CR-136789

MONTHLY REPORT JANUARY 1974
Contract Number NAS 9-13303

During this reporting period we scanned with the microdensitometer the SL3 S190 imagery and the accompanying step wedges. We discovered that the step wedge film was much smaller grain size than the image film. Comparison was between equivalent densities to account for the fact that the grain size is dependent on density. After measuring the step wedge with various aperture sizes it was concluded that a 46 μm circular aperture would be required to minimize grain noise. This can be compared with a 25 μm circular aperture used to scan the Apollo 9 S065 film. Upon subsequent scanning of the imagery with the 46 μm circular aperture it was apparent that the grain size was significantly larger than that of the step wedge and would require an even larger aperture to overcome grain noise. It is doubtful at this point whether the S190 imagery will be very useful due to the loss in resolution caused by the large grain size. If this proves to be true, it amounts to a sincere disappointment relative to the goals of the experiment. We will continue to investigate the imagery and report further next month. It should be noted that except for the 2424 film, the film used was different than that listed in the EREP users handbook. We must also question whether the step wedge is an accurate calibration of the image densities. Since they are different films they were possibly processed differently and independently. It was expected that the step wedge would be on the same film strip and exposed on the ground before and after the mission on the beginning and end of the film strip respectively to measure film degradation and simultaneously calibrate relative to film processing.

(E74-10307) [MICRODENSITOMETER SCANNING OF SL3 S190 IMAGERY AND ACCOMPANYING STEP WEDGES] Monthly Report, Jan. 1974 (Boeing Co., Kent, Wash.) ~~2~~ 34 p HC $4.00 CSCL 14B G3/13
N74-17095
Unclas 00307

Our work toward analytically inverting the brightness integral for non-180^{0} scatter remains unsuccessful. The 180^{0} scatter problem that we have analytically solved is being coded and will serve at least as an approximation until the general solution or some alternative is derived. If the error limits are small enough the 180^{0} scatter approximation may prove entirely satisfactory. In any case further analysis will not be impeded by the problem.

The pointing vector software which uses the vehicle state vectors and a model of the brightness to accurately locate the field of view is complete, subject to testing against actual state vectors. Any further development must wait for the Skybet tape to arrive and for software to be written for reading the tape.

It is believed that the S191 tape read routine is complete, subject to testing against the revised S191 tapes to be received. It is unfortunate that much effort and expense has been required and partially wasted with regard to these tapes. The data analysis may be seriously restricted due to budget limitations caused by the unexpected complexity of the S191, S192 magnetic tape data formats, repeated delays in receipt of the data, attempts to read erroneous data tapes, and necessity to prepare additional software to read the Skybet tapes.

In order to better understand the information content of the CCT's, consider the measurement sequence of the MSS. The instantaneous field of view of the MSS (fig. 3) encompasses an area on the terrain surface (picture-element or pixel) of about 1.1 acres. A scanning mirror causes the instantaneous field of view to be deflected along lines normal to the orbital path of the satellite and measurements are made at successive intervals along each scan line. In this manner the MSS sequentially measures the spectral reflectance of 3240 contiguous pixels along each scan line. A total of 2340 scan lines are required to define an ERTS-1 scene covering an area on the ground 100- by 100-nautical miles. The CCT's contain data for each of the four spectral bands of the MSS arranged so that the spatial relationship of the measurements is retained.

Users of MSS data have a choice of exploiting either the CCT's for a scene or a set of photographs (fig. 4) derived by exposing a piece of photographic film to a lamp that is intensity modulated in proportion to the radiance level recorded on the CCT. ERTS data users at the U. S. Army Engineer Waterways Experiment Station (WES) chose the CCT's because the objectivity required by the problems we sought to solve with ERTS-1 data dictated that the interpretive process be based on mathematic manipulation of the digital data by application of computer techniques.

Data Reduction Procedures

In the interest of optimizing data processing costs, versatility, and programming ease, the decision was made to accomplish the data processing on a PDP-15 computer with 16K words of core memory and two disk storage units rather than on a larger computer also available at the WES. However, this decision necessitated rewriting the NASA CCT's to permit processing the data without exceeding the memory capacity of the computer.

As shown in fig. 5, the original NASA CCT's contain the data for all MSS bands recorded in sequence for successive pixels. The CCT's are rewritten on four tapes with each tape containing all data for one spectral band and with the pixels in the proper sequence. Each pixel value is scaled to a number between 0 and 63 and recorded as a 12-bit word (fig. 6) with the least significant 6 bits containing the pixel radiance value and the most significant 6 bits left open for use in identifying the pixel.

The values between 0 and 63 can be converted to radiance (in mw/cm^2-SR) by the equation shown in fig. 7. This equation corrects for the gain of detectors in each of the four MSS bands and for atmospheric effects on the propagation of electromagnetic waves in each of the wavelength bands. Solving this equation gives the spectral radiance at ground level that would result in the radiance detected at satellite altitude. This is desireable so that ERTS-measured radiance values can be correlated with radiance measurements taken for ground truth purposes.

Data Interpretation

Three methods of interpretation are discussed in the following paragraphs. The first was developed as an aid in developing the computer programs for generating sediment concentration maps. The second was a by-product of the first. The concluding technique is the one used for sediment pattern studies. It is the most elaborate and promises to have numerous applications in addition to the one for which it was originally developed.

Land/water Separation

Near infrared radiation is strongly absorbed by water so that band 4 (0.8-1.1 μm) radiance values measured over water can be expected to be low. Upon examination of the values, it was found that radiance values over water were normally less than 0.2 mw/cm^2-SR and were significantly lower than values over land. Thus, band 4 provides a convenient way to digitally identify values corresponding to land areas. Band 4 data are scanned on a pixel-by-pixel basis (fig. 8) and in every case in which the radiance value is less than 0.2 mw/cm^2-SR, a binary "1" is placed in the first (most significant) bit position of the 12-bit word containing the pixel value. Every "water" pixel in the data array is identified in this manner.

The practical value of this is that the data in this form can be easily converted to water distribution maps and map overlays that show locations of water bodies. A film writing instrument, such as the one shown in fig. 9, is required. This instrument can be programmed to convert any value recorded on magnetic tape to a specified shade of gray or black on a piece of photographic film. Thus, by programming the film writer to give a maximum exposure whenever a binary "1" occurs in the most significant position of the pixel word, a map overlay (fig. 10) will be produced wherein water bodies are black and all other features are transparent.

Conversely, if the film writer is programmed to give maximum exposure only when there are no binary "1's" in the prescribed position of a pixel word, the result will be an overlay wherin water bodies are transparent and land areas are black (fig. 11). This type of overlay is particularly useful for studying land areas inundated by flood waters and making comparisons with the surface area during low water levels.

Water Body Inventory

The ability to apply ADP techniques and to distinguish in ERTS-1 data land pixels from water pixels has produced an unusual "spin-off" capability that has been used extensively at the WES to produce from the ERTS-1 data reservoir inventories needed in connection with the National Dam Safety Program. This capability has been exploited to produce inventories of water bodies for much of the southeastern United States.

The reservoir inventory (fig. 12) is a list that identifies every discrete water body by latitude and longitude, and gives an estimate of its water surface area. To produce these inventory lists a computer program is used that we call the contiguity routine. In the contunguity routine, the first scan line is placed in computer memory, where it may be thought of as a line of zeros and ones, (corresponding to land and water) as in fig. 13. Each individual "water" pixel is placed in a separate file on a disc, so that in the example, pixel 1-3 (line 1, pixel number 3) is in one file, pixel 1-7 is in another file, and so on. Scan line 2 is then placed in menory, and a search routine is then initiated. All pixels occupied by zeros are passed over, since they represent land. However, the discovery of a 1 in pixel 2-6 initiates a search routine:

Step	Question	Response	Action
1	Is pixel 1-5 a 1	No	Go to step 2
2	Is pixel 1-6 a 1	No	Go to step 3
3	Is pixel 1-7 a 1	Yes	Place pixel 2-6 in the same file as pixel 1-7; go to pixel 2-7 and resume search

The effect of this routine is to assemble a separate file for each group of contiguous pixels.

Upon completion of the search of scan line 2, scan line 1 is dropped from memory and scan line 3 is placed in memory (fig. 14). The search routine will detect the fact that the files holding pixels 2-6 and 2-10 are connected by a line of contiguous pixels in line 3. When this occurs, the two files are consolidated in a new file on the disc. After all scan lines have been searched, the disc contains a separate file for each water body, and the number of entries is equivalent to the number of pixels, which in turn can be used to calculate an approximate surface area. This process requires 1-2 hrs of computer time per ERTS scene depending upon the number of water bodies in the scene.

The latitude and longitude which appears on the inventory list is the position of the pixel at the midpoint of the longest line of pixels in the file, representing the water body (fig. 15).

Sediment Particle and Solute Concentration Maps

Use of the ERTS-1 data for the purpose of mapping sediment particle and solute concentration is, in actuality, a two step operation. In the first step, water pixels are separated from land pixels using band 4 data, and water pixels are identified by a binary "1" in the most significant position as previously mentioned. The computer tape with pixels identified in this manner is then used as a mask for separating water and land pixel values on the tapes containing band 1, 2, and 3 data. Data in these bands do not otherwise permit a clear land/water separation.

In the second step, a computer program combines the data from bands 1, 2, and 3 to define the spectral reflectance for each pixel. The spectral reflectance for each pixel is then compared with one or more reference spectra. If a match occurs, the pixel is identified according to the reference spectrum it matches. At the same time, the geometric relationship of each pixel comprising a scene is retained so that the results of analysis can be used to generate maps.

To accomplish the second step two inputs to the computer are required--the reference spectrum (or spectra) and a digital magnetic tape for each MSS band in a format compatible with the PDP-15 computer.

Determination of reference spectra. Reference spectra may be derived from one of three possible sources--prediction models, ground truth measurements, or ground truth coupled with MSS measurements. The exact procedure used to obtain reference spectra depends to a very large extent on the intended use of the ERTS data.

Prediction models suitable for defining the spectral characteristics of different objects or materials are being developed, but at this point are not developed to the extent that they can be used very extensively for remote sensor data interpretation. One such model developed at the WES has been used to determine the optimum film/filter combination for detecting a target whose spectral reflectance characteristics are known. In addition, the model computes the proper F-stop and shutter speed required to make the target appear on the film with a specified contrast ratio against its background or surroundings. This same model can be used to compute the spectral signature of any target as it would appear to a sensor at specified altitude and atmospheric conditions providing the scattering and absorption properties of the target are known.

Another model is being developed at Colorado State University by Dr. James A. Smith, et al. Their model computes the apparent directional reflectance of vegetation, on the basis of solar angle and view angle, canopy geometry and optical properties, and soil background.

Reference spectra can also be derived directly from ground truth measurements of the spectral reflectance of objects or features of interest. Measurements can be made using any one of several relatively inexpensive instruments (fig. 16) designed for this purpose. For best results the instrument should view a target through the same spectral bands as the ERTS-1 MSS and measurements should be corrected for atmospheric effects. Measurements should be made within a time frame that includes the satellite overpass.

The process of deriving reference spectra from ground truth coupled with MSS measurements is the least satisfying approach from a scientific standpoint, but it nevertheless results in a useful coupling of satellite and ground observations. Ground data are required on the physical properties of the material (and its environment) and their anticipated effect on the reflectance spectrum that will be measured by the MSS. In the case of suspended sediments, measurements of suspended material concentration, water temperature, conductivity, turbidity, dissolved oxygen, current velocity/direction, spectral transmittance, secchi depth, and pH might be considered appropriate. Measurements should be taken at a sufficient number of locations to adequately characterize the test area. Fig. 17 shows a typical sampling pattern that was used in our study of selected Chesapeake Bay estuaries.

Spectral data to be used in deriving reference spectra are obtained from computer printouts of the radiance values for bands 1, 2, and 3 (fig. 18). Values corresponding to each of the ground data collection locations are located in the printout and extracted to define a reference spectrum. In fig. 18 the reference spectrum is shown for the point inclosed in the small box. (Note that pixel values from land have not been printed as a result of applying the band 4 mask.) The sediment concentration determined from ground truth taken at that point was 6.5 mg/l.

When the measurements of concentrations of suspended sediments were plotted against the reference spectra determined in the manner described, the result is as shown in fig. 19. The center of the three lines on the graphs is the calculated regression line. The dashed lines define the limits of potential error introduced by instrumental variations (approximately $\pm$2.0 percent of full scale) in the ERTS MSS. With this in mind, a good correlation would be one in which all points fall inside the error band.

Given the correlations between sediment concentration and spectral composition as indicated by the Rappahannock data (fig. 20), it is possible to establish reference spectra. Instrumental variations preclude selection of a list of three radiance values, one for each band for each suspended sediment concentration; instead they must be ranges of values for each suspended sediment concentration range. Determination of ranges is largely a subjective process which is governed by the following guidelines: (a) the upper and lower limit of each range must relate to a whole number (between 0 and 63) that will occur on the CCT's, (b) the number of different ranges is reasonable for the sediment concentration range of the test area, and (c) most of the data within the limits of potential error fall into one of the classes. When these guidelines are applied to the Rappahannock data, the classes are as shown in fig. 20.

The Rappahannock River drains an area that is characterized by soils that are predominantly brown to dark brown in color. The York River, on the other hand, drains an area that is characterized by reddish sandy soil of the Cahaba series. Therefore, band 2 (visible red) radiance values for the York might be expected to be higher than those for the Rappahannock. The spectral signatures of the suspended materials in these two rivers are not as distinct as one would hope. If the correlation bands for these two rivers are placed on top of each other, as in fig. 21, the bands at the lower end of the suspended material concentration scale (i.e. below about 15 mg/l) overlap so completely that discrimination between sediment types is clearly impractical. However, at concentrations between 15 mg/l and 25 mg/l, band 3 provides some measure of discrimination, and at concentrations about 25 mg/l, both bands 2 and 3 separate, and thus provide discrimination. Thus, while the discrimination powers of the spectral signatures are far from absolute or ideal, they still appear to permit identification over a part of the range of interest.

Pixel spectrum identification. Having established a reference spectrum for each range of sediment concentration, the next step is to identify each pixel according to the reference spectrum it matches. In the computer program compares the radiance value of each band for each pixel and determines into which class the pixel falls. In effect, the result is a matrix, as illustrated in fig. 22. The radiance value for Band 1 in the figure is 1.14, and this fits into class 1; the value in Band 2 is 0.39, which fits into class 1. However, the value for Band 3 is 0.20, which fits into both classes 1 and 2, as shown in the matrix. The pixel is determined classified when there is a fit (i.e. an "X" in the matrix) in all three bands in any one class. When this condition is met, the program assigns a map symbol and a class value to that pixel. Upon the completion of the pixel-by-pixel comparison, there is in effect a new data file containing the location class number and map symbol of each pixel. If a pixel spectrum does not fit any of the reference spectra, that pixel is defined as unclassified, which is in effect a fifth category.

Map generation. This file can then be used to print out a map of the distribution of suspended sediment classes, as illustrated in fig. 23. Note especially the zeros, (which represent "no classification") and note that they occur most commonly near the land-water interface. There may be at least two reasons for this:

a. Shallow water may be causing the reflectance from the water to be modified by reflectance from the bottom.

b. Small-scale sediment clouds may be occuring in the near-shore zone as a result of shore-line erosion.

The basic data file can also be used as input to a film-writer, which can construct a photomap showing sediment concentration classes as shades of grey. In this procedure, an optical density is assigned to each sediment concentration class. In this case, the values listed in fig. 24 were used. The result is illustrated in fig. 25. Note that in this illustration only three classes of sediment concentrations were used.

SUMMARY

The WES had developed an analytical procedure which considers the ERTS-1 MSS as a part of a reflectance spectrophotometer. ADP techniques requiring only very limited computer capability are utilized to search the data defining the spectral reflectance characteristics of a scene on a pixel-by-pixel basis, identify each pixel with the reference spectrum it matches, and generate maps that show locations where spectrum matches occur and identify the spectrum that was matched. If the reference spectra are known to relate to a specific condition or feature on the ground, a map of the distribution of that condition or feature can be output as a dimensionally accurate overlay to maps of any selected scale. An example was given in which a map was produced showing the distribution of specific suspended sediment concentrations in an estuary of the Chesapeake Bay. By-products were described in which the ERTS-1 data were used to generate map overlays identifying water bodies and inventories of water bodies giving location and estimated size.

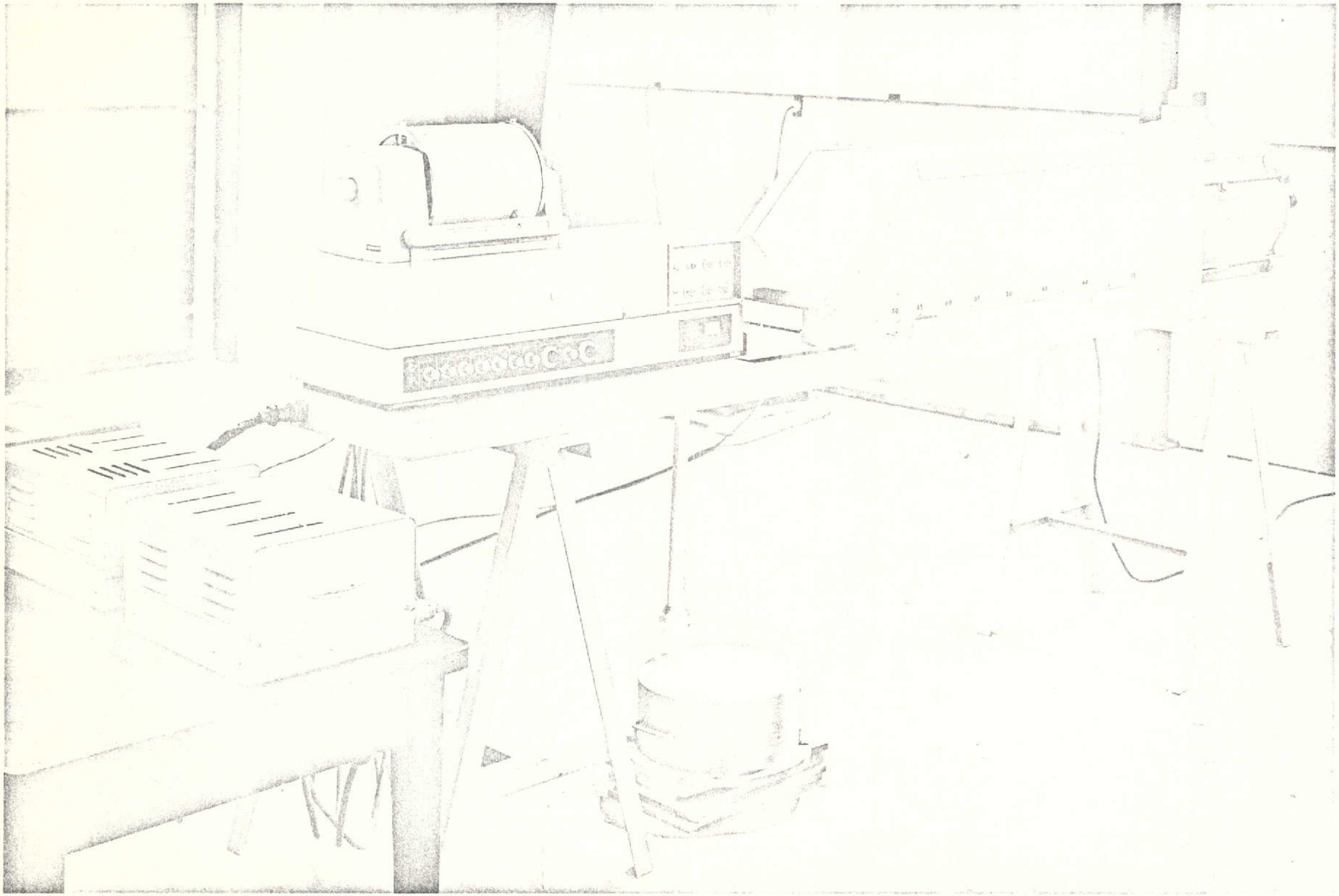


Fig. 1. Reflectance Spectrophotometer

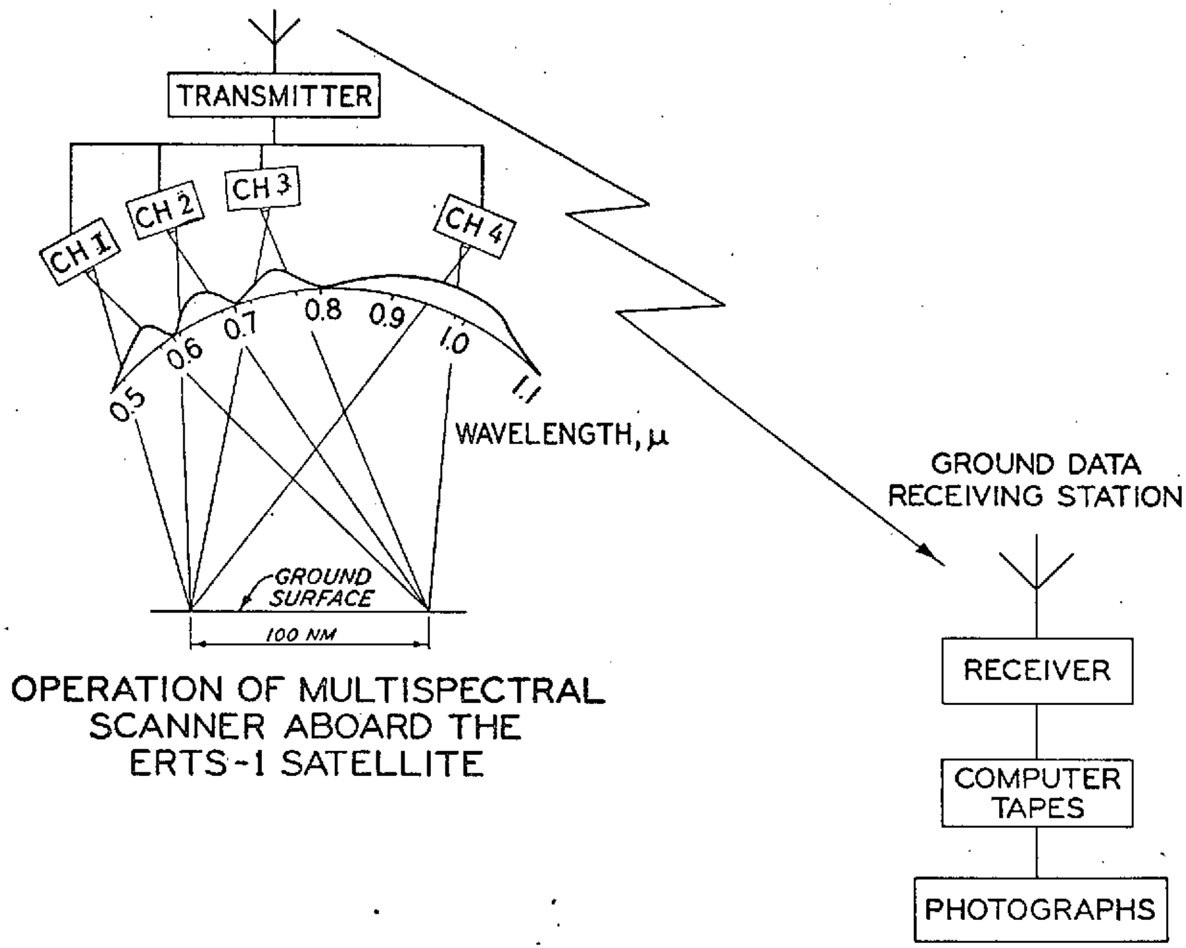


Fig. 2. Earth Resources Technology Satellite (ERTS-1)

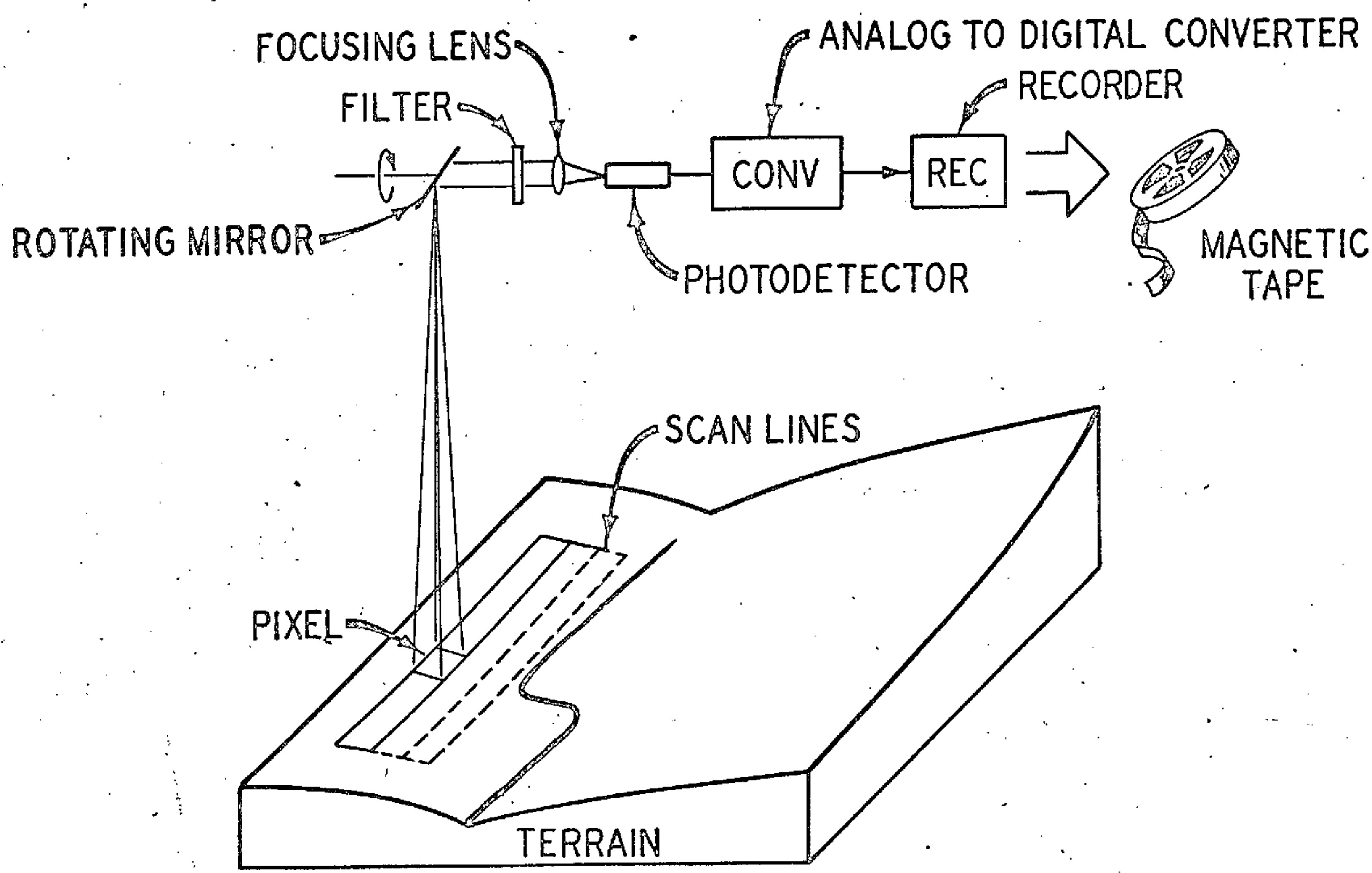
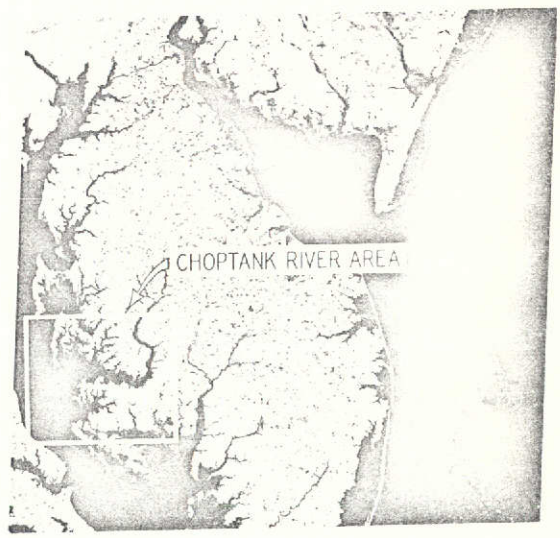


Fig. 3. Concept of ERTS MSS Scanning Function

MSS BAND 1
(0.5 - 0.6 MICROMETERS)

MSS BAND 2
(0.6 - 0.7 MICROMETERS)

MSS BAND 3
(0.7 - 0.8 MICROMETERS)



MSS BAND 4
(0.8 - 1.1 MICROMETERS)

Fig. 4. A Portion of Chesapeake Bay Study Area Viewed from Earth Resources Technology Satellite (ERTS-1)

DATE: 10 OCTOBER 1972

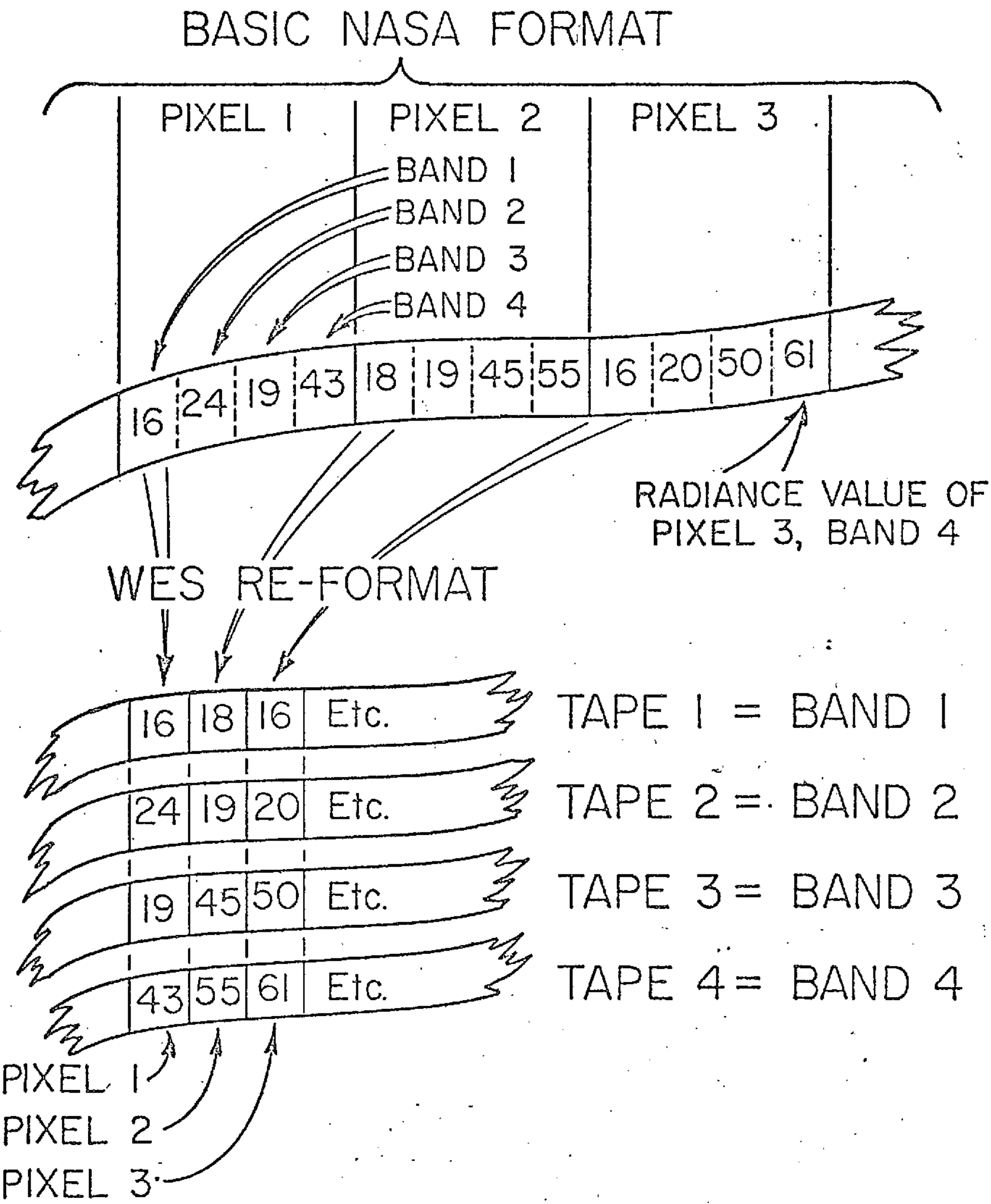


Fig. 5. Conversion of NASA Format to WES Format

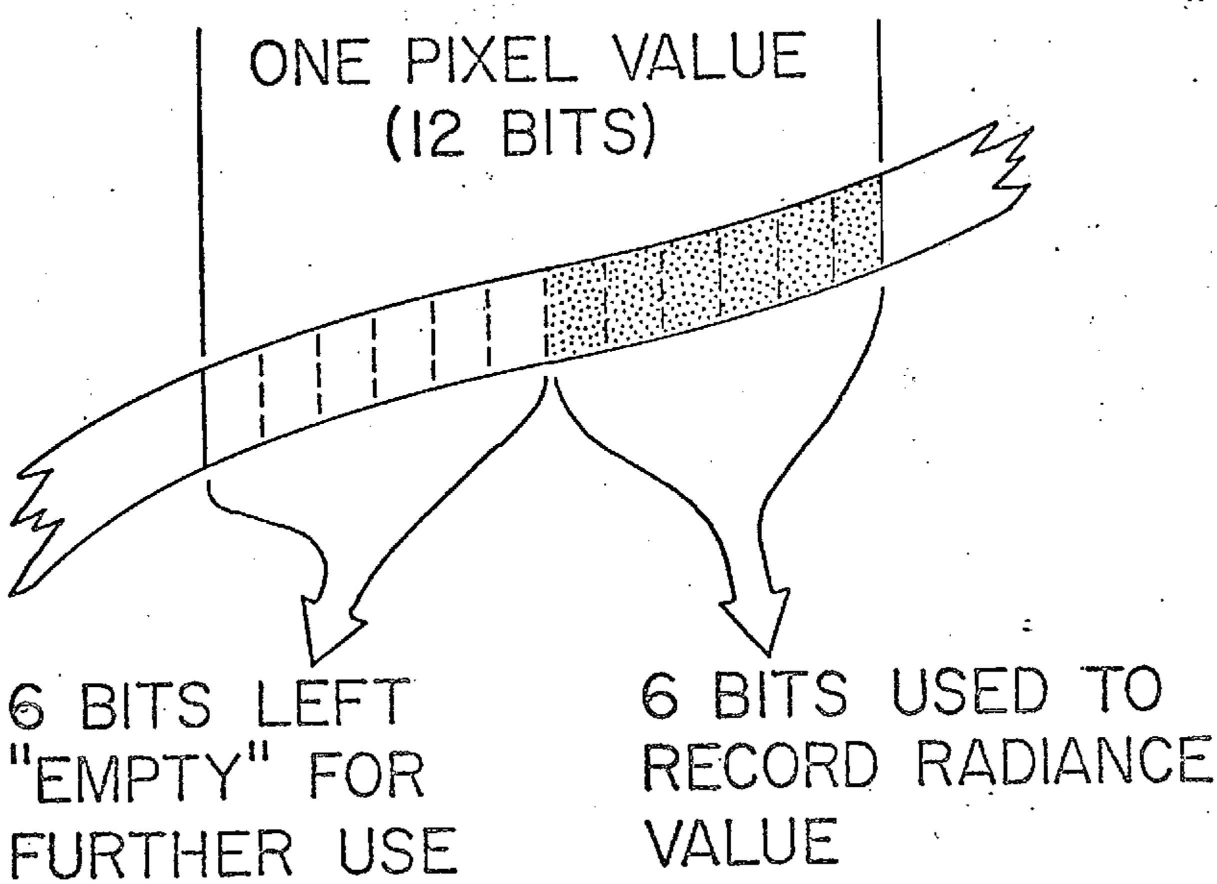


Fig. 6. Initial Utilization of 12-Bit Word

$$H = \frac{x \cdot M_i}{63 \cdot T_i}$$

WHERE: H = radiance in mw/cm^2-SR

x = value from computer compatible tape (CCT)

M_i = gain setting (from NASA)

T_i = atmospheric transmittance (from AFCRL model)

M_1 = 2.48	T_1 = 0.69
M_2 = 2.00	T_2 = 0.75
M_3 = 1.76	T_3 = 0.68
M_4 = 4.60	T_4 = 0.76

Fig. 7. Conversion of CCT Values to Radiance Values

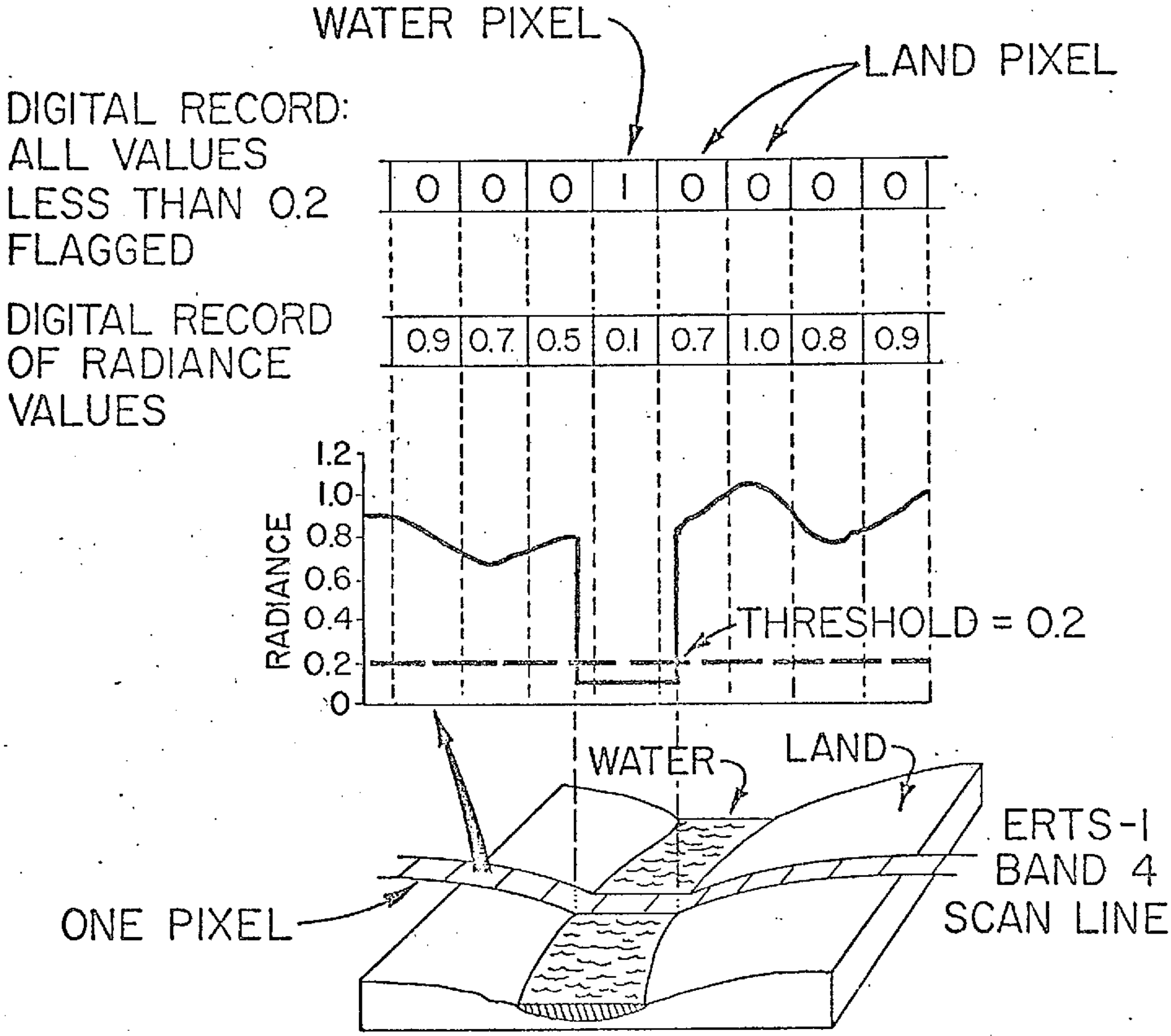


Fig. 8. Water Pixels vs. Land Pixels

OPTRONICS INTERNATIONAL, INC.
CHELMSFORD, MASS.
PHOTOMATION MARK II SYSTEM P-1700

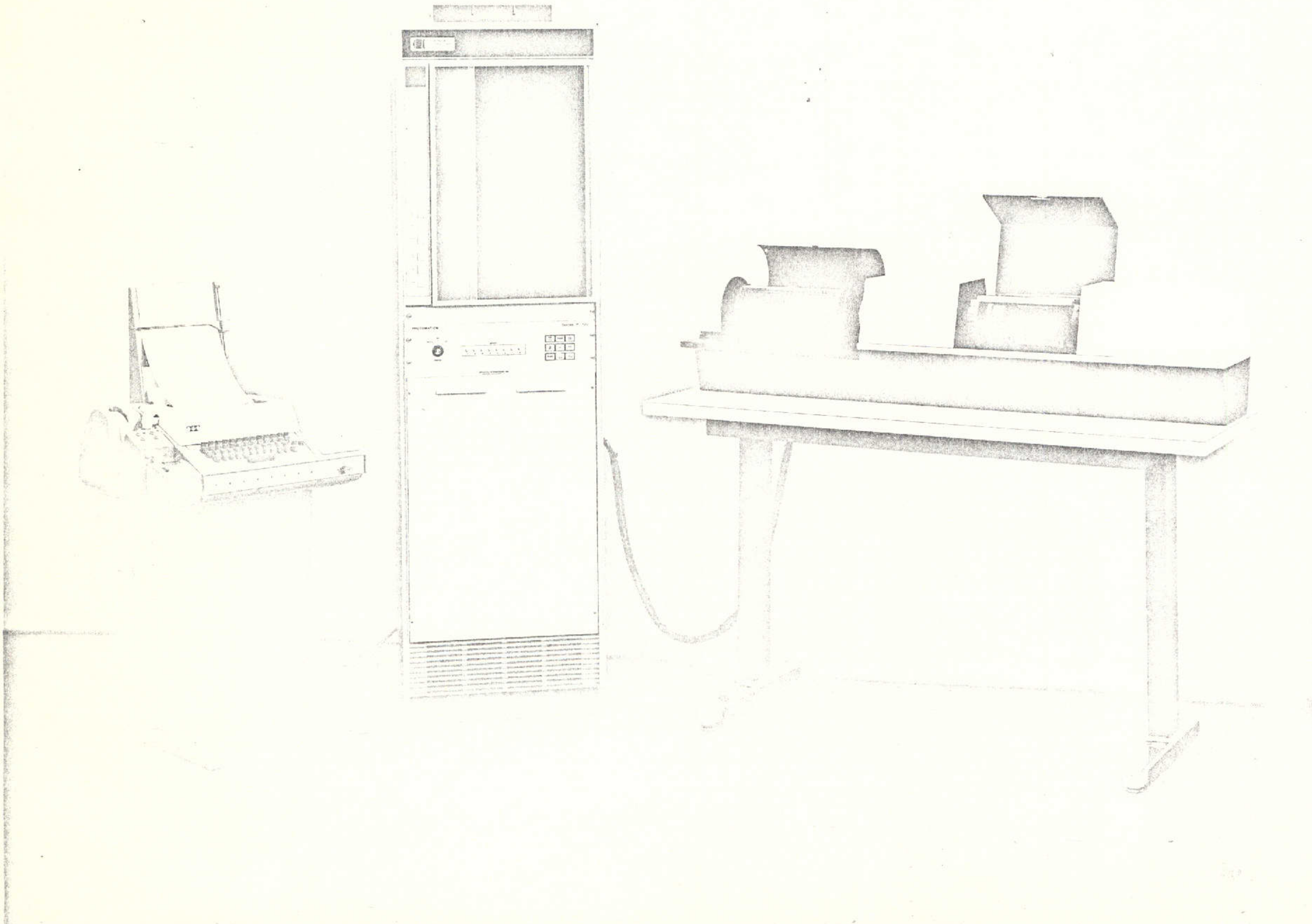


Fig. 9. Film Reader/Writer

Fig. 19

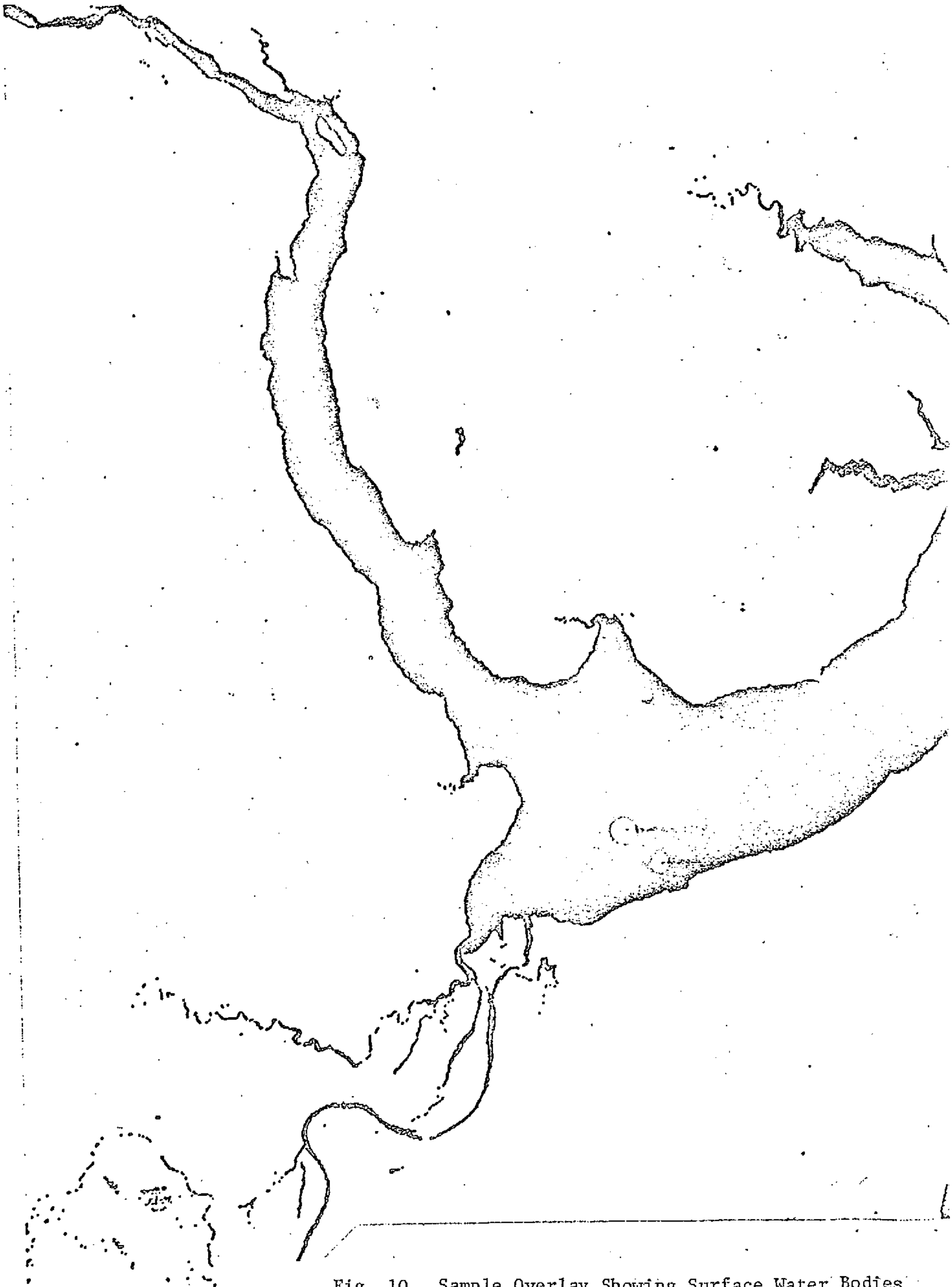
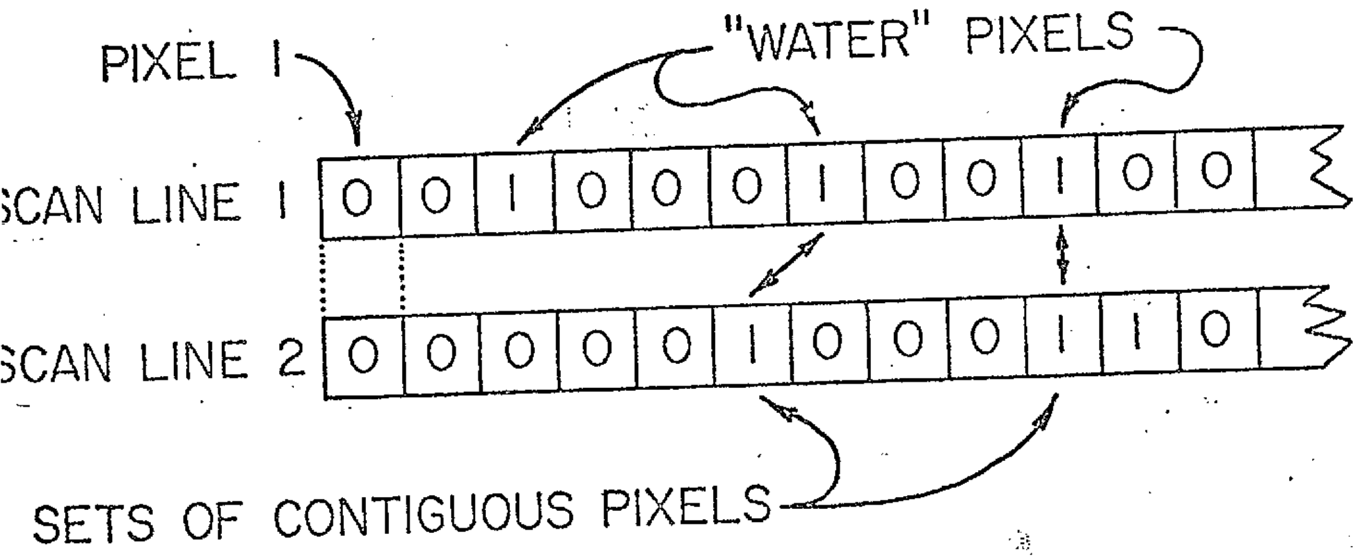


Fig. 10. Sample Overlay Showing Surface Water Bodies

Fig. 11. Sample Overlay of Flood in Lower Mississippi River Valley

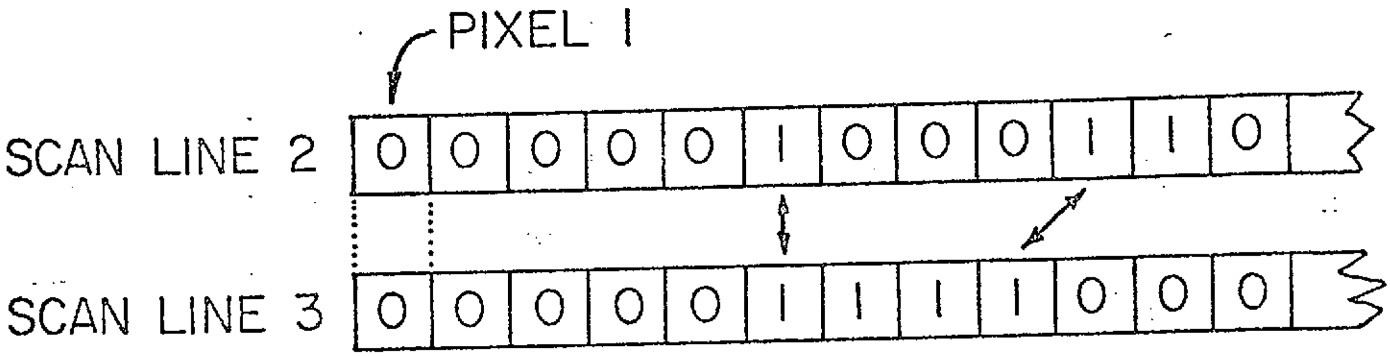
LATITUDE DEG MIN	LONGITUDE DEG MIN	PIXEL COUNT	EST. SURFACE ACRES
N35- 9.6	W 82-21.4	45.	50.
N35- 7.0	W 82- 4.8	1.	1.
N35- 9.2	W 82-18.9	2.	2.
N35- 9.6	W 82-21.7	1.	1.
N35- 9.6	W 82-21.9	3.	3.
N35- 6.3	W 82- 1.1	1.	1.
N35- 6.2	W 82- 1.0	1.	1.
N35- 9.5	W 82-21.9	1.	1.
N35- 8.8	W 82-17.6	2.	2.
N35- 6.2	W 82- 0.8	19.	21.
N35- 9.4	W 82-21.9	6.	7.
N35- 6.2	W 82- 1.6	2.	2.
N35- 6.1	W 82- 1.3	27.	30.
N35- 9.4	W 82-22.1	1.	1.
N35- 6.0	W 82- 0.7	10.	11.
N35- 6.7	W 82- 5.3	1.	1.

Fig. 12. Sample Printout of Inventory of Surface Water Bodies



FILES ESTABLISHED FOR SCAN LINE 1	FILE A 1 - 3	FILE B 1 - 7	FILE C 1 - 10
FILES AFTER SEARCH OF SCAN LINE 2	FILE A 1 - 3	FILE B 1 - 7 2 - 6	FILE C 1 - 10 2 - 10 2 - 11

Fig. 13. The Contiguity Rule



	FILE A	FILE B	FILE C	FILE D
STATUS OF FILES AFTER SEARCH OF SCAN LINE 2	1 – 3	1 – 7 2 – 6	1 – 10 2 – 10 2 – 11	
STATUS OF FILES AFTER SEARCH OF SCAN LINE 3	1 – 3			1 – 7 1 – 10 2 – 6 2 – 10 2 – 11 3 – 6 3 – 7 3 – 8 3 – 9

Fig. 14. File Consolidation

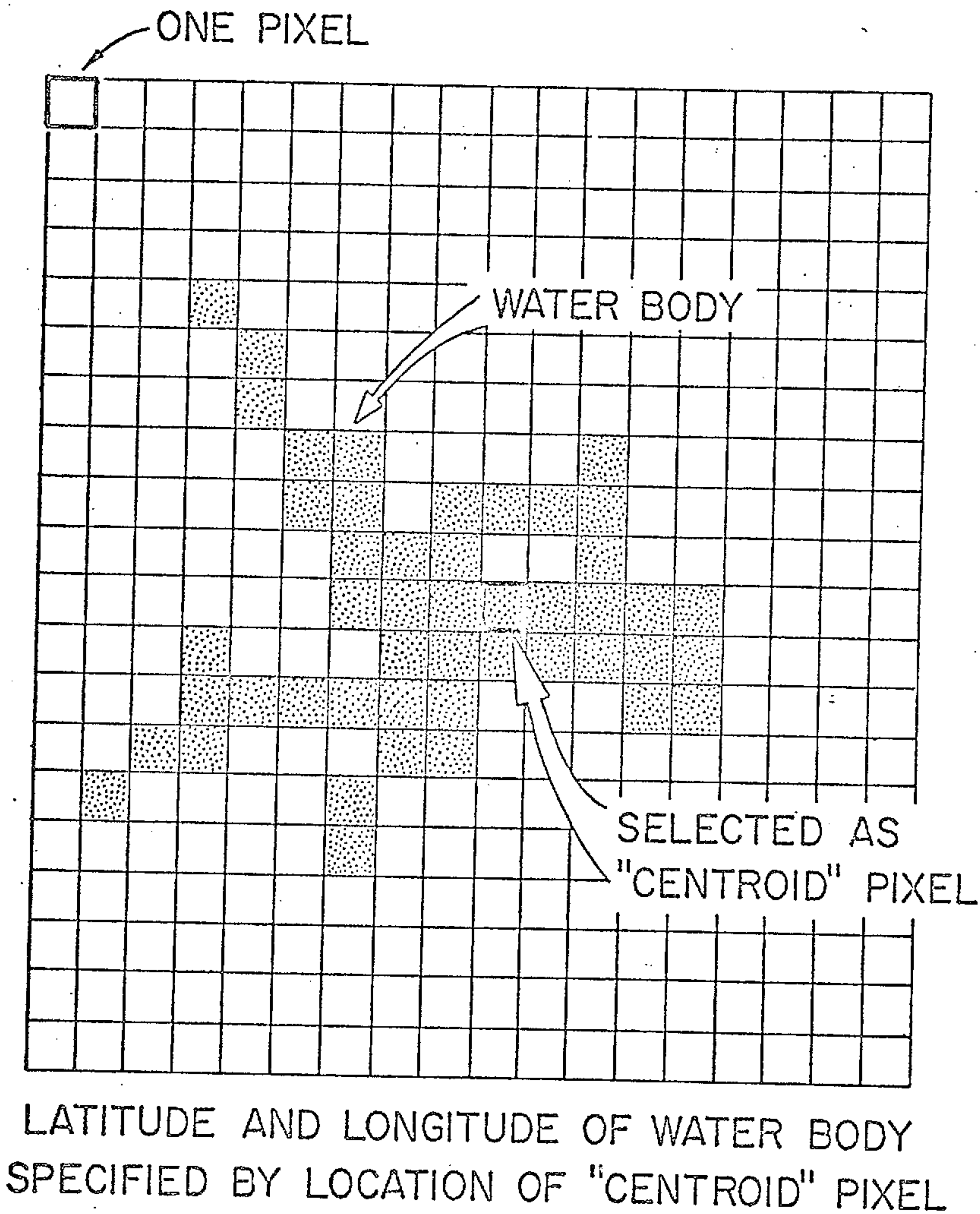


Fig. 15. Selection of "Centroid" Pixel

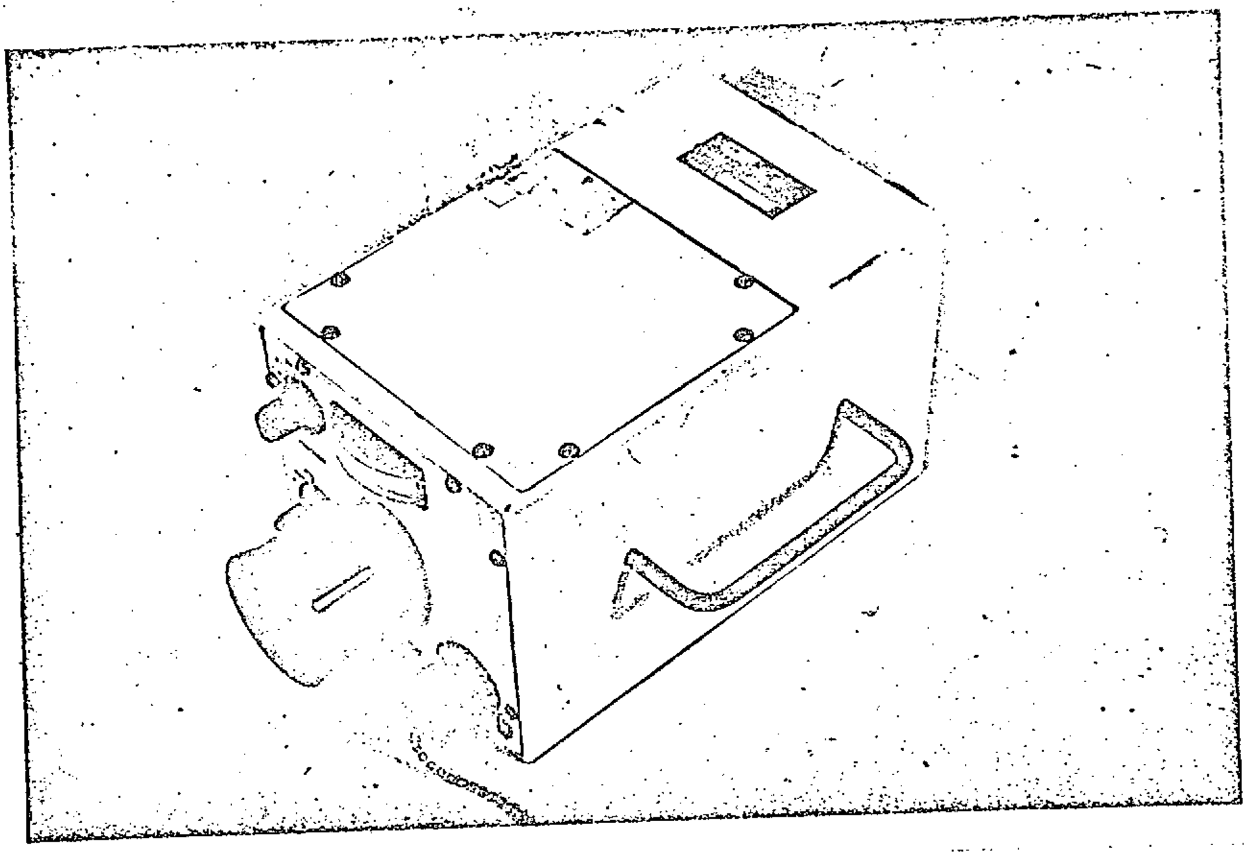


Fig. 16. Radiometer for ERTS-1 Studies

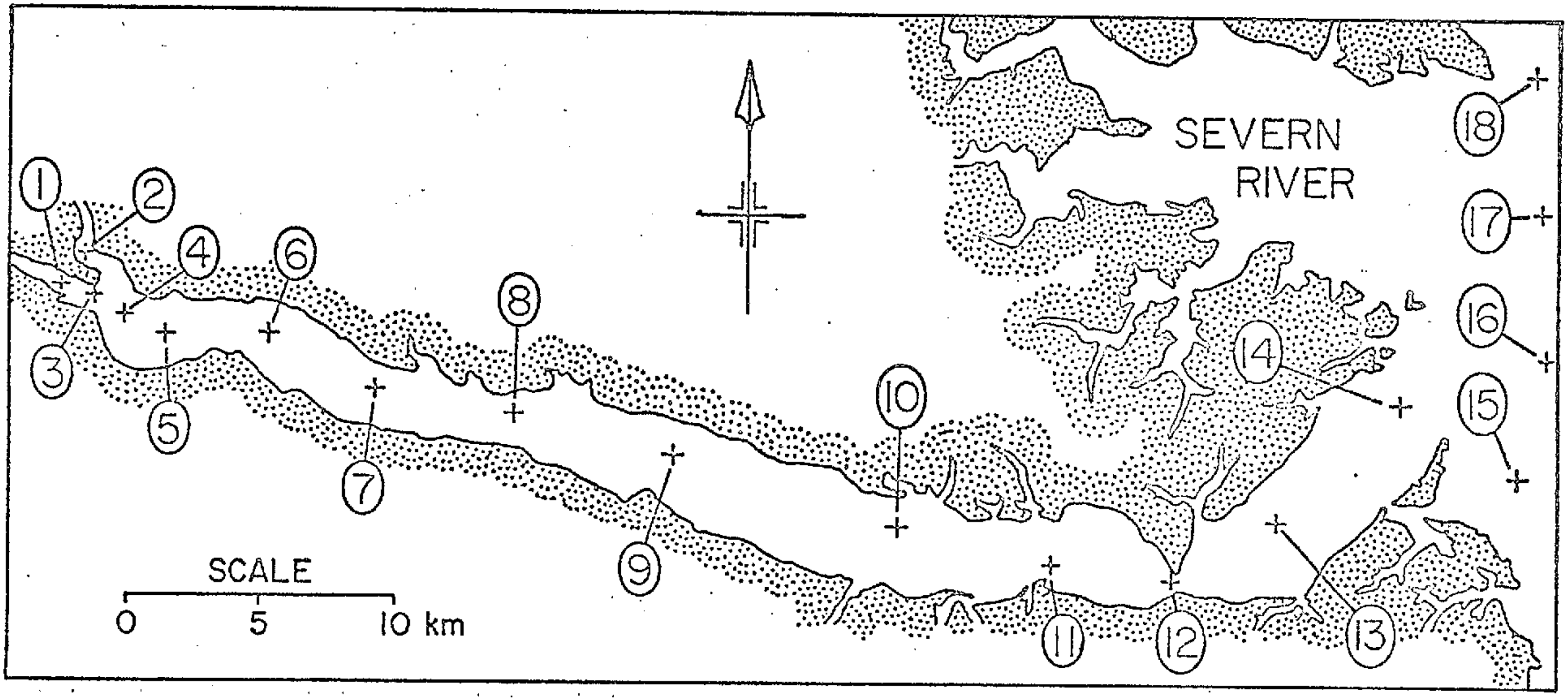


Fig. 17. Location of Ground Control Points in York River

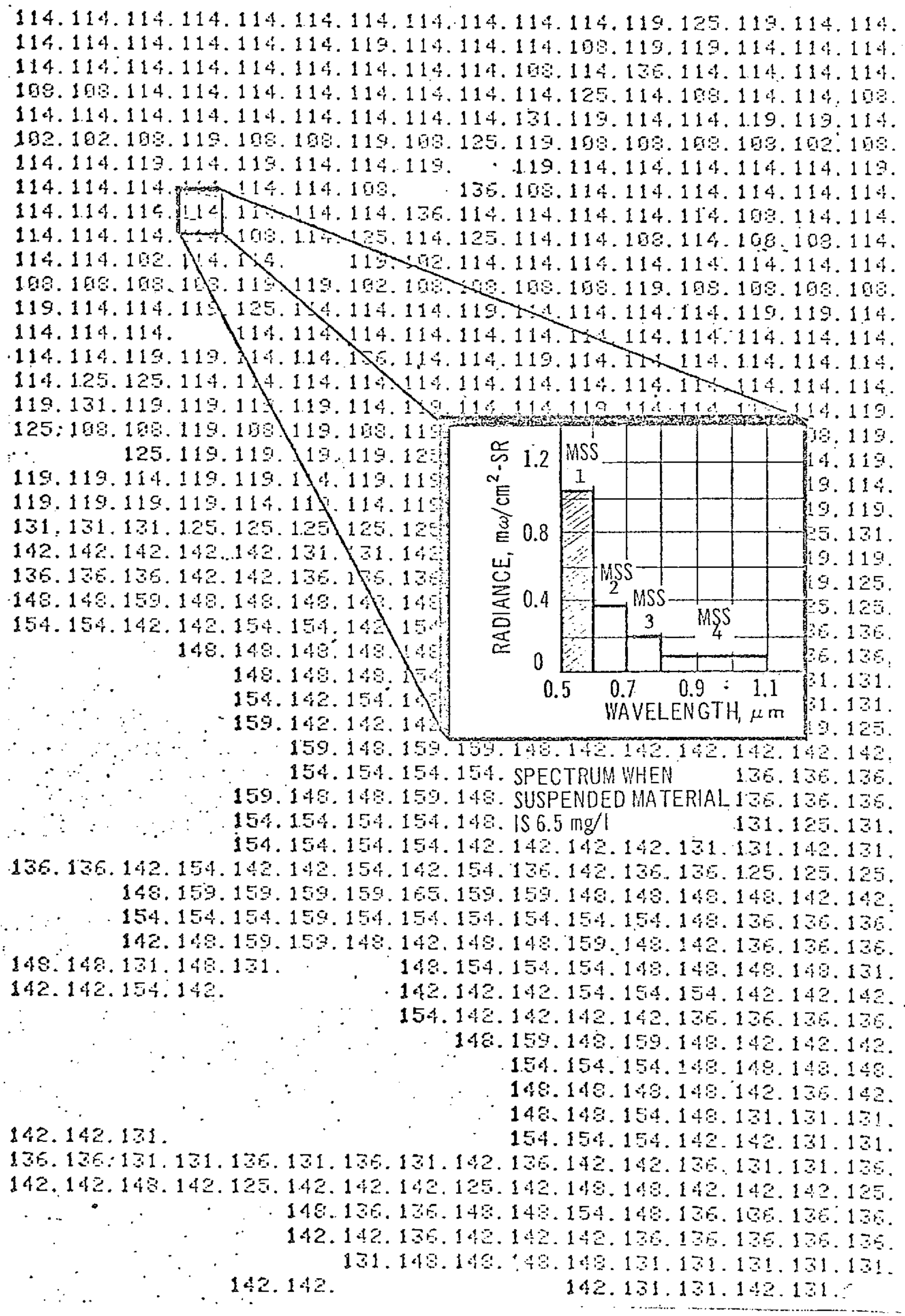


Fig. 18. Assembly of Radiance Spectra

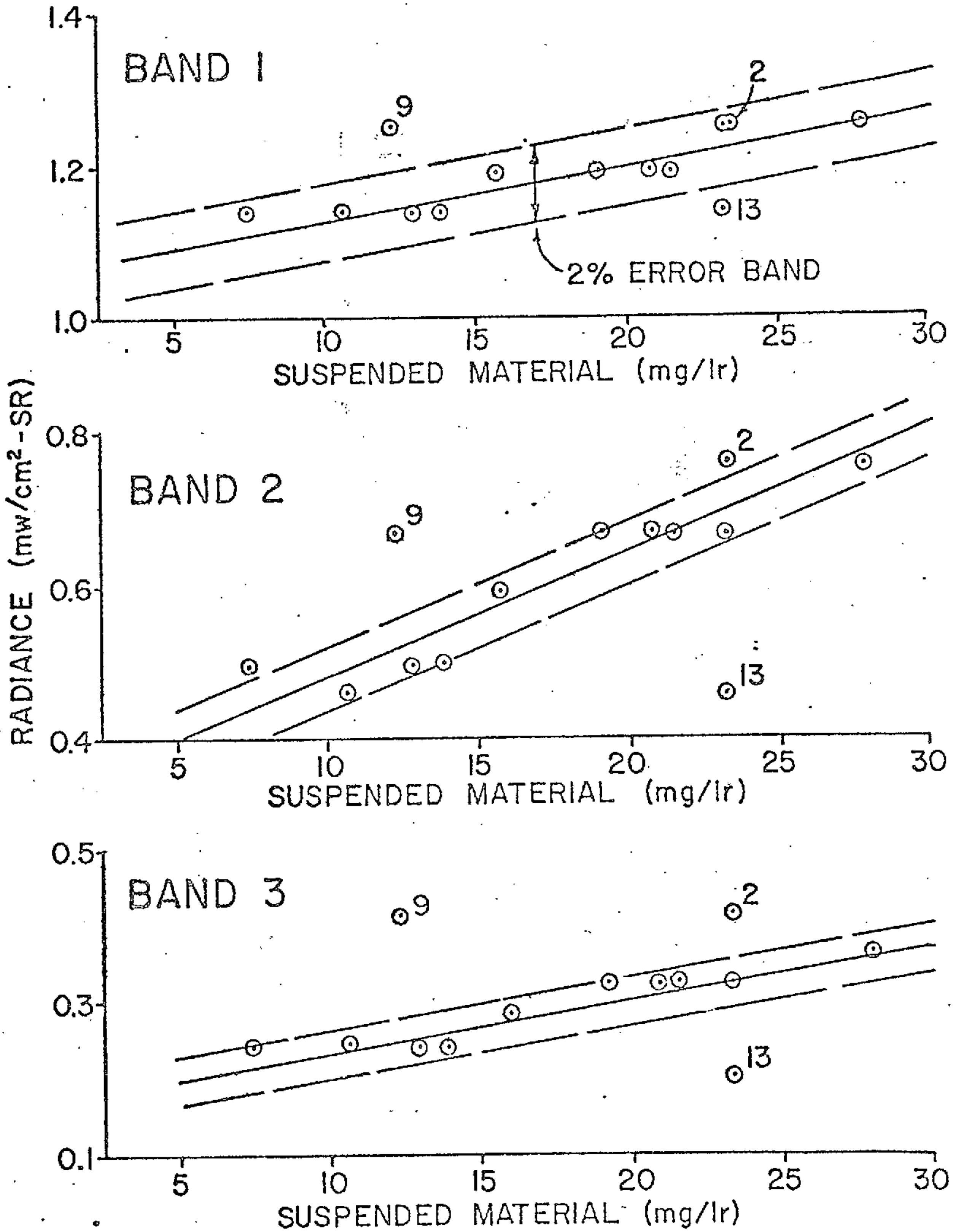


Fig. 19. Radiance vs. Suspended Material - York River Estuary

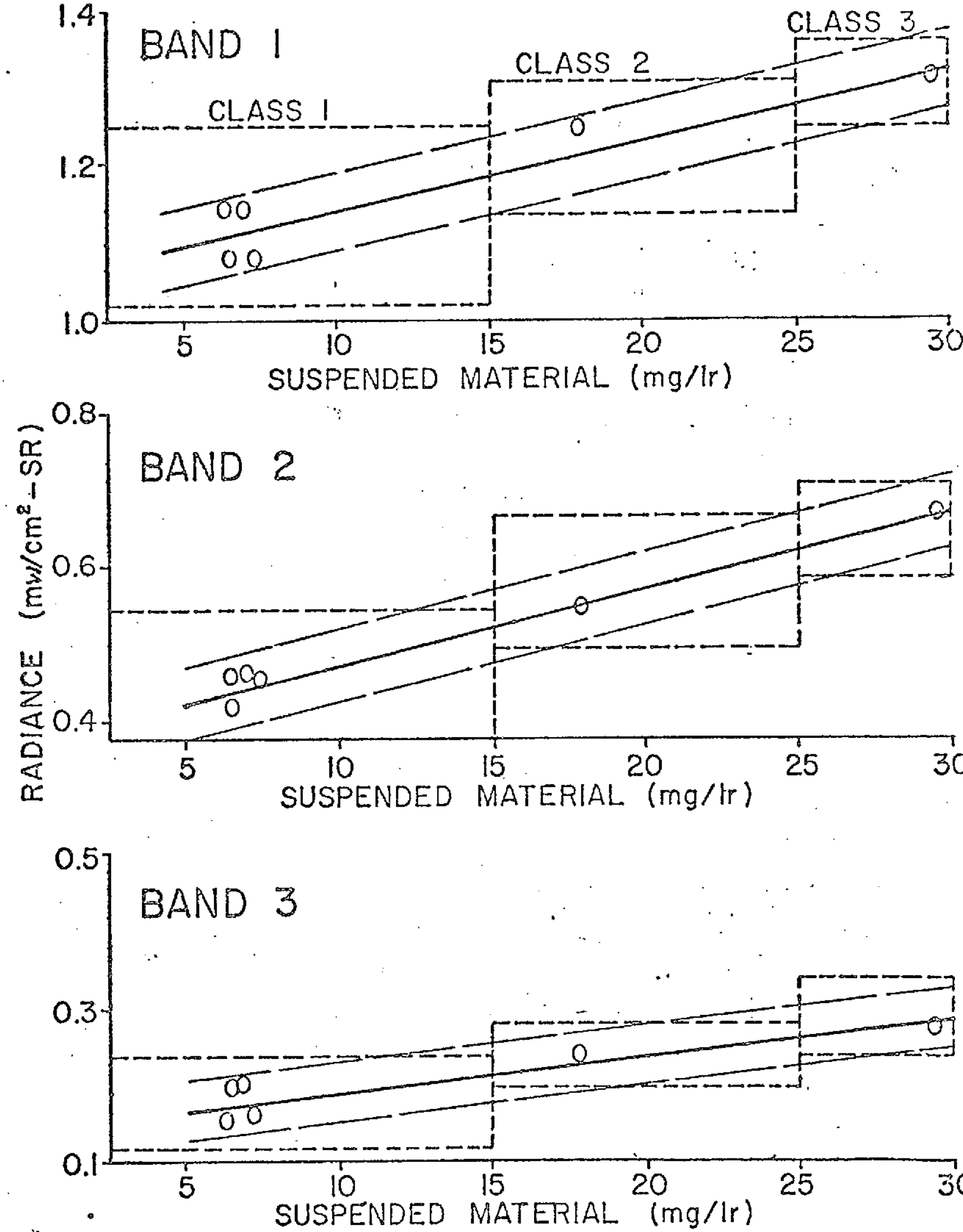


Fig. 20. Radiance vs. Suspended Material - Rappahannock River Estuary

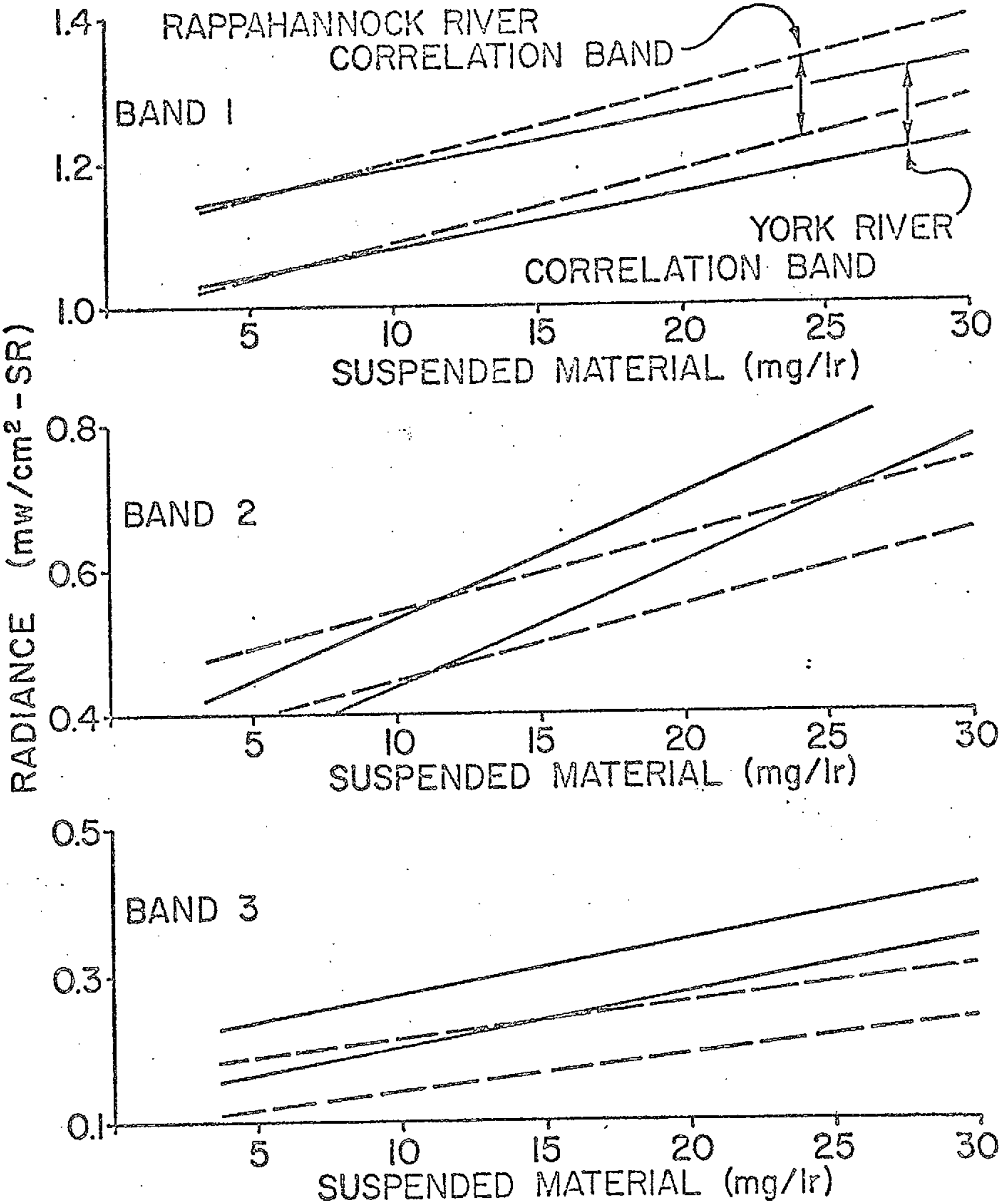


Fig. 21. Comparison of Radiance Signatures of York and Rappahannock Rivers

	RADIANCE (mw/cm²-SR) ERTS-I MSS BAND 1	2	3	CONCENTRATION OF SUSPENDED SEDIMENTS (mg/lr)	MAP SYMBOL	CLASS
REFERENCE SPECTRA	1.02-1.31	0.38-0.55	0.08-0.28	0-10	-	1
	1.36-1.48	0.46-0.71	0.16-0.32	10-20	+	2
	1.48-1.59	0.76-0.84	0.28-0.32	20-30	*	3
	1.48-1.59	0.76-0.84	0.36-0.41	>30	#	4
					O	UNCLASS.
PIXEL VALUES	1.14	0.39	0.20	0-10	-	1

ASSIGNED TO PIXEL BY COMPUTER PROGRAM

CLASSIFICATION MATRIX

SEDIMENT CONCENTRATION CLASS \ BAND NO.	1	2	3
1	X	X	X
2			X
3			
4			

Fig. 22. Classification of Pixels

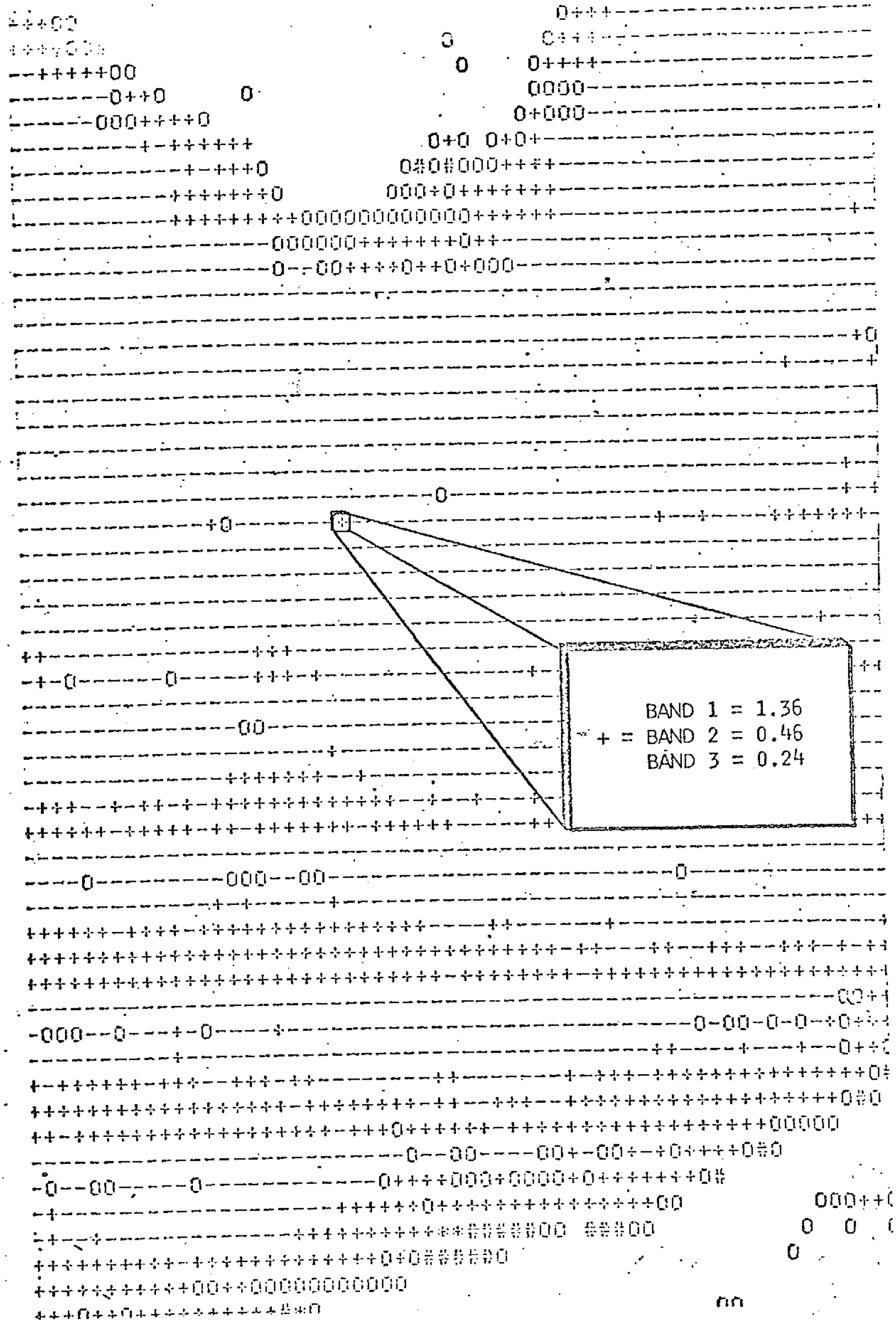


Fig. 23. Computer Generated Map

SEDIMENT CONCENTRATION CLASS	OPTICAL DENSITY
UNCLASSIFIED	3.0
1	1.68
2	1.08
3	0.49
LAND	0.0

Fig. 24. Optical Densities Used as Photomap of York River

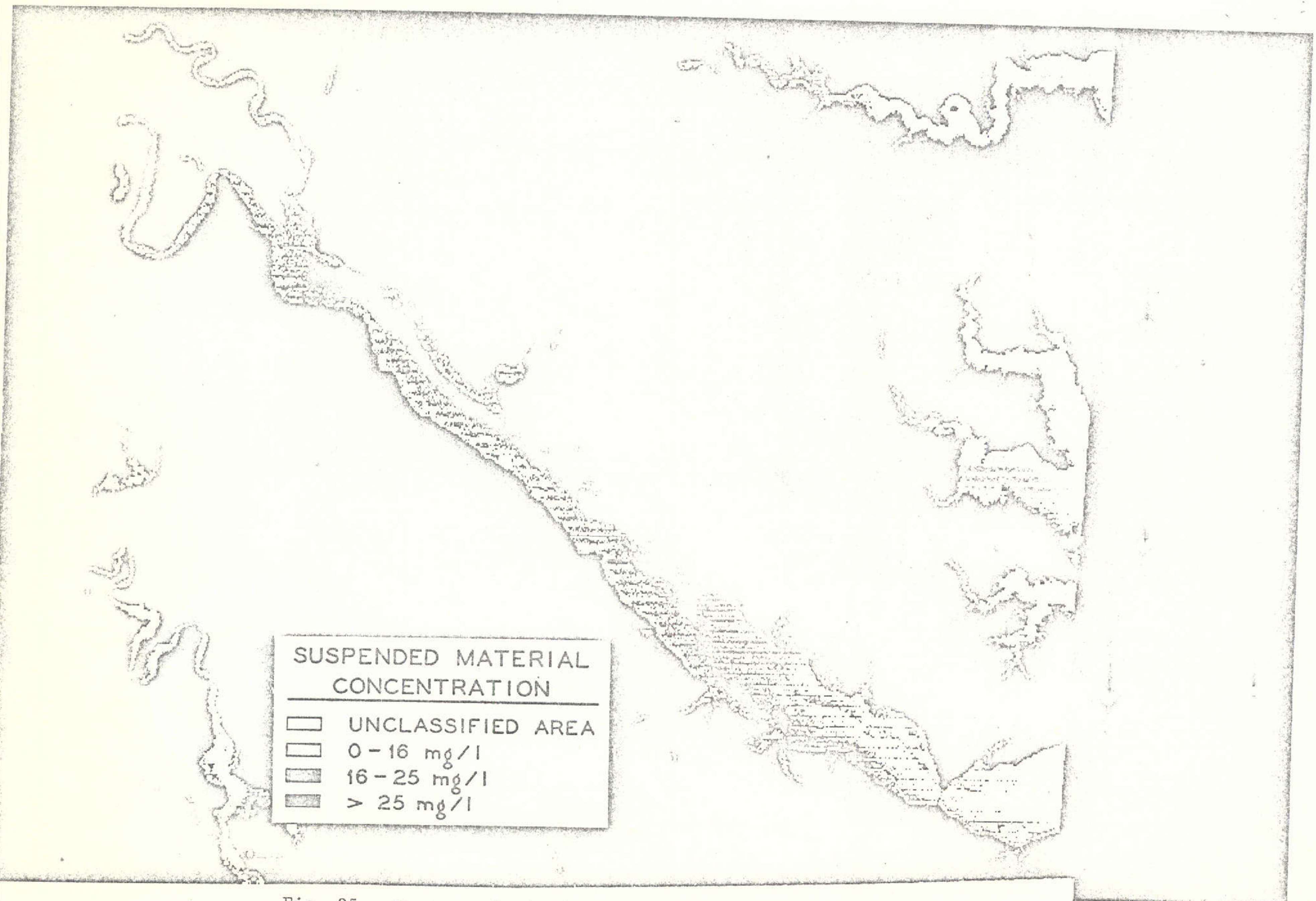


Fig. 25. Photomap Derived From Computer Analysis of ERTS-1 Data