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Landsat Estuarine Water Quality Assessment of Silviculture and Dredging Activities

LANDSAT ESTUARINE WATER QUALITY ASSESSMENT OF SILVICULTURE AND DREDGING ACTIVITIES

by

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FOREWORD

Protection of the environment requires effective regulatory actions based on sound technical and scientific data. The data must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of exposure to specific pollutants in the environment requires a total systems approach that transcends the media of air, water, and land. The Environmental Monitoring Systems Laboratory at Las Vegas contributes to the formation and enhancement of a sound monitoring-data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment

- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report describes the application of Landsat multispectral scanning to estuarine water quality with specific reference to dredging and silviculture practices. The synoptic view, orbital characteristics, and remote sensors of Landsat make it a valuable tool for the assessment and monitoring of environmental quality parameters in and around estuaries.

Environmental Monitoring Systems Laboratory
Las Vegas

ABSTRACT

The objective of this project was to define and demonstrate the role of Landsat multispectral scanner (MSS) data in monitoring environmental impact in estuaries and their associated drainage basins. Florida State University (FSU) has been collecting water quality data from Apalachicola Bay, Florida (East Bay in particular) almost biweekly since 1972. Landsat-1 was launched in 1972, thereby creating an invaluable and almost irreplaceable data base for correlative land-use/water quality investigations.

Landsat-1 data were examined to determine their use in detecting and delineating temporal distributions of water color and land-use categories in the bay system. Water color distributions were easily discriminated. Landsat data were successfully used to monitor the effects of man-made and natural structures (i.e., holes in barrier islands, channels, islands (bridges), and oyster bars) on the hydrodynamics of the bay. The distributions of water types (i.e., acidic swamp/forest runoff (a form of nonpoint source pollution), turbid river water, clear Gulf water) were monitored under numerous environmental conditions. Land-use categories, with an emphasis on silviculture activities (i.e., clear-cutting, pine plantations, swamp/forest communities) were also detected and delineated. The primary source of nonpoint source pollution in East Bay appears to be the lumber industry.

Trends in Landsat derived land-use activities followed trends in the improvement (recovery) of water quality in East Bay. The collection of tandem surface truth data would have greatly improved the quantitative aspects of this project. The use of Landsat data proved to be a more accurate method to monitor water color distributions and associated water patterns than the presently accepted traditional water sampling schemes. However, the most accurate presentation of water patterns would be derived if tandem water quality samples were required at the same time as the satellite overpass. These water quality data could be used as calibration points during the classification stages of the Landsat imagery.

The information derived from this research is being used by the University of Florida in the planning stages of their water quality sampling program and will eventually be used to help construct and validate hydrodynamic models of the East Bay drainage basin and Apalachicola Bay. The transfer of this technology to other estuaries around the nation (i.e., Lake Pontchartrain, Louisiana and the Chesapeake Bay, Maryland) should be encouraged.

This report covers the period from July 1, 1977 to July 21, 1978, when the project was completed.

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FIGURES (Continued)

FIGURES (Continued)

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LIST OF ABBREVIATIONS AND SYMBOLS

ACSC	Area of Critical State Concern
APHA	American Public Health Association
ASP	American Society of Photogrammetry
CCT	Computer Compatible Tape
cfs	cubic feet per second
CPU	Cobalt Platinum Units
DAS	Data Analysis System
DCS	Data Collection System
DRI	Developments of Regional Impact
EEL	Environmentally Endangered Lands
EPA	Environmental Protection Agency
FSU	Florida State University
FWPCA	Federal Water Pollution Control Act
Ha	hectares
ID	Identification
IPA	Interagency Personnel Act
JTU	Jackson Turbidity Units
m	meters
m^3/s	cubic meters per second
mg/l	milligrams per liter
MPN	Most Probable Number
MSS	Multispectral Scanner
N	North
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
nm	nanometers
NPS	Nonpoint Source Pollution
RBV	Return Beam Vidicon
UF	University of Florida
µg/l	micrograms per liter
USGS	United States Geological Survey
USPHS	United States Public Health Service
UTM	Universal Transverse Mercator
W	West
o/oo	parts per thousand

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SECTION 1

INTRODUCTION

Estuaries are an extremely valuable natural resource of national importance. Modified from Pritchard (1967), an estuary "is a semi-enclosed coastal body of water which has a free connection with the open sea; it is thus strongly affected by tidal action, and within it sea water is mixed (and usually measurably diluted) with fresh water from land drainage" (Odum 1971). Odum (1971) further states that estuaries are thought of as being transition zones between fresh and marine habitats, but many of their most important physical and biological attributes are not transitional, but unique. The uses and abuses of estuarine systems by man need to be understood, monitored, and wisely managed. Estuaries serve as nursery grounds for they provide protection and abundant food. The preservation of estuaries could thusly be justified solely on the basis of the numerous commercial and sport fisheries that exist, at least during portions of their life cycles, in these areas. Man is encroaching on those systems that are generally more productive than either the fresh-water drainage or the sea (Odum 1971).

The multiple use effects of human beings in most cases inevitably decrease the water quality along the coastal zone. Due to unsupervised development, prime estuaries have been destroyed and closed due to potential health hazards. There is no doubt that human interaction and settlement has generally focused near estuaries. Pollution related to urbanization, sewage, sedimentation, thermal and chemical contamination, construction changes resulting in hydrodynamic modification (i.e., bulkheading, dredging, filling), and land-use (watershed) activities generating nonpoint sources of pollution are present in and around the coastal zone. Estuaries can no longer be considered as a sump for societies' wastes. The "pressure" is on the nation's estuaries and, as the impact spreads, the repercussions increase. The added rapid and apparently unending increase in a search for energy sources will also continue to impact the estuaries. Rarely is any consideration made as to what gives present day man the right to deny the beauties and benefits of estuaries to future generations.

Institutions and agencies involved in the study and management of the nation's coastal zone are faced with a large-scale monitoring problem. The decline in quantity and quality of estuarine resources necessitates the development of best management practices for these resources. Scientists and management need timely, accurate inventories of impacts on the estuarine environment. These data have been traditionally collected through more time consuming, expensive and often inaccurate traditional sampling procedures, primarily field crews in boats and on land. Under present funding and staffing levels, it is impossible to rapidly and accurately monitor and access large coastal areas. Remote sensing techniques can often be applied to the needs of large scale monitoring programs in coastal environments. Remote sensing techniques offer many advantages over traditional sampling methods. These advantages include a synoptic view; an expansion of the spectral range and resolution of the human eye; a permanent and instantaneous record of a particular point in time; a quantitative capability to determine size, shape, and position of objects due to the precise geometry and digitization of some images; a near real-time capability; and an inexpensive monitoring technique by comparison with more traditional sampling schemes.

The objectives of this research program were to (1) evaluate the capability of Landsat multispectral scanner data to monitor water color distributions, which in turn can also represent baseline coastal environmental data, (2) identify and acquire temporal land-use information, with an emphasis on forest management practices, which have a high probability of being related to the amount and distribution of nonpoint source runoff and associated water quality in a bay system, (3) determine if there is a relationship between land use and water quality in the bay system, and (4) recommend how the results of this study can be applied to aid various local, state, and federal agencies in the development of monitoring programs leading to the establishment of best management practices, including predictive environmental modeling, for estuarine resources.

Not until the 1960's did Florida begin to realize that it had sacrificed many of its natural marine resources while developing coastal resources. Largely because of unsupervised development, many prime estuaries have either been destroyed due to siltation, pollution, or filling, or have been closed to the activities of man due to potential health hazards. Apalachicola Bay, Florida, being representative of lagoon type barrier island systems from Maine to Texas, was selected as the test site for this research. Apalachicola Bay, located in Florida's "panhandle," is one of the most pristine and economically valuable estuaries in the state. Biotic communities in and around the bay, having survived the rigors of centuries of variation in environmental parameters, are now being threatened. The primary land-use activity in the basin is silviculture. The major problems within the bay are related to transportation features such as bridges and related islands, intercoastal waterways, and cuts in barrier islands.

Starting in March of 1972, FSU conducted a project to determine important relationships between the Apalachicola River and the bay system for the purpose of utilizing this information as a basis for regional planning and resource management. The project was generated in response to numerous upland developments in the Apalachicola Drainage System. The project, under the direction of Dr. Robert J. Livingston (FSU), can be divided into two portions: (1) biological studies to determine certain fundamental trophic relationships of the bay system and its interaction with the river, and (2) an impact analysis to be made based on short- and long-term floristic and faunal changes in the bay. Landsat-1 was also launched in 1972, thereby creating an excellent data base to monitoring synoptic, temporal changes in land-use and water color distribution in the bay system. These two data bases also provide an excellent opportunity to compare the accuracy of data derived from traditional water-type distribution and land-use sampling procedures with that of Landsat-derived data.

SECTION 2

CONCLUSIONS

This research demonstrated that Landsat can provide temporal cause and effect information relating to land-use changes and water quality. Water types, based on water color, were easily discriminated at different times of the year and under varying environmental conditions (i.e., winds, tides, river stages).

Water patterns, which are nearly impossible to acquire under more traditional sampling schemes, were readily discerned. Inferences as to current direction, offshore water movements including reversals, location of gyres and areas of mixing, a real extent of river plumes, and the sources and dispersal sites of sediment and nonpoint source pollution (swamp and forest runoff) are possible. These patterns were also used to observe the effect of manmade structures, such as channels, islands and cuts in barrier islands, on current patterns in the bay. Commercial and sport fisheries could also use these seasonal Landsat images to effectively locate schools of fish under varying environmental conditions, if such data were ever available on a real-time basis.

Probably the greatest value of these Landsat-derived distributions of water classes is their use to obtain a seasonal overview of an area to be investigated. This would assist in the most advantageous placement of sampling stations, which would in turn provide the capability to correctly and more accurately extrapolate data spatially over large areas from a minimal number of sampling points. While only partially confirmed, apparent trends in land-use changes (forest resource management practices) and related water quality were obtained. In the past, ecologists have literally had the problem of "not being able to see the forest for the trees." Landsat, with its synoptic characteristics, is an excellent way to view an entire ecosystem. Regulatory and management agencies can use Landsat data to plan and initiate land-use management activities that best take bay communities into consideration. The water data can be used as a tool in the selection of the most environmentally beneficial sites for such facilities as drainage canals, pipelines channels, housing, industrial and recreational facilities, and power and sewage plants.

SECTION 3

RECOMMENDATIONS

Several recommendations are advanced. It is believed that a more accurate land-use classification could be achieved if the research had been finely tuned by using Landsat scenes that were closer together (i.e., 1 to 2 months apart). These additional scenes were not acquired due to a combination of funding and time limitations and an insufficient knowledge of the seasonal spectral signatures of target features at the start of the project. The acquisition of tandem aerial photographs and ground truth data at the time of a satellite overpass would also increase the classification of land-use practices.

Future Landsat-derived water color distributions would also be enhanced with the classification of additional Landsat scenes. More scenes would substantiate and even delineate more hydrodynamic features that exist in the bay under varying environmental conditions (i.e., tides, winds, river flow) that may have not been in effect during this investigation.

The major difficulty with respect to the identification of the same class in different scenes is the dynamic nature of the environment. Spectral signatures change with varying atmospheric conditions. Future Landsat investigations should include the acquisition of surface truth in the form of spectral signatures of specific land and/or water classes. This information could then be used to establish correction factors for such parameters as sea state, sun angle, and atmospheric haze. These parameters were not considered in this particular research effort, primarily because of computer software limitations. Several of these correction software packages exist at numerous digital data processing institutions around the country and should be acquired and incorporated into EPA's Digital Analysis System (DAS). The use of these correction factors in combination with ground truth samples collected at the time of the satellite overpass would greatly improve the quantitative accuracy of the Landsat classification of water types and land-use categories. Correlations between Landsat data and other water quality parameters (i.e., suspended solids, turbidity, pH, and dissolved oxygen) could also be evaluated using tandem water quality data and the above mentioned correction procedures. This research should also be expanded to derive correlations between basin land-use practices and water quality (nonpoint source pollution) in the neighboring estuary. This phase may be accomplished if Landsat-derived data can be incorporated into predictive environmental modeling schemes.

Since silviculture practices were easily identified and delineated, future studies should include the development of change detection algorithms -- that is to say, programs that will enable the investigator to quantify the amount of land-use change between various images.

These data could also be used to solve problems presently plaguing environmental modelers. It has not only been extremely difficult to acquire data as input to produce an accurate predictive enviromental quality model; most models are never verified. Landsat data are grided, synoptic, and instantaneous and are, therefore, amenable as input to both the initial development and final verification stages of so-called real-time water quality and hydrodynamic numerical models (Graham et al. 1978b). These land-use results for portions of the New River are being used by the University of Florida (UF) to calibrate an existing basin water quality model. Once the model is working, Landsat-derived land-use data from Tate's Hell Swamp could and should be used as input to the basin model, which will in turn run (drive) a hydraulic model of Apalachicola Bay.

UF is presently refining a hydrodynamic model of the Bay. These Landsat derived water color distributions should be used in two phases of this bay modeling effort. First, the water boundary information should be reformated and used as input data to refine and construct the model. Second, the model should be verified with the Landsat data. If the model were run for the same time as a satellite overpass, the model ouput and the Landsat-derived water color distributions could be scaled and overlayed for comparison purposes. If the two agree, the model is to a large degree verified. Landsat data have been used for models related to land use, but this is apparently the first attempt to use such data to verify a hydraulic model of an estuary. It is highly recommended that this particular phase of this research, namely model construction and verification, be continued.

Landsat has been demonstrated to be of use in the detection and quantification of possible causes and effects of large-scale environmental degradation in a coastal area. Once detected, higher resolution techniques (i.e., high resolution photography, ground truth teams) should be used to study particular aspects of the problem in greater detail. Lastly, since Apalachicola Bay is fairly representative of most lagoon type estauries along the entire Gulf and East Coasts of the United States, the use of Landsat can and should be extended to similar environmental areas around the nation. It is reasonable to assume that this technique could be used at least throughout the entire Southeast and most probably in areas along the East Coast (i.e., the Chesapeake Bay, Maryland).

SECTION 4

BACKGROUND

Just a little more than a century ago investigators interested in monitoring the earth's resources had to rely entirely upon direct on-the-ground observation to collect the desired information, (American Society of Photogrametry (ASP) 1975b). Managers of coastal resources, because of the difficult nature of the water medium, have often had to utilize hard to acquire and increasingly expensive ships to collect their data. Research vessels can cost $5,000 per day to operate. Other problems arise when water samples are collected over large areas. Because water is such a dynamic medium, it is often physically impossible to collect adequate water quality data in a sufficiently short period of time. When one ship is utilized to collect data, e.g., from a river plume entering an estuary, the cruise track followed often does not provide the necessary data needed to contour and study various water boundaries, because the sampling stations were located without a synoptic knowledge of the area being sampled. Coastal resource managers are continually looking for new techniques which can help them economically collect meaningful data.

Whether observed on the local, regional, national or global scale, the human demand on most of the earth's resources is rapidly depleating these resources both in terms of quantity and quality. The situation necessitates the development of best management practices for these resources. Management must be provided with timely, accurate inventories so that it will have an accurate up-to-date knowledge on the amount and quality of each resource within a particular geographic area of responsibility. Almost invariably such inventories can best be accomplished by the utilization of various remote sensing techniques (i.e., by obtaining photography and related data from aircraft and/or spacecraft during periodic overpasses) (ASP 1975b).

Remote Sensing is, as defined in the recent <u>Manual of Remote Sensing</u> (ASP 1975a),

> ...the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon under study, e.g. the utilization at a distance (as from aircraft, spacecraft or ship) of any device and its attendant display for gathering information pertinent to the environment, such as measurements of force fields, electromagnetic radiation, or acoustic energy.

Remote sensing systems, borne by satellites and aircraft offer investigators many advantages over traditional sampling procedures. The advantages as outlined by James and Shwartz (1972) include:

1. Synoptic overview. An observer on a ship or on the earth's surface is very limited in what he can see about the surrounding area. Satellite or aircraft acquired imagery enables the observer to increase his field of view to detect relevant features or conditions extending over hundreds of square kilometers.

2. Spectral range and resolution. These systems extend the spectral limitations of the human eye, which are normally about 400 to 700 nm.

3. Spatial resolution. Many remote sensors have a greater spatial resolution than the human eye. The human eye resolves approximately 5 lines per millimeter while images can often contain several hundred lines per millimeter.

4. Time record. Images provide an instantaneous record at a particular point in time. This particular advantage has a special value in the study of dynamic water systems.

5. Quantitative capability. These sensors are all energy sensors. The quantity of light reflected from the water surface is usually recorded in some manner. Whether it be computer sensor images, they can be quantitatively measured with such devices as computers or densitometers. The relatively precise geometry of most images (i.e., vertical aerial photographic and Landsat data permit the accurate determination of size, shape, and position of objects.

6. Digitization. The proper digitization of the data creates a grid which can often be incorporated into existing data bases. These data may then have potential as direct input to environmental quality models.

7. Near real-time capability. Near real-time images have been received onboard operational research vessels (Barker et al. 1975; Hill and Dillion 1976). This capability enables researchers to conserve valuable fuel and time by quickly locating the area of interest. Prevailing weather patterns surrounding the study area may also be readily observed and/or predicted.

8. Inexpensive. Once a reliable relationship has been established between the imagery and the surface truth, it is cheaper to acquire information from imagery as opposed to the alternative of expensive and time consuming field sampling teams and ships, especially when conducting seasonal, or long-term investigations.

Before conducting the most basic of remote sensing studies, the effects of varying atmospheric conditions on incoming solar radiate should be understood.

There are various regions of selective absorption which depend on the compositon of the air, primarily water vapor, carbon dioxide and ozone, and the particular wavelength of light. For wavelengths less than 290 nm, ozone and oxygen are responsible for absorbing ultraviolet radiation. Water vapor and carbon dioxide are primarily responsible for absorbing energy in the near infrared (Holter 1967). The atmospheric path length through which this energy must travel also affects its attenuation. James (1970) and Elterman and Toolin (1965) provide details on the subject of atmospheric attenuation.

Molecular scattering is of major importance under clear dry atmospheric conditions. The scattering by very small particles of molecular dimensions is inversely proprotional to the fourth power of the wavelength (Jensen 1968) and, therefore, affects shorter wavelengths more than longer ones. As particle sizes in the atmosphere increase, the wavelength of maximum scatter becomes less sensitive and extends beyond the blue and progresses into the green, yellow, and other regions of the spectrum (James 1970). As particles increase from molecular to aerosol size, the color of the sky changes toward a cloud white. For these reasons, the near infrared is less affected by atmospheric haze.

Once the sun's energy has passed through the atmosphere and reaches the surface of the water, two things happen (Figure 1). Some of the radiation is reflected (surface reflectance) and some is transmitted through the air-water interference, a portion of which is further refracted, transmitted, scattered, and/or absorbed in the water. If various constituents of water are to be investigated, that portion of scattered light which is directed upwards and which passes through the sea-air interface (volume reflectance) must be measured. Volume reflectance is difficult to measure with existing wideband Landsat multispectral scanners, James (1970) has described ways to subtract out its undesirable, additional effects.

The intensity and spectral character of radiation is modified by scattering and absorption as it travels through water. In a turbid medium the scattering is caused by the reflection and diffraction of light rays by small particles of suspended matter and colloidal solutions. Just as in the atmosphere, if the size of the particles is small compared to the wavelength of light, the intensity of the scattering is inversely proportional to the wavelength to the nth power, where the exponent n decreases with increasing particle size from a value of four for pure water to near zero for coarse suspended matter (Jensen 1968). Therefore, for solutions containing small particles, the blue light has the maximum scatter, and for solutions with large particles all colors are scattered approximately the same amount (James 1970). Work conducted by Tyler and Richardson (1958) indicates that light scattering in various solutions is directly related to the concentration of the contaminant. Jerlov (1968) states that in cases of scatttering by large particles, the intensity of scattered light is proportional to the particle surface area that is exposed to the incident beam. The intensity of the scattered light is proportional to the particle surface area that is exposed to the incident beam. The intensity of the scattered light is proportional to the turbidity if the particle size is uniform. Szekielda and Curran (1973) found that light penetration in water is affected by plankton and dissolved

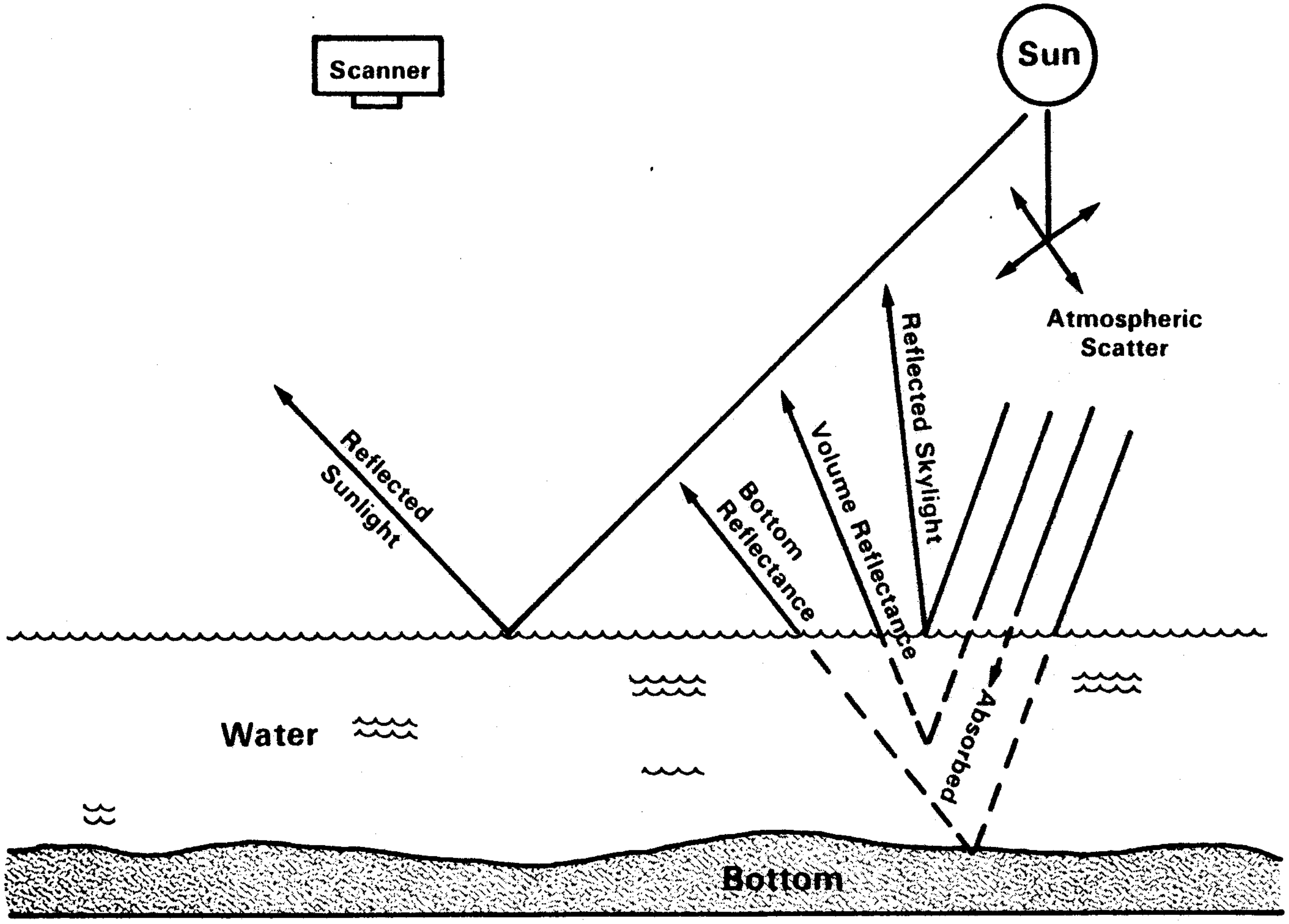

Figure 1. Pathways of various components of light from water that is received by a multispectral scanner.

and suspended matter. Therefore, the composition of backscattered light from below the air-sea interface is determined by the nature of some of the constituents in the water.

Other investigators stress the importance of the effect of dissolved and particulate substances on water color. Kalle (1937, 1938, 1939) and Jerlov (1951a, 1951b, 1953) indicated that in coastal waters the spectral change from blue to green is a result of selective absorption by gelbstoffe, yellow organic particulates, and possibly detritus produced by an aging community of phytoplankton in the water.

Ramsey (1968) states that the deep blue color of the oceans can be attributed to the selective scattering of light by small particles and water molecules. As productivity increases, the blue gradually changes to green. There is a decrease in the reflection coefficient in the blue region. This is due to an increase in yellow substances that are directly related to the organic material in water and is often dependent on the level of productivity. Blue water is, therefore, not very productive. Jerlov (1948) categorizes various marine water types from blue ocean waters to more productive inshore waters according to the transmission characteristics of visible light (Table 1).

TABLE 1. WAVELENGTH OF MAXIMUM TRANSMISSION AND THE PERCENTAGE OF LIGHT OF THIS COLOR TRANSMMITTED IN FIVE DIFFERENT TYPES OF OCEAN (Source: Jerlov 1948)

Types of Ocean Water	Wavelength of Maximum Transmission (nm)	Percent Transmission per Meter
Clearest oceans	470	98.1
Average coastal	475	89.0
Clearest coastal	500	88.6
Average coastal	550	72.4
Average inshore	600	60.8

Yentsch and Owen (1975) conducted research in an attempt to demonstrate how gelbstoffe and chlorophyll vary with respect to one another and to try to explain the spectral characteristics of the particulates. These investigations showed that the amount of yellow substance was inversely related to salinity. The pattern of distribution, therefore, closely represented the ratio between river and coastal ocean waters. Their study was conducted in July when production was nitrogen-limited near the Merrimack River. Fresh water was associated with enrichment. Since fresh water and yellow substance are correlated, yellow substance is also associated with enrichment. Their study results indicate a positive correlation between yellow substance and chloropyhyll.

A summary of the interrelationships between the absorbers phytoplankton and yellow substances) that Yentsch and Owen (1975) studied is as follows:

1) There appears to be a positive correlation between phytoplankton chlorophyll (band intensity at 670 nm) and the "particulate yellows" and "dissolved yellows".

2) There is a positive correlation between the "particulate yellows" and "dissolved yellows".

3) The source of the "particulate yellows" is not known. They could arise from the metabolic activities of the phytoplankton, or they may be a particulate form introduced with river water.

They found that in waters containing high concentrations of phytoplankton and yellow substances, the backscattered light spectra were categorized not only by a loss of short wavelengths, but long wavelengths were accentuated due to scattering.

Still other researchers have concentrated their research toward the detection of various sediment types and gelbstoffe. Blanchard and Leamer (1973) utilized a spectral radiometer to measure radiation in the visible and near-infrared portion of the spectrum in an attempt to examine: 1) different concentrations of red, black, and gray clay particles in water, and 2) several samples of natural pond water containing sediments and chlorophyll bearing algae. They found that reflectance (attenuation) curves in the near infrared (750 nm - 3000 nm) showed little change with changing sediment concentrations. Reflectance (attenuation) curves in the visible region (400 - 700 nm) were found to be sensitive to low concentrations of less than 200 ppm suspended solids (down to 75 ppm). This depended on the color and source of the sediments (Figures 2 and 3).

In studying four flood detention reservoirs containing green algae, Blanchard and Leamer (1973) observed a peak attenuation at 570 nm and a dip at 690 nm (Figure 4). They suggest the possibility of utilizing techniques that radio wavelengths to detect chlorophyll while simultaneously measuring low concentrations of suspended particulates. Although these relationships would be most useful if a narrow band multi-channel sensor were utilized, they indicate that sediments and algae can be monitored with sensors that operate in the visible and near infrared regions of the spectrum.

Yentsch and Owen (1975) made measurements which verify that the color of water depends, to a large extent, upon the depth of which light penetrates the water column. More light of shorter wavelengths is backscattered in areas of

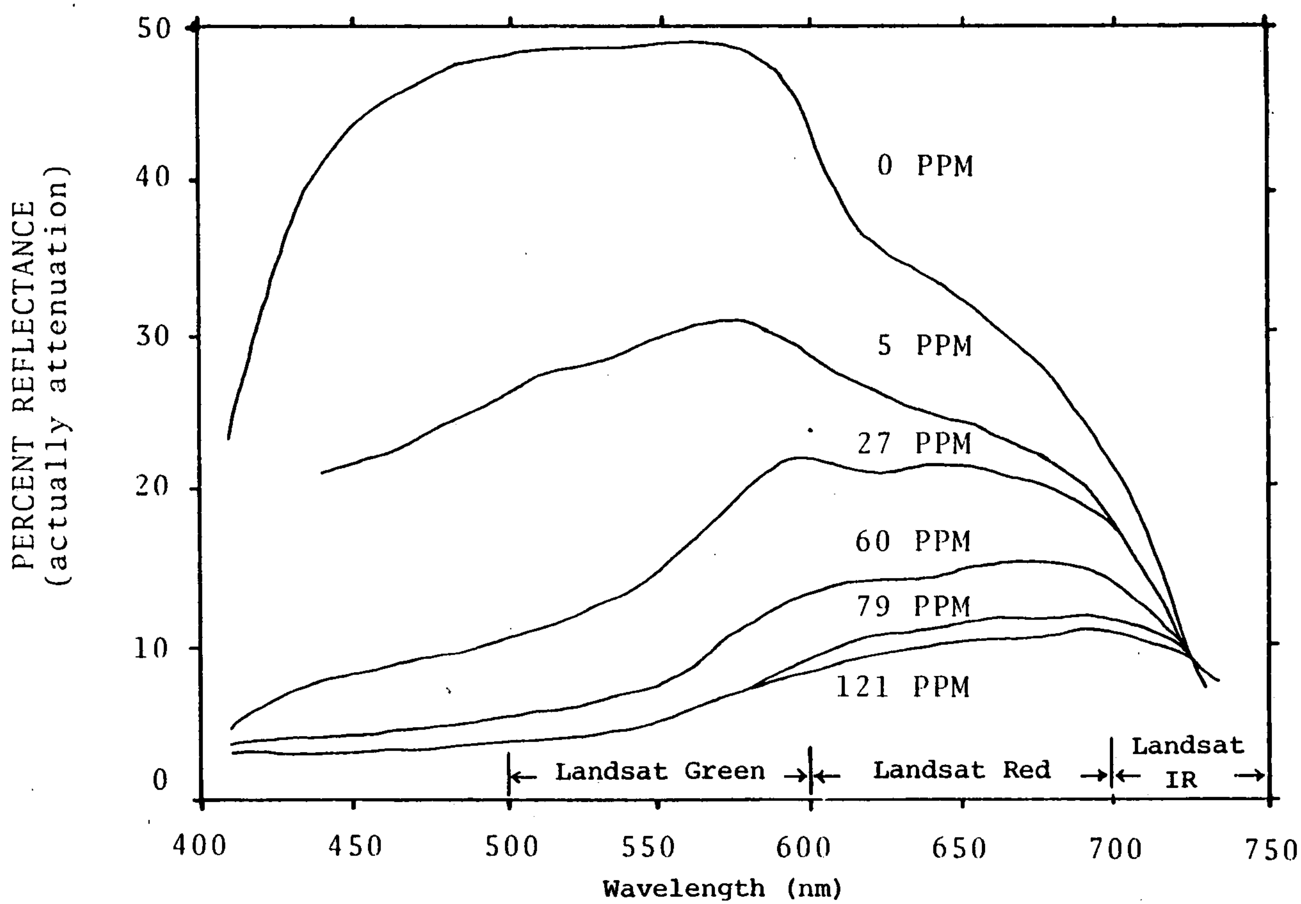

Figure 2. Percent reflectance for water with red sediment (source; Blanchard and Leamer 1973).

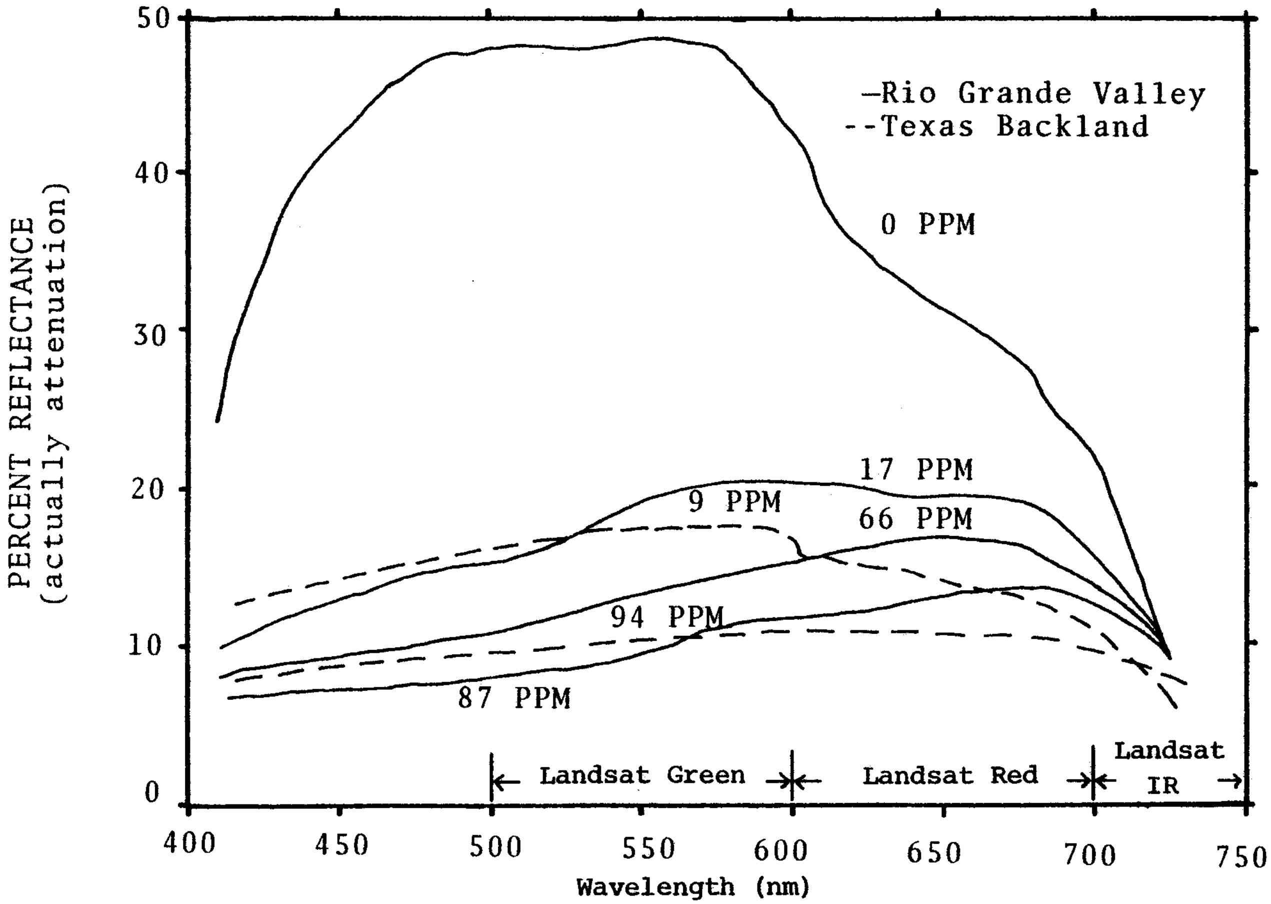

Figure 3. Percent reflectance for water with black sediment (Rio Grande Valley and Texas Blackland) (source; Blanchard and Leamer 1973).

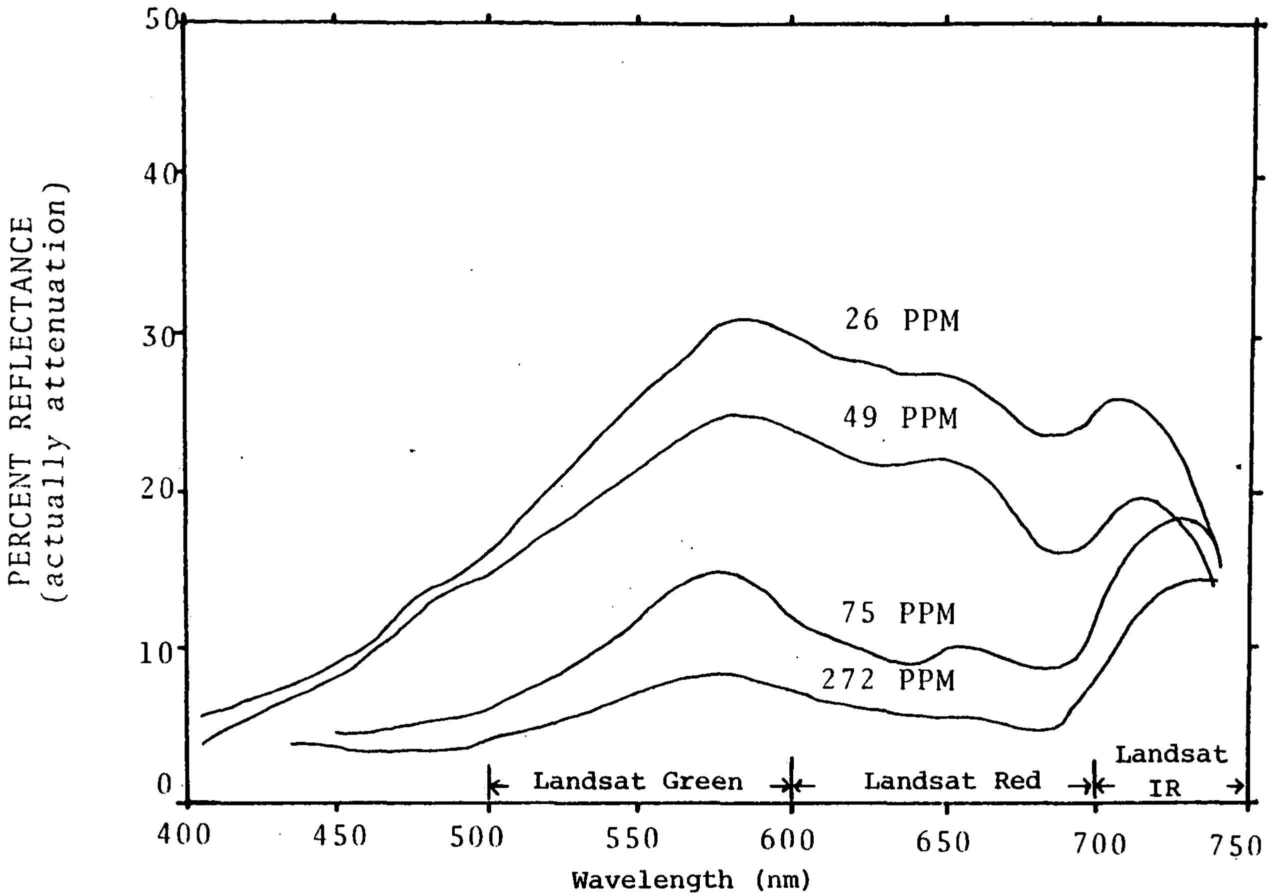

Figure 4. Percent reflectance for pond water with algae (Chickashe, Oklahoma) (source; Blanchard and Leamer 1973).

low transparency than in waters of high transparency. Since longer wavelengths strongly absorbed by water, any return in these wavelengths is due to scatters near or on the surface. Their observations also show that phytoplankton not only absorb blue wavelengths, but also strongly backscatter red wavelengths. They advocate the use of wood band sensors similar to Landsat multispectral scanners to develop a general scheme to distinguish yellow substances from phytoplankton. This separation capability would enable researchers to better study pollution related parameters (i.e., specific species of algae). They encourage the uses of Landsat in the study of selected parameters related to coastal eutrophication and water quality mapping.

MONITORING TURBIDITY QUALITATIVELY WITH LANDSAT

Landsats-1 and 2 MSS's have broad spectral channels which were primarily selected for monitoring the terrestrial environment. Landsat has, however, been established as an acceptable tool for the detection, estimation, mapping, and monitoring of selected water quality parameters.

Fleicher (1973) and Bowker et al. (1973) utilized Landsat digital data to map turbidity patterns which indicated the flow of water masses in the Chesapeake Bay, Maryland. Other investigators have used Landsat to distinguish and monitor circulation patterns and changes in the relative sediment load of discharging rivers. Such studies have been conducted by Anderson et al. (1973) in coastal areas around Alaska, Ruggles (1973) in Long Island Sound, Pluhowski (1973) for the Walland Canal and the Genessee and Ousego Rivers, and Kelmas (1973) in Delaware Bay.

Fisheries information related to turbidity has also been derived from Landsat data. Maughan et al. (1973) and Kemmerer and Benigno (1973) found Landsat was a useful tool in providing information significant to the harvesting of menhoden. Wright et al. (1973) utilized Landsat to plot areas of (probable) fish concentration of commercial importance.

Pollution has also been monitored using the synoptic view of Landsat. Lind et al. (1973) monitored a discharge plume from a major paper mill along the shore of Lake Champlain. Scherz et al. (1973) used Landsat to monitor turbidity patterns around the water intake for the cities of Duluth and Superior. Stumpf and Strong (1975) charted surface current patterns of southern Lake Superior and Lind et al. (1973) utilized Landsat imagery to map turbidity patterns in Lake Champlain. Klemas (1973) utilized Landsat data to observe water boundaries and fronts (regions of high horizontal gradient with associated horizontal convergence). From a pollution standpont, surface slicks and foam collected in areas along frontal convergence zones near boundaries contain concentrations of Cr, Cu, Fe, Hg, Pb, and Zn which are higher by two to four orders of magnitude than mean concentrations in ocean water (Szekielda et al. 1972), Maul and Gordon (1973) observed relationships between Landsat radiance values and watercolor gradients across oceanic fronts. Mairs et al. (1973) successfully collected the necessary information on offshore waste disposal and estuarine flushing dynamics along New Jersey's coast using Landsat data. Landsat data also proved useful in locating most major sewage effluent sources in the Potomac River-Estuary (Schubert and Mac Leod 1973).

The distribution of nonpoint source (NPS) pollution have also been observed by several investigators utilizing Landsat data. Carlson (1974) identified and described principal sources of turbid water such as rivers. He also determined that secondary sources, (e.g., landslides, beach cliff and headland erosion, reworking of the bottom by storm waves, plankton blooms, and waste effluents) can be observed, but are often masked by high river flows.

Lepley et al. (1973) determined the distribution and flow of water masses at four depth intervals by analyzing Landsat imagery through the use of optical models of classes of vertical oceanographic profiles for the Northern Gulf of Mexico. In a study of Kansas lakes, Osborne and Marzolf (1972) utilized Landsat to monitor turbidity which also correlated well with total suspended solids. Other investigators have examined the capability of Landsat to monitor various water types. Pirie and Steller (1973) detected the source and movements of sediments in the nearshore and offshore zones of California. An effort to correlate Landsat data with measurements of turbidity and transmittance from various water types in Lake Superior was conducted by Stortz and Sydor (1974). Landsat was found to be useful in determining general turbidity values. They demonstrated correlation between turbidity and suspended solids. Landsat data were used to map various water types in the Gulf of Carpentaria, Australia, by Teleki et al. (1973).

Landsat images of the Beaufort Sea, Alaska were used to distinguish three water types with the following characteristics (Barnes and Reimnitz 1973):

1. Turbid river runoff - low salinity (0-10) parts per thousand higher temperatures (1-11°C), and high turbidity (>15 light attenuation coefficient α).

2. Melt from pack ice - salinities from 5-15 parts per thousand temperatures from 0-2°C and low light attenuation (<3α).

3. "Oceanic water" - salinities from 25-30 parts per thousand, cold water temperatures (1°C) and relatively clear (<5α).

Landsat imagery was found to be especially useful in monitoring coastal processes in these often very remote areas.

MONITORING TURBIDITY QUANTITATIVELY WITH LANDSAT

Of equal interest to this research are the efforts of investigators to quantitatively estimate turbidity and related water quality parameters using Landsat data. Egan (1974) in experiments near St. Thomas Island found that Landsat data correlated well with surface turbidity while turbidity integrated over depth showed a weak correlation with Landsat data. Chlorophylls a and c, total chlorophyll and total carotenoids revealed an even weaker correlation. The lower limit of remote detection of turbidity was found to be about 0.2 JTU (Egan 1974). Egan believes that ". . . turbidity, or equivalently, the backscattered radiance in the blue, green, or red is the optical parameter that must be related to biology."

Concentrations of suspended sediment load up to 2 mg/l, in the Ventura Harbor-Anacapa Island area, showed a close correlation to variations in Landsat film density along the survey line (Steller and Pirie 1974). The radiance increased for sediment loads greater than 2 mg/l (Figure 5). Williamson and Grabau (1973) found that spectral "signatures" of suspended materials in the York and Rappahannock Rivers were not as distinct as they had previously expected. In Figure 6 the correlation bands for these two rivers are placed on top of each other. For concentrations below 15 mg/l, the correlation bands overlap so greatly that discrimination between sediment types was clearly impractical. Channel 3 did provide some differences for suspended material concentrations between 15 mg/l and 25 mg/l.

Wright and Sharma (1973), in studies of Alaskan coastal circulation patterns, found that photographic transparencies of Channel 1 best delineate (upon visual interpolation) suspended loads in the concentration range between 2 to 20 mg/l, and Channel 4 was best for concentrations over 1,000 mg/l. Channels 2 and 3 were good for estimating intermediate concentrations. Color density sliced transparencies used to produce enhanced prints correlated well with suspended load measurements.

In a study conducted using Landsat-1 to monitor two Kansas reservoirs, Channels 2 and 3 were found to best correlate with suspended load and sunlight penetration depth (Yarger et al. 1972). Channel 2 exhibited good correlations, but these varied with atmospheric conditions. These variations were however, not well explained in the article. Channel 4, although poorly correlated, revealed a brighter return, apparently over the other three channels, for suspended loads $\geq$100 ppm. Correlations deteriorated for concentrations greater than 100 ppm. Hunter (1973), in studies along the Texas coast, found that Landsat was capable of revealing differences as little as 0.7 mg/l in concentration of suspended particulate matter in surface waters. Sampled concentrations of suspended matter at the surface ranged from 0.2 to 1.8 mg/l.

A more definitive quantitative estimate of suspended particles was conducted in the New York Bight by Yost et al. (1973). They developed the following method to predict what they termed the absolute value of total suspended particles using Landsat composites of Channels 2 and 3 which were precisely made using the step wedge supplied on the imagery. It must be remembered that digital data, which was not considered in this project, yields even better estimates of suspended material than does photographic data. Positive images were made from negatives to bring out maximum water detail (Yost et al. 1973). The black-and-white image brightnesses of Channels 1, 2, 3 and 4 were obtained and a regression analysis performed with respect to an average extinction coefficient, total cell counts, and chlorophyll a. Following this analysis, Channels 1 and 2 were found to best predict the extinction coefficient. Positive images of Channels 2 and 3 provided the best estimates of total suspended particles. The images were then density sliced and put on a video display to construct a chart of water characteristics being analyzed. The brightness of the projected reprocessed positive image was then measured at each sampling station for each of the four individual MSS channels. The relationships between screen brightness in each channel and

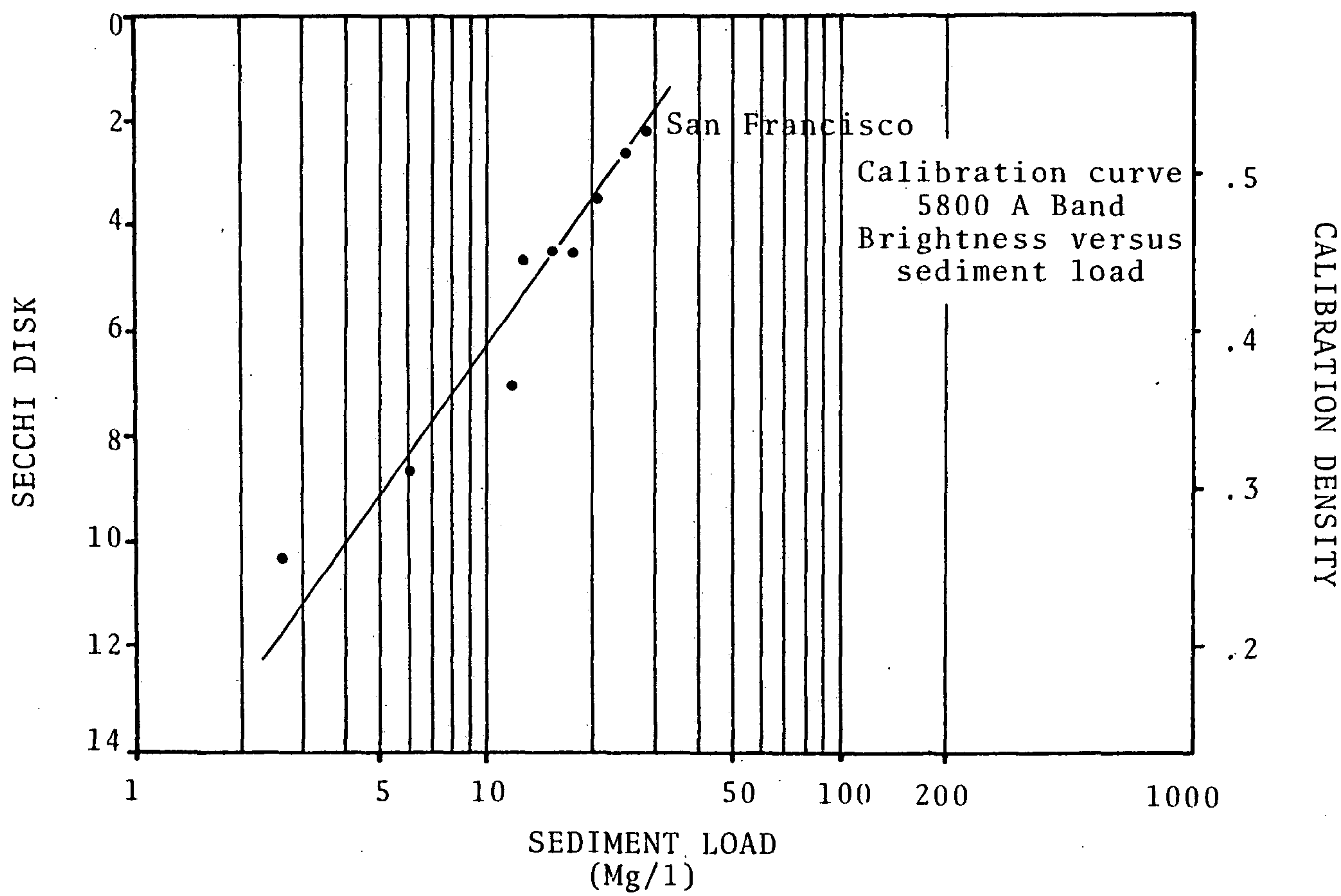

Figure 5. Calibration curve for sediment load versus film density in median California coastal water (source; Pirie and Steller 1973).

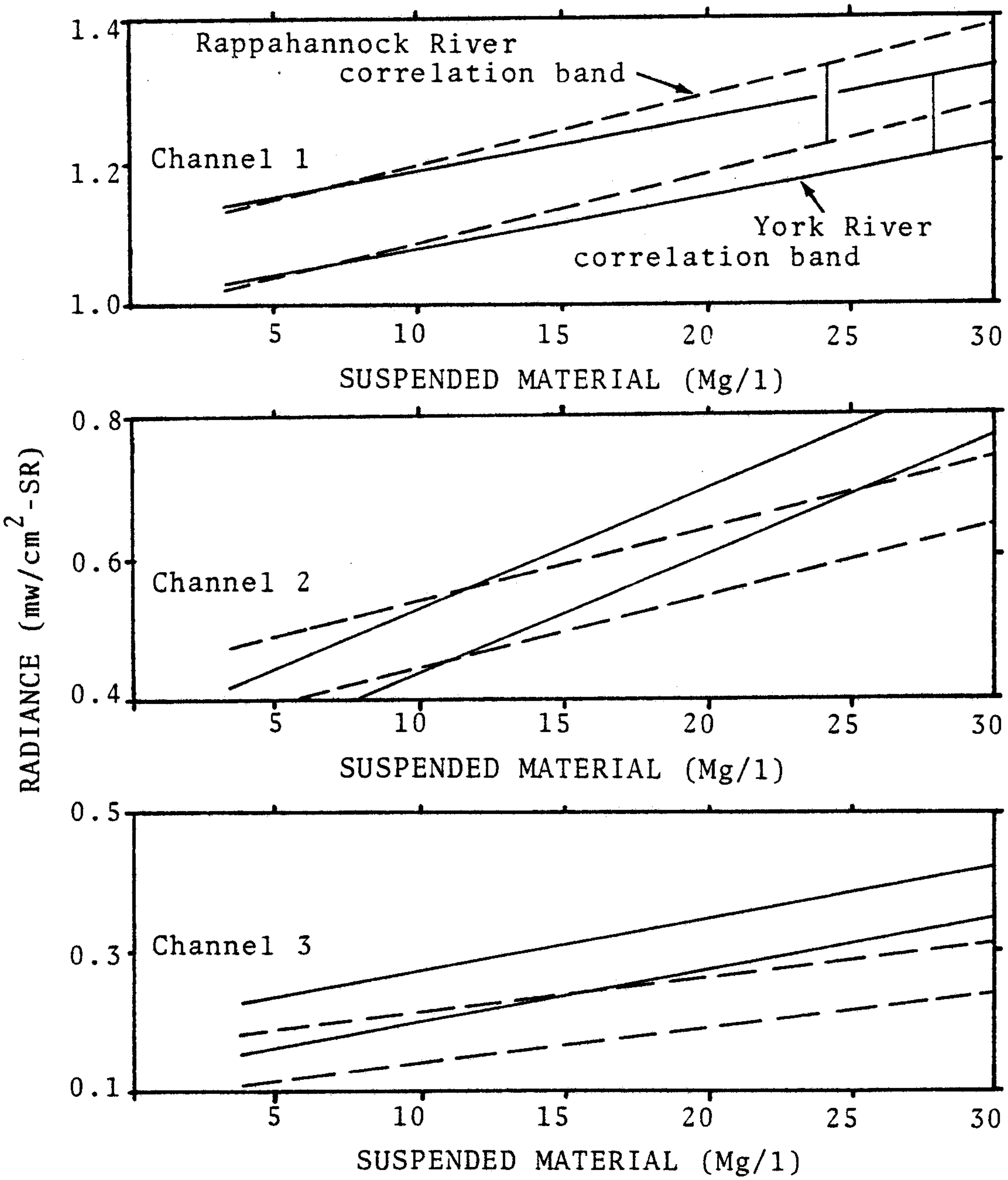

Figure 6. Comparison of radiance signatures of York and Rappahannock Rivers (source; Williamson and Grabau 1973).

total suspended particles were plotted and a linear regression was developed for each. These models showed that in the case of single channel images, little relationship is evident between total particles and image brightness. However, combined positive images of Channels 2 and 3 demonstrated a significant relationship (Figure 7). By using more precise controls on the processing of the positive Landsat images through calibration using the step wedge provided on each image, a quantitative relationship between image brightness and total particles can be derived. This same technique was used to calculate relative extinction coefficients for water from Channels 1 and 2, but atmospheric affects apparently caused variability in image characteristics which prevented the acquisition of absolute measurements.

In sum, these investigations demonstrated that in selected geographic areas, Landsat MSS data can be used to detect and often monitor such coastal zone features as water masses, river plumes, surface circulation patterns, current blockage, water types, sediment sources, sediment dispersal sites, upwellings and pollution (effluents and water boundaries). The MSS can also be used to estimate water quality parameters such as secchi depth; extinction coefficients, suspended solids, sediment load, and turbidity.

Because of the uniqueness of each and every coastal area, the usefulness of Landsat data in conjunction with water quality data must be evaluated for calibration purposes on an individual basis. Landsat, as with other remote sensing devices, does not always provide the necessary data from different geographic areas, under all environmental conditions, during each season of the year. Very few of the above mentioned Landsat applications have been accepted and utilized by the "true" user community; in this case, managers of coastal resources.

Table 2 summarizes Landsat channels identified by some investigators for the detection and monitoring of turbidity and turbidity related patterns. Photographic transparencies of Channels 1 and 2 were utilized for qualitative studies of plumes, water types, and circulation patterns. Although not stressed in the literature, it was assumed that digital data of Channels 1 and 2 have also been used to at least qualitatively, if not, quantitatively, study these parameters.

Transparencies and digital data from Channels 1 and 2 were found to best provide both qualitative and quantitative turbidity and suspended solids information. Channels 3 and 4 were occasionally utilized to derive concentrations of suspended solids when such concentrations were either relatively high or surface oriented.

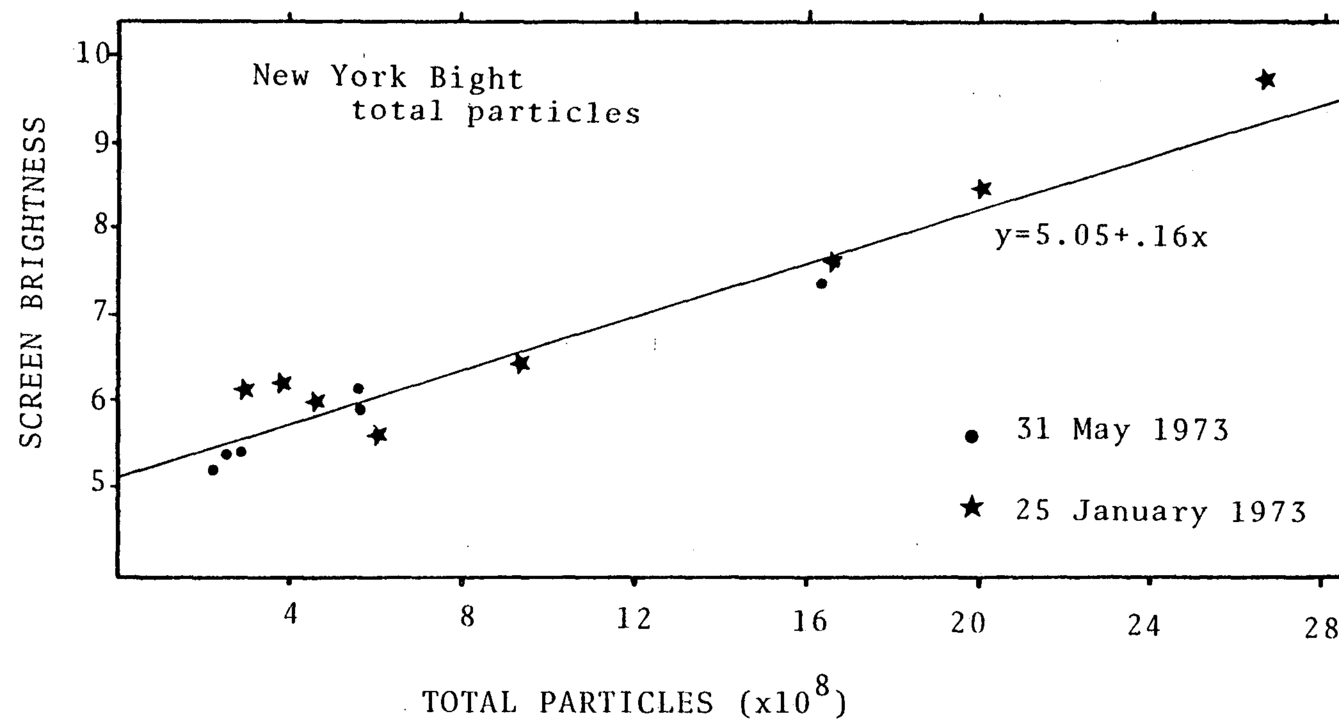

Figure 7. Total particles versus image brightness of accurately processed positive composites of Landsat Channels 2 and 3 (source; Yost et al. 1973).

TABLE 2. SUMMARY OF PREFERRED LANDSAT SPECTRAL CHANNELS (1, 2, 3 AND 4) FOR TURBIDITY RELATED RESULTS DERIVED FROM THE LITERATURE BY NUMBER OF PROJECTS

	Qualitative Results								Quantitative Results							
	Transparencies				Digital Data				Transparencies				Digital Data			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Turbidity	7	3		1	5	6			5	8						
Suspended sediments	2	3	6		5	6			6	3	7	1	2	3	5	5
Plumes	3	4	3													
Water types	3	3														
Circulation patterns	5	3														
Pollution	2	3	1													

SECTION 5

GEOGRAPHIC STUDY AREA

Because of its long coastline, Florida is a prime example of a state which could benefit from a monitoring program using remote sensing systems. Many Florida agencies are interested in assessing the environmental impact of land development occurring in rural areas, assessing the success of environmental recovery projects in wetland areas, and studying coastal zone ecology in an attempt to develop best management practices for their many natural resources. Universities, industry, and local, State, and Federal agencies are also collecting background water quality data in an effort to measure the impact of such activities as ranching silviculture, dredging, and damming on the ecology of estuarine systems. The U.S. Environmental Protection Agency is also interested in the acquisition of baseline water quality and land-use information.

The specific parameters measured depend upon the objective of the monitoring program and the constraints relating to personnel, money, time, and the availability of technology. Frequently estuarine monitoring programs measure and/or delineate current patterns, as well as the distribution of suspended sediments, nutrients, color, turbidity, pollution, and related patterns.

This information can be used in the selection of nuclear power plant sites, and the siting of submerged oil pipeline corridors, various other marine, and waterfront developments. Sites for the future propagation of new marine resources can be selected using the monitoring data. The utility of remote sensing techniques is accentuated when one considers the extreme variability from one estuary to another. Each estuary should be approached on an individual basis with such factors as latitude, drainage area, river flow, offshore circulation, and depth taken into consideration (Livingston 1975), while keeping in mind that delineated ecosystem boundaries can often be quite difficult.

The geographic area selected as the study area for this research program was the Apalachicola Bay System, Florida. Ninety percent of Florida's oysters and ten percent of the nation's oysters come from this particular bay. The bay system at present has a dependable source of comparatively pollution-free productive fresh water in an area of minimal urban and industrial population growth (Whitfield and Beaumariage 1975). The marshes surrounding the bay are also still relatively unaffected by man's activities. The bay system harbors several rare and endangered plants and animals (i.e., southern bald eagle, osprey, black bear, alligator, snapping turtle, southern sturgeon, in fact the highest species density of amphibians and reptiles in North America (north of Mexico) is found in the upper Apalachicola River Basin (Kiester 1971). This estuarine system also serves as a major nursery for penaeid shrimp, blue crabs and various fishes such as spot, croaker, redfish, seatrout, flounder, mullet, and sheepshead. The Apalachicola Bay ecosystem is very succeptable to man-induced perturbations (i.e., upland development forest resource management activities) which could reduce the populations of shellfish and finfish, thereby adversly impacting bay associated industries.

The Apalachicola Drainage System (Figure 8) encompasses more than 50,000 square kilometers (19,500 square miles) in three states (Florida, Georgia, and Alabama) (Graham, pers. comm. 1978). The system is composed of numerous streams, creeks and four major river systems (Flint, Cattahoochee, Chipola, and Apalachicola). The Cattahoochee and Flint rivers flow into Lake Seminole created by the Jim Woodruff Dam. Flow from the dam forms the Apalachicola River, which in combination with the Chipola River, is the major source of fresh water and nutrients received by the Apalachicola Bay System (Figures 9 and 10). The Apalachicola River represents the largest drainage in Florida, with an average flow rate of 23,460 cubic feet per second (cfs) (U.S. Geological Survey 1971). At present the drainage area is sparsely populated and not very developed in terms of agricultural and industrial activity. Livingston et al. (1974) state that the Apalachicola system is a multi-fold complex of interlocking wetland habits that include river-stream-creek associations, wooded and shrub swamplands, marshes, and an extensive estuarine-coastal area. They have found that the river flow is a very significant factor in the ecology of the bay system which in turn serves as an interface between the fresh water upland areas and the Gulf of Mexico. At present, the Apalachicola Drainage System is viewed as one of the largest relatively unpolluted areas in the United States and there is a widespread interest to keep it that way for future generations to enjoy.

The Apalachicola Bay System (latitudes 29° 35' N to 29° 50' N; longitudes 84° 40' W to 85° 15' W) is a shallow coastal estuary bounded by a series of barrier islands (Livingston et al. 1974). The total area of the bay is approximately 549 square kilometers (212 square miles) and is composed of East Bay, St. George Sound, Apalachicola Bay, Indian Lagoon, and St. Vincent Sound (Figure 9). A stable non-tidal current system is prohibited due to the enclosing barrier islands in conjunction with (seasonal) fresh water inflows. At mean low water the bay depth averages 2.7 m. The bottom consists of a quartz sand base covered by up to 20 m of sediment composed mainly of silt and clay. There are only four connections with the Gulf of Mexico, Sikes' Cut (a dredged pass), Indian Pass, West Pass, and St. George Sound.

Dawson (1955) in his description of the hydrography, of the bay stated that during periods of high river discharge, or influx of fresh water discharge, the bay is fresh while during other times of the year it is saline. Surface salinites are also affected by wind speed and direction. Winds over the bay are predominantly from the northwest during the winter months and from the south during the summer (Jordan 1973). Dawson (1955) expected that vertical stratification did not occur in the bay since it was so shallow

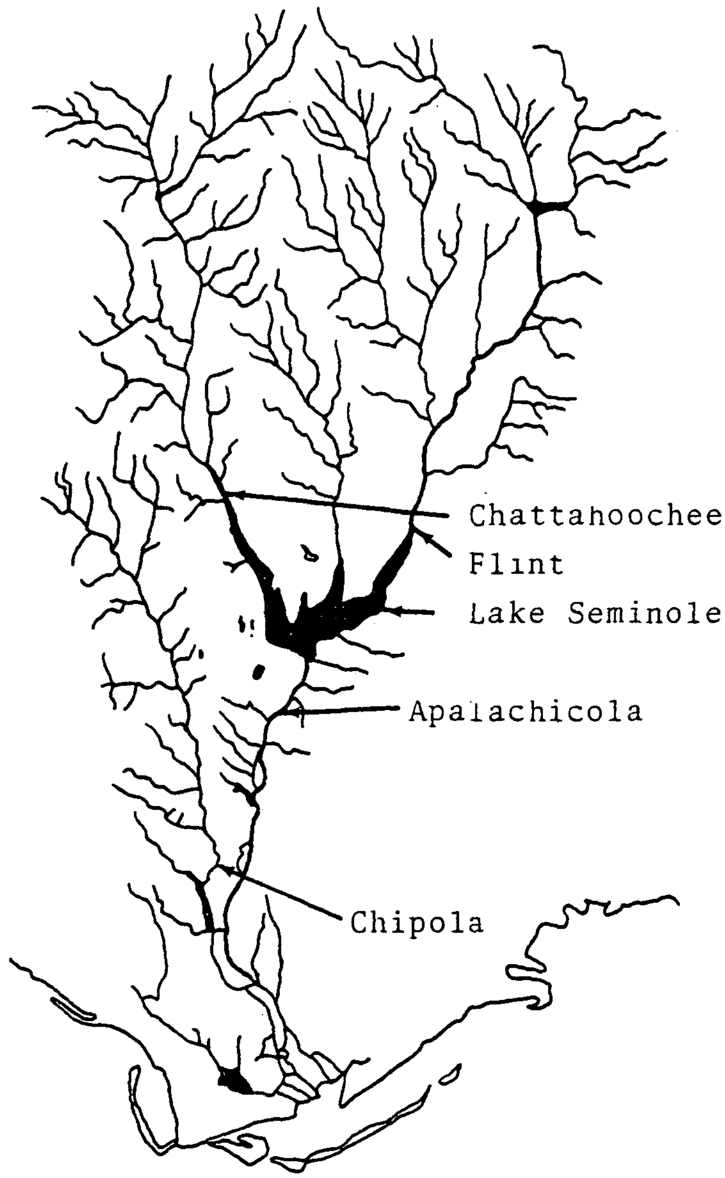

Figure 8. The Apalachicola drainage system including the major rivers that contribute to the Apalachicola Bay System (source; Livingston et al. 1974).

Figure 9. U.S. Geological Survey map of Apalachicola Bay, Florida and vicinity (scale 1:250,000).

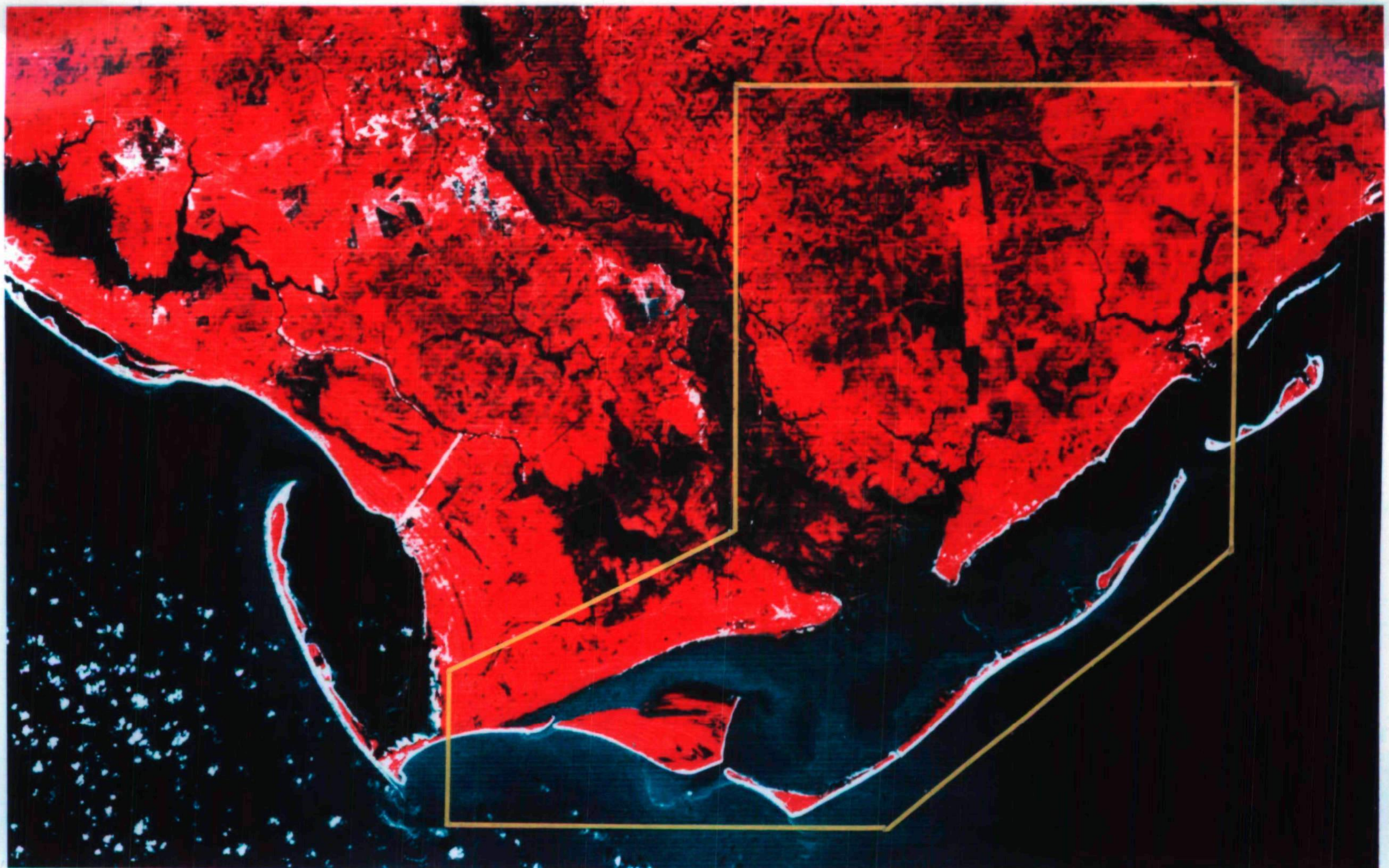

Figure 10. Landsat image (1516-15421) of Apalachicola Bay, Florida and vicinity with area of interest outlined.

and therefore rapidly mixed by wind action. Livingston et al. (1974) found the bay to be well mixed during periods of strong wind, but Estabrook (1973) found that under moderate wind conditions (great enough to drive surface waters but not strong enough to mix the water column), the surface salinity is uncoupled from bottom salinities. Plumes of high salinity water extend into the bay along the bottom and surface (at times) from both West Pass and Sikes' Pass. Surface water temperatures, with an annual range of monthly average temperatures of about 16.5°C, usually parallel the air temperatures (Dawson 1955). The tidal range is from approximately 0.5 m to 1.0 m. Tides in the bay are semidiurnal with diurnal inequality.

Water turbidity correlates strongly with river discharge except at times when bottom sediments are suspended in the water column as a result of wind mixing (Livingston et al. 1974). Nutrients varied widely with salinity, the highest values usually associated with the areas of fresh water. Average bay nutrient values vary seasonally with the highest nutrient concentrations occurring during high (winter) river discharge and corresponding low salinity.

The chlorophyll values for Apalachicola Bay range from 3 to 17 mg chlorophyll a/m^3 with bottom concentrations often exceeding surface values (Livingston et al. 1974). Minimal levels of chlorophyll a and productivity in February are associated with high river discharge which flush the bay system. The primary factor limiting the growth of phytoplankton is temperature. Light, turbidity, nutrients, grazing, and flushing rates are additional controlling factors. Livingston et al. (1974) postulated that decreased river discharge in the summer months is associated with decreases in nutrient concentrations. When compared to Tampa Bay (Sykes 1970) and Long Island Sound (Riley 1956), Apalachicola Bay is a very productive area. Less than 7 percent of the bay bottom is covered with submergent vegetation according to the National Estuary Study (1970). High turbidity is probably the cause for the relative paucity of the bottom vegetation. The economy of Franklin County, Florida is largely dependent on the commercial fisheries associated with Apalachicola Bay. The major commercial organisms include oysters, shrimp, blue crabs, and numerous finfishes (Livingston et al. 1974). At least three-fourths of the commercial landings are due to species that spend all or some part of their life history in Apalachicola Bay (Menzel and Cake 1969). If anything harmful were to happen to the bay's resources, the consequences would be disastrous to not only a multimillion dollar seafood industry, but also an entire way of life in Franklin County, Florida.

Several geographical areas in the bay system must be monitored in order to understand various ecological trends. Numerous research scientists are presently monitoring indicators of environmental change within these areas of suspected impact. Coliform indices are of value in measuring levels of domestic wastes and, in some cases, industrial wastes. The U.S. Public Health Service (USPHS) has set a limit most probable number (MPN) value of 70 for Group Coliform organisms in approved oyster growing areas. Based on sampled levels of coliform bacteria, the State has therefore classified Apalachicola Bay into an area where oyster harvesting is prohibited and other areas where harvesting is conditionally approved based on the above standards (Figure 11). Although values of Coliform Group MPN have not changed significantly since the 1940's, Livingston et al. (1974) believe that as population (people and animals) pressure in the area increases great water quality and related fisheries problems may arise. There appears to be a relationship between river stage and coliform MPN (Livingston et al. 1974). The river is probably the most significant factor in the distribution of coliform bacteria in the bay. At present, a stationary circle with an approximate two mile radius is drawn from the mouth of the river into the bay proper to delineate waters that are prohibited to shellfish harvesting. The coliform sampling program as well as the water classification program conducted by various state and local agencies would be greatly enhanced if water color patterns and related river plume boundaries could be remotely monitored and delineated.

Barrier island development is still another activity with the potential to damage the bay ecosystem. St. George Island appears to have the most important growth potential for tourism in Franklin County (Colberg et al. 1968). Livingston et al. (1974) state that although the impact of bridges in the area remains unknown, these structures could contribute to changes in current patterns and exchange rates. Because the island is narrow, there is little room for the natural filtering of human wastes and runoff. Remote sensing techniques are capable of providing information which can be used to site commercial and residential developments. Information of this type can be used in planning efforts which are aimed at minimizing adverse environmental impacts and preserving ecologically sensitive portions of an island such as marshes, dunes, and beaches.

Other land-use practices also need to be monitored. Ranching and farming activities include clearing, plowing, cultivating, harrowing, discing, dredging, dyking, and damming. Intensive forest management activities involving ditching, draining, clearcutting, and replanting occur in the East Bay drainage basin (Livingston et al. 1974). Fishermen in the local area have described and complained about the low quality of the "black" water draining from the East Bay drainage basin after heavy rains. Although unverified by scientific data, damage to shrimp, crabs, and gamefish has also been reported. Livingston (1974) has observed in the laboratory that shrimp avoid this water characterized by low pH and altered physical and chemical properties. However, runoff from undisturbed (stable) land, as well as recently clear-cut areas, has no observed deleterious effect on the feeding habits of various organisms (Hydroscience 1977). Silviculture practices actually slightly increase the pH of runoff (Hydroscience 1977), but research should be conducted into the determination of whether or not the key parameter to monitor may be the amount of drainage channels rather than the acreage of various land-use activities. Livingston (1974) also states that little is known about possible related alterations in the salinity structure of the bay and the long-term consequences resulting from the introduction of such chemicals as tannins, humates and fertilizers. Large quantities of highly colored low pH waters (sometimes with a pH of 4) have been observed draining directly from these clear-cut areas into the bay system. The runoff not only damages organisms which live in the East Bay System, but this type of land-use could increase the level of eutrophication. The forests included in these wetlands are believed to be a source of nutrients and detritus for the complex

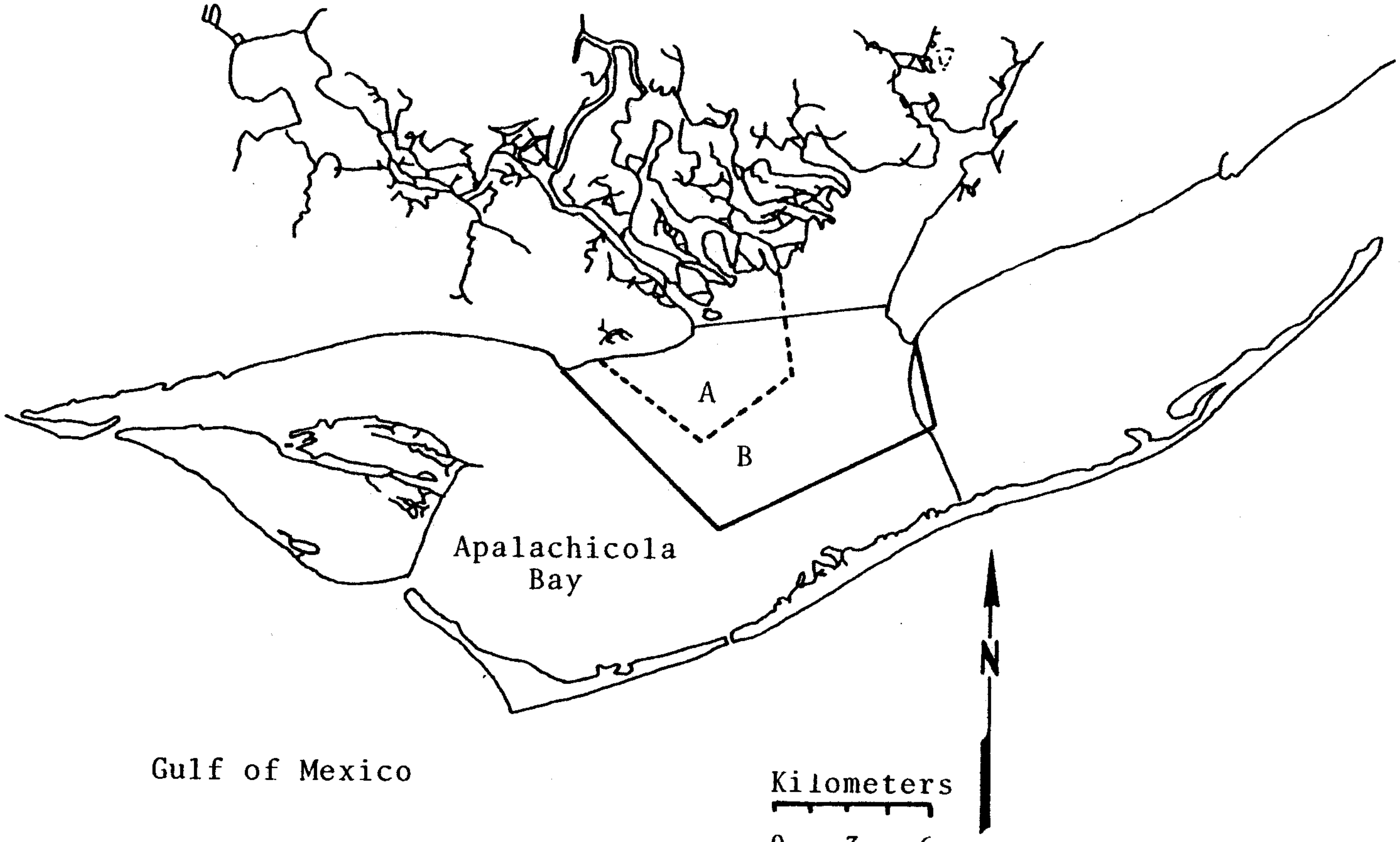

Figure 11. Classification of the harvesting of shellfish in Apalachicola Bay (Area A = prohibited; Area B = conditionally approved) (source; Livingston et al. 1974). Shellfish areas are delineated on the map located in the back pocket of this report.

food webs of the adjoining streams, rivers, and estuaries. Woodall and Wallace (1972) suggested that watershed vegetation may be a primary factor determining species abundance and composition in aquatic systems. Livingston et al. (1974) state that from the results of their studies of detrital-based food webs in Apalachicola Bay, it is very possible that the above-mentioned generalization might apply to this system.

The U.S. Army Corps of Engineers is presently conducting an extensive program to maintain maximum depths along the Apalachicola River for navigation. It is also conducting a study of a plan for damming portions of the river (Livingston et al. 1974). Such programs are expected to affect salinity and nutrient levels in the Apalachicola Bay System. Baseline environmental quality data are needed to answer questions reflecting the general lack of knowledge and the effects of future dams on the Apalachicola Drainage System. Numerous questions need to be answered. For example, is fresh water from the Apalachicola River being diverted into the Gulf of Mexico through Sikes' Cut, a channel through St. George Island? The diversion of this fresh water could increase the salinity of St. Vincent Sound, resulting in an influx of oyster predators normally found in regions of higher salinities (Menzel et al. 1957; Menzel et al. 1966). Oysters generally live in waters with salinities of 15-25°/oo.

The Apalachicola Basin and Bay are potential sites for industrial facilities as well as inexpensive transportation. Corps of Engineers' activities raise various questions concerning local habitat destruction by flooding, interruptions of migrations by anadromous fishes such as shad and striped bass, reduced nutrient and detritus flow, and alterations of temperature and salinity regimes in Apalachicola Bay (Livingston 1975). The Corps has constructed and maintained three relatively significant underwater channels within Apalachicola Bay. One channel is oriented in a north south direction and approaches the Apalachicola airport. A second, the intercoastal waterway, comes from the east, runs east-west, and turns north into the Apalachicola River. The third crosses an oyster bed off Cat Point and runs in a north-west/south-east direction (see map in pocket). The effects of such channels upon the bay ecosystem is presently being rigorously investigated by State and Federal agencies. Remote sensing techniques have the potential to acquire needed water current information to help answer several of the above-mentioned questions.

The various factors that stress an estuarine system are generally established (Odum 1970). What remains to be answered is just how these factors effect productivity and ecological relationships over long periods of time. Livingston et al. (1974) state that alterations, similar to those mentioned above, have already had significant effects on many estuarine systems in Florida. Despite attempts to manage the area, no integrated management program has yet been implemented in the Apalachicola Drainage System. Due to the size of the Bay System, the synoptic view offered by Landsat would greatly aid agencies in acquiring (at a minimum) a temporal overview of estuarine processes of ecological importance. At present, several long-term investigations of the Apalachicola Bay System are being conducted. The Landsat information derived from this research has been requested by numerous regulatory agencies and universities (FSU and UF), within the state of Florida, concurrently conducting related studies in and around the bay. Livingston (1975) in an effort to develop a resource management program for the Apalachicola Drainage System, outlined the following laws and administrative regulations (along with responsible agencies) designed to promote management and conservation of aquatic systems:

1. Federal

   A. Rivers and Harbors Act of 1899 (33 U.S. Code, Sections 401, 403, 404, 406-417)

   Applies to filling, excavating, or altering navigable waterways, also regulates discharge of pollutants, refuse, and dredge spoils into navigable waters. U.S. Army Corps of Engineers is responsible for permitting (in cooperation with Florida Board of Trustees and Department of Pollution Control).

   B. Federal Water Pollution Control Act (33 U.S. Code, Section 1141 et seq.) - amendments of 1972 (Title 33, U.S. Code, Section 1251 et seq.)

   Aims to restore and maintain chemical, physical, and biological intergrity of all waters of U.S. Calls for elimination of pollutant discharges by 1985 and achievement of water quality for protection and propagation of fish, shellfish, and wildlife by 1983. Responsible agencies include U.S. Environmental Protection Agency (EPA), U.S. Army Corps of Engineers, U.S. Coast Guard, with help from Florida Department of Pollution Control.

   C. National Environmental Policy Act (NEPA) of 1969 (42 U.S. Code, Sections 4332, 4344)

   Establishes environmental protection and restoration as national policy with provisions for generation of environmental impact statements concerning any actions of federal agencies that may impinge on the environment. The Council on Environmental Quality, established by NEPA, provides guidelines for such impact statements. U.S. Environmental Protection Agency is primary agency involved in enforcement, although most federal, state, and local agencies operate within NEPA.

   D. Marine Protection, Research and Sanctuaries Act of 1972 (33 U.S. Code, Section 1401 et seq.)

   Concerned with protection of oceans from pollutants discharged from vessels including dredge spoils, chemicals, etc. Responsible agencies include U.S. Environmental Protection Agency and U.S. Army Corps of Engineers.

E. Fish and Wildlife Coordination Act of 1958 (16 U.S. Code, Section 661-666C)

Requires consideration of effects of work in navigable waters on fish and wildlife. U.S. Army Corps of Engineers coordinates with other federal and state agencies.

F. Endangered Species Act of 1973 (Public Law 93-205)

Provides conservation measures for endangered and threatened species. Administered by U.S. Department of the Interior.

2. State

A. Florida Air and Water Pollution Control Act (Chapter 403,011, Florida statutes)

Public policy to conserve quality of state air and waters, provided that no wastes are discharged into water without proper treatment, etc. Administered by the Florida Department of Pollution Control with help from the Division of Health of the Florida Department of Health and Rehabilitative Services.

B. Florida Water Resources Act of 1972 (Chapter 373, (Florida Statues)

Relating to all state waters (except with respect to water quality), conservation and control programs for management and conservation of such related resources (fish, wildlife, etc.). Utilization of surface and ground water, prevention of damage by flooding, soil erosion, excessive drainage, etc. Administered by Florida Department of Natural Resources with delegation of powers to five regional water management districts. Presently involved in generation of a state water use plan.

C. Florida Environmental Land and Water Management Act of 1972 (Chapter 380, Florida Statutes)

Establishment of an Area of Critical State Concern (ACSC) program and the developments of regional impact (DRI) evaluation process. Areas of critical concern qualify for such designation by having environmental, historical, or archeological importance, or being affected by major development. The purpose is to formulate state decisions establishing land and water management policies for the guidance and coordination of local decisions concerning growth and development. This does not apply to more than 5 percent of the land of Florida as an ACSC, and agricultural activities are exempt from its provisions. A DRI is a report filled out by the developer according to specified questions that are to be answered concerning the overall impact of the development on the region's environment, natural resources, economy, etc. The Division of State Planning, Department of Administration implements this act; review of DRI's are considered by the appropriate regional planning agency with the local government conferring final approval, approval with conditions, or denial. The overall purpose of this act is to promote the creation of principles to guide development on the local level within specified state-sanctioned guidelines so that any major development in a given area is compatible with the local environment.

D. Florida State Comprehensive Planning Act of 1972 (Chapter 23, Florida Statutes)

Provides plan for long-term guidance for staff growth by establishing goals, objectives, and policies. This includes coordination of planning efforts among local, state, and federal agencies. Division of state planning is responsible for implementation of this act.

E. Land Conservation Act of 1972 (Chapter 259, Florida Statutes)

Environmentally Endangered Lands (EEL) Program based on analysis of available ecological information to determine priorities of environmentally endagered land. An EEL plan will be developed to guide the purchase by the state of endangered lands. In such purchases, there is no eminent domain power to implement land acquisition; this precludes identification and priority listing of endangered lands. The choice between acquisition and regulation depends on level of protection necessary to achieve the desired environmental aims. Emphasis is on ecological significance, the importance of submerged lands, and appropriate evaluation. Administration is by the Department of Natural Resources with input from other state agencies and a panel of experts on environmental and planning concerns. This includes interagency planning and advisory committees with final approval by the governor and cabinet.

F. Beach and Shore Preservation Act (Chapter 161, Florida Statutes)

Provides for beach nourishment, erosion control, regulation of coastal construction, and establishment of setback lines along beaches. Administered by the Department of Natural Resources.

Graham et al. (1978a) report that the Federal Water Pollution Control Act (FWPCA) of 1972 (Public Law 92-500) requires both point (201) and nonpoint (208) pollution control. The 208 section requires that basin water quality plans must include nonpoint sources of pollution. In Florida, such planning for silviculture practices is presently being coordinated by the Division of

Forestry and the Department of Environmental Regulation and should meet the deadline for completion. Section 208 (F) requires the use of:

> (F) a process to (i) identify, if appropriate, agriculturally and silviculturally related nonpoint sources of pollution . . ., and (ii) set forth procedures and methods (including land-use requirements) to control the extent feasible such sources.

The FWPCA also requires the investigation of the affect of drainage operations on fresh water hydrology (Graham et al. 1978a). The FWPCA therefore mandates the development and use of:

> (I) a process to (i) identify, if appropriate, salt water intrusion into rivers, lakes and estuaries resulting from reduction of fresh water flow from any cause, industry, irrigation . . ., and (ii) set forth procedures and methods which are otherwise parts of water treatment management plan.

Livingston (1975) stated that the Apalachicola system is an example of what is occurring in estuaries all around the country. Conflicting interests are competing for the use of terrestrial and aquatic resources. It was anticipated that this research would aid in the development of remote sensing techniques useful for long range planning and resource management programs which require the acquisition of extensive synoptic scientific data. The ultimate goal of an estuarine resource management program is to provide a specific management plan, based on objective scientific data, which allows for the application of intelligent alternatives to a given local or regional situation (Livingston 1975). Livingston (1975) stated that ". . . only in this way can the often difficult decisions be made which concern resource uses in our estuaries."

In summary, Apalachicola Bay, Florida is an enviromentally and economically valuable area. It is well worth preserving for the benefit of future generations. An extensive and rare surface truth (both water and land) data base has been acquired in the Bay System since 1972. The base includes detailed temporal water quality and land-use data. With such a unique surface truth data base already in existence, this project was conducted in an effort to utilize Landsat to temporally monitor land-use changes and water color distributions in the Apalachicola Bay System, Florida.

SECTION 6

MATERIALS AND METHODS

In some instances, photography is gradually being replaced by digital satellite and aircraft derived multispectral scanner data in an attempt to better acquire quantitative results. A digital format allows the data to be manipulated through utilization of a computer without degrading the quality of data which occurs in the processing of several generations of film (Van Wie et al. 1975). This section describes the Landsat system and procedures followed for the analysis of Landsat digital data used in this study. A much more detailed description of the analysis of Landsat digital data can be found in Hill (1978).

The greatest advance to data in the acquisition of earth-orbital imagery undoubtedly occurred with the launch of Landsat-1, the first Earth Resources Technology Satellite (ASP 1975a). Landsat-1 (formerly called ERTS, Earth Resources Technology Satellite) was launched on July 23, 1972 and was joined by Landsat-2 on January 22, 1975. Each satellite is synchronized to pass over the same point on the Earth every 18 days. The two satellites are nine days apart. Thus, ignoring the side overlap coverage, the same area is covered every nine days. Landsat, as it daily makes its way across the Earth, moves in a 1.43 degree westerly direction which separates each path from another by about 159 kilometers at the equator. The paths converge at the poles. Landsat operates at an altitude of approximately 920 kilometers. It circles the Earth every 103 minutes, completes 14 orbits for each of the 17 days and 13 on one day and can view the entire Earth every 18 days (National Aeronautics and Space Administration (NASA) 1972).

Landsat satellites are equipped with a Return Beam Vidicon (RBV) Camera, a Multispectral Scanner (MSS), and a Data Collection System (DCS). This research deals solely with the MSS. The MSS uses an oscillating mirror to continuously scan perpendicular to the path of the satellite. The system receives data from four spectral channels simultaneously with each sweep of the mirror. The four channels are in the visible and rear infrared spectral channels from 0.5 to 1.1 micrometers (500-600 nm, 600-700 nm, 700-800 nm, and 800-1100 nm). It is limited to a daylight operational mode. The swath width is approximatley 185 kilometers.

The six optical fibers for each of the four channels are arranged in a 6 x 4 matrix located in the focused area of the scanner's telescope (Figure 12). Light from the Earth is conducted to an individual detector, uniquely sensitive to a specific spectral band, through an optical fiber. An image

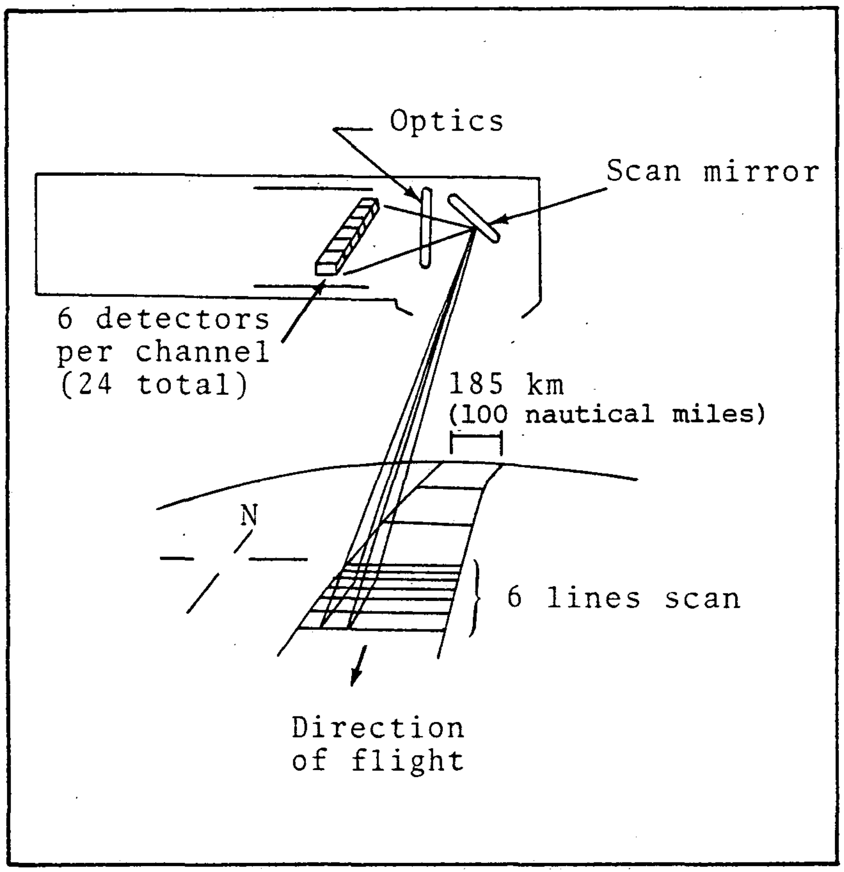

Figure 12. Landsat MSS scanning arrangement (source; NASA 1972).

of a line across the swath is swept across the fiber each time the mirror scans. A video signal is produced at the scanner output for each of 24 channels. These electronic signals are sampled, digitized, and formulated into a serial digital data stream. Figure 13 is an example of the ground coverage pattern derived from Landsat.

Landsat data are initially recorded in an analog format when received by a ground station. The data are then reformated into a digital format. Investigators have the option of receiving the digital data on computer-compatible tapes (CCT) or photographic images. This study used the Landsat digital data recorded on CCT's. All of the Landsat images in this report, with the exception of Figuire 10 which was reproduced from a color composite film positive, were generated from the digital data.

Upon receiving a complete list of sampling dates from FSU, the next stage was to determine the dates when Landsats 1 and 2 viewed the same area. The Browse Facility at the Remote Sensing Center of Texas A&M University was utilized to determine these dates. Before selection of the best overpass

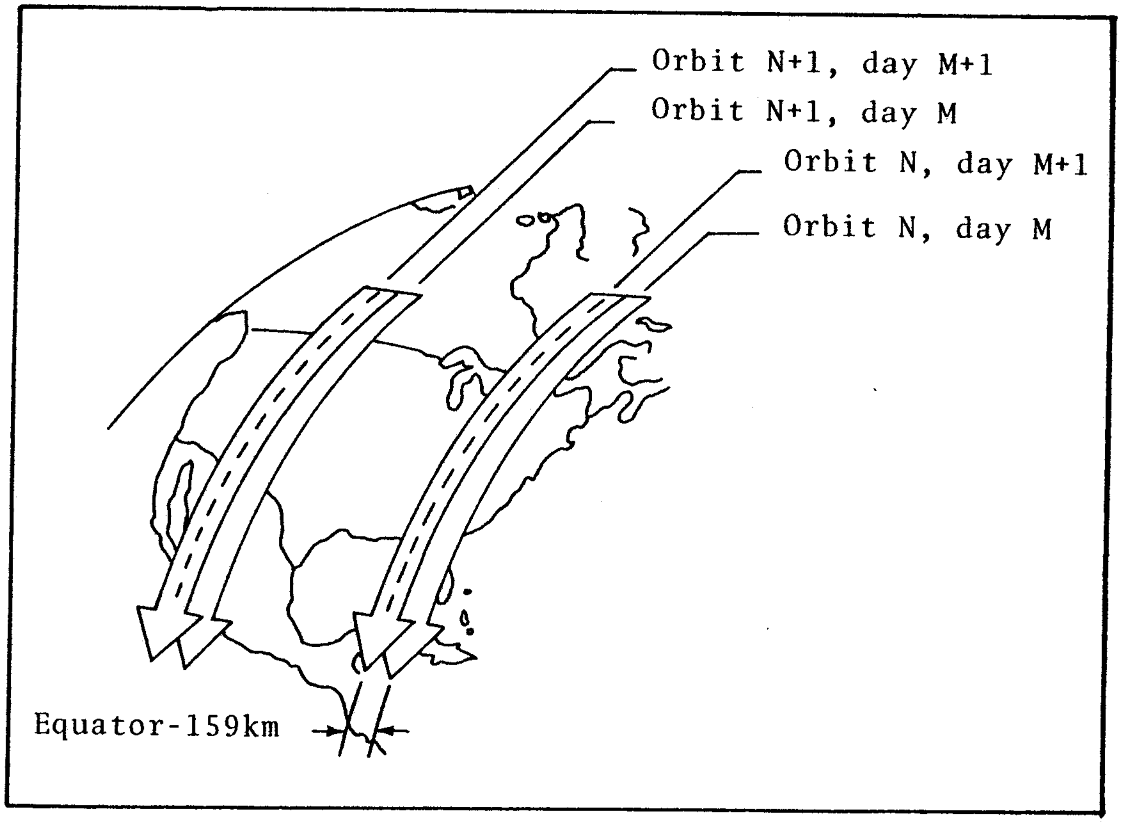

Figure 13. Landsat ground coverage pattern (source; NASA 1972).

dates, several factors were considered to assure that the selected images would provide the most valuable information. It was necessary to acquire images from specific times of the year in order to view such occurrences as high and low river flow, high and low flow of runoff from the East Bay drainage basin, various tidal stages, varying wind conditions, and seasonal vegetation changes on land. It was unfortunate, but water sampling dates did not coincide with those of the historical Landsat images. Taking into consideration the above-mentioned factors, Landsat CCT's were ordered in sets of two for ease of handling (Table 3).

TABLE 3. LIST OF LANDSAT COMPUTER COMPATIBLE TAPES RECEIVED FOR THE APALACHICOLA BAY PROJECT

Image Number	Date	Scene I.D. Number	Landsat 1 or 2
1*+	17 February 1973	1209-15394	1
2*	17 February 1973	1209-15401	1
3*+	13 April 1973	1264-15454	1
4	19 May 1973	1300-15452	1
5*+	21 December 1973	1516-15421	1
6*	3 March 1974	1588-15402	1
7*+	23 October 1974	1822-15333	1
8*+	26 February 1975	1948-15282	1
9*	20 July 1975	5092-15204	1
10	11 December 1975	5236-15120	1
11	12 February 1976	2386-15303	2
12*+	19 August 1976	5488-14542	1

* Fully analyzed Landsat computer-compatible tapes.
\+ Analyzed for land-use practices.

Once a pair of Goddard tapes are recieved at the Enviromental Protection Agency's (EPA) Environmental Monitoring Systems Laboratory (EMSL), they are taken to the Data Analysis System (DAS) (Figure 14) for analysis. The DAS system is a low-cost data analysis system for processing multispectral aircraft and satellite scanner data. The tapes are immediately reviewed for such information as proper format, damage, cloud cover, data compression, scan lines and elements encompassing the area of interest, and which of the four files comprising any one entire image, contain the study site. In order to save valuable processing time, a copy (one file per tape) is then made of only the pertinent data segments by skipping a predetermined number of san lines. The functional steps of the "supervised" processing of these Landsat MSS digital data are summarized in Figure 15. The MSS computer-compatible tapes are preprocessed before image analysis is initiated. Preprocessing entails destripping, an attempt to balance differences in detector responses due to varying gains, and converting the data into a format that is compatible with subsequent DAS programs.

DATA ANALYSIS SYSTEM

Figure 14. Components of the EPA Data Analysis System.

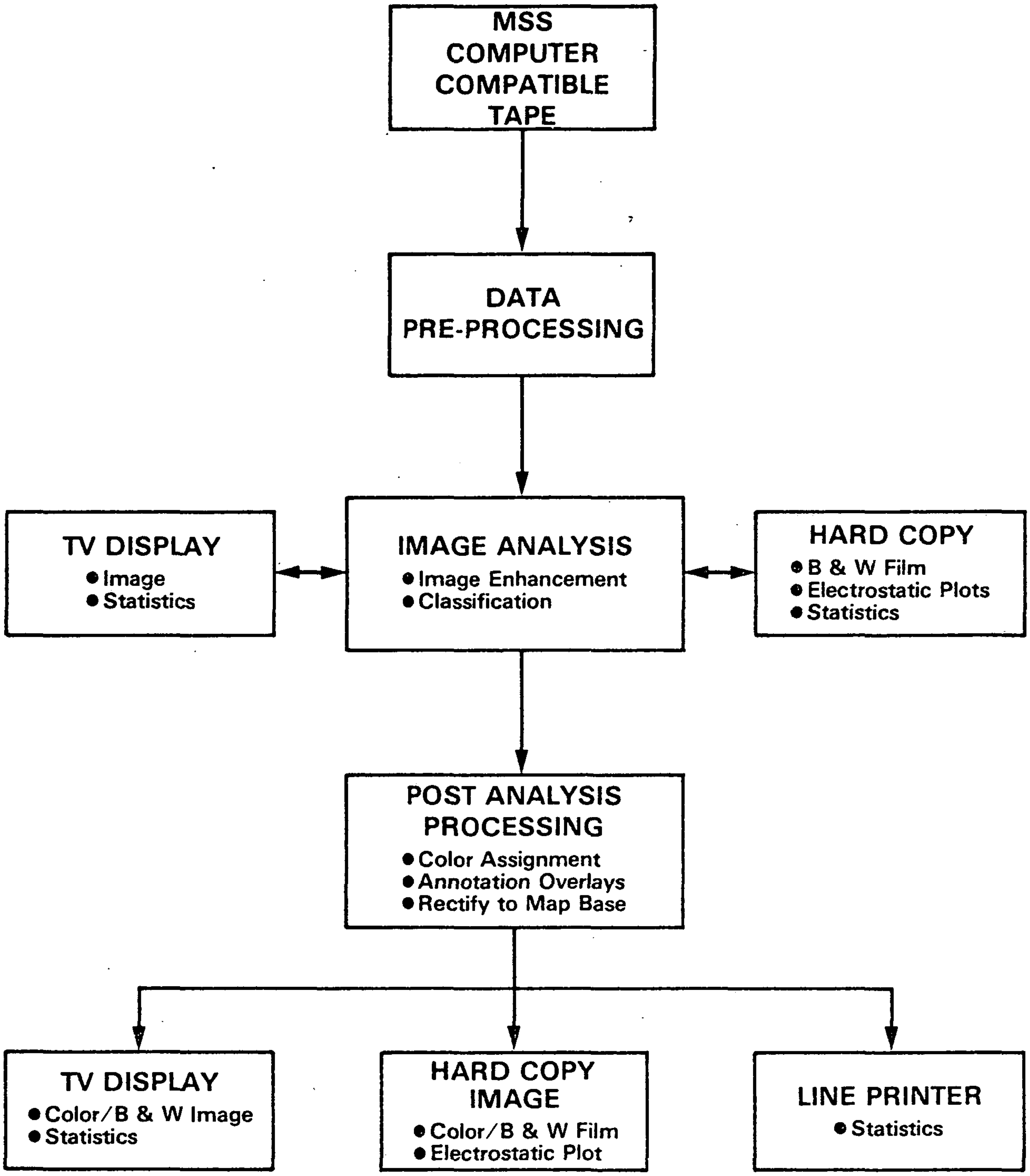

Figure 15. Simplified flow diagram of the functional steps of Landsat digital analysis.

The next phase is to create a tape that enhances desired features for the sole purpose of picking training fields. The Display Tape Program (DAPIDS) contrast stretches and level slices the raw data to generate an enhanced image. Channels 2 and 4 were used for the generation of this image. Two separate and different display tapes were produced, for it was necessary to (1) separate land from water in order to enhance land features, and (2) to separate water from land in order to enhance water types. Both of these tapes were used for the selection of training fields.

The next stage utilizes the Comtal (television screen) and the Comtal Varian Image Processing System (CVIPS). This phase of analysis, involving the selection of training fields, is probably the most critical phase of the entire operation, for it is only from class spectral signatures, derived from statistical comparisons of the individual training fields, that the computer decides how to classify every pixel or picture element, in the entire area of interest. A training field is a small area of a known land-use or highly suspected water type, selected from a display tape, which is to represent the spectral signature of a particular field of interest during classification.

Before even sitting down at the computer, the goals of the project are reviewed in detail, ground truth materials are gathered and studied, and potential training fields are selected. Since aircraft imagery was not available for the dates selected, it was decided to utilize USGS maps, National Ocean Survey maps, and maps supplied by the Buckeye Cellulose Corporation, as the sole source of ground truth information. Different criteria for the selection of training fields are followed, depending on the value of a particular class to the goals of the research. For classes such as clear-cut and swamp/forest runoff, it is necessary for the values in the training field to be relatively homogeneous when compared to the rather variable, but encompassing training fields such as marshes, cities, and natural forests. A goal was to classify all forested areas as forest, but not to actually break them up into forest types.

It is desirable to have the training fields of specific interest uniformly distributed over a scene, but this may not be always possible in nature. It is also helpful in most cases to include some noise within a training field so as not to drastically limit the range of a spectral signature. Through experience, it was determined that a sample size smaller than 15 pixels is not statistically representative of a specific spectral signature (except in the case of rivers and roads where 15 pixels are often difficult to acquire). It is also best, for statistical purposes, to select sample sizes that are approximately the same size. At least three samples are selected for each candidate class, except in the water where obvious differences and boundaries existed. Generally, land and water class spectral signatures determined from one tape are transferable to the neighboring tape, but it is procedure to at least view the adjoining tape within the Landsat scene, and in most cases, select several new training fields. At the end of this process, the image is reviewed with a computer graphic overlay of all the training fields. This is to insure that the entire area and all different areas of specific interest have been sampled, because the addition of training fields at a later date is time consuming and difficult.

Before processing begins, disk files under a specific qualifier (name) are created in order to store the data handled during most of the computer phases. Once experience is gained, it is most convenient to store the data area of interest on any of six scene files, since the entire area of interest is not viewed at any one time. The next scene is restored when the adjoining set of training fields are to be selected. The training fields are either selected by automatically drawing a box of a preselected size or by using the cursor to draw an irregular polygon around the area of interest.

Training fields for a particular class are chosen at the same time so as to simplify later stages of analysis. It is a practice to only sample areas that can be identified with a high degree of confidence as a specific land-use type on the accompanying ground truth maps.

The water enhanced display tape is thoroughly examined. Again, all necessary scenes are stored before the water training fields were selected. A color table (STEP 26), displaying a specific color for a particular count from 0 to 63, is selected which best separates the various water types. For the most satisfactory classification results over the very low counts in the water, the training fields include a lot of neighboring noise. Such noise is created by mixing of water types, striping due to detectors and even sea state. Including the noise widens the range of the specific class just enough to include most of the noise, thereby smoothing out the final classification.

If mixing zones between water types are as distinct as the bordering water types the boundary sampled and is generally made a separate class. If the boundary is not distinct (mixed) it is split statistically by widening the thresholds between the two mixing water classes thereby forming a more distinct boundary between even larger water types. In general, far fewer training fields are selected for a certain water type than are selected for landtypes. Up to 16 different types of water were identified. Even though the water types are only often one count apart, they display better separability qualities than land features which are often separated by many counts in several channels.

Late in this research effort the capability to interactively compute, view and store training field statistics was taught to EPA personnel during a NASA Transfer Technology Course. After the training fields are selected and stored in a file on the disk (TSIN file), the Compute Statistics (CS) routine is entered. This procedure was only performed on the last processed image, Image 5, due to time and resource limitations. The statistics of each training field are reviewed even before they are stored in the TSIN file. Although it takes approximately 1 minute to compute the statistics for one training field, several useful training field statistics are generated due to this extra processing. Approximately 100 training fields had to be selected for each of the 8 images in order to discern land and water classes.

Once all of the training field statistics for all four channels are computed and stored in a statistics file (STAT file), the histogram program (HISTOS) is run. This program presents a compact, yet comprehensive, printout of the relevant statistics of a training field. This process saves a lot of paper if used properly in comparison with several of the other statistical programs. Other products generated from the computed statistics are four channel spectral plots of either particular classes of similar training fields (i.e., all marsh training fields) or individual training fields. This is also another valuable tool used to group training fields into classes. These tapes are printed from a separate plot tape on the STATOS printer/plotter.

Lastly, the SCORECARD program is run to give a rather biased estimate of the accuracy of the final classification. This program merely gives a percentage of the classes into which each original training field was finally classified.

Returning again to the main flow of data analysis, all of the coordinates for the training fields are stored in a file on the disk. The next program (ISOFLD) uses the training field coordinates on the disk file to locate and isolate the individual training field raw data, in all four channels, from the reformatted DAS tape.

At this stage the pattern recognition routines are utilized with the end goal of grouping training fields into specific classes with unique spectral signatures. The specific program is called PATREC STATS, and it enables the analyst to calculate the following statistics on either individual training fields or classes; mean vectors, covariance matrices, correlation matrices, histograms, spectral plots and divergence. The four different modes of operation in the statistics package are ALLS, EDITS, POOLS, and DIVERG.

The ALLS program is first run to derive statistics on each and every separate training field. After observing the mean, standard deviation and spectral plot for each of the four channels, the training field is first determined to be a good sample (i.e., with a relatively normal distribution) and second, the field is compared to all other training fields and placed into similar spectral groups termed "classes". An added aid to training field grouping is an EDITS run which not only produces statistics on each training field but also produces an interfield divergence matrix which compares a particular training field with every other training field.

After grouping of individual training fields into classes, the POOLS mode is run. With a minimum amount of printout, statistical summaries of each class, class spectral plots, and the interclass divergence matrix (in conjunction with the class statistics as a double check) are used to compare the closeness of classes to one another. It is inevitable that similar classes would occur and a second and usually final POOLS is run. After being satisfied that the divergence matrix has not pointed out any conflicting classes, a signature tape (SIGTAP) is produced during a final run of the POOLS program. The SIGTAP has on it the characteristic spectral signatures of all land and water classes.

The ELIPSE program is then run to build a look-up table so that the pattern recognition can be accomplished on a pixel-by-pixel basis (Eppler 1974). As compared to the technique of computing and comparing probabilities during the process of classification, the table look-up technique saves a significant amount of computer time (Jones 1974). The ELIPSE program produces a table tape (TABTAP) containing look-up tables for the classification process.

The ASSIGN program actually performs the pattern recognition by using the previously produced table look-up algorithm to classify the reformatted raw data (LANREF tape) and thereby classifying the entire image. To shorten the process even more, this program first looks at the preceding pixel and, if similar, places the next pixel in the same class. For the ASSIGN run, each land class was usually weighted with a threshold (confidence level) of 13.28 (95%) and water classes had a threshold of 20.00 (99%). Water types had higher confidence levels due to their consistent spectral uniqueness, uniformity, and therefore, ease of separability. The classified data are output to computer tape (CLSTAP).

The results are first viewed at this stage. The classified image is viewed on the COMTAL. In approximately 75 percent of the cases, at least part of the image is either misclassified, unclassified, or classified in such a manner as to create an undesirable result. Two procedures can then be followed depending on the problem. If part of the classified or unclassified image is speckled, usually thresholds are lowered to incorporate these noisy points into nearby classes. Often boundaries between classes, especially areas of mixing between water types, can be absorbed in this matter. If the unclassified data in the area of interest are occurring in large areas, it necessitates the taking of new training fields from the unclassified area(s). The new training field(s) is then added to the end of the original ISOTAP by simply skipping the appropriate number of old training fields and adding the new field(s). The entire previously mentioned process from the running of the ISOFLD program to the final ASSIGN run is repeated. This process is normally conducted at least twice before a satisfactory classified image was produced.

The classified image by itself is useless other than for display purposes if it is not gographically corrected. In order to geographically correct a Landsat image, it is referenced to a Universal Transverse Mercator (UTM) coordinate data base (map). For this project, 1:250,000 USGS maps with an overlayed UTM grid were used due to a lack of updated 7.5 or 15 minute maps.

The GEOREF CONSTANTS Program utilize a least squares regression technique to derive the constants used as input to the transformation equations that position the pixels to correspond with the UTM base map. Two steps are required to perform the CONSTANTS Program. Control points are selected from the raw imagery in the first step. Display tapes are generally inaccurate for such purposes. For accurate determination of specific intersections, the zoom capability on the Comtal us used quite heavily. Scan lines and element values for each control point are recorded. Corresponding Northings and Eastings are calculated and recorded once the operator left the COMTAL. Channel 2 is best for viewing features such as road intersections, and Channel 4 is best for land-water boundaries depicting such features as river and creek intersections and points of land encompassed by water. The Georeference Program (GEOREF) corrects a one degree by one degree area. The best results are derived by selecting accurately located points from at least all four corners of the area of interest. This process often requires the incorporation of points from adjoining tapes.

The appropriate Northings, Eastings, scan lines and elements, along with a point identification code (i.e., P1, P24, P87), for each individual point are fed into the GEOREF CONSTANTS Program. A new time-saving process was developed (Levy, pers. comm., 1977) which cut down on the interactive guesswork needed to throw out bad points. The GEOREF Program fits the lines and elements to a transformation using the corresponding UTM coordinates. Each point is printed out by the program along with residuals and a 2 Sigma error for the entire set, for both scan lines and elements. Points are then interactively deleted and/or added until both scan lines and elements for as many points as possible (15-20 for a good scene) either has a residual of 5 or all were within the 2-Sigma error.

Points with a high degree of confidence were heavily weighted (by a factor of 7) and those with low confidence were weighted with a 1. The heavier weighted points are brought into range first, followed by an analysis of those with a weight of 1. The constants are printed at the end of the interactive GEOREF CONSTANTS run. These constants are fed into the GEOREF BUILDER Program which actually geographically corrects the classified image.

If the image is to be processed on the stand alone film recorder and eventually printed, the T-COLOR Program is executed. T-COLOR converts the image to the desired final scale. T-COLOR tapes are produced for each image at scales of 1:250,000 and 1:500,000. It was later discovered that at a scale of 1:250,000 the entire image was too wide for the film recorder format. The 1:500,000 images were enlarged by two on a second run to acquire a scale of 1:250,000.

There are several reasons why so much time was spent geographically correcting the data. Once all of the images are corrected, they are registered with one another. Data such as acreage estimates from one scene can be compared to all other scenes. The same basin coordinates, used to derive acreage of various classes, are used for all sets of data. There is also the overlay capability in which one data set, such as a USGS map, can then be overlayed on any or all the classified data sets.

In order to acquire acreage of all classes within a particular selected polygon(s), apex cooordinates (scan lines and elements) are selected. Longitude and latitude for a particular polygon (basin) are converted to Northings and Eastings and finally to scan lines and elements. The Defense Mapping Agency (DMA) through a phone call and eventual computer printout (mailed to EPA), converted the latitude and longitude into Northings and Eastings. A second T-COLOR run is made to assign (group) colors on the classified tape to the appropriate classes.

Multiple basins are then read into the Polygon Acreage Program (POLYAC) from cards. The resulting printout produced, by basin, the following information about each class: number of pixels, percent coverage over the basin, acreage, and square miles.

Aside from the Landsat data, it was necessary to acquire other supportive data. A local lumber company provided the clear-cutting, replanting, ground cover and East Bay drainage basin information in the form of several land-use maps (Hill 1978). One map indicated, on a year-by-year basis, the areas that were clear-cut on company owned land located wholly in the drainage basin of East Bay, Florida. A second map depicted the roads on company land along with the year they were constructed. Most of the roads are paralleled by drainage ditches.

The above-mentioned clear-cutting map was the source of land-use data used to pick training fields in the East Bay drainage system. A training field is a representative area, usually of limited size and of a known surface material, which is used to train the computer to identify all other areas having a like or similar spectral signature. USGS 7.5 and 15 minute topography maps. The lumber company derived clear-cutting map was used as guides to sample generalized land cover types (i.e., cities, beaches, marshes). According to the lumber company forest resource manager, they purge their clear-cutting information file about every three years. The maps they provided were constructed using any remaining information. The only information they retain for extended periods is the time and locations of replantings. This information was not received in time for training field selection. Had it been available, revegetated training areas might have been broken down into finer categories.

A third map was also provided which outlined all of the smaller individual drainage basins comprising the East Bay drainage system. Input coordinates delineating the boundary of the East Bay drainage basin were taken from this map and input to the computer for the purpose of acquiring acreage estimates of land-use types within the basin. A table of clear-cutting acreage by months within each plot accompanied this lumber company map, and was the primary information used to verify the results of the computer classification.

FSU, through the efforts of Dr. Robert J. Livingston, is currently conducting its seventh year of water quality monitoring in the estuary. Approximately 15 stations are sampled for some 15 pysicochemical parameters as frequently as once a week. Studies are also being conducted concerning assemblages of benthic infauna and epibenthic fishes and inverbrates. The station data are acquired in the following manner (Livingston and Woodsum 1976):

Physical-chemical data (by area, station, date, time of day, and depth)

- color - measured using an American Public Health Association (APHA) platinum-cobalt standard test
- turbidity - analyzed using Hach Model 2100A laboratory turbidimeter (±2% of scale) and expressed in Jackson Turbidity Units (JTU)
- Secchi disc depth - measured with a standard Secchi disc

- salinity - measured with a Beckman salinometer (±0.3°/oo) calibrated by a Bissett-Berman Model 6230 laboratory salinometer (±.003°/oo) and rechecked prior to sampling with a 47 ohm resistor (±10°/oo)

- pH - determined with a Leeds and Northrop portable pH meter

- river flow - taken at Blountstown, Florida and provided by the U.S. Army Corps of Engineers (Mobile, Alabama)

- rainfall - provided by the National Oceanic and Atmospheric Administration (Environmental Data Service, Apalachicola, Florida)

FSU supplied most of the pertinent water quality data, including station monthly means and standard deviations, and computer derived grey maps of pH and color. This information was requested because this study started out as a quantitative turbidity investigation, but was changed because of the lack of concurrent water truth data with the Landsat overpasses. Water quality data was collected, at best, two to three days earlier or later than any one particular overpass. This research therefore, turned into a qualitative water color study and a more quantitative land-use study, conducted to relate land-use to water quality. Figure 16 is a map depicting all of Livingston's water quality sampling stations.

Eight Landsat scenes were available to study seasonal fluctuations both in water and on land (Table 3). It would have been preferred to have tandem water quality data for the overpasses. Existing monthly means were, however, sufficient for at least identifying monitoring the distributions of water classes. While land-use information was not the best, it was quite sufficient to monitor temporal land-use changes in the East Bay drainage basin.

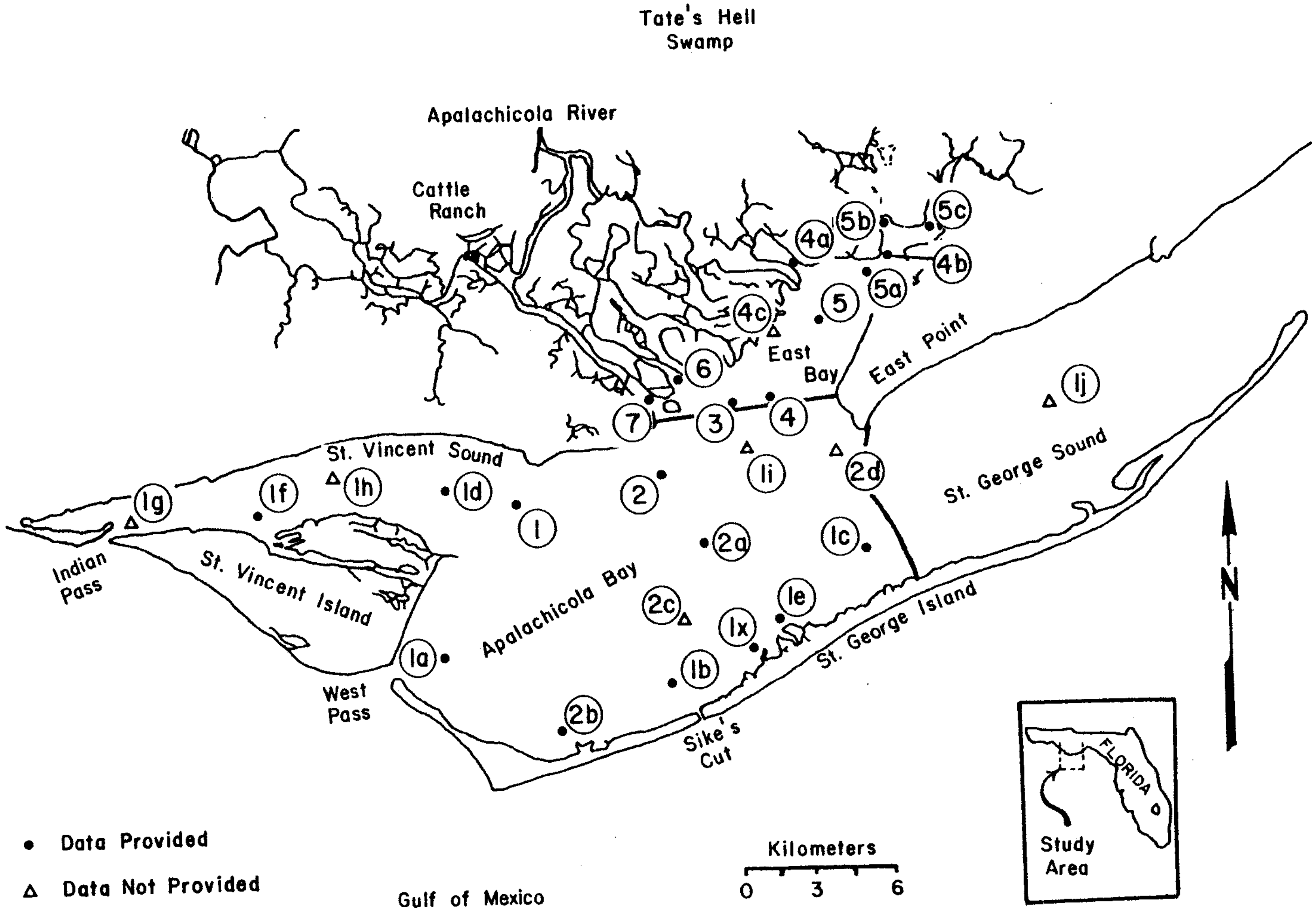

Figure 16. Map of FSU water quality sampling stations in the Apalachicola Bay System (provided by R. J. Livingston, FSU).

SECTION 7

RESULTS

Quantitative correlations between the Landsat channels and water quality parameters, such as turbidity, were not possible because the water samples and measurements were collected several days on either side of the historical Landsat imagery. Since water is such a dynamic medium, samples must be taken at very short time intervals on either side of an overpass. Through the author's experience, a maximum of one hour on either side of an overpass is usually sufficient.

During the investigation of water color distributions, it was discovered that runoff from the East Bay drainage basin could be easily identified by its spectral response in the four Landsat channels. There was only one major change related to land-use activity in the drainage basin; silviculture. As a result of these findings the research was expanded to utilize Landsat data to monitor changes in land cover due to silviculture practices. FSU started its water quality sampling program in 1972, the same year Landsat was launched. FSU was, therefore, studying the result of a problem (declining water quality) and Landsat could be used in this investigation to monitor the probable source of the problem, namely, silviculture activities around the bay.

DISCRIMINATION OF ESTUARINE WATER COLOR DISTRIBUTIONS

As previously mentioned, direct quantitative correlations with water quality data were not possible because the historical imagery was acquired several days earlier or later than the water quality sampling dates. The objective of this portion of research was to demonstrate the capabilty to discern various types of water according to their perspective colors in selected Landsat spectral channels.

The areas of specific interest were East Bay followed by Apalachicola Bay, St. Vincent Sound, and St. George Sound. The parameters monitored were the Landsat-derived four channel spectral reflectance responses of all water types within an image. As mentioned earlier, the detectors receive reflected energy and integrate these values over a given area, into single reflectance values (counts) within the four wavelength ranges of the detector. Spectral reflectance signatures (spectral plots) were derived by plotting count values (reflectance) versus wavelength. From Landsat four channel statistical (Table look-up Algorithms; Eppler 1974) correlations and group and individual training field spectral plots, water types were found to be fairly easy to discriminate from one another. Training fields for water types were selected on the basis of spectral signature geographic location, and available historical water quality data.

A total of sixteen water classes were distinguishable on the basis of their spectral characteristics. The Landsat spatial resolution of 0.44 hectares did not greatly affect the classification process, because the water classes were sufficiently large, areally speaking, to provide a good integration of reflectance over any particular pixel (picture element). Striping, due to differences between detectors, was partially corrected through use of a NASA supplied destriping program. In water, where the difference between classes was often one count or less, the destriping program did not do as good a job. The striping, although not usually noticeable in Apalachicola Bay, is very evident in imagery of the Gulf of Mexico. Hopefully, this problem will be corrected by NASA in data derived from future Landsat satellites.

The color assignments for the water types are as follows (Figure 17):

- Tan, orange, browns, and greens: waters presumably high in turbidity.

- Blues and greys: water classes with a likelihood of low turbidity.

- Deep red: suspected, swamp/forest runoff from the East Bay drainage basin; believed to be highly colored, not very turbid, and fairly acidic.

- Salmon: believed to be dilute swamp/forest runoff.

Figure 17 is an aid to the interpretation of the classified Landsat images. Visual comparisons between FSU's water quality data (Appendix A) and the water color distributions revealed an approximately 90 percent agreement between areas colored red and salmon with the high water color values. There was a one-to-one correspondence between turbidity values and color distribution in at least half of the images. Measurements of pH were often not available for comparison, but the water labeled as swamp/forest runoff in the images was located in the same area as highly colored swamp/forest runoff was observed and sampled by both Livingston (1978) and Hydroscience, Inc. (1977).

Livingston (pers. comm. 1978) stated that water color most closely correlated with rainfall in East Bay and the flow rate of the Apalachicola River. Proximity to the mouth of the Apalachicola River, also played a large role in the classification and coloring of water types. Water types of the same color in different geographic areas may vary in water chemistry, but have similar spectral reflectance characteristics. The color coding of water types and land-use types was done on an image-to-image basis because individual spectral signatures for the same class were quite different from scene to scene. This difference largely was due to varying atmospheric conditions. Colors assigned to the classes in one image do not necessarily represent the same types of water in another image. The two runoff water classes, the river plume, and the waters of the Gulf of Mexico would not necessarily represent similar water types from image to image. Conjunctive water quality data would also have helped to alleviate color differences between possibly similar water

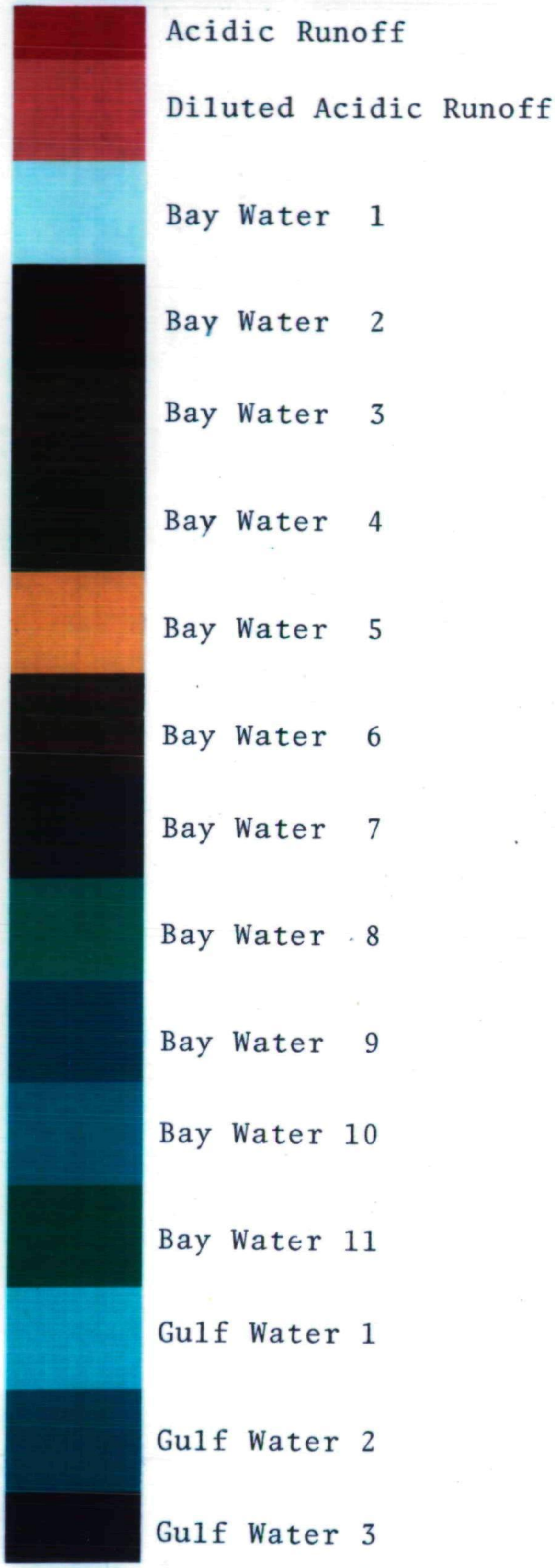

Figure 17. Standard water color table for classified images.

types. Each image should be viewed independently in terms of the color coding procedure. Unlike regular color photographs, the colors in these images were interactively selected and assigned by the author while operating the computer.

Water color distributions were compared with 1976 National Ocean Survey nautical charts and found to indicate bottom features only in the case of mud flats lining the delta of the Apalachicola River. These flats were observed by the author at low tide. Bottom reflectance was, therefore, not of concern to this project. There was also a need to determine whether sun angle had any significant effect on the spectral reflectance of water. Spectral response versus classes were plotted and compared with images from opposing seasons. Although the data were not substantial, due to the mean contributing variable, it was expected that reflectance would decrease with low sun angle in the winter. Summer scenes would have high sun angle and higher spectral reflectance responses. Comparison was difficult, for the same relative water types were not present in most images. General observations revealed only slightly higher reflectance values for the August 1976 scene in Channel 2. Winter and spring data overlapped, and in a few instances overlaped the summer data. Due to the small range (spectral resolution) in Channel 4 data, there was no apparent diffference between data from different seasons. The effects of the atmosphere were, without a doubt, present but were not subtracted from each image before processing.

The water type of interest was swamp/forest runoff. This runoff was easily distinguishable from other types when observed at the ground level because it was characteristically fresh, highly colored (coffee brown), acidic (pH 4-7) water. It was always found to be significantly different spectrally from other water types. As expected, in all four channels the swamp/forest runoff had low channel means, compared to other water types (Figures 18-24). Channel 1 means were the lowest of all water types (19.33, Table 4).

The water type termed "dilute swamp/forest runoff" had slightly higher channel means than the swamp/forest runoff in Channels 1, 2 and 3. Their responses were generally the same in Channel 4 (Figure 19, Table 4). The swamp/forest runoff was not very turbid and had a deep coffee color, while the dilute swamp/forest runoff had a higher reflectance because it had been diluted with the brighter, highly turbid water of the Apalachicola River.

Reflectance generally increases with increasing levels of turbidity. Figures 20, 21 and 22 illustrated that the river and bay waters had the highest spectral reflectances of all other classified water types. Monthly station means of water quality data for each image are presented in Appendix A. While such means were derived data collected on one to several different water sampling dates within the month, they are still indicative of general bay conditions at any particular station. The type and areal extent of each Landsat-derived bay water type is in agreement with average monthly water quality measurements of Secchi depth, color, turbidity, and salinity. The pH values do not follow the water type as closely. Landsat-measured spectral

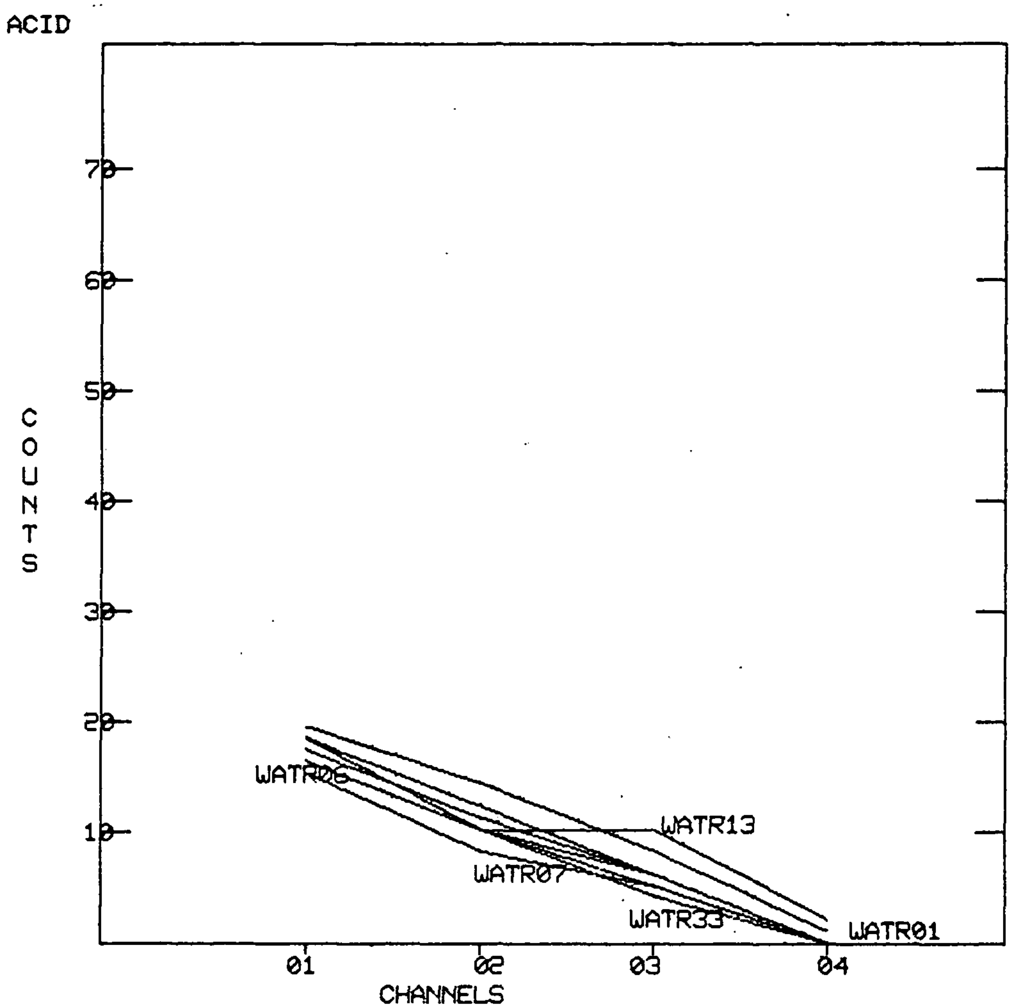

Figure 18. Computer-derived, four channel, spectral plots of acidic runoff training fields, Image 5.

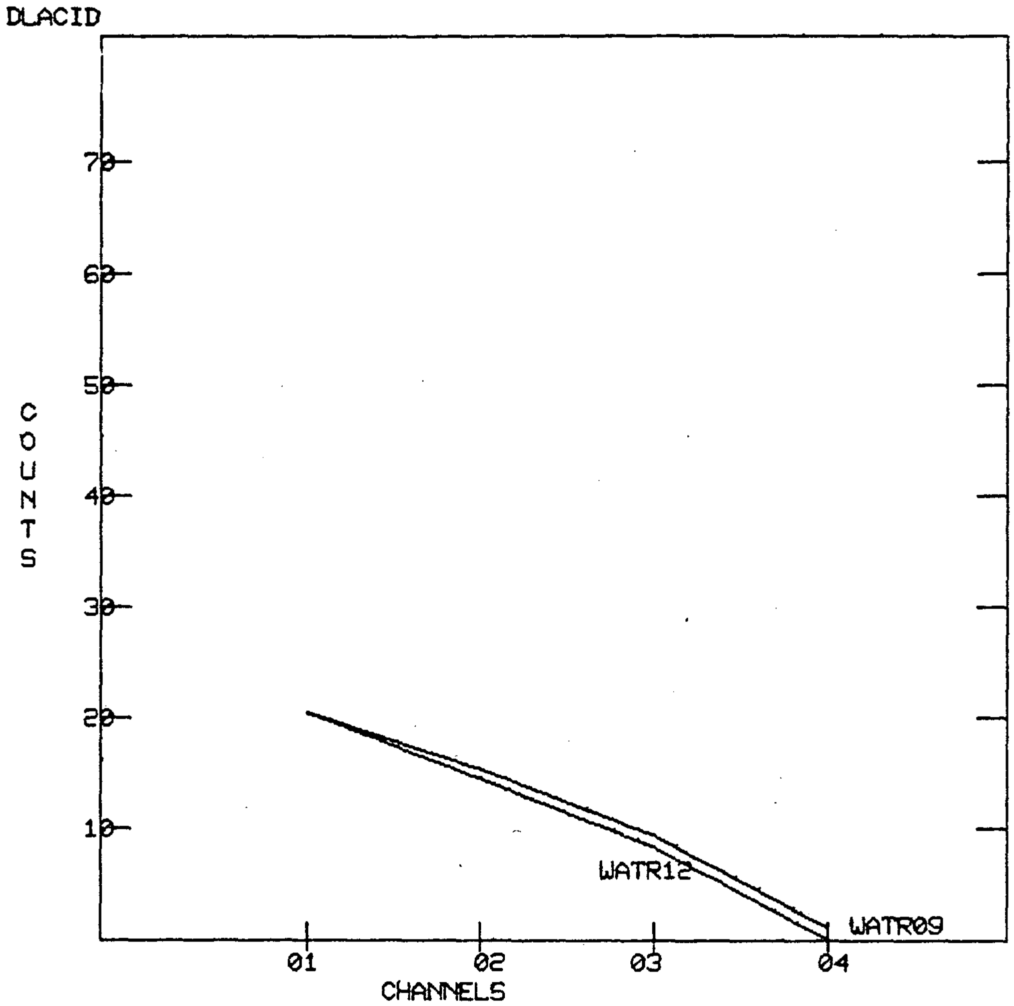

Figure 19. Computer-derived, four channel, spectral plots of diluted swamp/forest runoff training fields, Image 5.

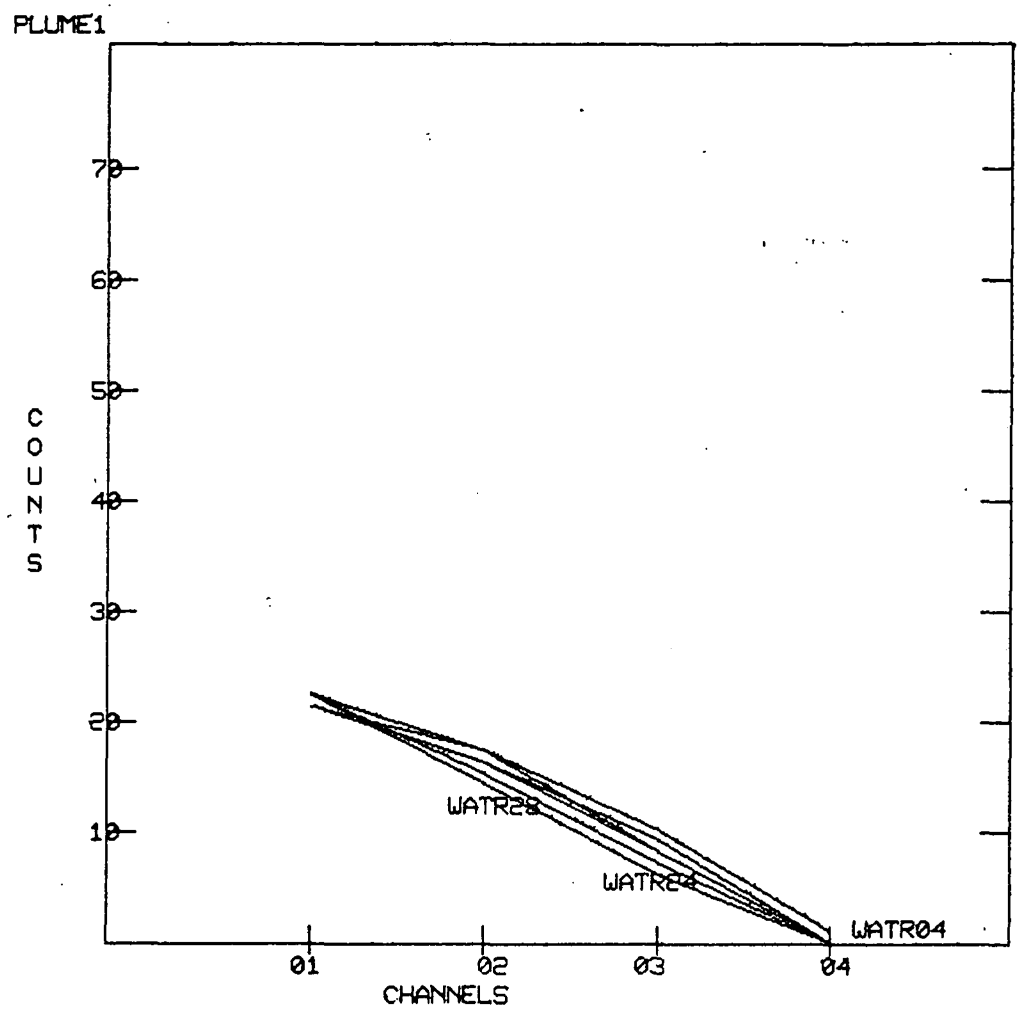

Figure 20. Computer-derived, four channel, spectral plots of highly turbid Apalachicola River plume training fields, Image 5.

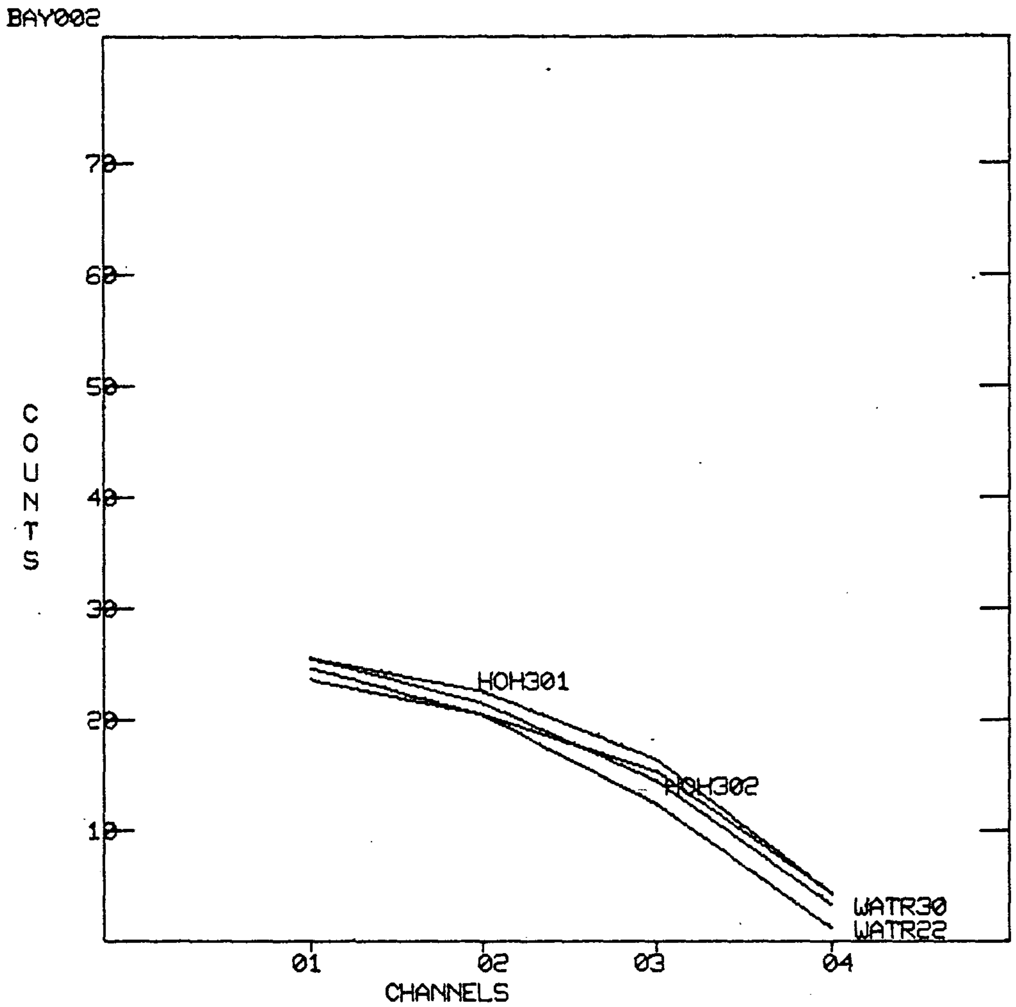

Figure 21. Computer-derived, four channel, spectral plots of a type of turbid Apalachicola Bay water training fields, Image 5.

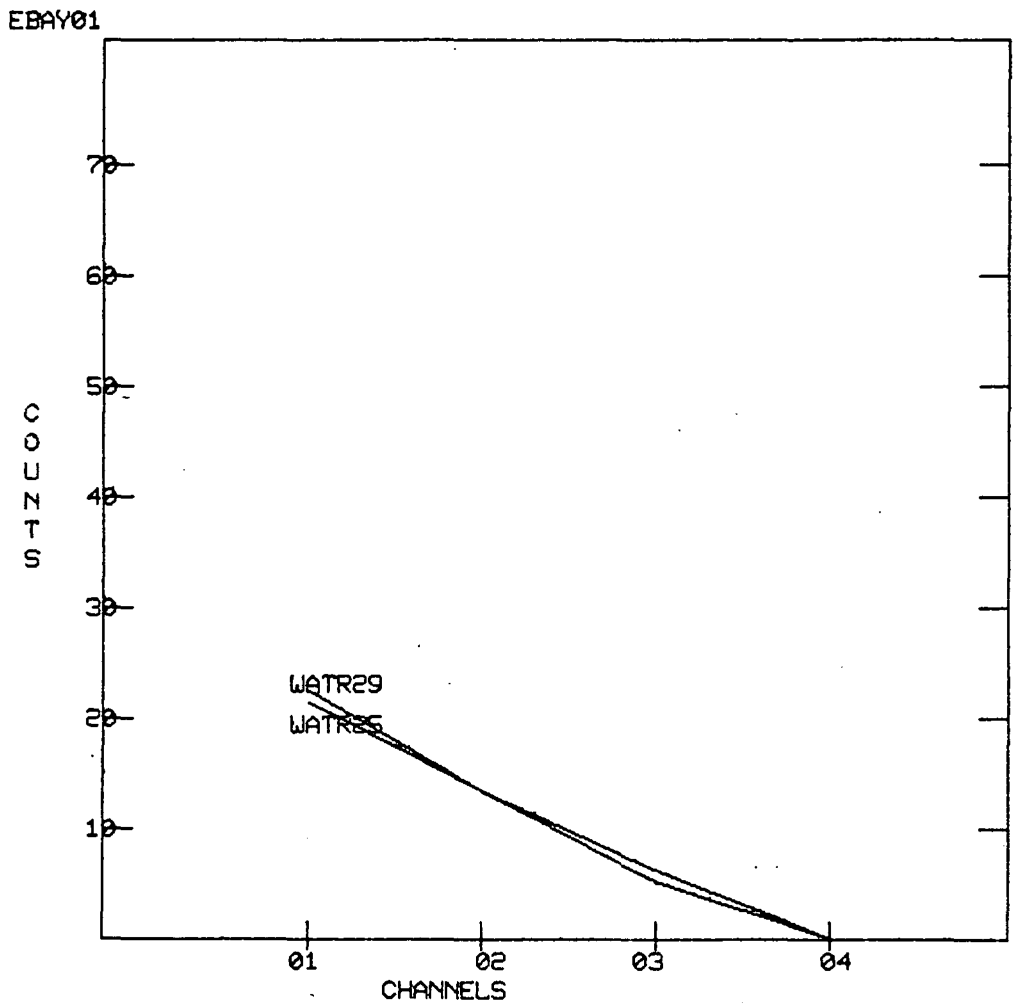

Figure 22. Computer-derived, four channel, spectral plots of a type of moderately turbid St. George Sound water training fields, Image 5.

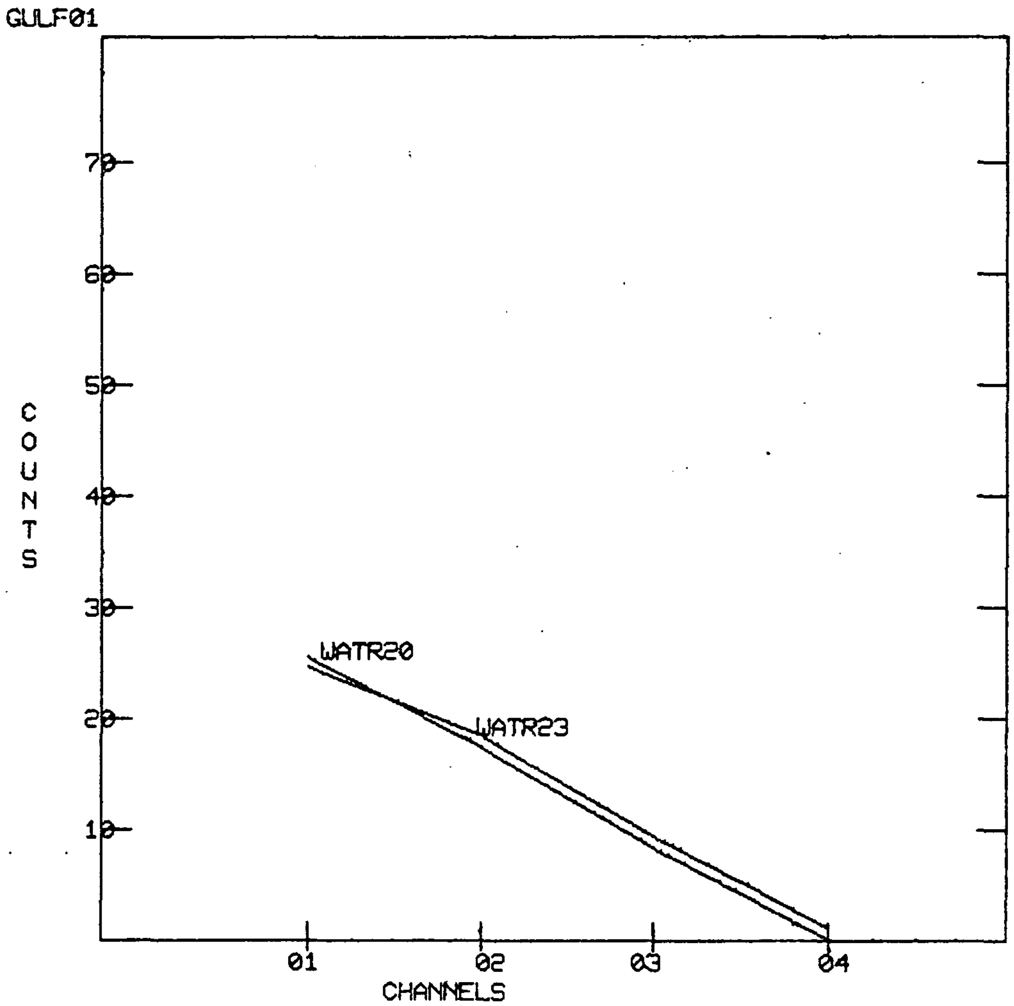

Figure 23. Computer-derived, four channel, spectral plots of shallow turbid Gulf water training fields, Image 5.

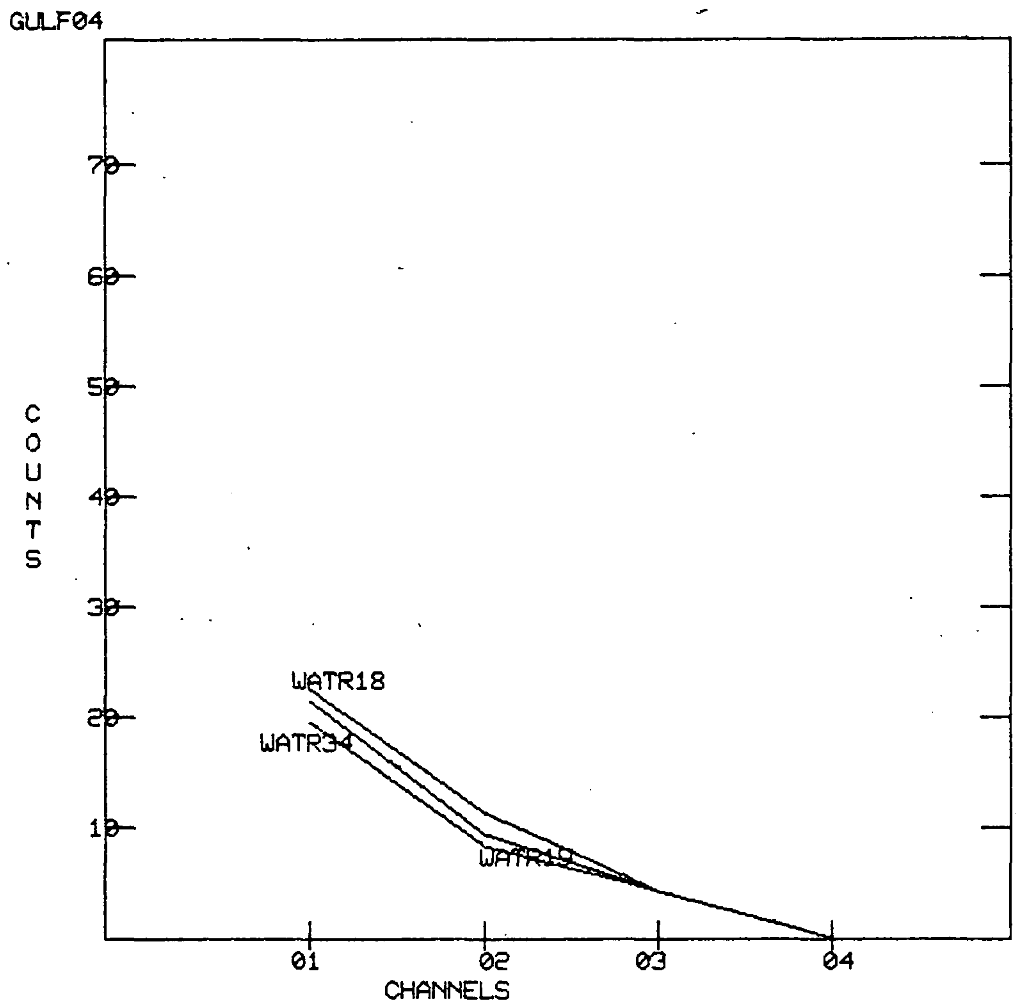

Figure 24. Computer-derived, four channel, spectral plots of clear, deep Gulf water training fields, Image 5.

TABLE 4. LANDSAT FOUR CHANNEL WATER CLASS COUNT MEANS FROM ALL CLASSIFIED IMAGES (Channels 1, 2 and 3 are on a compressed count value scale of 0 to 127 and channel 4 ranges from 0 to 64).

Class	Channel 1	Channel 2	Channel 3	Channel 4
Swamp runoff	19.33	12.60	7.91	1.40
Dilute runoff	22.04	15.25	9.34	1.40
Bay water 1	28.67	23.46	12.42	2.11
Bay water 2	29.82	22.50	12.30	2.15
Bay water 3	29.31	23.70	12.53	2.22
Bay water 4	29.34	23.56	11.90	1.63
Bay water 5	26.79	19.37	10.15	1.64
Bay water 6	28.01	26.24	8.72	0.86
Bay water 7	25.84	16.56	7.57	0.98
Bay water 8	21.85	12.67	5.54	0.49
Bay water 9	20.53	11.82	5.25	0.27
Bay water 10*	-	-	-	-
Bay water 11	25.78	16.60	9.54	2.37
Gulf water 1	28.78	15.56	7.39	1.12
Gulf water 2	24.44	12.05	5.97	0.83
Gulf water 3	23.73	12.21	6.05	0.88

* Only occurred in one Landsat image.

responses appear to correlate best with water color and turbidity, followed by Secchi depth.

FSU did not collect water quality information from the Gulf side of the barrier islands. It was, however, noted that as distance increases from the influence of the coast (islands) and approaches deeper areas, the percent reflectance of water drops off dramatically in Channel 2 and moderately in Channel 4. Count values for water in Channel 4 were always low as expected (Figures 23 and 24). It is very likely that both turbidity and spectral reflectance decreased with distance from the coast. Shallow coastal water types were also identified and suspected of having relatively high levels of turbidity.

TEMPORAL WATER COLOR (TYPE) DISTRIBUTIONS

After the water types were delineated and color-coded, the spatial distributions of the classes were examined in terms of the seasonal existing conditions at the particular time of image acquisition. An attempt was also made to identify possible environmental problem areas. For the interpretation of these images, it was important to keep in mind that Landsat, with minimal penetration capabilities into turbid coastal water, was only viewing surface water features. Features such as salt wedges characteristic of this estuary could be inferred. However, the bay system is usually considered to be vertically mixed.

The oldest image, 17 February 1973 (Figure 25), indicated relatively low wind conditions, primarily because water patterns were well defined. Being winter, the runoff was at an expected high. The flooding of the river has been found to be out of phase with rain and associated high amounts of runoff in the East Bay drainage basin (Livingston 1975). Generally, due to geographical distances and related atmospheric conditions, when it rains during the summer months to the north in the upper reaches of the Apalachicola River, land in the vicinity of East Bay is dry. During the winter the Apalachicola River is usually at low flow, but runoff is heavy from the East Bay basin. Table 5 has average monthly river flows, collected by the USGS, which also supported this statement (Graham et al. 1978b).

As in all observed images derived from MSS data, collected under low wind conditions, the swamp/forest runoff was held against the eastern shore of East Bay by the hydraulic head (pressure) produced by the easterly flow of river water from the Apalachicola River delta. The apparent primary sources of swamp/forest runoff are Cash and West Bayous. Swamp/forest runoff (Livingston, pers. comm; 1978) was also apparently being extruded, in an easterly direction, from the mouth of the Carrabelle River. There is probably less runoff present around the Carrabelle River than is shown in the classified image, because water that was not acidic was misclassified due to the striping effect.

At this time the swamp/forest runoff covered 16.34 percent or 1,120 hectares (2,765 acres) of East Bay (Table 6). Once the runoff reached Cat Point it was diverted into St. George Sound. There are two probable causes for this phenomenon. First, the net velocity of Apalachicola River water is in general toward the east, and second, there is an underwater channel, Bulkhead Shoals Channel, (see map in back pocket) which diverted water toward the south.

Water types within the bays and sounds appeared to be uniformly distributed. The barrier islands obstruct water leaving the Apalachicola River, forcing it to the east, west or south. Surface water is observed escaping to the south through Sikes' Cut, a channel in St. George Island. This suggests that river water which entered Apalachicola Bay is quickly forced into the Gulf by way of Sikes' Cut. The plume extruded from Sikes' Cut is readily apparent in this image. Water quality data at Station 1B (Figure 16), just inside the cut, lended credence to the hypothesis that fresh, nutrient laden water is lost to the Gulf of Mexico through Sikes' Cut. Station 1B had a high monthly mean surface nitrate/nitrogen value of 191 μg/l, an orthophosphate value of 8 μg/l, an ammonia reading of 16 μg/l, and a low salinity value of 2.3°/oo. This image was acquired during an ebb tide.

There is no appearance in this image (17 February 1973) of any diversionary effect upon current patterns due to the Gulf Intercoastal Waterway (see map in back pocket). There is, however, a visible boundary

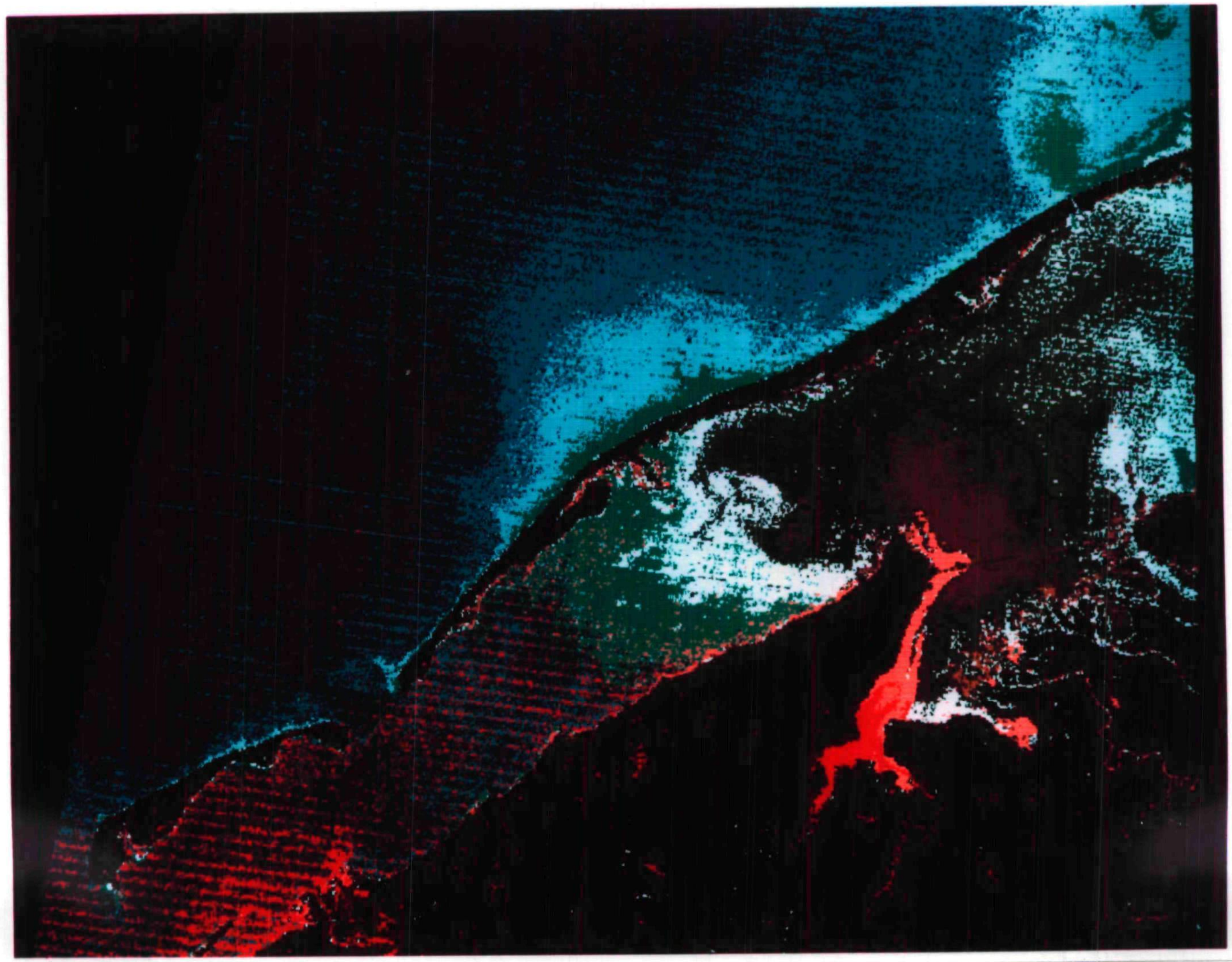

Figure 25. Classified Landsat image (17 February 1973) of water color distributions in Apalachicola Bay, Florida under low wind and ebb tide conditions (source; Hill 1978).

TABLE 5. AVERAGE MONTHLY FLOWS FOR THE APALACHICOLA RIVER AT BLOUNTSTOWN FOR PERIOD 1961-1976 (source; Graham et al. 1978b)

Month	Mean Discharge m^3s^{-1}	Ratio to Mean Annual Discharge
October	387	.55
November	391	.56
December	617	.88
Janaury	985	1.40
February	1,131	1.60
March	1,209	1.72
April	1,082	1.54
May	687	.97
June	580	.82
July	505	.71
August	496	.70
September	392	.56
$\bar{X}$	705	1.00

between two water classes formed where a channel, running north and south, extends from the center of the western side of Apalachicola Bay toward Apalachicola Municipal Airport. Such a boundary may indicate that aquatic communities in St. Vincent Sound are isolated to some as of yet undertermined extent from the nutrient laden waters of the Apalachicola River. Sufficient water quality data were not available for Station 1, but Station 2 data indicated high nutrient levels. Apalachicola Bay water extended to Dog Island at the time of image acquisition.

The second scene, 13 April 1973 (Figure 26), illustrates the same locations of swamp/forest runoff, namely West and Cash Bayous and the Carrabelle River. Runoff from the Carrabelle River is traced toward the east. The striping is less pronounced, at least for the bay water types. There is no apparent swamp/forest runoff in Round Bay. The river's hydraulic head is still keeping the runoff against the peninsula of East Point. This image depicts a flood tide situation. It is plausible that the runoff is ponding up in East Bay due to the effect of the incoming tide.

There were no apparent water boundaries caused by the presence of the Intercoastal Waterway which transverses southward across Apalachicola Bay from the river mouth. The river water has evidently flowed down the waterway in a southerly direction until it was pushed into an easterly direction by more influential bay currents. Apparently water leaves Apalachicola Bay, enters St. George Sound, and extends to the area just north of Dog Island. There was evidence that any water escape into the Gulf through East Pass between St. George Island and Dog Island.

TABLE 6. PERCENT AND HECTARES (ACREAGE) OF SWAMP/FOREST AND DILUTE RUNOFF FOR ALL IMAGES IN EAST BAY, APALACHICOLA BAY AND ST. GEORGE SOUND

Area and Water Type	Image Numbers						
	1	3	5	6	7	8	12
East Bay							
Swamp runoff	6.26 428.90 (1059)	6.83 468.18 (1156)	14.66 1004.80 (2481)	4.67 326.02 (805)	13.40 918.54 (2268)	9.47 664.20 (1640)	11.94 818.50 (2021)
Diluted runoff	10.08 690.93 (1706)	4.06 278.24 (687)	12.73 872.78 (2155)	.00 .00 (0)	22.00 1508.22 (3724)	3.45 236.12 (583)	18.11 1241.73 (3066)
Apalachicola Bay							
Swamp runoff	06 81.00 (200)	.02 3.64 (9)	1.34 304.56 (752)	.12 28.35 (70)	.04 8.50 (21)	.02 5.26 (13)	.04 8.91 (22)
Diluted runoff	1.17 265.28 (655)	.29 66.02 (163)	4.29 974.84 (2407)	.00 .00 (0)	.93 211.00 (521)	.29 64.80 (160)	1.49 339.98 (837)
St. George Sound							
Swamp runoff	.03 40.50 (100)	.07 12.15 (30)	1.72 315.09 (778)	.54 98.42 (243)	.61 110.97 (274)	.00 .00 (0)	.01 .81 (2)
Diluted runoff	.39 48.60 (120)	.72 132.44 (327)	6.21 1136.02 (2805)	.00 .00 (0)	18.25 3341.25 (8250)	.47 86.67 (214)	8.42 1541.43 (3806)

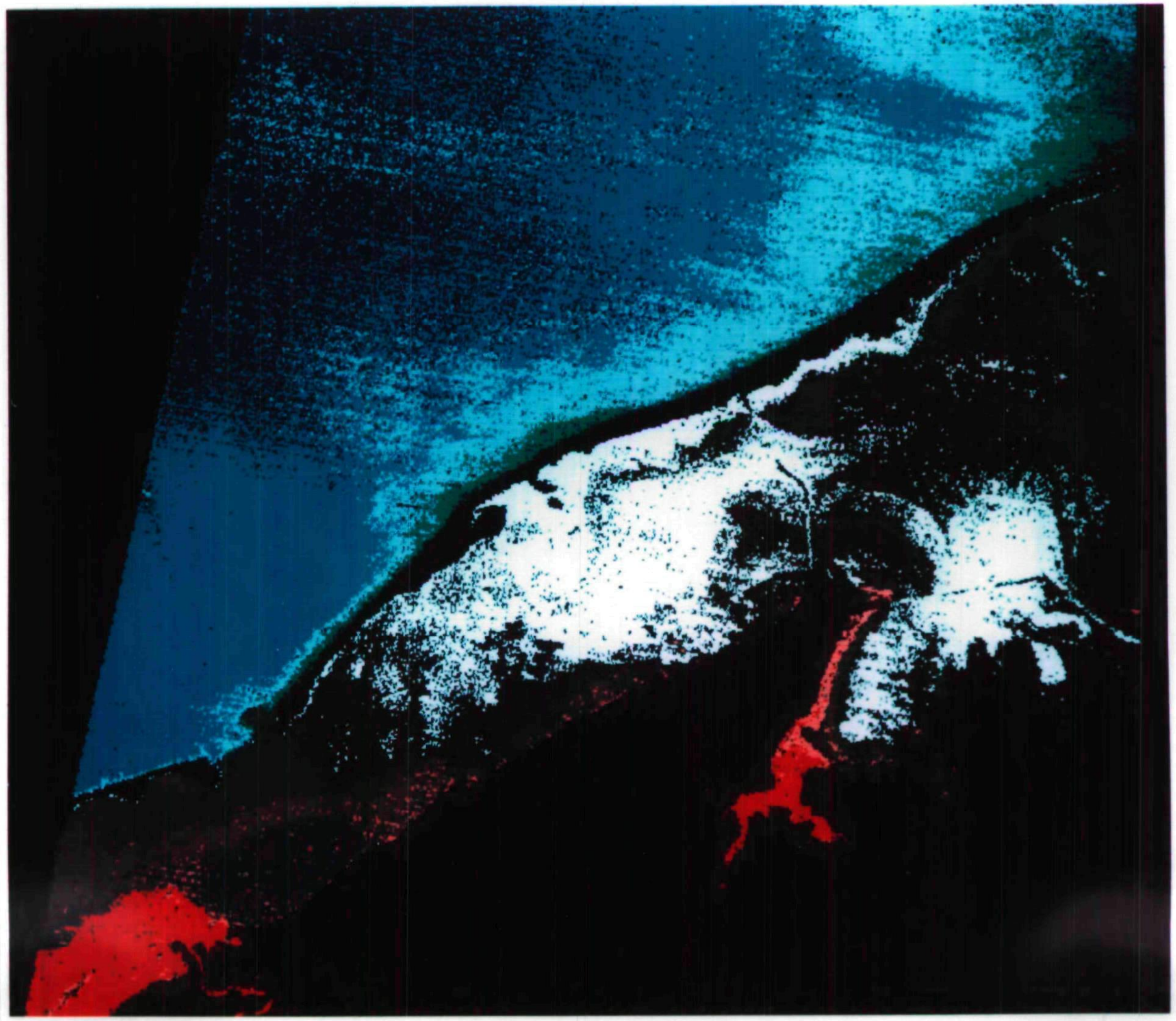

Figure 26. Classified Landsat image (13 April 1973) of water color distributions in Apalachicola Bay, Florida under low wind and flood tide conditions (source; Hill 1978).

The classification product generated from MSS data acquired 21 December 1973 (Figure 27) depicts the distributions of water types at a time of low flow in the Apalachicola River and moderate runoff from the East Bay drainage basin. Areas color-coded red outside the study area cannot be positively identified as swamp/forest runoff, but they may be highly suspected as such. The necessary water truth is lacking. The dilute swamp/forest runoff in this scene was apparently driven by the wind against the western shore of East Bay. Shoal Bayou, Alligator Bayou and numerous smaller inlets are affected. Wind broke up the many boundaries, which normally occur when there is little wind. While swamp/forest runoff covers a greater extent of East Bay, once the swamp/forest runoff enters Apalachicola Bay it is transported into St. George Sound. The plume of the Carrabelle River is also still oriented in an easterly direction. Apalachicola Bay waters enter St. George Sound and pass again to the vicinity of Dog Island. Some water is moving out into the Gulf instead of the area north of Dog Island. An apparently exposed spoil bank is present paralleling the Intercoastal Waterway just south of the town of Apalachicola (Figure 27). St. Vincent Point is more exposed than in previous scenes, indicating a low tidal condition.

Lines of foam are identified and misclassified as land. The foam lines, convergence or water boundary conditions, are located on the Gulf side of West Pass and off Cape St. George. The foam near West Pass implies that bay water, once it leaves West Pass, moves westward along St. Vincent Island. Lines of foam and debris often occur between fresh water and the more dense salt water. In this case, the less dense fresh water is from Apalachicola Bay and the saltier water is that of the Gulf of Mexico. This image depicts a situation in which an ebb tide is beginning to occur. Shoreline currents, on the Gulf side of the islands west of Cape St. George, appear to be moving eastward.

Tidal records indicated that the tide was beginning to flood the bay at the time the image of 3 March 1974 was acquired (Figure 28). The flow of the Apalachicola River at Blountstown was 923 m^3/s, but the average for the previous 10 days was 1,400 m^3/s (Graham et al. 1978b). Local runoff in either East Bay or near the mouth of the Carrabelle River. One type of highly turbid water is occurring in the major portions of East Bay, Apalachicola Bay, and St. Vincent Sound. There is a dispersed plume being emitted from Sikes' Cut. Water has moved into St. George Sound from the bay and is paralleling the mainland. Water distributions in the image suggest that an influx of Gulf water through East Pass is forcing this water against the mainland. As in previous images there is evidence of a large area of water mixing (swirling) just to the east of the toll bridge going to St. George Island in St. George Sound. Again, it is credible that water leaving Apalachicola Bay through West Pass moves westward. A sizeable sediment plume is traveling southward from Cape St. George. A longshore current is the most probable cause of this plume's direction. No apparent direction of shore line currents is evident. Of environmental concern in the Apalachicola Bay area is the effect of the island supporting the toll bridge from Cat Point to St. George Island on the neighboring water bodies. Two channels exist, one north and the other south of the island. As inferred from this classified image, surface water is evidentally transported into St. George Sound in a path parallel to these channels. The result is the eddy located on the east side of the island in St. George Sound. This particular event is apparent in

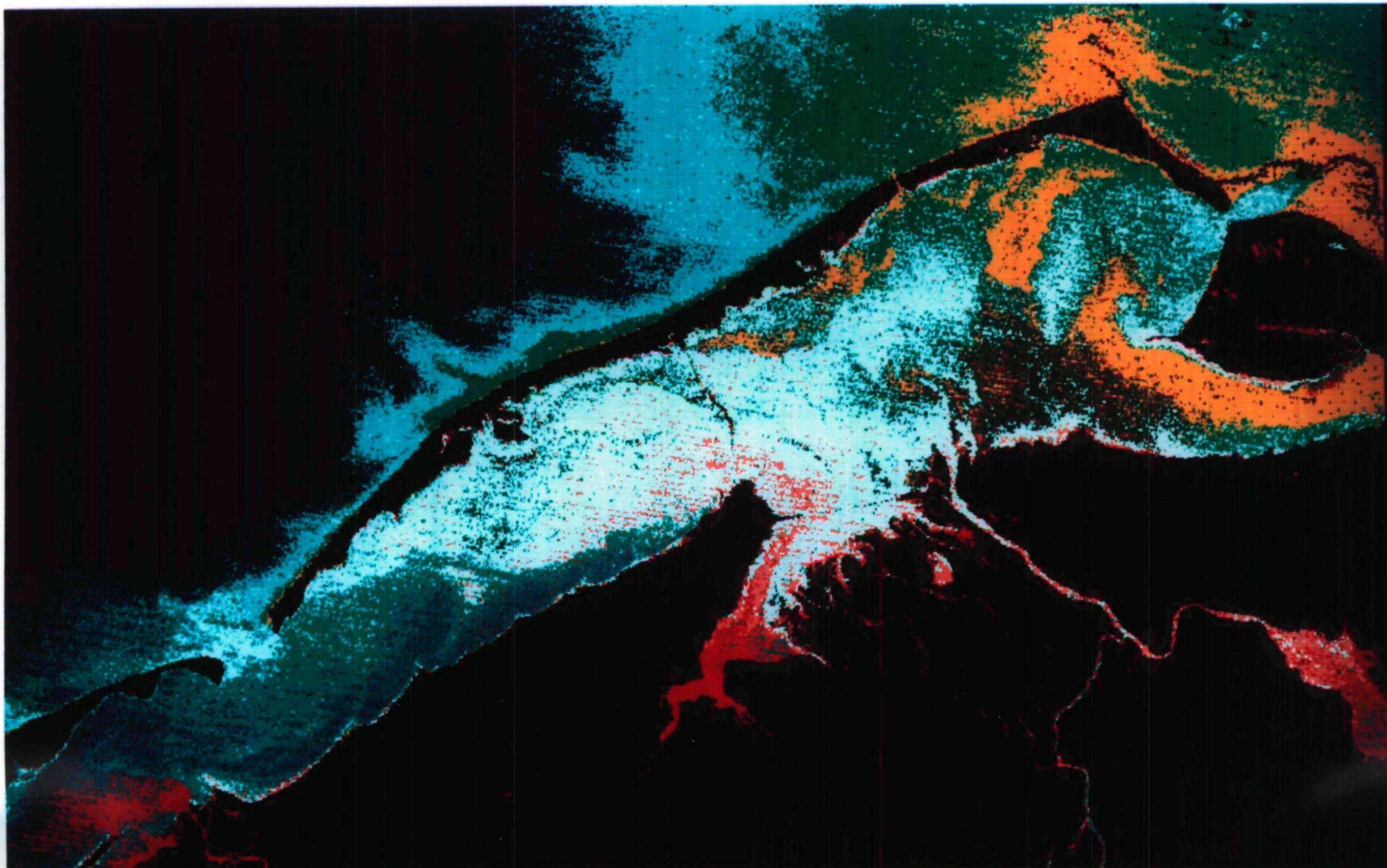

Figure 27. Classified Landsat image (21 December 1973) of water color distributions in Apalachicola Bay, Florida under moderate northeast wind and probable ebb tide conditions (source; Hill 1978).

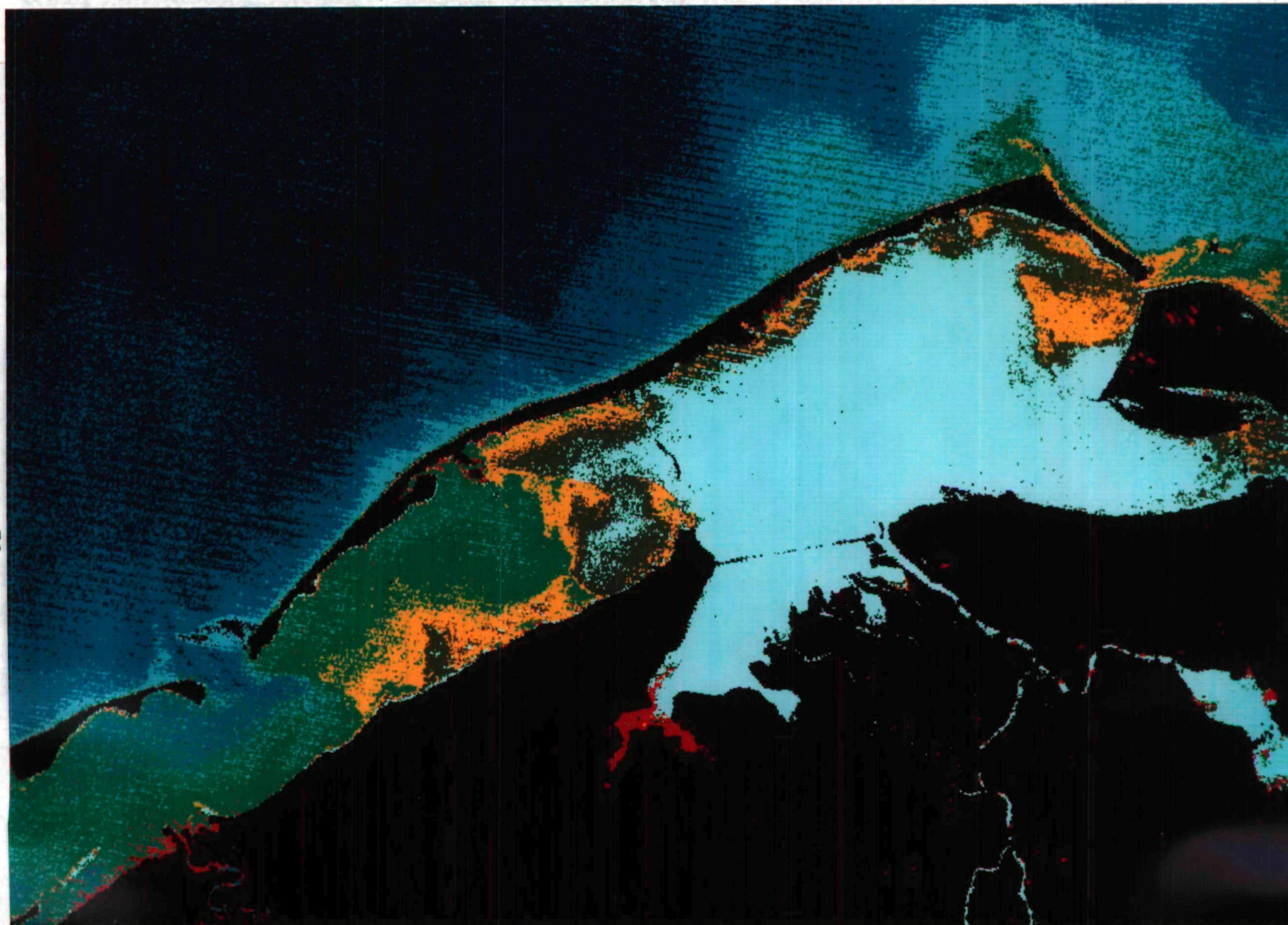

Figure 28. Classified Landsat image (3 March 1974) of water color distributions in Apalachicola Bay, Florida under low wind and beginning flood tide conditions (source; Hill 1978).

other images when wind conditions are low. The island influences mixing in St. George Sound.

The extensive oyster bed protruding southward from St. Vincent Point could conceivably offset the distribution of currents in the area of West Pass. Distributions of water types in several Landsat scenes support this hypothesis. Circulation patterns in St. Vincent Sound are also visible, but have a low degree of organization. Detailed in situ current studies must be conducted to fully understand circulation patterns in both of these areas.

Another excellent example of the dramatic effect of wind on this shallow bay is evident in the fifth image, 23 October 1974 (Figure 29). Although some clouds are present in southwest corner of this scene and the eastern portion of St. George Sound, general current patterns can still be examined. It is not uncommon for the wind to be out of the northeast at this time of year. The wind again distributed swamp/forest runoff into Round Bay, Shoal Bayou, Alligator Bayou, and all other inlets along the western shore of East Bay. This runoff covers 35.40 percent or 2,427 hectares (5,992 acres) of East Bay. Cloud shadows over water appear as swamp/forest runoff in east St. George Sound, because the results have a spectral signature that is nearly identical to that of the runoff. It is, therefore, difficult to discern the direction of the plume from the Carrabelle River. Wind is known to have an intensive mixing effect on this bay because it is only about four meters at its deepest point and has a long fetch. Ingle and Dawson (1953) emphasize that wind-induced flow can have a greater effect on bay hydrodynamics than the tide for short periods. Gorsline (1963) stated Apalachicola Bay tides are much affected by winds and under strong wind conditions the astronomic tide could be completely obscured. There are no visible homogeneities (brood areas that have the same spectral signature) in the surface waters of the bay under the wind conditions existing when the scene was recorded. Very little water appears to be moving from the bay into St. George Sound. Water from Apalachicola Bay and St. Vincent Sound is being forced out of Sikes' Cut and West Pass.

Water from St. George Sound is being blown into Apalachicola Bay, as indicated in the image and by the surface salinity reading of 33.7°/oo at Station 1C. The boundaries which normally delimit the edges of various water classes and/or underwater man-made structures are not visible, apparently because they were totally broken up by wind action. The net flow of water outside the islands is also in a southwesterly direction.

Of the eight classified images, the scene acquired 26 February 1975 (Figure 30) best illustrates the boundaries between water types. Wind conditions were low, and as in almost all previously observed images with water boundaries, water types and current patterns are easily discernible. The river flow was 2,062 (about 2.9 times the annual mean flow), and the tide was near ebb slack (Graham et al. 1978b). Swamp/forest runoff is protruding from the East Bay drainage basin and the Carrabelle River. The runoff in East Bay is again positioned against the East point peninsula. The western portion of East Bay, along with associated bays, bayous and inlets is free of runoff. The plume of the Carrabelle River is moving in an easterly direction, once again entering St. George Sound.

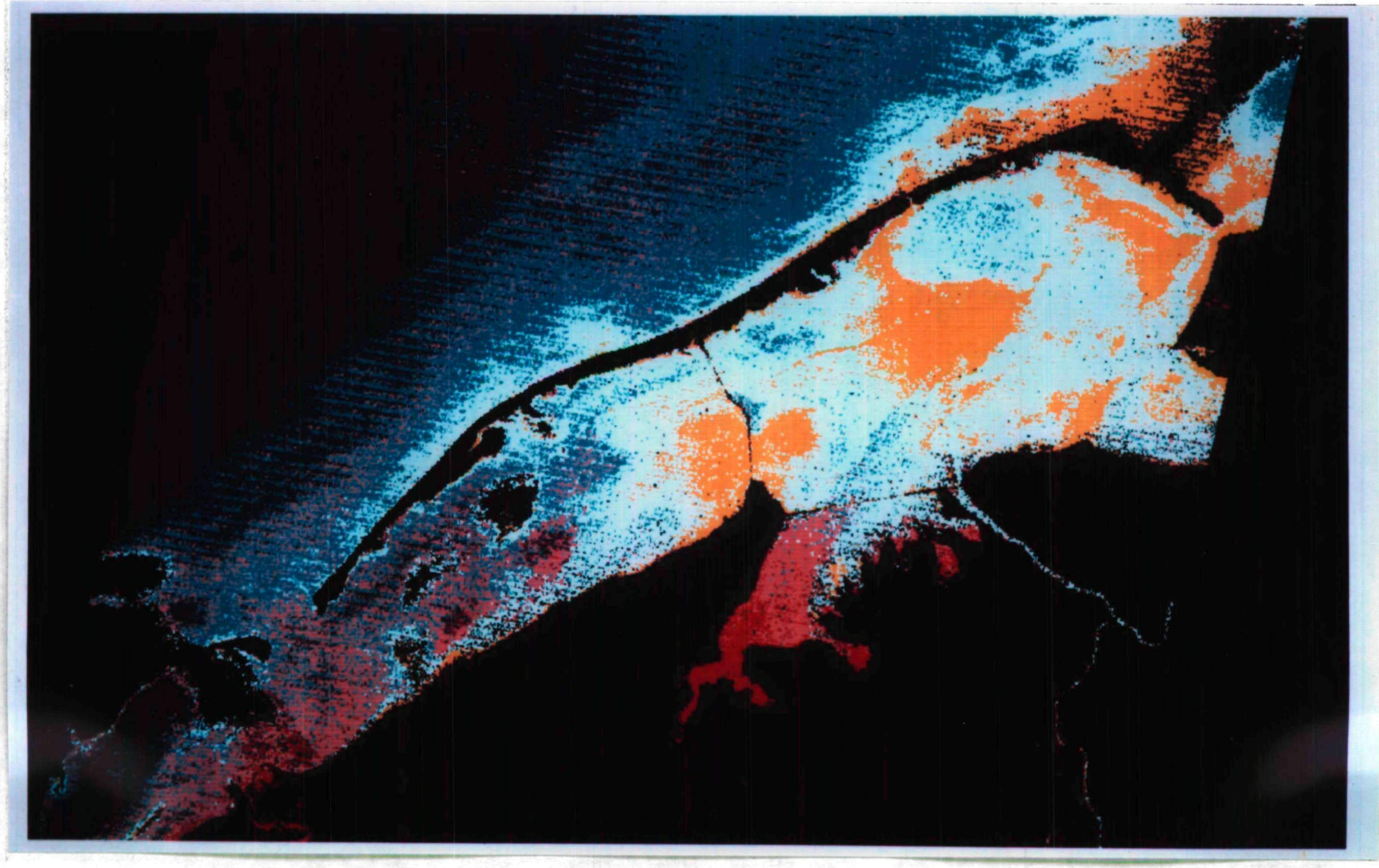

Figure 29. Classified Landsat image (23 October 1974) of water color distributions in Apalachicola Bay, Florida under strong northeast wind conditions (source; Hill 1978).

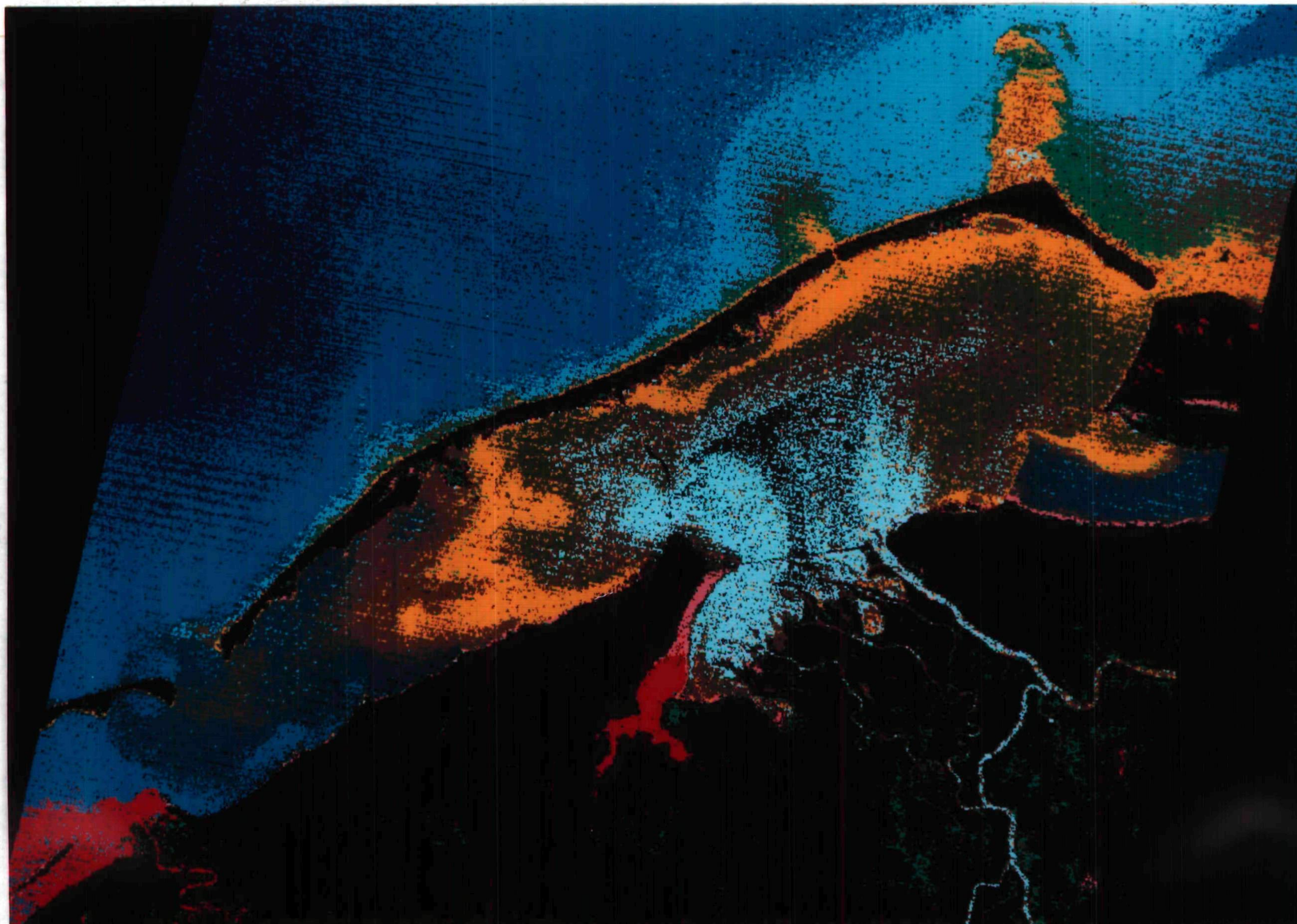

Figure 30. Classified Landsat image (26 February 1975) of water color distributions in Apalachicola Bay, Florida under low wind and near ebb slack tide conditions (source; Hill 1978).

Water types in Apalachicola Bay and neighboring sounds were uniformly distributed. Although water quality sampling stations were not adequately dispersed to collect data from each of the water types (they may never be), the water data make it possible to verify some of the inferences. The water color-coded tan and dark and light brown indeed had the lowest Secchi readings, the highest color (omitting swamp/forest runoff), the highest turbidity, and the lowest salinity of the water types in the bay. The water color-coded dark green represented a water type with high Secchi readings, low color, low turbidity, and high salinity. The water color-coded gold generally had a higher Secchi reading, a bit higher CPU (color) reading, lower turbidity, and higher salinity than the water color-coded dark green (Livingston, pers. comm.; 1978). Gulf waters probably had even lower color and turbidity, but also had higher salinity and Secchi depths than all the other water types. These data demonstrate that the water at the mouth of the Apalachicola River is the most turbid and sediment laden and has the highest reflectivity of all the bay waters. As the distance from the Bay mouth increases, water quality parameters change in the following manner; turbidity decreases, Secchi depth increases, color decreases, salinity increases, and spectral reflectance decreases.

The area of swirling (mixing) is again recognizable in the western portion of St. George Sound. The bay water is moving eastward and has reached the area just north of Dog Island. Apparently, very little water from St. George Sound is moving through East Pass and into the Gulf. As is observed in other images, the greatest amount of water leaving Apalachicola Bay travels by way of West Pass. Sikes' Cut again contributes to the loss of bay water to the Gulf. Monthly mean water quality data indicate that for February the water at Stations 1A and 1B was relatively high in nutrients. Surface orthophosphates were 2.2 μg/l and 3.7 μg/l respectively while surface nitrate/nitrogens were 59 μg/l and 117 μg/l, respectively. Shoreline currents at Cape St. George cause a sediment plume to be expelled into the Gulf. Water ejected from West Pass is moving to the west.

Several water boundaries were perhaps caused by the presence of man-made underwater structures. Even if the locations of the underwater structures were not known through other sources, their locations could be established through close scrutiny of water type boundaries found on the classified image. Bulkhead Shoals Channel (see map in back pocket), oriented parallel to East Point between Godley's Bluff and Cat Point, is diverting the swamp/forest runoff into St. George Sound. A boundary is visible over the approximate location of the channel. The boundary which is visible in the vicinity of the Gulf Intercoastal Waterway evidently indicates that the river water heading south toward St. George Island is diverted to the east and west by the causeway. This interpretation of the image requires substantiation by further water sampling investigations which will better define the hydrodynamics of the area. The third, and most striking boundary occurs just south of Green Point. It was first thought that the aforementioned channel leading the airport from the bay had caused this phenomenon. However, the channel is not in the immediate vicinity. Less dense fresh water from the river probably met the more saline waters of St. Vincent Sound, resulting in this particular boundary. Such a boundary should be further investigated, for it is highly likely that large oyster and other aquatic communities in St. Vincent Sound are cut off from the nutrient laden waters of the Apalachicola River and Bay System under these river flow, wind, and tidal conditions.

The seventh image, 20 July 1975 (Figure 31), is indicative of the effects of clouds, cloud shadows, and haze. Clouds obstructed most of the features in this image. This is a summer scene where, as expected, the river flow was low. There is a very small plume at the mouth of the Apalachicola River. A slight boundary is noted south of Green Point and there is a plume off of Cape St. George. The turbid waters are obviously confined by the barrier islands. Swamp/forest runoff is probably present, but is masked by the effects of weather. Clouds are a serious problem in gathering this type of remote sensing information.

Lastly, the image acquired 19 August 1976 (Figure 32) directly supports the observations and inferences made from the 23 October 1974 image (Figure 25). The wind is again out of the northeast. The distributions of the swamp/forest runoff in both scenes duplicate one another. The swamp/forest runoff transverses most of East Bay (30.05 percent; 2,060 hectares; Table 7). Round Bay, Shoal Bayou, Alligator Bayou, and all of the other inlets on the western shore of East Bay are inundated with runoff. Again the runoff from the Carrabelle River is dispersed in all directions, as opposed to its sometime easterly flow. The usual water boundaries are not visible in the bay and the likelihood is great that most of the bay water is being forced through West Pass. There is no readily discernible surface plume being emitted from Sikes' Cut. The water is well mixed as expected off Cape St. George. The nearshore Gulf Waters appear to be flowing in a southwesterly direction. Water from St. George Sound has pushed into Apalachicola Bay. These observations are qualitatively supported by the water quality data.

This portion of the study demonstrates the value of this technology to identify, delineate, and monitor the distribution of water types in an estuarine system. Field personnel at the Florida Department of Natural Resources Oyster Sanitation Station, are responsible for monitoring coliform bacteria and other pollution in Apalachicola Bay. They have corroborated the water patterns in these Landsat images, and the Landsat data verify their theories on coliform distributions. Such theories were a result of ten, plus, years of experience and sampling in the bay. The coastal engineers at the UF have already begun to utilize these Landsat data in the initial planning stages of a large scale hydrodynamic modeling program for the East Bay drainage basin and bay property. FSU personnel stated that the Landsat information will give tremendous spatial resolution to their hydrographic measurements and numerical model of Apalachicola Bay, Florida (Graham pers. comm.; 1978).

DISCRIMINATION OF LAND-USE ACTIVITIES

This section describes the results of the effort to use Landsat data to detect land-use activities with an emphasis on silviculture practices. This research was conducted to detect and monitor potential environmental impacts of land-use change in the East Bay drainage basin on water quality in the bay

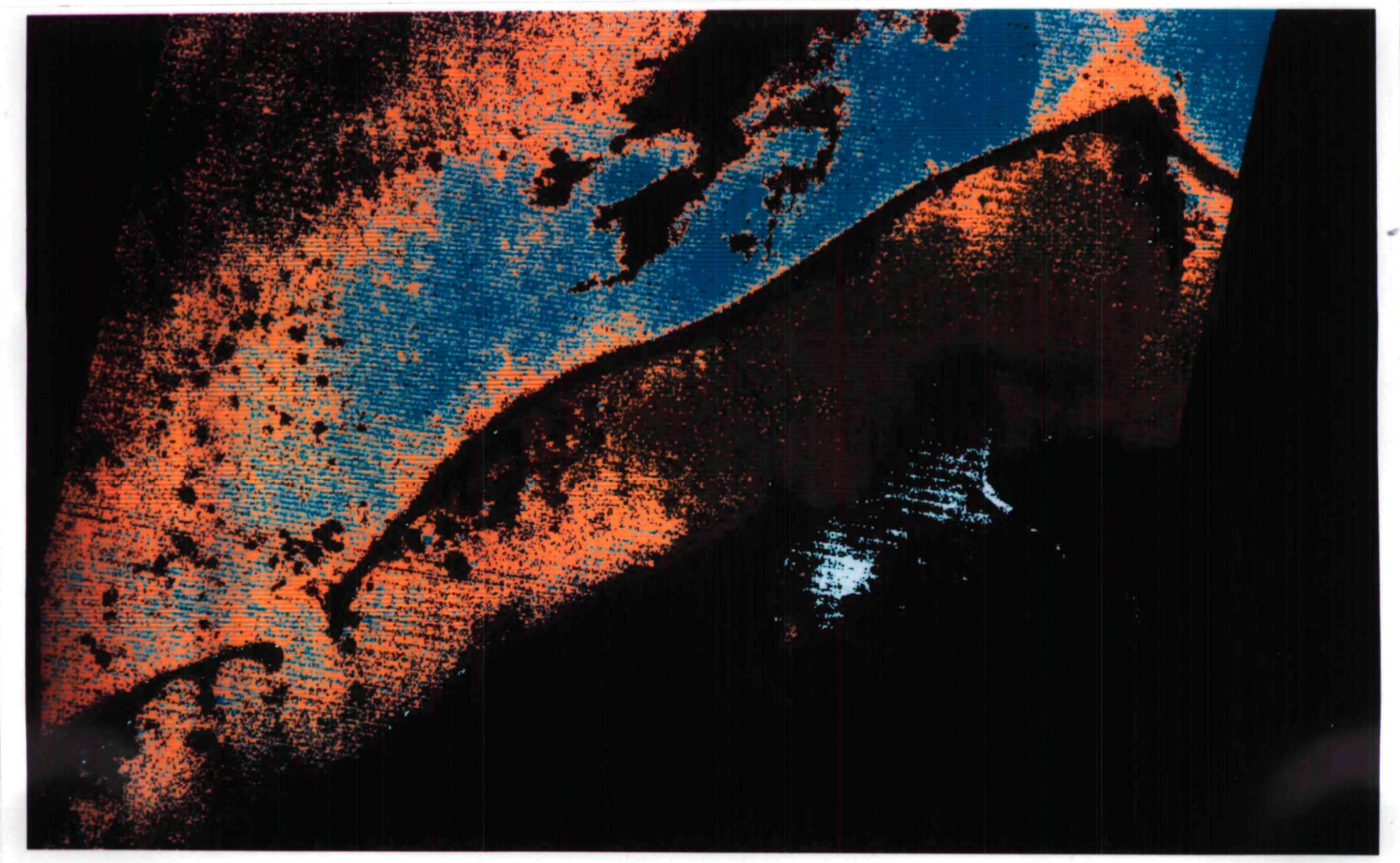

Figure 31. Classified Landsat image (20 July 1975) of water color distributions in Apalachicola Bay, Florida under much less than optimal atmospheric conditions (source; Hill 1978).

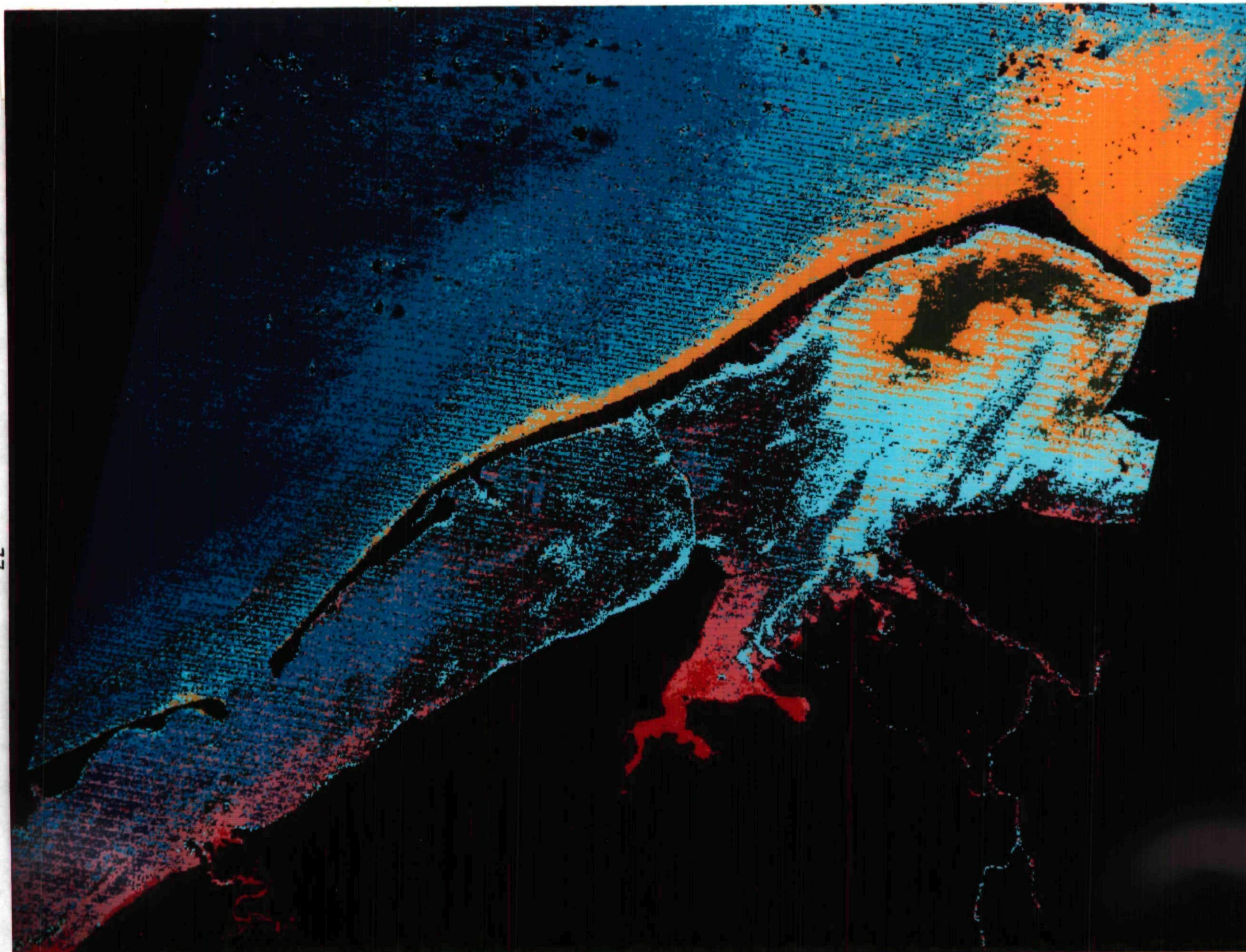

Figure 32. Classified Landsat image (19 August 1976) of water color distributions in Apalachicola Bay, Florida under strong northeast wind conditions (source; Hill 1978).

TABLE 7. LANDSAT FOUR CHANNEL LAND CLASS MEANS (IN COUNTS) FROM ALL CLASSIFIED IMAGES

Class	Channel 1	Channel 2	Channel 3	Channel 4
Urban	35.16	21.07	39.77	18.77
Marsh	24.21	18.48	26.43	13.32
Natural	22.05	15.21	25.70	13.80
Sand	60.76	65.62	65.21	30.28
Agriculture	36.15	35.64	42.15	20.25
Bank	21.85	17.82	17.38	7.51
Revegetated	20.80	15.65	23.27	15.14
Clear-cut	22.18	17.74	17.18	9.86

system. As previously mentioned, the lumber company which owns most of the land in the East Bay drainage basin supplied the bulk of the ground truth information used in this segment of the study. Six Landsat-1 scenes (Figures 33 and 34) were analyzed to produce the results in this section (Table 3).

The parameters monitored for this study were the Landsat-1 derived four channel spectral reflectance responses of selected land-use types within a particular scene. The major land categories (classes) of interest in the East Bay drainage basin are clear-cut (within one year), revegetated, swamp/forests, marshes, and roads. As previously mentioned, fourteen final land categories were selected. Figure 34 is the land color-code table for all land classified images.

This section describes the detectability of individual land-use classes and also presents a temporal interpretation of the classified images. This is followed by an assessment of the reliability of said data.

Urban areas in this particcular geographic area were found to have unique bimodal spectral signatures which made them easy to discriminate from all the other classes. Small rural towns, such as Apalachicola, often demonstrate this characteristic signature (Stone, pers. comm., 1977).

Next to clouds, sand beaches had the highest spectral reflectance. Average values for sand in Channels 1, 2 and 3 were 60.76, 65.62 and 65.21, respectively. Sand and urban classes were combined into one class since they both had highly reflective spectral signatures and represented non-vegetated areas.

There was very little agriculture in the study area. Small plots may exist, but the area is not conducive to traditional farming practices, especially in the East Bay drainage basin. There is, however, an area of specific interest to several regulatory agencies and universities along the

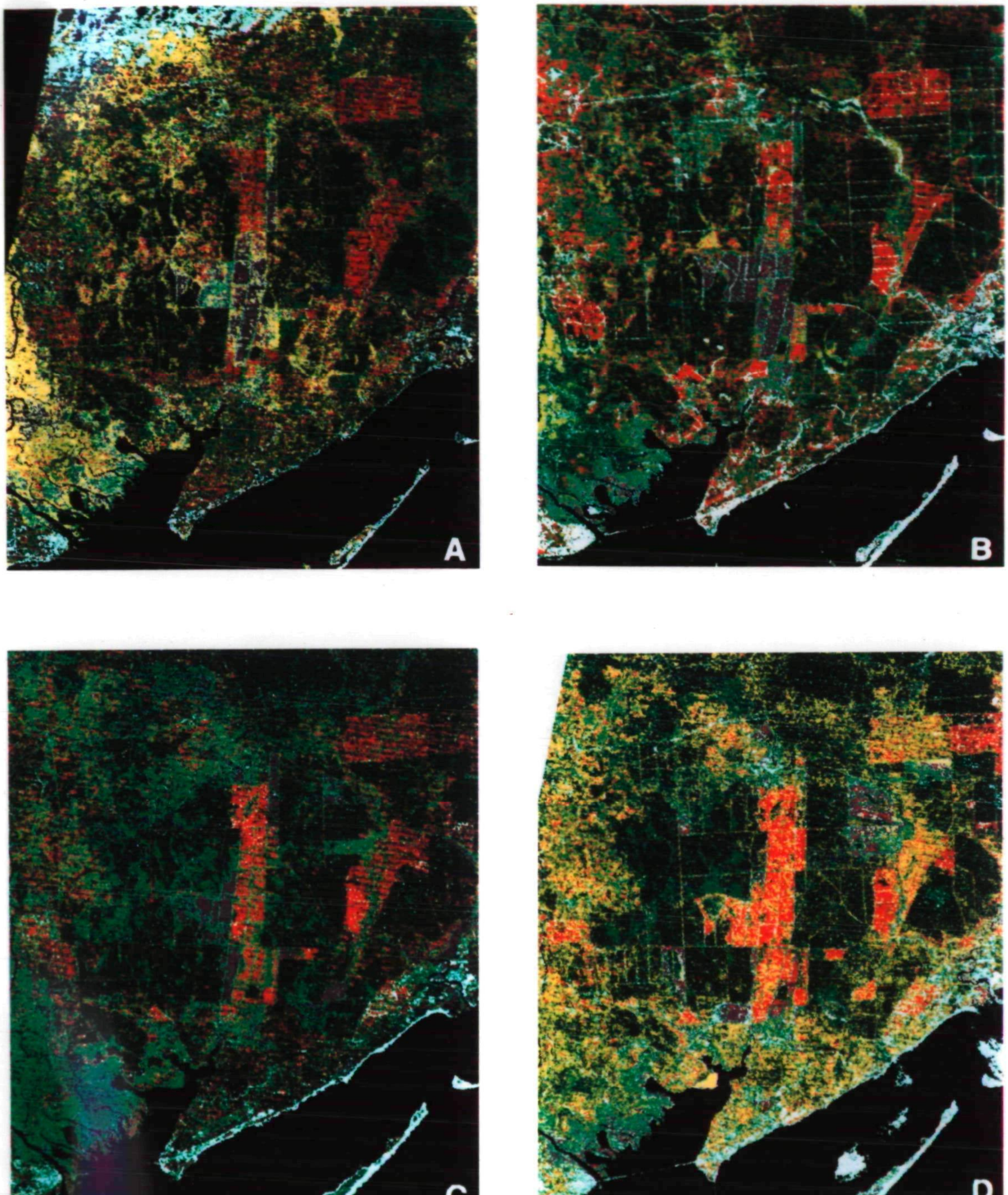

Figure 33. Classified Landsat images of land-use activities in East Bay drainage basin (A - 17 February 1973; B - 13 April 1973; C - 21 December 1973; D - 23 October 1974 (source; Hill 1978).

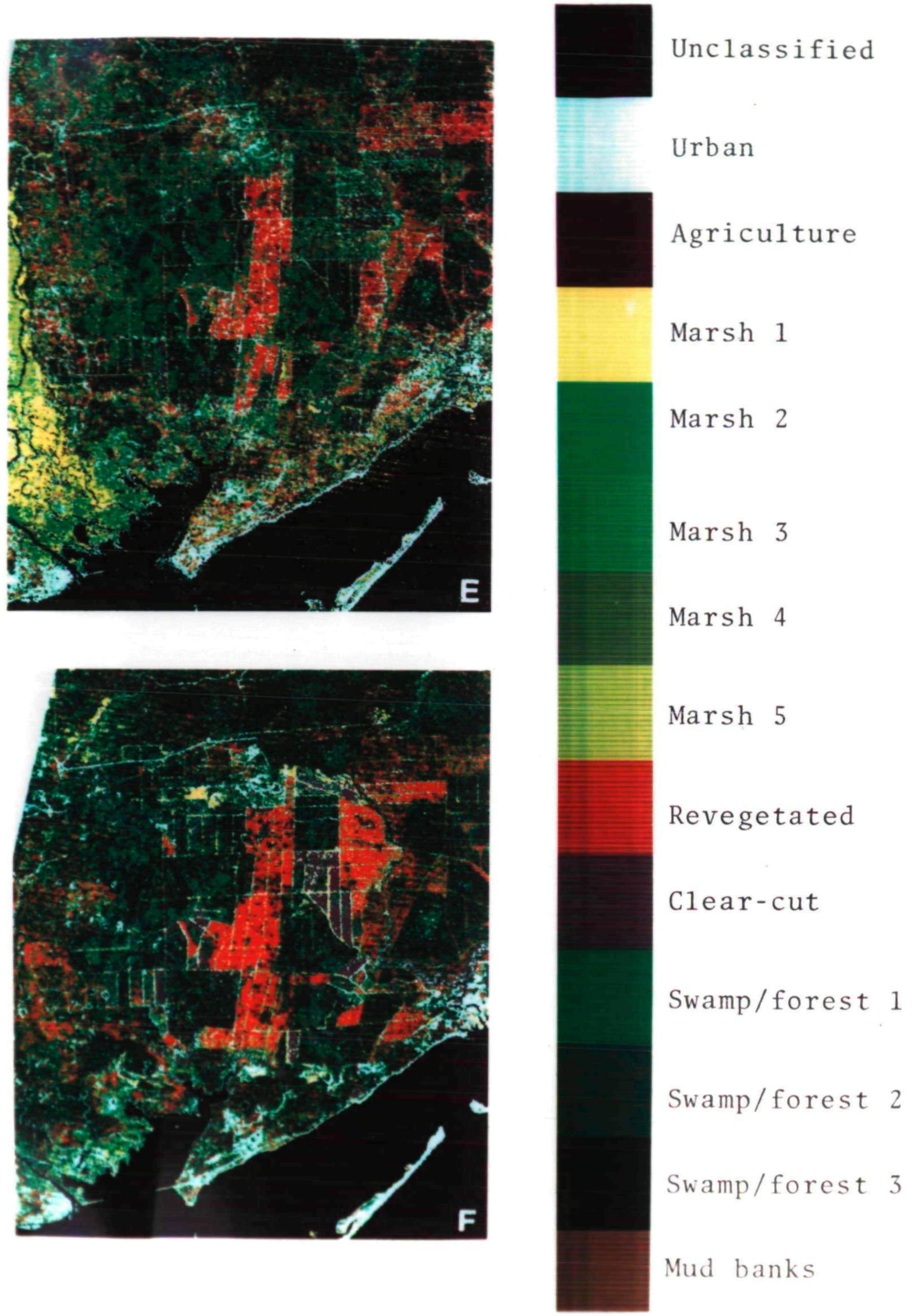

Figure 34. Classified Landsat images of land-use activities in East Bay drainage basin (E - 26 February 1975; F - 19 August 1976). Included is the land-use color table for classified images (source; Hill 1978).

Apalachicola River. This is the M and K Ranch located on the west bank of the Apalachicola River. Although not of direct interest to this project, the area was sampled. This particular land-use activity demonstrated high count values in Channels 1, 2 and 3. The area was found to have a unique spectral signature and was assigned a maroon color. The ranch was classified in three scenes; 13 April 1973, 21 December 1973 anmd 26 February 1975. On 21 December 1973, the ranch class conflicted with the urban and sand classes. For this date, the ranch was put into the urban and sand class and was colored white. The ranch was classified, but it was cropped from the final image because of picture size limitations, and it was of no particular importance to this particular project.

Marshes and swamp/forest categories were very difficult to discriminate from each other. Marshes are interspersed with swamp/forest communities, at least along shorelines of East Bay Seasonal characteristics, such as die-back and browning of vegetation, often hindered separation. The computer-derived four channel spectral plots (signatures) were of assistance in determining their separability. Figures 35 and 36 clearly demonstrate the spectral similarities of marsh and swamp/forest classes. The closeness of spectral means in all four channels of marsh and swamp/forest communities makes separation very difficult. Best marsh discriminations were achieved for the image 13 April 1973 (Figure 33-B). The marsh classes were separated from each other primarily by their different appearance on the image generated from the display tape and an examination of their spectral statistic. Vegetation may have been starting to "come alive" at this time. In this image it is easy to discern brackish marshes (color-coded light green) lining the bayous along the delta. These areas were verified as marshes through USGS maps. Plant species unique to the flood plain of the Apalachicola River were also found to be spectrally unique in the spring.

During the classification of land-use features a unique class appeared in a few images at the tips of the Apalachicola River delta. This feature is very pronounced in the 21 December 1973 image (Figure 33-C). Tidal data and nautical charts indicate that these features are either a product of depth penetration and the return of energy from a reflective bottom through several centimeters of turbid water or are exposed mud flats. The low count value in Channel 4, 7.51, indicated that this feature was probably water.

Roads often formed excellent boundaries around the fields of interest and frequently were the only points of reference in the study area. Some 500 miles of road lie within the lumber company's land in the vicinity of the East Bay drainage basin. The roads in the study area are usually composed of a highly reflective material. They may, however, be masked by overhanging trees or, due to the low spatial resolution of the satellite, may be indistinguishable from neighboring vegetation (i.e., marshes, revegetated areas). Roads may also have appeared as a marsh class, for the channels lining the roads often generate marsh communities (Figures 35 and 37).

Most roads are paralleled by drainage channels often 2 to 3 meters in width and approximately 2 meters deep. The channels drain swampy areas to provide suitable growing conditions for pine seedlings. The road and channel

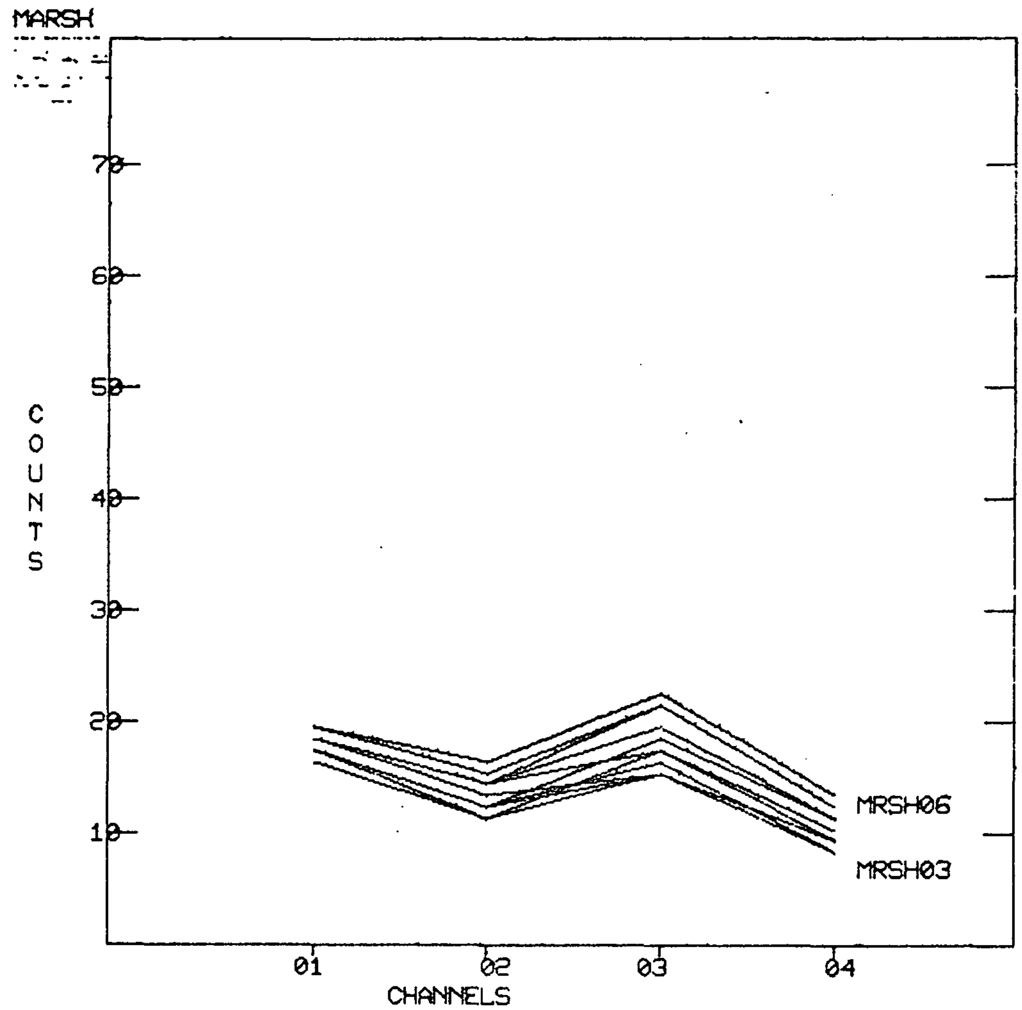

Figure 35. Computer-derived, four channel, spectral plots of all marsh training fields from Image 5.

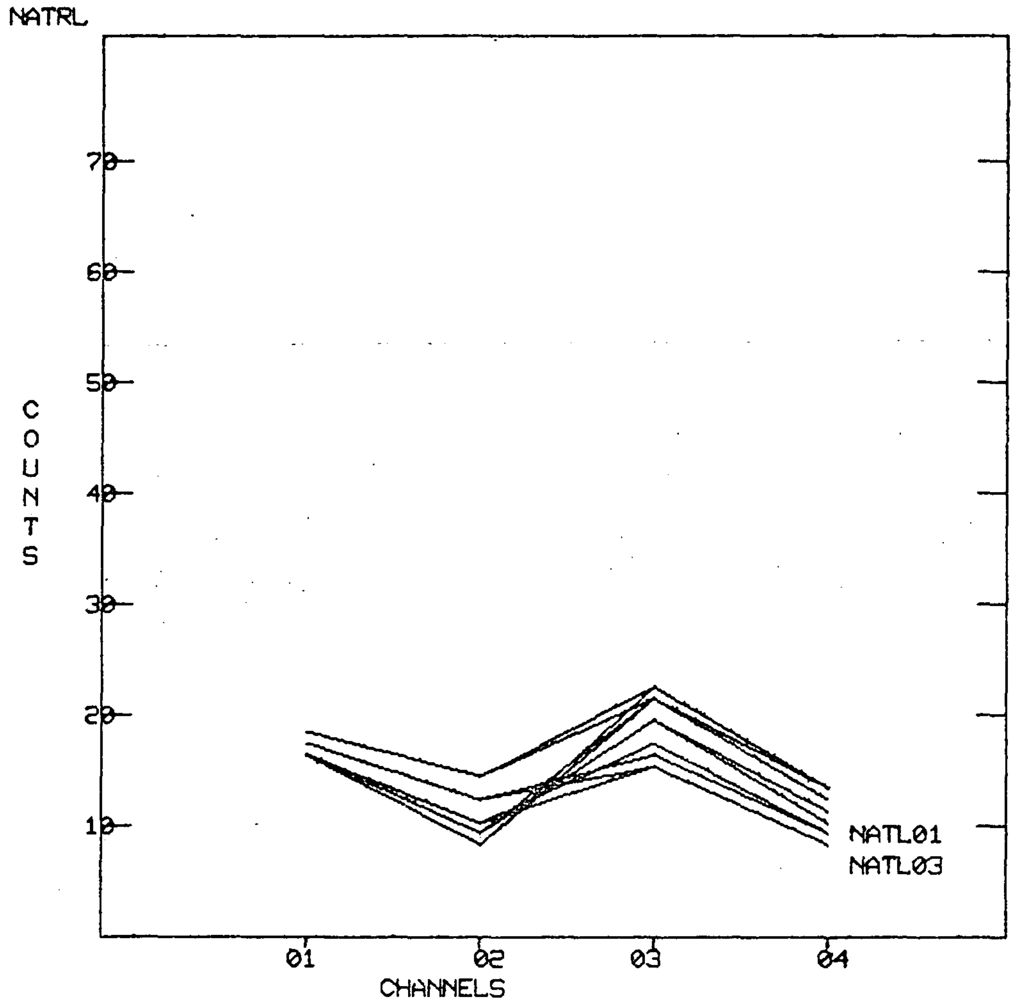

Figure 36. Computer-derived, four channel, spectral plots of all swamp/forest training fields from Image 5.

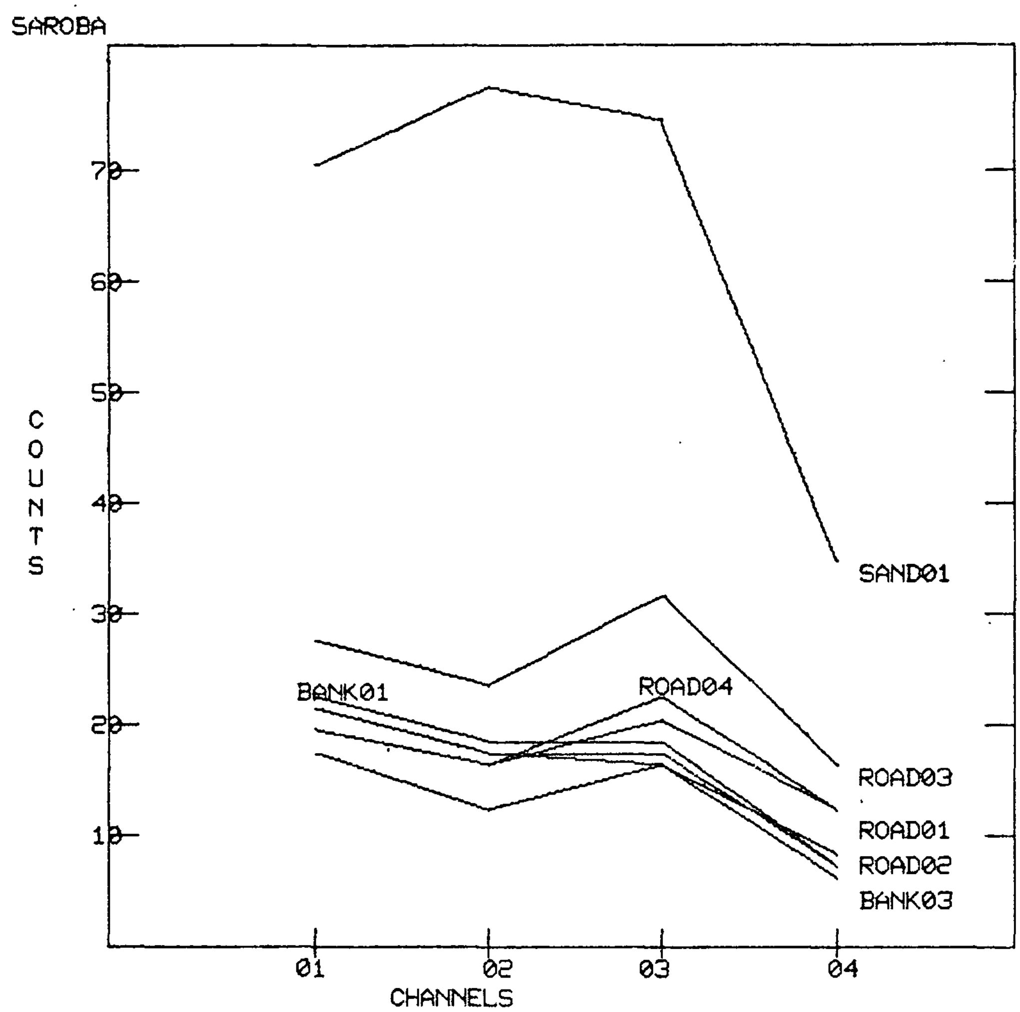

Figure 37. Computer-derived, four channel, spectral plots of all sand, mud bank, and road training fields from Image 5.

system is oriented primarily in a north-south direction, with the net water movement being to the south.

The various stages of clear-cutting are shown in Figure 38. After the construction of access roads and associated drainage channels, the underbrush, such as Titi, is cut down to gain access to natural timber. Once the natural stand of timber is removed, the slash, stumps, and brush are plowed into the soil. When a plowed field is dry enough to support pine trees, seedlings are planted on the mounds formed by plowing. A natural grass-type ground cover is usually established within six months after plowing. The trees mature and are ready for harvesting in 25 to 30 years. For most of the area under investigation it took more than six years to establish the resemblances of a climax community (Figure 38). However, current forest management practices prevent the establishment of a natural climax community on the plantations.

The clear-cut and revegetated areas were easily separated and classified due to their spectral differences. Mean spectral plots (signatures) of these two classes (Table 7) are similar in Channels 1 and 2, but differ significantly in Channels 3 and especially 4. Count values from the recently clear-cut areas are very low (9.86) in the near infrared (Channel 4) due to the lack of ground cover. However, when the revegetated fields began to resemble natural communities, it became difficult to separate the classes on the basis of their spectra. A few fields, due to seasonal variations and similar stages of succession, were sometimes classified as natural, and many months later, again resembled a revegetated field. The areas clear-cut in 1973 and 1974 were classified as clear-cut in this image, because they did not have time to develop established ground cover.

The Information Transfer Laboratory at NASA's Goddard Space Flight Center, in a cooperative project with the Weyerhauser Company (Williams and Haver 1976), attempted to use Landsat data as supplemental input to a forest inventory system. Their study area was in North Carolina. They experienced difficulty in classifying clear-cut areas with Landsat data. Their data had a low 54 percent of agreement with air photointerpretation data. The main reason for this difficulty was the fact that ground cover had established itself in the span of over one year between Landsat scenes. By this time, the clear-cut fields had the spectral signature of pine plantations. Winter scenes were found to be good for outlining hardwood and pine forest canopies. Spectral signatures were also extracted for clear-cut and replanted areas, but these broad categories could not be statistically divided into finer categories such as age, vigor or density. By using a combination of winter and summer data, a total of 8 channels with an emphasis on Channels 3 and 4, they were able to break the replanted fields into three crown closure categories:

- closed canopy pine - 100 percent canopy
- partial pine canopy closure - some exposed ground vegetation
- open pine canopy - 50 percent canopy, 50 percent ground vegetation

A. Newly cleared

B. Plowed

C. Six months after planting

D. Three years after planting

E. Six years after planting

F. Natural swamp

Figure 38. Stages of clear-cutting and vegetation (source; Livingston 1975).

Revegetated areas were not broken into finer categories due to the lack of detailed information available to the author at the beginning of the research in this EPA report. Such information is available and, as in the Goddard investigation, it may be possible to further break the revegetated class into finer subcategories. This research monitored changes in land-use activities, primarily forest management practices, in the East Bay drainage basin.

TEMPORAL LAND-USE DISTRIBUTIONS

Classified Landsat images are discussed in this section. An interpretation of temporal land-use changes in marshes, swamp/forests and other natural areas are discussed, but the emphasis is on the silviculture activities in the East Bay drainage basin.

Clouds are present in the northwest corner of the 17 February 1973 image (Figure 33-A), but fortunately they did not obscure the area of interest. Marsh communities along the Apalachicola River and the swamp/forests within the East Bay drainage basin are not readily separated on the basis of their spectra. This is probably due to a combination of spectral similarities of vegetation types during the winter and possibly the low sun angle causing merged signatures that at other times of the year are separable.

This scene indicates that extensive recent clear-cutting has occurred north of East Bayou. It is also inferred that the middle to upper reaches of the basin were clear-cut at an earlier date (1971) because the majority of the area is classified as revegetated. Lumber company data supported this finding. A few areas known to have been replanted are classified as marsh. Grasses present during the first stages of replanting are evidentally spectrally similar to marsh grasses. Again, this similarity is probably due to the winter die back of the vegetation.

It is likely that as the trees in the replanted fields mature and develop a canopy, spectral reflectances increase, especially in Channel 4. The older more mature pine plantations no longer overlapped spectrally with the marsh classes.

April appears to be a prime time for the discrimination of various marsh communities. The second classified scene, 13 April 1973 (Figure 29-B) depicts marsh species (color-coded light green) lining the delta. Due to their geographic location, these marsh species are probably more salt tolerant. Further up river along the Apalachicola flood plain, fresh water plant communities are color-coded a bright yellow. Due to minimal ground truth for the delta, one area which is erroneously labeled clear-cut remains unexplained. Roads are relatively well defined because their highly reflective sandy surface results in a spectral signature markedly different from that of the bordering lush vegetation.

It is apparent that in the two months which lapsed between the acquisition of the above scenes, the major lumber company successfully completed clear-cutting the timbered areas that were partially cut in the first image.

Timber harvesting in swampy areas is dependent upon the weather conditions. Therefore, only portions of fields may be clear-cut at any one time. Numerous areas are either very thick (i.e., stands of Titi) or too swampy to risk getting heavy equipment stuck. These areas are left alone. There is a speckled pattern of misclassified pixels over the entire image which represents an overlap between revegetated and marsh communities. A greening of vegetation in both areas at the same time resulting in similar spectral signature could have caused such confusion.

It is inferred that ground cover is quick to invade and grow in clear-cut fields during the spring. This cover, however, died back in the winter, returning the fields to a condition which spectrally resembles the clear-cut areas.

Winter is not the optimum time to spectrally discriminate marsh from swamp/forest communities. In the 21 December 1973 scene (Figure 33-C), the roads are masked by dying vegetation and are classified as marshes and swamp/forests. Further ground truth is needed to verify the brown delta features in terms of emerged mud flats, submerged mud flats or marsh grasses.

Very little new cutting is evident in this image. Lumber company data verify that relatively little cutting occurred at this time in 1973. Several clear-cut fields from the 13 April 1973 (Figure 33-B) image now resemble revegetated fields. Lumber company officials state that ground cover is normally well established within six months after a clear-cutting operation. This research revealed that under the temporal resolution of the available Landsat scenes, the clear-cut fields acquired ground cover within at least 8 to 10 months.

The marsh communities in the delta proper are still spectrally unique in October, but as demonstrated in the 23 October 1974 image (Figure 33-D), it was very difficult to discriminate marsh areas from swamp/forest communities. Portions of the delta marsh are again classified as clear-cut. Confusing classifications certainly warrant careful ground truth investigations and perhaps with more time a reclassification of this area would result in a better separation.

Most of the area classified as clear-cut in the previous image, 21 December 1973, are classified as revegetated in this scene. A few areas were labeled clear-cut, but these areas did not appear in the data provided by the lumber company. These few discrepancies observed between lumber company and Landsat data may lie in the data supplied by the lumber company, the classification technique, or in the actual field conditions. These particular fields may not have been replanted and/or possessed poor growing conditions. The same areas of concern gave similar conflicting results in the 21 December 1973 image. In the fifth image, 26 February 1975 (Figure 34-E), the marsh species along the Apalachicola River are relatively well defined. Clear-cutting in the East Bay drainage basin has apparently ceased. Areas of recent cutting in the previous scene (23 October 1974) still appear as clear-cut, but revealed minor amounts of regrowth in each.

The last of the images, 19 August 1976 (Figure 34-F) provides evidence of resumed cutting in small areas just north of West Bayou. This land is owned by one of the other four lumber companies in the area.

Landsat-derived acreage values for the basin are within those supplied by the lumber company (Table 8). Acreages computed from the images is moderately higher than that supplied by the lumber company, because this particular company owns most, but not all, of the drainage basin. Other lumber companies are also operating in the basin area. Livingston's data implies that water qualtiy was at its worst level in 1974 which coincides with the peak of clear-cutting activities during 1972 through 1974. The Landsat classified images verify 1974 as the year of heaviest cutting during this period. Livingston (pers. comm.) has reported that East Bay is presently in a state of recovery. He greatly encouraged the study of more recent Landsat images for the purpose of monitoring a continued recovery in water quality, as well as related land-use activities.

As the research effort to utilize Landsat data to temporally monitor land-use changes in the East Bay drainage basin progressed, significant changes were also observed to the east along the Carrabelle River. The land along the Carrabelle River was classified using spectral signatures derived from ground truthed training fields in the East Bay drainage basin. This is being a form of signature extensions. As with the East Bay drainage basin, silviculture activities were the only man-induced land-use changes apparent along the Carrabelle River. The northern extremes of this river lie within the relatively undisturbed Apalachicola National Forest.

It is inferred from the 17 February 1973 image (Figure 33-A) that large areas of revegetated land border both sides of the Carrabelle River. The purple area along the southern reaches of the river, just north of the town of Carrabelle, are misclassified as marshes. The 13 April 1973 image (Figure 33-B) suggests that no new cutting has occurred along the Carrabelle River, except perhaps for a small area east of the town of Carrabelle. More cutting is observed in the 21 December 1973 scene (Figure 33-C). Large forested sections were cut between 21 December 1973 and 23 October 1974 (Figures 33-C and 33-D). Just to the east of the northern most portion of the cutting in the East Bay drainage basin, lumber company activities have picked up in the New River drainage basin. Only minimal new cutting occurred during the following four months based on the changes noted between the 23 October 1974 image (Figure 33-D) and the 26 February 1975 image (Figure 34-E). The 19 August 1976 image (Figure 34-F) discloses extensive accelerated clear-cutting operations along the west side of the New River. Fishermen have reported a recent decline in catches within the area of St. George Sound affected by the Carrabelle River plume (Livingston, pers. comm.; 1977). The reports of these fishermen certainly warrant investigation. Land-use activities are very probably linked to water quality in East Bay and Apalachicola Bay, Florida.

SIGNATURE EXTENSION

The magnitude of this project generated thoughts of the possibility of signature extension over time. That is to say, if the spectral signature

TABLE 8. PERCENT AND HECTARES (ACREAGE) OF SUBMINOR, MINOR AND MAJOR WATERSHEDS IN EAST BAY DRAINAGE BASIN

Watershed	Subminor Watershed (Ha Acres)	Minor Watershed (Ha Acres)	Percent of East Bay Watershed	Major Watershed (Ha Acres)
Cash Bayou				11786 (29101)
Bear Creek		802 (1981)	2.50	
Cash Creek		10984 (27120)	34.25	
Cash Creek (small)	2293 (5662)			
Sand Bank Creek	2162 (5338)			
Rake Creek	2792 (6895)			
High Bluff	2941 (7262)			
Cash Creek ditch	179 (443)			
Cash Creek ditch #2	616 (1520)			
Cash Bayou ditch		820 (2025)	2.56	
West Bayou				16114 (39788)
Whiskey George Creek		16114 (39788)	50.25	
Whiskey Geo. Cr. (small)	6295 (15544)			
So. Juniper Creek	657 (1623)			
Doyle Creek	3576 (8830)			
Tower Road ditch	4992 (12325)			
West Bayou (small)	594 (1466)			
Round Bay				
Montgomery Slough and Saltwater Creek	-	1959 (4838)	6.11	1959 (4838)
Sand Beach Branch		1389 (3430)	4.33	1389 (3430)
Dot Grid watershed Grand Total			100.00	32069 (79182)
Computer-generated acreage Grand Total				32645 (80604)

of a specific class is identified, it can be used to classify that feature in all other scenes. This turned out to be unreliable. While reasonable mean spectral signatures are acquired for all classes (Tables 4 and 7), the individual signatures were quite different from scene to scene or date to date. Corrections related to sea state, atmospheric, and sun angle conditions can help alleviate most in-scene differences, but are as yet not incorporated into the DAS software. Land and water are readily separated from one another in different scenes using the previously described supervised classification technique. Due to the relative ease of separation of specific classes in this study, research should be encouraged to produce techniques (i.e., unsupervised classification, which is presently underway at several research centers) that would make classifications, in the near future, an assembly line process.

RELIABILITY OF CLASSIFICATION

It is a difficult task to determine the reliability of classification demonstrated in this report. The project was conducted without the aid of aerial photography and presented the opportunity to determine the near stand alone (with a minimum of ground truth data) capability, if any, of using Landsat data to accurately detect and monitor desired land and water features. This would have been best accomplished by a comparative study where aerial photographs were available during all stages of Landsat classification.

As mentioned by Williams and Haver (1976), human variables due to the interpreter always enter this type of study. Such variables are "fatigue", the interpreter's ability to detect gradual changes in color or cover type and the ability to make consistent decisions. Still another unavoidable problem exists because Landsat averaged conditions over each pixel (0.44 hectares; 1.1 acres). Williams and Haver (1976) stated that comparisons should be made in terms of percentage of "agreement" and not percent "correct".

EPA's desire was simply to use Landsat to synoptically, and quantitatively where possible, determine if there was environmental damage in the area. This goal was achieved, but first several procedures had to be followed to determine the reliability of the Landsat classifications and associated acreage data. The DAS system has various programs that aid the investigator in this verification process. One such program is termed SCORECARD. This program assigned to each of the possible classes gives the percentages of pixels which are in a specific original training field. SCORECARD is, however, biased because it decides how well an original training field chosen by the interpreter was classified. In other words, the investigator pretty well knew what it was before the classification process began. The program SCORECARD was only run on the third set of data (due to time limitations) to determine the reliability of the classification. Figure 40 is an abbreviated example of the product generated from SCORECARD. Sand classes (numbered 2 and 4) were classified 96 and 100 percent. Mud banks along the river were 82 percent. Marsh classes (numbered 5, 7, 12, and 16) varied with percents of 100, 98, 41, and 45, with the latter two values resulting in spectral similarities with the other marsh classes. Swamp/forest classes (numbered 6, 13, 14, 15, and 17) were classified with the following percentages: 0, 94, 55, 61, and 68. As expected, these classes are either in conflict with other

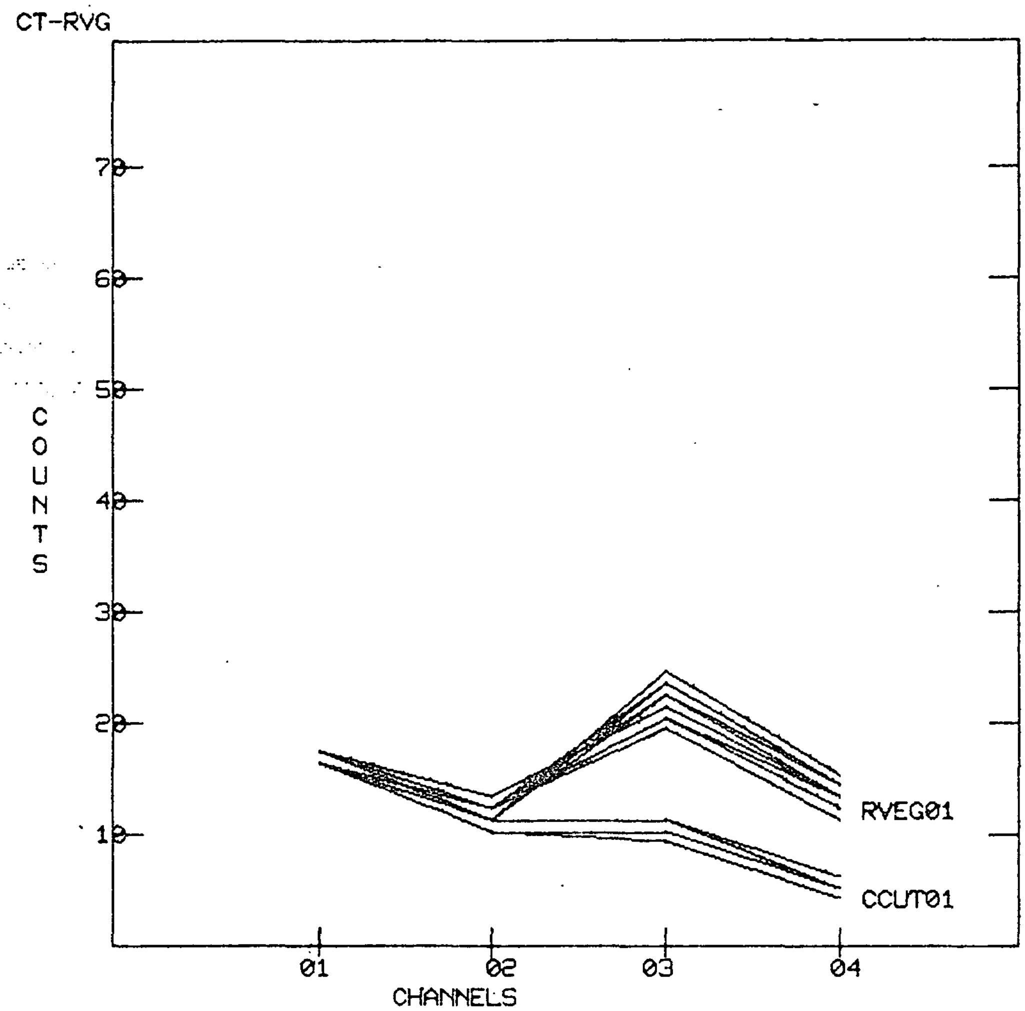

Figure 39. Computer-derived, four channel, spectral plots of all cut and revegetated training fields from Image 5.

PER CENT CLASSIFIED INTO CLASS

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1																			
2	1		96			3													
3	1			82											2	6	6		
4					100														
5						100													
6					50							50							
7								98			2								
8	2						4		11	15	1	4		1		1		10	51
9							7		1	65		3		9	1	3	2	7	1
10							1	1		2		9	18	1	25	12	32		
11					2							98							
12					24	7	9					19	41						
13	1									1				94	1	2			
14										1	1			28	55		15		
15	1								1		1			28		61		5	5
16								2		1		1	5		44	1	45		
17									2	2				2		4		68	22
18																		10	90
19																			
20																			
21								2			2								
22																			
23																			
24																			
25																			
26																			
27																			
28																			
29																			
30																			
31																			
32																			
33																			
34																			
35		7																	
36																			

Figure 40. Computer-derived SCORECARD for Image 5 (21 December 1973) indicating the percentage of original training field pixels assigned to each of the classes under consideration.

** PART TWO OF RVCARD **

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
	3																		
	27		29		19										1	13		11	
	2	59		7	4	18	9							1					
	2		93													1			
		5		75	15	5													
				2	96	2													
		13			1	78	2					3		4					
	2	6					92												
								89	7					3	1				
								4	82	8				1	5				
									7	82	7					4			
										8	75							17	
						1						99							
							3						92				5		
					10	4			3					75	8				
	1								3	1				6	83	6			
	2								1	14	2				8	73		1	
													9				84		
											9							91	
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37

3575. POINTS CORRECT OUT OF 5582.

TOTAL POINTS. 64.05 PER CENT ACCURACY.

AVERAGE ACCURACY BY CLASS 72.83 PER CENT

Figure 40 (Continued).

swamp/forest classes or marsh classes. Neither case had a great effect on the acreage estimates of the drainage basin.

Of specific interest, are the revegetated and clear-cut classes. The classification percentages for the three revegetated classes (numbered 8, 9, and 18) are 11, 65, and 90. This first and rather low classification is not a great problem when it was observed that this first revegetated class is mainly merged with the third revegetated class, and to a small extent, with a swamp/forest class. The second revegetated class is also competing with swamp/forest classes. This overlap was an expected response after viewing the overlapping character of the class spectral plots. The sole clear-cut class (numbered 11) has 98 percent of its original pixels classified into the expected or predicted class (i.e., clear-cut).

The average land class accuracy was 61.00 percent. These results, although biased, are quite good. When land and water classes were combined, 3,575 pixels from a total of 5,582 were correctly classified for an overall percent accuracy of 64.05 percent. The average accuracy by class for the third image is a respectable 72.83 percent. This means that certain individual classes were easily discriminated while others were more difficult, resulting in a lower overall accuracy but a fairly high individual class accuracy.

A final check on the reliability of the land classification products was made through a comparison of acreage estimates derived from the Landsat classifications with those provided by the lumber company (Table 9). Acreages computed from the classified Landsat images are not in direct agreement with that provided by the lumber company (Table 9), but the trend in cutting activities was apparent from both the lumber company and Landsat data. Several lumber companies are active in the basin and the Landsat values may include several of the areas under their control. Table 8 shows close agreement between the East Bay drainage basin acreage provided by the company (a dot grid estimate of the map provided by the lumber company) and the computer-generated basin acreage figures. However, more detailed ground truth must be incorporated into any follow-up investigation to develop more accurate estimates of silviculture activities.

It is far more difficult to determine the relaibility of the water classification because there are no concurrent water truth data to correlate with the water types. Three indirect methods were used to determine the accuracy of these classes. First, the biased SCORECARD program was run on water classes from the third image (21 December 1973). Second, a comparison of monthly mean station water quality data was made with water color in the images. Third, acreage estimates of individual water masses (i.e., East Bay, Apalachicola Bay) derived from the images were compared with acreage estimates acquired by using a standard stratified random dot grid over a 1:250,000 map of the area. These acreages agreed, indicating that at least a good land-water boundary had been selected. In general, water types were much easier to derive final classifications for than were the land classes. In this study, spectral signatures of water, although nearly always one count apart, were often more distinct than land signatures. It is felt that the boundaries

TABLE 9. PERCENTAGES AND AMOUNTS OF LANDSAT AND LUMBER COMPANY-DERIVED CLEAR-CUTTING DATA FOR EAST BAY DRAINAGE BASIN (32,645 hectares) Landsat derived revegetated data are also provided.

Date of Image	Landsat Clear-Cut Estimate	Lumber Company Clear-Cut Estimate	Landsat Revegetated Estimate
17 February 1973	8.96 * 2925 ** (7223)+	7.48 2443 (6033)	15.49 5057 (12486)
13 April 1973	10.31 3364 (8307)	6.24 2039 (5034)	20.20 6595 (16284)
21 December 1973	6.03 1968 (4860)	3.00 963 (2378)	14.52 4740 (11705)
23 October 1974	4.43 1446 (3571)	1.80 586 (1447)	15.59 5091 (12570)
26 February 1975	5.12 1671 (4127)	1.63 532 (1314)	19.08 6228 (15379)
19 August 1976	7.35 2459 (6071)	1.67 546 (1348)	20.36 6646 (16411)

* Percent of East Bay drainage basin.
**Area in hectares
\+ Area in acres

associated with water types were indeed true features of the bay at the time of the overpass. Another reason for the ease of discrimination of water types was probably that the individual water types are often relatively homogeneous over large areas. Land training fields, on the other hand, were not homogeneous because of the numerous features (i.e., trees, brush, grass, water) that contribute to a mass spectral reflectance from a land community.

SCORECARD was also run for the water types in the third image, 21 December 1973 (Figure 40).

The water types were classified to an average accuracy by type of 80.05 percent. This SCORECARD illustrated that it was easier to classify water than land.

The distribution of water types in this investigation was corroborated by other water quality investigations in Apalachicola Bay. Long-term water quality data (post 1972) collected by Livingston et al. (1974), agree with the location of several of the water types identified in the Landsat images. A survey conducted by Hydroscience, Inc. (1977) on 17 March 1976 showed the same general location of swamp/forest runoff as in several of the Landsat scenes under similar environmental conditions. Hydroscience also produced tidally assumed surface water color maps (one at high and one at low tide) which indicate swamp/forest runoff in the same general area of the bay as evidenced from the satellite images. The Landsat-derived water patterns also correspond with the Hydroscience output of a bay water color model (Hydroscience 1977).

Landsat is used in this study to monitor water color which can be used to infer other water quality parameters relating to specific types of water.

The MSS cannot directly sense salinity, pH, and dissolved oxygen. However, in this geographical setting, ph and disssolved oxygen (DO) values corrrelate well with water color (Figures 41 and 42). As tidally averaged surface values of pH and DO decrease, color increases. Other water quality parameters (i.e., Secchi depth) could have been considered, but Hydroscience chose to concentrate on pH and DO. To the point where mixing and dilution have a great influence on water types, inferences of values of other associated water quality parameters remain valid Graham et al. 1978).

Figures 43 and 44 are indicative of the water quality maps available at the start of this project. These maps were constructed from a simple linear extrapolation between water quality data collected at known water sampling stations. This is a very poor, but traditional way, to derive the distribution of water types within the bay. Landsat produced a synoptic, grided, instantaneous image of the entire bay. The water quality maps as they are presently being derived, produce an inadequate and incorrect picture of water patterns in the bay. Never under numerous environmental conditions did the water patterns in the bay, as represented in FSU's maps, closely resemble those in the Landsat images. Landsat images have been shown to represent a more accurate synoptic representation of water color patterns in the bay. However, the most accurate presentation would be derived if boats were acquiring water quality samples at the same time as the satellite overpass. These water quality data could then be used as calibration points during the classification stages of the Landsat imagery.

The results of this investigation have made researchers aware of a more accurate method to map water color distributions in Apalachicola Bay, Florida. It has also opened to them new ideas concerning water transport mechanisms in the bay. The transferability of this technique has already been proposed for other estuarine systems around the nation (i.e., Lake Pontchartrain, Louisiana, and Chesapeake Bay, Maryland).

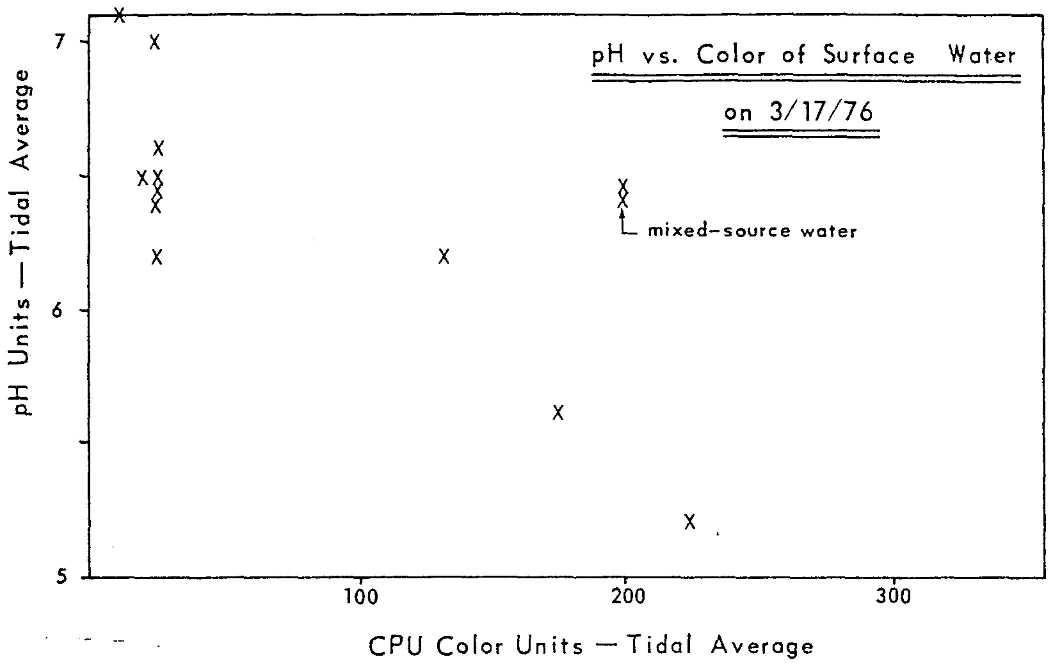

Figure 41. pH versus color of surface water in Apalachicola Bay, Florida on 17 March 1976 (source; Graham et al. 1978b).

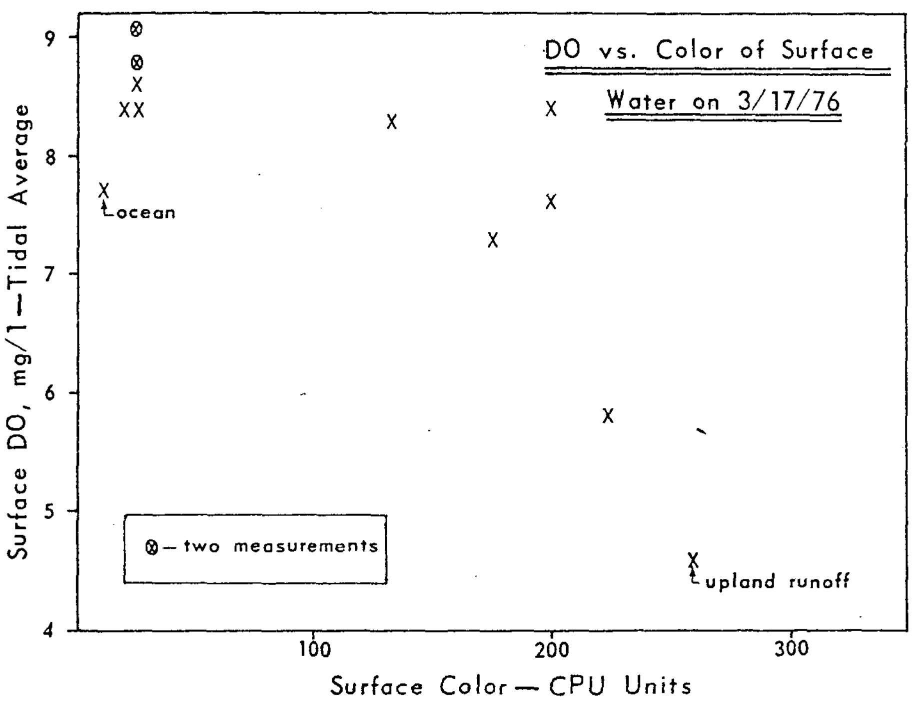

Figure 42. Dissolved oxygen versus color of surface water in Apalachicola Bay, Florida on 17 March 1976 (source; Graham et al. 1978b).

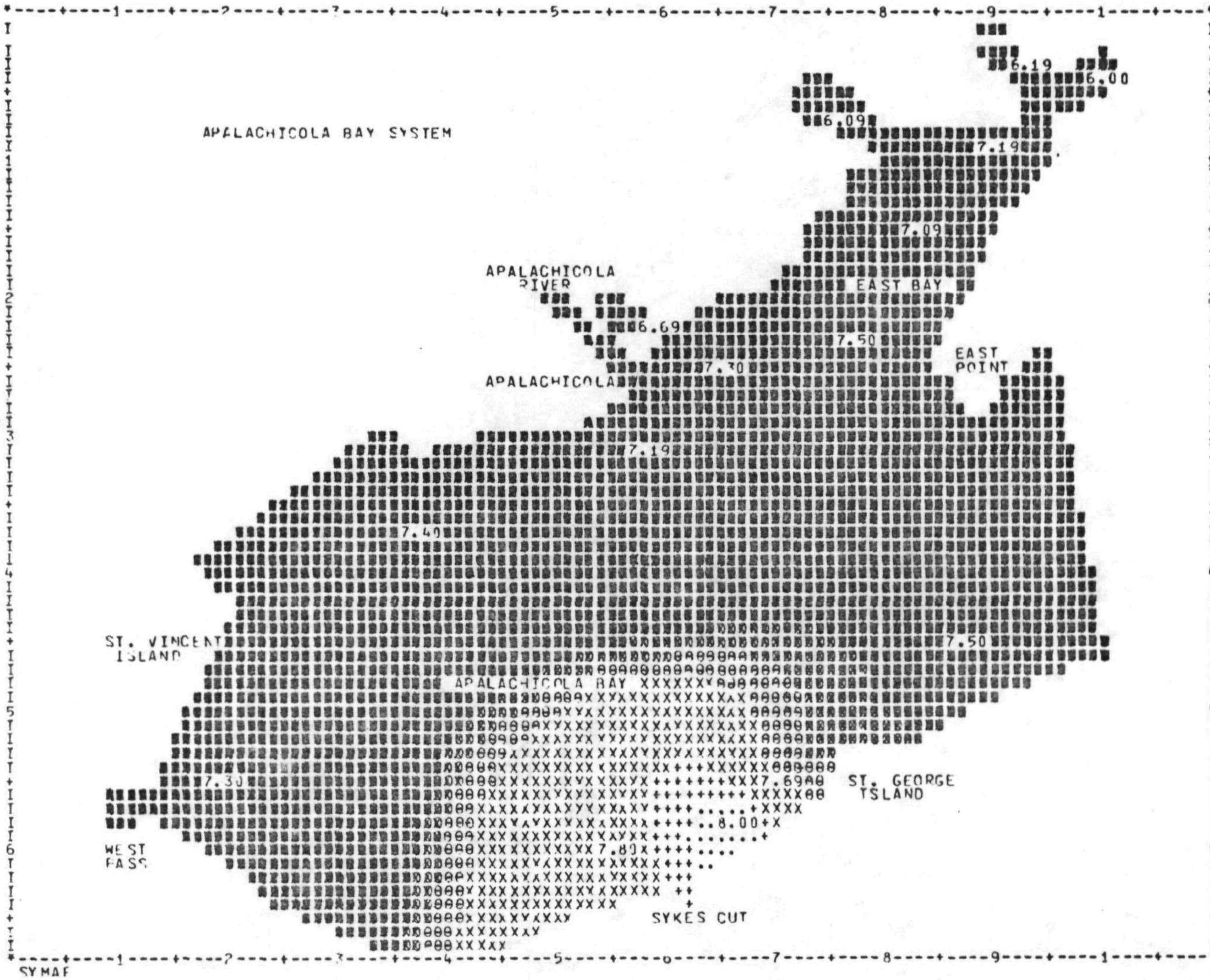

Figure 43. pH distribution from simple linear extrapolations of water quality data, February 1975 (provided by Livingston 1978).

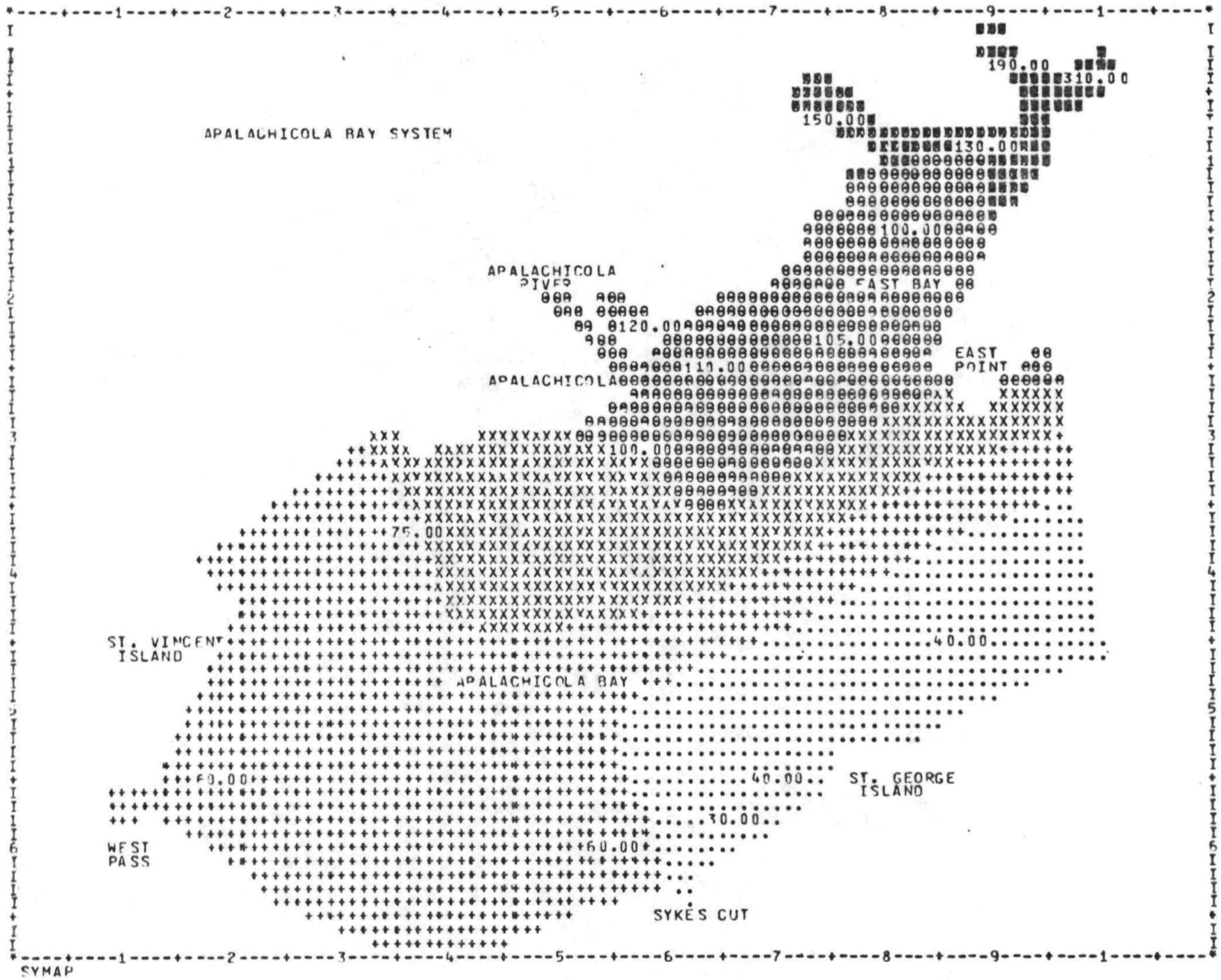

Figure 44. Water color map from simple linear extrapolations of water quality data, February 1975 (provided by Livingston 1978).

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APPENDIX

SAMPLING STATION LANDSAT IMAGE COLOR AND RELATED MEAN MONTHLY IN SITU DATA

Water quality data were not collected at the time of the satellite overpasses for the historic images, 1973 to 1976, studies in this research. A direct correlation between satellite and in situ water quality data was, therefore, impossible.

The location of various water classes appeared to be fairly consistent from year to year when under similar environmental conditions (wind, tide, river flow, etc.). A comparison of monthly station means for pertinent water quality data with the color of a water type derived from the classified Landsat image at the same station during the same month was conducted. This comparison (Tables A-1, A-8) at least partially, confirmed that the various water classes, the acidic swamp runoff in particular, had been properly identified for they occured in areas similar to those observed by surface investigations from research vessels.

The water quality parameters under investigation were Secchi depth, water color, turbidity, salinity, and pH. Occasionally water quality data existed for a sampling station that was not in the area encompassed by the image. The image color would in this case be labeled "Off Image" for the color could not be determined. The sampling stations are located on the map (see map in pocket). Water quality data were provided by Dr. Livingston (FSU) under Florida Sea Grant and U.S. EPA funded projects.

TABLE A-1. COLOR OF SAMPLING STATIONS ON LANDSAT IMAGE, 17 FEBRUARY 1973, AND RELATED IN SITU MEAN MONTHLY STATION DATA, FEBRUARY 1973, FOR ALL PERTINENT AVAILABLE STATIONS (Livingston, pers. comm., 1978)

Sampling Station	Image Color	Secchi Depth (m)	Water Color (PCU)	Turbidity (JTU)	Salinity (0/00)	pH
001	Off Image	0.2	180	205	0	-
002	White	0.6	105	38	0	-
003	Light Brown	0.3	130	60	-	-
004	Light Brown	0.2	155	88	0	-
005	Dark Brown	0.2	160	90	0	-
006	Dark Brown	0.3	100	52	0	-
007	White	0.4	110	37	0	-
01A	Off Image	0.7	0	27	5.3	-
01B	Green	0.3	75	40	2.3	-
01C	Green	1.3	0	16	5.8	-
01E	Green	-	-	-	2.7	-
01F	Off Image	-	-	-	3.2	-
02A	Green	-	0	32	2.7	-
02B	Off Image	-	-	22	4.2	-
05A	Salmon	0.1	370	160	0	-

TABLE A-2. COLOR OF SAMPLING STATIONS ON LANDSAT IMAGE, 13 APRIL 1973, AND RELATED IN SITU MEAN MONTHLY STATION DATA, APRIL 1973, FOR ALL PERTINENT AVAILABLE STATIONS (Livingston, pers. comm., 1978)

Sampling Station	Image Color	Secchi Depth (m)	Water Color (PCU)	Turbidity (JTU)	Salinity (0/00)	pH
002	Dark Brown	0.4	90	43	0	-
004	Tan	0.4	55	44	0.8	-
005	Tan	0.5	90	58	0.5	-
006	Tan	0.4	85	56	0	-
01B	Dark Brown	1.4	17	9	19.5	-
01C	Green	0.8	8	7	26.8	-
01D	Off Image	-	-	-	12.9	-
01E	Tan	-	-	-	21.8	-
01F	Off Image	-	-	-	28.6	-
02A	Green	-	-	7	21.8	-
02B	Off Image	-	-	5	12.9	-
05A	Salmon	0.3	75	82	0	-

TABLE A-3. COLOR OF SAMPLING STATIONS ON LANDSAT IMAGE 21 DECEMBER 1973, AND RELATED IN SITU MEAN MONTHLY STATION DATA, DECEMBER 1973, FOR ALL PERTINENT AVAILABLE STATIONS (Livingston, pers. comm., 1978)

Sampling Station	Image Color	Secchi Depth (m)	Water Color (PCU)	Turbidity (JTU)	Salinity (0/00)	pH
001	Dark Green	1.1	15	5	5.2	-
002	White	-	-	-	-	-
004	White	0.9	18	5	2.9	-
005	Salmon	0.8	25	10	0	-
007	White	-	-	4	-	-
01A	White	1.3	9	5	21.8	-
01B	Light Green	1.5	10	5	20.1	-
01C	White	1.4	12	8	18.4	-
02A	White	-	-	-	-	-
02B	Green	-	-	-	-	-
05A	Red	1.0	35	5	2.9	-

TABLE A-4. COLOR OF SAMPLING STATIONS ON LANDSAT IMAGE, 3 MARCH 1974, AND RELATED IN SITU MEAN MONTHLY STATION DATA, MARCH 1974, FOR ALL PERTINENT AVAILABLE STATIONS (Livingston, pers. comm., 1978)

Sampling Station	Image Color	Secchi Depth (m)	Water Color (PCU)	Turbidity (JTU)	Salinity (0/00)	pH
001	White	0.8	20	17	10.3	-
002	White	0.6	30	8	0	-
004	White	0.8	40	7	-	-
005	White	0.7	40	22	2.3	-
007	White	0.8	50	11	0	-
01B	White	0.9	20	4	11.5	-
01C	White	0.9	20	7	2.3	-
05A	White	0.6	50	17	0	-

TABLE A-5. COLOR OF SAMPLING STATIONS ON LANDSAT IMAGE, 23 OCTOBER 1974, AND RELATED IN SITU MEAN MONTHLY STATION DATA, OCTOBER 1974, FOR ALL PERTINENT AVAILABLE STATIONS (Livingston, pers. comm., 1978)

Sampling Station	Image Color	Secchi Depth (m)	Water Color (PCU)	Turbidity (JTU)	Salinity (0/00)	pH
001	White	1.6	20	1	23.0	-
002	White	1.6	20	2	10.1	-
003	White	1.1	15	2	11.8	-
004	Salmon	1.0	40	2	11.2	-
005	Salmon	1.0	25	3	10.1	-
006	Salmon	1.2	10	3	24.0	6.9
007	White	-	-	-	-	-
01A	Gold	1.7	0	1	25.7	-
01B	White	2.2	20	1	25.2	-
01C	White	1.9	10	1	33.7	-
01E	White	1.0	30	1	28.4	-
01X	Gold	1.3	22	1	25.9	-
02A	Gold	-	-	-	-	-
02B	White	-	-	-	-	-
04A	Salmon	1.1	5	1	-	-
05A	Salmon	1.2	20	2	27.3	-
05B	Red	1.0	55	2	24.2	-
05C	Red	1.0	55	2	25.7	-

TABLE A-6. COLOR OF SAMPLING STATIONS ON LANDSAT IMAGE, 26 FEBRUARY 1975, AND RELATED IN SITU MEAN MONTHLY STATION DATA, FEBRUARY 1975, FOR ALL PERTINENT AVAILABLE STATIONS (Livingston, pers. comm., 1978)

Sampling Station	Image Color	Secchi Depth (m)	Water Color (PCU)	Turbidity (JTU)	Salinity (0/00)	pH
001	Deep Blue	0.9	75	3	5.2	7.4
002	White	0.8	100	10	2.0	7.2
003	White	0.5	110	16	2.5	7.3
004	White	0.6	105	16	3.0	7.5
005	White	0.6	100	16	3.0	7.1
006	Light Brown	0.3	120	18	3.0	6.7
007	White	-	-	-	-	-
01A	Gold	1.1	60	2	7.9	7.3
01B	Gold	1.4	60	1	9.6	7.8
01C	Green	1.1	40	2	10.6	7.5
01E	Green	0.6	40	2	9.6	7.7
01X	Green	1.1	30	2	12.8	8.0
02A	Dark Brown	-	-	-	-	-
02B	Gold	-	-	-	-	-
04A	Light Brown	0.3	150	23	3.0	6.1
05A	Light Brown	0.4	130	20	2.5	7.2
05B	Red	0.3	190	5	3.0	6.2
05C	Red	0.3	285	5	3.0	6.0

TABLE A-7. COLOR OF SAMPLING STATIONS ON LANDSAT IMAGE, 20 JULY 1975, AND RELATED IN SITU MEAN MONTHLY STATION DATA, JULY 1975, FOR ALL PERTINENT AVAILABLE STATIONS (Livingston, pers. comm., 1978)

Sampling Station	Image Color	Secchi Depth (m)	Water Color (PCU)	Turbidity (JTU)	Salinity (0/00)	pH
001	Light Brown	-	-	-	-	-
002	Dark Brown	-	-	-	-	-
003	Dark Brown	0.7	50	6	7.9	8.0
004	Dark Brown	0.4	55	15	14.4	8.2
005	White	0.9	110	12	12.3	8.0
006	Dark Brown	0.4	55	14	10.1	7.9
007	White	-	-	-	-	-
01A	Gold	1.1	35	5	17.8	-
01B	Gold	1.1	33	8	30.2	7.8
01C	Light Brown	-	10	15	-	8.2
01E	Light Brown	-	10	25	-	8.1
01X	Light Brown	1.2	22	6	20.6	7.9
02A	Dark Brown	-	-	-	-	-
02B	Green	-	-	-	-	-
04A	Dark Brown	1.5	6	2	2.1	7.9
05A	Gold	0.8	60	15	8.5	8.0
05B	Dark Brown	0.8	117	4	1.3	6.3
05C	Black	0.6	148	2	2.1	6.7

TABLE A-8. COLOR OF SAMPLING STATIONS ON LANDSAT IMAGE, 19 AUGUST 1976, AND RELATED IN SITU MEAN MONTHLY STATION DATA, AUGUST 1976, FOR ALL PERTINENT AVAILABLE STATIONS (Livingston, pers. comm., 1978)

Sampling Station	Image Color	Secchi Depth (m)	Water Color (PCU)	Turbidity (JTU)	Salinity (0/00)	pH
001	White	1.0	-	5	-	-
002	White	0.6	2	13	4.0	0
003	White	0.6	20	15	12.2	6.9
004	Dark Brown	1.2	20	7	16.6	7.9
005	Salmon	0.6	20	11	15.0	7.6
006	Salmon	0.5	10	15	3.5	8.1
01A	Green	1.3	-	9	18.0	-
01B	Gold	2.0	-	4	30.8	-
01C	Dark Brown	1.2	-	11	32.5	-
01E	White	0.6	-	10	31.6	-
01X	White	1.3	-	10	31.6	-
02A	White	-	-	-	-	-
04A	Red	0.9	14	8	4.6	8.6
04B	Red	0.8	25	6	4.5	8.9
05A	Red	0.7	30	17	12.2	7.5
05B	Red	0.8	9	9	5.1	7.4
05C	Red	0.8	9	9	5.8	7.6

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16. ABSTRACT

This report describes the application of Landsat multispectral scanning to estuarine water quality, with specific reference to dredging and silviculture practices.

Water quality data collected biweekly since 1972 in the Apalachicola, Bay, Florida, by Florida State University, and Landsat data covering the same geographical area were used as data base for these correlative investigations.

The research indicates that Landsat can provide temporal cause and effect information relating to land-use changes and water quality. Water types, based on water color, were easily discriminated at different times of the year and under varying environmental conditions. Water patterns, which are nearly impossible to acquire under traditional sampling schemes, were readily discerned.

Among other advantages, Landsat-derived distributions of water classes provide a seasonal overview of an area, enabling the most advantageous placement of sampling stations, and, as a consequence, provide the capability to more accurately extrapolate data spatially over large areas from a minimal number of sampling points.

17. KEY WORDS AND DOCUMENT ANALYSIS

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