRCRAFT WATER MAPPING

Aircraft water mapping was performed as part of a double sample. This section discusses the result of that activity.

2.4.1 PROCEDURE

NASA aircraft MSS data were collected as nearly synchronous with overflights by Landsat as possible. The amount of aircraft data collected was small, due partly to the difficulty and cost of obtaining aircraft data over large areas in a timely fashion. Landsat data were used for a census of the bulk of Stratum 46, and the aircraft data were used as a double sample of a smaller area within the stratum.

Development of a sampling design occurred at the onset of this program. We chose to position the aircraft flight lines coincident with flight transects which have traditionally been used by the FWS in the conduct of their low altitude May and July surveys of birds and ponds. The existing FWS transects lie in the east-west orientation and amount to a cumulative lineal length of 1738 km (1080 miles) for the Stratum as a whole. For this particular investigation this cumulative lineal distance was divided into 180 units each 9.66 km (6 miles) long and 1.6 km (1 mile) wide. Eighteen sample units were randomly selected without replacement from the 180 units available. Prior to sample selection the Stratum was divided into two substrata units based upon two physiographic regions which existed within the stratum (i.e., a coteau and a drift plain feature). The sample used in this investigation was allocated between substrata based on the relative areas of the two substrata. The NASA aircraft were then directed to fly each of the 18 sample units at a ground to air height of 1524 m (5000 feet). After data retrieval, each sample unit was considered to be a rectangle 9.66 km long by 1610 m (5280 feet) wide, the latter dimension centered on the specified transect line. Thus each sample unit consisted of an area 15.55 km^2 (6 mi^2) in extent, and the 18 sample units summed to a total area of 279.9 km^2 (108 mi^2), or approximately a 1% sample of the total Stratum 46 area. Information on surface water features was then extracted from the aircraft data for each of the 18 sample units.

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(Three samples were unusable in the May data due to cloud cover on the Landsat data).

Generating pond data equivalent to Landsat data required delineating the sample areas on the geometrically corrected aircraft scanner data, which required a determination of average along-track and across-track scale. The UTM coordinates of these sample areas had to be precisely determined so that equivalent Landsat areas could be located for determination of number of ponds. Problems of mismatches of availability of Landsat and aircraft data had to be dealt with. It was not always possible to use sample unit areas exactly 6 mi^2 in extent, for example, as intended in the sample design.

Rules used for determing whether to include a water body in the pond count from imagery interpretation were equivalent to those used by the FWS in their aerial transect surveys, insofar as possible.

2.5 DOUBLE SAMPLING

This section describes the use of aircraft data in conjunction with Landsat data to make estimates of ponds present in FWS Stratum 46. The accuracy and cost-effectiveness of the technique are discussed.

2.5.1 LANDSAT/AIRCRAFT POND COMPARISON

Information on surface water features was extracted from the previously processed Landsat data so as to correspond specifically with each of the units sampled by the aircraft. The retrieval of the Landsat sample unit data was accomplished with the software program POSORT discussed previously. It was our intention to develop correction factors based upon a comparison of the two data sets and with which the large body of Landsat data could be adjusted. This comparison was made with a linear regression analysis, the results of which are given in Figures 23 and 24 for data of May and July, respectively. For the regression fitting of May pond data, an outlier test by Grubbs (1950) resulted in the rejection of one data point. With this one outlier omitted the coefficients of determination (R^2) were

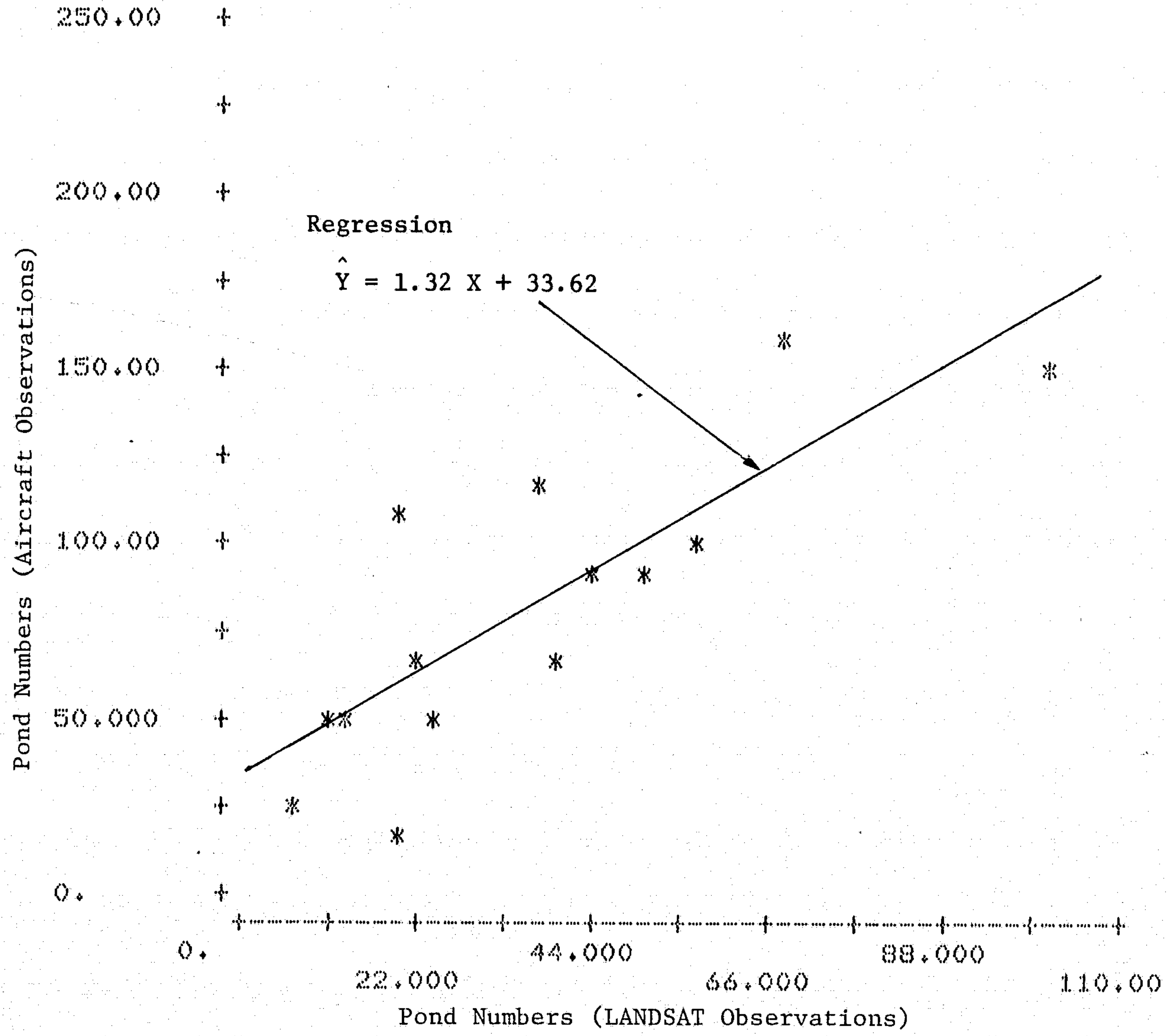

Figure 23. Sample linear regression of pond numbers (from aircraft data) on pond numbers (from LANDSAT data) for May 1975.

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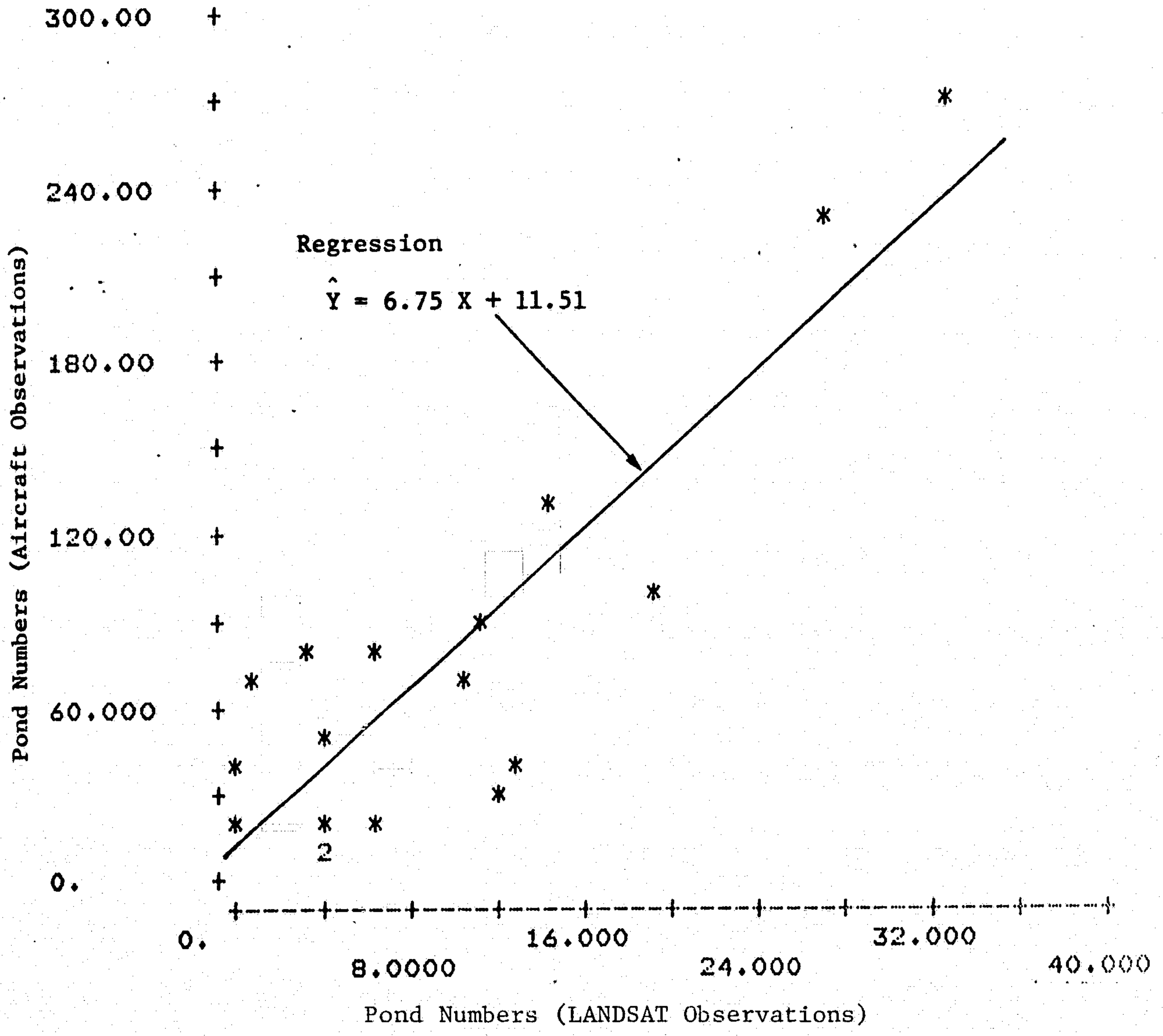

Figure 24. Sample linear regression of pond numbers (from aircraft data) on pond numbers (from LANDSAT data) for July 1975.

0.65 and 0.74 for the data of May and July, respectively. Standard statistical procedures (Cochran, 1953) were used to adjust the Landsat pond counts to actual pond numbers based on the regression relationships shown in figures 23 and 24.

The specific regression expansion formula used was

$$\hat{Y}_{pop} = N \; [\bar{y} + b \; (\bar{X} - \bar{x})]$$

where $\hat{Y}_{pop}$ = estimate of population number of ponds for whole population

$\bar{y}$ = sample mean of aircraft pond counts

$\bar{x}$ = sample mean of Landsat pond counts

$\bar{X}$ = population mean of Landsat pond counts per "sample units"

N = number of sample units within the population

b = slope of the regression curve ($\hat{y} = a + bx$) between individual corresponding aircraft (dependent) and Landsat (independent) pond counts.

The double-sample corrected Landsat pond numbers for Stratum 46 are 168,813 (May) and 150,565 (July). These figures are 108 and 97 percent, respectively, of FWS pond number estimates which were based upon visual observations made from low flying aircraft. It must be emphasized that this is a comparison of one estimate with another, both of which are subject to error.

The approach to estimating pond population which we have implemented is to use a small Landsat/aircraft double sample relation to correct a total Landsat enumeration (census), which we suspected from previous work on the intensive study site produced a substanital underestimate of the pond population. The value of the complete Landsat census, however, is that it gives a better representation of the characteristics of the entire population than a small sample. The degree to which this is true is indicated by the difference between the Landsat indication of the average number of ponds determined per "6 mi^2 area" based on a total enumeration, and the Landsat estimate based on the 1% sample of 6 mi^2 sample units. For both May and July data this difference is substantial (Table 3). It can be seen that there is a 22.6 percent difference for May data and a 19.1 percent difference for July data.

If the Landsat total enumeration is assumed to have the same accuracy (in terms of bias) as the Landsat 1% sample, the data in Table 3 suggest that the Landsat total enumeration has improved the estimate of total number of ponds in the stratum over that which could be obtained from the 1% sample by about 20 percent. This improvement could be partly due to the fact that the Landsat sample was constructed along FWS transects, and hence was not truly random. It also could be due to sampling error, which suggests that the 18 sampling units comprising a 1% sample of the total area such as we used may not be sufficient to precisely characterize a population as variable from sample unit to sample unit as this pond population apparently is (Table 4). Perhaps a larger number of smaller sample units would improve the precision of the estimate. The FWS aerial transect estimates are apparently based on more sample units (sixty 18 mile segments) with less area per sample unit (2.25 mi^2 per segment).

In order to make a double sample adjustment of a Landsat pond count, the sample must be made at nearly the same time as the Landsat data. As an illustration of this, if the July 1975 double sample adjustment were applied to the May 1975 Landsat data, an estimate of 483,172 ponds would result, which is over three times the FWS estimate of number of ponds for May.

For the same reason, May and July 1975 correction factors cannot be applied to Landsat estimates of other years. Therefore, comparisons of adjusted Landsat pond counts and resulting inferences of duck production cannot be made on any data other than May 1975, the only data for which we have produced an aircraft double sampling.

TABLE 3. DIFFERENCE BETWEEN LANDSAT AVERAGE COUNTS PER 6 MI^2 UNIT BASED ON TOTAL ENUMERATION AND BASED ON A 1% SAMPLE OF 6 MI^2 SAMPLE UNITS.

	Total Enumeration = $\overline{X}$	1% Sample = $\overline{x}$	% Difference $\left(\frac{\overline{X}-\overline{x}}{\overline{x}}\right)$
May	28.46	36.79	22.6
July	7.69	9.50	19.1

TABLE 4. STANDARD DEVIATION (σ) AND COEFFICIENT OF VARIATION (σ/m) OF LANDSAT 1% SAMPLE POND COUNTS IN MAY AND JULY 1975.

	MAY		JULY	
	σ	σ/m	σ	σ/m
Landsat	26.28	0.714	9.17	0.965

3

MULTITEMPORAL LANDSAT TERRAIN MAPPING

Previous sections of this report were concerned with mapping and detecting changes in open surface water. This section is concerned with mapping various scene classes. Compared with changes in open surface water, the changes in vegetation tend to occur more slowly. Monitoring condition and change in vegetation is important for analyzing long term habitat quality and waterfowl carrying capacity.

In previous work we have found Landsat classification of terrain types was less accurate than desired for certain classes of materials. For example, we had some difficulty differentiating small grains and shallow marsh with July 1973 data (Work, et al., 1974).

In an attempt to improve classification performance we decided to implement multitemporal Landsat data processing. Since July data had previously been identified as a near optimal time for classification of most terrain classes, we searched for another time of year (phenological stage) which would facilitate differentiation of classes which proved troublesome with only July data.

We did this by examining ground truth designations of terrain classes on aerial photographs, and by extrapolating these identifications to Landsat color IR composites. Twelve color IR composites were examined, encompassing the time from May to October. On the basis of this analysis it was concluded that a September data set would best complement a July data set for differentiation of terrain classes. This result is in agreement with analyses made on aerial oblique photographs taken over a period of several years.

The two specific dates which were chosen for multitemporal processing were 15 July 1975 (observation 5087-16304) and 16 September 1975 (observation 2237-16415). The procedures followed in processing and analyzing these two dates of Landsat data are described in the following sections.

3.1 PROCEDURE

The procedures necessary to process the Landsat data for multitemporal classification are indicated in Figure 25. The data were initially reformatted in order to make them compatible with the ERIM computer system. The next procedure was to rotate and scale the data so that the two dates of Landsat data were oriented north-south, were georeferenced to the same coordinate system, and had equivalent scales. The georeference system used for both data sets was the UTM system as indicated on topographic maps of the area. The referencing was done by independently performing a least-squares regression of Landsat pixels with 21 easily identifiable control points on the topographic map for each data set. The resulting regressions resulted in standard errors of estimates of between 14 and 27 meters (less than 1/2 pixel).

Once the Landsat data from the two dates had been georeferenced to the same base map, their relationship to each other was defined. At this point, the two Landsat data sets (4 channels each) were merged so that equivalent pixels from the two dates overlayed each other. The product of this operation was a merged 8-channel Landsat data tape.

Since the separate Landsat dates covered different total areas, there were some pixels from both dates that did not have equivalent pixels from the other data. These areas in which only 4 channels of information were available were edited out by a program called ADCHAN.

Once the July and September data were temporally merged, procedures for producing a classification map were implemented. The first step was to locate and define "training areas" for the classes of material we wished to differentiate. This was done principally in the region where we had aerial photography on which classes of materials had been identified by field work. Eight-channel temporal-spectral signatures were subsequently determined for each of the identified training areas.

The next step was to try to reduce the number of spectral-temporal channels to use in classification from the 8 available, since processing costs are a function of the number of channels used. In order

FIGURE 25. MULTITEMPORAL PROCESSING - 1975 DATA

NASA Tapes

↓

convert tape 1 (file 1) of July to LIGMALS format (all channels)

↓

convert tape 1 (file 1) of September to LIGMALS format (all channels)

↓

select control points (based on 1:500,000 Landsat images) for July and September (same points)

↓

map control points in MSS7 for July and September; locate in terms of lines and points

↓

regress control points for July (lines and points vs UTMs)

↓

regress control points for September

↓

rotate and scale July

↓

rotate and scale September

↓

map July and September; overlay and compare

↓

MERGE

↓

choose training sets, STAT

↓

STEPL (best channel analysis)

↓

signature analysis (EPLOT, PEC)

↓

ADCHAN (5 channel: $\overbrace{2,3,4}^{\text{JUL}}$ $\overbrace{6,8}^{\text{SEPT}}$)

↓

CLASFY W/WCLAS

↓

map (inkjet)

↓

analysis of results

to determine the optimum subset of 4 channels for classification of the data, a program called STEPL was run. An output of this program is the optimum ordering of channels for best classification and the associated average probability of misclassification that would result as a function of the number of channels used.

Previous experience had indicated that Landsat data are basically 2-dimensional, with highly correlated information in the two visible channels (MSS4, MSS5), and highly correlated information in the two IR channels (MSS6, MSS7). Therefore, we anticipated that the optimum 4 bands would include a visible and an IR band from each of the two Landsat dates. In addition, previous work has shown that generally classification accuracy does not increase appreciably with the addition of more than a total of 4 bands. For these reasons, we decided to pick the optimum 4 spectral-temporal bands for processing. As expected, our analysis of these data (STEPL) indicated these 4 bands included a visible and an IR band from each of the two dates. Specifically, the indicated four optimum spectral-termporal bands were: 15 July MSS5, MSS6 and 16 September MSS5, MSS7. In addition, the incorporation of more spectral-temporal bands showed no appreciable increase in classification accuracy, so our decision to use only four bands seemed warranted.

The signatures were then used to classify a small test portion of the scene which included some of the training area. This test classification revealed several areas that had not been classified as any of the training materials, because the spectral signatures of these areas were significantly different from any of the initial training signatures. Additional signatures were obtained for the unrecognized areas, and were labeled as a result of visual analysis of color IR Landsat imagery. The result of these activities was a total of 39 training locations representing 14 types of terrain features.

Before a final classification map was produced, two types of signature analysis were performed in order to alleviate potential problems. One analysis consisted of examining 2-channel ellipse plots of the training signatures for the optimum bands selected. These plots indicated which signatures overlapped each other, and the size of the ellipse indicated the tightness (homogeneity) of the signature. Another analysis computed theoretical classification accuracies and misclassification accuracies as a function of the signature used.

These two diagnostics furnished a basis for editing some troublesome signatures, and for aggregating classes that were not readily differentiable from each other. As a result of this procedure we used 27 signatures to identify 7 classes of materials. The materials classified were: 1) deep marsh; 2) shallow marsh; 3) bare soil (fallow); 4) small grain (including wheat and oats); 5) row crops (including sunflower); 6) upland grasses (including pasture); and 7) hay.

From previous results we have discovered that classification of water is well accomplished using a level slice of MSS7. Since we had already examined the 15 July data to determine the MSS7 slicing level for ponds, we chose to use that channel to edit out (classify) water subsequent to the recognition processing. This is accomplished with a classifiction module called WCHAN. Since we were using 15 July MSS7 for classification of water, we decided to add this channel to the four optimum channels in performing classification of the other scene materials, thereby resulting in a 5-channel classification.

3.2 RESULTS

The color-coded multitemporal classification map that was produced is shown in Figure 26. Since most of the areas for which identification is known (from field work) were used in training, we do not have a good objective basis on which to assess the classification accuracy of the map. However, the following discussion is our subjective analysis of the accuracy of the classification map.

The marsh categories were recognized reasonably well, although there was some confusion (misclassification) between shallow marsh and deep marsh. Bare soil was generally recognized quite well.

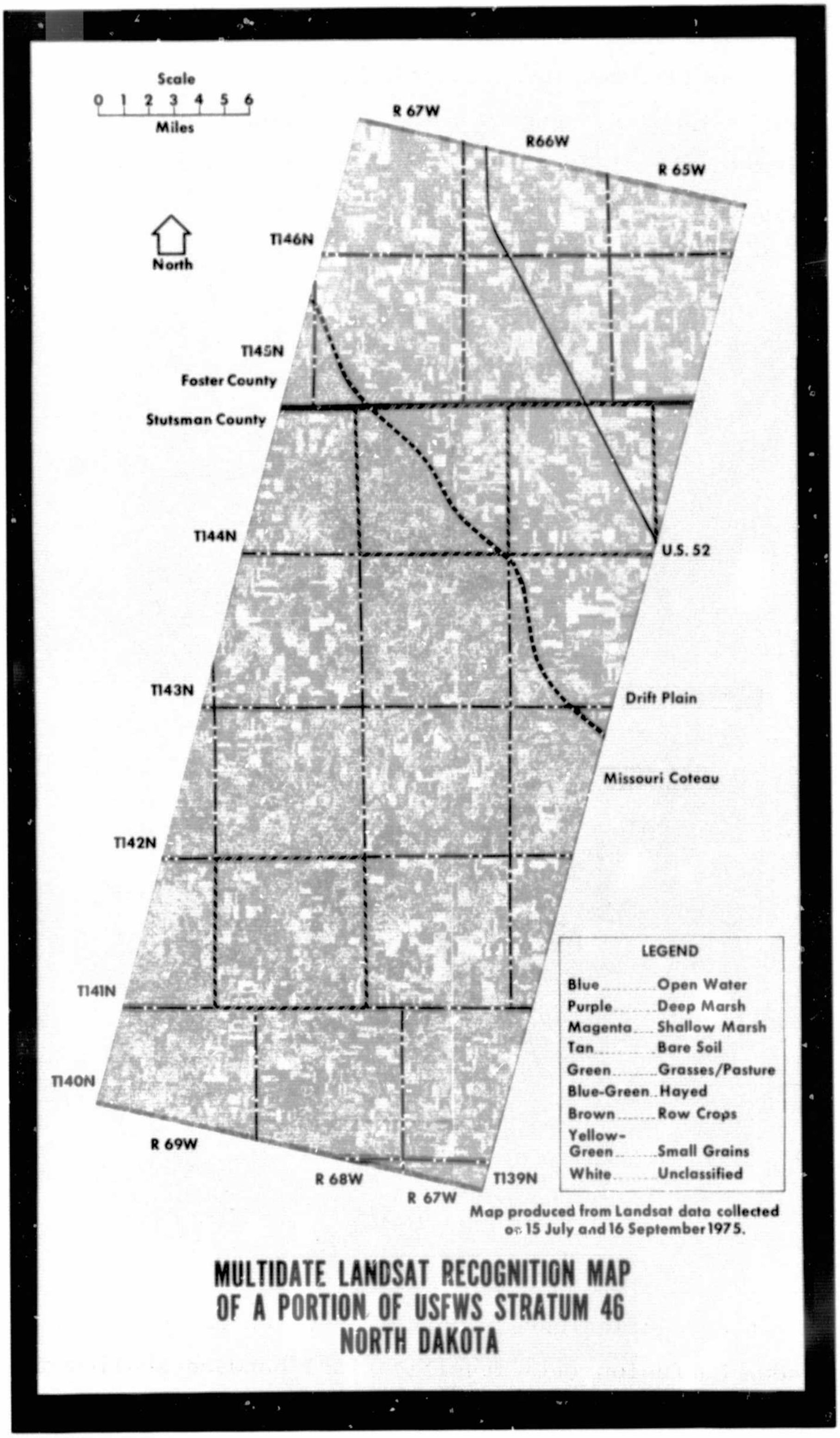

FIGURE 26. MULTITEMPORAL RECOGNITION MAP OF A PORTION OF STRATUM 46.

The other upland terrain classes, as a single entity, were accurately identified. However, there were misclassifications when any of the individual classes had abnormal characteristics due to different cropping or grazing practices. Hayed fields were sometimes confused with recently emergent (immature) crops. Pasture (rangeland) was probably the most frequently misclassified material because its appearance was quite variable, depending on the grazing intensity to which it had been subjected and the topographic position it occupied. Pasture (rangeland) frequently had a mottled appearance, and the resulting spectral characteristics may be confused with small grain or row crops.

Another basis on which to assess the classification accuracy of the map was the PEC program output, which indicates the theoretical probabilities of correct and incorrect classification. These figures indicate how good the classification would be if the test scene materials had the same spectral characteristics as the training materials. As such, these probabilities represent an upper limit on classification accuracy, which almost certainly was not obtained over the whole area of the map. The probabilities of correct classification based on this test are indicated in Table 5. For purposes of comparison, the approximately corresponding figures achieved with a single date of Landsat data in a previous study (7 July 1973) are also presented. This comparison suggests that, whatever the absolute accuracy of the spectral-temporal classification map, it is considerably superior to single date classification.

TABLE 5. THEORETICAL PROBABILITY OF CORRECT CLASSIFICATION BY CLASS USING LANDSAT DATA FOR 7 JULY 1973 ONLY AND FOR 15 JULY AND 6 SEPTEMBER 1975 COMBINED

	(Multidate) 1975	(Single Date) 1973
Bare Soil	96.4	90.4
Deep Marsh	86.4	60.6
Shallow Marsh	86.2	48.1
Small Grain	85.3	36.5
Row Crop	89.9	74.8
Range	79.8	68.1

4

UTILIZATION OF LANDSAT DATA

The preceding discussions have addressed the capability of remote sensing to generate information concerning water bodies and other terrain classes present in the prairie-pothole region of North Dakota. As was mentioned before, this information could be valuable in its own right as a baseline characterization of conditions (inventory). However, the baseline data could be of even greater value if methods could be formulated for deriving information from the data relevant to specific tasks in waterfowl management. As indicated earlier, the approach to waterfowl management is essentially two-fold: 1) manipulation of annual hunting regulations; and 2) management of habitat. Therefore, in the following sections we attempt to formulate and demonstrate methods for:1) assessing current year's duck production using information on the water bodies; and 2) assessing relative waterfowl habitat quality, using information on water bodies and upland terrain classes.

4.1 ESTIMATING DUCK PRODUCTION FROM LANDSAT POND DATA

Numerous investigators have indicated a relationship between amount and timing of water bodies and current year's duck production. In general, the more the ponds, the greater the production is likely to be for a given level of the breeding population. Early-season ponds are of some importance in attracting the migrating ducks. In the absence of adequate ponds, some of the potential breeding population may overfly the area. Later in the year ponds are important for breeding pairs. Still later, ponds are important for brood rearing.

Geis, et al. (1969) found that the number of July ponds and the size of the breeding population were both correlated with number of mallard young; the number of ponds was nearly twice as important as the size of breeding population. Other investigators have concluded that there is a relationship between the number of water areas and the number of ducks produced (e.g., Evans and Black, 1956; Cooch, 1969).

Given the fact that there is a relationship between ponds and duck production, we now proceed to demonstrate how that relationship might enable Landsat pond counts to estimate duck production. In order to demonstrate the concept of how current remote sensing data, and current and historical FWS survey data, could be utilized together in order to give timely estimates of duck production, we present the following illustration.

Borrowing from the concepts of Evans and Black (1956), Geis, et al. (1969), Cooch (1969), and others, we constructed the following model for prediction of duck production:

$$\hat{Y} = MDBP \times \frac{JP}{MP} \times \frac{MP}{NMP} \times NP$$

where $\hat{Y}$ = the prediction of young ducks produced

MDBP = the May Duck Breeding Population

NP = Normal Production per breeding duck

JP = number of July ponds

MP = number of May ponds

NMP = Normal number of May ponds

MDBP could be obtained from the current year's FWS May Waterfowl Breeding Population Survey. NMP could be obtained from historical average values from the May Waterfowl Breeding Population Survey. MP would not have to be determined because it cancels in the product of the two pond-correction factors. JP could be determined from a remote sensing census and double sampling procedure involving Landsat data and aircraft data, as discussed in section 2.5. NP could be determined from historical data or research findings.

As an example of how the model might be implemented, we present the following calculations using: 1) 1975 aircraft corrected Landsat counts of number of ponds for July for Stratum 46 (JP); 2) 1975 FWS estimates of total duck breeding population in Stratum 46 (MDBP); 3) an NP value computed from FWS historical data over the period 1968-1974;

and 4) an NMP value computed from 1968-1975 historical data. The result is

$$\hat{Y} = 829735 \times 2.84 \times \frac{150,565}{121,713} = 2,921,995$$

The FWS estimate of total duck production for Stratum 46 for 1975 is 2,936,000, within 0.5% of the conceptual model estimate.

The point of this illustration is not to indicate how accurately the above model can predict production with remote sensing inputs. In the first place, we are simply comparing one estimate with another, both of which are subject to error. In addition, the model assumes that reproductive behavior and habitat requirements are the same for all species of ducks, which they are not. Over large areas, such as the entire Prairie Pothole Region, species differences may produce compensating effects. However, at the stratum level, we suspect that several different models developed for particular species or groups of species for particular strata may be required for consistently good results. Additional types of information may also have to be included in a reliable model.

A model of the form presented here has certain desirable characteristics. It does not require any current information from the July Waterfowl Production Survey. In addition, it requires information on ponds at only one time, July (since May ponds cancel), thereby requiring only one remote sensing survey. This July pond information potentially could be made available in a timely fashion, thereby facilitating generation of data in a time-frame that would enhance setting of hunting regulations in August.

4.2 TERRAIN CHARACTERISTICS AS AN INDICATOR OF HABITAT QUALITY

Waterfowl habitat quality is a function of both water conditions and the terrrain characteristics of the surrounding wetlands and upland cover types. If these relationships can be quantified then it should be possible to develop a formal model which uses terrain type information as input, and provides an objective evaluation of habitat quality as output. The feasibility of using a computer to make the numerous calculations required to characterize terrain types over an area of any significant size has been described previously (Sattinger, et al. 1975; and Roller, 1977). These studies also showed that processed Landsat data could serve as a source of data to such a model. In this study we have attempted to design a habitat quality model based on biological criteria. Although we have developed our model for use with Landsat data, it should be pointed out that other models, based on the same principles, could be developed involving conventionally gathered field survey data, or a combination of remotly sensed and field gathered data.

Habitat quality, as we are using the term, relates to the potential of a unit of habitat to attract breeding waterfowl and furnishing them with their requirements for survival and successful rearing of broods to the point where the young participate in the fall flight.

The quality of habitat as noted here does not indicate actual duck production for any given year. In order to predict production additional information, namely breeding population size, is needed. Rather, we are assessing the relative production potential of an area in a given year.

Based on our review of the literature we believe several factors influence waterfowl habitat quality. Yet, the specific relationships and relative importance between these factors are not presently known in any detail. As a result, we have had to use a semi-empirical approach to developing our model, in which sections* identified by FWS waterfowl biologists have been used to calibrate the important relationships between the factors of our model. The model we have developed using this procedure is one that evaluates waterfowl habitat quality on the basis of two things: 1) water conditions and;2) terrain characteristcs. The specific water conditions considered are: 1) pond

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*A legal land survey unit nominally covering 1 sq mile; there are 36 sections in one township.

number; 2) pond area; and 3) pond size-class distribution. The terrain characteristics evaluated are the presence and spatial arrangement of certain terrain types.

Although the model is based on available biological information, we intend it to serve primarily to illustrate the nature and usefulness of such a model in the hope that such a demonstration will stimulate the generation of additional information required to construct a truly valid model.

Since we are evaluating habitat quality on a per unit area basis in relation to the activity of breeding ducks, the physical size of the unit should correspond approximately to the pair's home range. For some waterfowl, (e.g., mallards) home range is approximately 1 mi^2 in extent, resembling a section (Dzubin, 1955). Furthermore, the study area is gridded into sections on topograpic maps. We therefore found it convenient and reasonable to demonstrate the concept of waterfowl habitat quality by generating ratings on a section-by-section basis. Although this procedure imposes an artificial grid system on the natural characteristics of the study area, it also characterizes habitat on the basis of readily definable land ownership and management units, a significant advantage. Ultimately, some averaging of the section-by-section ratings over a larger unit of area may prove desirable.

Once we developed the general form of a waterfowl habitat quality model, it was calibrated to a specific area with specific data inputs. To do this we needed training (calibration) sections with a range of habitat quality. Our procedure for obtaining this information considered the following methods.

One way of independently assessing (or defining) good habitat from poor habitat is to get a consensus of opinions from wildlife biologists familiar with the area. However, the opinions of individuals may vary, and the criteria each one uses may be rather subjective and not readily definable.

Another way of assessing relative habitat quality is to count the number of breeding pairs present in an area, the number of nesting sites, and/or the number and size of broods. This method is quantifiable, but it is difficult to accurately measure these parameters.

We have chosen to use both kinds of information in locating areas of varying quality habitat, insofar as that is possible. Specifically, FWS personnel have indicated several sections as good and poor waterfowl habitat, based on subjective assessments and counting number of broods. Areas of intermediate habitat quality were chosen after discussions between ERIM and NPWRC personnel regarding critical aspects of waterfowl habitat quality.

In this manner, the general model was constructed. We will now discuss separately the significant aspects of the Water Factors sub-model, and the Terrain Factors sub-model.

4.2.1. WATER FACTORS SUB-MODEL

As we indicated earlier in this report, water conditions are important determinants of waterfowl habitat quality and production potential. Ideally, we would have liked to use information on water conditions from at least two dates, such as May (breeding season) and July (brood season). However, due to cloud cover in part of the May 1975 Landsat data we could get only partial congruence in aerial coverage between the May data and the July-September recognition map containing the terrain information. Therefore, the model uses only information on water conditions in July, for which there is total congruence with the terrain information.

The July water data were used to generate three types of information: 1) a pond number factor; 2) a pond area factor; and 3) a pond size class distribution factor. Each factor was calculated on a section-by-section basis. The way each of these factors were determined is discussed in the following sections.

4.2.1.1 POND NUMBER FACTOR (PNF)

The literature suggests that 10 or more ponds per section is optimal for duck production, depending on the species of duck and physiographic region. However, very small ponds cannot be detected with Landsat data due to resolution constraints, so we empirically determined the average number of ponds for high quality habitat by counting the number of ponds that were actually detected by Landsat on the sections identified as good habitat by FWS biologists. This average figure was 3.8 ponds per square mile. Thus, any section with four or more ponds was considered good habitat. Such a section was given a pond number factor rating of 1.0. Any section with 3 or fewer ponds was given a pond number factor rating of

$$\text{PNF} = \text{sine}\ [\frac{90}{3.8} \times (\text{Number of Ponds})]^*$$

This non-linear relationship gives the following values based on number of ponds.

No. of Ponds	PNF
0	0.00
1	0.40
2	0.74
3	0.95
4	1.00

4.2.1.2 POND AREA FACTOR (PAF)

We determined an "optimal" amount of water area, as before, by empirically determining the average water area mapped by Landsat in the sections identified as good habitat. This value was 17.5 ha. We assumed that any water area in excess of 17.5 ha did not improve habitat quality. The non-linear pond area factor rating was computed as

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*The factor (90/3.8) scales the PNF so that its value is 1.0 when the pond number is 3.8, the desired result. For four or more ponds the PNF is given a value of 1.0, and for zero ponds it is given a value of 0.0. Similar evaluation was given to PAF.

$$PAF = \text{sine} \left[\frac{90}{17.5} \times (\text{Pond Area (ha)}) \right]$$

4.2.1.3 POND SIZE FACTOR (PSF)

The literature suggests that both large and small ponds are important for good waterfowl habitat, although there is some disagreement as to their relative importance. We have semi-arbitrarily assumed that 2 ha (5 acres) is the appropriate dividing line between large and small ponds, and that large ponds are more important than small ponds, since they are more likely to be available through brood rearing. If both large and small ponds are present, the PSF is given the value 1.0, whereas if only large ponds were present the PSF rating was given the value 0.7, and when only small ponds were present the PSF rating was given the value 0.5. For no ponds, PSF = 0. Table 6 summarizes this rating system.

TABLE 6. POND SIZE FACTOR RATING SYSTEM

PSF	>2 ha	< 2 ha
1.0	yes	yes
0.7	yes	no
0.5	no	yes
0.0	no	no

4.2.1.4 INTEGRATED POND FACTOR (IPF)

A factor indicating the relative integrated quality of all pond conditions (on a scale from 0 to 1) was calculated from the individual water factors by use of the relationship

$$IPF = PNF \, [.67 \, PAF + .33 \, PSF]$$

The pond number factor was made multiplicative to indicate that the number of ponds is the most important factor, and that without ponds the water quality rating goes to zero (as do all the individual factors). Of the remaining two factors PAF was considered twice as important as PSF. The weighting coefficients allow the term in parentheses to achieve a value of 1.0 if both PAF and PSF are valued 1.0.

4.2.2 TERRAIN FACTORS SUB-MODEL

The presence of water bodies is only a partial indicator of waterfowl habitat quality. Other terrain classes are also important. For example, the presence of upland cover has long been known to be essential to good waterfowl habitat. In addition, the spatial arrangement of the various components of habitat, which affects their interspersion and juxtaposition, is known to be important. In this section we describe how such terrain information is incorporated into our model for evaluating waterfowl habitat quality. For this demonstration, we have chosen to greatly simplify and generalize upon habitat relations in order that the concept we are illustrating not be lost in unnecessary detail.

The Terrain Factors sub-model evaluates the presence of cover types and their spatial arrangement. Although the factors could have been considered separately, we incorporate presence and spatial arrangement into a single factor represented by the amount of edge between desirable terrain types.

The components we chose to use for the Terrain Factors sub-model are aggregations of the individual classes of materials we classified using multidate Landsat data. Since the components are aggregations of classes which, although separable from other terrain features were not entirely differentiable from one another, the aggregated components are more accurately classified than were the individual recognition map classes. Specifically, these components are:

1) OW = open water
2) WL = wetland vegetation
3) COV = upland cover (hay, grasses and pasture)
4) AG = upland areas providing some cover during part of the year

and possibly some food in the fall (small grains, row crops)

5) OTHER = upland areas providing no particular value to waterfowl (e.g., bare soil)

The edges considered, and their assumed relative importance, based partially on literature review and on an analysis of good and poor quality habitat are:

1)	OW/WL	1.0
2)	WL/COV	0.8
3)	OW/COV	0.7
4)	OW/AG	0.5
5)	WL/AG	0.3
6)	COV/AG	0.2

It is assumed that edges including OTHER have no value since there is no advantage to waterfowl in crossing such a boundary.

The Terrain Factor sub-model computed was the sum of the weighted proportions of all the edges considered, normalized to the average amount of useful edge in sections considered to be good habitat. Specifically, the Terrain Factor sub-model form is:

$$\mathrm{TF} = \frac{1.0\ \mathrm{OW/WL} + .8\ \mathrm{WL/COV} + .7\ \mathrm{OW/COV} + .5\ \mathrm{OW/AG} + .3\ \mathrm{WL/AG} + .2\ \mathrm{COV/AG}}{\text{Average Total Edge of Good Habitat}}$$

4.2.3 INTEGRATION OF WATER AND TERRAIN FACTORS

The output of the Terrain Factors sub-model was subsequently additively combined with the results of the Water Factors sub-model to obtain an integrated value of Waterfowl Habitat Quality. Since we feel that water is an essential ingredient that is somewhat more important than terrain conditions we weighted the two factors 60%/40%. The resulting model for Waterfowl Habitat Quality is:

$$\begin{aligned} \mathrm{WHQ} &= [.6\ \text{Water} + .4\ \text{Terrain}] \times 100 \\ &= 60\ [\mathrm{PNF}\ (.67\ \mathrm{PAF} + .33\ \mathrm{PSF})] + 40\ [\mathrm{TF}] \end{aligned}$$

Three townships of 36 sections each which contain good, poor, and intermediate waterfowl habitat were subsequently evaluated to see if differences in habitat quality could be detected. The results are shown in Figures 27a, 27b, and 27c. The township which contains primarily good habitat (Fig. 27a) is located on the Missouri Coteau physiographic province; the township which contains primarily poor habitat (Fig. 27c) is located on the Drift Plain physiographic province;and the transitional township (Fig. 27b) is on the boundary between the two physiographic provinces and contains both good and poor habitat.

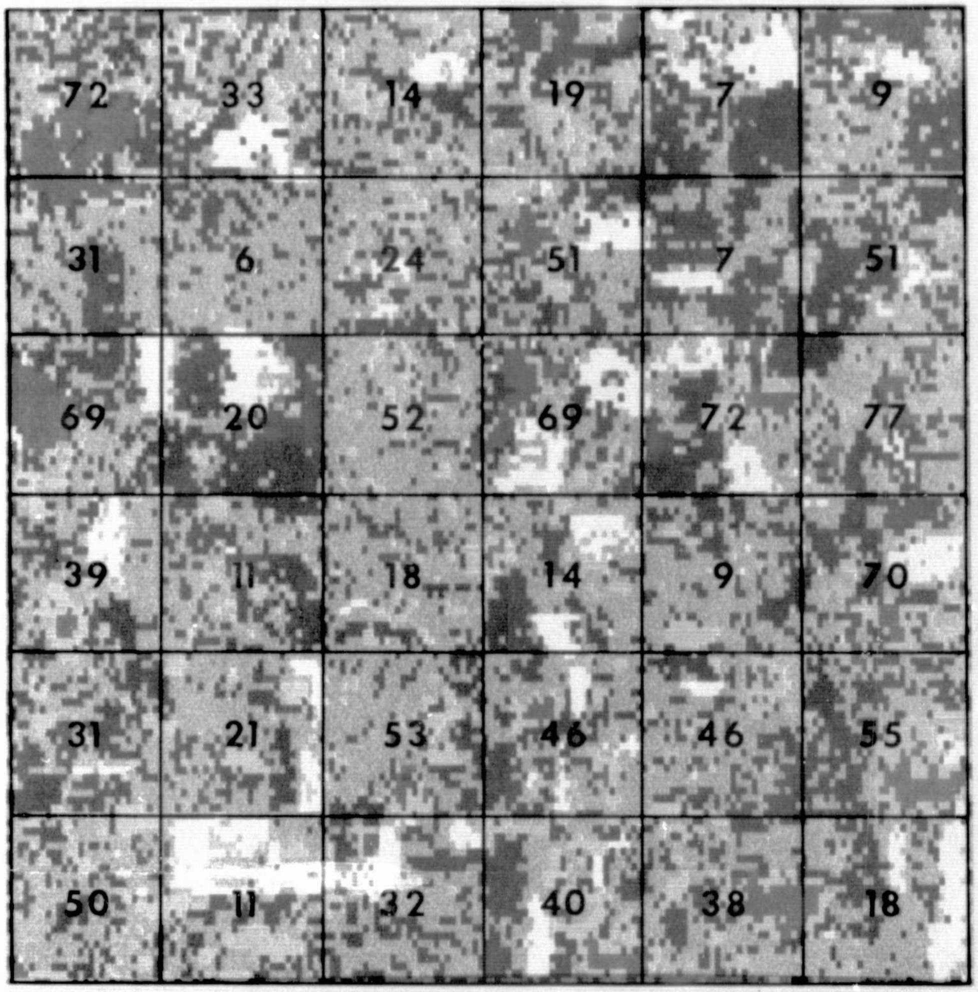
No detailed analysis of the "accuracy" of the model ratings has been made, and may not be warranted, given the preliminary nature and limited objective of this demonstration, except as a means of improving the model for implementation on other data.

We reiterate that the above described habitat model is preliminary. The available knowledge of the relative importance of various charateristics and their relationship with each other is limited at this time. In addition, we have had to omit certain aspects of habitat quality which we know are important (e.g., May pond characteristics), because of limitations in the present (Landsat) data base. However, we still chose to illustrate the concept of modeling waterfowl habitat, because neither of the above limitations are fundamental. For example, a better data base of habitat characteristics could be obtained from satellites with improved spatial resolution, from aircraft, from field studies, or some optimum mix of all three.

Better biological information is also in existence, but diffused throughout the scientific community and unavailable to us because of time and money constraints involved with the present effort. One of the purposes of this illustration is to stimulate comment from waterfowl biologists regarding true relationships and importance of habitat conditions in an attempt to better synthesize the knowledge available for use in subsequent work.

As has been stressed before, there are limitations to the use of Landsat data, chiefly due to the coarse Landsat resolution, which pre-

WATERFOWL HABITAT QUALITY RATINGS



T141N, R68W
Stutsman Co., North Dakota
Condition: Good Habitat

LEGEND

Blue-	Open Water
Magenta -	Wetlands
Light Green -	Cover
Dark Green -	Agriculture
Yellow -	Other

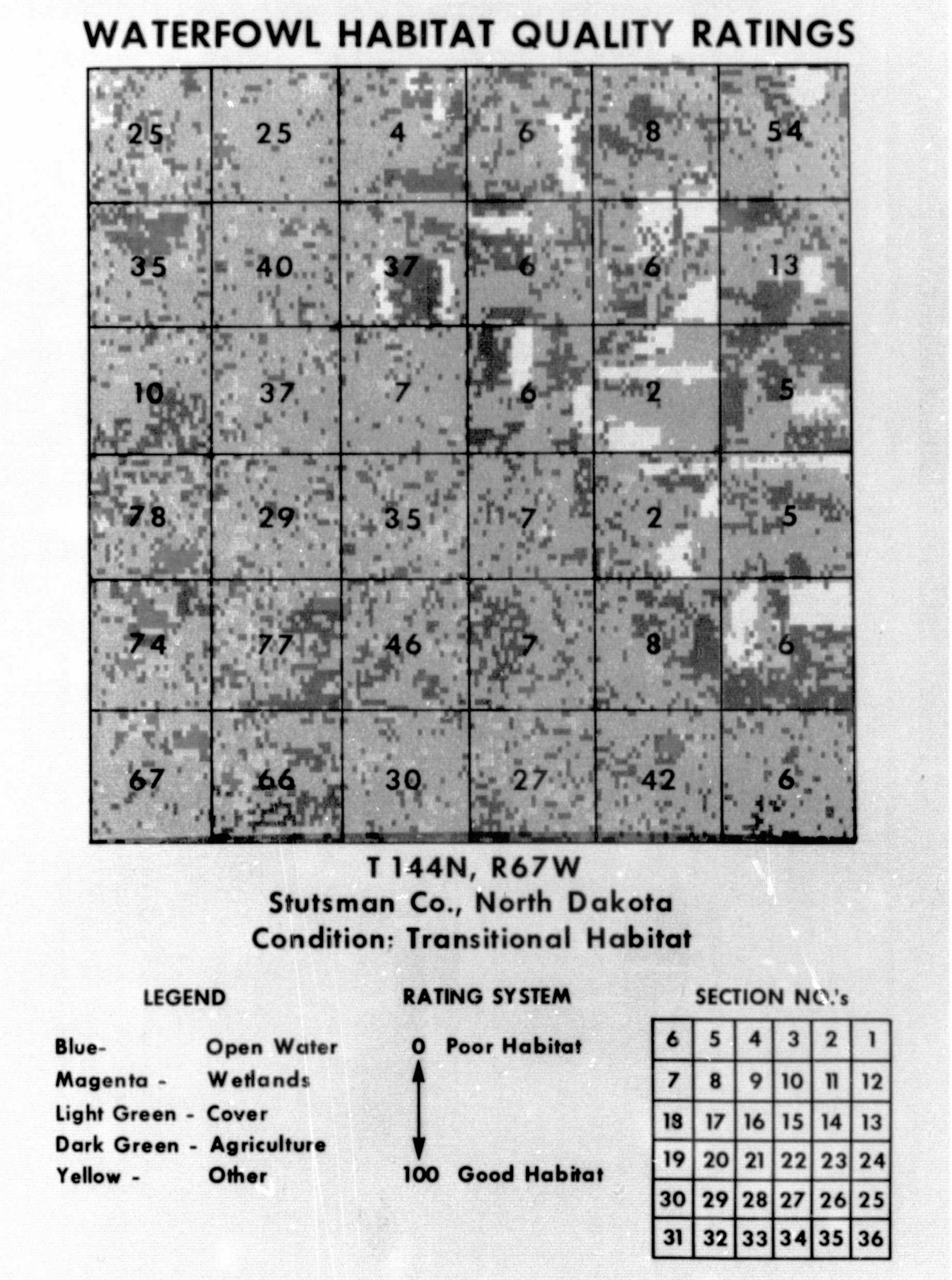
RATING SYSTEM

0 Poor Habitat
↕
100 Good Habitat

SECTION NO.'s

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

FIGURE 27a. WATERFOWL HABITAT QUALITY RATINGS - GOOD HABITAT



25	25	4	6	8	54
35	40	37	6	6	13
10	37	7	6	2	5
78	29	35	7	2	5
74	77	46	7	8	6
67	66	30	27	42	6

T 144N, R67W
Stutsman Co., North Dakota
Condition: Transitional Habitat

LEGEND

Blue-	Open Water
Magenta -	Wetlands
Light Green -	Cover
Dark Green -	Agriculture
Yellow -	Other

RATING SYSTEM

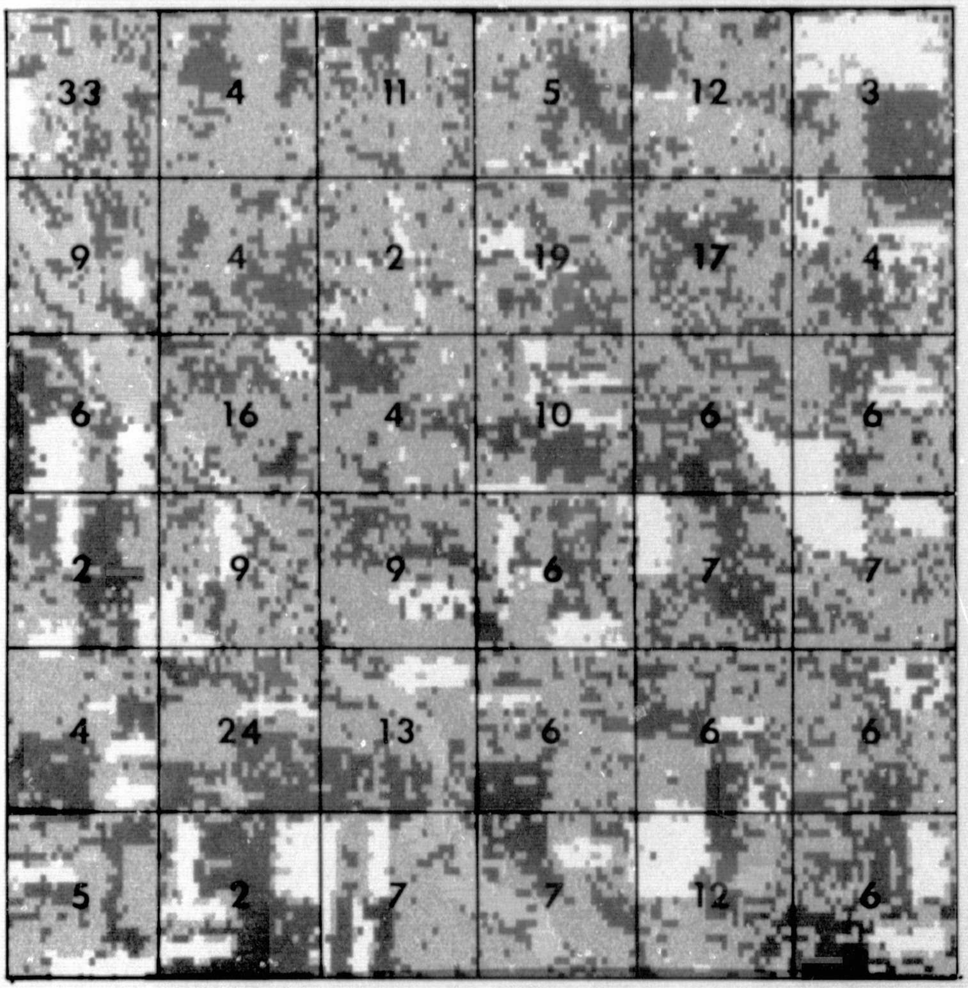
0 Poor Habitat
↕
100 Good Habitat

SECTION NO.'s

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

FIGURE 27b. WATERFOWL HABITAT QUALITY RATINGS - TRANSITION HABITAT

WATERFOWL HABITAT QUALITY RATINGS



T 144N, R66W
Stutsman Co., North Dakota
Condition: Poor Habitat

LEGEND	
Blue-	Open Water
Magenta -	Wetlands
Light Green -	Cover
Dark Green -	Agriculture
Yellow -	Other

RATING SYSTEM

0 Poor Habitat
↕
100 Good Habitat

SECTION NO.'s

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

FIGURE 27c. WATERFOWL HABITAT QUALITY RATINGS - POOR HABITAT

cludes detection of small ponds. Landsat ratings of habitat quality are, therefore, likely to be least accurate in sections with numerous small ponds.

Compared with alternative existing data, however, Landsat data still appear to have significant benefits. For example, topographic maps at sufficient scale for all of the ponds to be indicated are not available for parts of Stratum 46. Even if they were, condition of ponds is sufficiently variable both seasonally and annually so that documentation of pond conditions at some time in the past may not be useful for assessing present conditions. Furthermore, very little information on terrain classes is available from topographic maps, and again it is not current information. Finally, Landsat data are inherently produced in a digitized georeferenceable format, whereas topographic map data currently are not.

The fact that we constructed different categories of materials for implementation of the waterfowl habitat model than were used in the recognition map indicates the versatility of a data base such as the Landsat recognition data base. Different categories can be formed from the data base for different purposes. In this case, the two purposes were: 1) general land characteristics (for the map); and 2) significant waterfowl habitat requirements (for the model). Other aggregations could be made for other purposes, such as for different species of waterfowl. Another example of the data base versatility is that all depressions (potential water basins) might be mapped by aggregating open water, shallow marsh, and deep marsh into a single class.

Thus, a spatially encoded data base like the Landsat data can be manipulated in a variety of ways for a variety of purposes, and a recognition map need not, and in fact generally should not, be the final product for any remote sensing effort. All data processing results should be synthesized into information useful to a natural resource manager. The fact that such a capability potentially is available is the most important message of our illustration of rating waterfowl habitat quality.

5

SUMMARY AND CONCLUSIONS

This effort has succeeded in accomplishing the investigation's major objectives by: 1) demonstrating the capability of mapping ponds over a very large area with multi-date, multi-frame Landsat imagery; 2) demonstrating how a small double sample of aircraft data makes it possible to adjust a Landsat large-area census; 3) showing improved terrain classification by use of multitemporal Landsat data; 4) demonstrating the concepts of using remotely determined pond data, in conjunction with FWS estimates of breeding population, in order to estimate waterfowl production; and 5) demonstrating the use of pond and terrain data to characterize relative waterfowl habitat quality on a section by section basis.

As a result of the activities that have occurred as a part of this investigation we make the following conclusions:

1) A coarse large area Landsat census of ponds can help improve the estimate of the number of ponds in a population with respect to what can be done with an accurate small sample, as from low flying aircraft. One reason for this is the large semi-random variability in pond area per small sample unit.
2) There may be a relationship between pond numbers in May and July derived by remote sensing and waterfowl production under some circumstances. Whether this relationship is consistent enough to be useful in estimating waterfowl production on an annual basis remains to be determined.
3) Multitemporal Landsat data improve the capability for terrain classification over what could be achieved with a single date of Landsat data, but at an increase in cost.
4) Waterfowl habitat quality is related to pond and terrain conditions which may be determined from remote sensing (Landsat) data.

5) Perhaps the most significant long-term potential contribution of the activities documented here is the concept that habitat quality can and should be formulated in a semi-objective, quantitive fashion.

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RECOMMENDATIONS

Based on the result of our activites during this investigation and previous related investigations we make the following recommendations for future action:

1) Decide how accurately pond data must be known. Assess the optimal number of Landsat and/or aircraft samples required in order to cost-effectively achieve the desired accuracy.

2) Determine whether there is additional value in having data on specific ponds, including centroid location, area, perimeter, and shape factor which can be used in a given year or as a comparison over time for determining trends.

3) The most costly process in the double sampling procedure we implemented is the collection of aircraft scanner data. Operationally, a more cost-effective approach might be to collect aerial photos using a light aircraft, since this can be done for considerably less cost, perhaps using FWS personnel and equipment.

It is possible that aircraft remote sensing data can be eliminated altogether, if desired, and be replaced by a FWS visual aerial survey of specific transects which would serve as the double-sample to correct Landsat estimates. Since visual surveys will probably continue to be required for counting ducks and the like, this may be the optimal procedure. However, the characteristics of the transect samples might have to be altered (e.g., by making the visual survey over a wider swath, which could be more readily located and defined on Landsat data).

4) There should be continued efforts in the area of habitat quality modeling. When a credible model is developed, it could be calibrated to 1975 Landsat data and known habitat quality and then applied to another year's data. This would

have the value of indicating: a) what changes have occurred in "instantaneous" habitat quality during the time interval; and b) what properties of the habitat may be relatively fundamental (less temporally variable) aspects of habitat quality.

5) There should be an investigation of the advantages and disadvantages of using interpretation of aerial photos or existing terrain class/topographic maps for assessing components of the habitat for inclusion in a habitat quality rating model. This may be the best way to assess true performance of a model, independent of terrain class misclassification.

6) Eventually, a habitat quality model should be used to assess the "before" and "after" habitat quality of an area that has been disrupted (e.g., due to extensive drainage or tillage).

7) Use concepts from the habitat quality modeling (with or without remote sensing) to recommend habitat areas to be preserved and treatments that should be performed to improve Waterfowl Production Areas, and Wildlife Refuges, as well as privately owned lands.

APPENDIX I

LANDSAT POND AREA DETERMINATION

Although not as important as a determination of pond occurrence, a determination of pond area may also be of significance to duck production. Accordingly, we investigated the capability of Landsat to estimate pond areas.

Procedure

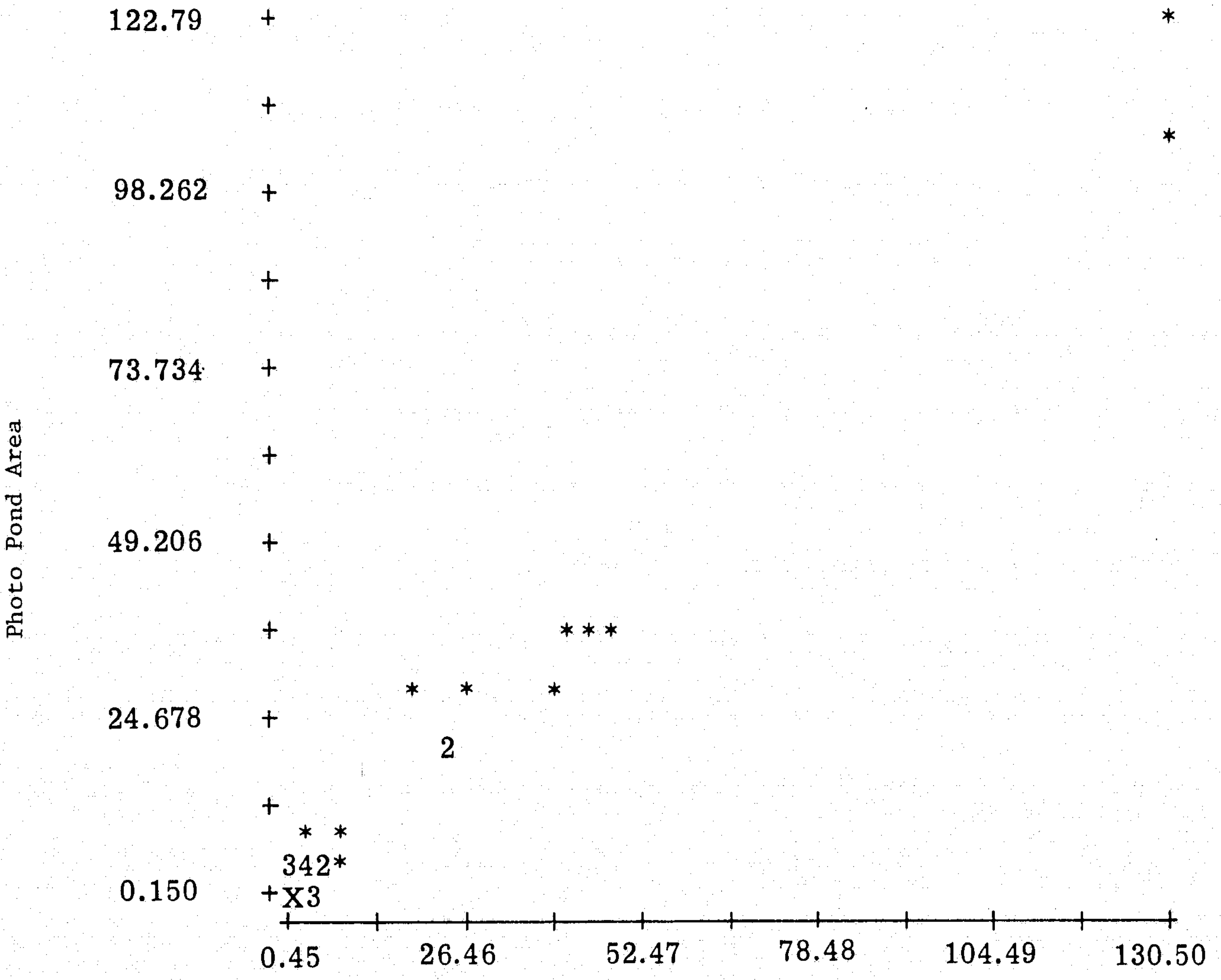
For this experiment, we chose a study site that contained a good distribution of sizes and shapes of ponds. We identified this region on color IR aerial photo transparencies taken in May and July. These transparencies were magnified on a viewing screen with a zoom-transfer scope. The area of every pond in the study site was then determined for both May and July photos by means of a dot-grid measurement of area. Both May and July data were included in order to simulate a variety of water conditions and shapes.

The study site was then located on May and July Landsat data (by UTM coordinates), and corresponding pond areas were determined for each lake for both dates by counting the number of pixels and multiplying by the known size of a Landsat pixel.

Results of Landsat/Aircraft Pond Area Analysis

A plot of the corresponding aircraft and Landsat pond areas is shown in Figure 28. A linear least squares regression between these two measurements results in a standard error of the estimate of 3.3 ha, when the regression is forced to go through the origin (zero intercept). For this example Landsat data seems to be highly correlated with "true" (aircraft) data.

This conclusion is not necessarily warranted. An error of 3.3 ha in estimating the area of a 300 ha pond may be insignificant, but the same error in estimating the area of a 3 ha pond may be unacceptable. What this analysis suggests is that Landsat data may be useful for estimating the total area represented by many ponds, but not necessarily for estimating the area of specific small ponds.



Landsat Pond Area

FIGURE 28. Scatter plot of corresponding aircraft and Landsat pond area.

This analysis was carried one step further. Since we suspect that area estimation accuracy using Landsat data is a function of the shape of the pond as well as its size, we examined the relationship between Landsat and aircraft data for one shape of pond, namely circular. For 9 circular ponds that were identified as having 5 or fewer Landsat pixels, the ratio of aircraft to Landsat area was computed to be 1.39. For 7 circular ponds that were identified as having 10 or more pixels, the ratio was 0.81. In other words, for circular ponds Landsat underestimated the area of small ponds and overestimated the area of large ponds. Relationships for other shapes could not be determined for lack of enough cases for a given shape.

Total water area in the stratum can be estimated by use of the relations between aircraft corrected Landsat pond numbers and aircraft corrected pond area. Specifically

$$Y = \#\text{ ponds} \times \frac{\text{Ave Landsat Area}}{\text{Pond}} \times \text{aircraft correction for area} =$$
$$(168813) \times (3.58\text{ha})\ (.87563) = 529{,}187\text{ha for May, and}$$
$$(150565) \times (4.75\text{ha})\ (.87563) = 626{,}236\text{ha for July}$$

The average Landsat area per pond was determined from the total number of ponds and total pond area indicated by the POSORT output. Note that, although the number of ponds is less in July, the July ponds tend to be larger, with the result that there is greater total surface area of water. This kind of information may be of additional utility for estimating duck production.

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