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APPLICATION OF LANDSAT SYSTEM FOR IMPROVING METHODOLOGY FOR INVENTORY AND CLASSIFICATION OF WETLANDS

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15. Supplementary Notes

16. Abstract

Development and testing of a computer software system for inventorying prairie wetlands using LANDSAT CCT's has progressed on schedule. This software uses level thresholding in a single near-infrared data channel. After each pixel is classified as water or nonwater, the system then recognizes water features as sets of contiguous pixels or as single isolated pixels in the case of very small ponds. After delineating each water feature the software system then assigns each feature a position based upon a geographic grid system and calculates the features planimetric area, perimeter, and shape factor. Applications of the software system and results based on LANDSAT data collected prior to 1975 are discussed. Recently published literature describing various phases of this work are cited. Some difficulties have been experienced in obtaining LANDSAT CCT's for the period considered in this investigation; however, receipt of acceptable tapes is anticipated within the next few weeks.

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Type II Progress Report
LANDSAT-2

Title: Application of LANDSAT system for improving methodology for
        inventory and classification of wetlands.

LANDSAT Proposal No.: 23000

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A. Problems

All LANDSAT computer compatible tapes ordered to date were received
in two shipments late in this reporting period (9 June 1976 and 28
June 1976). Some delays were encountered in receiving these tapes
due to the fact that the EROS Sioux Falls Data Center does not
currently have in-house capability for producing the requested 7-
track format tapes. This necessitated their contracting this work
to an outside vendor. Since receipt of these tapes, we have examined
several and have ascertained the following:

   (1) The tapes commence with an end-of-file notation. This
        problem, however, can be overcome.

   (2) The tapes are written in an even parity mode. While not
        in itself a major problem, this is a significant departure
        from previous experience with LANDSAT CCT's.

   (3) It appears that when the 9-track to 7-track conversion
        occurred, the same number of bytes per record (3296) were
        produced as existed in the original 9-track form. Apparently
        an EBCDIC to BCD character converter was used with all of
        the data. This resulted in the proper conversion of the
        data characters such as in the file header but the incorrect
        conversion of all integer coded information which, in fact,
        comprises the bulk of the data.

Based on the above information, we concluded that the data were
unsatisfactory, and we informed the EROS Data Center of our opinion
on 29 June 1976. The EROS office was very cooperative and requested
that we return the CCT's to them while at the same time they re-
initiated production of new data tapes. The fact remains, however,
that we are still without the 1975 LANDSAT data which were to be
processed under this program.

1

B. Accomplishments.

Based upon a review of LANDSAT MSS imagery, we have determined that portion of the CCT data which will be processed upon receipt. Basically, we anticipate a wetland inventory of the total area encompassed by an existing U.S. Fish and Wildlife Service survey stratum (Stratum No. 46) using July 1975 LANDSAT observations. The same area will be surveyed using May 1975 data but at approximately a 60% sampling level due to the occlusion of certain scene areas by clouds during that period.

A major accomplishment during this reporting period has been the development and testing of a software system designed to delineate and collate wetland surface water features. Since 1975-LANDSAT CCT data have not as yet been available to us, previously acquired LANDSAT data were utilized for the testing of the software system. The results of this testing are discussed under the Significant Results of this report.

C. Significant Results

A newly developed software system for generating statistics on surface water features was tested using LANDSAT data acquired previous to 1975. This software test provided a satisfactory evaluation of the system and also allowed us to expand our data base on prairie water features, and to fill a gap in data between an earlier LANDSAT-1 investigation (encompassing the 1972-73 period) and the current investigation which will generate data for 1975. The software system recognizes water on the basis of a classification algorithm. This classification is accomplished by level thresholding a single near-infrared data channel. After each pixel is classified as water or non-water, the software system then recognizes ponds or lakes as sets of contiguous pixels or as single isolated pixels in the case of very small ponds. Pixels are considered to be contiguous if they are adjacent along a scan line and/or they are vertically or diagonally adjacent between successive scan lines. After delineating each water feature, the software system then assigns the feature a position based upon a geographic grid system and calculates the feature's planimetric area, its perimeter, and a parameter known as the "shape factor".

The position of each pond or lake is defined as the areal centroid of that feature. The software system first computes this centroid in terms of scan line number and pixel number along that scan line. Conversion to a geographic grid system is accomplished by use of several control points located within the scene and a multiple linear regression. In the present test, five control points were adequate for use within an observation encompassing 6100 km^2 (2355 mi^2). Standard errors for these control points ranged between 22.3 and 39.6 meters, values considerably less than the major dimensions of the pixel. In the current test the areal centroid of each pond or lake was computed in Universal Transverse Mercator (UTM) grid coordinates.

The tabulated pond and lake areas are the summation of the number of pixels, which constitute the feature, multiplied by the nominal pixel area (57 x 79 = 4503 m^2). The perimeter is the summation of total pixel margins which formed a land/water interface. The parameter known as "shape factor" was originally a measure used by limnologists for expressing the shoreline irregularity of a lake. The formula which expresses this parameter and which normalizes it to 1 for a circular feature (that feature having the least possible perimeter per area enclosed) is:

$$\text{Shape Factor} = \frac{P}{2\sqrt{A\pi}}$$

where P is the perimeter and A is the area.

The outcome of the area, perimeter, and shape factor calculations plus a summary of frequency of occurrence for each is tabulated and listed in the computer's printed output stream as well as on punched cards, one of which is generated for each recognized water body. The information on these cards is essentially the same as contained in the printed output plus a 20 character scene and processing date identifier. Examples of these pond and lake tabulations are shown in Figure 1. Figure 2 shows computer generated summaries which were derived from a tabulation of these pond and lake statistics.

During the course of our software testing, thematic maps of open surface water were also produced. The maps were generated at a scale of approximately 1:130,000 using a computer controlled ink-jet printer. Their function was to allow for verification of the classification process and to provide a visual display of the area surveyed. The maps were not given a skew correction (i.e., correction needed to compensate for earth rotational effects between successive scan lines) nor aspect scale corrections (i.e., correction needed to compensate between actual pixel aspect and that which the printer was able to achieve - a difference of two percent). For the purposes intended, however, these map corrections were not necessary. Figures 3 through 5 are photo-reduced reproductions of several of these thematic water maps which show an area near Jamestown, North Dakota. Each map is presented at a scale of approximately 1:500,000.

Marked variations in pond and lake numbers and distributions are apparent in the maps. In particular, the observation of 14 June 1974 (Figure 5) shows an abundance of surface water throughout both the Coteau and Drift Plain substrata. During this period, the James River system (including Arrowwood, Mud and Jim Lakes and Jamestown Reservoir) experienced high water and many agricultural fields in the Drift Plain were saturated and/or inundated. At the same time several nearby counties had been declared Federal disaster areas due to rain induced losses to crop production. On the other hand, this hyper-abundance of water provided favorable nesting conditions for certain species of ducks. In particular, this would have included the pintail which seems well adapted to a breeding habitat with sparse vegetation and temporary water. At the

- 3 -

other extreme, the observation of 7 July 1973 (Figure 2) depicts a low in surface water features for the period covered by this study. Dramatic changes in certain large water bodies are also readily apparent from the maps. For example, Pipestem Reservoir (Figure 5) is a new impoundment completed in early 1974 and thus does not appear on earlier maps.

Figures 6 and 7 are graphical displays resulting from the summaries collated by the computer. These figures summarize changes in two different biotic regions (the Coteau and Drift Plain). During the last observation (7 August 1974) numbers of ponds observed in most size classes were intermediate between the extremes of the two previous observations. A comparison of these and other data not illustrated suggests that pond number variability is greater in the Drift Plain than in the Coteau. If this condition is typical it would be consistent with what waterfowl biologists generally concede, specifically that the Coteau biotic area is a consistent waterfowl production area while the Drift Plain is inconsistent but in good years can be the factor which causes regional production to be much above average.

The LANDSAT sensors do not, of course, resolve the many small surface water features present in the prairies. A comparison of the LANDSAT data analyzed to date with U.S. Fish and Wildlife pond count surveys conducted at approximately the same time from low flying light aircraft indicates that on the average we have observed 19.2 percent of the ponds estimated to be present. These results appear consistent with and are indicative of the fact that a great number of prairie ponds are less than 0.4 hectare (1 acre) in size. For example, based upon observations in northeastern South Dakota, several researchers in 1969 noted that 73 percent of the wetland depressions were less than 1 acre (0.4 hectare) while another investigator working at three widely scattered sites in Saskatchewan found that between 82.0 and 87.5 percent of the basins were 1 acre or less in size. Further work to be carried out as part of the current investigation will employ double sampling techniques (i.e., aircraft and spacecraft data) to estimate that fraction of pond numbers not detected in the satellite data and to derive appropriate correction factors.

D. Publications

During this reporting period, two articles which related to waterfowl habitat surveys using LANDSAT data and which were written by the principal investigator and co-investigator have been published. Citations for these articles are as follows:

Gilmer, D. S. and E. A. Work, Jr. 1976. Eyes in the sky for wildlife in North Dakota Outdoors 38(8):14-19.

Work, E. A., Jr. and D. S. Gilmer. 1976. Utilization of satellite
    data for inventorying prairie ponds and lakes.. Photogrammetric
    . Engineering and Remote Sensing 42(5):685-694.

Reprints of each of these articles are enclosed.

E. Recommendations

As of this writing, it appears that efforts to obtain satisfactory
LANDSAT CCT's will soon be successful. We will remain in telephone
contact with our NASA technical monitor and advise him if additional
assistance should be required.

F. Funds Expended

Total Expenditures Allowed	Expenditures during this reporting period	Cumulative Expenditures
$130,233*	$21,000	$39,400

*Amount is exclusive of data purchase allowances.

G. Data Use

	Value of data allowed*	Value of data ordered	Value of data received
Imagery (#G23000)	$6800.00	$5471.00	$5471.00
CCT (#GB30000)	$3600.00	$2000.00**	0.0
Aircraft (#GW30000)	$7920.00	$5967.00	$5967.00

*NASA/GSFC funded accounts at EROS Data Center, Sioux Falls, SD

** These data have been received but were unsatisfactory per the
explanation given in section A of this report. The data were returned
to EROS, Sioux Falls for replacement.

H. Aircraft Data

Supporting aircraft data were collected by NASA/JSC in May 1975
(Mission 305) and July 1975 (Mission 316). Photographic products
from these missions were received several months ago and we are now
in receipt of CCT's and scanner imagery for Mission 316. To date
we have not received scanner imagery and CCT's for Mission 305 nor
have we received scanner data logs for either mission. We have been
in touch with NASA/JSC personnel regarding these delays and will
continue to press for production of the data.

07AUG74 C N47-25/.098-15 N N47

SCENE FEATURE TABULATED = LAKES

SCENE = NO COTEAU - 7 AUG 1974, OBS 1745-16455

UTM ZONE = 14

TABULATION OF RECOGNIZED LAKES

UTM N	UTM E	AREA (HECTARES)	AREA (ACRES)	PERIMETER (METERS)	PERIMETER (FEET)	SHAPE FACTOR
5247878	468223	4.95	12.24	930	3051	1.18
5246576	468195	9.91	24.48	2018	6621	1.81
5246671	465890	0.45	1.11	272	892	1.14
5243233	480428	1.80	4.45	658	2159	1.38
5245585	469384	3.15	7.79	886	2907	1.41
5243123	480279	0.45	1.11	272	892	1.14
5242963	480624	0.90	2.23	386	1266	1.15
5242767	481318	0.90	2.23	450	1411	1.28
5245662	467469	0.45	1.11	272	892	1.11
5242838	480063	0.45	1.11	272	892	1.14

(a)   Printed Listing

(b)   Punched Cards

FIGURE 1.   EXAMPLES OF COMPUTER TABULATIONS OF PONDS AND LAKES RECOG-
NIZED FROM A LANDSAT OBSERVATION OVER EAST-CENTRAL NORTH DAKOTA ON
7 AUGUST 1974.

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07AUG74 C N47-25/W098-15 N N47

SCENE = ND COTEAU - 7 AUG 1974, OBS 1745-16453

TOTAL SCENE AREA =2312.55 SQ. KM. = 892.64 SQ. MI.

VERTICES OF SCENE POLYGON:

   SCAN LINE    POINT     UTM N      UTM E
     1455.0      43.0   5250263.0   465960.3
     1502.0     343.0   5242847.0   481876.4
     1598.0     570.0   5232564.0   492662.6
     1789.0     742.0   5215628.0   498375.8
     1941.0     792.0   5203245.0   498030.1
     2208.0     987.0   5180144.0   503457.9
     2208.0       8.0   5192485.0   448328.4
     1455.0      43.0   5250263.0   465960.3

PIXEL WIDTH = 57.00 METERS, PIXEL LENGTH = 79.00 METERS

PIXELS COUNTED IF DATA VALUE IS .GE. 0 AND .LE. 9 IN CHANNEL 1
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DISTRIBUTION OF RECOGNIZED LAKES

BY AREA

HECTARES	ACRES	FREQUENCY
0.0 TO 0.40	0.0 TO 1.00	0
0.40 TO 0.80	1.00 TO 2.00	198
0.80 TO 1.20	2.00 TO 3.00	93
1.20 TO 1.60	3.00 TO 4.00	66
1.60 TO 2.00	4.00 TO 5.00	38
2.00 TO 2.40	5.00 TO 6.00	27
2.40 TO 3.20	6.00 TO 8.00	39
3.20 TO 4.00	8.00 TO 10.00	14
4.00 TO 6.00	10.00 TO 15.00	49
6.00 TO 8.00	15.00 TO 20.00	18
8.00 TO 10.00	20.00 TO 25.00	19
10.00 TO 12.00	25.00 TO 30.00	10
12.00 TO 16.00	30.00 TO 40.00	15
16.00 TO 20.00	40.00 TO 50.00	13
20.00 TO 30.00	50.00 TO 75.00	16
30.00 TO 40.00	75.00 TO 100.00	8
40.00 TO 60.00	100.00 TO 150.00	8
60.00 TO 80.00	150.00 TO 200.00	6
OVER 80.00	OVER 200.00	10

TOTAL NUMBER OF LAKES   =   647

BY PERIMETER			BY SHAPE	
METERS	FEET	FREQUENCY	SHAPE FACTOR	FREQUENCY
0 TO 300	0 TO 984	200	0.0 TO 1.0	4
300 TO 600	984 TO 1968	158	1.0 TO 1.1	1
600 TO 900	1968 TO 2952	85	1.1 TO 1.2	273
900 TO 1200	2952 TO 3937	52	1.2 TO 1.3	57
1200 TO 1500	3937 TO 4921	39	1.3 TO 1.4	88
1500 TO 1800	4921 TO 5905	30	1.4 TO 1.5	49
1800 TO 2100	5905 TO 6890	14	1.5 TO 1.6	50
2100 TO 2400	6890 TO 7874	9	1.6 TO 1.7	40
2400 TO 2700	7874 TO 8858	9	1.7 TO 1.8	31
2700 TO 3000	8858 TO 9842	12	1.8 TO 1.9	15
3000 TO 3300	9842 TO 10827	6	1.9 TO 2.0	12
3300 TO 3600	10827 TO 11811	5	2.0 TO 2.2	11
3600 TO 4200	11811 TO 13780	7	2.2 TO 2.4	12
4200 TO 4800	13780 TO 15748	5	2.4 TO 2.6	1
4800 TO 5400	15748 TO 17717	4	2.6 TO 2.8	2
5400 TO 6000	17717 TO 19685	2	2.8 TO 3.0	0
6000 TO 6600	19685 TO 21654	2	3.0 TO 3.5	1
6600 TO 7600	21654 TO 24935	0	3.5 TO 4.0	0
OVER 7600	OVER 24935	8	OVER 4.0	0

FIGURE 2. EXAMPLE OF COMPUTER SUMMARIES DERIVED FROM A TABULATION OF INDIVIDUAL PONDS AND LAKES. These data resulted from a LANDSAT observation over east-central North Dakota on 7 August 1974.

N

W——E

S

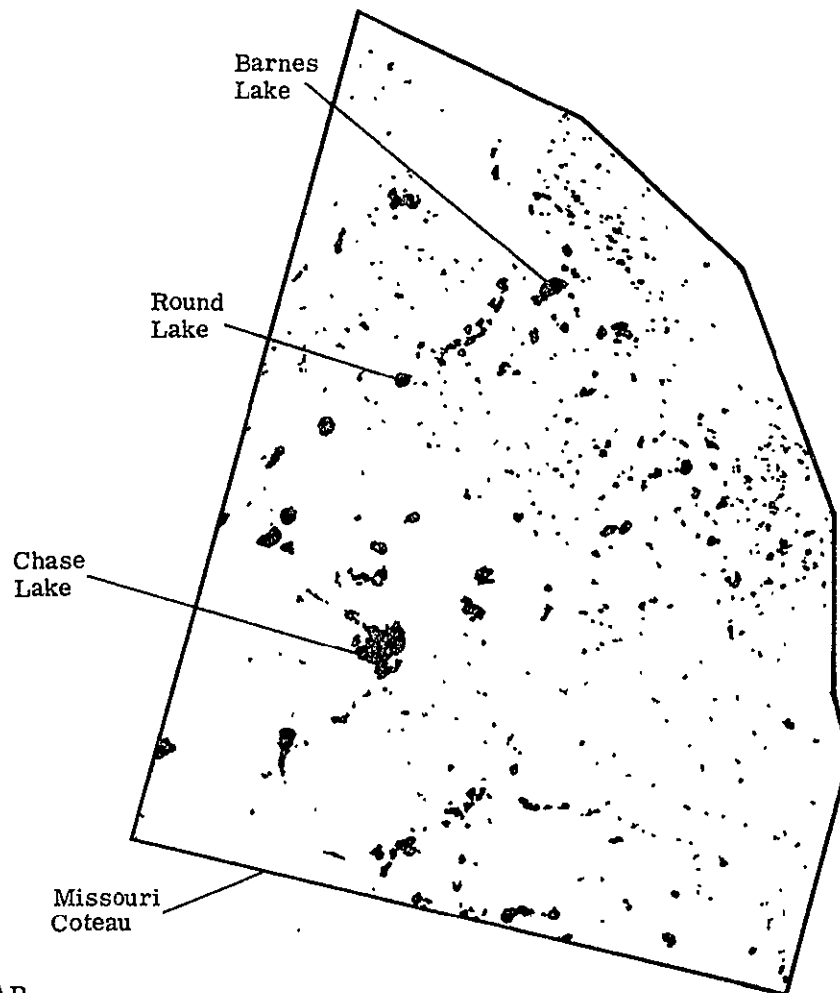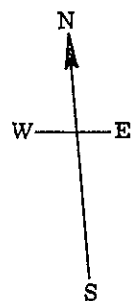Barnes
Lake

Round
Lake

Chase
Lake

Missouri
Coteau

Figure 3. 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.
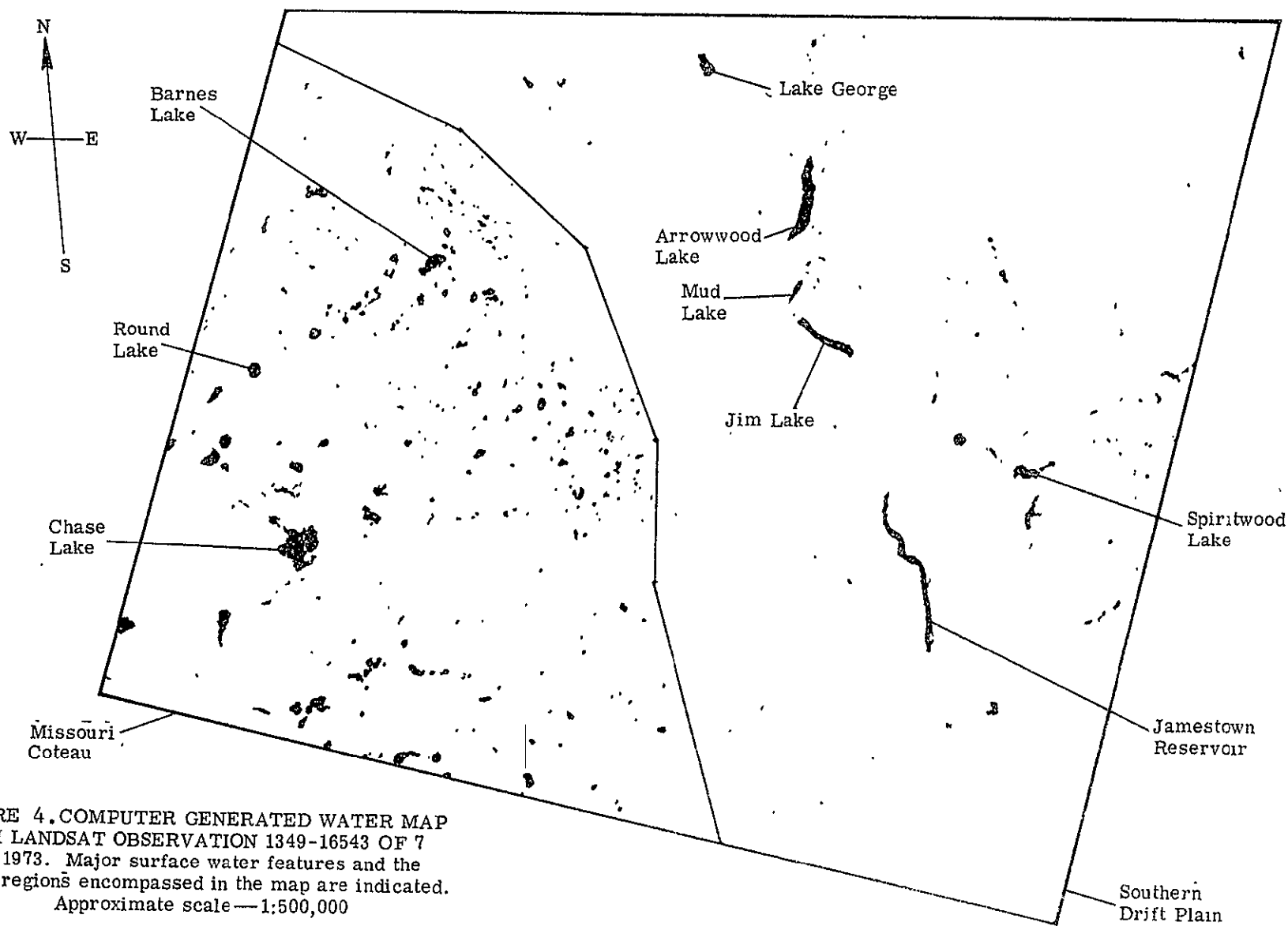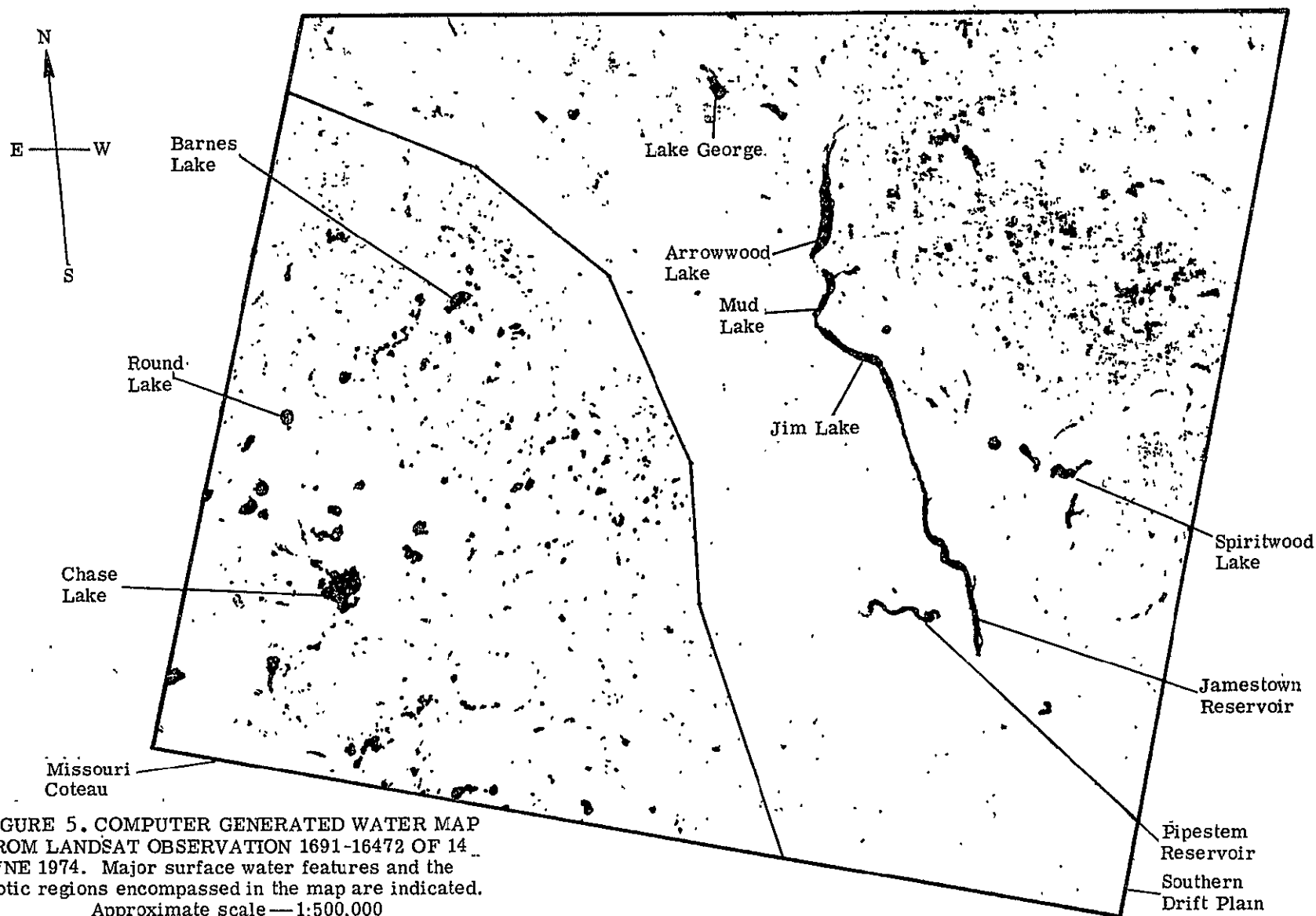Approximate scale — 1:500,000

N

W —— E

S

Barnes
Lake

Lake George

Arrowwood
Lake

Mud
Lake

Round
Lake

Jim Lake

Spiritwood
Lake

Chase
Lake

Missouri
Coteau

Jamestown
Reservoir

FIGURE 4.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

Southern
Drift Plain

FIGURE 5. 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
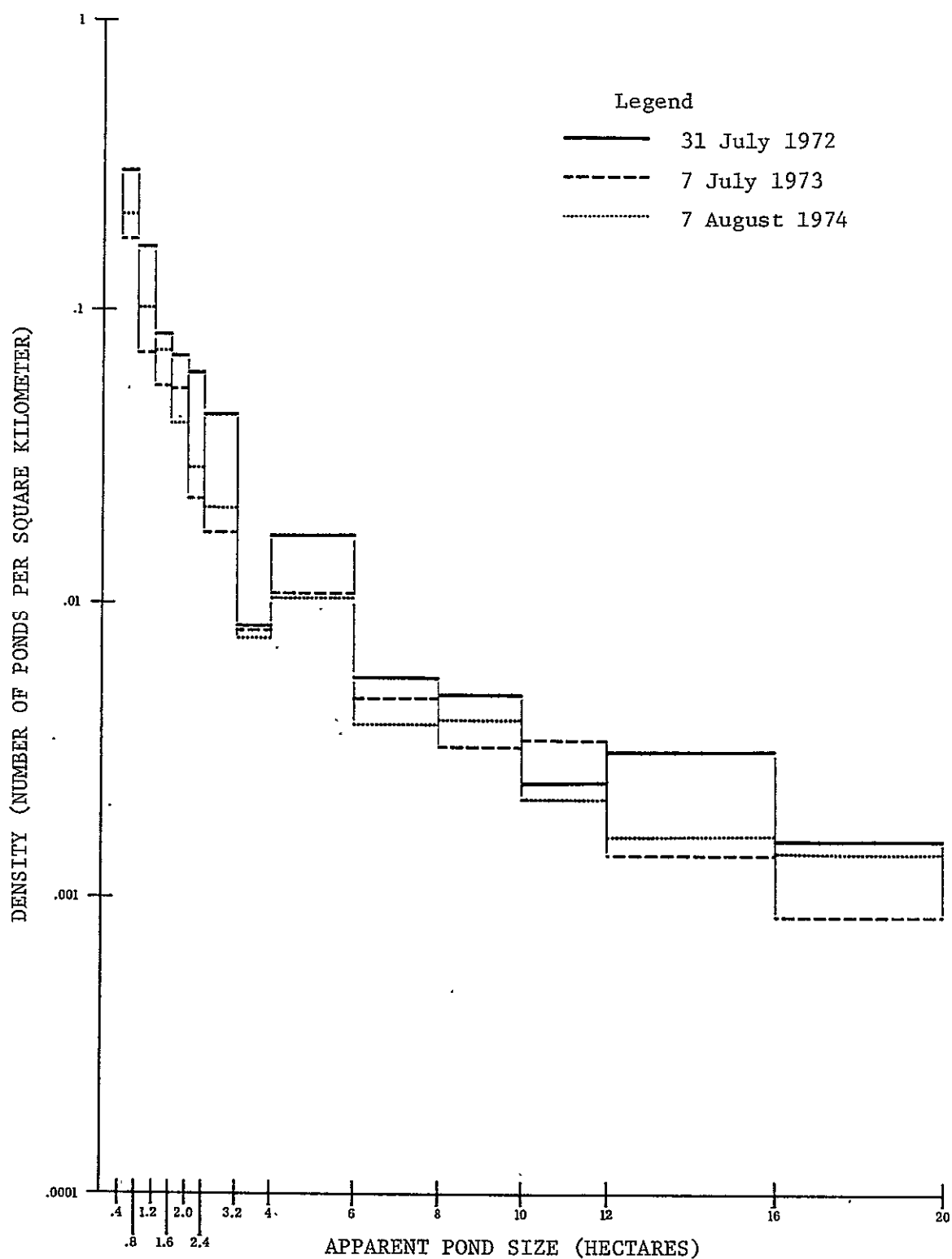
FIGURE 6. CHANGES IN SIZE DISTRIBUTION OF PONDS IN THE COTEAU
SUBSTRATUM AS OBSERVED ANNUALLY DURING THE WATERFOWL BROOD
SEASON. Data within the various pond size increments have each
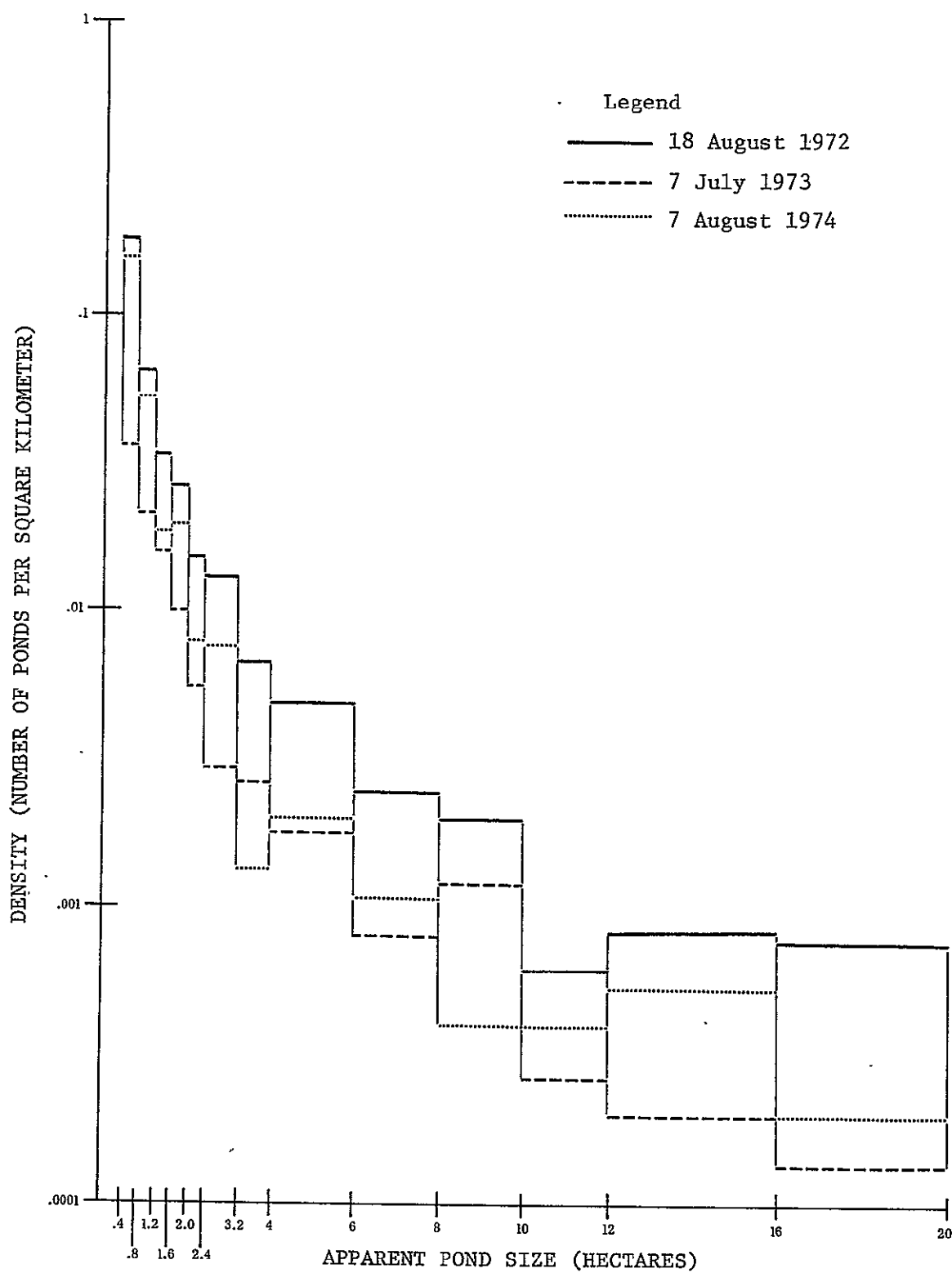been normalized to a nominal one-hectare increment.

FIGURE 7.: CHANGES IN SIZE DISTRIBUTION OF PONDS IN THE DRIFT PLAIN SUBSTRATUM AS OBSERVED ANNUALLY DURING THE WATERFOWL BROOD SEASON. Data within the various pond size increments have each been normalized to a nominal one-hectare increment.

12

Remote Sensing Techniques used to Assess Waterfowl Habitat Resources

N

JAMESTOWN

Eyes in the Sky for Wildlife
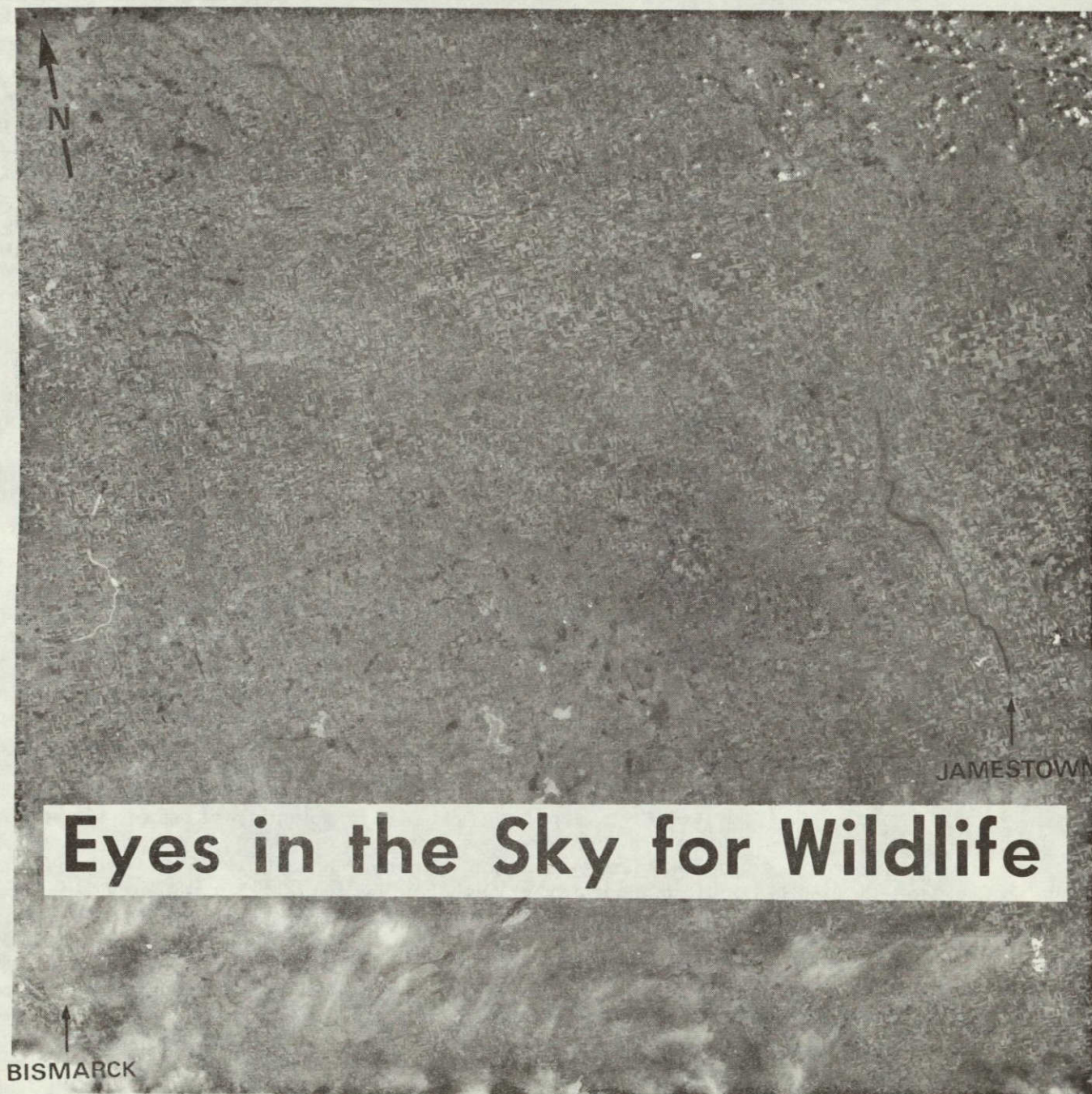
BISMARCK

Imagery collected by the LANDSAT-1 satellite over central North Dakota on 31 July 1972 from an altitude of 570 miles. The area shown contains approximately 12,000 square miles. Bismarck is partially hidden by cirrus clouds near the lower left corner and Jamestown is visible near the right edge of the image. Interstate Highway 94 passes diagonally across the lower half of the image. Portions of the McClusky Canal of the Garrison Diversion project are visible as light thread-like traces at left edge center. The puffy objects in the upper right corner are cumulous clouds. Land-use patterns are indicated by the mosaic of rectangular shapes of various shades of gray. Most surface water areas show as dark objects in this image. This picture was derived by photographing a video image of a tape recorded electronic signal. The electronic signal had previously been transmitted from the satellite to a ground receiving station.

Imagery of North Dakota taken from a satellite orbiting hundreds of miles above the earth may resemble modern art to the untrained eye, but data derived from these sources are providing

Spacecraft
(Orbital Altitude)

Sensor

Spacecraft Program

Aircraft Program

High Altitude
(60,000 ft.)
RB-57

Sensor

Low Altitude
(15,000 ft.)
C-47

Sensor

Theoretical Analysis

Laboratory Experiments

Field Experiment

Sensor

Target

Ground Data

Remote sensing is a term used to describe the study of objects from a distance, such as the examination of the earth's surface using aircraft or spacecraft sensors. The sensors used in this type of work may include conventional cameras or more sophisticated equipment for detecting and recording wavelength information that cannot be seen by the human eye. Sensors used at lower altitudes are capable of providing fine spatial detail while the high altitude sensors tend to provide a synoptic or wide-area overview. The above illustration shows the various "levels" at which remote sensing information is acquired. Ground data, often called "ground truth," are collected at or near the earth surface in order to help interpret the larger amounts of data obtained from much greater distances.

By David S. Gilmer, Northern Prairie Wildlife Research Center
U. S. Fish and Wildlife Service
and
Edgar A. Work, Jr., Environmental Research Institute of Michigan

a wealth of information for managers and scientists interested in earth resources problems. "Remote sensing" is a relatively new term, coined to describe the remote study of objects on the earth by detection and analysis of radiation either reflecting or emitting from them. The relative amounts of energy received by remote sensing instruments is often a function of the physical properties of these objects. In a traditional case, remote sensing is accomplished by trained photo interpreters who analyze photographs taken with aerial cameras. Within the past decade other sensors and interpretive techniques have gained wide acceptance from natural resources scientists and managers.

Today the field of remote sensing includes a wide range of sensory devices which can be carried above the earth's surface on aircraft or satellites. The newer devices include mechanically-driven optical scanners and microwave sensors (such as radar). These devices are capable of collecting information in many different spectral or wavelength regions in addition to the visible region to which the human eye and ordinary photographic film are sensitive. Some sensors are capable of simultaneously collecting information in several spectral regions. These devices, described as multispectral, are designed to assimilate large amounts of information over short periods of time. This information is usually recorded in the form of electrical signals on magnetic tape and is analyzed by coupling the tape recorded signal into a high speed computer. But how does this affect wildlife?

The annual production of waterfowl on the breeding grounds in the Dakotas and prairie provinces of Canada de-

pends to a large degree on the abundance of wetlands and suitable nesting cover. Timely and accurate information on habitat conditions are needed in order to formulate annual hunting regulations and to monitor long term changes in wetland resources. Since 1947, surveys of the breeding grounds have been conducted each May and July by U.S. Fish and Wildlife biologists assisted by Canadian and State wildlife agencies. These surveys require weeks of effort involving many light aircraft and highly trained biologists, yet only a small portion of the wetland breeding grounds is observed. Because of the large area comprising the prairie region and the need for timely information, remote sensing seemed ideally suited for the tasks of assessing breeding ground conditions.

In 1968, the Northern Prairie Wildlife Research Center in cooperation with the Environmental Research Institute of Michigan began a program to evaluate the potentials of remote sensing systems for assessing waterfowl breeding habitat. Funding for this work has been provided by the Earth Resources Observation Systems (EROS) program of the U.S. Department of Interior and by the National Aeronautics and Space Administration (NASA). Experimental work was first conducted using the Center's field station at Woodworth as a test site. Data were collected from an aircraft with a multispectral scanner. The scanner recorded information in the visible wavelenghts as well as the ultraviolet and infrared regions of the spectrum. This information was continuously collected along the aircraft's flight path. Computers were used to evaluate the data to see how well the wetlands and other terrain features could be detected and identified. As this work progres-

sed, ways were discovered which improved our ability to map surface water conditions. Certain wavebands were found to be more sensitive for water detection and certain computers were found to be most useful in data analysis. Development of a digital computer program for producing statistics on pond numbers, size, and shape was a significant achievement during this work. Analyses techniques were also developed for statistically quantifying vegetation types and land-use classes.

In addition to using multispectral scanner data we also used aerial photographs obtained from a wide variety of sources. NASA's high flying RB-57 provided us with a very valuable source of photography for some areas in North Dakota. If we wanted up-to-date aerial views of specific locations, we satisfied our requirements by taking pictures from low flying light aircraft with a hand-held camera. These various kinds of photographs provided a means of checking the accuracy of computer analysis of the multispectral scanner data. In addition to the aircraft data, detailed information such as water surface conditions, turbidity, water depth, plant species, and distributions was collected by ground crews to document actual conditions on the study site at the time scanner data were collected. These kinds of data are commonly referred to as "ground truth." Experimental work with scanners, computer processing techniques, and other remote sensing technology provided important background upon which we could gradually expand the scope of our investigations.

In 1972, the first Earth Resources Technology Satellite (originally designated as ERTS-1, this satellite has recently been redesignated LANDSAT-1) was launched. Subsequently, a NASA funded study to evaluate the LANDSAT system for monitoring wetlands was carried out by the U.S. Fish and Wildlife Service. For this experiment satellite multispectral scanner data were collected in July 1972 and in May
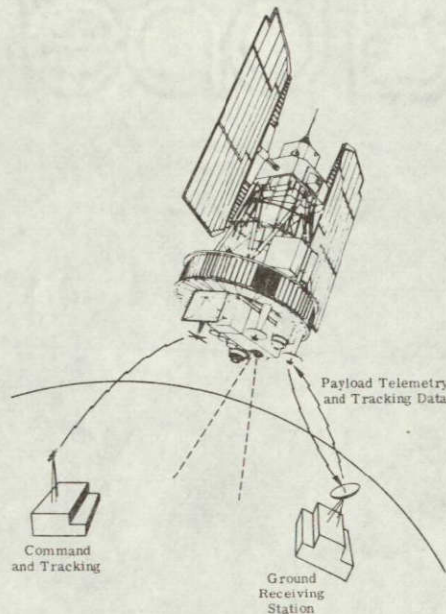

Diagram of the LANDSAT earth resources survey system. The satellite is in a near-polar orbit circling the earth 14 times each day and passes over any locations on the earth's surface once every 18 days. This repetitive coverage allows landsat to monitor time-dependent changes on the surface such as annual and seasonal variations in waterfowl habitat in the prairie region. The multispectral scanner aboard the satellite provides electrical signals which vary according to observed ground features. These signals are radioed to ground receiving stations where they are recorded on magnetic tape. The scanner detects solar energy reflected from the earth in four bands of the electromagnetic spectrum: green, red, and two near infrared bands.


Aircraft MSS Video 1.0-1.4 um. 28 July 1972, 4500 ft.
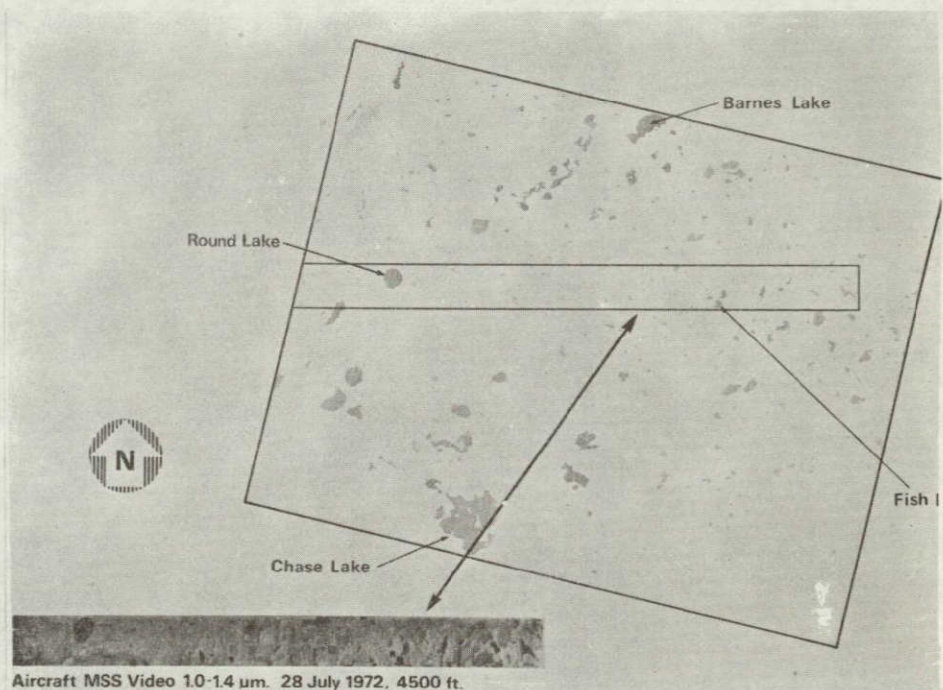
A computer generated recognition map of ponds and lakes in an area of approximately 400 square miles centered 35 miles northwest of Jamestown. Wildlife biologists are interested in the numbers and distributions of these water bodies in the northern prairie region for use in predicting annual waterfowl production. The above map was generated from electronic data telemetered from the LANDSAT satellite, tape recorded on the ground, and analyzed by a digital computer. The computer is programmed to produce these maps and also tabulates the area and location of each pond and lake and statistically summarizes these data for use by the biologist. The above LANDSAT observation occurred on 31 July 1972. The video image at the lower left was obtained by a multispectral scanner flown in an aircraft at an altitude of 4,500 feet above the terrain three days before the LANDSAT observation. This video display represents information present in an infrared spectral region (1.0 to 1.4 micrometers) which can only be detected by special remote sensing equipment. At these wavelengths all water features appear extremely dark.
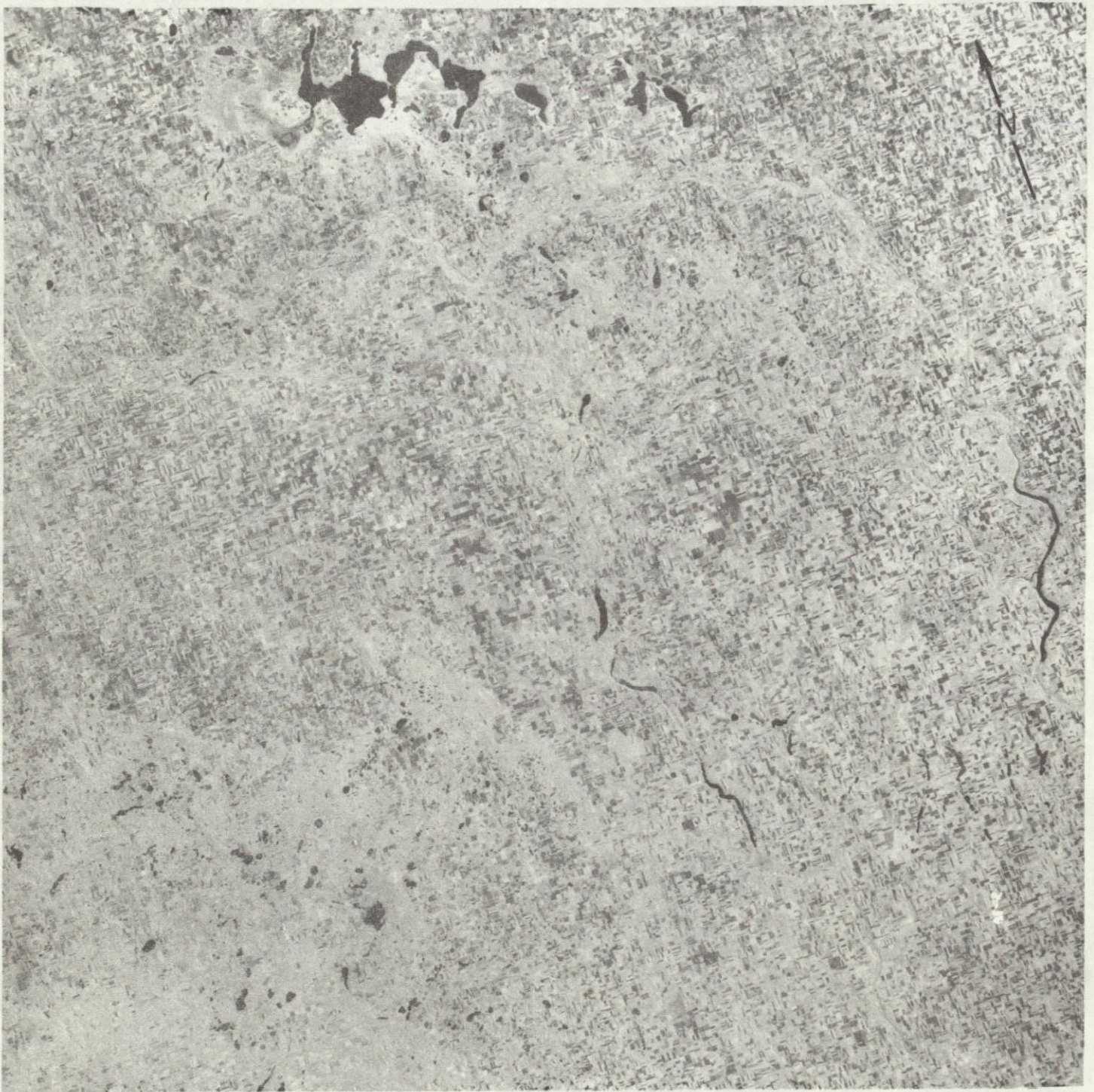
An infrared photograph taken over east-central North Dakota from SKYLAB on 12 June 1973. The satellite was travelling in an orbit approximately 270 miles above the earth. This photograph includes an area approximately 100 miles on a side. Devils Lake is near the upper edge of the photograph while portions of the James and Sheyenne River systems lie at right-center and the extreme right, respectively. Agricultural fields show as clearly defined patterns. Many of the darker fields were in summer fallow or were recently seeded. Photography is capable of finer image detail (resolution) than many other sensor devices but a disadvantage is that photographic films are sensitive to only visible light and a limited range of infrared radiation.
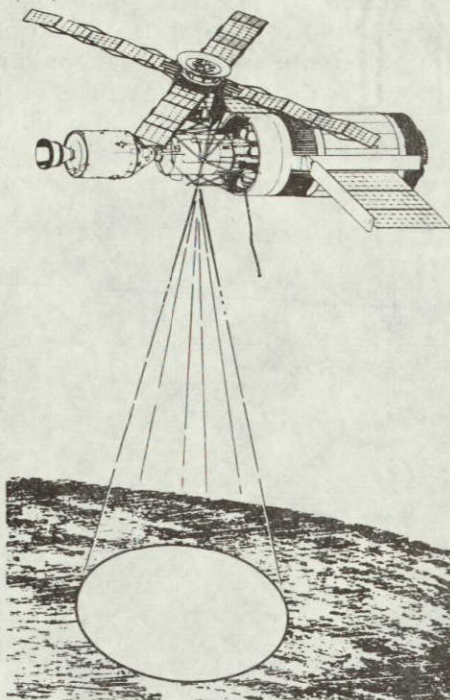
Courtesy Martin-Marietta

SKYLAB shown here as an artist's rendition was launched in May 1973 and was operated until February 1974. During this period the satellite was manned by three different astronaut crews. One of the main purposes of the SKYLAB program was to conduct earth resources remote sensing studies. Earth observations were recorded using a variety of sensors including photographic cameras, a multispectral scanner, and passive microwave and radar systems. Data obtained during the experiments were returned to earth with the astronaut crew members. Several kinds of photography and 12 bands of multispectral scanner data were collected over selected sites in North Dakota for use in evaluating the SKYLAB system for assessing waterfowl habitat conditions.

and July 1973 over a 1,280-square-mile area in east-central North Dakota. Another NASA funded remote sensing experiment was initiated in May 1973 when the space laboratory SKYLAB was launched. This manned satellite carried experimental equipment including a multispectral scanner, cameras, and other sensors for examining earth resources. The main objectives of these studies were to detect and map wetlands in North Dakota using data derived from the multispectral scanners aboard these two space platforms.
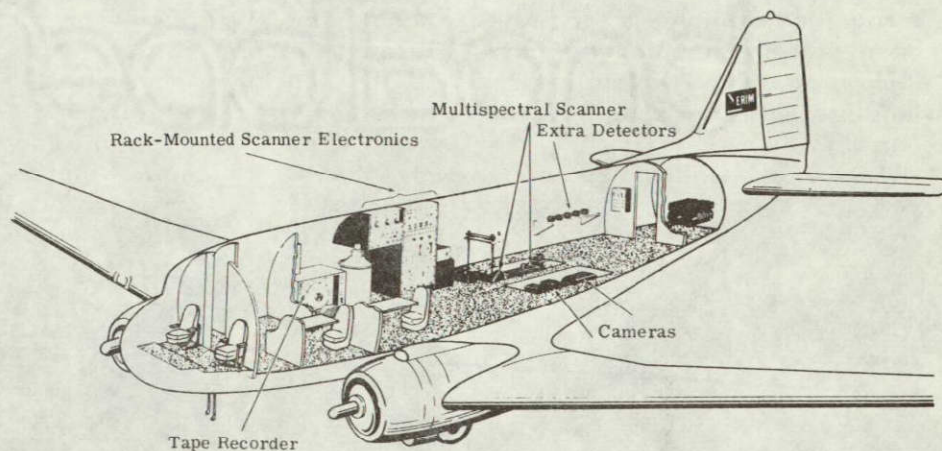
A cutaway illustration of a remcte sensing DC-3 aircraft operated by the Environmental Research Institute of Michigan (ERIM). Since 1968, this aircraft has made numerous survey flights over North Dakota in support of remote sensing studies of waterfowl habitat. The instrument complement of this aircraft includes five cameras and a multispectral scanner capable of simultaneously sensing radiation in many discrete wavelengths throughout the visible spectral region as well as portions of the ultraviolet and infrared spectral regions. The aircraft's maximum operating altitude is 15,000 feet. Other aircraft that have conducted survey flights over North Dakota include NASA's NP-3A and the RB-57 capable of flights at altitudes up to 60,000 feet. Both aircraft carry sophisticated remote sensing equipment such as cameras, scanners, and microwave sensors.

As the work of producing computer generated maps of water and vegetation progressed from airborne to spaceborne systems, a need for quantifying the resultant product became very apparent. Because maps often required large amounts of time to produce, assemble, and interpret it seemed desirable to generate statistical summaries of wetlands distributions. We have found that these summaries provide the most useful assessment of wetland conditions.

Satellites have introduced a whole new dimension in remote sensing capabilities but also posed new problems in data handling, analyses, and interpretation. Several problem areas have been encountered in the use of satellites for wetland detection. Although resolution capabilites of scanners aboard LANDSAT and SKYLAB are not quite sufficient to consistently detect wetlands smaller than about four acres, these smaller ponds are of major importance to breeding ducks. Another problem is the accurate classification of a variety of vegetation types using the wavelength bands recorded by the LANDSAT scanner. We have made considerable progress

in solving some of these problems. For instance, by applying certain computer processing techniques we can actually improve the interpretability of the data by a considerable amount. Better capability in classifying vegetation will be achieved by using data collected at several stages during the growing season. We also realize that in future surveys of large geographic areas satellite data will probably be used to provide a regional view of "Big Picture," while aircraft data collected near the earth's surface will provide a detailed look at specific areas.

During January 1975, the second earth resources satellite, LANDSAT-2, was launched. This satellite, similar to LANDSAT-1, will permit continued investigation of remote sensing data after the now aged LANDSAT-1 ceases to operate. NASA has recently funded the U.S. Fish and Wildlife Service for continued investigations in the use of satellite data for wetland resources studies. In this effort we are attempting to integrate aircraft-and satellite-acquired remote sensing data in order to inventory wetlands in a 40,000-square-mile region of North Dakota. Besides wetland

recognition, emphasis also has been placed on obtaining information on upland vegetation and land-use utilizing satellite scanner data.

This work will be completed about June 1976. At that time recommendations can be made as to the feasibility and effectiveness of using sophisticated remote sensing techniques to inventory and monitor waterfowl breeding areas. It is apparent at this stage that aircraft and satellite remote sensing technology has indicated considerable potential for future use in wildlife conservation and research.
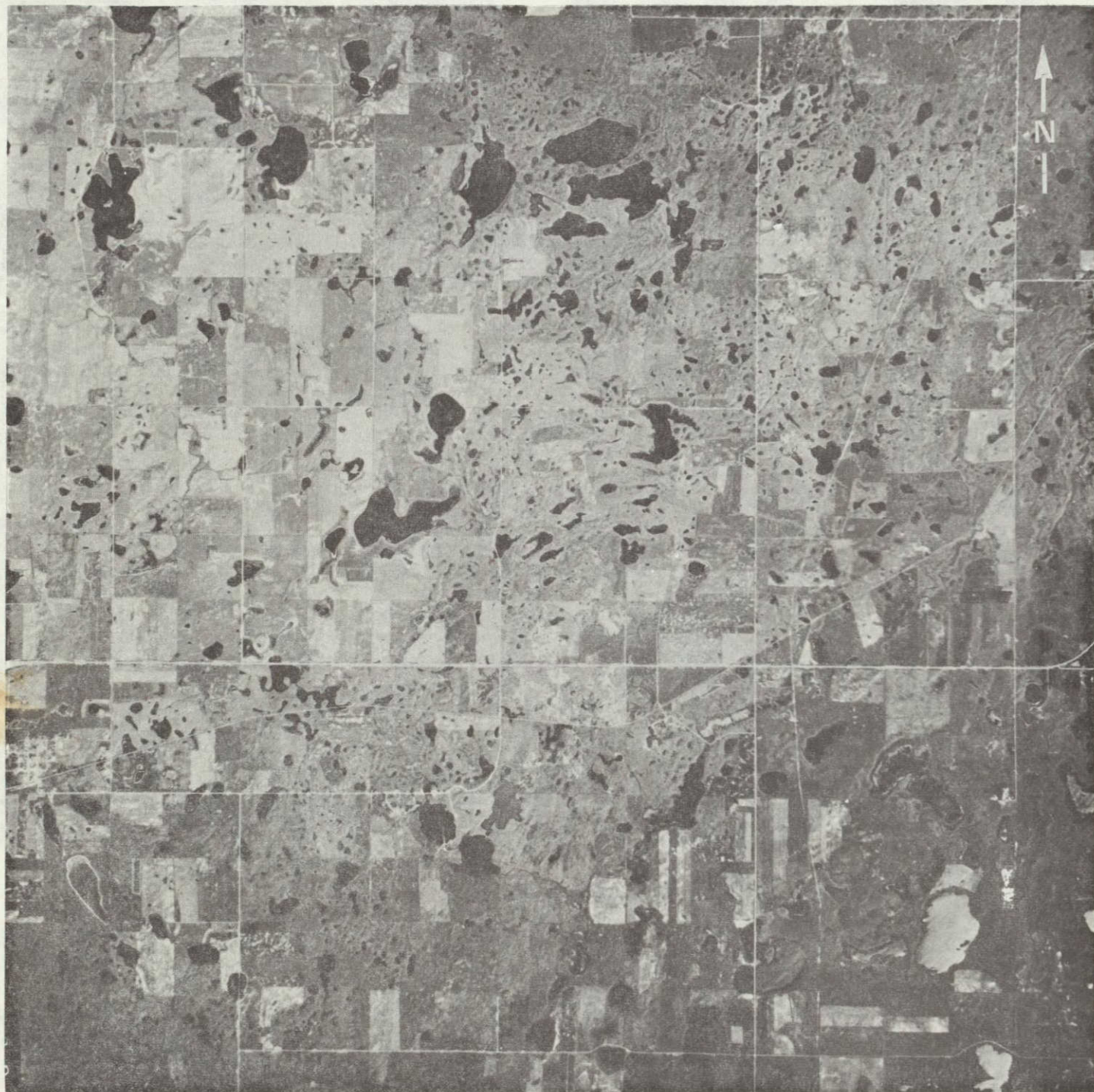
This photograph was obtained in the vicinity of Woodworth on 1 July 1970 using an aerial camera system mounted in NASA's RB-57 aircraft flying at an altitude of approximately 60,000 feet. Features such as small wetlands and stock ponds are clearly indicated in this type of aerial photography. Data collected over the same area from satellite and aircraft as well as by crews on the ground enable us to examine waterfowl habitat at various levels. This kind of statistical design is often used in remote sensing studies and is termed "multistage" sampling. The satellite provides a "region wide" view of the area in which we are interested but at satellite altitudes we cannot detect detailed terrain features such as small wetlands. Photography and scanner data obtained from aircraft operating at various altitudes below the satellite provide increasingly greater detail but only cover small areas within the satellite picture. Finally, data collected by ground crews provide detailed information used to interpret aircraft and satellite imagery.