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Final Report

WATER QUALITY MONITORING USING ERTS-1 DATA

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16. Abstract

The use of ERTS-1 for the detection and measurement of suspended solids, turbidity, and phytoplankton blooms is discussed. Results from the New York Bight, Lake Erie, Tampa Bay and other locations are presented.

The quantitative relationships between signal levels as recorded on ERTS digital tapes and concentration of suspended solids and turbidity units are examined. The use of spectral ratios MSS6/MSS5 for the detection of phytoplankton blooms is discussed.

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PREFACE

The general objectives of the program described in this report were to investigate the use of ERTS-1 for the detection and measurement of suspended solids, turbidity, and phytoplankton blooms; and to determine the extent to which ERTS-1 could be useful for monitoring specific pollution practices and large-scale processes. Results from the New York Bight, Lake Erie, Tampa Bay and other locations are presented and discussed.

The quantitative relationships between signal levels (as recorded on ERTS digital tapes) in MSS5 and concentration of suspended solids and turbidity units were investigated. Empirical expressions relating signal levels and concentrations or units, were derived. The use of spectral ratios MSS6/MSS5 for the detection of phytoplankton blooms was demonstrated. The limitations of ERTS-1 for water quality monitoring are discussed.

This report was submitted in fulfillment of Contract No. NAS5-21783, Mod. 3, Task VIII: "Water Quality Monitoring." The results are based on ERTS-1 data received prior to 31 August 1973.

Several organizations and individuals have contributed to the project described in this report. In particular the support provided by N. Thomas of the U.S. Environmental Protection Agency, Grosse Ile Laboratory is acknowledged with sincere thanks. ERIM personnel who contributed to this study include N. Roller and D. Urbassik. Portions of the study were related to other programs at ERIM. The phytoplankton analysis work in Lake Erie and work in New York Lower Bay were related to programs supported by NOAA and thereby received partial support from that organization.

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WATER QUALITY MONITORING USING ERTS-1 DATA

1
INTRODUCTION

It is generally recognized that new monitoring techniques must be developed to meet the needs of current and future environmental management. The limitations of existing methods of data acquisition are particularly evident in the case of large environmental systems such as the Great Lakes, coastal areas, oceans, and large river systems. Virtually all major reports dealing with the contemporary environmental challenge stress the necessity for developing new monitoring techniques to meet it.

The term monitoring as applied to water resources and water pollution control embraces a vast array of functions and procedures for detection, measuring, and analyzing materials on the surface of the water, materials suspended in the water, and materials dissolved in the water. Expressed in general terms, monitoring is performed for the following purposes:

(1) establishment of water quality baselines
(2) detection of spills, discharges, and seeps of polluting substances into the aquatic environment
(3) identification of pollutant sources
(4) determination of the extent of the pollutant and tracking its movement
(5) evaluation of the effect of pollutants on designated beneficial uses of the water resource and the total ecology
(6) characterization of autochthonous and allochtonous materials and/or substances in solution, suspension, and in the form of surface films, for various environmental and resource management purposes

Clearly, a wide range of surveillance and analytical techniques are needed to acquire the necessary physical, chemical, and biological data required in water quality monitoring. In general, it must be recognized that the aquatic environment is a complex heterogeneous system which normally does not lend itself to simple analytical procedures. Nevertheless, in view of the magnitude and complexity of the monitoring problem, it is appropriate and necessary that the capabilities of ERTS-1 be examined. Certain limited observations and monitoring functions appear to be feasible through satellite remote sensing.

The general objectives of the program described in this report were to investigate the use of ERTS-1 for the detection of suspended solids, turbidity, and phytoplankton blooms and to determine the extent to which ERTS-1 could be useful for monitoring specific pollution practices.

Because of ERTS-1 instrumental constraints, large-scale events were selected for study. The program was directed toward an investigation of the following processes and phenomena:

(1) barge dumping of wastes
(2) turbidity and color anomalies in Lakes Erie and Michigan
(3) turbidity and color anomalies in Tampa Bay
(4) ocean outfalls

2
STUDY LOCATIONS

A description of the test sites selected for this investigation together with a description of the water pollution problems at each location is presented in the sections which follow. The discussion is subdivided under the headings: New York Bight, Lake Erie, Tampa Bay, and other test locations.

2.1 NEW YORK BIGHT

The coastal waters adjacent to the New York Metropolitan Region are the repository for substantial quantities of sewage sludge, industrial acid-waste, construction debris, and dredge spoils. The designated dumping areas are shown in Figure 1.

Sewage sludge is normally deposited at a location approximately 19 km south of Long Island. At the present time, approximately 9,500 m^3 per day are dumped at this location. In addition to nutrient enrichment of the overlying waters and the introduction of heavy metals, etc. at the immediate dump location, the practice often results in the formation of extensive surface films.

Acid-iron wastes are normally dumped at a location approximately 20 km east of New Jersey and 24 km south of Long Island. The waste solution contains approximately 8% H_2SO_4, 10% $FeSO_4$, and small quantities of various metallic elements. The wastes are dispersed by barge over a hairpin-shaped course approximately 10 km long. The subsequent oxidation of the iron from the ferrous to the ferric state produces a suspension which tends to remain in a distinct pattern for long periods after dispersal.

In addition to the above substances, dredging spoils from the New York metropolitan harbor area and construction debris are dumped in the New York Bight.

2.2 LAKE ERIE (WESTERN BASIN)

A variety of water quality management problems exist in this area as a result of the high level of industrial and agricultural activities, and high population density. Suspended solids and

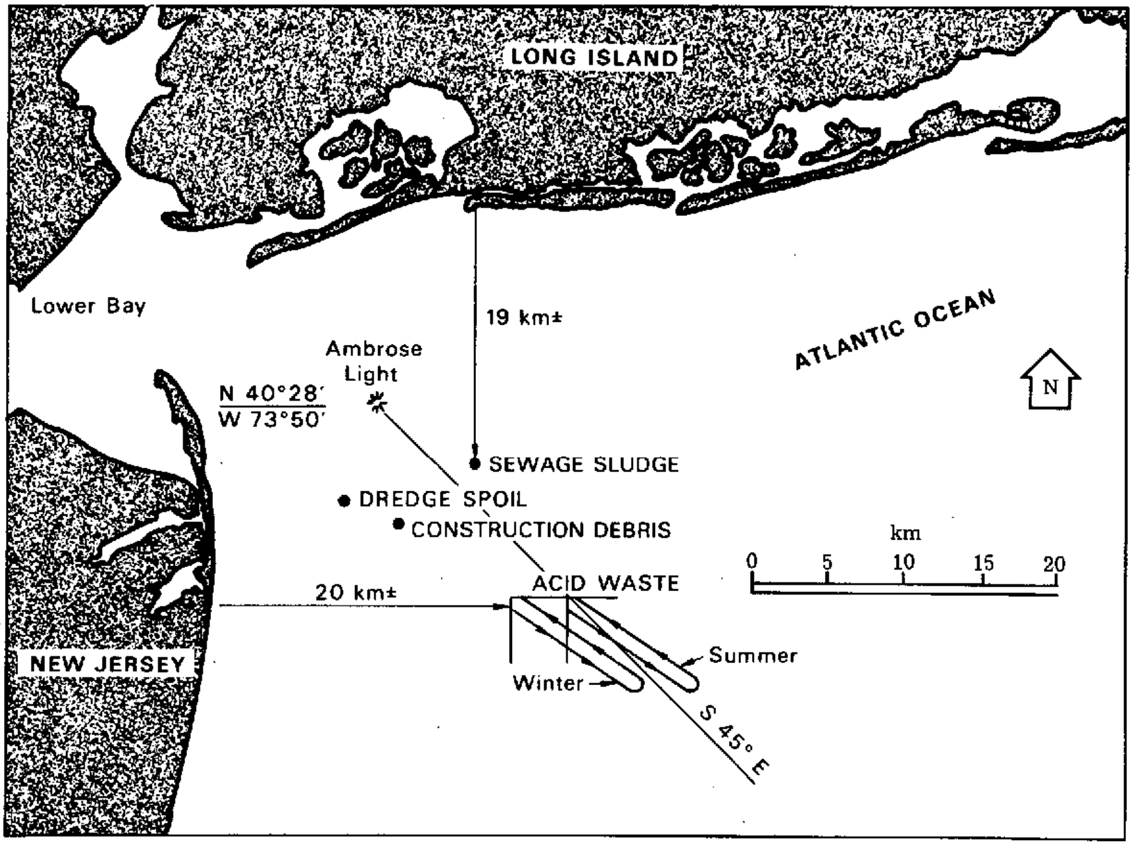


FIGURE 1. WASTE DISPOSAL SITES IN THE NEW YORK BIGHT

nutrient loadings resulting from the various cultural and natural sources in the basin are among the major water quality management concerns in the basin.

In this investigation, the use of ERTS-1 to measure variations in turbidity, suspended solids and to detect phytoplankton blooms was examined. The movement of water masses, as evidenced by turbidity patterns, was also of concern to this investigation.

2.3 TAMPA BAY

Portions of Tampa Bay, particularly the Hillsborough Bay arm, have experienced serious water quality problems due to extremely high phosphorus levels, poor circulation features, and point sources of wastes. Excessive growths of phytoplankton and benthic growths in the Bay are primarily the result of existing high nutrient levels. The primary objective of the study at this location was to investigate the relationship between observed suspended solids and color, and existing water quality.

2.4 OTHER TEST LOCATIONS

The major effort in this investigation was directed toward work at the three primary test sites described above. In addition, data were examined at two other locations: S. E. Florida and Lake Michigan.

2.4.1 S. E. FLORIDA

Population increases along Florida's lower east coast have resulted in the installation of a number of ocean outfalls for the disposal of municipal wastewater. Although these installations may have had minimal or even insignificant impact on local ecology at the time of construction, the current rate of growth calls for a re-assessment of the impact of existing installations on the environment.

Numerous ocean outfalls discharge partially treated or untreated effluent into the marine environment in this region at locations from approximately 1.6 to 3.2 km from shore, as shown in Figure 2. During a calm sea state the sewage "boils" to the surface. The subsequent dispersion of the sewage depends on sea state and local currents. The objective in this phase of the program was to determine the ability of ERTS-1 to locate effluent fields associated with the larger outfalls in the area.

2.4.2 LAKE MICHIGAN

The water quality problems in Lake Michigan are similar to those in Lake Erie. The area of primary interest in this investigation was southern Lake Michigan. Large amounts of

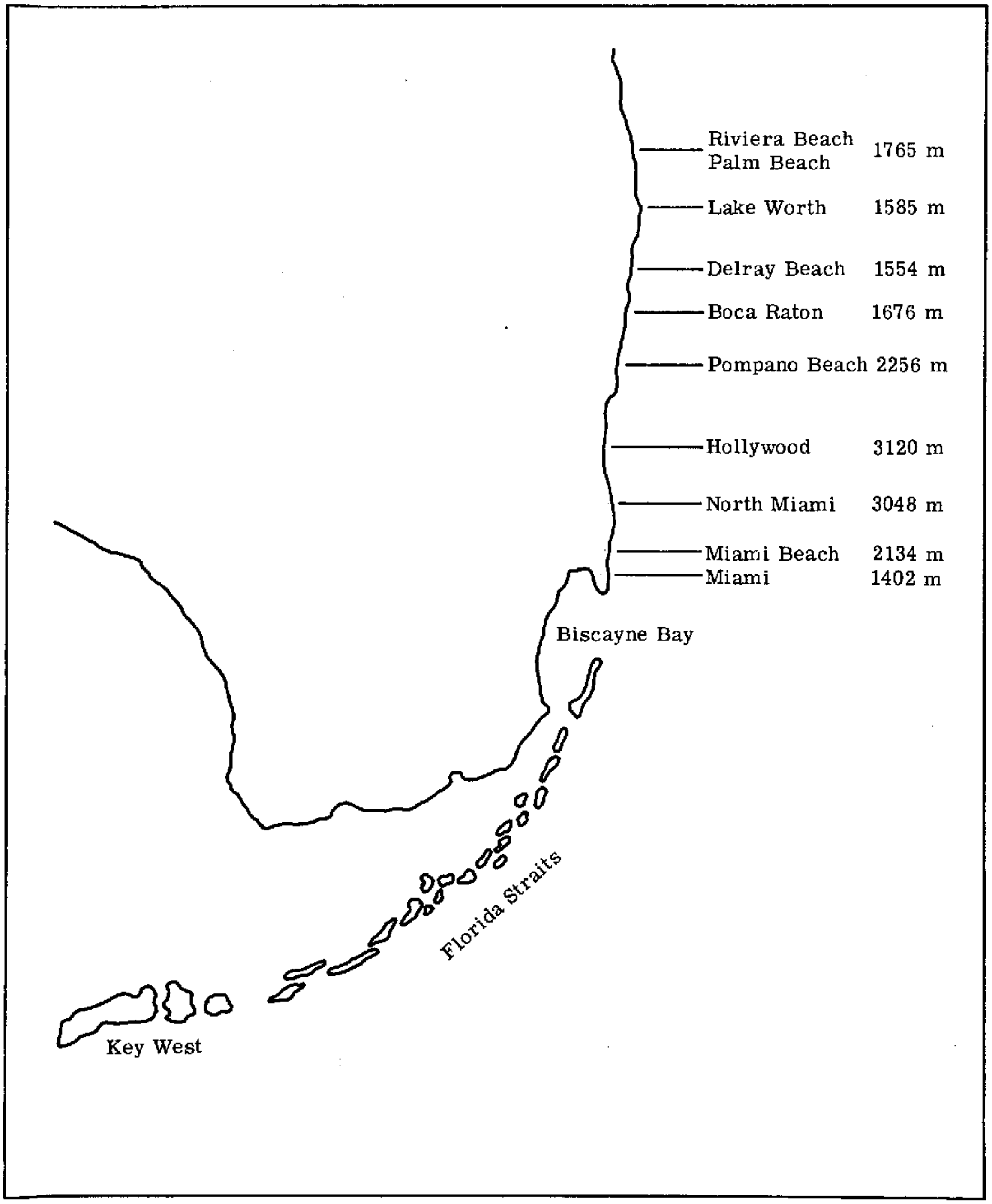


FIGURE 2. LOCATION OF OCEAN OUTFALLS, S.E. FLORIDA

industrial and municipal wastes are discharged in the southern portion of the lake. Frequently, polluted water masses are transported for considerable distances along the shore by coastal currents. Charting the movement of pollution by these currents was the purpose of this phase of the investigation.

3
METHODS

The data obtained in the ERTS-1 program was applied to the study of the problems described through an analysis of ERTS-1 imagery: direct interpretation and computer processing using ERTS-1 computer-compatible tapes (CCT).

The data supplied by NASA were collected by the ERTS-1 multispectral scanner (MSS) from an altitude of approximately 915 km in the following spectral bands:

Spectral Band	Wavelength (μm)
4	0.5 - 0.6
5	0.6 - 0.7
6	0.7 - 0.8
7	0.8 - 1.1

The area of each resolution element was approximately 0.45 hectares. The information in Bands 4, 5, and 6 was recorded with a 7-bit resolution (127 grey levels), and in Band 7 with a 6-bit resolution (64 grey levels). Since the system was not optimized for data collection over water, the total information content for water areas was generally limited to a few grey levels.

3.1 ERTS DATA PROCESSING

The processing of ERTS data recorded on CCT's included density-level slicing of individual spectral bands, ratioing, and statistical analysis of selected target areas. Grey maps and color-coded digital displays were produced as required. De-striping and smoothing of the CCT data was applied on two occasions to produce maps free of the characteristic ERTS stripes caused by detector non-uniformity.

The general processing procedure included: (1) reformatting of the data onto a 7-track digital tape, (2) preparation of working grey maps, and (3) production of line-prints through selected target areas. Based on an analysis of line-print data, integer levels for the production of final digital products were established. Spectral Band 7 was used to edit-out land areas. Statistical data for selected target areas were generated using standard ERIM statistical programs. The STAT program determines signatures of specified training sets of MSS data, and optionally prints histograms and/or statistical information about each field. All of the above procedures are documented in several reports [1, 2, 3].

Smoothing of the data to produce maps free of the characteristic ERTS-1 stripes was accomplished using a program (WINDOW) written by D. Lyzenga of ERIM. WINDOW is a sliding-rectangle smoothing program designed to average data values over an arbitrary size rectangle of points. The output tape has the same number of lines and points as the input tape, but each output data value is the average of nL × mP input data values. In this case smoothing was applied using a 6 × 6 resolution element rectangle.

3.2 GROUND TRUTH AND AIRCRAFT DATA COLLECTION AND ANALYSIS

Water quality samples in support of the program were collected and analyzed in accordance with the procedures outlined in Standard Methods [4] and Biological Field and Laboratory Methods [5]. On-site determinations included transparency, salinity and Forel-Ule color. All other analyses were performed using laboratory procedures.

Chlorophyll a determinations were performed using the Trichromatic Method. Turbidity measurements were made using the Hach 2100 A turbidimeter. Suspended-solids determinations, defined as "total non-filtrable residue," were performed using the Standard Methods procedure [4]. A standard 50 cm oceanographic Secchi disk was used for transparency measurement.

At the Lake Erie test site, a substantial portion of the total ground-truth data were collected and analyzed by the Environmental Protection Agency, Grosse Ile Laboratory.

Aircraft missions in support of the program were conducted using the ERIM remote sensing aircraft [2]. Multispectral scanner and photographic data were collected at the New York and Florida test sites. Analysis of aircraft data consisted of direct interpretation of data in the individual spectral bands and ratio-processed imagery. Ratio processing was executed, using the ERIM play-back facility, by dividing signals recorded in selected spectral bands and printing the resulting ratio on film.

4
REFLECTANCE CHARACTERISTICS OF AQUEOUS SOLUTIONS AND SUSPENSIONS

From a theoretical standpoint, the number of water quality parameters or substances measurable through an analysis of ERTS-1 data is severely limited. Suspended solids, optical properties such as turbidity or transparency, phytoplankton and oil constitute the only substances or properties which can be considered "potentially measurable" in the analysis of ERTS-1 data. The limited number, positioning, and width of the spectral bands of the ERTS-1 multispectral system all limit the measurement capability of this system. Other system characteristics impose additional restrictions on the measurement of the above substances and properties. Prior to a review of the results of this investigation it is necessary to consider the manner in which the reflectance characteristics of water are altered by the substances listed above. Since oil pollution was not a subject of this investigation, the discussion which follows does not address this topic.

4.1 TURBIDITY AND SUSPENDED SOLIDS

No simple correlations exist between the concept of turbidity as an optical property and weight per unit volume of suspended matter. However, for the purposes of this report, turbidity may be defined as an optical property which in surface waters is largely a result of absorption and scattering by materials in suspension.

Both pure and polluted waters will absorb and scatter light. Generally, scattering and absorption is caused by water molecules and by any suspended particulate materials present. The relative importance of scattering and absorption as mechanisms of attenuation is dependent upon wavelength, as shown in Figure 3. The attenuation-wavelength relationship in typical surface waters is illustrated in Figure 4.

The introduction of particulates into a body of water will result in the alteration of its reflectance spectra in the manner shown in Figure 5. The illustration represents an example in which the receiving waters are clear, free of other pollutants, and of sufficient depth so that bottom reflectance is not a factor. Admittedly, the curves represent a somewhat simple and "ideal" case. However, the major point to be drawn from the curves is the fact that a major change in the reflectance spectra occurs in the 0.6-0.7 μm spectral band (MSS5). Although reflectance levels are higher in MSS4, the utility of this spectral band will be governed in part by atmospheric conditions at the time of observation. The relationship shown is not linear and represents both particle size and concentration. Beyond 0.7 μm the curves for inorganic particulates will drop off. Additionally, the attenuation coefficient in the near-infrared will increase rapidly, limiting observations to essentially the water surface.

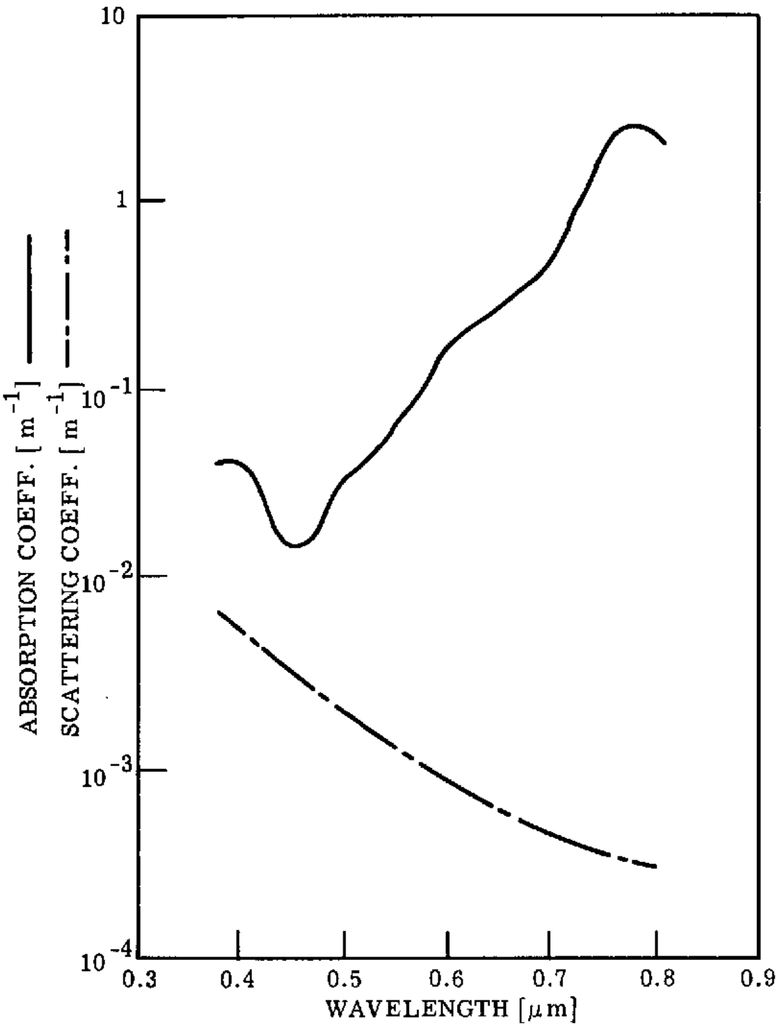


FIGURE 3. ABSORPTION AND SCATTERING COEFFICIENTS OF PURE WATER AS A FUNCTION OF WAVELENGTH [6]

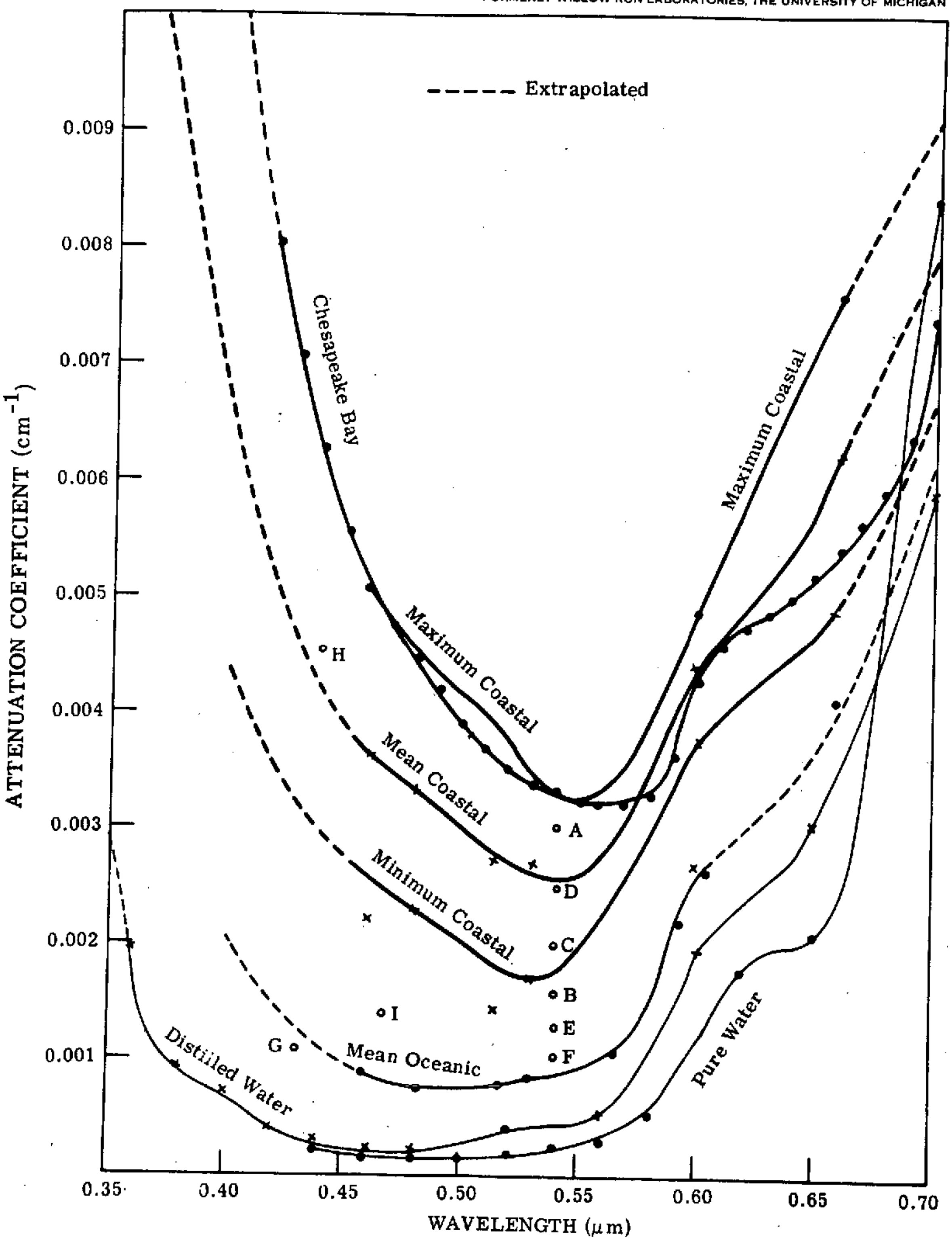


FIGURE 4. ATTENUATION - WAVELENGTH RELATIONSHIPS IN TYPICAL SURFACE WATERS

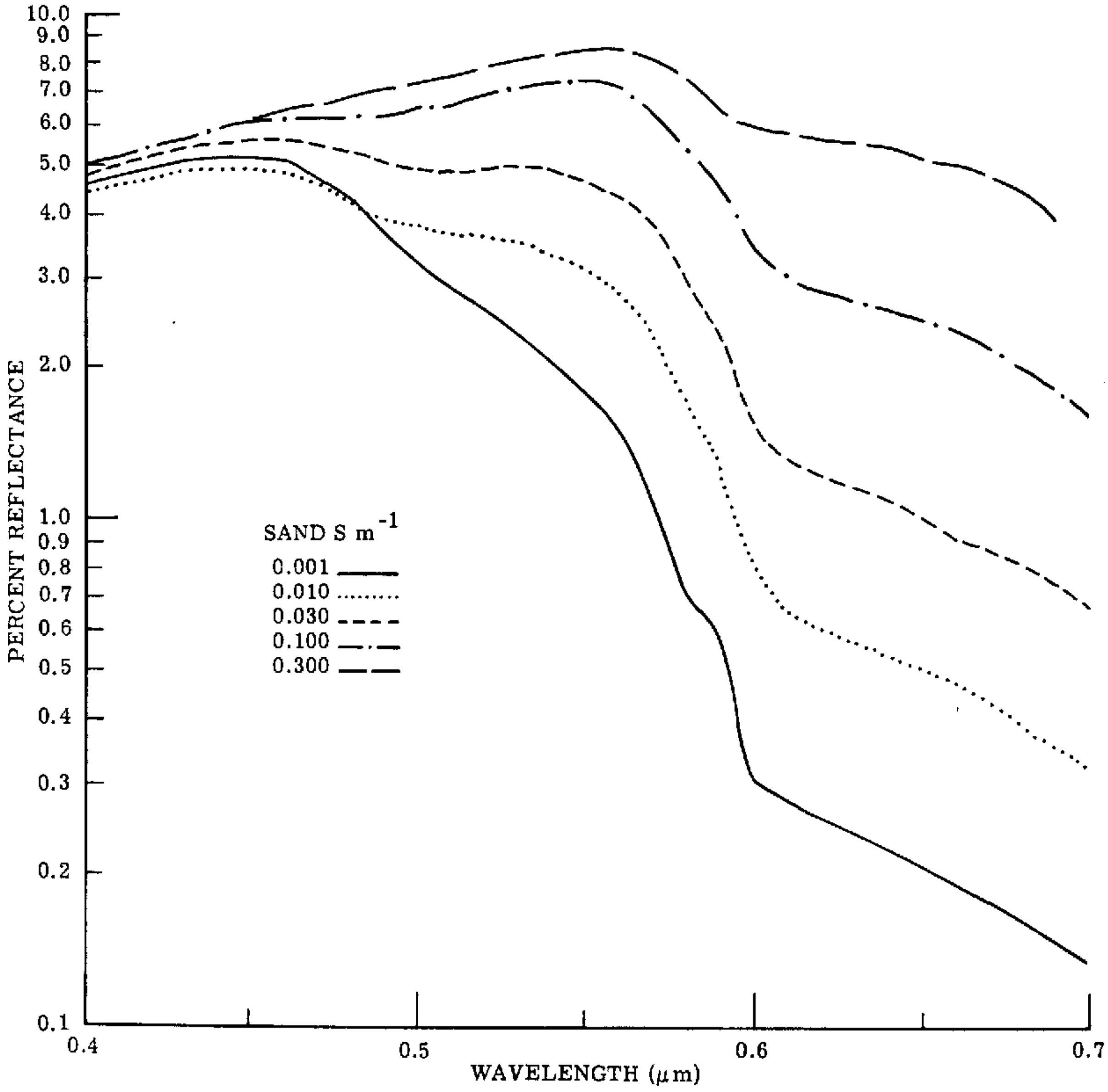


FIGURE 5. CALCULATED CHANGES IN REFLECTANCE OF WATER WITH INCREASING CONCENTRATION OF SUSPENDED SOLIDS [7]

4.2 PHYTOPLANKTON

The expected spectral response for a body of water which contains varying concentrations of phytoplankton is shown in Figure 6. The response in MSS5 is caused by the fact that phytoplankton are "particulates" and by the presence of photosynthetic pigments. The substances responsible for the absorption of light are the chlorophyll pigments, carotenoids, and special accessory pigments. Chlorophyll a is found in all green plants and is the predominant pigment in planktonic algae. Chlorophyll b appears to be present only in the Chlorophyceae whereas Chlorophyll c is found in several algae including all of the diatoms.

It should be noted in Figure 6 that as the phytoplankton concentration increases toward bloom proportions, the reflectance increases in the near-infrared. This is the opposite of the expected response for inorganic particulates. Although the attenuation coefficient is high in the near-infrared, this region of the spectrum is potentially useful for the detection of phytoplankton blooms.

The foregoing remarks are presented simply to underscore the fact that in principle a basis exists for detecting variation in suspended solids and delineating phytoplankton blooms using ERTS-1 spectral bands. In practice, however, the success achieved will be governed by the characteristics of the instrumental system and atmospheric conditions at the time of data collection.

4.3 ACID-IRON WASTE

As the acid-iron wastes are dumped into the marine environment a series of chemical reactions take place during which the acid is neutralized and the ferrous iron is rapidly oxidized to the ferric state, as shown in the following equations:

$$2FeSO_4 + 2H_2SO_4 + O_2 \rightarrow Fe_2(SO_4)_3 \downarrow + H_2O + H_2SO_4$$

$$Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 \downarrow + 3H_2SO_4$$

Due to the low solubility of iron at the pH of seawater, precipitates are formed. The ferric compounds produced tend to remain in suspension for considerable periods of time. The oxidized waste field is yellow or orange in color.

Detection of the waste using ERTS bands is possible because of light scattering in the red band and the fortuitous color of the waste. Essentially, acid-iron waste detection is a suspended-solids measurement in the ERTS system.

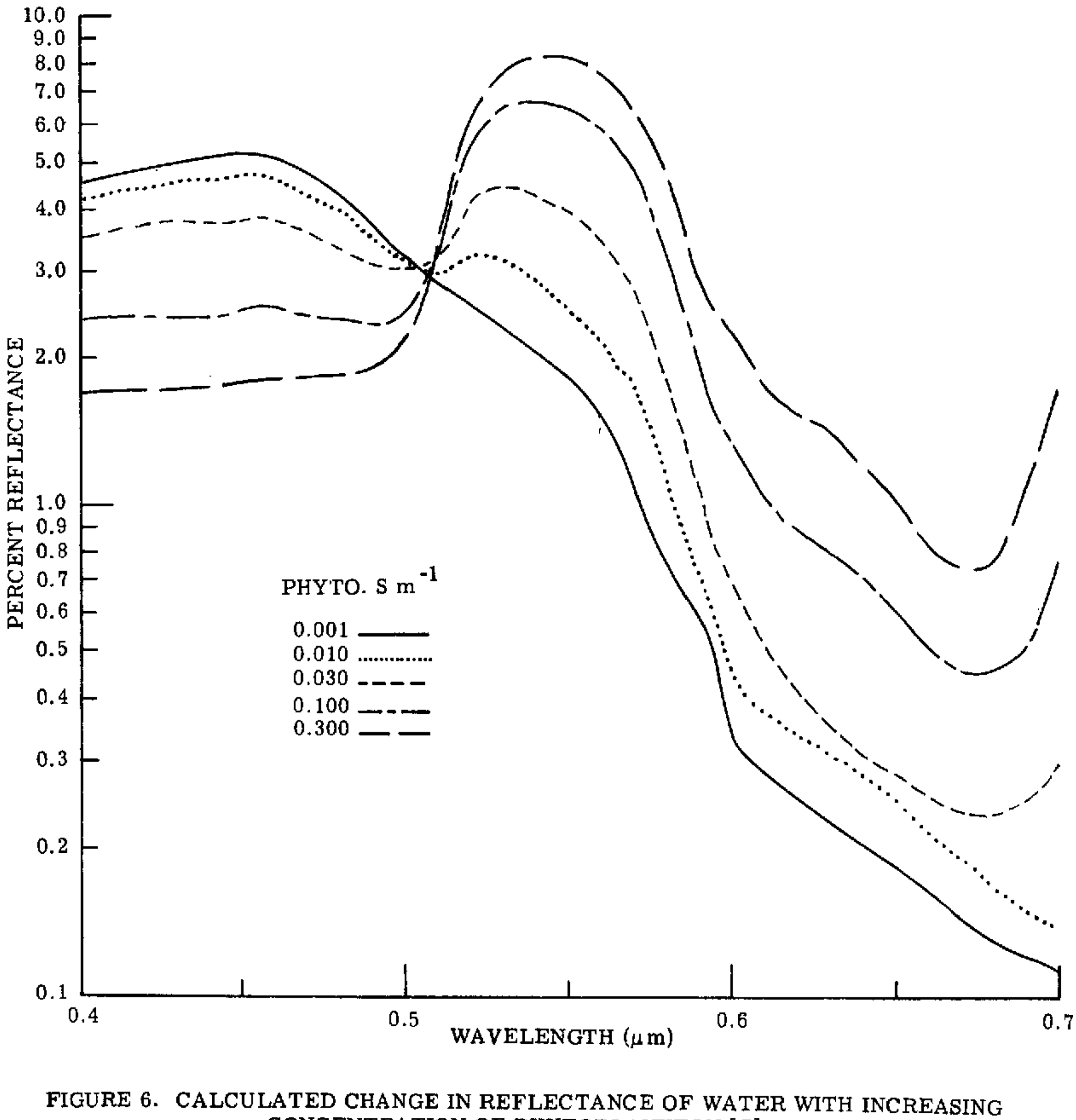


FIGURE 6. CALCULATED CHANGE IN REFLECTANCE OF WATER WITH INCREASING CONCENTRATION OF PHYTOPLANKTON [7]

5
RESULTS AND DISCUSSION

5.1 LAKE ERIE (WESTERN BASIN)

Several suitable ERTS frames of the western basin of Lake Erie were available, showing major circulation features, shore erosion processes, and variation in terms of turbidity and suspended solids. All of these features are clearly visible in Figure 7, which includes the western basin. Data analysis at this study location was directed toward evaluating the use of ERTS for turbidity and suspended-solids measurement. Additionally, data were examined to determine the applicability of ERTS-1 for detecting phytoplankton blooms.

5.1.1 ERTS DATA ANALYSIS - SUSPENDED SOLIDS AND TURBIDITY

Digital processing of ERTS frames E1247-15481 (27 March 1973), E 1265-15480 (14 April 1973), and E 1319-15474 (7 June 1973) was performed to investigate the relationship between CCT data value (grey level) in MSS5 and turbidity and suspended-solids concentrations. An initial analysis of the data at selected transects (Figures 8 and 9) illustrated the general relationship between signal level in MSS5 and the concentration of particulates.

Data collected on 14 April 1973 and 7 June 1973 provided the best opportunity to further investigate these relationships at this study location. A data set was required in which the turbidity and suspended-solids values were well distributed.

Ground-truth data in the western basin were collected at the locations indicated in Figure 10. Water quality data together with data values (grey levels) for MSS5 at the selected sampling stations are listed in Table 1. The variability in turbidity and suspended solids offers a good distribution of values which would permit a meaningful analysis of data as recorded on ERTS computer-compatible tapes. All of the sampling stations used in the analysis were at deep-water locations in order to eliminate the bottom-reflectance component from the analysis. Stations below high-altitude vapor trails were rejected.

The data values listed in Table 1 represent the means of approximately 100 to 200 resolution elements at each sampling location. Initially, digital grey maps which displayed each resolution element in the scene were prepared. Sampling locations were plotted and areas of approximately 10 lines by 10 to 20 points selected. Obvious anamolous lines in the data were avoided. Means and standard deviations were calculated for each area. The use of the area-averaging technique provided a more representative data value for each target area, by "smoothing" the effect of system noise.

Turbidity and suspended-solids values in April 1973 were high, although not unusual for the western basin. Suspended solids ranged between 21 and 80 mg/ℓ, and turbidities between 20 and 60 JTU. Values for both parameters are normally well below 20 in the western basin

FIGURE 7. SOUTHERN LAKE HURON, LAKE ST. CLAIR, WESTERN BASIN LAKE ERIE, 27 MARCH 1973. ERTS-1 Data, MSS5, E-1247-15474, E-1247-15481.

FIGURE 8. LAKE ERIE, 27 MARCH 1973. ERTS-1 Data, E-1247-15481-5.

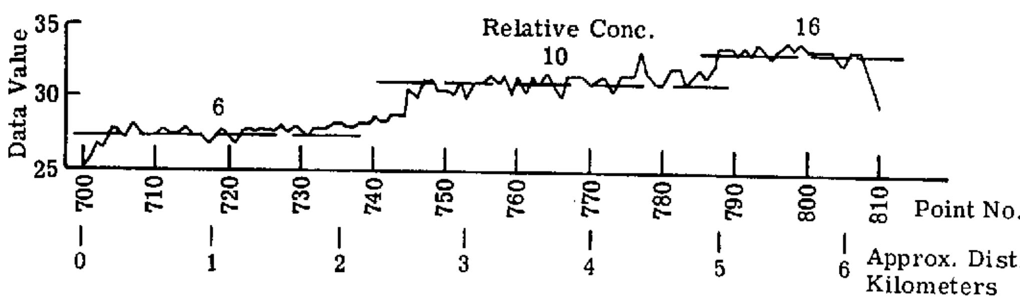


FIGURE 9. DETROIT RIVER TRANSECT, SUSPENDED SOLIDS VERSUS ERTS DATA VALUE MSS5, 27 March 1973, E-1247-15481. Average of four lines. 240,000 cfs.

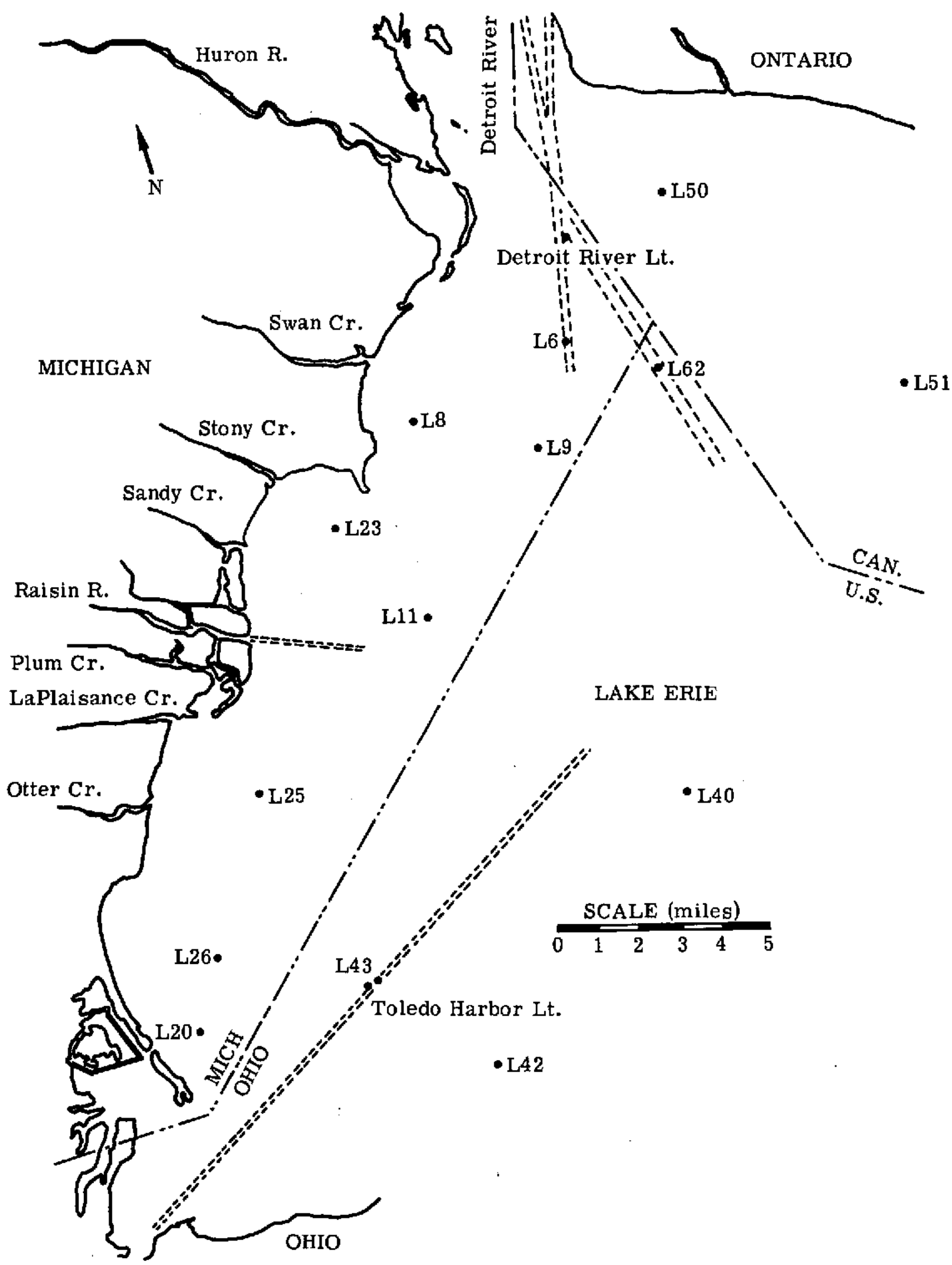


FIGURE 10. LOCATION OF SAMPLING STATIONS - LAKE ERIE

TABLE 1. TURBIDITY AND SUSPENDED SOLIDS FIELD DATA, WESTERN BASIN LAKE ERIE, 14 APRIL 1973 AND 7 JUNE 1973

Station	Latitude (N) Longitude (E)	Turbidity (JTU)	Suspended Solids (mg/ℓ)	Data Value Mean, MSS5
14 April 1973				
L6	41-57-49 83-09-17	40	48	32.65
L62	41-56-58 83-07-05	30	32	29.75
L9	41-55-54 83-10-52	45	48	30.57
L8	41-57-00 83-13-54	45	55	31.92
L11	41-52-53 83-15-13	40	43	30.10
L50	42-00-36 83-04-52	60	80	37.51
L51	41-55-30 82-59-20	20	25	26.89
L25	41-50-16 83-20-55	30	31	28.89
L26	41-47-09 83-23-19	35	35	29.82
L20	41-45-42 83-24-27	45	52	30.74
L43	41-46-00 83-19-00	30	32	29.83
L42	41-43-00 83-17-00	30	40	29.64
L40	41-48-00 83-09-00	20	21	27.72
7 June 1973				
L11		4	7	15.57
L6		4	7	17.83
L40		2	5	14.14
L9		2	3	15.72
L8		3	6	17.13
L43		3	10	16.07

after prolonged periods of no precipitation and low wind velocities. Data for 7 June 1973 represented the latter condition.

Radiance and reflectance data were calculated using atmospheric parameters measured with the Bendix radiant power measuring instrument (RPMI) [8] and ERTS conversion factors as published in the ERTS User's Handbook [9]. Calculations were performed using the following expressions:

$$\rho = \frac{(L - L_A)\pi}{TE}$$

where ρ = reflectance of the target

L = total radiance

L_A = path radiance

T = transmissivity of the atmosphere

E = target irradiance

The value for total radiance (L) was calculated for MSS5 as follows:

$$L_5 = D_5(0.0157 \text{ mw/cm}^2 \text{ sr})$$

where D_5 = data value (grey level) recorded on ERTS CCT. Values for transmissivity, path radiance, and target irradiance were available for 14 April 1973 and used in the direct calculation of the target radiance and reflectance data listed in Table 2. The values identified in the table as concrete and coal were large targets in the scene used as natural reflectance panels in the subsequent analysis of 7 June 1973 data.

The following expression was derived for use in calculating path radiance, 7 June 1973, using natural reflectance panels:

$$\frac{D_C - \frac{\rho_C}{\rho_B} D_B}{1 - \frac{\rho_C}{\rho_B}} = D_P$$

where D_P = data value equivalent of path radiance

D_C = data value, concrete

D_B = data value, coal

ρ_C = reflectance, concrete

ρ_B = reflectance, coal

TABLE 2. RADIANCE AND REFLECTANCE DATA, LAKE ERIE, 14 APRIL 1973, MSS5

$\rho = (L - L_A)\pi/TE$ — for MSS 5: $T = 0.815$

$L_5 = D_5 \times 0.0157$ mw/cm^2 sr — $L_A = 0.165$ mw/cm^2 sr

"D" equivalent of path radiance = 10.5 — $E = 10.3$ mw/cm^2

Data Value Mean	Station	L_5 (mw/cm^2 sr)	$L_5 - L_A$ (mw/cm^2 sr)	ρ	Measured Suspended Solids (mg/ℓ)	Measured Turbidity (JTU)
32.65	L6	0.5126	0.3476	0.130	48	40
29.75	L62	0.4671	0.3021	0.113	32	30
30.57	L9	0.4799	0.3149	0.118	48	45
31.92	L8	0.5011	0.3361	0.126	55	45
30.10	L11	0.4726	0.3076	0.115	43	40
37.51	L50	0.5889	0.4239	0.159	80	60
26.89	L51	0.4222	0.2572	0.096	25	20
28.89	L25	0.4536	0.2886	0.108	31	30
29.82	L26	0.4682	0.3032	0.113	35	35
30.74	L20	0.4826	0.3176	0.119	52	45
29.83	L43	0.4683	0.3033	0.113	32	30
29.64	L42	0.4653	0.3003	0.112	40	30
27.72	L40	0.4352	0.2702	0.101	21	20
18.33	LX	0.2878	0.1228	0.046	--	--
57	Concrete	0.8949	0.7299	0.273	--	--
15	Coal	0.2355	0.0705	0.026	--	--

Converting D_p to path radiance (L_A), the parameter $K = \pi/TE$ was calculated using the concrete as a reflectance panel. Radiance and reflectance data for 7 June 1973, MSS5, are presented in Table 3.

Experience at this and other locations indicates that the expression relating signal level and concentration of suspended solids assumes the following forum for the concentration range below approximately 60 mg/ℓ:

$$C = aD^b$$

where C = concentration
a, b = constants
D = data value (grey level)

Empirical equations were derived which describe the data and calculations made to compare field measurements and calculated values using ERTS data. The following expressions were derived for suspended solids and turbidity, using 14 April 1973 data:

(1) Suspended Solids

$$C = 0.03991\ \rho_5^{2.8216}$$

where C = suspended solids (mg/ℓ)
ρ_5 = reflectance (%), MSS5

(2) Turbidity

$$T = 0.03516\ \rho_s^{2.8216}$$

where T = turbidity (JTU)
ρ_s = reflectance (%), MSS5

The bulk volume reflectance of an aqueous suspension is the product of particle size, shape and color, as well as concentration. Therefore, the constants in the above expressions apply only to the 14 April data set and cannot be readily transferred to other situations.

The equations for turbidity and suspended solids are similar in this case because the turbidity was largely due to scattering by suspended solids. In principle, there is no relationship between turbidity and suspended solids except in an empirical sense under conditions similar to those present in this particular data set.

Comparisons of measured versus calculated values for the two parameters are presented in Tables 4 and 5. The average deviations for suspended solids and turbidity were 13.0% and 13.3%, respectively. These percentages correspond to average deviations of 5.4 mg/ℓ

TABLE 3. RADIANCE AND REFLECTANCE DATA, LAKE ERIE, 7 JUNE 1973, MSS5

$L_5 = D \times 0.0157$ mw/cm^2 sr

$L_A = 0.159$ mw/cm^2 sr

$\rho = (L_5 - 0.159)0.3418$

Station	Data Value Mean	L_5 (mw/cm^2 sr)	$L_5 - L_A$ (mw/cm^2 sr)	ρ	Measured Suspended Solids (mg/ℓ)	Measured Turbidity (JTU)
L11	15.57	0.2444	0.0854	0.029	7	4
L6	17.83	0.2799	0.1201	0.041	7	4
L40	14.14	0.2220	0.063	0.022	5	2
L9	15.72	0.2468	0.0878	0.030	3	2
L8	17.13	0.2689	0.1099	0.038	6	3
L43	16.07	0.2523	0.0933	0.032	10	3

TABLE 4. SUSPENDED SOLIDS, LAKE ERIE, 14 APRIL 1973

Station	ρ (%)	Measured Suspended Solids (mg/ℓ)	Calculated Suspended Solids (mg/ℓ)	Deviation (%)
L6	13.0	48	55.5	+15.6
L62	11.3	32	37.4	+16.9
L9	11.8	48	42.2	-12.1
L8	12.6	55	50.8	- 7.6
L11	11.5	43	39.3	- 8.6
L50	15.9	80	97.9	+22.4
L51	9.6	25	23.6	- 5.6
L25	10.8	31	32.9	+ 6.1
L26	11.3	35	37.4	+ 6.9
L20	11.9	52	43.2	-16.9
L43	11.3	32	37.4	+16.9
L42	11.2	40	36.4	- 9.0
L40	10.1	21	27.2	+24.8
	av = 11.7	av = 41.7		av = 13.0
				max = 24.8
				min = 6.1

TABLE 5. TURBIDITY, LAKE ERIE, 14 APRIL 1973

Station	ρ (%)	Measured Turbidity (JTU)	Calculated Turbidity (JTU)	Deviation (%)
L6	13.0	40	48.9	+22.3
L62	11.3	30	32.9	+ 9.7
L9	11.8	45	37.2	-17.3
L8	12.6	45	44.8	- 0.4
L11	11.5	40	34.6	-13.5
L50	15.9	60	86.3	+43.8
L51	9.6	20	20.8	+ 4.0
L25	10.8	30	29.0	- 3.3
L26	11.3	35	32.9	- 6.0
L20	11.9	45	38.1	-15.3
L43	11.3	30	32.9	+ 9.7
L42	11.2	30	32.1	+ 7.0
L40	10.1	20	24.0	+20.0
	av = 11.7	av = 36.2		av = 13.3
				max = 43.8
				min = 0.4

suspended solids and 4.8 JTU turbidity. A system "noise" equal to one data value would produce deviations of equal magnitude in the above data set.

The large deviations for the high values in the data set and the directions of these deviations simply confirm the fact that at very high turbidity and suspended-solids values, the curves approach a plateau due to multiple scattering. As a result, large concentration changes are reflected in small changes in data value and measurement accuracy becomes very poor.

The 7 June 1973 analysis provides data for the concentration range below 10 mg/ℓ suspended solids. The resulting expressions for suspended solids and turbidity are:

(1) Suspended Solids

$$C = 0.4000\, \rho_5^{2.3219}$$

(2) Turbidity

$$T = 0.2334\, \rho_5^{2.3219}$$

Comparisons of measured versus calculated values are presented in Tables 6 and 7. Considerable scatter in the data, at this and other locations, has been noted for the low concentration ranges. In this case, the average deviations for suspended solids and turbidity were 48.8% and 41.7%, respectively. Deviations of this magnitude would be produced by a systems noise of approximately one data value in this particular data set.

Although the curves for the two scene dates are nearly parallel, there is a substantial lateral displacement between them, undoubtedly caused by different particle-size distributions.

5.1.2 ERTS DATA ANALYSIS - PHYTOPLANKTON

The potential of ERTS-1 for measuring phytoplankton (chlorophyll) is extremely limited due to the broad spectral bands and other instrumental characteristics of the multispectral scanner used. Because of these factors the potential is largely restricted to the detection of phytoplankton blooms, although "fortuitous correlations" between signal levels and chlorophyll in surface waters can be expected in those cases where the materials in suspension are largely phytoplankton.

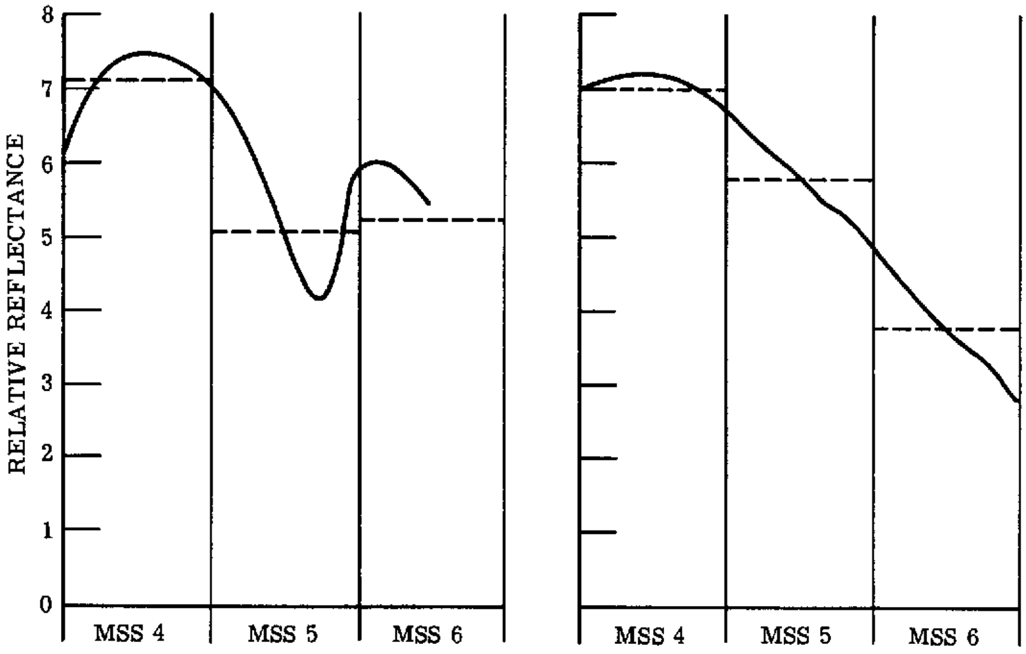
For the case of phytoplankton blooms or algae mats, a scientific basis exists for detection and for differentiating the bloom (or algae mat) from non-chlorophyll bearing particulates. As indicated in Section 4.2, the signal in MSS6 relative to MSS5 will be elevated in the case of algae and decreased in the case of sand in aqueous suspension. The general relationships are illustrated in Figure 11. The conditions described are surface or near-surface; therefore, the high attenuation coefficient in the near-infrared does not limit the utility of MSS6.

TABLE 6. SUSPENDED SOLIDS, LAKE ERIE, 7 JUNE 1973

Station	ρ (%)	Measured Suspended Solids mg/ℓ	Calculated Suspended Solids mg/ℓ	Deviation (%)
L11	2.9	7	4.7	-32.8
L6	4.1	7	10.6	+51.4
L40	2.2	5	2.5	-50.0
L9	3.0	3	5.1	+70.0
L8	3.8	6	8.9	+48.3
L43	3.2	10	6.0	-40.0
		av = 6.3		av = 48.8
				av dev = 3.1 mg/ℓ

TABLE 7. TURBIDITY, LAKE ERIE, 7 JUNE 1973

Station	ρ (%)	Measured Turbidity (JTU)	Calculated Turbidity (JTU)	Deviation (%)
L11	2.9	4	2.8	-30.0
L6	4.1	4	6.2	+55.0
L40	2.2	2	1.5	-25.0
L9	3.0	2	3.0	+50.0
L8	3.8	3	5.2	+73.3
L43	3.2	3	3.5	+16.7
				av = 41.7



(a) Relative Reflectance of Algae in Surface Waters

(b) Relative Reflectance of Sand in Water Suspension

FIGURE 11. TYPICAL ALGAE-SAND REFLECTANCE CURVES IN AQUEOUS SUSPENSION

Analysis of ERTS data for the detection of a reported phytoplankton bloom was performed using E 1048-15411 data for 9 September 1972. Data in the vicinity of Pt. Pelee were processed. De-striped and smoothed digital maps of the study area are shown in Figures 12 and 13.

Figure 12 also shows the four selected target areas. Site 1 was arbitrarily selected as being representative of background waters, i.e., an area where phytoplankton and suspended solids concentrations are relatively low. This site served as a water quality and atmospheric "benchmark" for the adjustment of data for the other targets in the scene. Site 2 was selected as a suspected algae bloom target. In view of the strong currents near shore on the west side of Pt. Pelee and the high turbidities normally found in this area, Site 3 was considered a good suspended solids target area in which the materials in suspension would be largely non-chlorophyll particles. Site 4 was selected as another likely area with high suspended-solids values. Data used for the calculation of signatures are presented in Table 8.

Shown in Figure 14 are the uncorrected bar-graph signatures for Sites 2, 3, and 4. Included are signatures for Site 2 using both smoothed (using WINDOW) and averaged data. Because of the path-radiance component in the data, interpretation of Figure 14 is somewhat difficult, in that important differences between the algae and suspended solids targets are not immediately apparent. Taking the ratio MSS6/MSS5, however, does suggest that a decision boundary separating the two targets could be drawn.

A more effective approach to the problem is to use Site 1 as the "benchmark" (typical background waters containing relatively low or insignificant concentrations of phytoplankton and suspended solids) and to subtract the data values observed in the several channels from the data for the other target areas. This procedure can be expected to remove various background effects including path radiance. Values are then corrected to "apparent radiance differences" using the appropriate conversion factors for each spectral band. Re-stated, the net result is a group of signatures which describe the differences between the several targets and the background (Site 1). The results are shown in Figure 15.

The signatures presented in Figure 15 show important differences between the suspected algae bloom area and the suspended-solids areas. The ratio of MSS6/MSS5 is approximately 0.9 for algae whereas the ratios for the suspended-solids targets are substantially lower. The observed relationships between Bands 5 and 6 for the targets support the conclusion that Site 2 is an algae bloom target and that Sites 3 and 4 are suspended solids consisting largely of non-chlorophyll bearing particulates. The theoretical basis for this conclusion is illustrated in Figure 11. In the case of algae, an increase in MSS6 relative to MSS5 is expected; whereas in the case of sand, MSS6 would be lower than MSS5. The relflectance curve for sand is the result of particle scattering, whereas in the case of algae the results represent the net effect

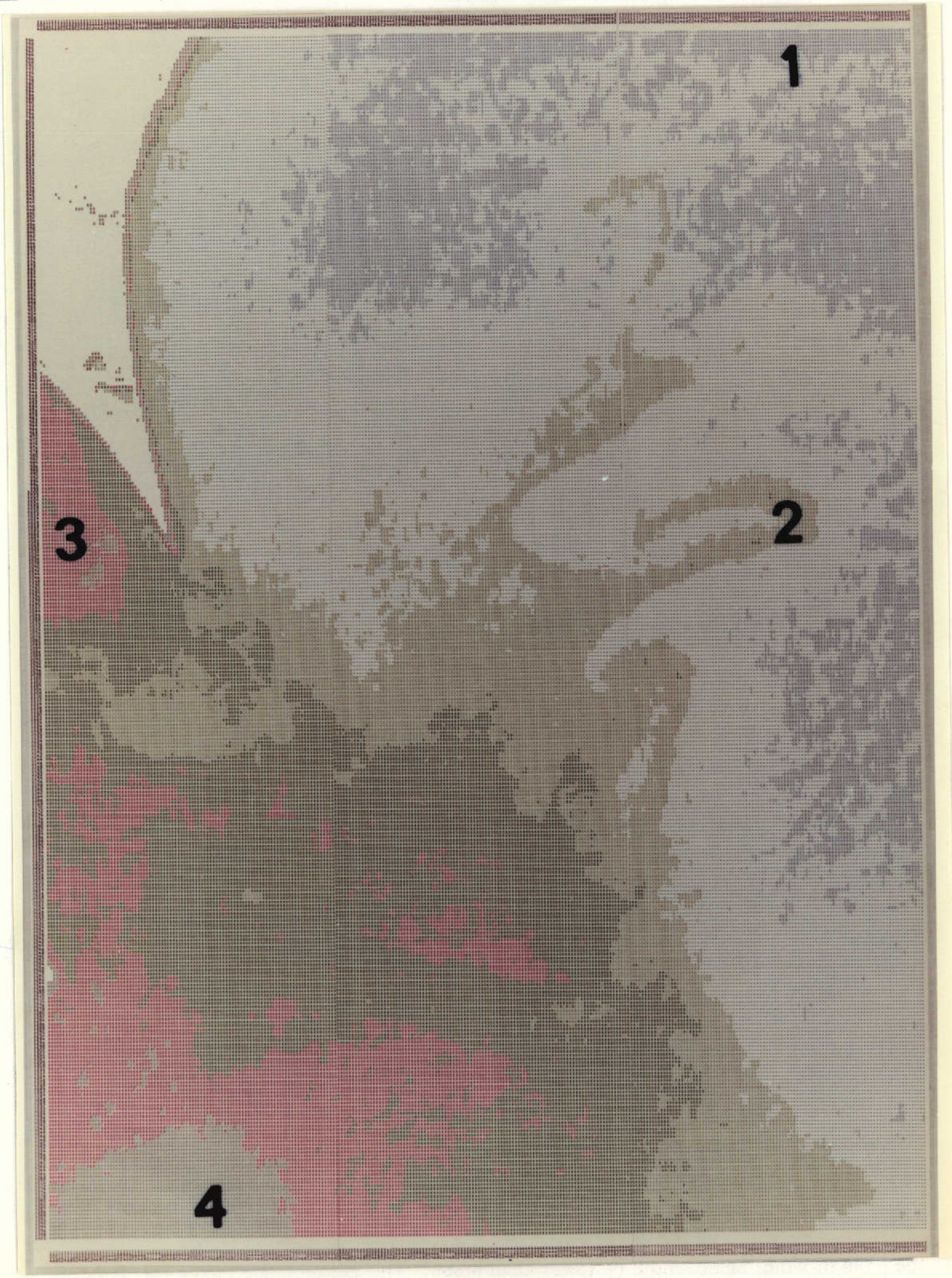


FIGURE 12. LAKE ERIE, 9 September 1972, MSS5. ERTS-1 Data, E-1048-15411.

FIGURE 13. LAKE ERIE, 9 September 1972, MSS6. ERTS-1 Data, E-1048-15411.

TABLE 8. SIGNATURE DATA, LAKE ERIE, 9 SEPTEMBER 1972

Station		MSS Band 4	MSS Band 5	MSS Band 6	Number of Points in Calculation
Site 1	Data Mean	19.0	8.97	5.09	1333
	Std. dev.	0.133	0.20	0.17	
Site 2	Data Mean	21.78	10.71	6.62	126
	Std. dev.	0.43	0.19	0.36	
Site 3	Data Mean	25.10	12.73	6.68	399
	Std. dev.	0.14	0.28	0.18	
Site 4	Data Mean	24.60	13.67	6.46	395
	Std. dev.	0.93	0.67	0.81	
Site 2 (Averaged Data)	Data Mean	20.82	10.58	6.58	243
	Std. dev.	1.38	0.63	0.84	

CORRECTED SIGNATURE DATA (Apparent Radiance Differences: mw/cm^2 sr × 100)

Station	MSS Band 4	MSS Band 5	MSS Band 6	MSS5/MSS6
Site 2	5.42	2.73	2.13	0.778
Site 3	11.90	5.90	2.21	0.374
Site 4	10.92	7.38	1.90	0.258
Site 2 (Averaged Data)	5.44	2.68	2.70	1.004

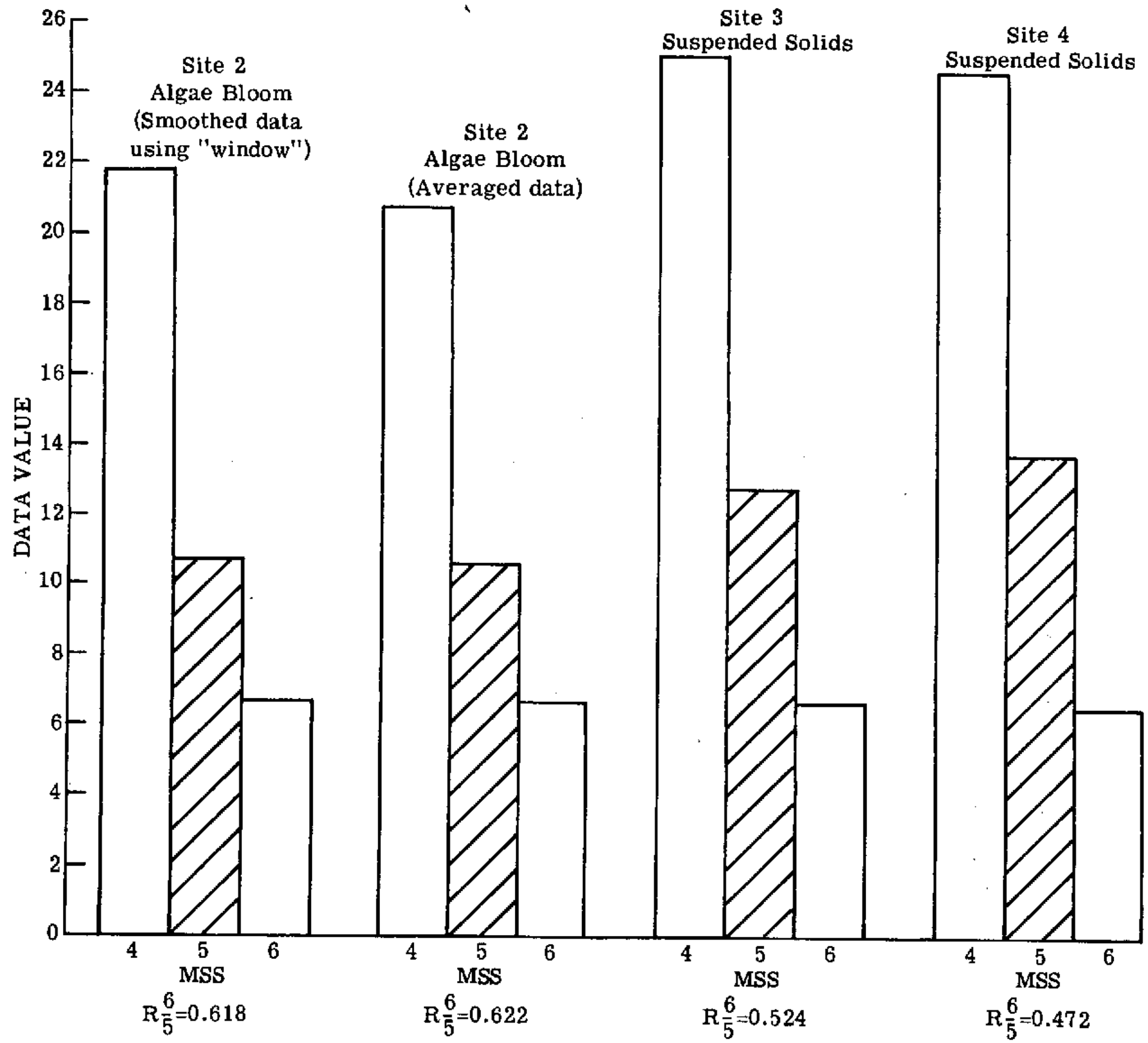


FIGURE 14. UNCORRECTED SIGNATURES - LAKE ERIE 9 September 1972, E 1048-15411

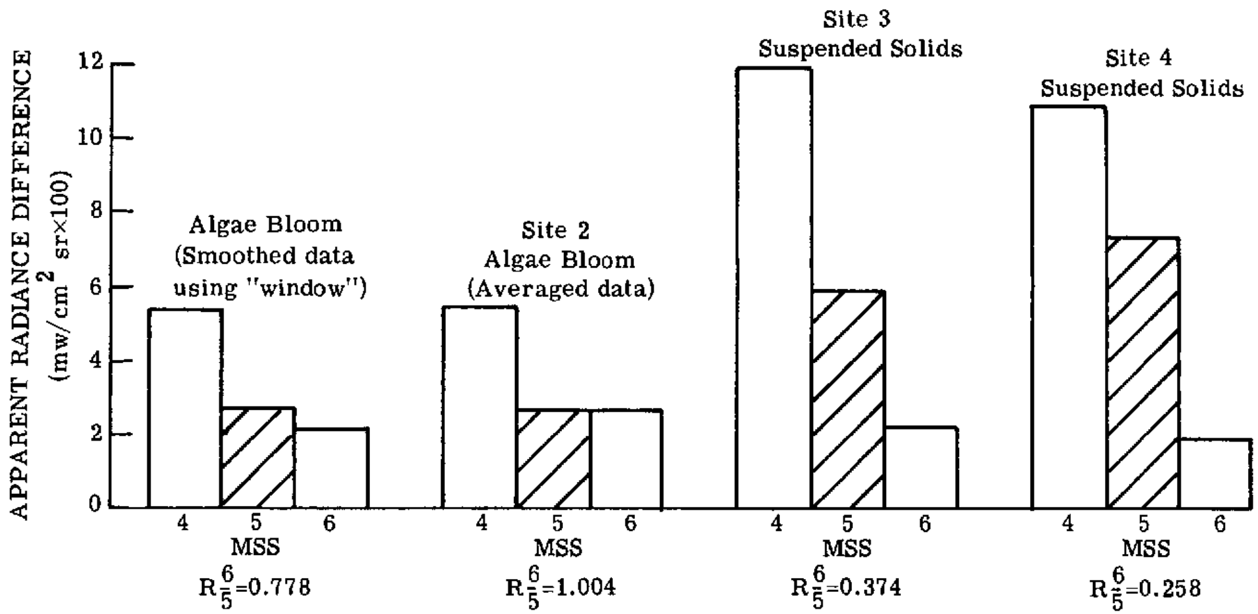


FIGURE 15. CORRECTED SIGNATURES - LAKE ERIE 9 September 1972, E 1048-15411

of scattering and photosynthetic pigments. The presence of an algae bloom in the area was confirmed two days after the satellite pass.

The natural extension of the work initiated in this program would be to produce a map using the signatures indicated in Figure 15. Areas conforming to the algae bloom and suspended-solids signatures would be displayed. All other areas would be classified as mixtures or undefined.

From a theoretical standpoint, oil on water could be expected to produce a similar ratio of MSS6/MSS5. For this reason it is important to include MSS4 in the signature analysis. An increase in reflectance in MSS4 relative to MSS5 confirms the "green" of the algae bloom; in the case of oil the signal in MSS4 would probably be slightly less than the signal in MSS5.

5.2 NEW YORK BIGHT

Work in the New York Bight area included analysis of data collected on 16 August 1972 (E 1024-15071) and 7 April 1973 (E 1258-15082). Atmospheric conditions on both dates were good, and on both occasions successful aircraft multispectral missions were conducted by ERIM at a time coincident with the satellite pass over the area. Aircraft missions were included in the program in order to provide corroborative evidence for use in the interpretation of space data. The study area is large and included low-contrast phenomena of varying size and distribution. Hence aircraft data were utilized to document features of interest in the subsequent ERTS-1 analysis.

Field data were collected in support of the program at the locations shown in Figure 16. Typical surface-water quality determinations for the study period are presented in Table 9. As expected, a sharp increase in total iron was found in the acid grounds area. Immediately after a dump, concentrations will normally be approximately 100 mg/ℓ Fe. Typical concentrations in old residual fields were found to be approximately 800 μg/ℓ. This compares with 20 μg/ℓ in adjacent ocean waters. Most of the iron is in the form of particulate iron.

Figure 17 presents photographic evidence of a typical acid-iron dumping operation and the subsequent oxidation and dispersion of the waste. The waste solution changes in appearance from green-yellow to orange as the material undergoes oxidation from the ferrous to ferric state. The orange water mass in the lower right-hand corner of Figure 17 is a suspension of $Fe_2(SO_4)_3$ from an earlier dump. Figures 18 and 19 document the scene at the time of the ERTS pass over the study area on the 16 August 1972 and 7 April 1973, respectively. In both cases acid-iron waste is clearly evident.

Shown in Figure 20 is the waste field area at approximately 1530 EST, during an outgoing tide at Sandy Hook. Dye markers depict a general southwesterly movement of the waste field. The tendency for the waste field to move in a southwesterly direction (toward shore) was also

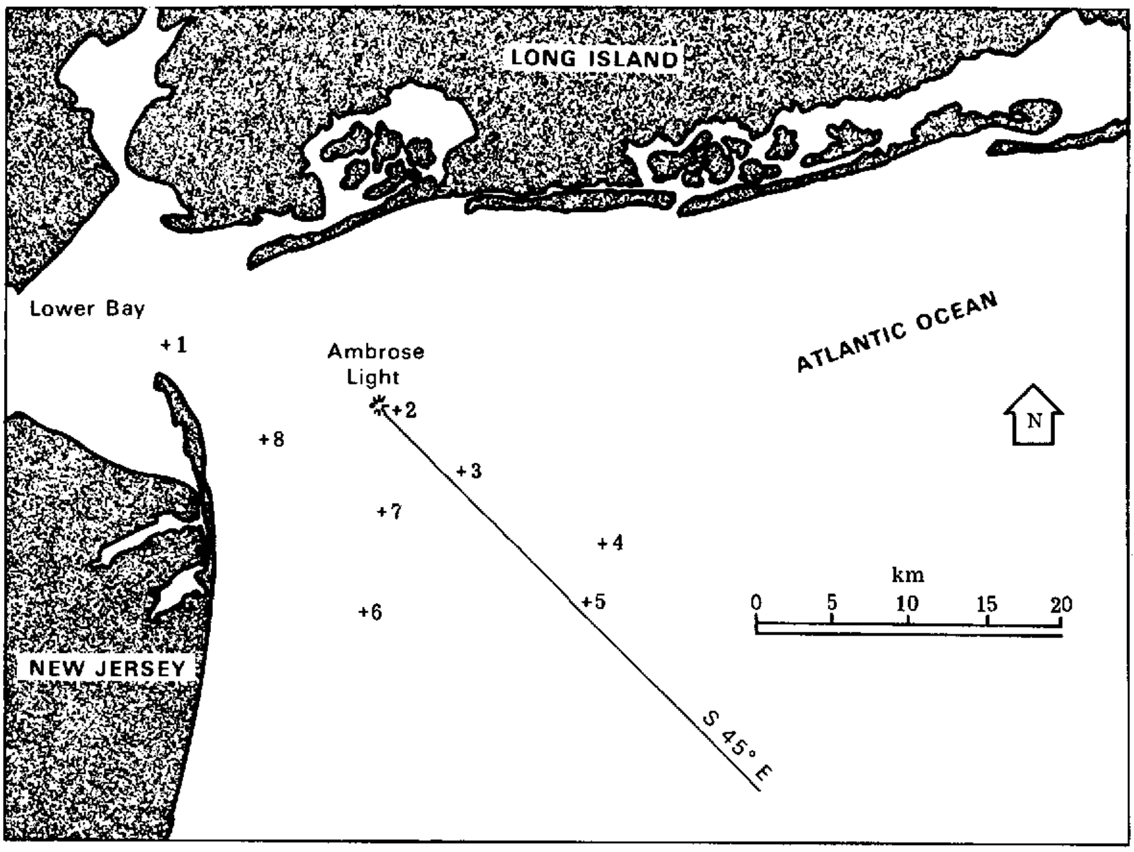


FIGURE 16. LOCATION OF SAMPLING STATIONS, NEW YORK BIGHT

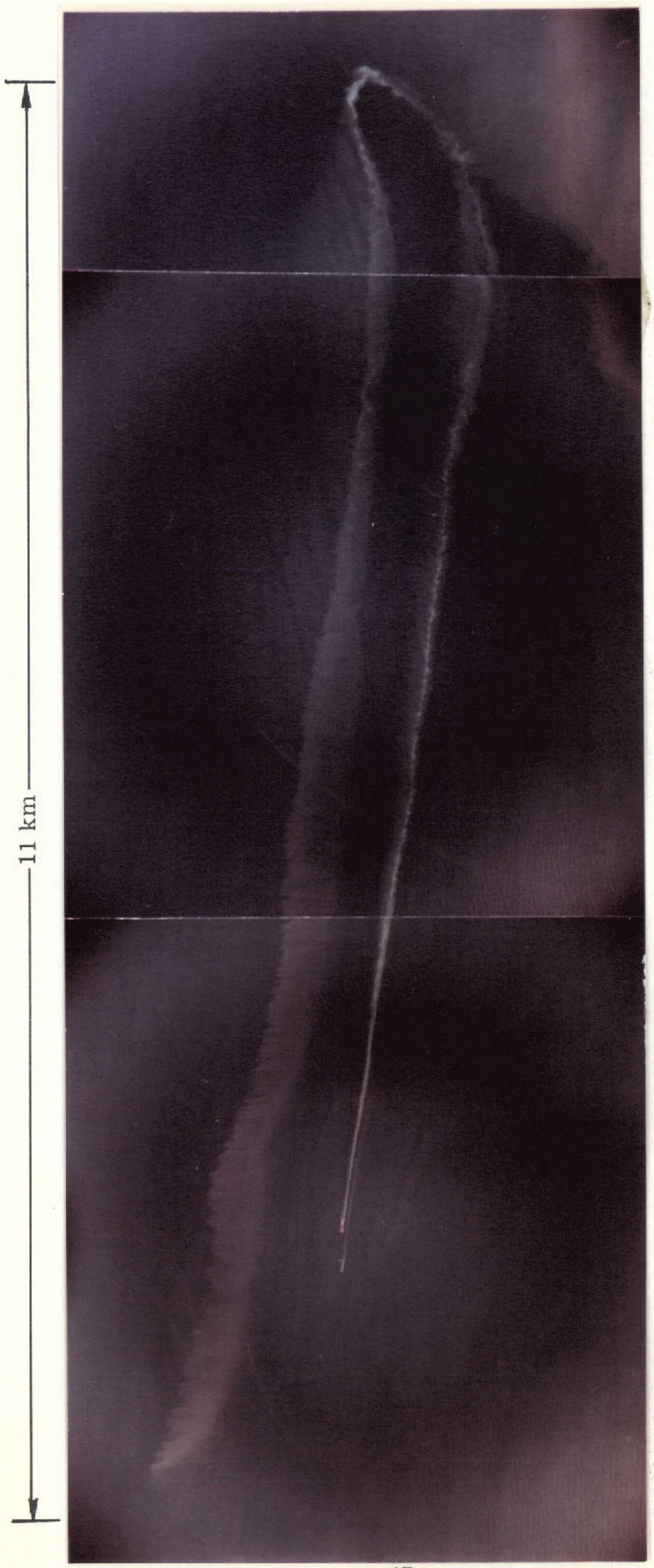
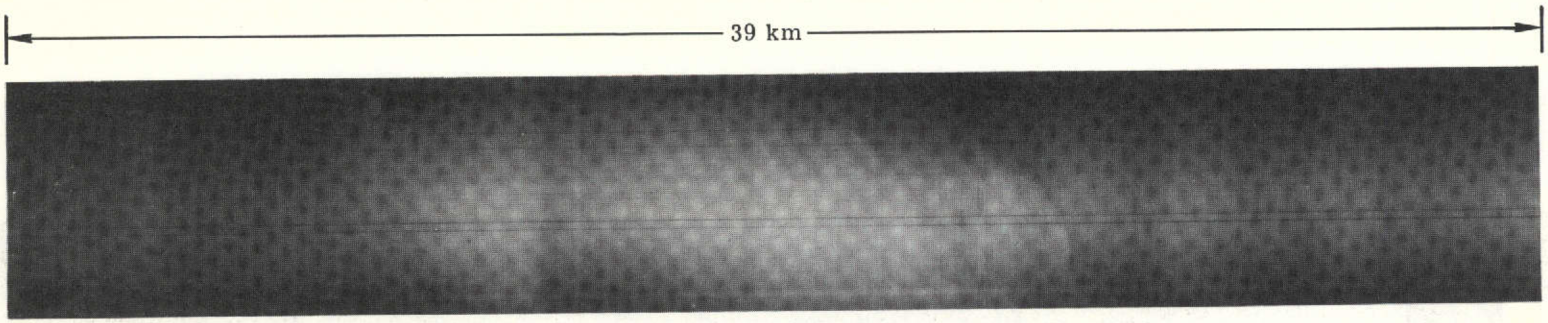
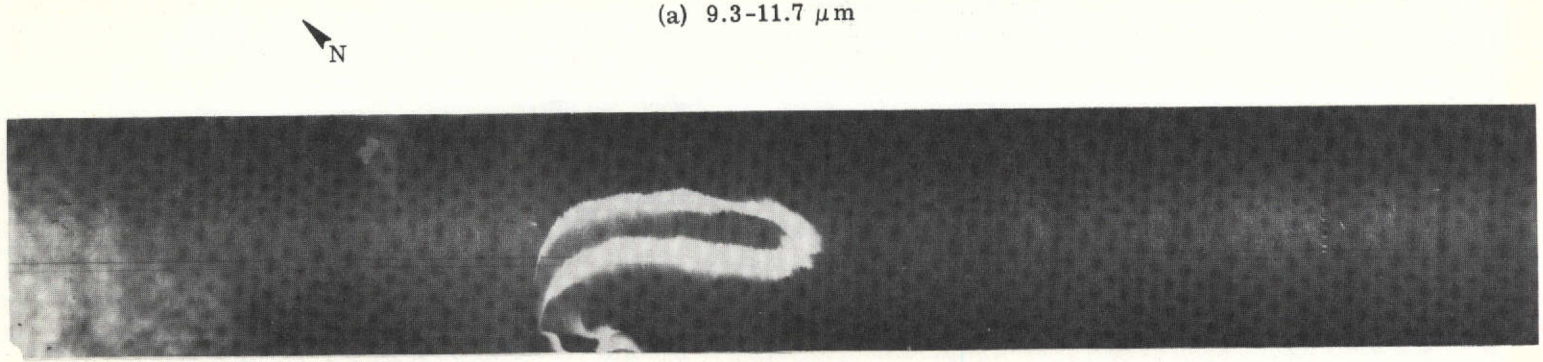


FIGURE 17. ACID WASTE, NEW YORK BIGHT, 7 APRIL 1973.
Aircraft Imagery, Altitude 3048 m.

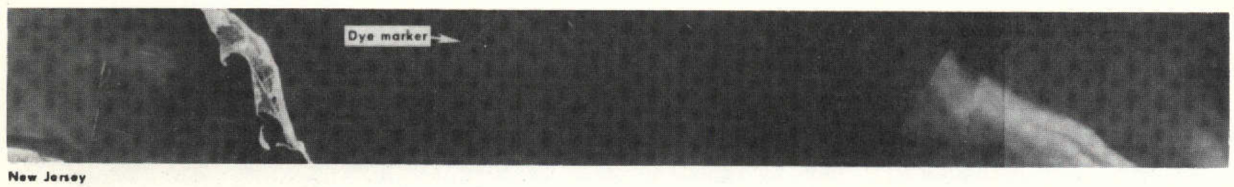


(a) 9.3-11.7 μm



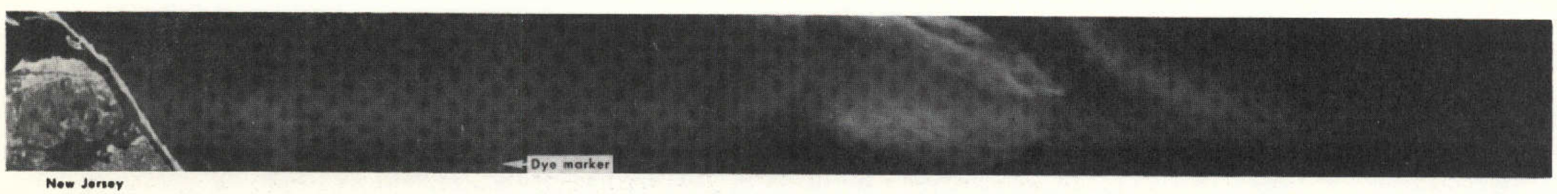
(b) 0.62-0.70 μm

FIGURE 18. NEW YORK BIGHT, 16 AUGUST 1972.
Aircraft Imagery, Altitude 3048 m.



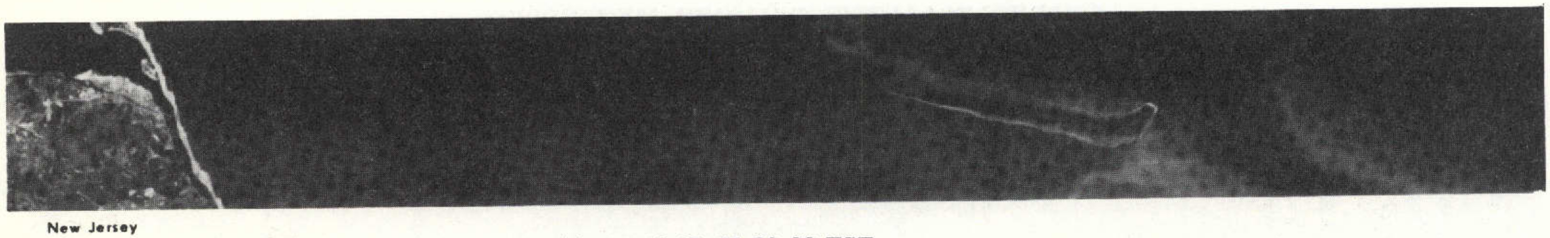
(a) 09:56:40-10:08:45 EST

N



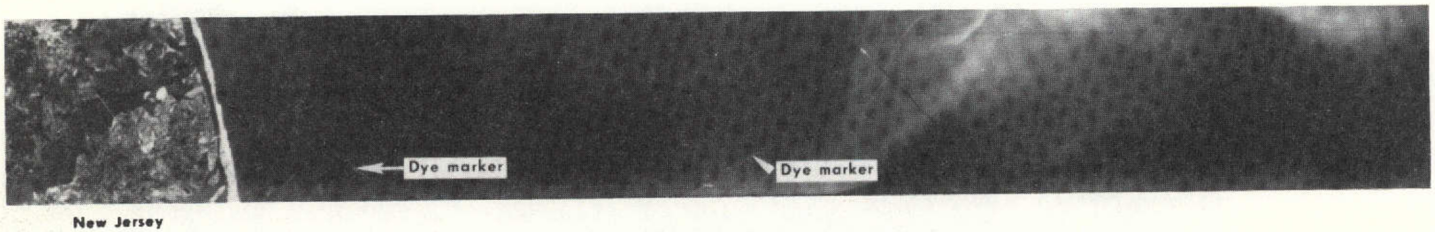
(b) 10:15:23-10:26:40 EST

FIGURE 19. NEW YORK BIGHT, 7 APRIL 1973.
Aircraft Imagery, Altitude 3048 m., 0.52-0.57 μm.



(a) 15:18:40-15:30:22 EST

N



(b) 15:33:28-15:44:28 EST

FIGURE 20. ACID-IRON WASTE, NEW YORK BIGHT, 7 APRIL 1973.
Aircraft Imagery, Altitude 3048 m., 0.52-0.57 μm.

TABLE 9. SURFACE WATER QUALITY DATA, NEW YORK BIGHT

Station	pH	Turbidity (JTU)	Suspended Solids (mg/ℓ)	Total Solids (gm/ℓ)	Salinity (0/00)	Chlorophyll a (mg/m^3)	PO_4 - P (μg/ℓ)	Total Fe (μg/ℓ)	Secchi Disk (meters) White	Secchi Disk (meters) Black
1 (Outgoing Tide)	8.0	6.6	14	18.4	17	35	100	—	1.07	0.61
2 Ambrose Tower	8.1	3.7	7	26.0	24	4	20	—	3.05	1.52
3 Sewage Sludge Dump Area	8.0	7.0	31	31.7	28	1	140	—	1.07	0.46
4 Ocean Background	8.0	1.3	4	33.4	31	1.4	15	20	6.40	2.44
5 Residual Acid-Iron Field	8.0	2.9	6.5	33.7	30	0.9	5	800	2.44	1.52

supported by field observations on 25 April 1973. The western edge of a large dispersed yellow water mass (acid-iron waste) was located on that date at a position approximately 10 km off the New Jersey coast.

5.2.1 ERTS DATA ANALYSIS

Waste fields created by barge dumping were evident in all clear frames of the study area. Acid-iron waste in the process of being discharged, recently dumped waste, as well as relatively old waste suspensions have been detected. Also clearly visible were turbidity anomalies associated with variability in suspended-solids concentration. The study area, as seen by ERTS-1 on 16 August 1972 and 7 April 1973, is shown in Figures 21 and 22, respectively.

Digital processing of ERTS was performed to calculate the physical dimensions of waste fields, to differentiate water masses in terms of major suspended solids differences, and to investigate the quantitative relationships between CCT data values (grey levels) and suspended solids concentration. Examples of the digital products produced during the course of this investigation are shown in Figures 23, 24 and 25. Figure 25 was de-striped and smoothed.

As indicated in the earlier discussion of the reflectance characteristics of aqueous solutions and suspensions, an introduction of particulates into a water column will result in an increased reflectance in MSS5 (0.6-0.7 μm). In the New York Bight case, turbidities are normally high. Additionally, the peak reflectance of the acid-iron waste is in the orange part of the spectrum. Because of scattering and waste color, MSS5 is the preferred ERTS-1 spectral band for the detection of acid-iron waste.

The mean data values and standard deviations for major target areas are presented in Figures 26 and 27. The values shown represent the means of approximately 100 points for each selected area. The "ocean" area in the tables represents the relatively clean background waters away from high-turbidity or waste-dump areas. Typical suspended-solids concentrations in this area are 4 mg/ℓ. The figures suggest that at this location suspended-solids concentrations above 4 mg/ℓ are measurable, subject to instrumental constraints. The values identified as "sewage sludge" refer to the area designated for this purpose and do not represent values for the sludge itself. The sludge as it is being dumped is generally dark in color (digested sludge), is high in total solids and includes digester supernatant. The heavier solids settle out rapidly leaving an increased concentration of suspended solids in the overlying waters and a variable amount of floatable substances in the area.

Since the study area was large and highly dynamic, the collection of suitable field data over a wide range of suspended-solids concentrations, in order to allow a meaningful analysis of ERTS CCT's, proved to be a difficult undertaking. Table 10 lists the data values (grey levels) derived from the CCT's by averaging over selected areas. The values were used in determining the relationship between data value and concentration.

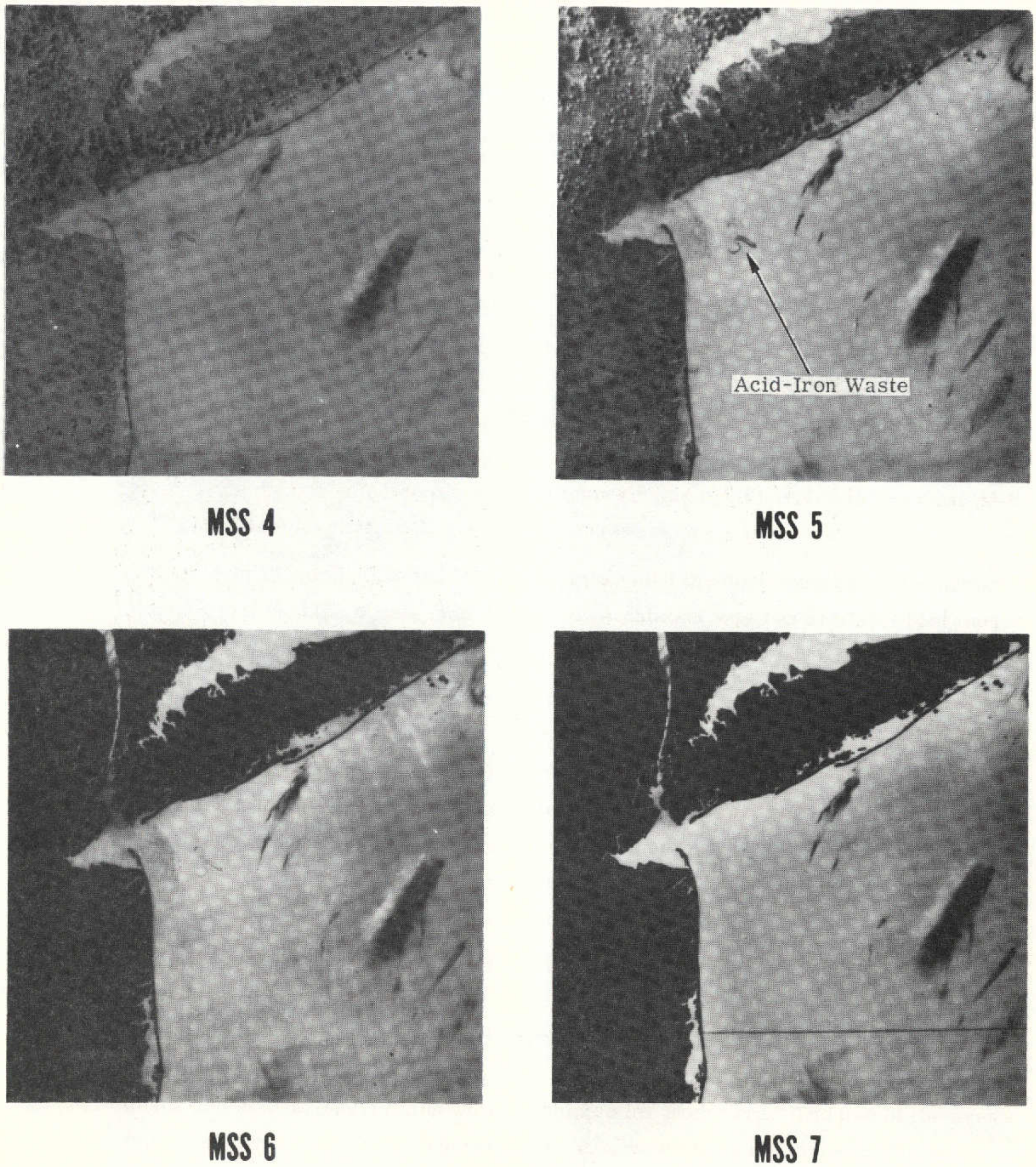


FIGURE 21. NEW YORK BIGHT, 16 AUGUST 1972. ERTS-1 Data, E-1024-15071

← N —

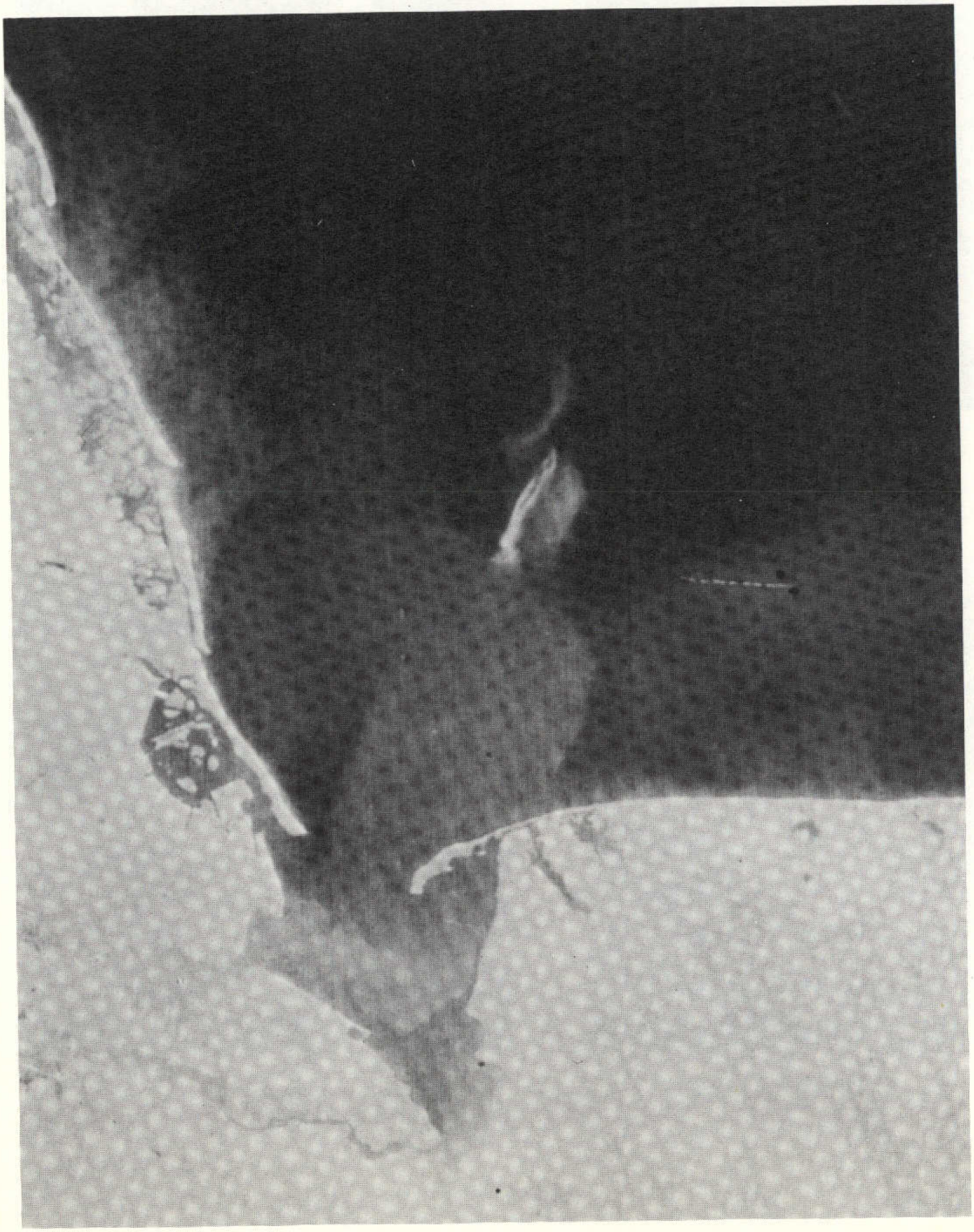


FIGURE 22. NEW YORK BIGHT, 7 APRIL 1973.
ERTS-1 Data, MSS5 (0.6-0.7 μm), E-1258-15082

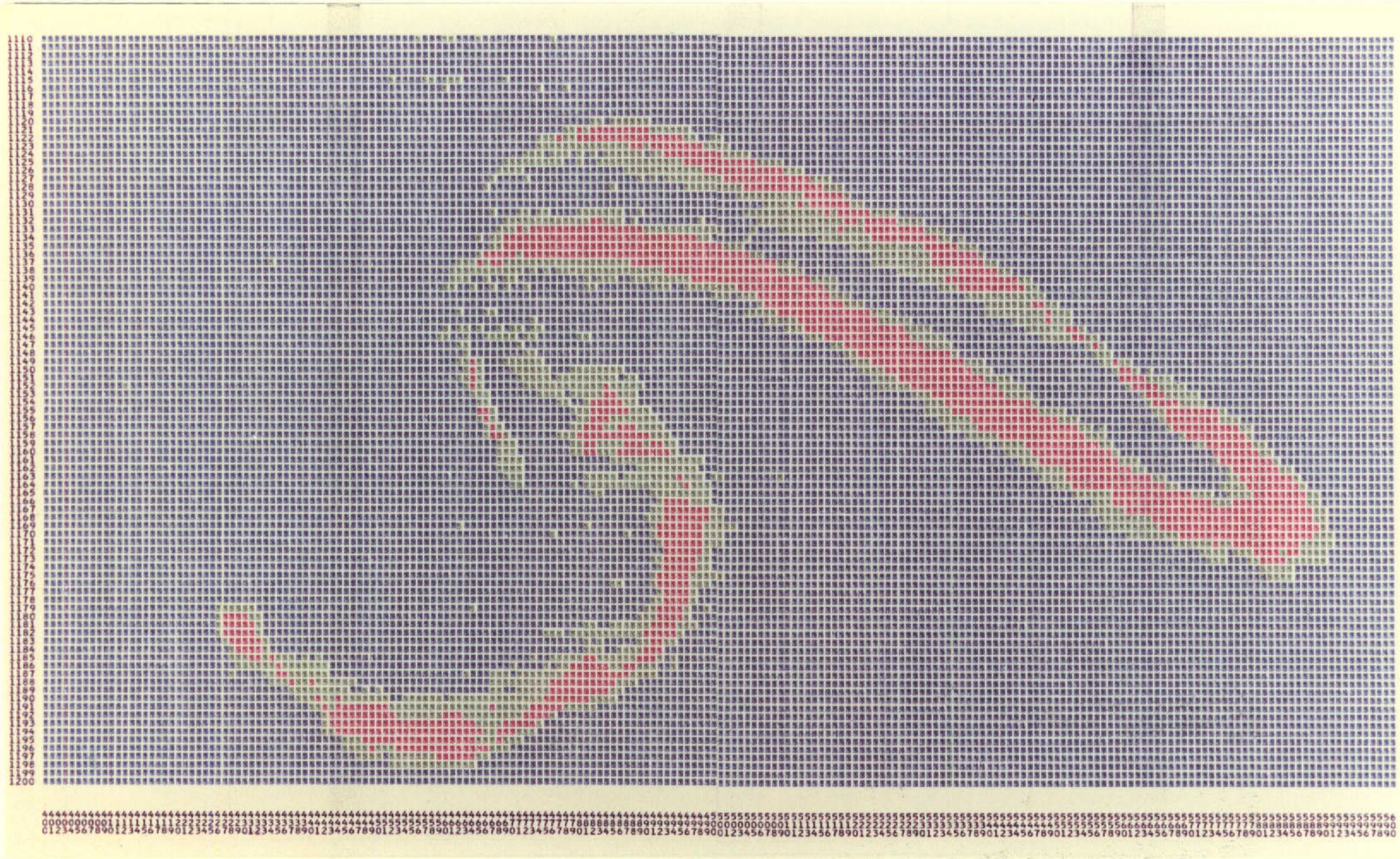


FIGURE 23. DIGITAL MAP, ACID-IRON WASTE, NEW YORK BIGHT, 16 August 1972. MSS5 (0.6-0.7 μm). Surface area = 1250 ha (lines 426 to 592 = 9.4 km; lines 1120 to 1198 = 6.16 km).

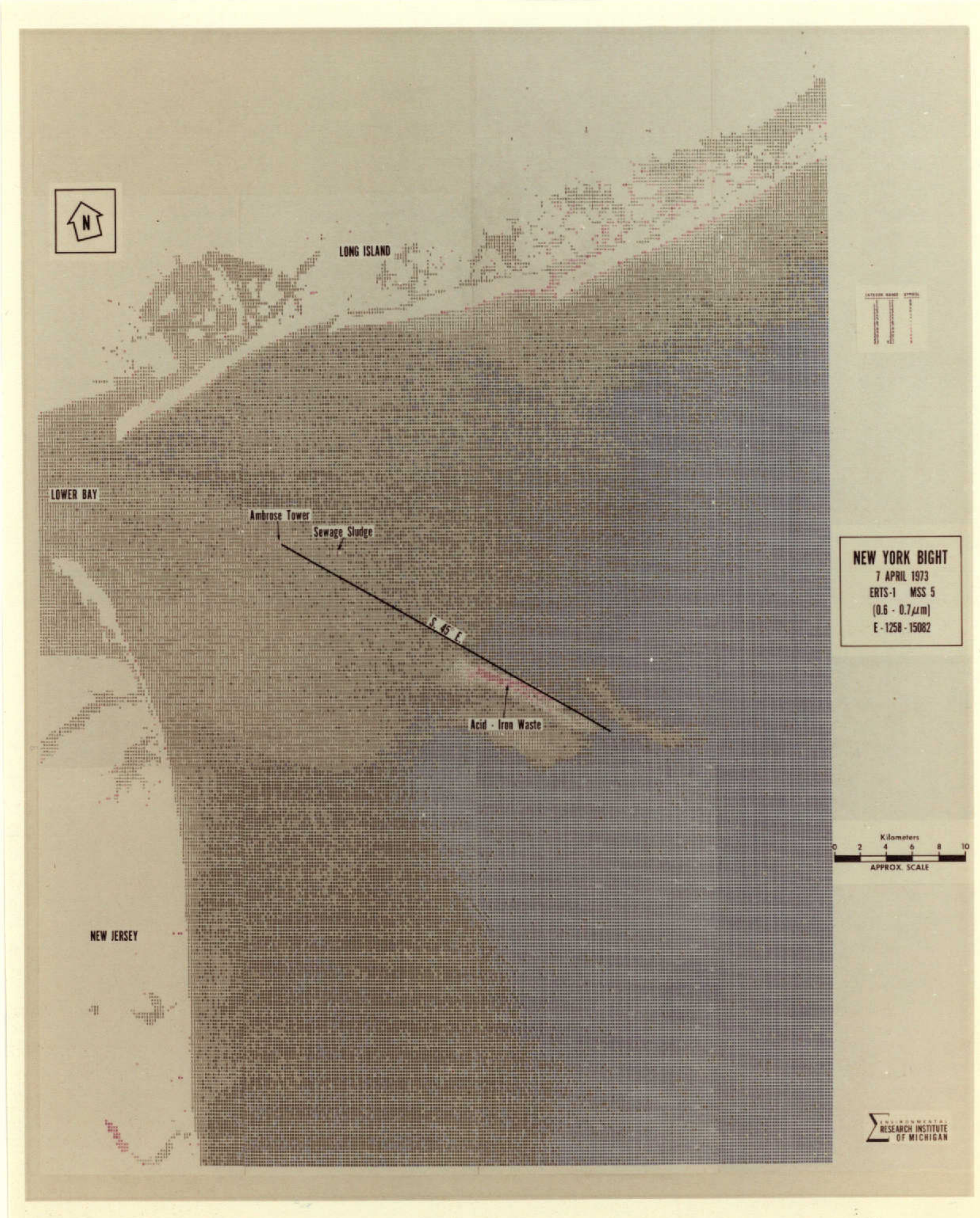


FIGURE 24. DIGITAL MAP, NEW YORK BIGHT, 7 APRIL 1973. MSS5 (0.6-0.7 μm), E-1258-15082

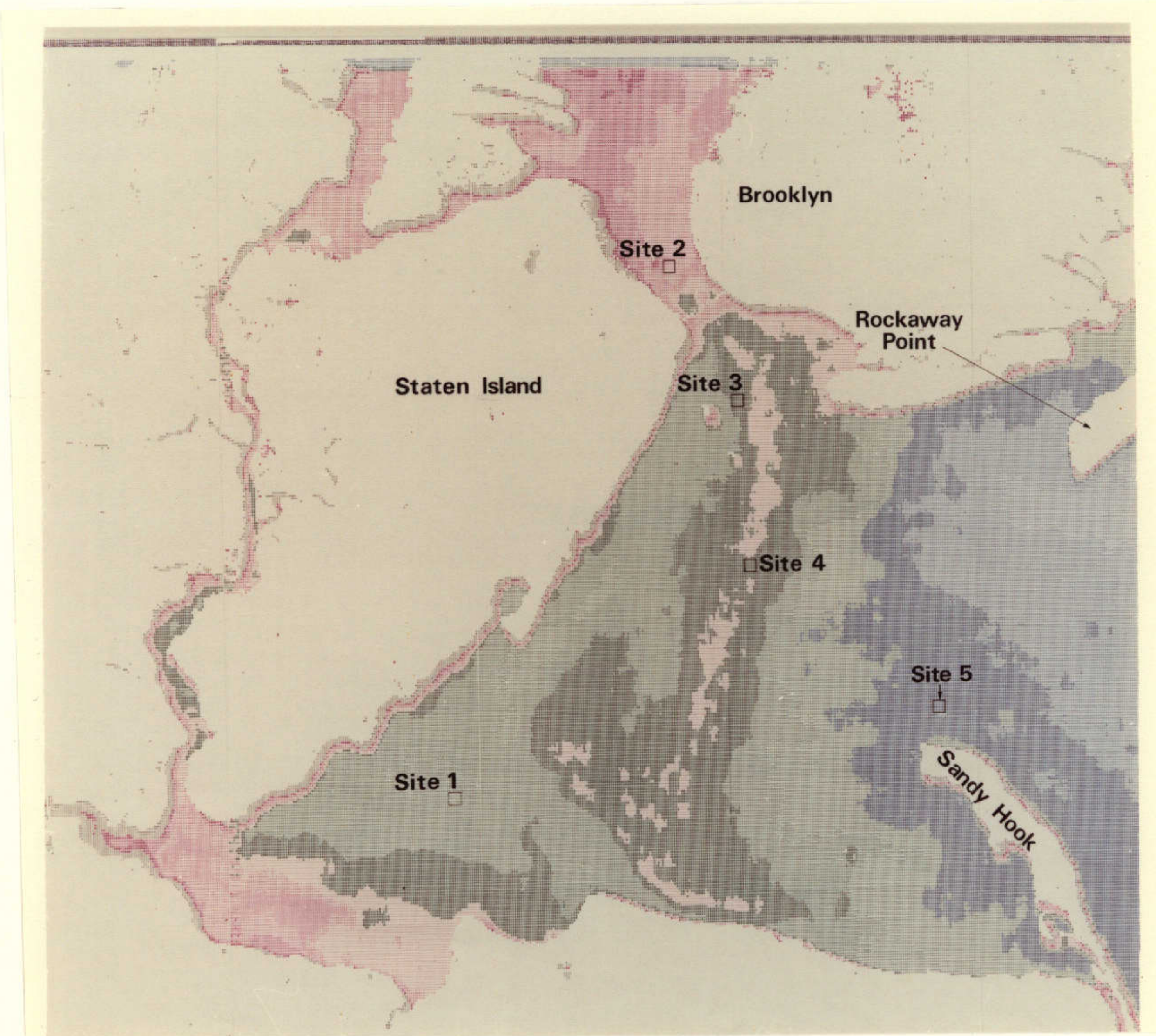
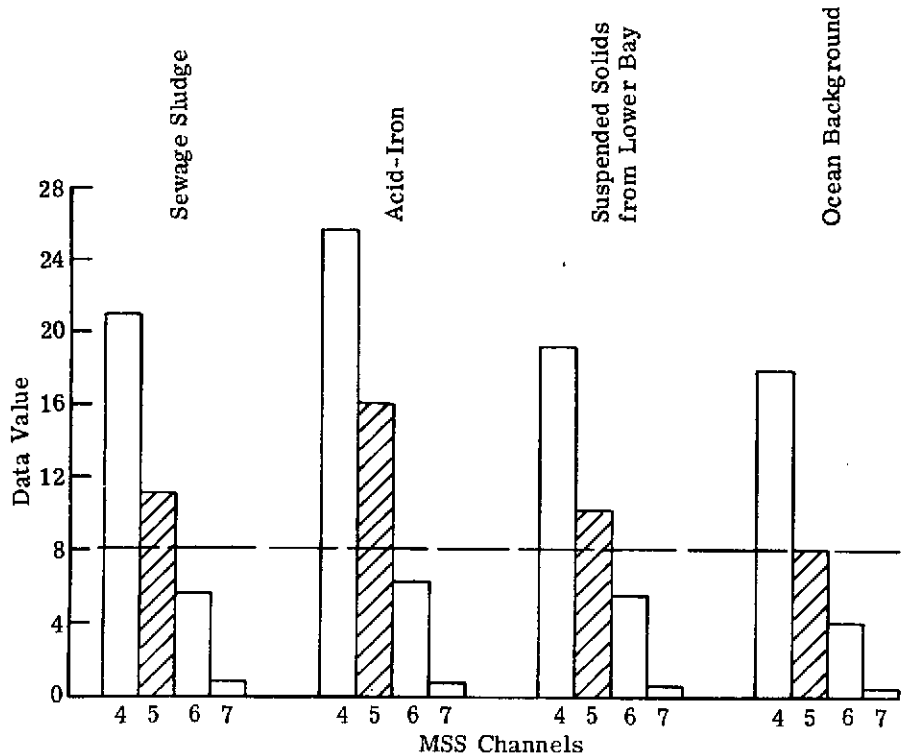
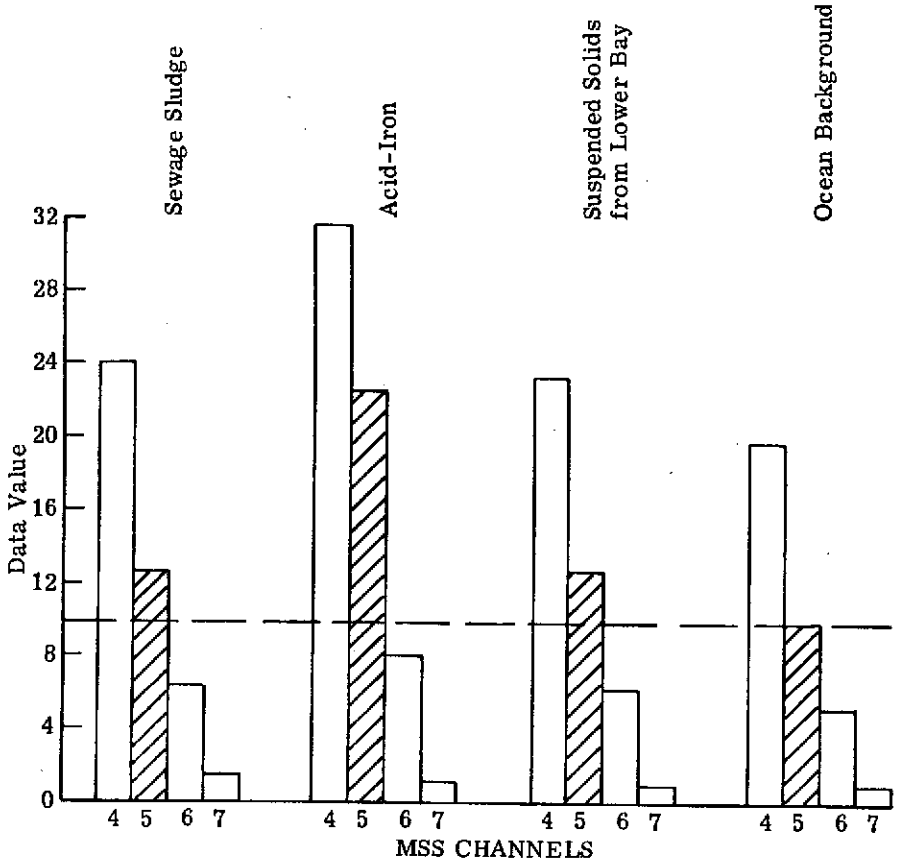


FIGURE 25. NEW YORK HARBOR AREA, 7 APRIL 1972. MSS5, E-1258-15082



	Channel	Data Value Mean	Std. Dev.
Sew. Sludge	4	20.97	1.73
	5	11.08	0.97
	6	5.50	1.58
	7	0.77	0.66
Acid-Iron	4	25.82	1.07
	5	16.22	1.79
	6	6.31	0.86
	7	0.70	0.56
Lower Bay	4	19.24	0.77
	5	10.20	0.69
	6	5.49	0.63
	7	0.64	0.57
Ocean	4	18.03	
	5	7.97	
	6	4.10	
	7	0.46	

FIGURE 26. ERTS DATA VALUES, NEW YORK BIGHT, 16 AUGUST 1972. E-1024-15071.



	Channel	Data Value Mean	Std. Dev.
Sew. Sludge	4	24.15	0.38
	5	12.54	0.52
	6	6.15	0.38
	7	1.54	0.52
Acid-Iron	4	31.76	1.21
	5	22.56	1.63
	6	8.02	0.90
	7	1.16	0.51
Lower Bay	4	23.38	0.93
	5	12.73	0.71
	6	6.18	0.73
	7	0.93	0.55
Ocean	4	19.82	0.54
	5	9.79	0.72
	6	5.33	0.67
	7	0.87	0.57

FIGURE 27. ERTS DATA VALUES, NEW YORK BIGHT, 7 APRIL 1973. E-1258-15082

TABLE 10. ERTS-1 DATA, NEW YORK BIGHT, 7 APRIL 1973, MSS5 (0.6-0.7 μm)

Data Value	Measured Suspended Solids mg/ℓ	Calculated Suspended Solids mg/ℓ	Deviation (%)	Δ Suspended Solids (mg/ℓ)	Δ Data Value	Δρ (%)
9.8 Ocean Background	4	3.9	- 2.5	—	—	—
14.0	14	13.9	- 0.7	10	4.2	2.00
16.0	24	22.4	- 6.7	20	6.2	2.96
13.0	9	10.7	+18.9	5	3.2	1.53
13.0	10	10.7	- 7.0	6	3.2	1.53
13.8	11	13.2	+20.0	7	4.0	1.91
22.6 Acid-Iron	100 ±	76.6	-23.4	—	12.8	6.10
			av = 11.3%			

The following empirical relationship was found to describe the data:

$$C = 0.00116\ D^{3.55953}$$

where C = mg/ℓ suspended solids
D = data value (grey level) MSS5

Table 10 presents a comparison of measured versus calculated values.

Using a typical standard deviation of 0.7 data values (calculated from the mean of approximately 100 data points for each target area), calculations indicate a measurement capability of ±3.5 mg/ℓ at a data value (grey level) of 12. This measurement capability applies to near-surface concentrations, integrated over approximately Secchi Disk depth. In view of the fact that particle size and background conditions are factors in the resulting spectral response, the foregoing results apply only to this study location.

Also included in Table 10 are the reflectance differences between the "ocean background" and other targets in the scene. These values were calculated by subtracting the data value for "ocean background" from all other points and converting the differences into reflectance differences using field-measured irradiance data and calculated radiances. The latter were calculated using conversion factors published in the ERTS Handbook [9]. The results represent the difference in radiance and bulk volume reflectance between the ocean area selected as the "benchmark" and other points in the scene, and show a substantial reflectance difference between the acid-iron waste and other targets.

A three-channel signature can be used to differentiate the acid-iron waste from other substances in the scene. As indicated in the earlier discussion, the observed spectral response is largely due to scattering by particulates in a spectral region where the scattering coefficient of water is low. Additionally, in the case of oxidized acid-iron waste the color component tends to increase the reflectance in MSS5 relative to MSS4 and MSS6. These characteristics are evident in Table 11. A decision-boundary based on the use of spectral ratios can be used to separate the waste from other water masses in the scene.

5.2.2 SUMMARY

Acid-iron waste has been observed in all clear ERTS frames of the study area. Due to particle scattering and color of the waste, MSS5 (0.6-0.7 μm) is suitable for the detection of the waste. Ratios of spectral bands are useful for differentiating the waste from other substances in the scene.

A relationship between data level (grey level) as recorded on ERTS CCT's and suspended-solids concentration has been noted. Due to noise in the system, a variability in the data of ±3.5 mg/ℓ was determined. Noise along a scan line of one data value appears to be typical.

TABLE 11. RATIOS OF SPECTRAL BANDS, NEW YORK BIGHT

	MSS5/MSS4	MSS5/MSS6	MSS5/MSS4	MSS5/MSS6
Acid-Iron Waste	0.63	2.57	0.71	2.81
Sewage-Sludge Area	0.53	2.02	0.52	2.04
Lower Bay	0.53	1.86	0.54	2.06
Ocean Background	0.44	1.94	0.49	1.84
	16 August 1972		7 April 1973	

Smoothing of the data by averaging over selected target areas was used to arrive at more representative values.

5.3 TAMPA BAY

ERTS imagery of the study area was screened. Several frames were considered suitable for the purposes of this investigation and were selected for digital processing. The following ERTS frames were used in subsequent analysis: E 1099-15284 (30 October 1972), E 1117-15285 (17 November 1972), and E 1208-15345 (16 February 1973). The Tampa Bay area on the above dates is shown in Figures 28-30.

Interesting data is largely contained in MSS5 and MSS6, although under favorable conditions MSS4 does provide useful information. During periods of high humidity, which is generally the case in the summer months at this location, the utility of MSS4 is severely limited due to atmospheric attenuation.

Water quality data were collected at the locations shown in Figure 31. Data collected on 16 February 1973 are tabulated in Table 12. The data indicate that turbidity levels, phosphorus, and chlorophyll a concentrations are relatively high in the Hillsborough arm of the Bay.

A color digital map of Tampa Bay was produced using MSS5, to display turbidity differences in the scene. The results are shown in Figure 32. The differences in turbidity levels (and suspended solids) as shown also serve to delineate the movement of water masses. The red plume near the center of the Bay was produced by dredging operations in the shipping channel. Dredging operations are also evident in the 30 October 1972 data.

Tampa Bay is relatively shallow. As a consequence, data analysis was restricted to locations where bottom reflectance was not a factor. Secchi Disk transparency readings during the study period ranged between 0.82 m and 3.26 m. The corresponding attenuation coefficients in the green band were 1.96 m^{-1} and 0.49 m^{-1}. Extrapolating these values to the red band and calculating the depth at which incident light is attenuated to 1%, yielded values of 1.43 m and 4.6 m respectively. In the Hillsborough arm of the Bay, Secchi Disk transparency values of 1 m are typical. In this area no signal return can be expected from the bottom, in the red band, at locations where water depth exceeds approximately 2 m. At other locations in the Bay, the controlling water depth was 4 to 5 m.

Because of the water-depth limitation and the added difficulties of sampling in a tidal area, subsequent analysis to further investigate the ERTS chlorophyll measurement potential was limited to four key stations in the area, plus the dredging operation.

Using the procedures described in previous sections of this report, data value means and standard deviations were calculated for the selected target areas. The results are tabulated

FIGURE 28. TAMPA BAY, 30 OCTOBER 1972. MSS5

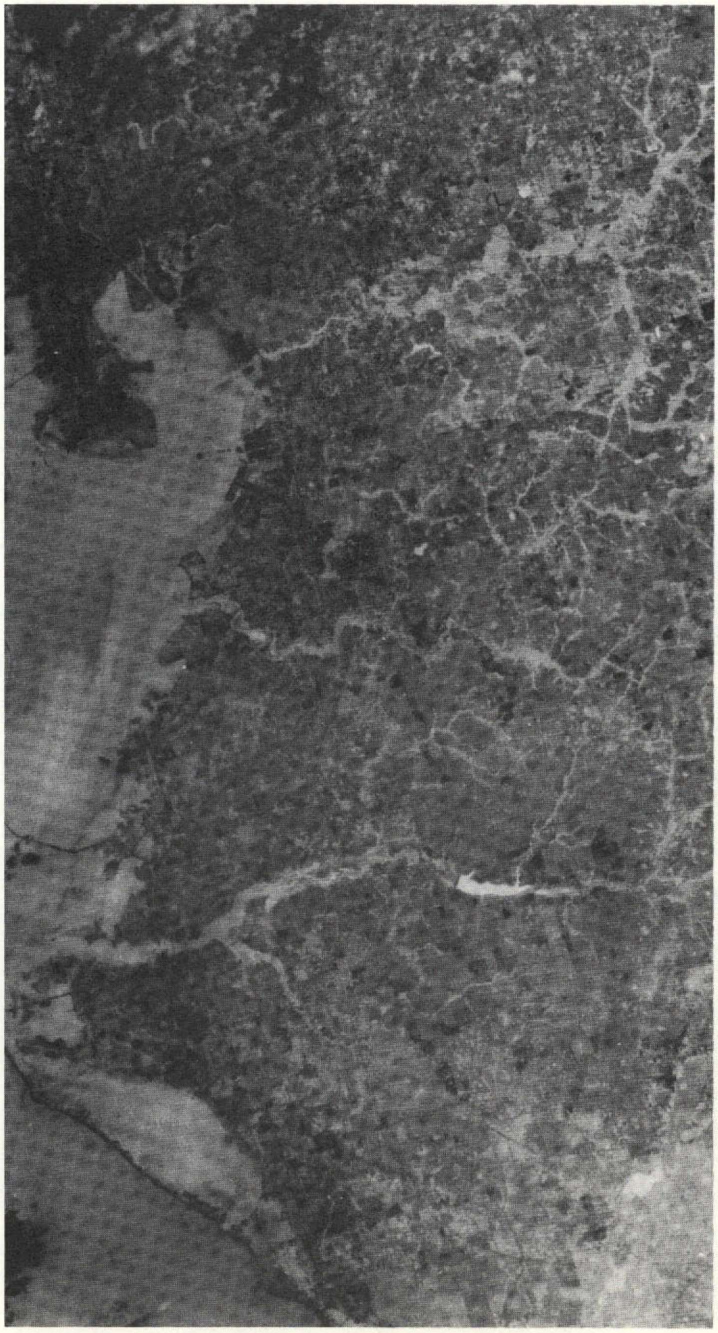


FIGURE 29. TAMPA BAY, 17 NOVEMBER 1972. MSS 5
(Negative print)

FIGURE 30. TAMPA BAY, 16 FEBRUARY 1973. MSS5

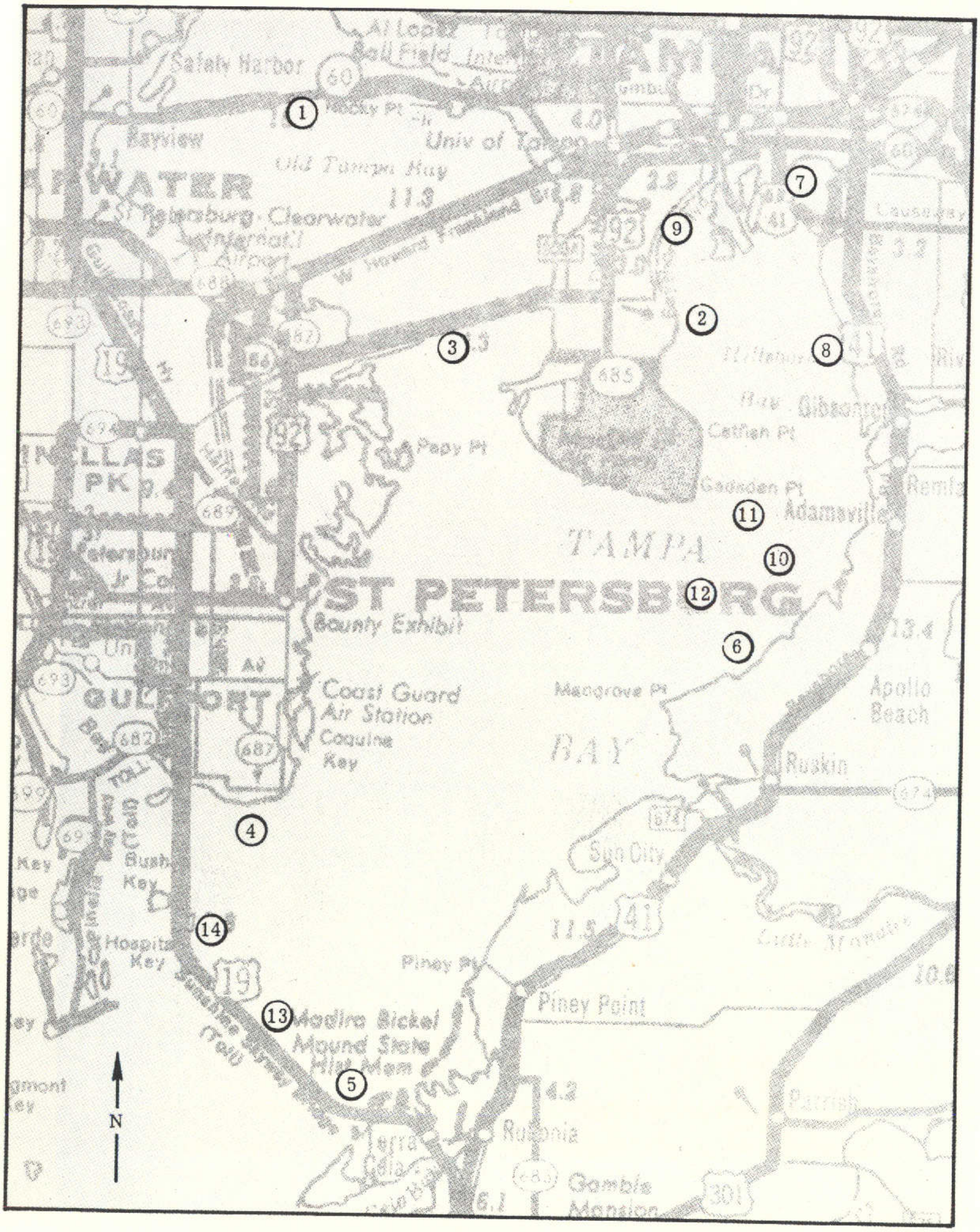


FIGURE 31. LOCATION OF SAMPLING STATIONS, TAMPA BAY

FIGURE 32. TAMPA BAY, 17 NOVEMBER 1972. ERTS-1 Data, E-1117-15285-5.

TABLE 12. WATER QUALITY DATA, TAMPA BAY

(a) Station 1, Courtney Campbell, 16 February 1973

Temperature =	16°C
Forel Ule Color =	XIII
Turbidity =	4.2 FTU
Suspended solids =	18.0 mg/ℓ
Dissolved solids =	26.0 gm/ℓ
Salinity 0/00 =	22
Chlorophyll "a" =	3.5 mg/m^3
PO_4 =	2.4 mg/ℓ
NO_3 - N =	<0.1 mg/ℓ
Coliforms =	800/100 mℓ
Secchi disk (50 cm):	white = — black = —

(b) Station 2, Ballast Pt., 16 February 1973

Temperature =	18°C
Forel Ule Color =	XVII
Turbidity =	6.2 FTU
Suspended solids =	31 mg/ℓ
Dissolved solids =	22 gm/ℓ
Salinity 0/00 =	21.5
Chlorophyll "a" =	13 mg/m^3
PO_4 =	4.6 mg/ℓ
NO_3 - N =	<0.1 mg/ℓ
Coliforms =	2000/100 mℓ
Secchi disk (50 cm):	white = 0.82 m black = 0.46 m

TABLE 12. WATER QUALITY DATA, TAMPA BAY (Continued)

(c) Station 3, Gandy Bridge, 16 February 1973

Temperature =	17°C
Forel Ule Color =	X
Turbidity =	3.0 FTU
Suspended solids =	18.0 mg/ℓ
Dissolved solids =	29.5 gm/ℓ
Salinity 0/00 =	25
Chlorophyll "a" =	5 mg/m^3
PO_4 =	2.6 mg/ℓ
NO_3 - N =	<0.1 mg/ℓ
Coliforms =	1000/100 mℓ
Secchi disk (50 cm):	white = 3.26 m black = 1.83 m

(d) Station 4, Pinellas Pt., 16 February 1973

Temperature =	17°C
Forel Ule Color	X
Turbidity =	3.8 FTU
Suspended solids =	12.7 mg/ℓ
Dissolved solids =	31.3 gm/ℓ
Salinity 0/00 =	28
Chlorophyll "a" =	—
PO_4 =	1.6 mg/ℓ
NO_3 - N =	<0.1 mg/ℓ
Coliforms =	500/100 mℓ
Secchi disk (50 cm):	white = — black = —

TABLE 12. WATER QUALITY DATA, TAMPA BAY (Continued)

(e) Station 5, Sunshine Skyway E., 16 February 1973

Temperature =	17°C
Forel Ule Color =	XII
Turbidity =	4.3 FTU
Suspended solids =	18.8 mg/ℓ
Dissolved solids =	33.4 gm/ℓ
Salinity 0/00 =	28
Chlorophyl "a" =	1.8 mg/m^3
PO_4 =	1.35 mg/ℓ
NO_3 - N =	trace
Coliforms =	—
Secchi disk (50 cm):	white = 3.96 m black = 1.83 m

(f) Station 6, Apollo Beach, 16 February 1973

Temperature =	19°C
Forel Ule Color =	XVI
Turbidity =	7.0 FTU
Suspended solids =	27.7 mg/ℓ
Dissolved solids =	27.1 gm/ℓ
Salinity 0/00 =	24
Chlorophyll "a" =	3 mg/m^3
PO_4 =	4.4 mg/ℓ
NO_3 - N =	0.1 mg/ℓ
Coliforms =	1000/100 mℓ
Secchi disk (50 cm):	white = 1.04 m black = 0.55 m

TABLE 12. WATER QUALITY DATA, TAMPA BAY (Continued)

(g) Station 7, McKay Bay, 16 February 1973

Temperature =	18°C
Forel Ule Color =	XVII
Turbidity =	7.0 FTU
Suspended solids =	28.2 mg/ℓ
Dissolved solids =	23.6 gm/ℓ
Salinity 0/00 =	22
Chlorophyll "a" =	—
PO_4 =	5.0 mg/ℓ
NO_3 - N =	0.1 mg/ℓ
Coliforms =	3000/100 mℓ
Secchi disk (50 cm):	white = 0.91 m black = 0.46 m

(h) Station 8, Alafia River, 16 February 1973

Temperature =	18°C
Forel Ule Color =	XVII
Turbidity =	6.3 FTU
Suspended solids =	17.8 mg/ℓ
Dissolved solids =	13.3 gm/ℓ
Salinity 0/00 =	13.5
Chlorophyll "a" =	—
PO_4 =	17.5 mg/ℓ
NO_3 - N =	0.1 mg/ℓ
Coliforms =	500/100 mℓ
Secchi disk (50 cm):	white = 0.91 m black = 0.46 m

TABLE 12. WATER QUALITY DATA, TAMPA BAY

(i) Station 9, Davis Island, 16 February 1973

Temperature =	16°C
Forel Ule Color =	XVI
Turbidity =	4.3 FTU
Suspended solids =	17.0 mg/ℓ
Dissolved solids =	18.0 gm/ℓ
Salinity 0/00 =	16
Chlorophyll "a" =	32.8 mg/m^3
PO_4 =	3.7 mg/ℓ
NO_3 - N =	0.1 mg/ℓ
Coliforms =	1000/100 mℓ
Secchi disk (50 cm):	white = — black = —

(j) Station 10, 16 February 1973

Temperature =	18°C
Forel Ule Color =	XVII
Turbidity =	6.7 FTU
Suspended solids =	24.6 mg/ℓ
Dissolved solids =	25.6 gm/ℓ
Salinity 0/00 =	23
Chlorophyll "a" =	—
PO_4 =	5.0 mg/ℓ
NO_3 - N =	0.1 mg/ℓ
Coliforms =	—
Secchi disk (50 cm):	white = 1.00 m black = 0.58 m

TABLE 12. WATER QUALITY DATA, TAMPA BAY (Continued)

(k) Station 11, 16 February 1973

Temperature =	18°C
Forel Ule Color =	XVII
Turbidity =	9.3 FTU
Suspended solids =	34.4 mg/ℓ
Dissolved solids =	24.9 gm/ℓ
Salinity 0/00 =	21
Chlorophyll "a" =	—
PO_4 =	5.0 mg/ℓ
NO_3 - N =	0.1 mg/ℓ
Coliforms =	—
Secchi disk (50 cm):	white = 0.76 m black = 0.46 m

(l) Station 12, 16 February 1973

Temperature =	15°C
Forel Ule Color =	XVII
Turbidity =	5.8 FTU
Suspended solids =	24.8 mg/ℓ
Dissolved solids =	26.7 gm/ℓ
Salinity 0/00 =	24.5
Chlorophyll "a" =	—
PO_4 =	—
NO_3 - N =	—
Coliforms =	—
Secchi disk (50 cm):	white = 1.43 m black = 0.76 m

TABLE 12. WATER QUALITY DATA, TAMPA BAY (Concluded)

(m) Station 13, Sunshine Skyway (Center), 16 February 1973

Temperature =	17°C
Forel Ule Color =	XII
Turbidity =	6.2 FTU
Suspended solids =	26.2 mg/ℓ
Dissolved solids =	33.8 gm/ℓ
Salinity 0/00 =	—
Chlorophyll "a" =	1.8 mg/ℓ
PO_4 =	1.0 mg/ℓ
NO_3 - N =	trace
Coliforms =	—
Secchi disk (50 cm):	white = — black = —

(n) Station 14, Sunshine Skyway (West), 16 February 1973

Temperature =	17°C
Forel Ule Color =	XII
Turbidity =	5.7 FTU
Suspended solids =	22.4 mg/ℓ
Dissolved solids =	34.2 gm/ℓ
Salinity 0/00 =	—
Chlorophyll "a" =	—
PO_4 =	1.0 mg/ℓ
NO_3 - N =	trace
Coliforms =	—
Secchi disk (50 cm):	white = — black = —

in Table 13. The number of points used in the calculations ranged from 19 to 275 depending on the size of the target.

A ratio of MSS6/MSS5, both unadjusted values and values adjusted by using Station 13 as a baseline, confirm the previously described observations regarding phytoplankton bloom detection and chlorophyll measurement in productive areas. Lowest ratios were obtained in the dredging plume (high inorganics, low chlorophyll) and highest values in Hillsborough Bay (most productive area) at Station 2. Results are presented in Table 14. These relationships are most evident in the adjusted data. The lack of other good stations in the Bay and the relatively high standard deviations in MSS6 prevented investigation of the quantitative relationships involved.

5.4 OTHER RESULTS AND OBSERVATIONS

5.4.1 LAKE MICHIGAN

A description of the physical factors involved in the dispersal of conservative pollutants in the Great Lakes has been presented by Csanady [10], Gedney and Lick [11], and on a more limited basis by several other investigators. Csanady used the term "coastal jet" to describe the coastal currents which develop near the shore with directions parallel to it. From a water quality viewpoint, the significance of "coastal jet" development is that effluents discharged near shore will be transported along it, often for considerable distances. The phenomenon of coastal entrapment is further enhanced during the springtime development of the "thermal bar" [12].

These physical processes were well described in the literature prior to the launch of ERTS-1. However, the availability of ERTS serves to document them and could be of aid in the placement of water intakes and sewer outfalls. The phenomenon of coastal entrapment is evident in Figures 33 and 34. Figure 34 provides evidence of the transport of discharges from the highly industrial Burns Harbor area into Michigan waters.

A "milky-water" phenomenon in Lake Michigan has been reported by many investigators in recent years. The phenomenon is believed to be due to calcium carbonate precipitation resulting from pH shifts induced by phytoplankton [13]. The ERTS view of Lake Michigan on 21 August 1973 (Figure 35) shows an increased reflectance in MSS4 (0.5-0.6 μm) which may be due to this phenomenon. The results are not as evident in MSS5, indicating that the suspension is not a surface or near-surface phenomenon.

5.4.2 S. E. FLORIDA - OCEAN OUTFALLS

Data for the coastal strip from Palm Beach to Miami Beach were examined. Numerous ocean outfalls discharge partially treated or untreated effluent into the marine environment in this region at locations from approximately 1 to 2 miles from shore.

TABLE 13. SIGNATURE DATA, TAMPA BAY

30 October 1972 E 1099-15284				17 November 1972 E 1117-15285				16 February 1973 E 1208-15345			
Station*	Channel	Data Value Mean	Standard Deviation	Station*	Channel	Data Value Mean	Standard Deviation	Station*	Channel	Data Value Mean	Standard Deviation
3	1	21.28	0.61	3	1	26.22	0.71	3	1	21.56	1.09
	2	10.94	0.63		2	14.45	0.54		2	11.83	0.82
	3	5.39	0.90		3	8.02	1.15		3	6.77	0.82
	4	0.72	0.45		4	1.47	0.57		4	1.39	0.54
2	1	23.80	1.28	2	1	25.57	0.95	2	1	20.63	0.68
	2	13.77	0.55		2	14.70	0.63		2	12.37	0.65
	3	7.91	0.92		3	8.91	1.04		3	7.23	0.97
	4	1.11	0.63		4	1.70	0.70		4	1.34	0.51
12	1	24.20	0.89	12	1	26.57	0.62	12	1	21.73	0.97
	2	13.16	0.82		2	15.45	0.53		2	13.09	0.74
	3	6.44	0.89		3	8.54	0.92		3	7.26	0.83
	4	0.76	0.57		4	1.30	0.59		4	1.34	0.56
13	1	20.87	0.86	13	1	24.49	1.25	13	1	22.10	1.06
	2	8.80	0.41		2	12.73	0.64		2	11.18	0.74
	3	3.93	0.78		3	7.11	0.89		3	6.21	0.90
	4	0.33	—		4	1.40	0.55		4	1.24	0.57
Dredge	1	35.36	1.73	Dredge	1	34.63	1.54				
	2	18.96	1.71		2	21.53	1.02				
	3	7.04	0.92		3	9.58	1.12				
	4	0.68	0.55		4	1.79	0.42				

*Station numbers refer to Figure 31.

TABLE 14. TAMPA BAY RATIOS MSS6/MSS5

UNCORRECTED DATA

Station	30 October 1972	17 November 1972	16 February 1973
3	0.493	0.555	0.572
2	0.574	0.606	0.584
12	0.489	0.553	0.554
13	0.447	0.559	0.555
Dredge	0.371	0.445	—

ADJUSTED DATA*

Station	30 October 1972	17 November 1972	16 February 1973
3	0.682	0.529	0.862
2	0.800	0.913	0.857
12	0.576	0.526	0.550
13	—	—	—
Dredge	0.306	0.281	—

*Station 13 used as baseline.

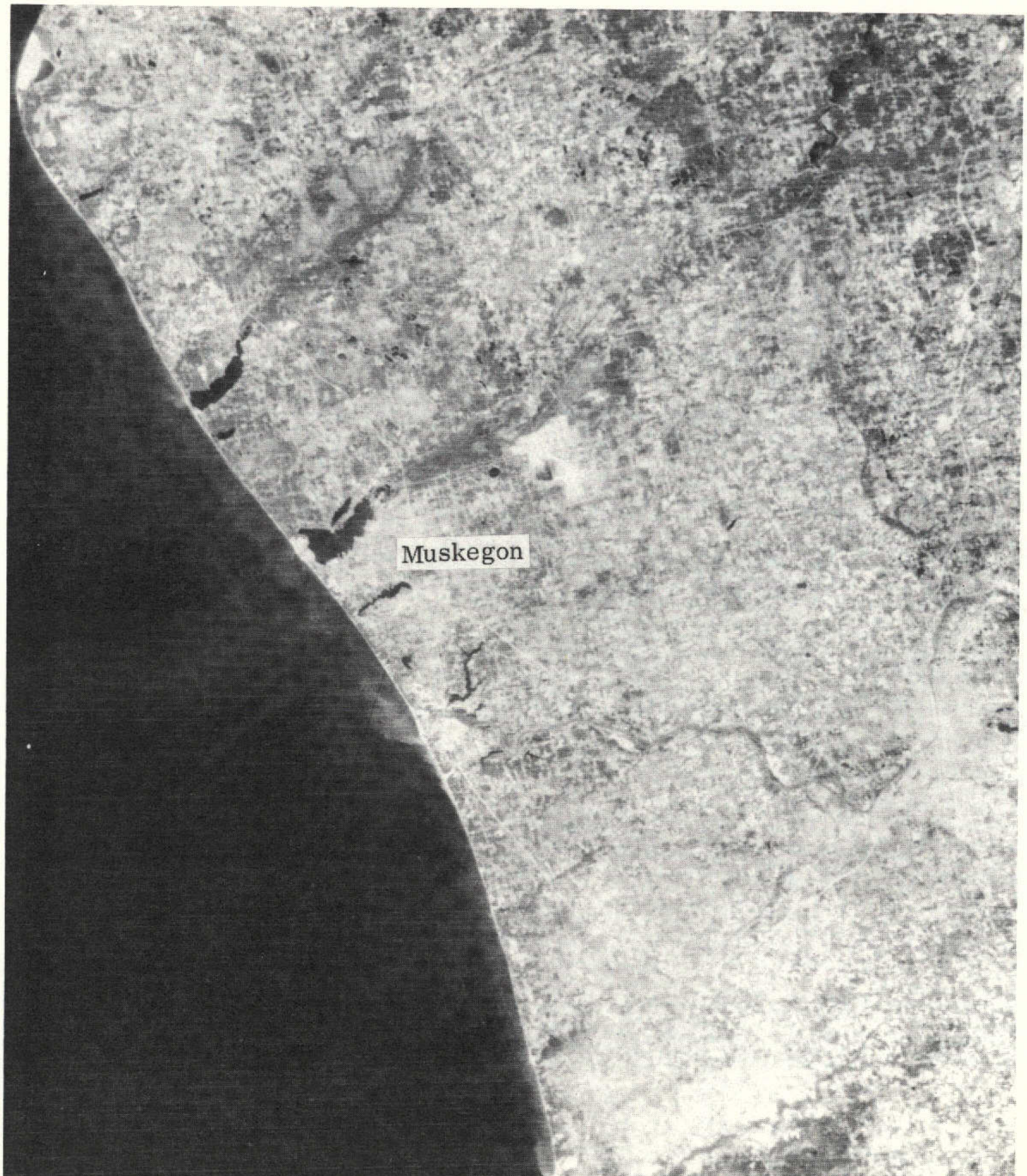


FIGURE 33. LAKE MICHIGAN SHORELINE, 9 JUNE 1973.
ERTS-1, MSS4 (0.5-0.6 μm), E-1321-15584

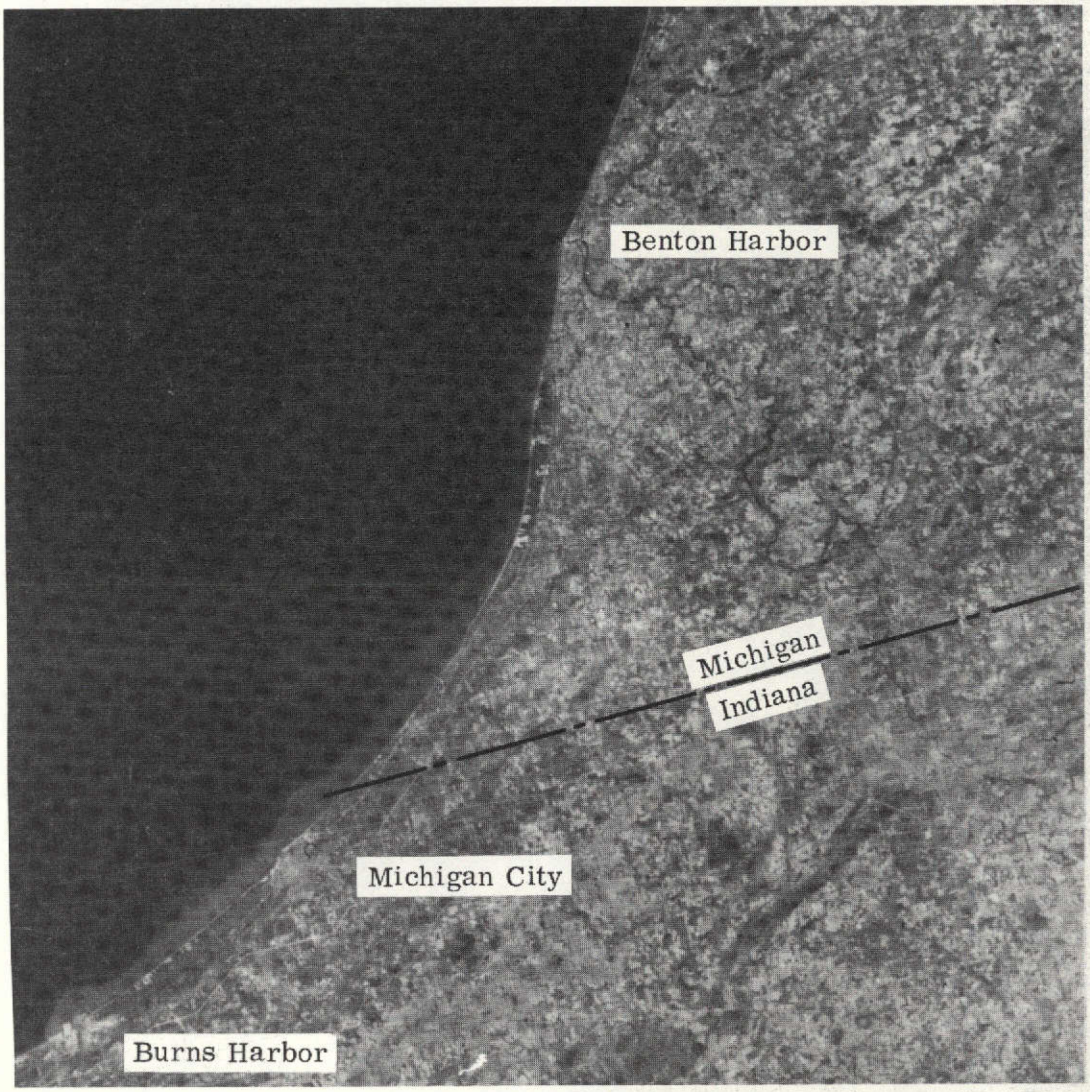


FIGURE 34. LAKE MICHIGAN, MICHIGAN-INDIANA BOUNDARY AREA, 9 JUNE 1973. ERTS-1, MSS4 (0.5-0.6 μm), E-1321-15590

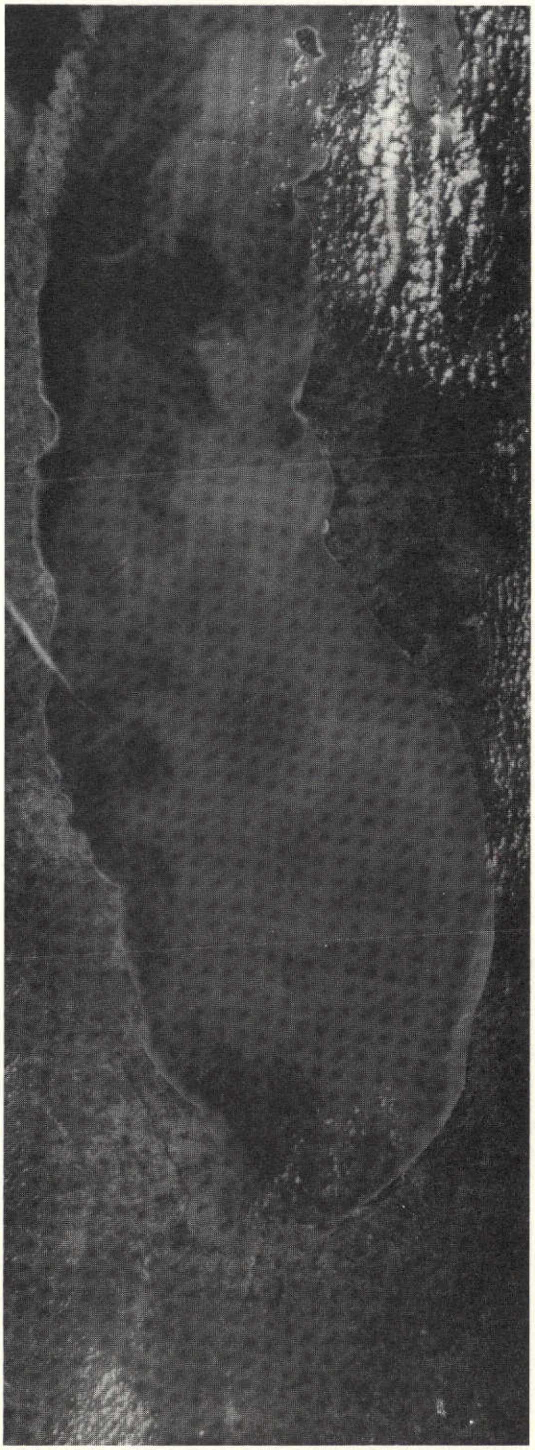


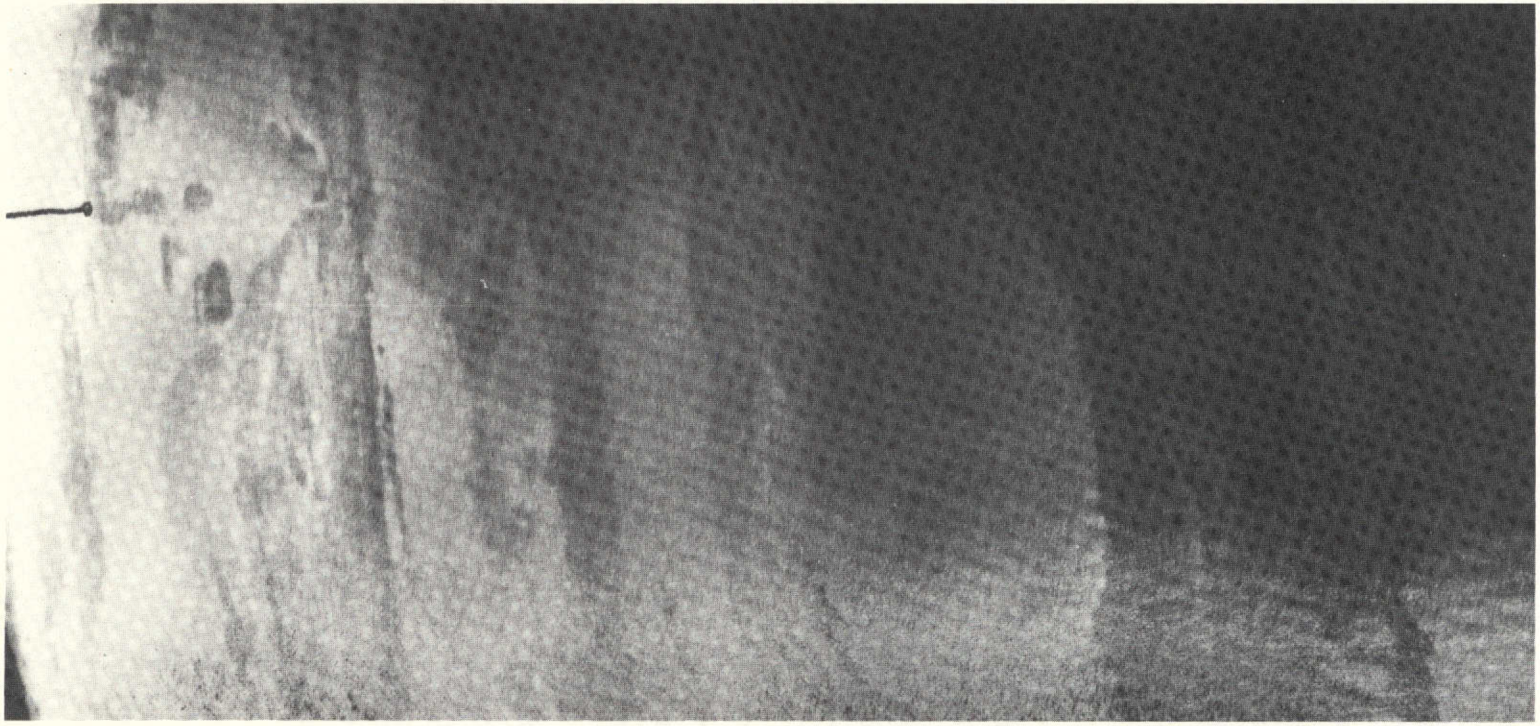
FIGURE 35. LAKE MICHIGAN, 21 AUGUST 1973.
ERTS-1, MSS4 (0.5-0.6 μm), E-1394-16030

Detailed plans and preparations were made to support the ERTS data collection program. Two missions were carried out by the ERIM multispectral aircraft, on 18 August and 16 November 1972. Both missions took place at a time coincident with the scheduled ERTS pass over the area. While each mission was productive, the second was far more effective in terms of data acquisition useful in this investigation. This is due in part to seasonal factors such as humidity, water temperature (density differences) etc. and in part to favorable tides, calm sea state, and excellent atmospheric conditions. As a result, an excellent aircraft data set was obtained.

The situation with regard to ocean disposal of wastes in the region is typified by the case at Pompano Beach. Partially treated sewage is discharged at a location 2,256 m from shore. When the sea is calm the sewage "boils" to the surface; its subsequent dispersion depends on sea state and local currents. The situation observed on 16 November 1972 is illustrated in Figure 36. During an ebb tide, water from the Hillsborough Inlet usually moves south as a littoral current. On 16 November 1972 the leading edge of this current was located very near the sewage field.

ERTS imagery of the study area was screened and found to be unsatisfactory for the purposes of this phase of the investigation. Because of the small size of the sewage fields at this location and the relatively subtle spectral changes produced, satellite data collected under ideal conditions was required. On at least one occasion, ERTS data were not collected over the area although field and atmospheric conditions were excellent. On 16 November 1972, atmospheric conditions were ideal: no cloud cover, low humidity, favorable tides, calm sea, sewage "boils" in evidence, and "red tide" in the area. Unfortunately, ERTS data collection on this particular orbit was terminated one frame north of the study area.

ERTS imagery of the Southern California coast was also screened for the detection of effluent fields from ocean outfalls. Unlike those in S. E. Florida, the outfalls in California are well designed, discharge at much greater depths, and include diffusers to provide mixing. It appears that because of good mixing and thermal stratification, surfacing is a rare event. Additionally, wastewater in Southern California is given at least primary treatment and hence is not as readily observable.



Sewage Effluent

FIGURE 36. POMPANO BEACH OUTFALL, 16 NOVEMBER 1972.

Altitude 2,000 ft

$$\text{Ratio} = \frac{0.50\text{-}0.54\ \mu m}{0.41\text{-}0.48\ \mu m}$$

6
CONCLUSIONS

The investigation demonstrates that major color and turbidity differences are detectable through an analysis of ERTS-1 data. The results indicate that this capability can be applied to the study of specific events such as ocean dumping of wastes, physical limnology of large lakes, and large-scale pollution investigations. However, the coarse spatial resolution of the system (0.45 ha) and the low signal-to-noise ratio limit the applications to large-scale and relatively high-contrast study situations.

Water quality analysis does not lend itself to simple analytical procedures. The four broad bands in the spectral range 0.5 - 1.1 μm offer a limited water quality measurements potential which is essentially restricted to suspended-solids and turbidity measurement, and the detection of phytoplankton blooms. Correlations of ERTS data with other substances in aqueous suspension are essentially suspended-solids measurements. The detection of oil pollution was not investigated in this program.

From a quantitative standpoint, the results indicate a relationship between signal level in MSS5 and the near-surface suspended-solids concentration and/or turbidity units (JTU). Due to system noise and differences between detectors, some form of averaging or smoothing over selected target areas is essential. The target areas must be large and essentially homogeneous. Subject to these conditions, the deviations between field measurements and calculated values (ERTS data) for suspended solids and turbidity were found to be 13.0% and 13.3% respectively, for the concentration range of 20 to 80 mg/ℓ suspended solids. At lower concentrations the deviations are very high.

The ratio MSS6/MSS5 is useful for the detection of phytoplankton blooms or mats. An increase in signal level in MSS6 relative to MSS5 (and an increase in MSS4 relative to MSS5) is characteristic of a plankton bloom. Because of instrumental constraints, the above technique is restricted to high phytoplankton (chlorophyll) concentrations.

As a pioneering effort, ERTS-1 has demonstrated, to a very modest degree, the potential role of satellite remote sensing for environmental monitoring. Future satellites, with advanced instrumentation, can fill an important gap in the monitoring of large environmental systems.

7
RECOMMENDATIONS

Instrumental improvements in terms of spatial resolution, spectral bands, and particularly signal-to-noise ratio are obvious requirements for future unmanned satellite systems intended, in part, for monitoring the aquatic environment. With respect to ERTS-1 and its successor ERTS-B, it is recommended that work dealing with suspended solids and turbidity measurement be continued.

C-16

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