EDGAR A. WORK, JR.
Environmental Research Institute of Michigan
Ann Arbor, MI 48107
DAVID S. GILMER
U. S. Fish and Wildlife Service
Jamestown, ND 58401

Utilization of Satellite Data for Inventorying Prairie Ponds and Lakes

LANDSAT-1 data were used to discriminate ponds and lakes for waterfowl management.

INTRODUCTION

THE PRIMARY BREEDING AREAS of North American waterfowl are the Dakotas, the southern portions of the prairie provinces, northwestern Canada, and parts of Alaska. These areas are annually the sites of systematic surveys conducted by the U.S. Fish and Wildlife Service (FWS) in cooperation with the Canadian Wildlife Service and various states and provinces. The surveys serve to aid management decisions relating to annual hunting regulations and research needs by providing an estimate of population size and annual reproduction. These surveys rely chiefly upon observations made from low-flying light aircraft traveling established sampling transects. Numbers and distributions of natural ponds and lakes as tabulated during these flights are an important criteria used in assessing annual waterfowl production. In order to explore procedures which could enhance FWS capabilities for monitoring annual and seasonal changes in water conditions, an evaluation of LANDSAT-1 (formerly ERTS-1) sensors was conducted (Work 1974; Work *et al.*, in press). Objectives of that investigation were to map and tabulate statistics on surface water conditions and to determine changes in wetness between spring and summer during a two-year period in a glaciated prairie region located in east-central North Dakota. This

ABSTRACT: *By using data acquired by LANDSAT-1 (formerly ERTS-1), studies were conducted in extracting information necessary for formulating management decisions relating to migratory waterfowl. Management decisions are based in part on an assessment of habitat characteristics, specifically numbers, distribution, and quality of ponds and lakes in the prime breeding range. This paper reports on a study concerned with mapping open surface water features in the glaciated prairies. Emphasis was placed on the recognition of these features based upon water's uniquely low radiance in a single near-infrared waveband. The results of this recognition were thematic maps and statistics relating to open surface water. In a related effort, the added information content of multiple spectral wavebands was used for discriminating surface water at a level of detail finer than the virtual resolution of the data. The basic theory of this technique and some preliminary results are described.*

paper reports on the techniques used to detect and characterize open surface water features.

Preliminary Considerations

Level thresholding of a radiation signal in a near-infrared waveband is a reliable and simple technique for delineating surface water. This technique is effective because at near-infrared wavelengths the apparent radiance of water is usually uniform and lower than for other terrain objects. Thus, using an appropriate near-infrared waveband, water may be delineated by accepting scene points with low radiance values (classified as water) while rejecting all values above a certain threshold (non-water). In order to appreciate the use of and limitations to this technique a brief discussion follows.

The apparent radiance of a body of water is the result of (1) reflections at the air-water interface, (2) reflections from particulate matter suspended in the water volume, and (3) reflections from the bottom. Because the field-of-view of the LANDSAT scanner is limited to near vertical observations (nominally to within 5.78 degrees of satellite nadir) and because water surfaces reflect specularly, radiation reflected by water to the scanner must emanate from a sky position near the zenith. Given the northerly latitudes which characterize the glaciated prairies, the LANDSAT scanner does not view water-reflected direct solar radiation (i.e., the ground specular point is at a considerable distance outside the field-of-view of the scanner).* This leaves only that fraction of diffuse skylight which emanates from a near-zenith sky location to impinge upon the water surface and thence to be reflected to the scanner. In relative magnitude, however, diffuse skylight is much weaker than direct solar radiation, especially in the near-infrared and under clear sky conditions when optimal satellite observations are possible. McDowell (1974) illustrated the magnitude and spectral differences between diffuse skylight and direct solar radiation (Figure 1). In addition, the reflected skylight component is further diminished because water surfaces are a uniformly weak reflector of radiation which impinges at any but very oblique angles (Figure 2).

In considering reflections emanating from particulates within the water volume and from the bottom surface, water's absorptivity must be considered. In the near-infrared, that fraction of radiation which penetrates the air-water interface is largely absorbed, the extent of absorption being dependent upon the wavelength and the length of the water path. This situation is shown quantitatively in Figure 3, which illustrates the spectral transmission of pure water for a variety of path lengths. Consequently, a sensor viewing a water body in a near-infrared band receives little or no radiation that may have been reflected by the bottom or volume suspended particulates.

The relative utility of different near-infrared bands for detecting water should not be predicated purely on the basis of longer wavelengths. For example, the use of a waveband in the 2.0- to 2.6-μm atmospheric window is not optimal because of the decreasing amount of solar radiation at these wavelengths. It must be remembered that most terrestrial objects are relatively strong diffuse reflectors and that with adequate solar illumination such targets will contrast sharply with darker surface water features. An ideal waveband for delineating surface water is the 1.5- to 1.8-μm spectral interval (Work and Thomson 1974; Work 1974). Sufficient solar illumination is available in this waveband to illuminate background objects. By using this waveband, it is also possible in many instances to distinguish water which is occluded by aquatic plants. These capabilities are of particular importance for lower-altitude aircraft data in which case it is both possible and desirable to identify small ponds, sheet water, and shoreline patterns of larger ponds and lakes. Analyzing LANDSAT-1 scanner data, however, we found band-7 (0.8 to 1.1 μm) to be satisfactory except for an occasional omission error

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

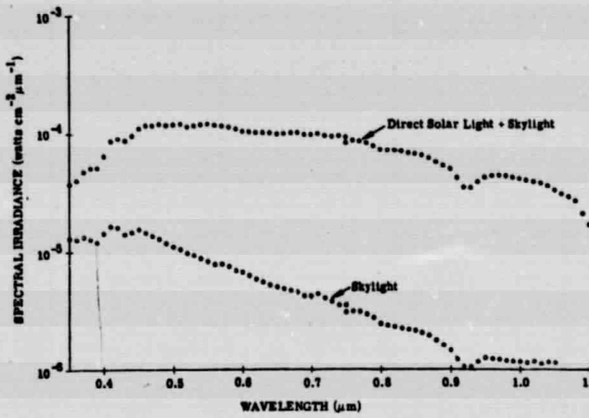

FIG. 1. Scene irradiance components for a clear day. (After McDowell, 1974.) Spectral irradiance levels attributable to skylight alone may be significantly different and variable with wavelength due to variations in atmospheric haze. The conditions shown were recorded on an exceptionally clear day in New Mexico on 30 October 1970 at a sun elevation angle of 43 degrees.

in the case of shallow ponds carrying high sediment loads.

METHODS

Our delineation of surface water was accomplished by using a high-speed digital computer which examined each scene pixel (picture element) and classified the pixel as either water or non-water. In training the computer for this automated classification, data samples were examined in order to determine typical water radiance levels and the radiance levels of other scene materials also known to have low radiance characteristics. Experience has shown that various scene objects exhibit radiances that may approach the low radiance of water depending upon the specific near-infrared waveband under consideration, the geographic locale, and the phenologic state of scene objects. In eastern North Dakota, dark prairie soils,

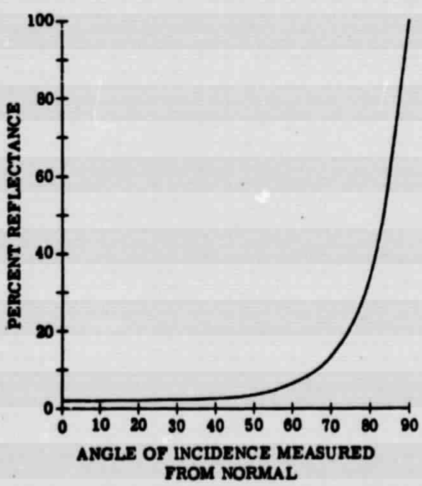

FIG. 2. Variation of reflecting power of the air-water interface as a function of the angle of incidence (Natural or unpolarized light of wavelength 0.589 μm).

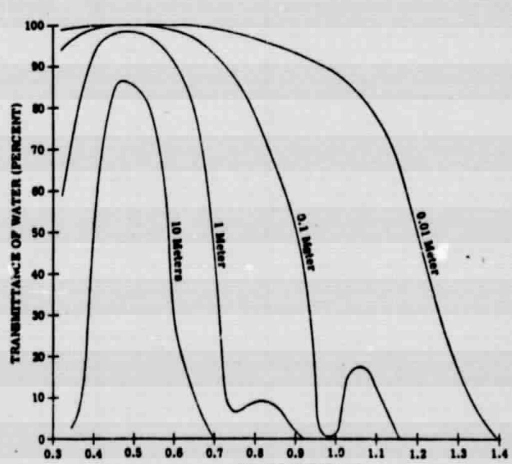

FIG. 3. Spectral transmittance of pure water for different path lengths. (Plotted after data from Sverdrup *et al.*, 1942.)

3

Mollisols (formely referred to as Chernozems), have consistently approached the low radiance values of water in the 0.8- to 1.1-μm waveband. In such a situation, sampled water and soil radiance values were examined in order to discern relative differences. Typical histograms or frequency distributions are shown in Figure 4. In these data, both water and soil had distributions which were displaced from each other although slight overlap occurred in the tail regions. We have found that shallow water features are often represented within the leading tail of such a water distribution; as a result, the threshold or decision boundary was located nearer to the soil's density peak in order to group the shallow water situations with other surface water categories.

Results

The intent of the recognition process was to monitor changes in surface water conditions for a seasonal (May-to-July) and an annual period (July-to-July). Data gathered by LANDSAT-1 on 31 July 1972, 14 May 1973, and 7 July 1973 were analyzed. The same area comprising 3311 km^2 (1278 mi^2) was observed on each of these dates. The study area included portions of two different physiographic regions: a coteau or moraine feature created by stagnation ice, and a drift plain or low relief feature of numerous ground moraines. The drift plain inherently has fewer potholes or basin features and, because of its low relief, has been subjected to numerous wetland drainage projects. This difference in wetland occurrence warranted a stratification of the numerical results based on these physiographic variations.

A computer-generated thematic map identifying surface water in a portion of the study area located almost wholly within the coteau physiographic region was produced (Figure 5). Although a digital map of the type illustrated graphically portrays water conditions, it does not represent an efficient form of data management. Thematic maps as such, and

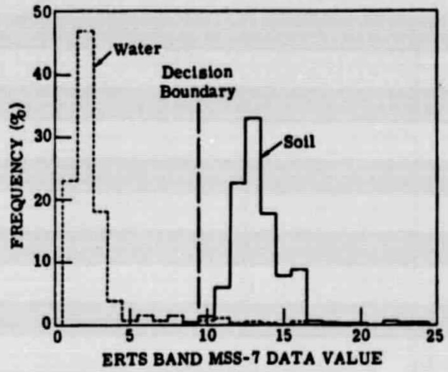

Fig. 4. Histograms used to locate a decision or threshold boundary for separating water from non-water terrain features.

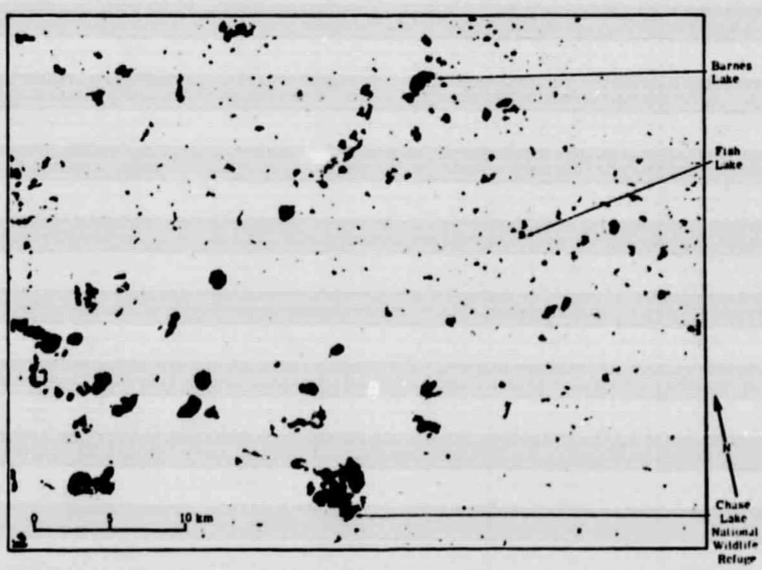

Fig. 5. Digital water recognition map from ERTS observation 1008-16594 of 31 July 1972. The map, obtained by thresholding channel MSS-7, depicts an area northwest of Jamestown, North Dakota.

4

the required manual interpretation, are not feasible for wide area surveys on a routine basis. For purposes of analysis, the data generally has greater value if it is presented in terms of statistical tables. Figure 6 illustrates a computer-generated statistical tabulation of ponds and lakes observed on 7 July 1973 in that portion of the study area lying in the coteau physiographic region. The upper listing itemizes all ponds recognized in the scene and provides the location of each pond based on a coordinate system derived from the sensor's scanning geometry and also on a geographic coordinate system. A size frequency distribution of ponds in the entire scene is presented in the lower tabulation.

A graphical summary of pond frequency for two dates illustrates the pond size distribution for the coteau portion of the study area (Figure 7). The two curves show that a decrease in pond numbers occurred in the 1973 May-to-July interval. Information on changes in pond numbers over this seasonal period is an important data input to models

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

TABULATION OF RECOGNIZED WATER BODIES

LAT	LONG	SCAN LINE	POINT	AREA (ACRES)	AREA (HECTARES)
47.3710	99.4194	1439	194	20.867	8.445
47.3909	99.5535	1440	13	1.098	.444
47.3733	99.4483	1442	156	1.098	.444
47.3637	99.4051	1446	216	7.688	3.111
47.3668	99.4399	1449	170	1.098	.444
47.3320	99.2560	1458	422	1.098	.444
47.3288	99.2353	1458	450	1.098	.444
47.3281	99.2403	1460	444	4.393	1.778
47.3489	99.3953	1464	236	2.196	.889
47.3282	99.2599	1464	419	2.196	.889
47.3193	99.2149	1467	481	3.295	1.333
47.3176	99.2053	1467	494	2.196	.889
47.3268	99.2699	1468	407	4.393	1.778
47.3532	99.4564	1471	156	1.098	.444
47.3194	99.2509	1474	435	2.196	.889
47.3164	99.2458	1477	443	1.098	.444
47.3270	99.3193	1478	344	3.295	1.333
46.8292	99.2766	2154	655	76.877	31.112
46.9153	99.2597	2157	706	2.196	.889
46.9163	99.2510	2158	691	27.456	11.111
46.8419	99.4221	2159	460	1.098	.444
46.9124	99.3655	2160	537	83.466	33.779
46.8122	99.2338	2160	715	1.098	.444
46.8236	99.3183	2166	603	46.126	18.667
46.8418	99.4842	2172	381	2.196	.889
46.8051	99.2446	2172	705	19.768	8.000
46.8024	99.2417	2175	710	4.393	1.778

SCENE N.D. COTEAU

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

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

PIXEL LENGTH = 79.00 METERS PIXEL WIDTH = 56.26 METERS

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

DISTRIBUTION OF LAKES IN THE SCENE

BY AREA

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

FIG. 6. Example of computer printout of pond and lake statistics for an area within the Coteau du Missouri physiographic region of North Dakota. Data collected by ERTS-1 at 1654 GMT on 7 July 1973.

5

currently used for predicting waterfowl production (Geis *et al.*, 1969).

In examining these data it should be recognized that the pond sizes listed by the computer should in practice be termed "apparent size." This is because each pixel of data was examined and determined to be either totally water or not water. Many pixels lying on the perimeters of ponds and lakes undoubtedly contained some unrecognized and untabulated water. This caused the surface areas of virtually all water features to be underestimated. In terms of percentage, the error were greater for the smaller ponds and for those of irregular shape (i.e., those having a high ratio of perimeter length to area). The very small ponds, of course, would not be recognized. Generally a pond must have been at least 0.4 hectare (1.0 acre) in size to be recognized. Recognition of a 0.4 hectare pond was dependent upon whether the pond was wholly included in one digital sample (i.e., within a pixel) or fractionally distributed over several pixels. In general, it is problematic whether ponds in the 0.4- to 1.6-hectare (1.0- to 4-acre) size class were recognized. Above 1.6 hectares, ponds were nearly always recognized but not necessarily recognized at their full areal extent.

Improvements in Spatial Resolution

Because prairie ponds are frequently smaller than 0.4 hectare (1.0 acre), it was apparent that many water bodies were not tabulated. We , therefore, undertook a radically different recognition technique which offered promise for improving the data's resolution limit. The remainder of this paper describes that approach and discusses some preliminary results.

When the instantaneous-field-of-view (IFOV) of a scanner is large with respect to the scene objects being scanned, a single resolution cell may contain a mixture of materials. In attempting to improve upon the data's resolution capabilities, we have utilized the added information content of multiple spectral wavebands to estimate the proportions or fractions of materials which fill the IFOV. The technique termed "proportion estimation" or "mixtures extimation" was first outlined by Horwitz *et al.* (1971) and further described by Nalepka *et al.* (1972). Before this study, the application of this technique was largely developmental in nature, and its use in this and another LANDSAT-1 study (Malila and Nalepka, 1973 and 1974) must be considered to be among the first attempts to test its applicability in an operational context.

A discussion of proportion estimation theory is beyond the scope of this paper, however the essence of the technique can be described in geometric terms. Assume that a data set comprised of two spectral channels, λ_1 and λ_2, contains three pure and unique materials — A, B, and C. This situation is depicted in Figure 8 where the signature

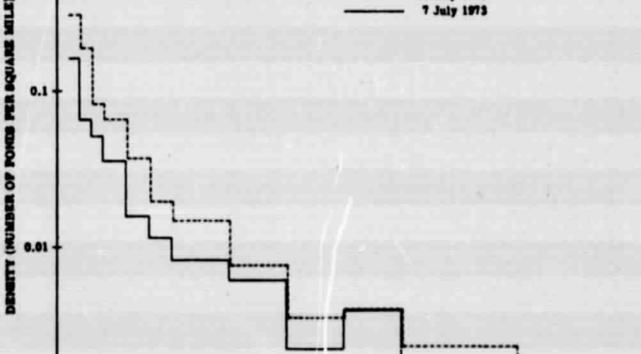

Fig. 7. Summary of size distribution of ponds in the coteau stratum for a seasonal period. Where the pond size increments are greater than one-acre, the data have been averaged over the increment.

means for the three materials are shown in two-dimensional signal space. In the nondegenerate case, each pure signature is a distinct vertex of the closed geometric figure or signature triangle. If an unknown scene element (IFOV) consists of a mixture of all three materials, the signature generated by this unknown element, X, lies within the simplex. An estimate of the proportion of each pure material constituting the unknown element is obtained by drawing a line from a vertex through the signal to be classified to the opposite leg of the simplex. The fraction of the line between the crossover point and opposite leg defines the proportion of the corresponding vertex material in the unknown. For the case illustrated in Figure 8, the unknown happens to lie at the centroid of the triangle, and its composition would be in the ratio of 1/3, 1/3, and 1/3 of materials A, B, and C respectively. A case requiring special geometric interpretation is shown in Figure 9. In this instance the unknown, Z, lies outside or on the edge of the signature simplex. The unknown is determined to be comprised of only materials A and C in the inverse ratio by which the simplex triangle's leg A-C is divided by a line drawn from Z orthogonally to that leg. If the unknown is quite distant from the signature simplex (described in terms of a χ^2 distance), the algorithm designates the unknown as an alien object or an object composed of none of the simplex materials.

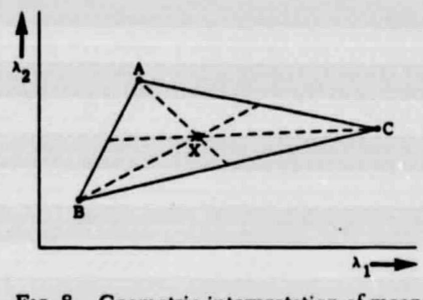

Fig. 8. Geometric interpretation of means of signature mixtures. In the case illustrated, the unknown, X, is a mixture of three pure materials - A, B, and C - which form the vertices of the signature simplex.

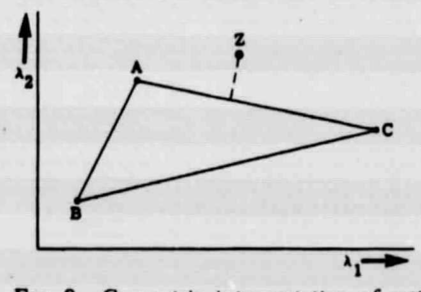

Fig. 9. Geometric interpretation of estimate for a special case. The unknown, Z, lying outside the signature simplex is a mixture of materials A and C.

Although the above description has been limited to three pure and unique materials in two-dimensional space, the concept is easily expanded to situations where many object materials exist in a spectral hyperspace. In applying the algorithm, however, it is necessary that two operational constraints be observed: (1) at least n-1 spectral channels of information are required to satisfactorily estimate mixtures of n-object materials, and (2) the signatures for the materials in a mixture must not be similar and no one signature must come close to the weighted average of the other signatures. If either of these latter conditions occur, the signature simplex is said to be degenerate, and the estimate of proportions may be poor or invalid.

In our study, the intent was to delineate water in a mixture of scene materials, thereby making it possible to improve the size estimates of larger ponds and, more significantly, to recognize small ponds which otherwise would not have been detected. Examining the data collected in the July 1973 time frame, it appeared that only two of the four LANDSAT wavebands were unique in representing the majority of scene materials present in eastern North Dakota. Bands 5 (0.6 to 0.7 μm) and 7 (0.8 to 1.1 μm) appeared to be best for distinguishing most scene materials while bands 4 (0.5 to 0.6 μm) and 6 (0.7 to 0.8 μm) were respectively redundant. This being the case, it appeared unlikely that the proportion estimation algorithm could function in using more than three signatures. As a result, we chose for processing signatures representing water, bare soils, and green vegetation. Using these signatures, the computational algorithm was applied to an area of 287 km^2 (110 mi^2). The resultant computer output was a set of water proportions for each scene pixel. A water recognition map generated from this output is shown in Figure 10 and, for comparison, a map generated by using the single waveband thresholding algorithm is shown in Figure 11. In the proportion estimation map, the symbol density is related to the proportion of water estimated for that pixel. In order for the map accurately to portray the scene, certain percentage or acceptance

7

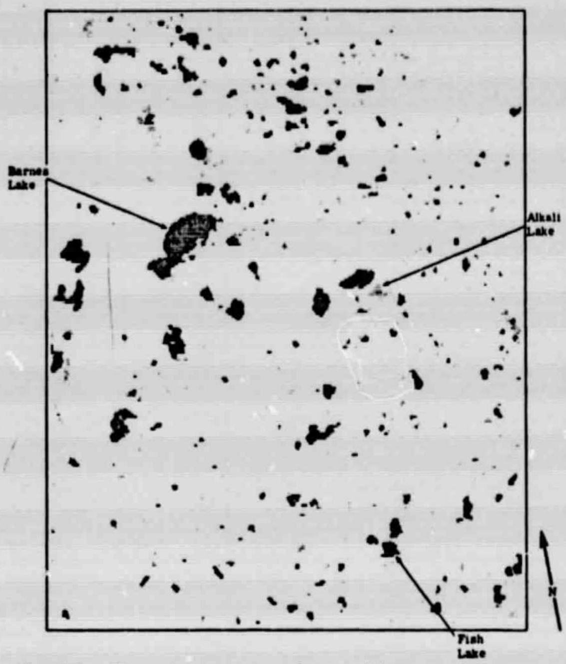

Fig. 10. Water recognition obtained by use of the proportion estimation algorithm. The symbol density is related to the proportion of water estimated for that pixel.

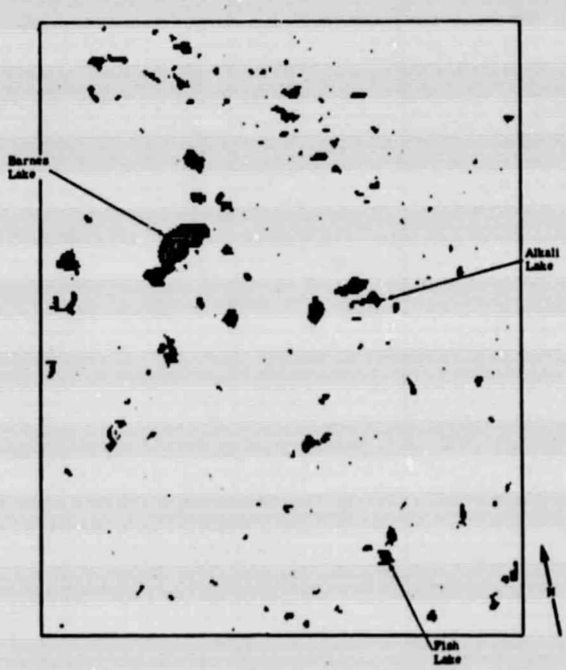

Fig. 11. Water recognition obtained by thresholding channel MSS-7. The decision criteria is such that each pixel has been classified as either totally water or not water.

8

limits were determined for the output of the algorithm. For example, it seemed appropriate to count pixel values of 86 per cent and above as totally water. This procedure tended to account for the likelihood that a value close to the signature mean (i.e., close in terms of its probability of being that material) may in fact have been a pure sample related to that mean. Similarly, pixels showing less than 30 per cent water were assumed to contain no water at all.

In general, a detailed comparison of the classification maps and related imagery indicated that proportion estimation significantly improved pond shape definition. Fish Lake and several nearby lakes shown in Figures 10 and 11 illustrate this fact. Alkali Lake (Figure 10), although recognized, was not accurately delineated. As implied by its name, the lake apparently was high in dissolved and precipitated solids and as such was a lacustrine feature for which the water signature utilized was not representative. An inspection of this same lake in aerial photography indicated a color hue similar to the highly saline (c.f., alkaline) lakes found occasionally throughout this area of North Dakota particularly during periods of low water. It should be noted that Alkali Lake was not omitted from our enumeration, only mis-recognized in terms of size. Our prime objective in applying the proportion estimation algorithm was to recognize many of the smaller water features which otherwise would not have been detected. From an examination of the results, it appears that all ponds larger than 0.5 hectare (1.3 acres) were consistently recognized and that many smaller ponds to 0.13 hectare (0.33 acre) as a minimum were recorded. This was a threefold improvement relative to the single-waveband thresholding technique. For the 287 km² area illustrated both in Figures 10 and 11, an increase of 131 per cent in the number of water bodies tabulated was observed relative to the number tabulated by using the thresholding algorithm.

Summary and Conclusions

The mapping of open water as an indicator of waterfowl habitat quality has been carried out by using two different recognition techniques, a single waveband thresholding approach and a multiple waveband approach termed "proportion estimation." The single waveband technique has proven simple to implement. Its computer algorithm was rapid and accurately recognized prairie lakes and large ponds. The resultant products of this processing technique were thematic maps and statistical tabulations describing open surface water conditons. The maps served to portray visually the location and frequency of surface water bodies but usually necessitated additional interpretation. Statistical tabulations provided a useful collation and data summary.

The proportion estimation technique, which utilizes the increased information content of multiple spectral bands, estimates the fraction of a resolution cell which may be composed of open water. This technique allowed for the recognition of a greater number of small ponds not previously identified and improved the apparent spatial resolution of the data by a factor of three in comparison to the single waveband thresholding technique.

Because of the effectiveness of the several recognition techniques described, development of an operational system using high-altitude sensors for synoptically characterizing wetland habitat conditions appears to be a realistic goal. In future operational systems which require the delineation of water features smaller than a resolution cell in size, we feel that a combination of the single waveband and the proportion estimation techniques is likely to be employed for the sake of accuracy and efficiency. Such a dual processing approach would effectively use the single waveband technique to identify those resolution cells comprised totally of water. The proportion estimation algorithm which is slower running and consequently more costly would be used to delineate only water peripheral to already identified ponds and lakes and those water features which are less than a resolution cell in size.

Acknowledgments

This work was supported in part by NASA Contract S-70243AG-4 to the U. S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Jamestown, North Dakota and their subcontract, USDI 14-16-0008-75 to the Environmental Research Institute of Michigan, Ann Arbor. We are especially grateful to Harvey K. Nelson who was the principal investigator on this program and to A. T. Klett who ably assisted in much of the associated field work.

References

Geis, A. D., R. K. Martinson, and D. R. Anderson. 1969. Establishing hunting regulations and allowable harvest of mallards in the United States. *J. Wildl. Mgmt.* 33(4): 848-859.

Horwitz, H. M., R. F. Nalepka, P. D. Hyde, and J.

9

P. Morgenstern. 1971. Estimating the proportions of objects within a single resolution element of a multispectral scanner. *Proc. of 7th Internat'l Symp. on Remote Sensing of Environment*, Willow Run Labs., Inst. of Sci. and Technol., The University of Michigan, Ann Arbor, pp. 1307-1930.

Malila, W. A., and R. F. Nalepka. 1973. Atmospheric effects in ERTS-1 data and advanced information extraction techniques. *Proc. Symposium on Significant Results from the Earth Resources Technology Satellite-1*, Vol. I, 5-9 Mar. 1973, New Carrollton, Md., sponsored by NASA/Goddard Space Flight Center, Greenbelt, Md., pp. 1097-1104.

Malila, W. A., and R. F. Nalepka. 1974. Advanced processing and information extraction techniques applied to ERTS-1 MSS data. *Proc. Third Earth Resource Technology Satellite-1 Symposium*, Vol. I. 10-14 Dec. 1973, Washington, D. C. sponsored by NASA/Goddard Space Flight Center, Greenbelt, Md., pp. 1743-1772.

McDowell, D. Q. 1974. Spectral distribution of skylight energy for two haze conditions. *Photogrammetric Engineering* 40(5): 569-571.

Nalepka, R. F., H. M. Horwitz , and P. D. Hyde. 1972. *Estimating proportions of objects from multispectral data.* Tech. Rep. No. 31650-73-T, Willow Run Labs., Inst. of Sci. and Technol., The University of Michigan, Ann Arbor. 47 pp.

Strong, A. E. 1973. ERTS-1 anomalous dark patches. *NASA ERSP Weekly Abstracts*, NTIS (E73-10747), U. S. Dept. of Commerce, Washington, D. C., pp 119-120.

Stumpf, H. G. and A. E. Strong. 1974. ERTS-1 views an oil slick? *Remote Sensing of Environment* 3: 87-90.

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1942. *The Oceans.* Prentice-Hall, Inc., Englewood Cliffs, N. J. 1087 pp.

Work, E. A., Jr. 1974. *Application of the Earth Resources Technology Satellite for monitoring the breeding habitat of migratory waterfowl in the glaciated prairies.* Master's Thesis. The University of Michigan. 107 pp. available from University Microfilms, Ann Arbor, Mich. (Thesis Abstr. M-6698.)

Work, E. A., Jr., D. S. Gilmer, A. T. Klett. (in press). *Utilization of ERTS-1 for appraising changes in continental migratory bird habitat.* Type III Final Report prepared for NASA, Goddard Space Flight Center, under contract.

Work, E. A., Jr. and F. J. Thomson. 1974. *A study of waterfowl habitat in North Dakota using remote sensing techniques: phase II.* Tech. Rep. No. 101000-12 T, Environmental Research Institute of Michigan, Ann Arbor. 96 pp.

10