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MOVEMENT OF SUSPENDED PARTICLE AND SOLUTE CONCENTRATIONS WITH INFLOW AND TIDAL ACTION

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16. Abstract

ERTS-1 data recorded on computer compatible tapes (CCT's) augmented with data derived from ground truth measurements are being used to determine the feasibility of delineating flow patterns, flushing actions of the estuary, and sediment and pollutant dispersion at five test sites within the Chesapeake Bay area. Techniques have been developed for using a PDP-15 computer to demultiplex the CCT's, extract radiance values for correlation with ground truth data, and generate maps that show where ERTS-derived reflectance spectra match reference reflectance spectra. This report describes the computer techniques and the manner in which they may be used.

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Figure 2. Technical Report Standard Title Page

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Preface

The overall objective of the ERTS-1 study at the U. S. Army Engineer Waterways Experiment Station is to detect from remote imagery the alterations to the optical properties of water caused by movement of suspended particles and solutes in selected areas of the Chesapeake Bay and correlate the data to determine the feasibility of delineating flow patterns, flushing actions of the estuary, and sediment and pollutant dispersion. In a step toward accomplishing this objective, computer techniques have been developed to demultiplex the computer compatible tapes, extract radiance values for correlation with ground truth data, and generate "maps" that show areas where spectrum matches occur.

This report describes the computer techniques and the manner in which they may be used. ERTS-1 and ground truth data taken on 10 October 1972 are used in an example that shows an application of the ADP techniques.

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ILLUSTRATIONS

PART I: INTRODUCTION

1. Solar radiation impinging upon a body of water will be absorbed and/or scattered in a manner depending, among other things, upon the concentration and type of material in suspension in the water. The objective of the ERTS-1 study being conducted by the U. S. Army Engineer Waterways Experiment Station (WES) is to detect in the satellite data alterations to the absorption and scattering properties of water caused by movement of suspended particles and solutes in selected areas of the Chesapeake Bay and to correlate the data to determine the feasibility of delineating flow patterns, flushing action of the estuary, and sediment and pollutant dispersion.

Ground Truth Data

2. Figure 1 shows the data acquisition and analysis plan for the ERTS-1 study in the Chesapeake Bay study area (CBSA). During the period of this report, ground truth data collection stations were selected in the York, Rappahannock, Wicomico, and Choptank Rivers and the Chesapeake and Delaware (C&D) Canal. ERTS-1 overpasses were supported by collection of ground truth data at 72 stations on 10 October and 63 stations on 28 October. As weather conditions precluded collection of data on the Choptank River on 28 October, data were collected at 11 stations on the Choptank on 29 October. Where local conditions permitted, the following parameters were measured: suspended material concentration, water temperature, conductivity, turbidity, dissolved oxygen, current velocity/direction, spectral transmittance, secchi depth, and pH.

3. A data collection platform (DCP) connected to a water quality analyzer for monitoring temperature, conductivity, pH, and dissolved oxygen and a multichannel recorder connected to sensors for monitoring water temperature, wind speed and direction, rainfall, and incident and reflected solar radiation were used to collect data at one station in the Choptank River and one in the Rappahannock.

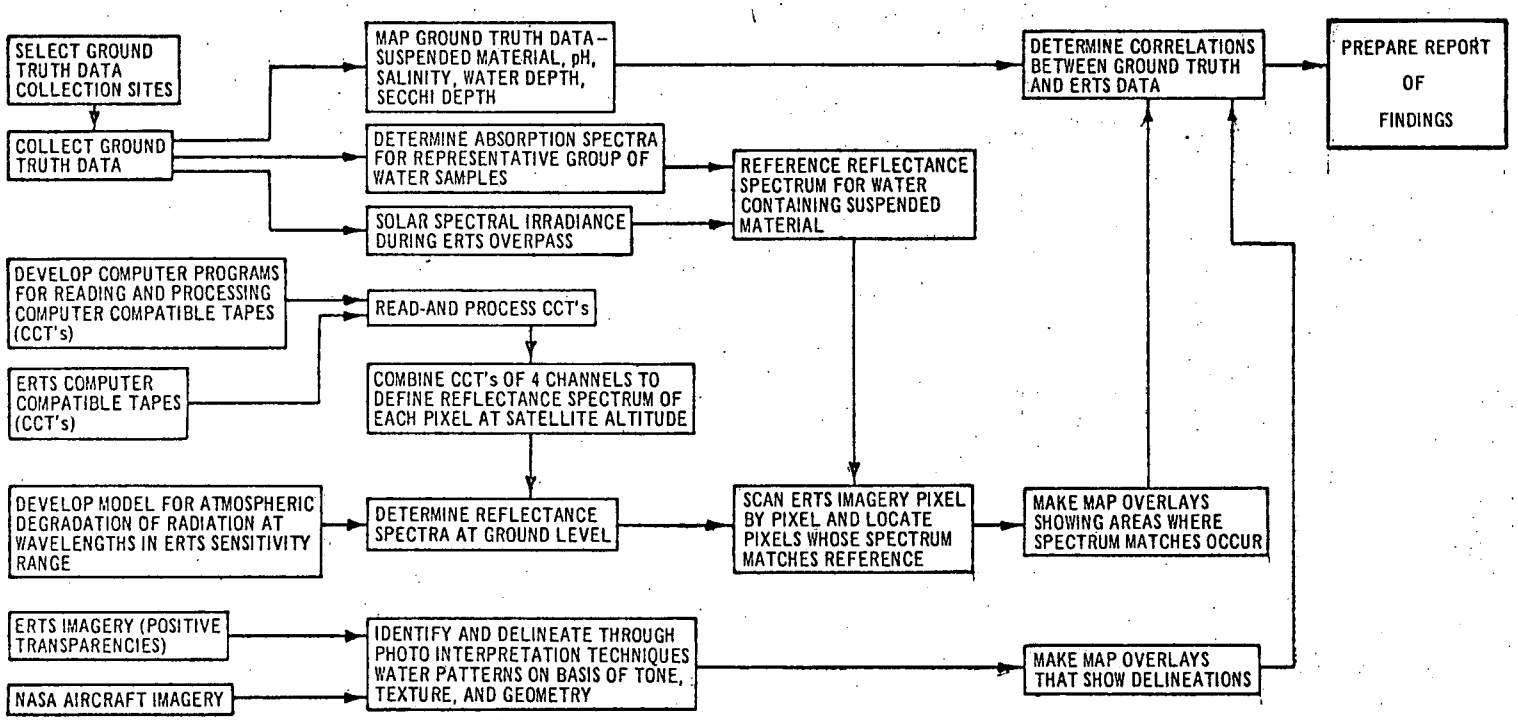

FIG. 1. ERTS-1 CHESAPEAKE BAY STUDY
DATA ACQUISITION AND ANALYSIS PLAN

Computer Program Development

4. Two computer programs have been developed to aid in achieving the objectives of this study. One program accepts data derived from computer compatible tapes (CCT's) and, with atmospheric correction applied, outputs a record of radiometric conditions existing near the ground (water) at the time the ERTS-1 data are taken. The data are arranged so that the geometric relationship of the individual pixels* is retained.

5. The other program reads and decodes data on IBM cards resulting from DCP measurements. The results are printed as a tabular listing with measured values given in engineering terms, i.e. temperature in ^{o}C, etc., or alternatively as an xy plot.

Model for Atmospheric Degradation

6. At the initiation of this study, it was planned to develop a model for atmospheric degradation of radiation at wavelengths within the ERTS-1 sensitivity range. However, contacts with other researchers revealed that such a model in a rather basic form already existed, and improvements are currently under way. Inputs to the model in its present configuration are pressure, temperature, density, water vapor concentration and ozone concentration as a function of altitude. The output is percent transmittance between any two points in the terrestrial atmosphere.

7. A detailed description of the model is given in the report "Optical Properties of the Atmosphere" (Third Edition).[1] This report contains a set of tables and charts from which transmittance between two points can be calculated for five model atmospheres--tropical, mid-latitude summer, mid-latitude winter, subarctic summer, and subarctic winter. In addition, data for two aerosol models are given.

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*A pixel is the smallest resolvable element in an array of elements that define a scene.

[1] R. A. McClatchey, et. al., Optical Properties of the Atmosphere (Third Edition), National Technical Information Center, AFCRL-72-0497, 24 August 1972.

8. The atmospheric model was coded for use on the WES computer, and sensitivity tests were made in an attempt to isolate atmospheric parameters that must be monitored if radiometric analyses of ERTS data are to be made. These tests failed to isolate any specific set of parameters that must be monitored, suggesting that a description of all the parameters would be required for accurate radiometric analysis. Acquisition of data in the detail required for these descriptions was clearly beyond the scope of this study.

9. On this basis, the decision was made to base corrections for atmospheric effects on data contained in the report and interface at a later date with researchers who are currently working on the specific problem of obtaining atmospheric descriptions useful for remote sensing applications.

Scope of this Report

10. This report describes in general terms the computer program(s) for reading and processing data recorded on the CCT's, and presents a technique developed at the WES for searching the ERTS-1 data for spectral conditions related to concentrations of suspended material. A portion of the ground truth data and associated ERTS-1 data taken on 10 October 1972 in the Rappahannock River is used to show how the technique is employed.

PART II: DATA REDUCTION

11. Each CCT contains all the data from each of the four MSS channels for an area on the surface of the earth 25 nautical miles wide and approximately 100 nautical miles long. Four such tapes, each containing 2340 scan lines with 810 pixel values, are required to describe a full 100- by 100-nautical mile scene. Data are interleaved on the CCT's in the format 4455667744..., where 4 = a pixel value from MSS channel 4, etc., and the geometric relationship of the individual pixels comprising a scene is retained in order that a scene may be reconstructed in the form of an orthogonal number array or a photograph. The data reduction computer program is designed to (a) separate the interleaved MSS data according to band, (b) convert the data to radiometric terms, and (c) correct the radiometric values for atmospheric effects on the propagation of electromagnetic radiation in the 0.5 to 1.1-micrometer band. This results in a record of radiometric conditions that exist near the ground (water) at the time the ERTS-1 data are taken.

Data Separation

12. Because of the limited capability at the WES to process 9-track computer tapes, the tapes received from NASA are converted to a 7-track format with values ranging from 0 to 63. In this process pixel values originally recorded as 16 bit (two 8-bit bytes) words are recorded as words 24 bits (four 6-bit bytes) in length to permit processing data on a PDP-15 computer, which affords considerably greater flexibility and versatility in processing CCT data than does the larger GE 427/435 computer at the WES.

13. The 24-bit words defining the area of interest are unpacked, the data are separated according to MSS band, and a new tape is written for each of the 4 MSS bands. Each pixel value on the new tapes is written as a 12-bit word. The maximum pixel value is 63, and the data are right justified so that the first 6 bits of each 12-bit word remain free for future use (see paragraph 19).

Data Conversion and Atmospheric Corrections

14. In order that they may be compared with other remote sensor data taken at lower altitudes or with radiometric measurements made on the ground (water), the ERTS-1 data must be converted to radiometric terms (mw/cm^2-SR) and corrected for effects caused by the propagation through the earth's atmosphere of electromagnetic radiation in the 0.5- to 1.1-micrometer band.

15. The values recorded on the tapes correspond to radiance values between 0 and 100 percent. A "63" on the tape corresponds to the maximum radiance detectable by an MSS band. Maximum radiance values found in the ERTS Data User's Handbook for MSS 4 through 7 are 2.48, 2.00, 1.76, and 4.60 mw/cm^2-SR, respectively. Radiance can therefore be determined from the tape-recorded data by the equation:

$$R = M_i \left(\frac{x}{63}\right) \tag{1}$$

where

R = radiance in mw/cm^2-SR

x = value between 0 and 63 from recorded tape

M_4 = 2.48 mw/cm^2-SR

M_5 = 2.00 mw/cm^2-SR

M_6 = 1.76 mw/cm^2-SR

M_7 = 4.60 mw/cm^2-SR

16. Solutions to equation 1 give radiance at the ERTS-1 altitude. Atmospheric attenuation constants for a mid-latitude summer were determined from data in the report "Optical Properties of the Atmosphere" (Third Edition) and were used to compute the transmittance as a function of wavelengths between 0.5 and 1.1 micrometers. The results are shown graphically in fig. 2. The solutions to equation 1 divided by the average of the computed transmittance values (τ) for each of the MSS bands give the radiance near the ground (water). Thus, equation 1 may be stated as follows:

$$R = \frac{M_i \left(\frac{x}{63}\right)}{\tau_i} \qquad (2)$$

where

τ = atmospheric transmittance

$\tau_4 = 0.69$

$\tau_5 = 0.75$

$\tau_6 = 0.68$

$\tau_7 = 0.76$

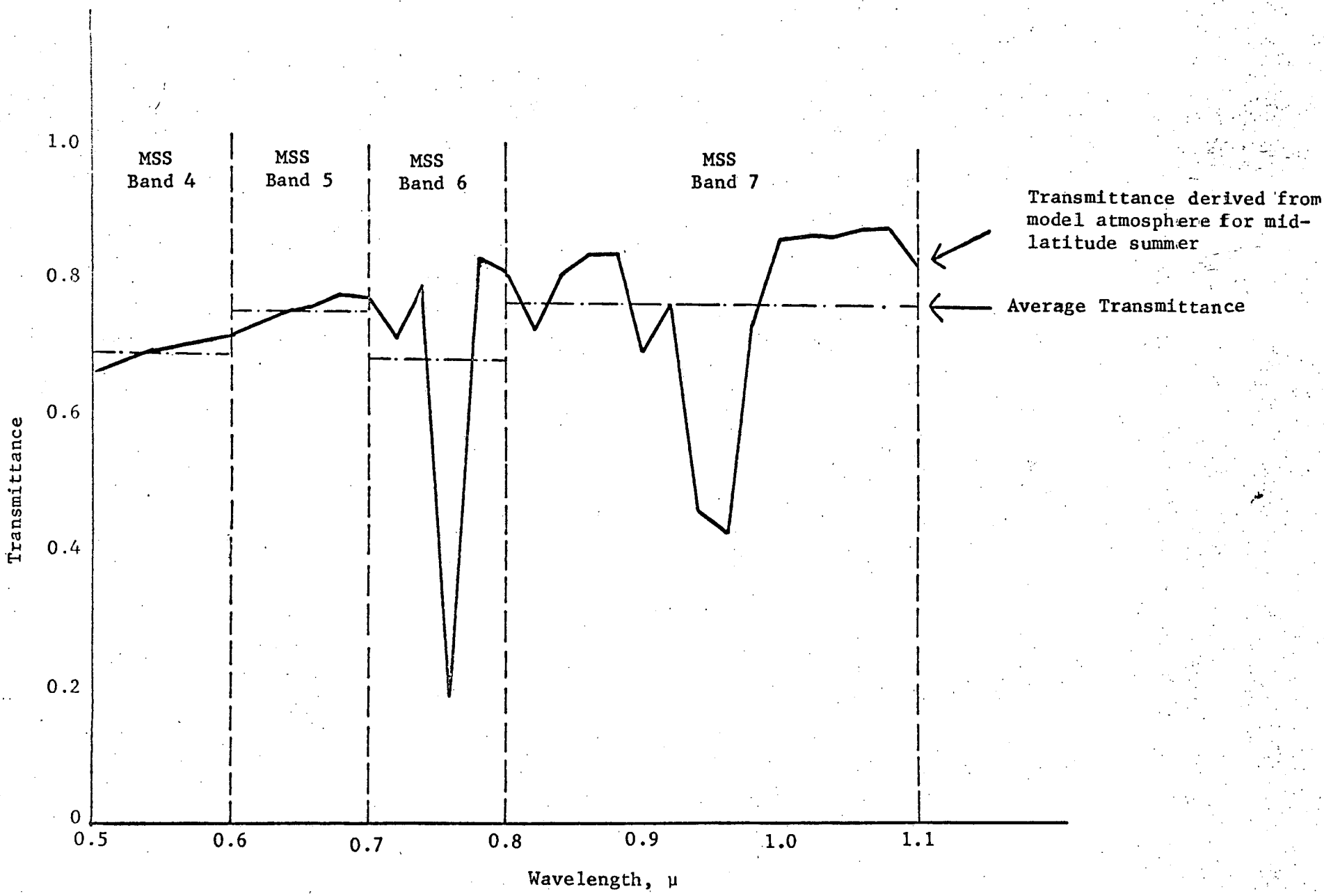

Fig. 2. Transmittance versus wavelength

PART III: ANALYSIS OF DATA

17. In the data analysis, the ERTS-1 is considered to be a reflectance spectrophotometer whose output is a series of spectra of radiance versus wavelength (reflectance spectra) that describe a scene. Each spectrum in the series contains an MSS band 4, 5, 6, and 7 value that corresponds to a common area on the earth's surface.

18. Alterations to the optical properties of water caused by suspended particles and solutes are detected by checking each reflectance spectrum in a series for a match with any one of a group of reference spectra. The results are printed out in the form of a "map" that identifies the locations where spectrum matches occur and denotes spectra that were matched. The resulting patterns indicate flow patterns, flushing actions, and sediment and pollutant dispersions.

Determination of Reference Reflectance Spectra

19. MSS band 7 values measured over water bodies are very low, normally less than 0.20 mw/cm -SR, due to the low reflectance of water in the 0.8- to 1.1-micrometer band; and the values contrast sharply with those measured over land areas. This band therefore provides a convenient way to digitally mask or identify values corresponding to land areas in band 4, 5, and 6 data where land-water separations are not always clearly defined. MSS band 7 data are scanned on a pixel-by-pixel basis; and in each case where the value exceeds 0.20 mw/cw -SR (or a higher value in unusual circumstances), a binary "1" is placed in the first bit position of the 12-bit word containing the pixel value. The tape of MSS band 7 data then becomes a "mask" for printing out data for the other MSS bands.

20. Radiance values for MSS bands 4, 5, and 6 are each printed out using the band 7 mask to inhibit printing of values measured over land. Values for each band corresponding to a ground data collection station are located and are extracted from the printouts to define the reference spectra.

21. Figure 3 shows a portion of a printout for MSS band 4 wherein the digital mask has been used to eliminate values measured over land.

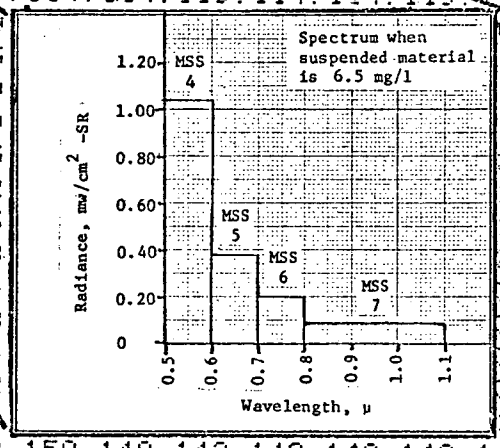

Fig. 3. Portion of computer printout of radiance values derived from MSS Band 4 (Values are in mw/cm^2-SR X 0.01)

Each printed value (in mw/cm^2-SR X .01) corresponds to a measurement over water. The number in the box is located at a position in the record that corresponds to a ground truth data collection station. The reflectance spectrum for this point is shown in the inset. At this point, the suspended material concentration was determined from the ground truth data to be 6.5 mg/1. The blank area in the lower portion of the printout corresponds to a land area--Grey Point on the Rappahannock River.

22. Correlations of reflectance spectra derived from the ERTS data and suspended material concentrations measured at ground data collections station in the Rappahannock River on 10 October 1972 show that the reflectance spectra relate to concentrations of suspended material in the following manner:

Suspended Material			Radiance, mw/cm^2-SR MSS Band		
Class	Map Symbol	Concentration (mg/1)	4	5	6
1	-	0-10	1.02-1.31	0.38-0.55	0.08-0.28
2	+	>10-20*	1.36-1.48	0.46-0.71	0.16-0.32
3	*	>20-30*	1.48-1.59	0.76-0.84	0.28-0.32
4	#	>30*	1.48-1.59	0.76-0.84	0.36-0.41

*Estimated concentration ranges.

Ground truth data were collected at 19 points in the Rappahannock River. Water samples collected at 14 of these points contained less than 10 mg/1 of suspended material, water from 3 points contained between 10 and 20 mg/1 of material, and water from the remaining 2 points contained between 20 and 30 mg/1 of material. Thus, the concentration ranges for class 2 and 3 are estimates based on a very limited amount of data. Likewise, the lower limit of class 4 could only be estimated.

The use of bands of radiance values to define a class as shown in the above table precludes the necessity to account for variations in

radiance values (± 2% of full scale) introduced by the ERTS multispectral scanner.

Spectrum Matching

23. Through use of ADP techniques, radiance values for MSS bands 4, 5, and 6 are scanned on a pixel-by-pixel basis and spectrum matches are identified according to the range in which the values fall. If the radiance value for a pixel in MSS band 4 and the corresponding pixel value for MSS band 5 and MSS band 6 all sort into ranges according to one of the classes designated above, that pixel is reidentified by one of the map symbols shown in the table above. For example, the reflectance spectrum for the point designated by the box in fig. 4 has values as follows:

MSS band 4 = 1.36 mw/cm^2-SR
MSS band 5 = 0.46 mw/cm^2-SR
MSS band 6 = 0.24 mw/cm^2-SR

All the values fall within the ranges designated for class 2 in the table, and the pixel at that location is therefore identified by the symbol "+". A "0" in fig. 4 denotes pixel locations whose reflectance spectrum did not match a reference reflectance spectrum.

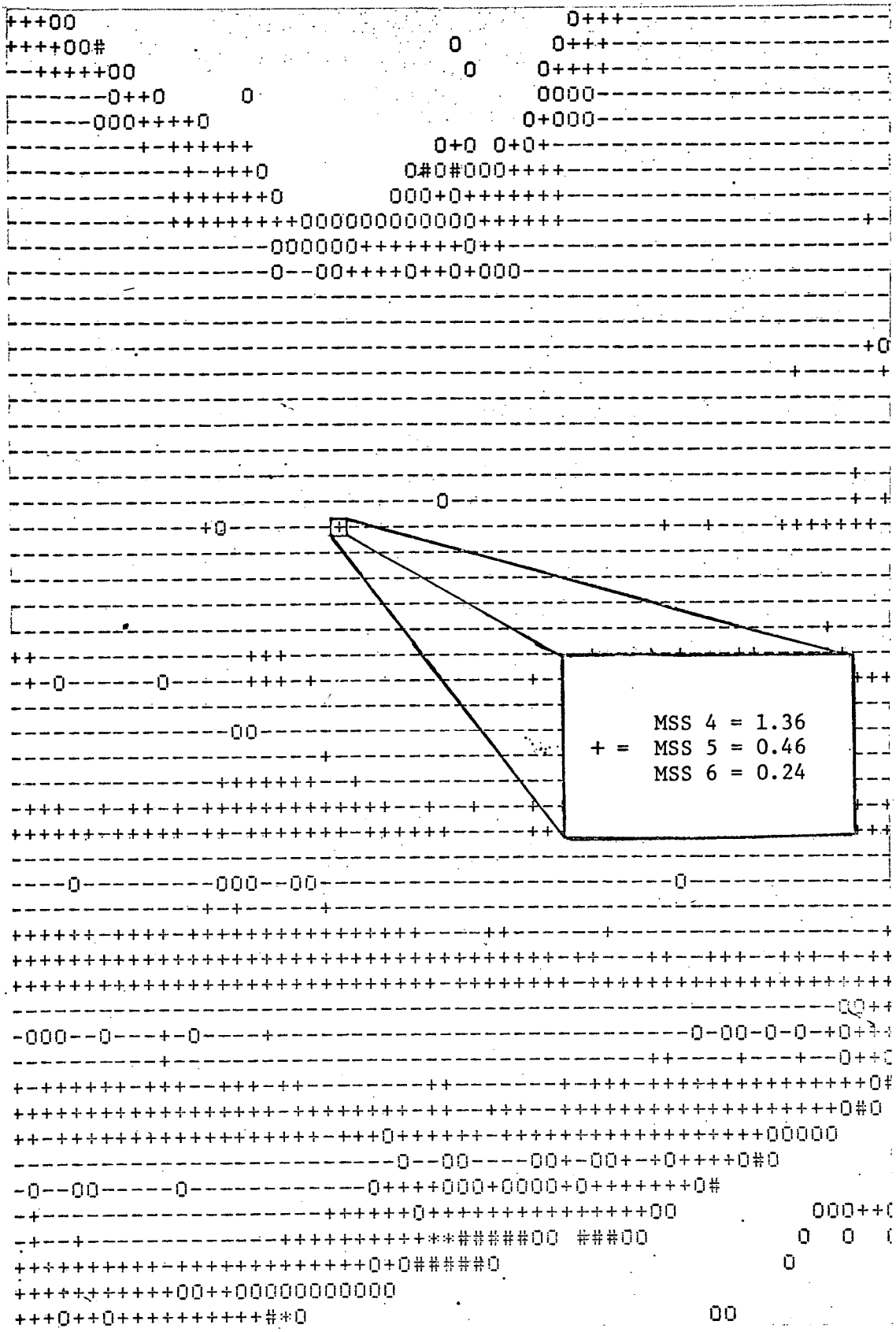

Fig. 4. Portion of computer printout showing points where spectrum matches occur

PART IV: PROGRAM FOR NEXT REPORTING PERIOD

24. Data for the C&D Canal, and the York, Rappahannock, Choptank, and Wicomico Rivers will be reduced and analyzed through use of procedures discussed in the preceding paragraphs. Printouts similar to that shown in fig. 4 will be generated and used to delineate flow patterns, flushing action, and sediment and pollutant dispersion. Techniques will be developed for reducing and interpreting in a similar manner Bendix 24-channel scanner data and I^2S imagery of the study area.

25. Ground truth and aircraft data are scheduled to be taken on 21 March and 8 April to augment the data taken during the ERTS-1 overpass of the test area. An aircraft equipped with a video tape recorder and an Exotech radiometer will fly at low altitude (approximately 500 ft) to obtain simultaneously a video recording of the study area and a recording of radiometric conditions in four bands corresponding to the ERTS-1 MSS bands. Data from the low-altitude flights made during an ERTS overpass are expected to be useful in determining the effects that materials in suspension have on absorption properties of water.

PART V: CONCLUSIONS

26. Although this report is limited to a description of the data processing and other procedures that have thus far been developed and are being used to achieve the objectives of the WES study, the following conclusions can be drawn:

a. The digital data on CCT's contain a great amount of detail, radiometrically speaking, that is not apparent on imagery.

b. The high land-water contrast apparent in MSS 7 data is valuable for automatically delineating land-water interfaces. An automatic technique for this purpose enables shoreline maps to be rapidly produced and reservoir inventories, floodwater delineations, etc., to be accomplished rapidly and with a high degree of accuracy.