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EARTH RESOURCES PROGRAM

DEVELOPMENT OF A COMPUTER-AIDED PROCEDURE FOR THE NATIONAL PROGRAM OF INSPECTION OF DAMS

SCIENCE AND APPLICATIONS DIRECTORATE

National Aeronautics and Space Administration

LYNDON B. JOHNSON SPACE CENTER

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DEVELOPMENT OF A COMPUTER-AIDED PROCEDURE FOR THE NATIONAL PROGRAM OF INSPECTION OF DAMS

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PREFACE

The purpose of this document is to describe the development and performance evaluation, by the Earth Observations Division (EOD), of selected computer-aided procedures using data from the multispectral scanner (MSS) on board the Earth Resources Technology Satellite (ERTS-1), for the detection and location of surface water.

This document includes background information; a statement of the problem; a detailed description of the technical approach used, a statement of the performance results; conclusions; and a recommended procedure.

This document was prepared pursuant to requirements identified within the Applications Office of the Earth Observations Division. It is comprised of a joint effort of personnel within the Earth Observations Division and personnel within the Earth Resources Department, Lockheed Electronics Compnay, Inc. Prime author of this document was B. H. Moore, Principal Scientist. Activities by the contractor were authorized under Contract NAS 9-12200.

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LIST OF ACRONYMS

ADP	Automatic Data Processing
CCT	Computer Compatible Tape
COE	Corps of Engineers
EOD	Earth Observations Division
ERTS-1	Earth Resources Technology Satellite
JSC	Johnson Space Center, Houston, Texas
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NPID	National Program of Inspection of Dams
TWRC	Texas Water Rights Commission
USGS	United States Geological Survey

1.0 SUMMARY

Within the Johnson Space Center/Earth Observations Division (JSC/EOD) an effort was undertaken to determine the utility of ERTS-1 MSS data, together with automatic data processing (ADP) techniques, to detect and locate surface water pursuant to legislation within the jurisdiction of the U.S. Corps of Engineers (COE), and transfer the related technology to the Texas Water Rights Commission (TWRC). For this purpose, a test site was selected, ERTS-1 MSS and ancillary data obtained, and existent ADP classification programs applied. During the course of this effort a linear discriminant function was developed. The results were evaluated for potential candidates for a transferable procedure.

As a result, a computer-aided technique using a linear discriminant function was selected and recommended, for inclusion in an operational system, which met detection and location criteria established jointly by NASA, the TWRC, and the COE. Specifically, evaluation of the selected computer-aided procedure for the test site resulted in the detection of 100 percent of areas of surface water 10 acres or greater in areal extent and the geographic location of areas classified as water to a positional accuracy of 1000 feet or closer. The procedure was recommended for inclusion in an operational computer-aided procedure for transfer to TWRC.

2.0 INTRODUCTION

In August 1972, the President signed into law Public Law 92-367 to authorize the Secretary of the Army to undertake a National Program of Inspection of Dams (NPID). The need for dam safety was brought to national attention when water impoundments in West Virginia and South Dakota gave way, resulting in significant loss of life and property.

In brief, the law authorizes the Secretary of the Army, acting through the Chief of Engineers, to carry out a national program of inspection of dams. To determine whether a dam (including the waters impounded by such dam), constitutes a danger to human life or property, the Secretary shall take into consideration the possibility that the dam might be endangered by overtopping, seepage, settlement, erosion, sediment, cracking, earth movement, earthquakes, failure of bulkheads, flashboard, gates on conduits, or other conditions which exist or which might occur in any area in the vicinity of the dam.

The report by the Secretary of the Army to Congress is due on or before July 1, 1974. The report shall include (1) an inventory of all dams located in the United States, (2) a review of each inspection made, the recommendations furnished to the governor of the state in which such dam is located and information as to the implementation of such recommendations, and (3) recommendations for a comprehensive national program for the inspection, and regulation for safety purposes of dams of the nation, and the respective responsibilities which should be assumed by the federal, state, and local governments and by public and private interest.

3.0 BACKGROUND

In December, 1972, the Texas Water Rights Commission (TWRC) submitted, through the Office of the Governor of Texas, a request for assistance by NASA/JSC/EOD in the development of a procedure for utilizing data acquired by the Earth Resources Technology Satellite (ERTS-1) in detecting and locating water impoundments. The Chief of Engineers, acting through the Division offices of the Corps of Engineers, is enlisting the aid of cooperating states to conduct the inventory of dams authorized by the Public Law. The TWRC has contracted with the Southwest Division of the COE to perform the inventory for Texas.

The ERTS-1 satellite was placed in orbit to gather data relative to the environment of the Earth. The ERTS-1 satellite orbits the Earth in a circular, sun-synchronous, near-polar orbit at an altitude of approximately 494 nautical miles. The satellite orbits the Earth approximately 14 times each day and views the same scene on the Earth approximately every 18 days. Figure 1 gives an illustration of the ERTS-1 satellite and the ground coverage of its instruments.

The ERTS-1 Multispectral Scanner (MSS) receives spectral information in four channels covering the following wavelengths:

Channel	Spectral Band	Wavelength (micrometers)	
1	4	0.5 - 0.6	visible
2	5	0.6 - 0.7	
3	6	0.7 - 0.8	reflective infrared
4	7	0.8 - 1.1	

The MSS data are recorded and transmitted in digital format to the NASA data processing facility. Two image products are produced; photographic images and digital images in the form of computer compatible tapes (CCT's).

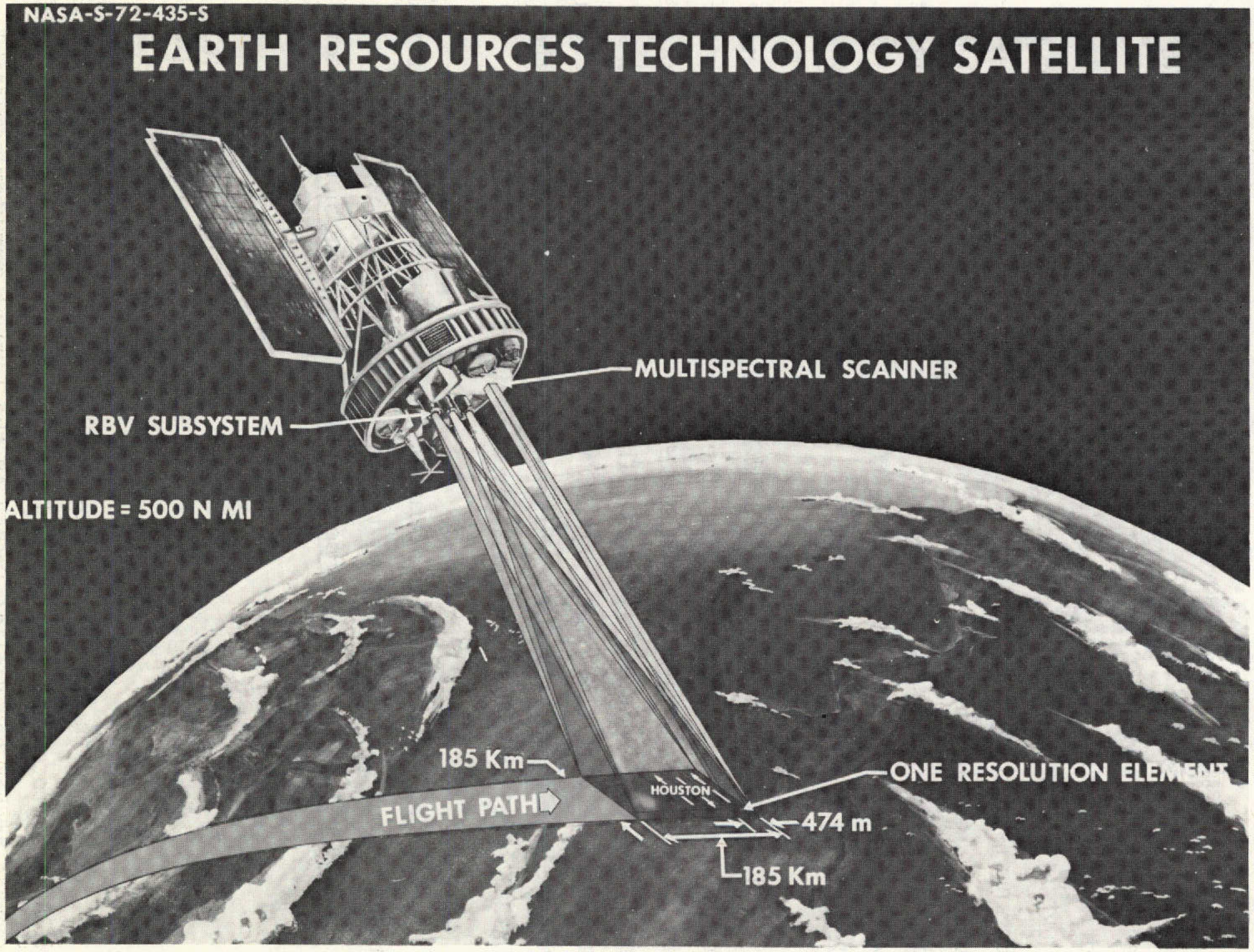

Figure 1. — An illustration of ERTS-1 with earth coverage.

These MSS products will be used for the procedures described in this document; (1) 9 1/2" x 9 1/2" system corrected photographic images and, (2) system corrected computer compatible digital tapes (CCT). Each digital image consists of four CCT's each covering a strip 25 by 96.3 nautical miles.

4.0 STATEMENT OF THE PROBLEM

The essential purpose of the Public Law is the determination of the conditions of dams in the United States such that those impounding sufficient water to pose a threat and in danger of failure will be detected and corrective action taken to prevent potential damage to life and property. The Federal congress has estimated that there is a sufficient number of dams of interest which are not presently adequately recorded, and as a result, has authorized, as the first step towards an inspection program, an inventory of all dams of interest.

Remote sensing technology offers a means to accomplish a part of the inventory by detection and location of areas of surface water which may be impoundments. The ERTS-1 MSS, with its complete coverage of the United States, provides data which are a prime candidate for accomplishing the detection and location part of the inventory. Additionally, the repetitive coverage of the ERTS-1 MSS provides a means to monitor changes.

The problem for the EOD was to determine if the detection and location could be accomplished using ERTS-1 data, and to transfer the technology thus derived to a user agency.

5.0 OBJECTIVE

The effort related to the National Program of Inspection of Dams was initiated within the EOD with the objective to develop and evaluate, in conjunction with the TWRC and the COE, a transferable procedure(s) for detecting and locating surface water using ERTS-1 MSS data.

6.0 TECHNICAL APPROACH

The steps taken to meet the objectives of the National Program of Inspection of Dams (NPID), are described in this section. The following subsections will describe, in order:

- o establishment of performance criteria for the evaluation of developed computer-aided procedures.
- o development of a performance evaluation procedure.
- o development of procedures for exercising candidate automatic data processing (ADP) techniques.
- o selection of a test site for testing the performance of candidate ADP techniques using the performance evaluation procedure.
- o development of a ground truth overlay for the test site detailing the locations and sizes of surface water area of interest.
- o processing of ERTS-1 MSS data using each of the candidate ADP techniques according to developed procedures.
- o evaluation of results.

6.1 ESTABLISHMENT OF PERFORMANCE CRITERIA

The Public Law addresses the physical dimensions of impounding dams together with the volume of water capable of being impounded by the dams. Ground resolved distances within ERTS-1 MSS data precludes the determination of physical dimensions of dams but is compatible with the resolution of surface water 10 acres or greater in areal extent.

Discussions were held between NASA and the TWRC, together with the COE, to arrive at a surface area threshold which could reasonably be correlated with minimum volumes of impounded water as addressed in the Public Law. TWRC decided that water bodies in Texas with an areal extent of ten surface acres or greater would be a reasonable approximation to the requirements defined in the Public Law. Onsite investigations by personnel of the TWRC of those water bodies detected and located would yield additional data required pursuant to the Public Law.

The discussions culminated in an agreement by the NASA, the TWRC, and the COE to the following evaluation criteria to be applied to each procedure tested. This criteria is as follows:

A procedure is acceptable if all areas of surface water 10 acres or greater in areal extent are correctly detected and identified with an accuracy of 90% or greater with a frequency of false detection of 10% or less. In addition, the information to be extracted is to be registrable to a scale of 1:24,000 with the geographic location of each resolution element (pixel)[1] classified as water determined to a positional accuracy of 1,000 feet or closer.

6.2 PERFORMANCE EVALUATION PROCEDURE

The computer-aided procedures for the detection and location of surface water each produce results in the form of symbols on computer line printer output. Each symbol corresponds to the ADP classification of an ERTS-1 MSS pixel as water. The line printer output is defined as a classification map.

Initial experience gained in the conduct of this investigation indicated a correlation between actual water surface area and the number of line printer symbols classified by the ADP technique to be water.

To analyze the results, it was decided to define three surface water area classes based on the number of contiguous ADP identifications of water on the classification map:

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[1] A pixel is each recorded sample corresponding to the area on the earth's surface imaged by the MSS's instantaneous field-of-view as it scans.

a. Class I area - A classification map area containing one (1) ADP symbol is defined as the ADP identification of areas of surface water of 2 to 6.9 acres.

b. Class II area - A classification map area containing two (2) contiguous ADP symbols is defined as the ADP identification of areas of surface water of 7.0 to 9.9 acres.

c. Class III area - A classification map area containing three (3) or more contiguous ADP symbols is defined as the ADP identification of areas of surface water of 10 or more acres.

Figure 2 shows portions of a typical line printer output generated during this investigation which demonstrates the three classes of surface water.

Following the definitions of classes of surface water according to the number of ADP classification symbols, an evaluation technique was developed based on the defined classes. Table 1 gives the evaluation equations which were applied to the various ADP techniques employed. The values for each evaluation appear in the Results and Recommendations Section of this document.

6.3 ADP PROCEDURES EMPLOYED

In the interest of generating a technique transferable to the TWRC to be utilized in an operational system, it was decided that only those techniques which are compatible with the Univac 1100 series computers and associated hardware, would be evaluated.

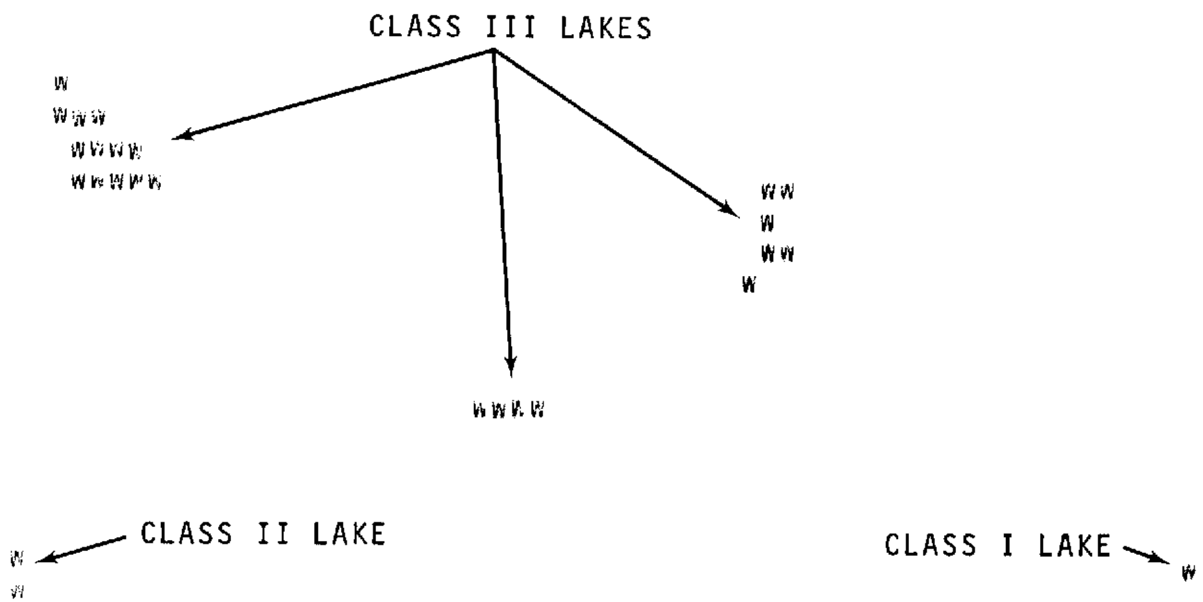

Figure 2. - A reproduction of a portion of computer print-out showing Class I, II, and III lakes.

TABLE 1

	Class I	Class II	Class III
Percent of each class identified as Class I	F_{11}	F_{12}	F_{13}
Percent of each class identified as Class II	F_{21}	F_{22}	F_{23}
Percent of each class identified as Class III	F_{31}	F_{32}	F_{33}
Percent of each class falsely identified	F_{01}	F_{02}	F_{03}

F_{ij} = frequency with which ADP identification of class j areas were actually class i areas (i.e. class j areas mis-identified as class i areas).

F_{oj} = frequency with which ADP identifications of class j areas were actually not an area of any class. (Frequency of False Detection)

$F_{ii}=\frac{L_i}{M_i}$ $\qquad$ $F_{ij}=\frac{K_{ij}}{N_j}$

L_i = the total number of correct ADP identifications of class i areas.

M_i = the total number of class i areas in study area.

N_j = the total number class j areas.

K_{ij} = number of ADP identifications of class j areas which were actually class i areas.

K_{oj} = number of ADP identifications of class j areas which were actually not an area of any class.

Within the EOD there existed a set of spectral pattern recognition algorithms implementing the maximum likelihood classification technique. The technique has been successfully applied to various problems, such as classification of agricultural crops.

The various procedures employed in this investigation were all associated with the existing maximum likelihood classification technique. It was decided to use the computer algorithms associated with the maximum likelihood technique in that several variations of procedures showed promise for satisfying the investigation objectives. The set of algorithms allows several variations based on the subroutines and input options in the set.

Five ADP procedures were selected. Three used variations on training field selection for the maximum likelihood classifier together with data from all four ERTS-1 MSS channels. Two of these procedures differed only in the training method and required an analyst to train the classifier on water only. One training method required the data analyst to know the location of water within the ERTS-1 scene, the other method required no knowledge of water location. The third procedure required the analyst to train the classifier on water and a similar class but did not require the knowledge of the location of the classes. The fourth procedure used density slicing on the one ERTS-1 MSS channel (channel 4) which showed the greatest promise for a one-channel classification. The fifth procedure was developed during the course of the investigation and involved the manipulation of input to the maximum likelihood classifier such that only Channel 1 and Channel 4 were processed and a linear discriminant boundary was used to separate water from all other classes. The details of each procedure are presented in Appendix A.

6.4 SELECTION OF STUDY AREA

To evaluate the ADP techniques it was necessary to select a study area in which an inventory of surface water, 10 acres or greater, together with an intensive study area with 2-10 acre surface water was available. Such information could be provided by selecting an area for which there existed nearly concurrent overpasses of ERTS-1 and aircraft photography missions. The inventory of surface water in the selected study area determined from aircraft photography would constitute the "ground truth" for evaluation.

A survey was therefore made of available in-house ERTS-1 tapes being used within the EOD ERTS-1 Project. The corresponding 1:24,000 United States Geological Survey (USGS) topographic sheets were reviewed to identify areas with lakes of various sizes. The review indicated that the Lake Somerville area of East-Central Texas was desirable for selection of a study area. An area was found which had both ERTS-1 coverage and relatively concurrent aircraft photography, both cloud-free. This area had aircraft photography from Mission 220, flown 8 November 1972, and is a subportion (approximately 1/4) of the area covered by the 23 October 1972, ERTS-1 computer compatible tape (CCT), number 3 of 4 (ERTS-1 scene E1092-16305). The area extends from the Colorado River north to the Bryan-College Station area. Therefore, the specific area covered by Mission 220 was selected. The ERTS-1 CCT, Mission 220 photography, and the corresponding 1:24,000 topographic sheets were acquired as tools for this investigation. Figure 3 shows the complete ERTS-1 frame and the third strip containing the study area. The study area is the Mission 220 photographic coverage.

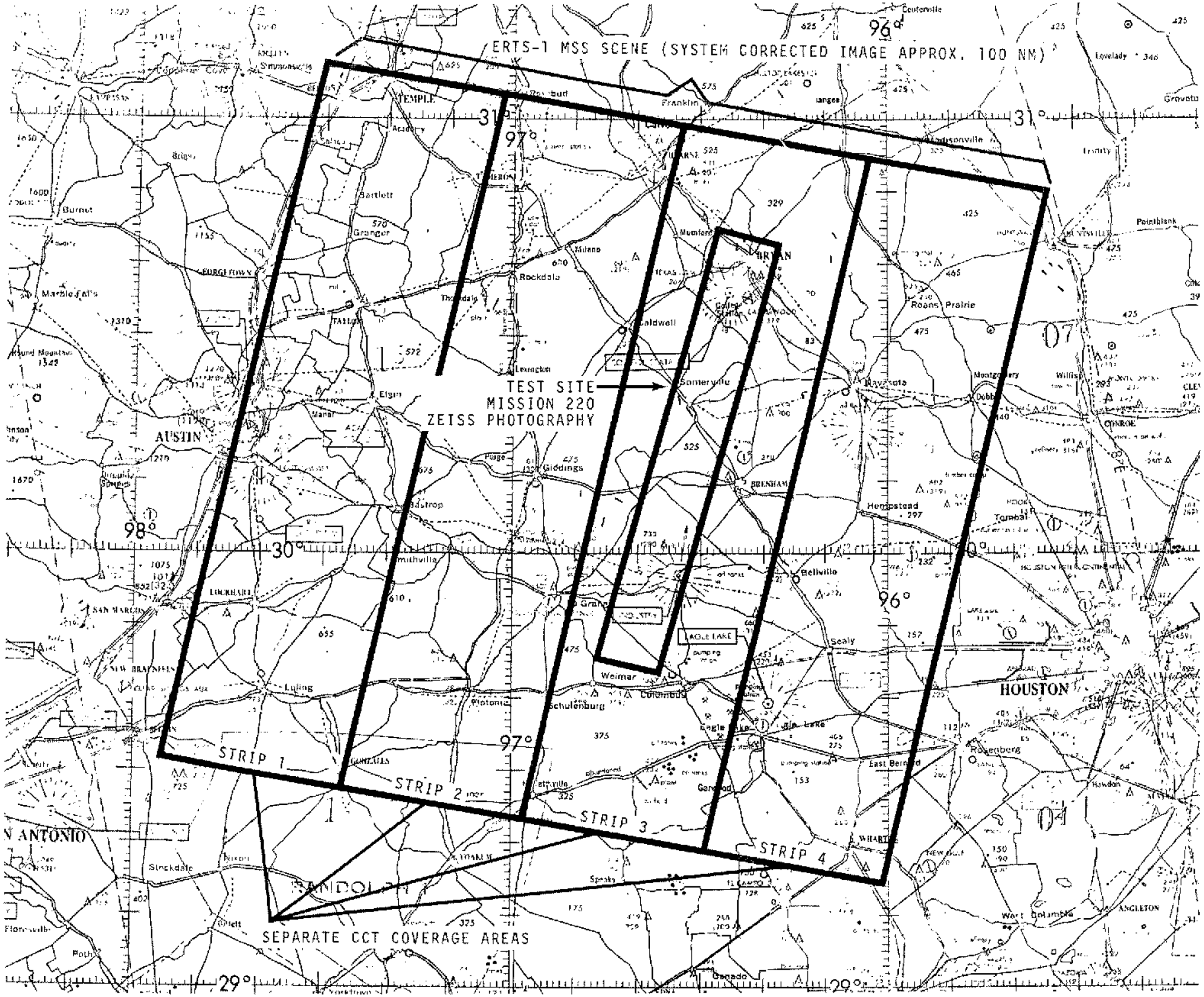

Figure 3. — An illustration of the ERTS-1 frame coverage on 1:1,000,000 scale ONC chart with strip 3 and the study area covered by Mission 220 aircraft photography.

6.5 GENERATION OF GROUND TRUTH OVERLAY

The study area photography was analyzed to provide the surface water inventory. Information was obtained for the total number of water bodies above about 8 acres, for the surface areas of each water body, and for the location of each water body compiled at a scale of 1:24,000. To faciliate the use of the ground truth a clear acetate overlay was produced containing the derived information.

The following is a description of the steps employed in generating the ground truth overlay:

a. The 21 frames of Mission 220 photography, roll number 3, frames 45 through 66, relating to the study area were acquired together with 1:24,000 topographic maps for the same area.

b. With the topographic maps as a base, the photographs were used on an Analytical Stereo Plotter to produce vellum overlays with all water bodies approximately 8 surface acres and larger compiled at a 1:24,000 scale. The 21 frames of photography yielded 20 vellum overlays at 1:24,000 scale.

c. Frame number 53, of the test site photography, was analyzed in complete detail for the occurrence of all distinguishable water bodies. The area covered by this frame was designated as the intensive study area.

d. The vellum overlays on which the water body boundaries were indicated were analyzed with a digital planimeteric device to obtain surface area measurements.

e. The 20 vellum overlays were mosaicked, a single sheet of clear acetate overlaid onto the mosaic and the data on the vellums transferred to the acetate overlay.

The clear acetate overlay of water bodies at 1:24,000 scale together with the tabular data on sizes of the water bodies constituted the ground truth for evaluation of the automatic data processing technique.

Figure 4 shows a portion of the clear acetate overlay and shows the overlay position on a corresponding 1:24,000 topographic sheet as well as a 1:24,000 scale computer line-printer output depicting water classification symbols.

6.6 COMPUTERIZED DATA PROCESSING

The data flow diagram depicting the five approaches used in the computerized processing is shown in Figure 5. The following sections describe the three methods employed using training fields, the method using a two-channel linear discriminant, and the method using density slicing with channel 4.

6.6.1 Training Field Selection

The following is a description of each of the three steps employed using training fields as described in Appendix A.

a. The ERTS-1 CCT from Goddard was reformatted to make it compatible with the existent computer programs.

b. The reformatted tape was used to produce a grey map using the first 10 radiance levels in channel 4.

c. Control points were chosen using identifiable features on the channel 4, 9-1/2 inch system-corrected photographic image, on the channel 4 grey map, and on the 1:24,000 topographic maps. The coordinates of these points were input, along with the reformatted tape, to a registra-

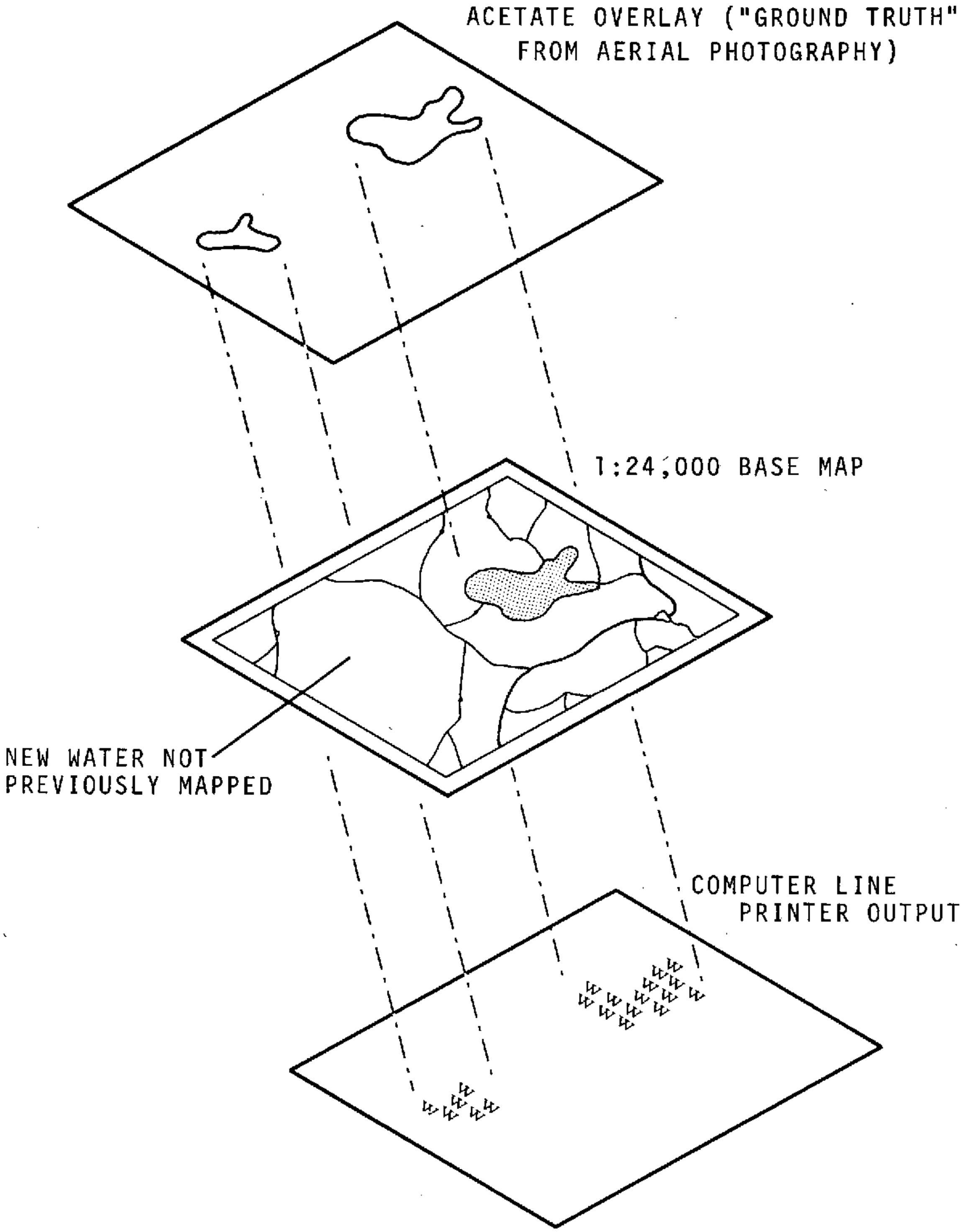

Figure 4. — Interrelationship of evaluation materials.

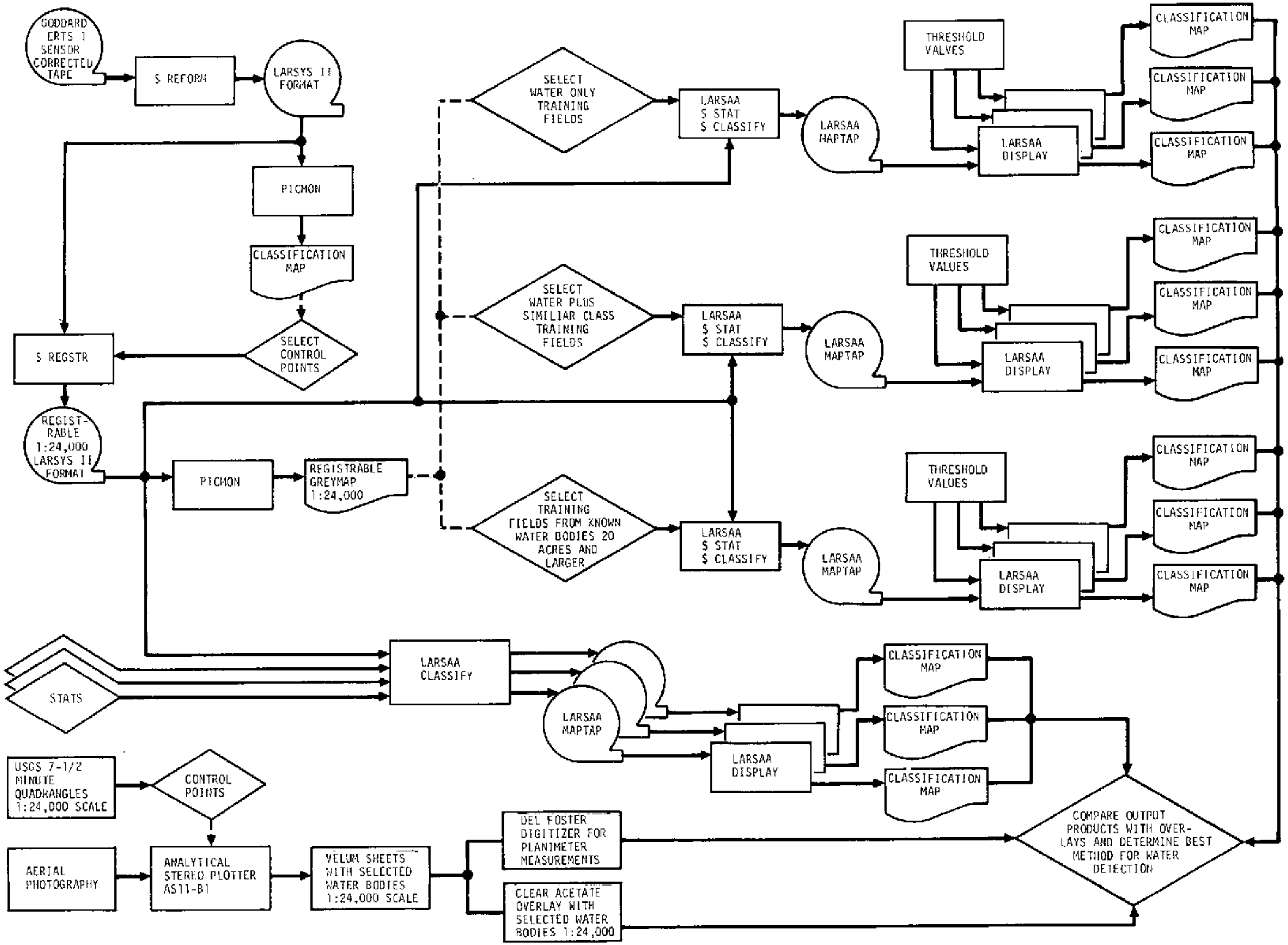

Figure 5. - Detailed data processing diagram of the evaluation for the National Program of the Inspection of Dams.

tion program which produced a newly formatted tape with the data registrable at 1:24,000 scale.[2]

d. This registrable tape was used to produce a grey map of channel 4 registrable at 1:24,000 scale. The grey map was composed of one symbol (M) for the first 7 radiance levels, one symbol (*) for radiance levels 8 through 10, and blanks for all radiance levels above 10.

e. Training fields were picked from the registrable 1:24,000 grey map using the following criteria: a rectangular array of from 8 to 30 contiguous ADP symbols containing at least 50% M's denotes a water body; a rectangular array of from 8 to 30 contiguous ADP symbols containing all asterisks denotes an area similar to, but not, a water body. Additionally, the 1:24,000 registrable grey map was compared to aerial photography and a set of training fields selected from lakes positively identified as larger than 20 surface acres. Figure 6 shows several portions of the registrable grey map with training fields noted.

f. Classification tapes were generated using these three types of training fields. The three sets of training fields consisted of; (a) water body training fields, (b) water body and similar area training fields, and (c) water bodies from lakes larger than 20 surface acres chosen.

g. A range of threshold values from 1 to 10 were selected and several classification maps, registrable to a scale of 1:24,000, of the test site produced, one for each threshold and each of the classification tapes using a display program. The threshold values were selected drawing on empirical findings within the EOD ERTS-1 Project.

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[2]Reference: "Procedures Manual for Detection and Location of Surface Water Using ERTS-1 Multispectral Scanner Data: Vol. III, Control Network Establishment," JSC-08451, Lyndon B. Johnson Space Center, Houston, Texas, November 1973.

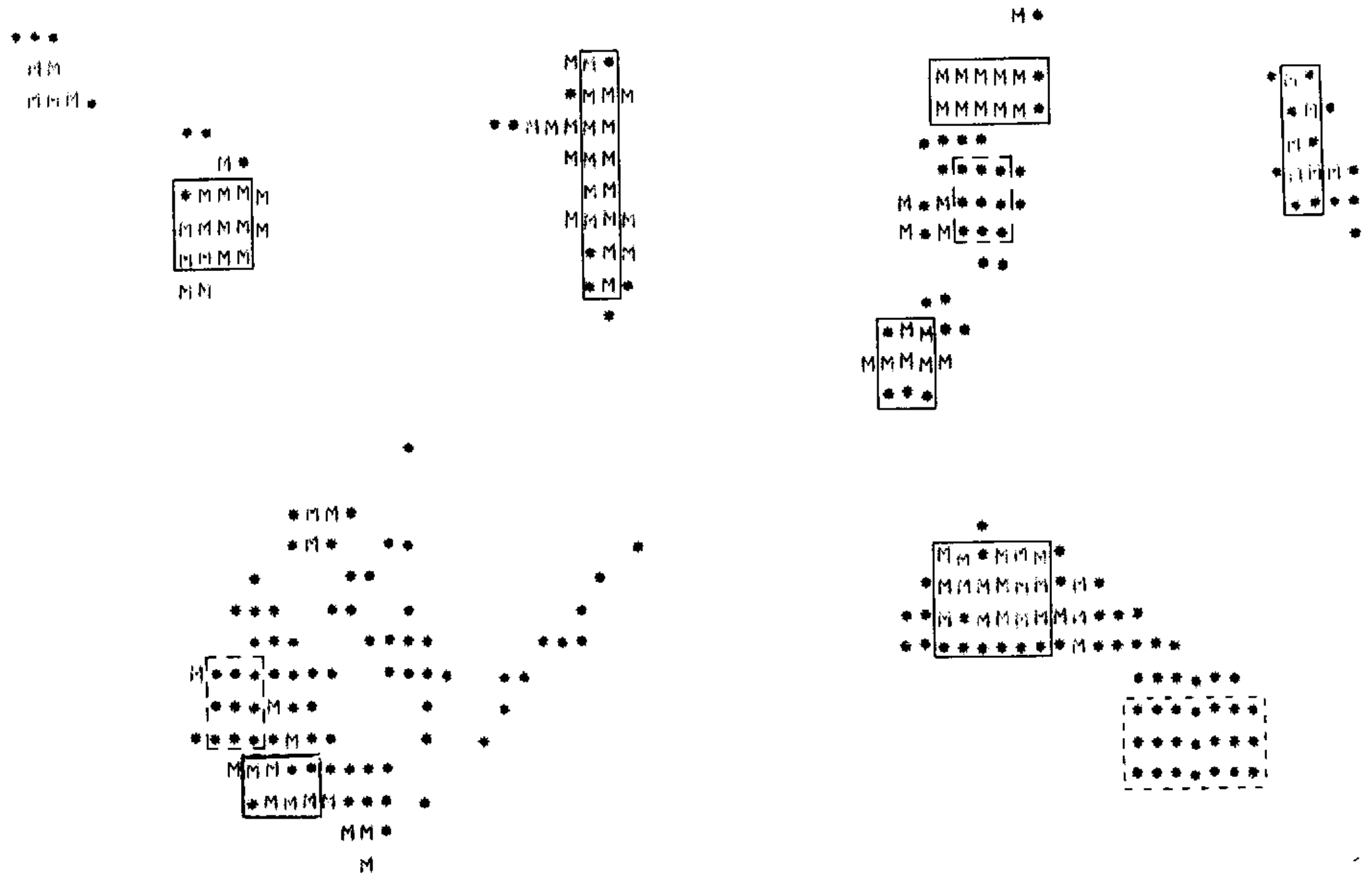

Figure 6. - A reproduction of portions of the channel 4 grey map showing M's, *'s, and training fields. Water training fields are outlined by solid lines, similar class training fields are outlined by dashed lines.

h. The various thresholded recognition maps were examined and the apparent best results from each type of classification were mosaicked for comparison to the ground truth overlay.

6.6.2 Two-Channel Linear Discriminant

The following is a description of each of the steps employed using the two-channel discriminant technique, which was developed using results from NASA/EOD ERTS-1 Analysis Teams' investigations, described in Appendix A.

a. A two-channel cluster[3] diagram was generated for channel 1 versus channel 4 using available information from the ERTS-1 analysis teams for water clusters as of early May 1973. To this cluster diagram was added selected information for other features such as vegetation, bare soil, and mixtures of water and other surface materials.

b. Three different discriminant lines were drawn in the cluster diagram by varying slopes and intercepts, in an attempt to separate clusters for areas of surface water from clusters for all other features.

c. The three lines were converted to covariance matrices which were input to the maximum likelihood classifier, together with channels 1 and 4 from the registrable 1:24,000 scale tape. Three classifications, one for each line, were generated and recognition maps of the study area produced.

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[3]clusters: groupings of multispectral data into sets of similar data.

d. The preliminary classification results were mosaicked for comparison and correlation to the ground truth overlay.

6.6.3 Density Slicing With Channel 4

The following is a description of the steps employed in the single channel 4 density slicing technique which are described in Appendix A.

a. The registrable 1:24,000 scale tape was input to a density slicing program and two registrable grey maps produced. The first grey map contained the first six levels in channel 4, designated as symbols 0 through 5 and all other levels suppressed. The other grey map contained the first seven levels in channel 4, symbols 0 through 6 and all other levels suppressed.

b. The two resultant grey maps were mosaicked for comparison and correlation to the ground truth overlay.

6.7 PERFORMANCE EVALUATION

Each of the results obtained from the computerized data processing steps was screened by comparison with the ground truth overlay. The apparent best results of each classification technique were selected for detailed examination.

In each case, the mosaicked computer output was laid out and the ground truth overlay placed over it for evaluation. A careful scan was made of the correspondence between the overlay data and each mosaicked computer output. Each occurrence of an ADP identification of a water body was recorded. Following that step, the study area was re-examined for all indications of Class III ADP identifications of water bodies where none was detected in the "ground truth" imagery. These were recorded as false identifications. Lastly, the Intensive Study Area was examined for occurrences of all three classes and false detections. Figure 7 shows a photograph of the process of evaluation taking place.

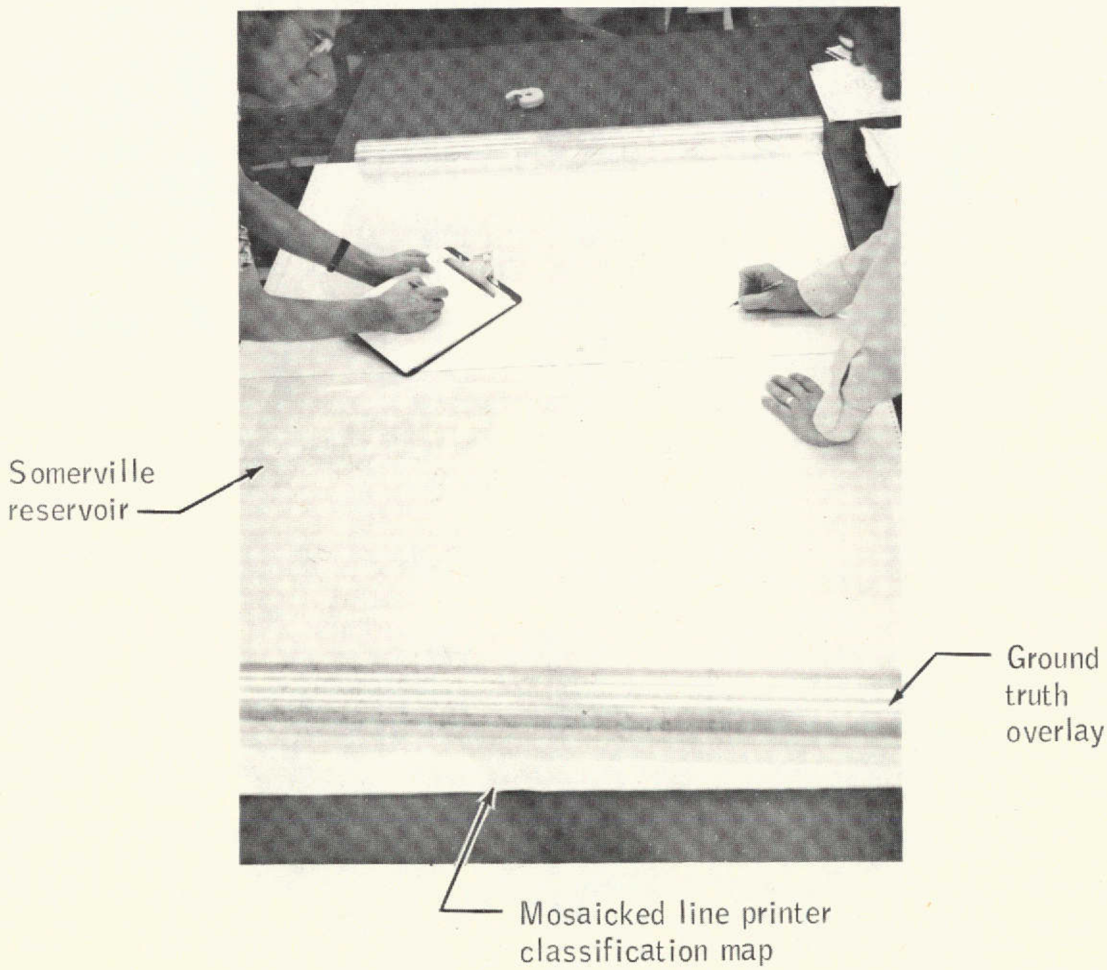

Figure 7. — The evaluation process using mosaicked computer output overlaid with the ground truth acetate. Water classification symbols on the output are correlated with ground truth data and recorded for each ADP technique.

7.0 RESULTS AND RECOMMENDATIONS

7.1 EVALUATION RESULTS

Using the matrix of performance parameters defined previously in Table 1, the best results of each candidate automatic technique are listed in the following tables together with a reference number for each method:

a. Table 3 - Water Class Only with Thresholding, Threshold = 3.0, Method No. 1.

b. Table 4 - Maximum Likelihood Classification, Water Plus a Similar Class Training Field, Threshold = 5.0, Method No. 2.

c. Table 5 - Water Class Only with Thresholding, Training Fields Selected from Water Bodies Greater than 20 Acres, Threshold = 4.0, Method No. 3.

d. Table 6 - Density Slicing, Channel 4, First Six Levels (0-5), Method No. 4.

e. Table 7 - Density Slicing, Channel 4, First Seven Levels (0-6), Method No. 5.

f. Table 8 - Two-Channel Ratio Technique, Channels 1 and 4, Method No. 6.

TABLE NO. 3

METHOD NO. 1

WATER CLASS ONLY

WITH THRESHOLDING

T = 3.0

	Class I	Class II	Class III
Percent of each class identified as Class I	F_{11} = 16%	F_{12} = 18.7%	F_{13} = 0
Percent of each class identified as Class II	F_{21} = 2.6%	F_{22} = 14.3%	F_{23} = 1.25%
Percent of each class identified as Class III	F_{31} = 5.1%	F_{32} = 6.3%	F_{33} = 82.5%
Percent of each class falsely identified	F_{01} = 82%	F_{02} = 69%	F_{03} = 82.5%

TABLE NO. 4

METHOD NO. 2

MAXIMUM LIKELIHOOD CLASSIFICATION

WATER PLUS A SIMILAR CLASS

T = 5.0

	Class I	Class II	Class III
Percent of each class identified as Class I	F_{11} = 20%	F_{12} = 33%	F_{13} = 2%
Percent of each class identified as Class II	F_{21} = 3%	F_{22} = 14%	F_{23} = 2%
Percent of each class identified as Class III	F_{31} = 3%	F_{32} = 0	F_{33} = 94.2%
Percent of each class falsely identified	F_{01} = 79%	F_{02} = 56%	F_{03} = 66%

TABLE NO. 5

METHOD NO. 3

WATER CLASS ONLY WITH THRESHOLDING; TRAINING FIELDS SELECTED FROM WATER BODIES GREATER THAN 20 ACRES

T = 4.0

	Class I	Class II	Class III
Percent of each class identified as Class I	F_{11} = 32%	F_{12} = 20%	F_{13} = 2%
Percent of each class identified as Class II	F_{21} = 4%	F_{22} = 0	F_{23} = 1%
Percent of each class identified as Class III	F_{31} = 1%	F_{32} = 7%	F_{33} = 70.6%
Percent of each class falsely identified	F_{01} = 85%	F_{02} = 80%	F_{03} = 88%

TABLE NO. 6

METHOD NO. 4

DENSITY SLICING, CHANNEL 4

FIRST 6 LEVELS (0-5)

	Class I	Class II	Class III
Percent of each class identified as Class I	F_{11} = 19.7%	F_{12} = 0	F_{13} = 0
Percent of each class identified as Class II	F_{21} = 8%	F_{22} = 28.6%	F_{23} = 6.3%
Percent of each class identified as Class III	F_{31} = 4%	F_{32} = 33%	F_{33} = 82.4%
Percent of each class falsely identified	F_{01} = 35%	F_{02} = 33%	F_{03} = 12.5%

TABLE NO. 7

METHOD NO. 5

DENSITY SLICING, CHANNEL 4

FIRST 7 LEVELS (0-6)

	Class I	Class II	Class III
Percent of each class identified as Class I	F_{11} = 20%	F_{12} = 18%	F_{13} = 0
Percent of each class identified as Class II	F_{21} = 17%	F_{22} = 28.6%	F_{23} = 5%
Percent of each class identified as Class III	F_{31} = 8%	F_{32} = 9%	F_{33} = 88.2%
Percent of each class falsely identified	F_{01} = 33%	F_{02} = 46%	F_{03} = 57%

TABLE NO. 8

METHOD NO. 6

TWO-CHANNEL RATIO TECHNIQUE

CHANNELS 1 AND 4

	Class I	Class II	Class III
Percent of each class identified as Class I	F_{11} = 8%	F_{12} = 29%	F_{13} = 0
Percent of each class identified as Class II	F_{21} = 0	F_{22} = 43%	F_{23} = 6.7%
Percent of each class identified as Class III	F_{31} = 0	F_{32} = 14%	F_{33} = 88.2%
Percent of each class falsely identified	F_{01} = 0	F_{02} = 0	F_{03} = 0

7.2 DISCUSSION OF RESULTS

The evaluation matrix was derived such that an evaluation could be made of the ability of using ERTS-1 MSS data to detect areas of surface water as small as two acres. For the purpose of meeting the requirements established with the TWRC and the COE, the important matrix values are the two in the lower right hand corner of each table; F_{03} and F_{33}, the percentages of correctly identified lakes of 10 acres or greater, and the percentages of false identifications of lakes 10 surface acres or greater, respectively. F_{33} should be 90% or more and F_{03} should be 10% or less. Figure 8 is a histogram summarizing the F_{33} and F_{03} results from the evaluation matrixes for each candidate automatic technique. The closes contender for both criteria is the two-channel discriminant technique, Method No. 6, with F_{33} = 88.2% and F_{03} = 0%.

The registration program used for 1:24,000 scale reformatted tape eliminates approximately 25% of the data points from the system corrected ERTS-1 data tape, therefore it was decided to determine the effect this caused on the performance results. To establish this, the two-channel discriminant technique was applied to the original CCT which had not gone through the registration process. The resultant mosaicked recognition map was visually correlated to the 1:24,000 scale grey map produced using the same two-channel discriminator technique. It was found that the registration process was responsible for all misidentifications of lakes with areas of 10 acres or more. Without the data dropout due to registration a correct detection rate, F_{33} value of 100% was achieved and the false detection rate, F_{03} remained zero.

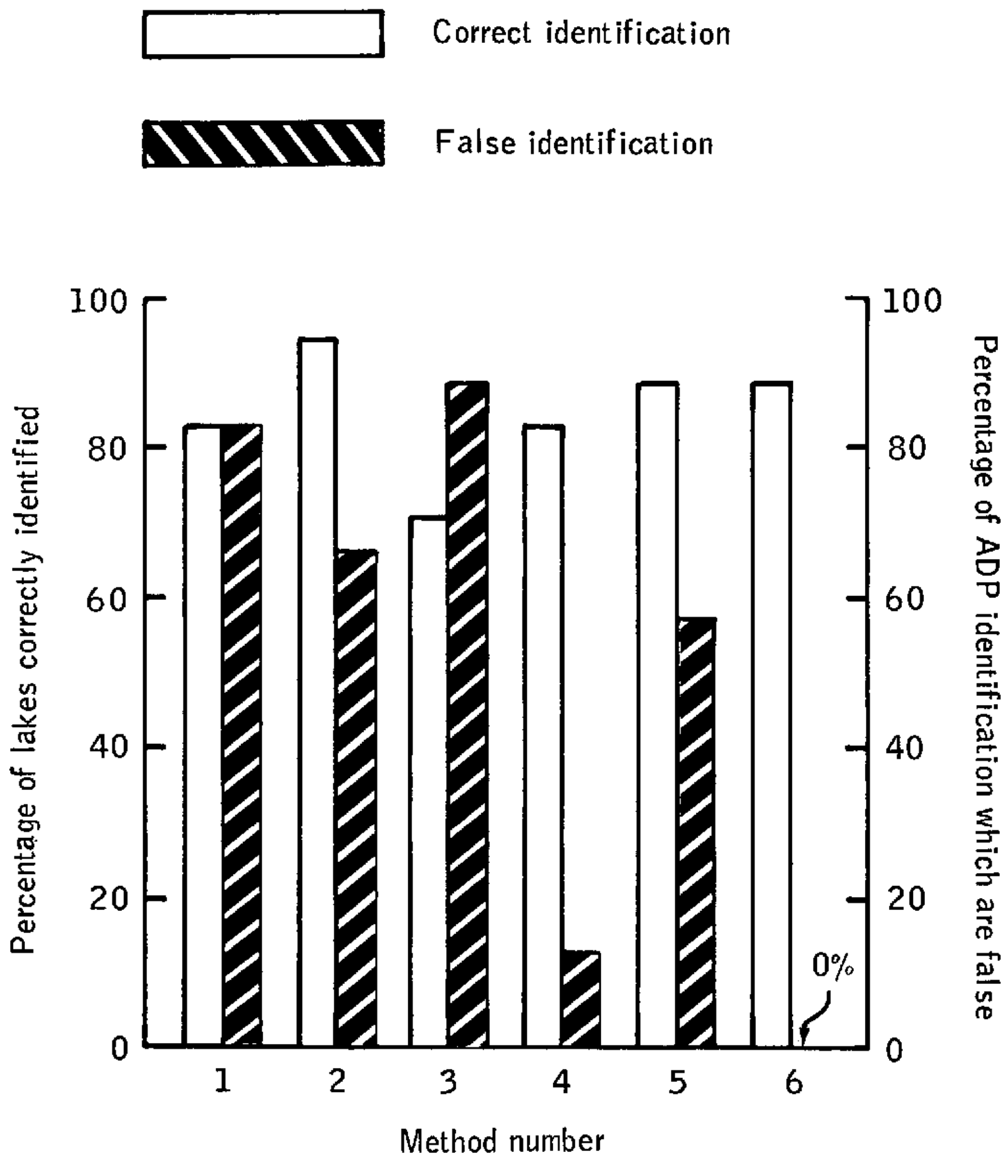

Figure 8. - Evaluation results for the six ADP methods. The percent of correct identifications refers to the total number of ten, or greater, surface acre lakes in the study area. The percent of false identifications refers to the total number of ADP identifications for the study area.

7.3 CHOSEN PROCEDURE AND RATIONALE

The superior performance of the two-channel linear discriminant technique for the study area caused it to be the prime contender for the recommended technique. The additional fact that the technique was developed by forcing the maximum likelihood classifier to establish the chosen linear discriminant line in two-channel spectral space indicated that an alternate programming effort could be undertaken to greatly simplify the computer processing steps and achieve more efficient execution on digital computers. Finally, it was determined from previous work in the EOD that it was feasible to incorporate a registration technique into the prepared computer program which classified first, retained elements classified as water, then registered retaining those elements otherwise dropped. For these reasons, it was recommended to the EOD that the two-channel linear discriminant technique be streamlined and transferred to the TWRC.

7.4 DISCUSSION OF OVERALL RECOMMENDED PROCEDURE

Experience gained in the conduct of this investigation led to many conclusions concerning the establishment of a total, transferable, computer-aided procedure. The following discussion will give the general step for such a procedure and comments on each. The steps generally describe the preliminary computer-aided procedure transferred to the TWRC in June, 1973, and are based on the preliminary versions of the streamlined computer programs.

The chronological steps to be taken are:

a. Obtain background information. This step is composed of acquiring the basic data to be screened for selecting the ERTS-1 MSS coverage, the ancillary data for control point selection, and for the determination of the final scale of the results.

(1) ERTS-1 data - Microfilm cartridges of reconstituted ERTS-1 MSS images are available for screening at several locations in the United States. These microfilm images can be screened for cloud-free coverage over the geographical area of interest.

(2) Weather data - The United States Weather Bureau publishes tables of daily rainfall for the United States. These data for the area of interest should be obtained for correlation with available cloud-free ERTS-1 MSS coverage.

(3) Ancillary data - Maps are required for three purposes in the procedure; for delineation of exact ERTS-1 coverage, for selection of control points for registration, and for use as base maps at the desired scale to which the ADP detection and location information can be related. Complete USGS map coverage of the United States is available for scales up to 1:250,000. Current indexes of maps as large as 1:24,000 scale should be obtained for the area of interest; not all of the United States is currently mapped at either 1:24,000 or 1:62,500 scales. Maps of the area of interest at 1:1,000,000 are needed since ERTS-1 MSS transparent images are available at that scale and are used to determine exact ground coverage of each CCT. Maps of the area of interest at scales of either 1:24,000 or 1:62,500 are desirable for control point selection. If not available, then the largest scale possible should be acquired. Maps at the desired output scale should be acquired. These might be USGS 1:24,000 or 1:62,500 scale, if available, or county highways maps.

b. Select and obtain ERTS-1 MSS coverage - The microfilm images of ERTS-1 MSS coverage should be screened for cloud-free coverage of the area of interest. The candidate ERTS-1 coverages should be correlated with rainfall preceding the coverage.

When the selection is complete, order both the ERTS-1 MSS computer compatible tapes and the 9 1/2-inch system corrected images for the selected scene.

c. Determine exact ERTS-1 MSS coverage - The channel 1, 9 1/2-inch duplicate positive transparency should be overlaid on a 1:1,000,000 scale Operational Navigation Chart (ONC), and adjusted such that roads match. Alternately, the channel 4 transparency may be used and aligned with surface water bodies. Then mark on the map the extent of the ERTS-1 coverage. Divide the area into four equal vertical strips. Each strip then denotes the ground coverage of each one of the four CCT's required to cover that scene.

d. Obtain control points and coefficients - Each CCT requires a minimum of 6 control points for registration. Run the grey map program for the strip or strips of interest with the first ten levels of channel 4. Visibly correlate the occurrence of water bodies from the grey map with both those in the channel 4 image and those shown on the control point maps. Pick the sharpest features available, at least six, which mutually occur. Measure their coordinates and input them to a computer program which derives coefficients for registration.

e. Obtain the line printer output indicating the detection and location of water bodies - Input the control coefficeints into the detection and location computer program together with the desired output scale factor for each CCT of the strips of interest and obtain the line printer output.

f. Process Results - The scale desired for output will determine the volume of paper to be mosaicked. For the larger scales, the computer line printer paper for a complete strip might need to be mosaicked in sections. Whatever the scale, trim each continuous page of line printer output according to symbols marded on the right hand side. Overlay the continuous paper, side to side, and align the column headings from page to page. Tape the paper together carefully. If the base maps are 1:24,000 or 1:62,500, only one sheet need be correctly identified between the base map and the mosaicked output. The map index will give all succeeding locations relative to the first. Lay the section of the mosaicked output corresponding to a base map sheet over a light table, and lay the base map sheet on top. With an appropriate marking devise, transfer the detection and location information from the output to the base map.

7.5 POTENTIAL TRANSFERABILITY OF THE CHOSEN COMPUTER-AIDED PROCEDURE

The two-channel discriminant procedure was recommended to satisy the Texas Water Rights Commission's needs for an inventory of water impoundments in the State of Texas and subsequently transferred to the TWRC in preliminary form in June, 1973.

This procedure, as developed, used computer algorithms which are not optimized for rapid execution. In addition, the procedure uses a tape reformatting step which is not essential for an operational system.

Discussions with EOD personnel indicated the feasibility of generating computer programs which will detect and locate using the two-channel discriminant at approximately the speed required to read tape. It was recommended, and an effort was undertaken, to generate the appropriate computer programs capable of rapid execution prior to delivery of the technology to an outside user agency.

A preliminary version of these computer programs was delivered to a TWRC representative who spent a two-week training session for the computer-aided procedure at the EOD in June, 1973.

APPENDIX A

COMPUTER-AIDED PROCEDURES

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COMPUTER-AIDED PROCEDURES

Five computer-aided procedures were selected for evaluation in this project. These procedures are presented in the following paragraphs.

1.0 SEVERAL CLASSES OF WATER AND THRESHOLDING

This procedure is defined for use with existing JSC software packages that are presently implemented on the Univac 1100 series computers at JSC. The procedure involves the following steps:

a. Select the appropriate ERTS-1 System Corrected Computer Compatible tape.

b. Using program REFORM convert the tape to a LARSYS II format.

c. Using program PICMON obtain a grey map of channel 4 (caution: use the default mode for symbol selection).

d. Select the appropriate base maps and select ground control points. Relate these ground control points to line and column locations on the channel 4 grey map.

f. Using program PICMON obtain a geometrically corrected grey map of channel 4. Use the following symbols for the appropriate count range.

symbol	counts
m	0 thru 6
*	7 thru 9
blank	10 thru 63

g. Using the geometrically corrected grey map locate all areas which contain 8 or more contiguous pixels represented by an m or an *. Each area must have at least 25% of the pixels represented as m.

h. From the areas selected in step g select the largest rectangular training field which contains a minimum of 8 pixels but no more than

30 pixels. These rectangular areas must have at least 50% of the pixels represented as m.

i. Using program ISOCLS obtain a statistics deck which contains statistics for use with program LARSAA (Note: 4 clusters , NMIN = 16, STDMAX = 0.5, DLMIN = 1.0, ISTOP = 20, PUNCH = 1)

j. Using the statistics deck from step i and the program LARSAA classify the selected test area.

k. Using LARSAA (DISPLAY) obtain five displays of the classified test area. Values of threshold T equal to 1.0, 2.0, 3.0, 4.0, and 5.0 shall be used in the respective display runs.

2.0 SEVERAL CLASSES OF WATER PLUS SIMILAR CLASS AND THRESHOLDING

This procedure is defined for use with existing JSC software packages that are presently implemented on the Univac 1100 series computers at JSC. The procedure involves the following steps.

a. Select the appropriate ERTS-1 System Corrected Computer Compatible tape.

b. Using program REFORM convert the tape to a LARSYS II format.

c. Using program PICMON obtain a grey map of channel 4 (caution: use the default mode for symbol selection).

d. Select the appropriate base maps and select ground control points. Relate these ground control points to line and column locations on the channel 4 grey map.

e. Using program REGSTR obtain a geometrically corrected LARSYS II tape.

f. Using program PICMON obtain a geometrically corrected grey map of channel 4. Use the following symbols for the appropriate count range.

symbol	counts
m	0 thru 6
*	7 thru 9
blank	10 thru 63

g. Using the geometrically corrected grey map locate all areas which contain 8 or more contiguous pixels represented by a m or an *. Each area must have at least 25% of the pixels represented as m.

h. For the water training classes select, from the areas selected in step g, the largest rectangular training field which contains a minimum of 8 pixels but no more than 30 pixels. These rectangular areas must have at least 50% of the pixels represented as m.

i. Using program ISOCLS obtain a statistics deck to be used with program LARSYS (Note: 4 clusters , NMIN = 16, STDMAX = 0.5, DLMIN = 1.0, ISTOP = 20, PUNCH = 1.

j. For the similar training classes select, from the areas selected in step g, the largest rectangular training field which contains a minimum of 8 pixels but no more than 30 pixels. These rectangular areas must contain only pixels represented by an *.

k. Using program ISOCLS obtain a statistics deck to be used with program LARSAA (Note: 3 clusters, NMIN = 16, STDMAX = 0.5, DLMIN = 1.0, ISTOP = 20, PUNCH = 1).

l. Combine the statistics decks obtained in steps i and k into one deck and using program LARSAA classify the selected test area.

m. Using LARSAA (DISPLAY) obtain five displays of the classified test area. For the water classes use a value of threshold T equal to 1.0, 2.0, 3.0, 4.0, 5.0 in the respective display runs. For all display runs use a value of threshold T = 0 for all similar classes.

3.0 TWENTY-ACRE LAKES OR GREATER AND THRESHOLDING

This procedure is defined for use with existing JSC software packages that are presently implemented on the Univac 1100 series computers at JSC. The procedure involves the following steps.

a. Select the appropriate ERTS-1 System Corrected Computer Compatible tape.

b. Using program REFORM convert the tape to a LARSYS II format.

c. Using program PICMON obtain a grey map of channel 4 (caution: use the default mode for symbol selection).

d. Select the appropriate base maps and select ground control points. Relate these ground control points to line and column locations on the channel 4 grey map.

e. Using program REGSTR obtain a geometrically corrected LARSYS II tape.

f. Using program PICMON obtain a geometrically corrected grey map of channel 4. Use the following symbols for the appropriate count range.

symbol	counts
m	0 thru 6
*	7 thru 9
blank	10 thru 63

g. Using all available ancillary information (e.g., USGS map, NASA A/C photography, etc.), locate each area on the geometrically corrected grey map obtained in step f which is related to a known lake with a surface area of 20 acres or greater.

h. Select rectangular training fields of at least 16 pixels and no more than 30 pixels from within each area selected in step g (if possible choose training fields from all of the known 20 acre or greater lakes). All pixels selected should be within the perimeter of the lake.

i. Using program ISOCLS obtain a statistics deck which contains statistics for use with program LARSAA (Note: 4 clusters, NMIN = 16, STDMAX = 0.5, DLMIN = 1.0, ISTOP = 20, PUNCH = 1).

j. Using the statistics deck from step i and the program LARSAA classify the selected test area.

k. Using LARSAA (DISPLAY) obtain five displays of the classified test area. Values of threshold T equal 1.0, 2.0, 3.0, 4.0, and 5.0 shall be used in the respective display runs.

4.0 GREY SCALE MAP

This procedure is defined for use with existing JSC software packages that are presently implemented on the Univac 1100 series computers at JSC. The procedure involves the following steps.

a. Select the appropriate ERTS-1 System Corrected Computer Compatible tape.

b. Using progtam REFORM convert the tape to a LARSYS II format.

c. Using program PICMON obtain a grey map of channel 4 (caution: use the default mode for symbol selection).

d. Select the appropriate base maps and select ground control points. Relate these ground control points to line and column locations on the channel 4 grey map.

e. Using program REGSTR obtain a geometrically corrected LARSYS II tape.

f. Using program PICMON obtain two geometrically corrected grey maps of channel 4. Use the following symbols for the appropriate count range.

FIRST MAP

Symbol	Counts
0 thru 5	0 thru 5
blank	6 thru 63

SECOND MAP

Symbol	Counts
0 thru 6	0 thru 6
blank	7 thru 63

5.0 TWO-CHANNEL LINEAR DISCRIMINANT FUNCTION

This procedure is defined for use with existing JSC software packages that are presently implemented on the Univac 1100 series computer at JSC. The procedure involves the following steps.

a. Select the appropriate ERTS-1 System Corrected Computer Compatible tape.

b. Using program REFORM convert the tape to a LARSYS II format.

c. Using the program ISOCLS obtain cluster means for the ground features covered by the LARSYS II tape.

d. Using all available ancillary data (e.g., USGS maps, NASA aircraft photography, etc.), relate the cluster means to identifiable ground features (e.g., water, vegetation, bare soil, mixtures of water and other features, etc.).

e. Plot the cluster means in three two-dimensional spectral diagrams; channel 1 versus channel 4, channel 2 versus channel 4, and channel 3 versus channel 4.

f. Select the two-channel diagram which shows the greatest separation of water cluster means from all other features.

g. Determine a linear discriminator line in the two-channel diagram which best separates water from other features.

h. Generate a statistics deck with which program LARSAA will generate the separation desired in spectral space and use only the two channels from the two-dimensional diagram.

i. Using the statistics deck and program LARSAA, classify the selected area.

j. Using LARSAA (DISPLAY) obtain a display of the classified test area.

k. Iterate this procedure from g through j until satisfactory results are obtained.