National Aeronautics and
Space Administration

DEC 2 9 1980

Lyndon B. Johnson Space Center
Houston, Texas 77058

NASA CR-161012

DEVELOPMENT OF A UNIVERSAL WATER SIGNATURE FOR THE LANDSAT-3 MULTISPECTRAL SCANNER (part 1 of 2)

(NASA-CR-161012) DEVELOPMENT OF A UNIVERSAL WATER SIGNATURE FOR THE LANDSAT-3 MULTISPECTRAL SCANNER, PART 1 Final Report, Jan. - Sep. 1980 (Lockheed Engineering and Management) 27 p HC A03/MF A01 CSCL 08H G3/43

N81-26530

Unclas
30066

NAS 9-15800
LEMSCO-15621 (part 1)
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Prepared for
EARTH OBSERVATIONS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS 77058

JSC-17003, Part 1

1. Report No. JSC-17003, Part 1

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
DEVELOPMENT OF A UNIVERSAL WATER SIGNATURE FOR THE LANDSAT-3 MULTISPECTRAL SCANNER (Part 1 of 2)

5. Report Date
September 1980

6. Performing Organization Code

7. Author(s)
Edward H. Schlosser

8. Performing Organization Report No.
LEMSCO-15621 (Part 1)

9. Performing Organization Name and Address
Lockheed Engineering and Management Services Co., Inc.
1830 NASA Road 1
Houston, Texas 77058

10. Work Unit No.

11. Contract or Grant No.
NAS 9-15800

12. Sponsoring Agency Name and Address
O. G. Smith
Earth Observations Division
Lyndon B. Johnson Space Center, Houston, Texas 77058

13. Type of Report and Period Covered
Final, Jan - Sep 1980

14. Sponsoring Agency Code

15. Supplementary Notes
The water-classification discriminant and a water-ness transformation based on it have been incorporated in version 8009 of the Detection And Mapping (DAM) package for processing Landsat digital data.

16. Abstract
A generalized four-channel hyperplane to discriminate water from non-water was developed using Landsat-3 multispectral scanner (MSS) scenes and matching same/next-day color infrared aerial photography.

The MSS scenes over upstate New York, eastern Washington, Montana and Louisiana taken between May and October 1978 varied in sun elevation angle from 40 to 58 degrees. The 28 matching air photo frames selected for analysis contained over 1400 water bodies larger than one surface acre. A preliminary water discriminant, based on previously labelled cluster means from Landsat-3 scenes in east Texas, was used to screen the data and eliminate from further consideration all pixels distant from water in MSS spectral space. Approximately 1300 pixels, half of them non-edge water pixels and half non-water pixels spectrally close to water, were labelled. A linear discriminant was iteratively fitted to the labelled pixels, giving more weight to those pixels that were difficult to discriminate. This discriminant correctly classified 98.7 percent of the water pixels and 98.6 percent of the non-water pixels.

Per feature analysis of all 28 air photo frames indicated that the discriminant detected (with one or more pixels) 91.3 percent of the 414 water bodies over 10 acres in surface area. The discriminant misclassified as water 36 groups of contiguous non-water pixels, a "false alarm" rate equal to 8.7 percent of the water bodies over 10 acres.

17. Key Words (Suggested by Author(s))
Computer programs, Earth resources, Earth satellites, land use, Landsat satellites, mapping, remote sensors, surface water, thematic mapping

18. Distribution Statement

19. Security Classif. (of this report): Unclassified

20. Security Classif. (of this page): Unclassified

21. No. of Pages

22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161

PREFACE

This report documents the development of a universal four-channel water discriminant for the Landsat-3 multispectral scanner (MSS). The report is divided into two volumes. Part 1 describes the approach, data, preprocessing, analysis, and results. Part 2 contains technical appendices listing the input data, software, and computer-generated output.

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CONTENTS

FIGURES

Figure

1. PURPOSE

Multispectral scanners onboard NASA unmanned Landsat satellites provide valuable sources of current data for earth resources applications. A serious problem in utilizing Landsat data is the cost and difficulty of developing an individual set of signatures for each scene to be processed. This report describes the development of a 'universal' water signature for use with Landsat-3 multispectral scanner (MSS) digital data.

1.1 BACKGROUND

The U. S. Army Corps of Engineers is required by Public Law 92-367 to inventory and inspect qualifying non-federal dams. The qualifications are based on a combination of structure height and volume of water impounded. The Corps has been using surface water maps generated by the Detection And Mapping (DAM) package from Landsat-1 and Landsat-2 multispectral scanner (MSS) digital data to help update the existing inventory of dams. The set of spectral signatures being used to classify water were previously developed from Landsat-1 data in Texas and Landsat-2 data in Alabama. They are not useable with Landsat-3 MSS data due to differences in sensor response and calibration.

1.2 PERFORMANCE CRITERIA

Manual procedures documented as part of the DAM package eliminate certain urban features and terrain shadows incorrectly classified as water by the computer processing. The final classification results required by the Corps of this combined computer and manual processing are stated as percentages of the total number of water bodies ten acres or larger:

^ 90 percent or better correct detection of water bodies 10 acres or larger

^ 10 percent or fewer 'false alarms' (groups of non-water pixels misclassified as water bodies)

Although some proportion of impoundments less than 10 surface acres are expected to qualify for inclusion in the inventory, no criteria for their detection have been specified by the Corps.

2. STUDY DESIGN

2.1 CONSTRAINTS

This study was limited by the availability of hardware, software, and human resources supporting or available to the Earth Observations Division at the NASA Johnson Space Center in Houston. Site selection was limited to areas covered by retrospective data only. The Earth Resources Interactive Processing System (ERIPS) at JSC, the Bendix-100 digitizing system at JSC, and the On-Line Pattern Analysis and Recognition System (OLPARS) at Rome Air Development Center were not available for use in this study. Technical problems prevented the use of EOD LARSYS. No resources were available for field trips to any of the study sites.

2.2 APPROACH

Most of the United States surface area is neither water nor composed of materials which are spectrally near to water in the Landsat-3 MSS channels. The approach taken in this study is to select diverse study sites which have significant numbers of water bodies between two and fifty acres in size, to select only portions of those sites which have the greatest density of water bodies, and then to analyze intensively only those pixels which are spectrally near to water.

Figure 1 illustrates this approach. Preprocessing of both the Landsat and air photo data is designed to select only ground features and pixels which are water or (spectrally) near-water, and to eliminate other features and pixels from subsequent processing. To further reduce the effect of pixels lying far from the water/non-water spectral boundary, a linear discriminant hyperplane is fitted iteratively, with correctly classified pixels far from the hyperplane receiving less weight on subsequent iterations.

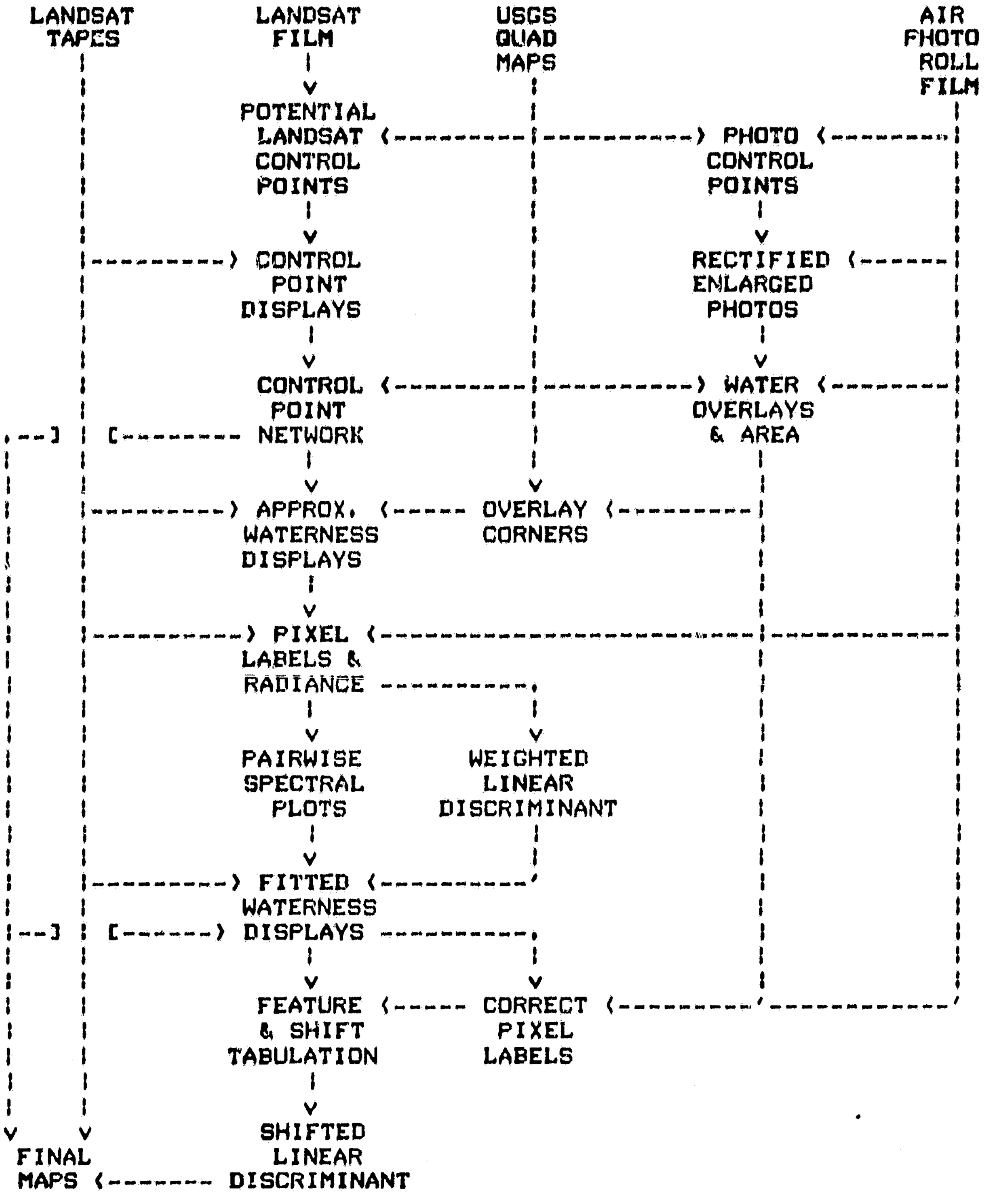

Figure 1. - Work flow.

3. DATA AND PREPROCESSING

3.1 SITE AND FRAME SELECTION

Great care was taken to select a set of study sites which varied in terrain, climate, vegation, time of year, and sun elevation angle. Nevertheless, all study sites were required to meet the following criteria:

- Landsat and color infrared air photo coverage within one week of each other
- No significant precipitation immediately before or between the Landsat and air photo coverage
- No extensive clouds or haze in the parts of the Landsat scene covered by air photos
- No scenes with sun elevation angles less than 35 degrees
- Significant number of water bodies between two and fifty acres
- Some (spectrally) near-water features, such as intensive urban, industrial, terrain shadows
- Published maps available at 1:24,000 or 1:62,500

An approximate count of water bodies by size was made for every air photo frame in each site. Based on this count, the variety of shape and color, and the presence of likely 'near-water' features, individual frames (not necessarily contiguous) were selected within each site.

Figure 2 lists the selected sites, together with information on the Landsat and air photo data.

3.2 AIR PHOTO PREPROCESSING

Each of the 28 selected air photos was individually rectified and enlarged to a scale of 1:24,000 using published 7.5 and 15 minute quadrangle maps for control. All water bodies over two acres were then delineated on a mylar sheet over each rectified

LANDSAT-3 SCENE NUMBER	STATE	DATE	SUN ELEV (DEG)	CENTER (DEG:MIN:SEC) LATITUDE NORTH	LONGITUDE WEST
30082-15120	NEW YORK	26MAY78	58	43:00:30	76:43:58
30130-18032	WASHINGTON	13JUL78	55	47:15:46	118:06:00
30194-17182	MONTANA	15SEP78	40	47:16:07	106:39:18
30216-16024	LOUISIANA	07OCT78	44	31:37:00	91:59:44

MISSION SITE FLIGHT	STATE	DATE	FOCAL LENGTH (IN)	ALTITUDE (FEET)	NUMBER OF FRAMES SELECTED
JSC-382-344-7	NEW YORK	26MAY78	6	58,000	12
AMES-78-092	WASHINGTON	13JUL78	6	65,000	9
AMES-78-136	MONTANA	16SEP78	6	65,000	3
AMES-78-143	LOUISIANA	08OCT78	12	65,000	4

Figure 2. - Landsat scenes and aerial photography.

frame. When necessary, the quadrangle maps were used and the roll film was interpreted using a stereoscope. The area of each delineated water body less than 50 acres was then measured with a digitizer.

Each rectified air photo was also overlaid with the corresponding quadrangle maps, and the UTM coordinates of each photo corner recorded for later use in generating matching computer displays and maps.

3.3 LANDSAT PREPROCESSING

A set of potential control points was selected for each of the four Landsat scenes. Displays of Landsat data for these points were visually correlated with the corresponding quadrangle maps and both Universal Transverse Mercator (UTM) coordinates and scanner coordinates measured for each point. The control network for each scene was then adjusted using the CONTROL program in the DAM package. Root-mean-square (RMS) errors for the network adjustments of these scenes ranged from 53 meters to 64 meters.

A quick test with Landsat-3 data soon demonstrated that the Landsat-2 series of water signatures used with the DAM package were not adequate to generate even the preliminary water-ness displays needed to screen out the obvious non-water pixels. Cluster means from four Landsat-3 scenes near the Sabine River in east Texas, previously generated and labelled for another project, were used to fit an approximate water-ness transformation using MSS channels 1 (Band 4) and 4 (Band 7).

Approximate water-ness displays were now generated for each rectified air photo by the DAM package, using this transformation and the previously measured photo corner UTM coordinates.

4. ANALYSIS

Although this chapter is divided into distinct sections covering the different types of analysis performed on the preprocessed data, much of this work was actually performed in parallel. Thus, analysis of preliminary spectral plots or the performance of a preliminary discriminant fit for just one photo frame, or for just the frames in one site, typically helped to point out labelling errors, or even preprocessing errors.

4.1 GROUND FEATURE SELECTION AND LABELLING

Using the approximate water-ness displays, rectified air photos, and the delineated overlays, approximately 1300 pixels, spread approximately equally between water bodies and non-water features spectrally near to water, were identified and labelled.

The labels and their meanings are shown in Figure 3. The label MX (for mixture pixels) was not used originally but was added to relabel those water pixols which, upon closer scrutiny, appeared to be edge pixels rather than solely water pixels.

The water-ness displays generated with the approximate Sabine transformation were used to label the Louisiana, Washington, and New York sites. The displays of the sparsely vegetated Montana site were not adequate for labelling this arid site since they showed far too many water and 'near-water' pixels. The Montana displays were re-run using a revised transformation derived from a linear discriminant fitted in a single pass to labelled pixels from the other three sites.

4.2 PAIRWISE SPECTRAL PLOTS

Various pairwise spectral plots were produced, by grouping labels together into classes and then assigning symbols to the classes. These spectral plots were used to detect labelling errors and to help develop an intuitive feel for the data.

Figure 4 shows two spectral plots, one of channels 1 and 4, the

CL = Cloud

SH = Shadow

BS = Bare Soil

SD = Sand Dunes

WL = Wetlands

PA = Pavement

BR = Building Roofs

CO = Commercial

IN = Industrial

DT = Downtown

TP = Treatment Ponds

RL = River Light Blue

RM = River Medium Blue

RD = River Dark Blue

PL = Pond Light Blue

PM = Pond Medium Blue

PD = Pond Dark Blue

LL = Lake Light Blue

LM = Lake Medium Blue

LD = Lake Dark Blue

MX = Mixture pixels

Figure 3. - Pixel labels.

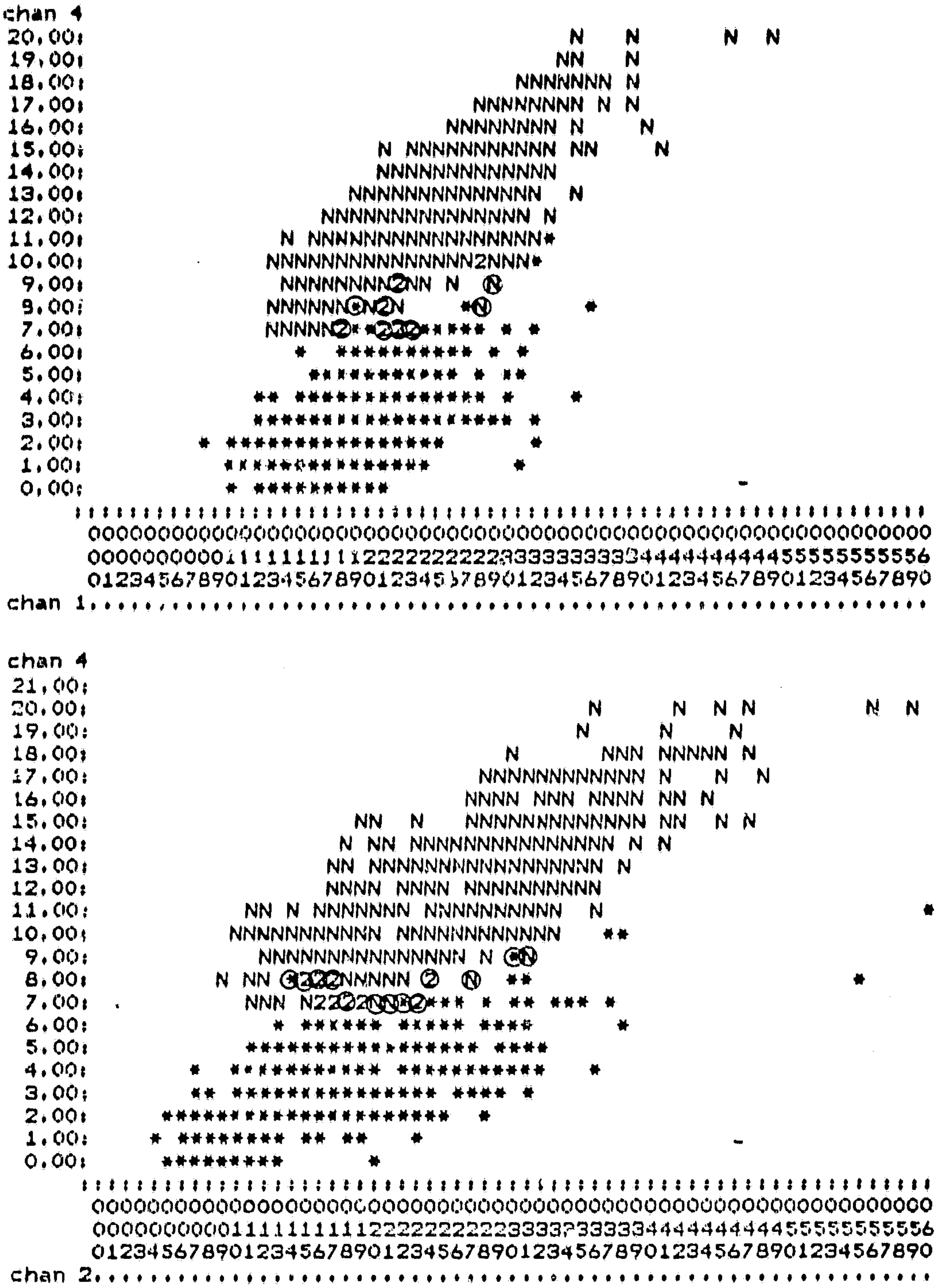

Figure 4. - Spectral plots of channel 4 with channels 1 and 2.

other of channels 2 and 4. These plots are derived from all 1300 points on all 28 frames. 'N' symbolizes one or more non-water pixels, '*' symbolizes one or more water pixels, and '2' symbolizes at least one non-water pixel AND one water pixel at the same location in the spectral plane. (The circles drawn around some spectral locations are explained in the next section.) Not surprisingly, channel 4, the farthest of the near infrared channels, is the best single channel to separate water from non-water and channels 1 and 4, the least correlated of the Landsat MSS channels, are the best two channels.

Figure 5 shows a spectral plot of channels 3 and 4. Notice that although these two channels are highly correlated, lying very nearly on a straight line, still the water and non-water pixels overlap very little on this plot. In spite of their high correlation, this pair of channels discriminates far better than the less correlated pair of channels 2 and 4 in Figure 4.

4.3 WEIGHTED LINEAR DISCRIMINANT FIT

All the pixels with water labels were grouped into class 1 and all the non-water pixels (except shadows and mixture) were grouped into class 2. The first iteration to fit a discriminant hyperplane between the two distributions was performed giving the same weight to all pixels. On subsequent iterations, pixels closer to the hyperplane (and therefore in danger of being misclassified) received more weight than pixels farther away which were in no danger of being misclassified.

Figure 6 shows the coefficients after the final iteration. On the left side of the figure is a general summary of how this discriminant classified all the pixels. On the right side is a detailed summary of how the discriminant classified those pixels close to the hyperplane (including all misclassified pixels).

A total of 9 out of 700 water pixels (or 1.3 percent) and 8 out of 574 non-water pixels (or 1.4 percent) are misclassified by this discriminant. Figure 7 lists all 17 misclassified pixels. Several are isolated pixels in the Mississippi River. It was not possible to determine whether any of these might have been associated with barges in the river. The bauxite mill and commercial building roofs are in industrial and commercial areas and probably could have been eliminated by an analyst without referring to any supplemental data sources other than the published quadrangle maps. The dark sand dune faces in eastern

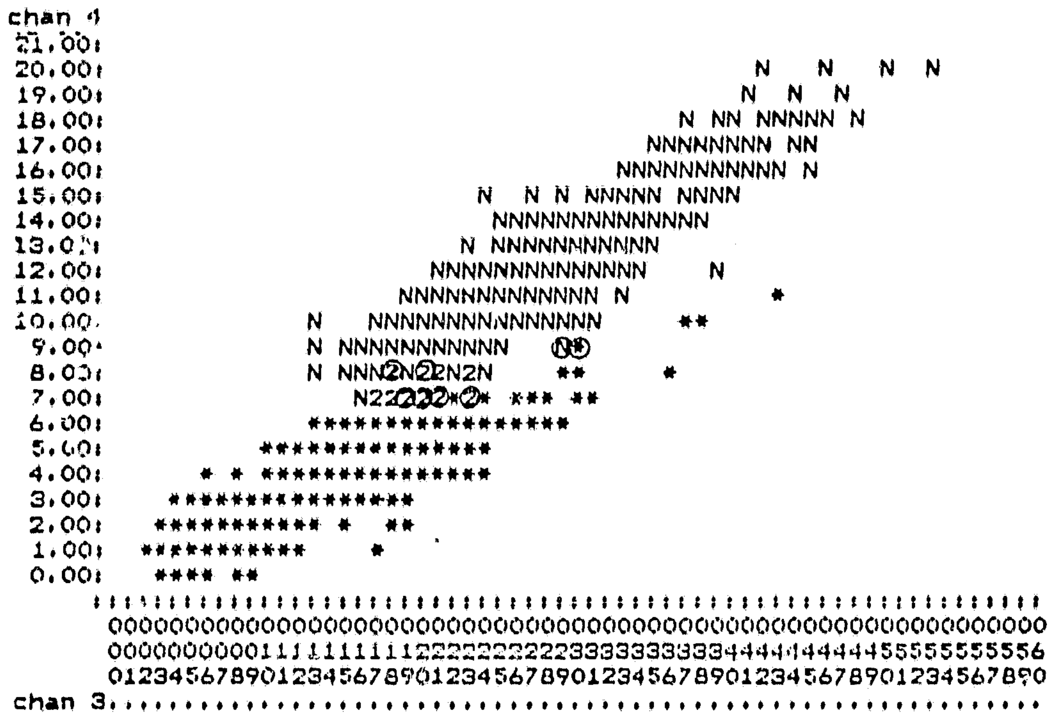

Figure 5. - Spectral plot of channel 4 with channel 3.

LINDISC: LA,WA,NY,MT LABELS DATE: 08/12/80 TIME: 10:00

coefficients of linear discriminant function

0.315889	0.031991	0.295913	-2.76792	7.12827

DISCRIM	Class1	Class2
-24.00	0	1
-23.00	0	0
-22.00	0	0
-21.00	0	3
-20.00	0	6
-19.00	0	14
-18.00	0	18
-17.00	0	23
-16.00	0	31
-15.00	0	28
-14.00	0	32
-13.00	0	41
-12.00	0	31
-11.00	0	43
-10.00	0	36
-9.00	0	39
-8.00	0	36
-7.00	0	31
-6.00	0	30
-5.00	0	34
-4.00	0	28
-3.00	2	18
-2.00	2	24
-1.00	5	18
0.00	3	2
1.00	16	5
2.00	17	1
3.00	37	1
4.00	43	0
5.00	54	0
6.00	62	0
7.00	71	0
8.00	87	0
9.00	92	0
10.00	58	0
11.00	60	0
12.00	38	0
13.00	23	0
14.00	18	0
15.00	6	0
16.00	3	0
17.00	2	0
18.00	1	0
TOTAL	700	574

	Class1	Class2
-4.00	0	6
-3.80	0	6
-3.60	0	3
-3.40	0	5
-3.20	0	1
-3.00	0	2
-2.80	0	4
-2.60	2	6
-2.40	0	2
-2.20	0	7
-2.00	1	6
-1.80	0	3
-1.60	1	6
-1.40	4	3
-1.20	0	5
-1.00	1	7
-0.80	0	1
-0.60	0	2
-0.40	0	0
-0.20	0	1
0.00	0	0
0.20	1	1
0.40	2	0
0.60	2	1
0.80	7	0
1.00	3	3
1.20	1	1
1.40	3	0
1.60	3	0
1.80	4	1
2.00	2	0
2.20	4	0
2.40	4	0
2.60	9	1
2.80	7	0
3.00	6	0
3.20	7	0
3.40	8	0
3.60	6	0
3.80	12	0
4.00	7	0

Figure 6. - Final pass of weighted linear discriminant.

STATE	FRAME #	FEAT #	CHANNEL 1	2	3	4	CLASS	LABEL	DISCR	FEATURE DESCRIPTION
LA	9734	504	21	24	21	8	1	RL	-1.4	MISS. RIVER
LA	9734	504	19	24	23	8	1	RL	-1.4	MISS. RIVER
LA	9691	508	22	30	30	9	1	RM	-1.0	MISS. RIVER
LA	9691	507	19	24	23	8	1	RM	-1.4	MISS. RIVER
LA	9691	507	21	24	21	8	1	RM	-1.4	MISS. RIVER
WA	1440	609	21	21	19	7	2	IN	0.7	BAUXITE MILL
WA	1440	502	23	23	23	7	2	BR	2.6	DK BLDG ROOF
WA	1440	502	21	21	20	7	2	BR	1.0	DK BLDG ROOF
WA	1440	502	22	21	20	7	2	BR	1.3	DK BLDG ROOF
WA	1440	508	21	20	20	7	2	DT	0.9	DK BLDG ROOF
WA	1535	514	29	31	29	9	2	SD	1.0	DK DUNE FACE
WA	1535	519	28	27	24	8	2	SD	1.8	DK DUNE FACE
NY	076	20	21	14	18	8	1	LD	-2.6	DK LAKE
NY	076	20	21	16	21	8	1	LD	-1.7	DK LAKE
NY	076	20	21	15	18	8	1	LD	-2.6	DK LAKE
NY	076	20	21	17	20	8	1	LD	-1.9	DK LAKE
MT	9100	540	18	18	21	7	2	BS	0.2	DK BARE SOIL

CLASS 1 = WATER

CLASS 2 = NON-WATER

Figure 7. - Pixels misclassified by linear discriminant.

Washington are in the vicinity of Potholes Lake. They are spectrally identical in all four MSS channels to some interior (non-edge) water pixels. The pixels in the dark lake (feature number 20) in upstate New York are spectrally different from typical water pixels.

The misclassified pixels listed in Figure 7 are circled on the spectral plots in Figures 4 and 5. Many circles occur over 2's, where the same spectral values in these channels are shared by both a water pixel and a non-water pixel. Note that any possible linear two-channel spectral limits would have more classification errors than the four-channel linear discriminant hyperplane.

4.4 PER FEATURE AND SHIFTING TABULATION

Based on the discriminant coefficients reported in section 4.3, a new series of water-ness displays was generated in which each increment in symbols displayed indicated a shift, or translation, of the hyperplane corresponding to a change of 0.2 in the bias term of the discriminant. The water bodies on these displays were tabulated by number of pixels for ten different shifted positions of the hyperplane. Figure 8 shows that for water bodies of ten acres or greater the unshifted discriminant is best, with a per feature false alarm rate of 8.7 percent and a miss rate of 8.7 percent, based on the occurrence of one or more pixels. The unshifted discriminant (with a bias term of 7.128) exceeds the performance criteria and is recommended.

The miss rate of 8.7 percent is an average for all 414 water bodies 10 acres or larger in surface area. The discriminant had a higher miss rate for the smaller water bodies in this group and a lower miss rate for the larger water bodies in this group, as may be seen from Figure 9.

The number of pixels detected per water body also varied with surface area, as shown in Figure 10. However, differences in shape and in pixel alignment with respect to the water body introduce considerable random variation; although the mean number of pixels in a 10 acre water body is approximately three, the standard deviation is nearly 2.5 pixels. These data suggest the difficulty of attempting to estimate the area of small water bodies from Landsat MSS pixel counts.

By using the complete tabulations in Appendix-G, it is possible to estimate the performance of any of the shifted discriminants for water bodies of other size ranges. Likewise, performance

SYMBOLS	BIAS TERM	FALSE ALARMS NUMBER	FALSE ALARMS PERCENT	MISSES NUMBER	MISSES PERCENT
0 to 0	6.728	28	6.8%	36	8.7%
0 to 1	6.928	35	8.4%	36	8.7%
0 to 2	7.128*	36	8.7%	36	8.7%
0 to 3	7.328	38	9.2%	36	8.7%
0 to 4	7.528	45	10.9%	35	8.4%
0 to 5	7.728	48	11.6%	34	8.2%
0 to 6	7.928	52	12.6%	32	7.7%
0 to 7	8.128	62	15.0%	30	7.2%
0 to 8	8.328	74	17.9%	29	7.0%
0 to 9	8.528	91	22.0%	27	6.5%

* Bias term from weighted linear discriminant fit

(414 water bodies 10 acres or larger)

Figure 8. - Effect of bias term on 10 acre water bodies

SIZE (acres)	WATER BODIES MISSED #	%	TOTAL #
2 - 2.9	299	92	326
3 - 3.9	145	77	188
4 - 4.9	98	69	143
5 - 5.9	60	55	109
6 - 6.9	26	41	64
7 - 7.9	28	49	57
8 - 8.9	11	21	52
9 - 9.9	9	24	38
10 - 10.9	10	22	46
11 - 11.9	5	20	25
12 - 12.9	5	18	28
13 - 13.9	1	7	14
14 - 14.9	2	9	23
15 - 15.9	1	7	15
16 - 16.9	2	15	13
17 - 17.9	3	19	16
18 - 18.9	0	0	12
19 - 19.9	1	9	11
20 - 20.9	1	13	8
21 - 999	5	2	203

SIZE (acres)	WATER BODIES MISSED #	%	TOTAL #
2 - 999	712	51	1391
3 - 999	413	39	1065
4 - 999	268	31	877
5 - 999	170	23	734
6 - 999	110	18	625
7 - 999	84	15	561
8 - 999	56	11	504
9 - 999	45	10	452
10 - 999	36	9	414
11 - 999	26	7	368
12 - 999	21	6	343
13 - 999	16	5	315
14 - 999	15	5	301
15 - 999	13	5	278
16 - 999	12	5	263
17 - 999	10	4	250
18 - 999	7	3	234
19 - 999	7	3	222
20 - 999	6	3	211
21 - 999	5	2	203

Figure 9. - Discriminant performance, by size of water body

SIZE OF WATER BODY (acres)	NUMBER OF PIXELS PER WATER BODY			AVERAGE ACRES PER PIXEL
	STANDARD DEVIATION	MEAN	MOVING AVERAGE	
2 - 2.9	0.38	0.10	- -	- -
3 - 3.9	0.95	0.38	0.32	10.9
4 - 4.9	0.81	0.48	0.54	8.3
5 - 5.9	1.02	0.77	0.93	5.9
6 - 6.9	1.71	1.55	1.23	5.3
7 - 7.9	1.86	1.37	1.68	4.5
8 - 8.9	1.89	2.13	2.07	4.1
9 - 9.9	2.40	2.71	2.72	3.5
10 - 10.9	2.47	3.30	3.11	3.4
11 - 11.9	3.25	3.32	3.20	3.6
12 - 12.9	2.38	2.96	3.21	3.9
13 - 13.9	2.06	3.36	3.77	3.6
14 - 14.9	3.59	5.00	4.79	3.0
15 - 15.9	3.64	6.00	5.26	2.9
16 - 16.9	3.65	4.77	5.61	2.9
17 - 17.9	4.31	6.06	6.11	2.9
18 - 18.9	3.70	7.50	6.94	2.7
19 - 19.9	3.41	7.27	6.97	2.9
20 - 20.9	3.31	6.12	7.16	2.9
21 - 21.9	4.11	8.09	7.81	2.8
22 - 22.9	2.94	9.20	9.35	2.4
23 - 23.9	5.01	10.75	- -	- -

Figure 10. - Number of pixels detected, by size of water body

can be estimated if, to further minimize the already acceptable false alarm rate, we wish to require more than one contiguous pixel for a water body to qualify. Since the stated performance criteria are met by the original fitted discriminant on a single pixel basis, such devices have been not been needed in the present study.

5. CONCLUSIONS

The techniques used in screening the data and in iteratively fitting the discriminant to pixel values weighted by their closeness to the hyperplane provided a signature which appears to be optimum at least with respect to translation of the hyperplane. Time and resources did not permit the evaluation of the effect on discriminant performance of different rotations of the hyperplane.

Intermediate discriminants derived from data for only two sites did far less well in classifying the remaining sites, suggesting that a sufficiently large and diverse sample is very important in attempting to develop truly 'universal' signatures.

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