Remote Sensing Inland Wetlands: A Multispectral Approach

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ABSTRACT: Airborne Multispectral Scanner (MSS) data, large-scale aerial photography, and Landsat MSS and Thematic Mapper (TM) data were used to map a variety of wetland conditions along the Savannah River watershed in South Carolina. Predawn thermal infrared MSS imagery were analyzed to map the spatial distribution and migration of thermal effluent entering a portion of the Savannah River floodplain and the Savannah River below Augusta, Georgia. Daytime airborne MSS data were used to classify specific wetland vegetation types and associate them with their apparent (remotely sensed) temperature. Large-scale, multiple date aerial photography was ideally suited to follow the vegetational changes associated with the thermal discharges into the floodplain. Landsat MSS imagery obtained in the spring was used effectively to map the entire Savannah River watershed. Landsat TM imagery obtained in the summer was of limited use in regional wetland mapping.

INTRODUCTION

THE USE OF various types of multispectral remote sensor data to map and characterize inland (nontidal) wetlands along the Savannah River watershed in South Carolina is described. This watershed encompasses 27,000 square kilometres, including 1044 square kilometres of forested and nonforested wetlands (Plate 1). A listing by individual standard USGS hydrologic units by land-use cover type is given in Table 1.

Approximately 3000 hectares of these wetlands border the Savannah River Plant (SRP) within hydrologic unit number 6, located near Aiken, South Carolina (Figure 1). Cooling water from SRP operations is released to streams that drain into the Savannah River floodplain wetlands on the SRP. Some of the heat carried by the streams is dissipated in the Savannah River floodplain wetlands, altering previous vegetation communities. Thus, these wetlands represent a variety of wetland conditions ranging from ambient to thermally altered. This research summarizes the utility of various types of multispectral remotely sensed data for mapping wetland characteristics found in this complex environment.

Specific applications included the following:

- Measurement of surface temperatures of thermal effluent discharged into the SRP Savannah River floodplain wetlands using predawn, thermal infrared multispectral scanner (MSS) data,
- Determination of the type and spatial distribution of wetland vegetation found on individual creek deltas within the Savannah River floodplain using high resolution MSS data,
- Correlation of wetland vegetation type with temperature using high resolution daytime thermal infrared and visible/near-infrared MSS data,
- Detection of wetland change using historical, large-scale aerial photography, and
- Wetland mapping of the entire Savannah River watershed using Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) imagery.

Complete details of each application are not discussed in this overview of inland wetland mapping in South Carolina. The reader is encouraged to consult the references in each section for additional information.

REMOTE SENSING THERMAL EFFLUENT IN A WETLAND ENVIRONMENT

Thermal effluents are discharged into the SRP Savannah River wetlands by way of Beaver Dam Creek, Four Mile Creek, and Pen Branch (Figure 1). The effluents migrate through the floodplain and enter the Savannah River. The Savannah River Plant rou-

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TABLE 1. LAND USE OF THE SAVANNAH RIVER WATERSHED BY U.S. GEOLOGICAL SURVEY HYDROLOGIC UNIT USING 1977 MULTIPLE DATE LANDSAT MSS DATA*

Hydrologic Unit	Forest	Water	Agriculture	Urban	Wetlands	Unclassified	Total
1	1659.7	190.4	752.5	53.3	0.0	23.0	2678.9
2	1926.7	83.8	510.4	52.4	0.0	12.1	2585.6
3	2853.8	188.8	1610.9	51.0	0.2	70.9	4775.5
4	2504.3	0.3	1350.2	49.4	0.0	10.9	3915.2
5	1491.8	78.4	354.6	22.1	5.9	14.2	1967.0
6	2877.1	29.5	918.1	489.4	509.3	39.7	4863.0
7	1592.0	0.6	318.4	18.9	2.2	5.9	1938.1
8	1074.2	1.4	560.3	371.5	142.2	7.2	2157.0
9	1416.0	28.5	523.7	31.8	384.2	142.2	2526.4
	17395.7	601.8	6899.0	1044.0	1044.0	326.2	27406.7

*Square kilometres

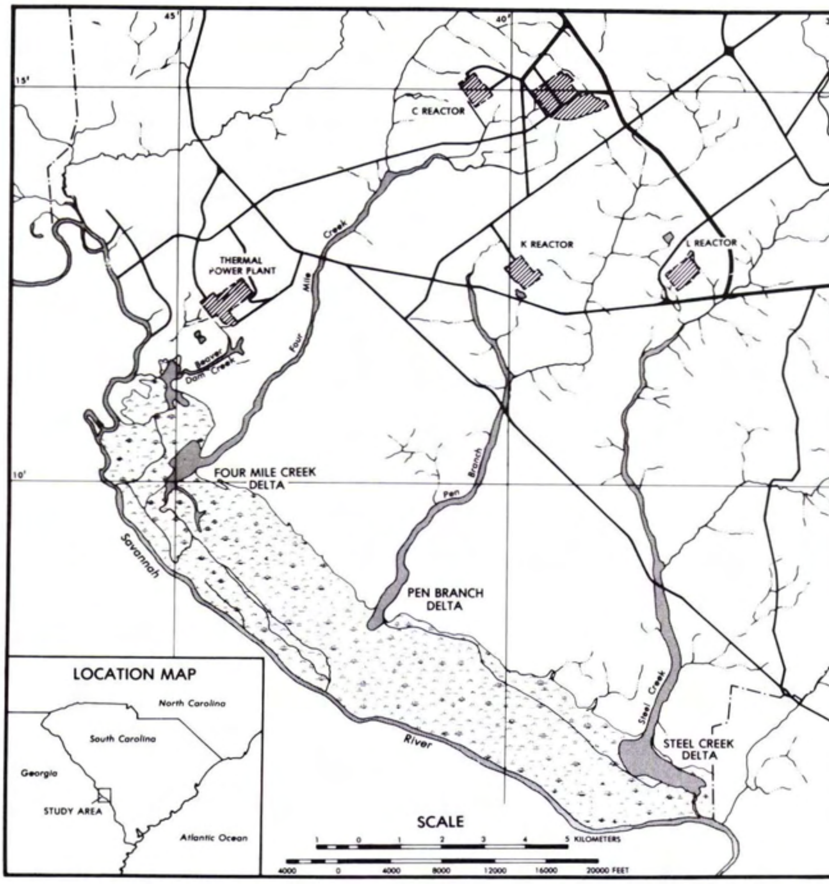


FIG.1. A map of the Savannah River floodplain wetlands on the Savannah River Plant near Aiken, South Carolina. Two nuclear reactors (C and K) and a coal-fired powerplant discharge thermal effluents into creeks which flow into the Savannah River floodplain.

tinely monitors the temperature and spatial distribution of the effluent in the Savannah River using *in situ* measurement techniques. The point measurements are then interpolated to map the spatial distribution of the thermal effluent in the river. In addition to routine monitoring, a comprehensive data acquisition program was initiated in 1981 by the Energy Measurements Group of EG&G, Las Vegas, Nevada, to determine the contribution that thermal infrared remote sensing could make to mapping the

PLATE 1. A land-cover map of the Savannah River watershed based on an analysis of multiple date 1977 MSS imagery. The data were digitally mosaicked, geometrically rectified to a UTM projection, and classified into Mixed Upland Forest (dark green), Wetland (green), Agriculture (yellow), Urban/Bare Soil (red), Water (blue), and Unclassified (black) categories using supervised classification techniques. The land use in the watershed by standard U. S. Geological Survey Hydrologic Unit boundaries is summarized in Table 1.

temperature of the effluents in both the SRP Savannah River floodplain and in the Savannah River.

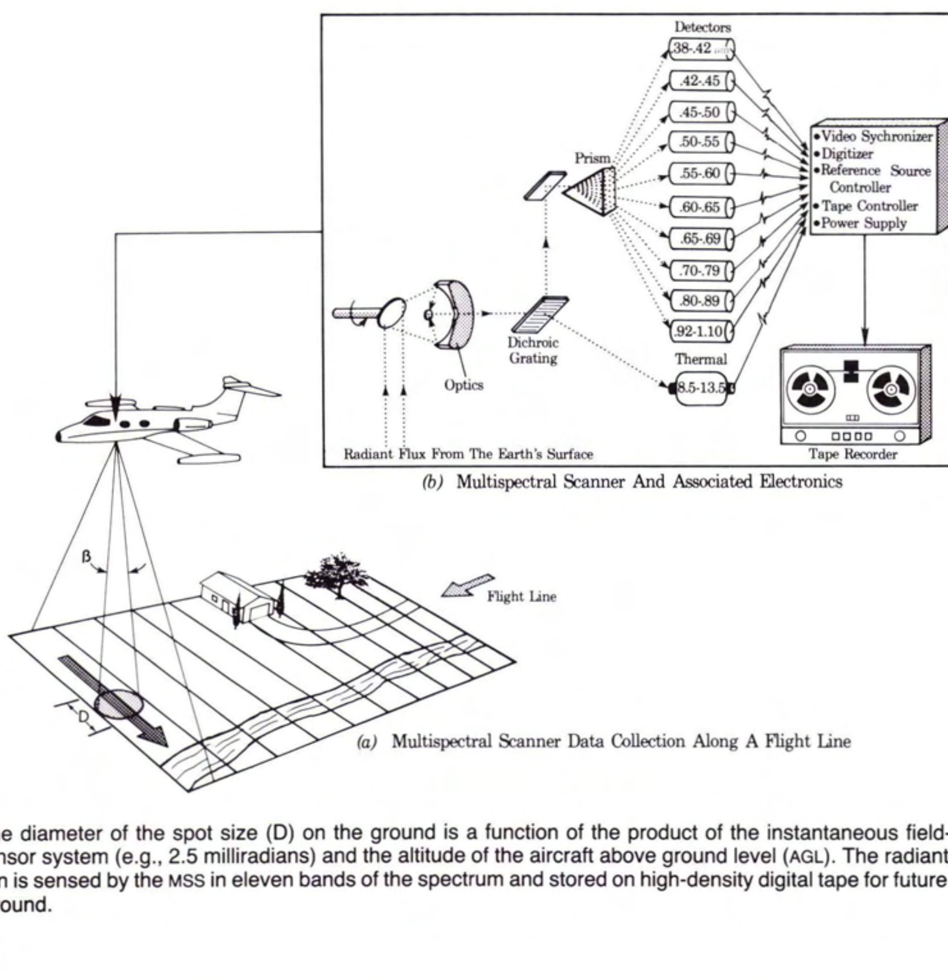
To be useful, the apparent temperature of the terrain in the remotely sensed data had to be accurate to within ±0.1°C of the true temperature. This radiometric requirement resulted in the use of a Daedalus DS-1260 Multispectral Scanner (MSS) system that sensed in the 8- to 14-μm region using a mercury-cadmium-telluride (Hg; Cd; Te) detector. Remotely sensed data were calibrated to ±0.1°C using internal blackbody source referencing (Shines and Tinney, 1984). A diagram of the MSS sensor system and its associated electronics is shown in Figure 2. The sensor specifications are summarized in Table 2. The MSS data were collected at approximately 1200-m above ground level (AGL). The data were geometrically corrected for two types of scanner distortion: (1) variation in the instantaneous-field-of-view across a scan line (S-bend or panoramic distortion), and (2) overlap of consecutive scan lines (velocity/height or aspect distortion). These two corrections provided relative accuracies of ±10 percent in the linear dimensions of the imagery (Hawley, 1981). The spatial resolution was approximately 3 m by 3 m.

Discrimination and analysis of warm water features are best performed using thermal infrared data collected during predawn hours when there is a significant thermal contrast between land and water surfaces. After sundown, dry land cools more rapidly, and within a few hours is cooler than the water. Also, predawn imagery eliminates the effects of shadows and solar heating. High relative humidity can also reduce the quality of thermal infrared data. For the latter reason, data typically were collected in the spring, after the passage of a cold front. This study describes the analysis of data obtained from such a predawn flight on 28 May 1983.

Three flight lines of predawn, thermal infrared imagery are shown in Plate 2. These data were color-coded (density sliced) according to the legend shown in Plate 2. The Savannah River was used as the ambient temperature because it appears in all three flight lines and has the least amount of temperature variation in the large floodplain area which was analyzed and color-coded. Temperatures ranging from 1 to 2.8°C above river ambient were displayed in shades of blue; those 2.8 to 5°C in shades of yellow; those from 5 to 10°C in shades of orange; and those >10°C in shades of red (Shines and Tinney, 1984). This isotherm map provides valuable information about the spatial distribution of the temperature of the effluent as it enters and migrates through the Savannah River floodplain. For example, a por-

TABLE 2. DAEDALUS MODEL DS-1260 MULTISPECTRAL SCANNER SPECIFICATIONS

Scan rate			12.5, 25, 50, and 100 scans/sec (selectable)
Instantaneous field-of-view			2.5 mrad
Total field-of-view			85.92°
Temperature resolution			Infrared: <0.1°C
Roll correction			±15°
Reference sources			Infrared: two controllable thermal black bodies
Pixels per scan line			716
Digitizer gains			0.5, 1, 2, 4, and 8 (selectable)
Quantization levels			0 – 255 (8-bits)
Spectral bands			
		Wavelength Interval (μm)	Spectral Region
	1	0.38 – 0.42	Near-ultraviolet
	2	0.42 – 0.45	Blue
	3	0.45 – 0.50	Blue
	4	0.50 – 0.55	Green
	5	0.55 – 0.60	Green/yellow
	6	0.60 – 0.65	Orange/red
	7	0.65 – 0.70	Red
	8	0.70 – 0.79	Near-infrared
	9	0.80 – 0.89	Near-infrared
	10	0.92 – 1.10	Near-infrared
	11	8.00 – 14.00	Thermal infrared



(b) Multispectral Scanner And Associated Electronics

(a) Multispectral Scanner Data Collection Along A Flight Line

FIG.2. The diameter of the spot size (D) on the ground is a function of the product of the instantaneous field-of-view (B) of the sensor system (e.g., 2.5 milliradians) and the altitude of the aircraft above ground level (AGL). The radiant flux exiting the terrain is sensed by the MSS in eleven bands of the spectrum and stored on high-density digital tape for future processing on the ground.

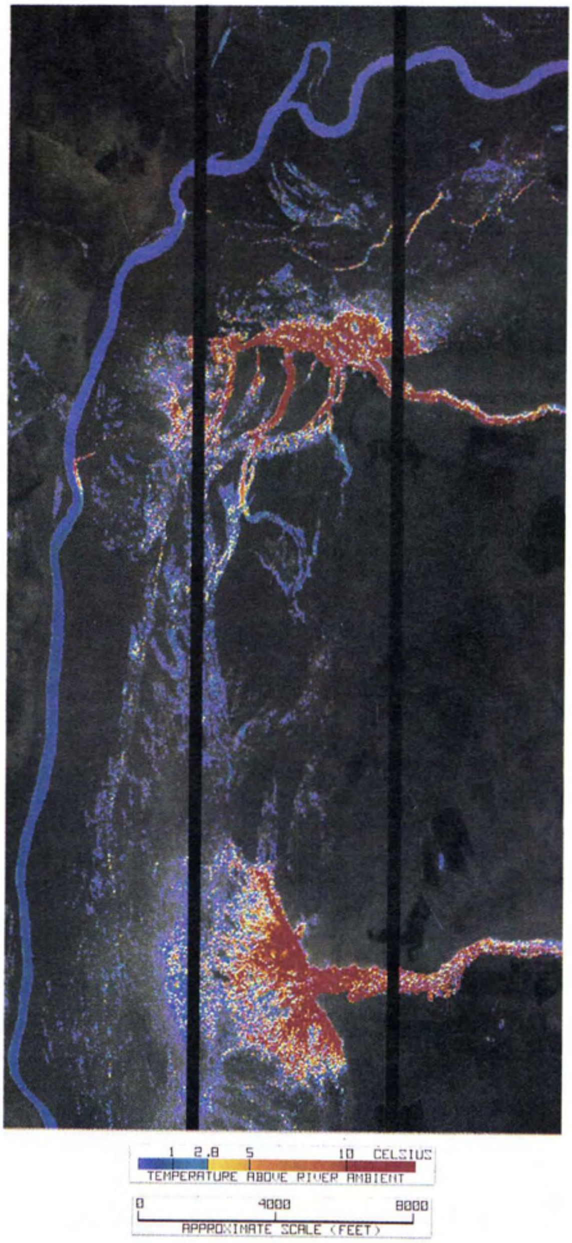


PLATE 2. Three flight lines of predawn thermal infrared imagery collected over the Four Mile Creek and Pen Branch delta study areas on 28 May 1983 at approximately 3:07 A.M. The data are color-coded (density sliced) according to their temperature above the Savannah River ambient temperature.

tion of the thermal effluent from Four Mile Creek can be observed to merge with effluent from Pen Branch. This is of significant value in determining how well the wetland acts as a natural heat sink.

A portion of the thermal effluent from Four Mile Creek reaches the mouth of the creek at the Savannah River. Thermal infrared data of the plume in the river are displayed at 4 × magnification in Plate 3. The data were density sliced according to the criteria previously discussed with the addition of isolines that identify the transition between the ambient, 1, 2.8, 5, and >10°C class intervals (Shines and Tinney, 1984). The ambient river temperature was determined by evaluating pixels within the rectangle located just above the plume. Passing transects through the plume provided quantitative information about the size of the plume with apparent surface temperature greater than river ambient (Plate 3B). Graphs of transects A, B, and K are shown in Figure 3. Graphs of transects A and B can be used to identify the size of the surface of the thermal plume relative to river width (Figure 3). Graphs of transects passed parallel to the plume (for example, transect K) are useful for evaluating the rate of thermal dissipation downstream in the plume.

WETLAND VEGETATION MAPPING USING HIGH RESOLUTION MSS DATA

National wetland inventory maps are being compiled for the United States at a scale of 1:100,000 by the U.S. Fish and Wildlife Service. Unfortunately, these data have a minimum mapping unit of approximately 6.25 hectares (Carter, 1982). Many local or regional agencies require minimum mapping units of less than 4 hectares. For example, the wetland studies on the Savannah River Plant often require minimum mapping units of <0.5 hectares. When such data requirements exist, potential mapping techniques include (1) the collection and analysis of *in situ* wetland information; (2) the acquisition and analysis of aerial photography or multispectral scanner (MSS) data, and (3) a combined *in situ* and remote sensing approach (Roller, 1977).

Extensive field collection of wetland data is often not practical because of the difficulty of traversing and navigating the wetland environment. Thematic mapping results that are not planimetric may result from *in situ* measurements if the field scientists cannot accurately determine geographic locations within wetlands. In addition, alligators, poisonous snakes, etc., may present personnel hazards in the wetlands of the southeastern United States. These considerations favor a remote sensing approach.

The interpretation of aerial photography is the most widely used method of obtaining detailed wetlands data (Huber, 1981). Aerial photography is preferred by many biologists for wetlands mapping because it is in a familiar picture format and can be analyzed economically using inexpensive instruments and generally effective photointerpretation techniques (Wicker and Meyer-Arendt, 1981; Carter, 1982). However, color and color infrared aerial photography have relatively poor spectral resolution (Colvocoresses, 1984). This can make it difficult to

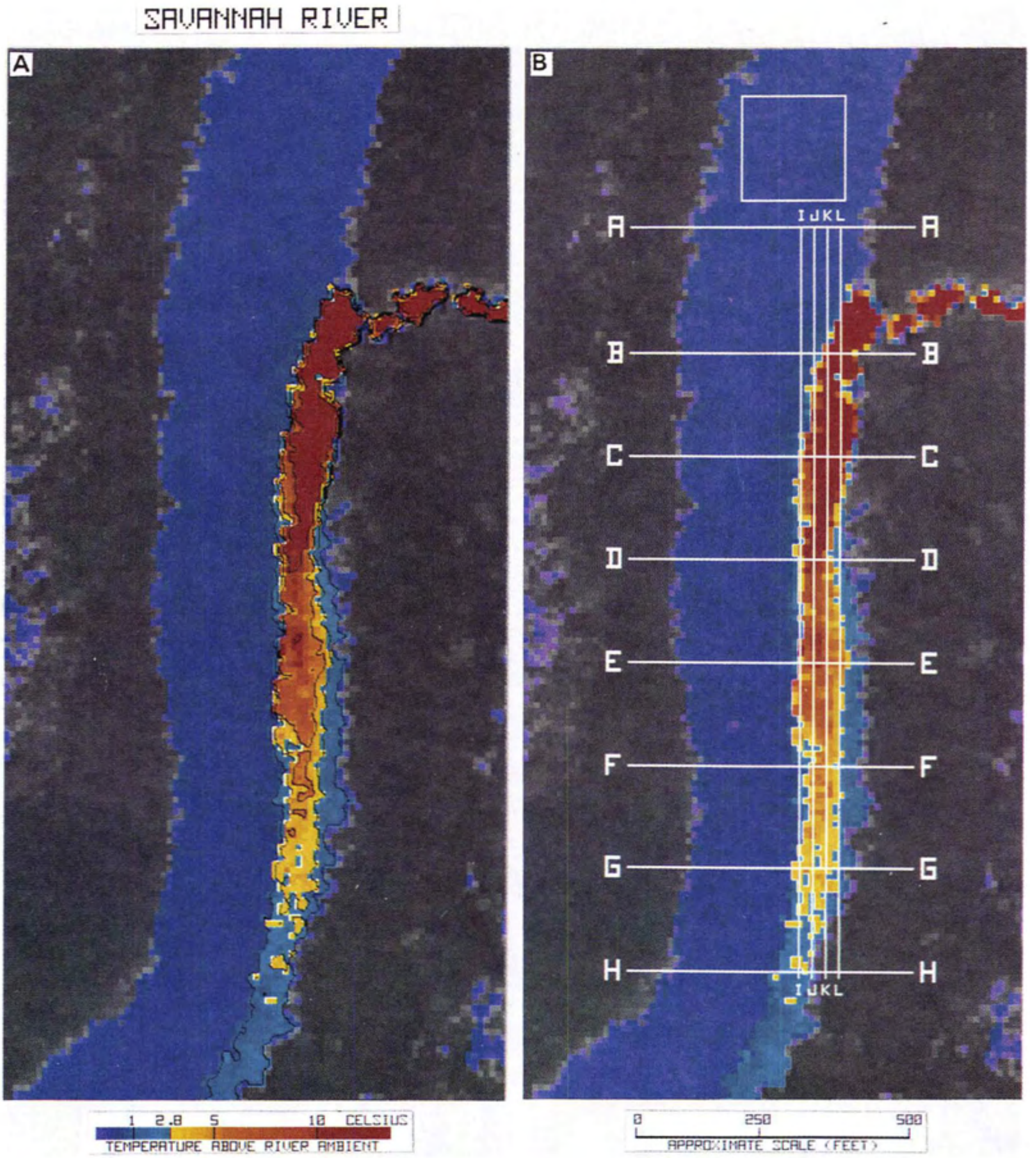


PLATE 3. (A) Effluent from Four Mile Creek is shown entering the Savannah River. The data are shown at 4 × magnification using the temperature class intervals previously discussed. (B) Transects are passed parallel and perpendicular to the plume to obtain quantitative information.

distinguish between certain species of wetland vegetation types based solely on their spectral characteristics. Basically, very little quantitative information about the spectral nature of inland wetland vegetation is available from the aerial photography.

MSS data for mapping wetlands may be acquired using satellite or aircraft borne sensors. Although expensive to acquire, high spectral and spatial resolution MSS data obtained from an aircraft platform provides detailed spectral information that can be used to discriminate between various wetland classes, particularly if these are closely spaced or intermixed with each other. The following section described the collection and analysis of high resolution airborne MSS data for SRP wetland mapping. The use of Landsat MSS and TM data for regional wetland mapping of the Savannah River watershed is discussed in a subsequent section.

Four Mile Creek Transects - 28 May 1983
Relative Surface Water Temperature

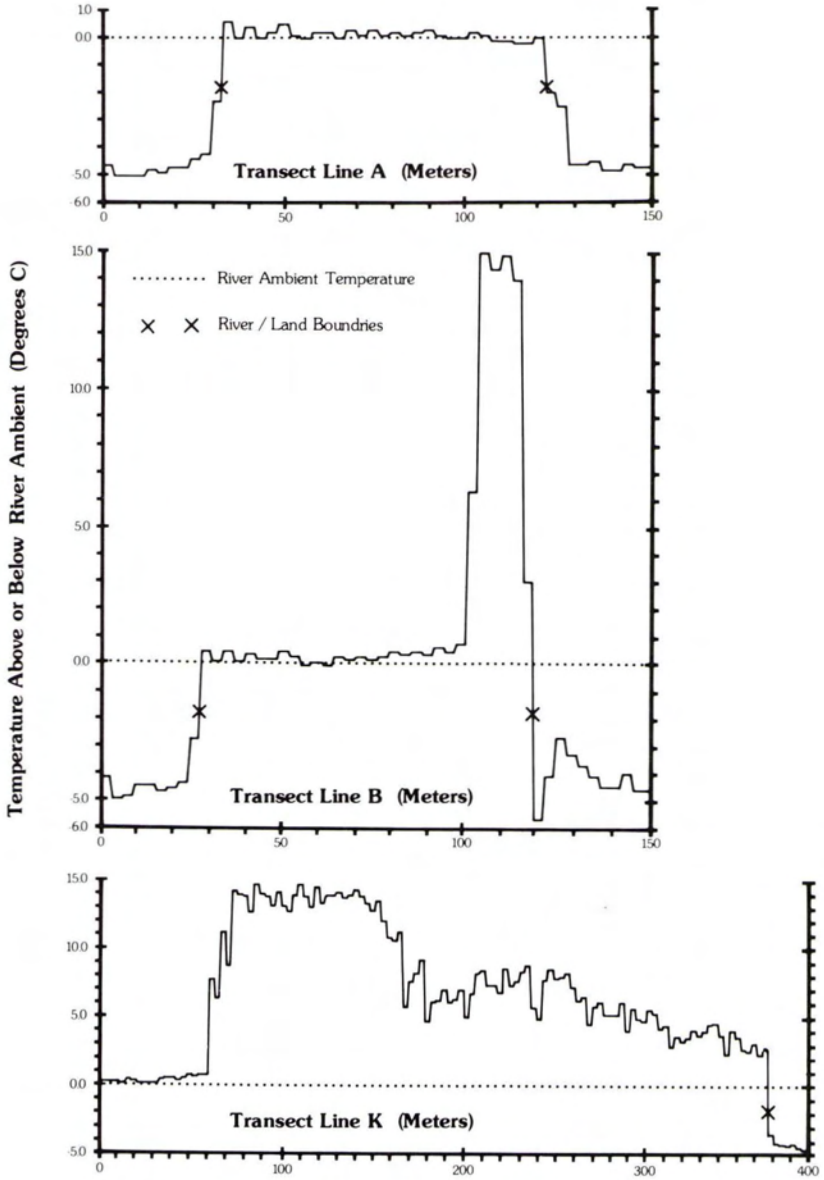


FIG.3. Transect A documents the stability of the Savannah River ambient temperature above the Four Mile Creek plume. Transect B provides quantitative information on how warm the plume is relative to the ambient river temperature for exact locations within the river channel. Transect K is used to identify the rate at which the plume temperature dissipates as it progresses downstream.

Wetland Mapping in the SRP Savannah River Floodplain Using High Resolution MSS Data

At the location where the thermal creeks enter the Savannah River floodplain, the forested wetlands have been replaced by sedimentation deltas, open water, and marsh-type wetland vegetation (Figure 4). Remote sensing wetland mapping has been completed for each of the deltas; however, this section will only report on results from the Four Mile Creek delta (Plate 4).

Black-and-white, color, and color infrared aerial

Aircraft MSS Imagery Obtained on 31 March 1981 at 1220 Meters Above Ground Level (.8 -.9 μm)

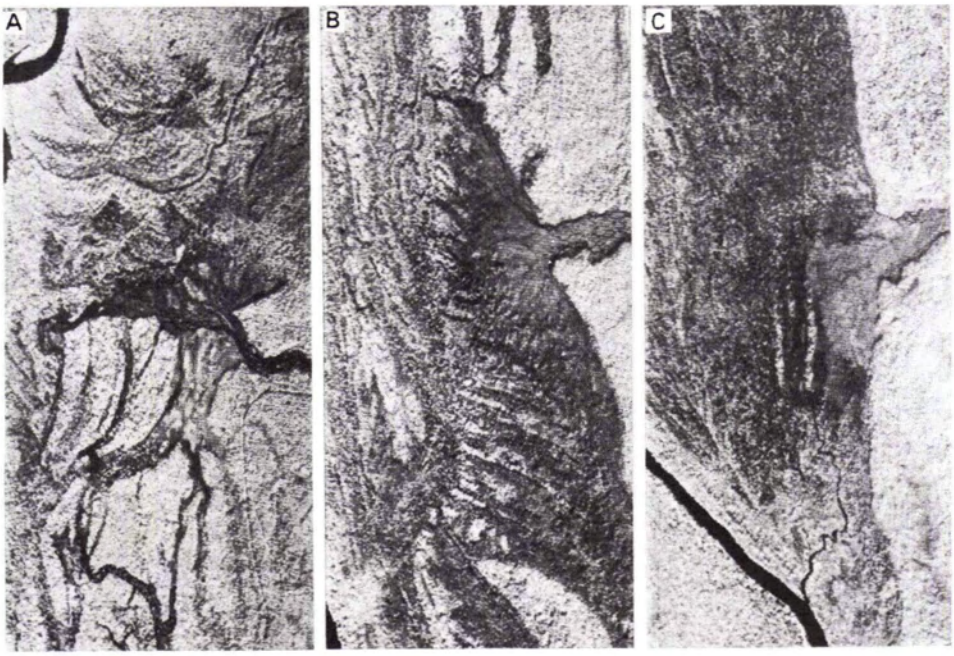


FIG.4. Imagery of Four Mile Creek, Pen Branch, and Steel Creek deltas obtained on 31 March 1981 using a DS-1260 Multispectral Scanning System (MSS). Eleven bands of spectral data were collected at a 3- by 3-meter spatial resolution.

photography of the Four Mile Creek delta were not optimal for mapping the numerous and highly intermixed wetland vegetation types. Consequently, high spectral and spatial resolution aircraft MSS imagery were obtained to classify the wetland vegetation according to the Cowardin wetland classification system (Cowardin *et al.*, 1979; Stewart *et al.*, 1980). The MSS data were collected on 31 March 1981 at 1220 metres AGL using the sensor system described in Table 2. This resulted in an MSS dataset consisting of eleven spectral measurements for each 3 by 3 m pixel. A single band of near-infrared imagery (0.8 to 0.9 μm) is shown in Figure 4A.

Ecologists familiar with swamp vegetation characteristics assisted in the supervised classification of the Four Mile Creek delta into the following wetland categories: Persistent Emergent Marsh (PE), Nonpersistent Emergent Marsh (NPE), Scrub/Shrub (SS), Algal Mat (AM), Mixed Deciduous Upland Forest (MDUF), and Mixed Deciduous Swamp Forest (MDSF). A description of the species within each class is found in Table 3 (Whipple *et al.*, 1981; Jensen *et al.*, 1984). A transformed divergence analysis identified the optimum subset of nine bands taken four at a time as bands 5 (0.55 – 0.60 μm), 7 (0.65 – 0.70 μm), 8 (0.70 – 0.79 μm), and 10 (0.92 – 1.10 μm). Using more than four bands did not add significantly to the separability of the wetland vegetation types. Note that at least one band from each of the major spectral regions useful for vegetation studies was selected, i.e., green, red, and near-infrared (Best *et al.*, 1981). The study did not evaluate the utility of any middle-infrared bands (especially 1.5 – 1.8 μm) which have proven of value in some nontidal wetland mapping studies (Work and Thomson, 1974).

A minimum distance classification algorithm was applied to the data set, yielding a thematic map of the wetland vegetation classes (Plate 4A). The map is approximately 83 percent accurate with only one category (NPE) falling below 80 percent. The error evaluation was performed by comparing picture elements in the thematic map with wetland information obtained on the ground along transects that were investigated by scientists who waded or canoed through the swamp (Jensen *et al.*, 1984). Such accuracy is comparable with Thomson's (1970) study of tree islands and saw grass in the Florida Everglades which were mapped with 80 to 90 percent accuracy and the Sellman *et al.* (1974) study which achieved approximately 94 percent accuracy of emergent plant

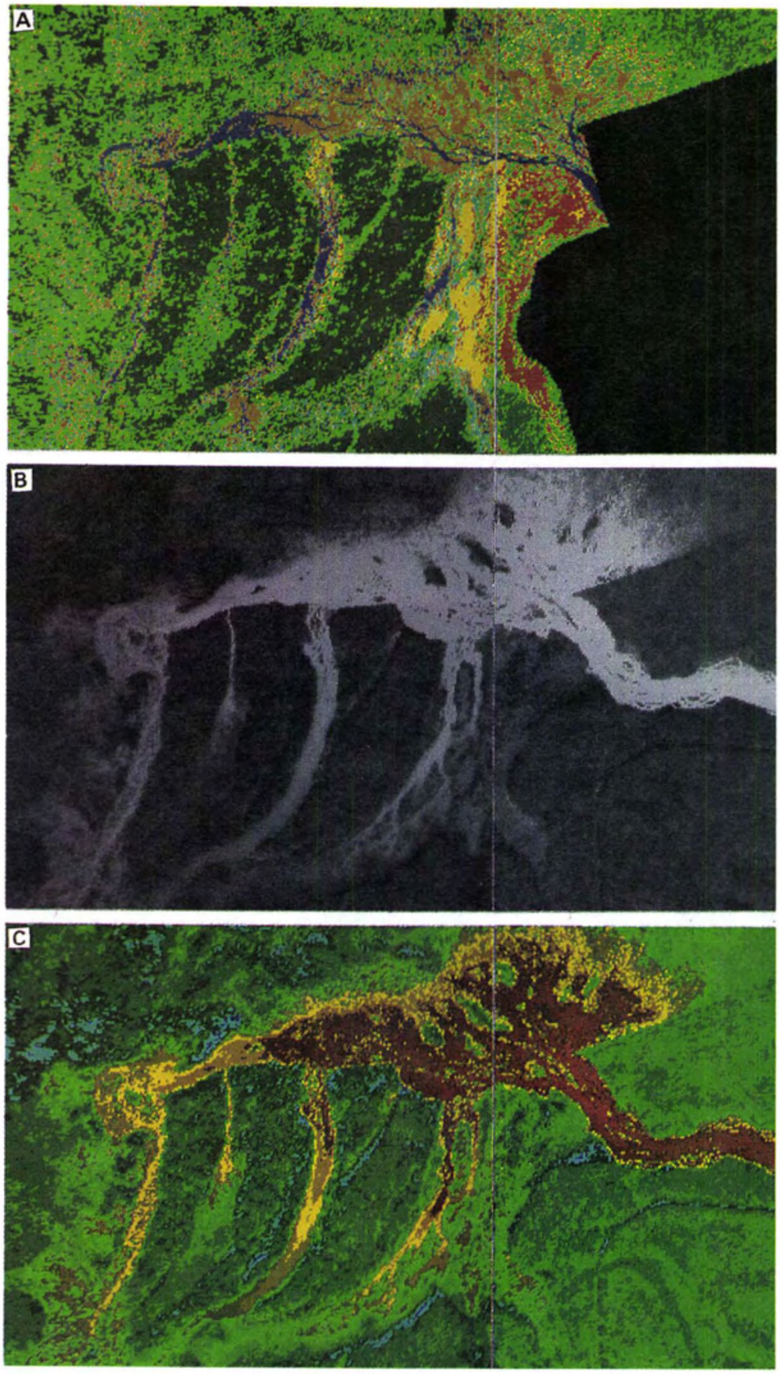


PLATE 4. Four Mile Creek Delta. (A) Wetland map based on analysis of MSS data collected on 31 March 1981 using bands 5, 7, 8, and 10. The color codes and description of each class are summarized in Table 3. (B) Thermal infrared data acquired at the same time as the visible/near-infrared data. (C) The thermal infrared data density sliced using 15 equal class intervals. There are two shades of blue, four of green, four of yellow, and five of red. The progression is from coolest (blue) to warmest (red). The relationship between surface temperature class interval and wetland class is summarized in Figure 5.

TABLE 3. CLASSIFICATION SCHEME FOR THE FOUR MILE CREEK DELTA

Class	Color	Common Name	Scientific Name
Water – W	Blue	—	—
Mixed Deciduous Upland Forest – MDUF	Dark green	Oak Loblolly pine Sweetgum Red maple Hickory	*Quercus* spp. *Pinus taeda* *Liquidambar styraciflua* *Acer rubrum* *Carya* spp.
Mixed Deciduous Swamp Forest – MDSF	Green	Bald cypress Tupelo gum	*Taxodium distichum* *Nyssa aquatica*
Scrub/Shrub – SS	Red	Willow Buttonbush	*Salix* spp. *Cephalanthus occidentalis*
Persistent Emergent Marsh – PE	Yellow	Knotweed Cutgrass False nettle	*Scripus cyperinus* *Leersia* spp. *Boehmeria cylindirica*
Nonpersistent Emergent Marsh – NPE	Cyan	Water primrose	*Ludwigia* spp.
Algal Mat – AM	Tan	Algae	—
Unclassified	Black	—	

species in Michigan using airborne MSS data. A detailed description of where the various wetland classes cluster in two- and three-dimensional feature space using early Spring MSS data is described in Jensen *et al.* (1984).

Studies have been conducted to relate the various types of vegetation present on the Four Mile Creek delta with water temperature. This information was obtained by comparing the wetland vegetation thematic map with thermal infrared data. Daytime thermal infrared MSS data (Plate 4B) were acquired during the same overflight as the visible and reflective near-infrared data on 31 March 1981. Therefore, these data were already in registration. To determine if there were any relationships between wetland vegetation and thermal patterns, the original thermal infrared imagery of the delta were analyzed and color-coded using 15 class intervals (Plate 4C). The Cowardin wetland class of each pixel was then cross-tabulated with the apparent temperature of the pixel recorded by the thermal infrared data. The relationship between apparent surface temperature and vegetation type is shown in Figure 5. A Chi-square analysis revealed that a statistically significant association exists between the vegetation types and their apparent temperature class intervals. For example, the Nonpersistent Emergent Marsh (NPE) is the most thermally tolerant wetland class, followed by Persistent Emergent marsh (PE) and Scrub-Shrub (SS). As the delta continues to expand, the less tolerant Cypress-Tupelo swamp (MDSF) will be replaced by these species. Subsurface Algal Mat (AM) will thrive in the warmest water. Other factors such as sedimentation and oxygen stress may play a role in establishment of different plant community types.

WETLAND CHANGE DETECTION USING LARGE-SCALE AERIAL PHOTOGRAPHY

Multispectral data were good for mapping recent patterns in wetland communities; however, these types of data are usually not available for mapping long-term changes. Large scale aerial photography was available for the SRP Savannah River swamp and was useful for mapping the wetland vegetation on the individual deltas over a 25- to 30-year time period. The methodology is demonstrated using the Steel Creek delta (Figure 1). This delta underwent expansion from 1954 to early 1968, while thermal

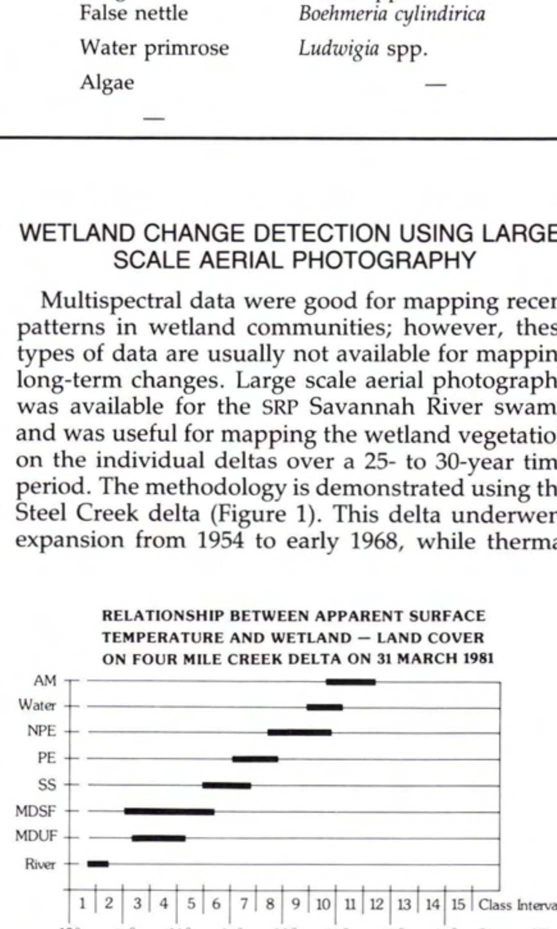


FIG. 5. The relationship between 15 temperature class intervals and the major wetland and land-cover-types found on and adjacent to the Four Mile Creek delta on 31 March 1981 based on an analysis of aircraft MSS data. Algal mat was found on the warmest areas with Mixed Deciduous Upland Forest (MDUF) and Mixed Deciduous Swamp Forest (MDSF) located in the cooler environments. The bars represent the mean ±1 standard deviation in temperature (°C).

effluents from reactor operations were discharged into the creek. Since shutdown of the Reactor in 1968, the delta has experienced extensive revegetation. Vegetational changes were based on the identification of areas on or adjacent to the delta where indigenous cypress-tupelo swamp forest canopy density was reduced due to exposure to thermal effluent and/or sediment. The following classification scheme was adopted to determine if damage had occurred, was under way, or if vegetation recovery had taken place:

- no canopy density loss
- partial canopy density loss (0 to 95 percent)
- complete canopy density loss (96 to 100 percent)

Six dates of aerial photography were analyzed at contact scale using stereoscopic photointerpretation techniques (Figure 6). Ecologists from the Savannah River Ecology Laboratory, and the Savannah River Laboratory interpreted the aerial photography independently to locate the canopy density boundaries. However, the final polygon boundaries for each date were mutually agreed upon. The canopy loss polygons were then transferred to a 1:10,000-scale planimetric basemap in a Universal Transverse Mercator (UTM) projection. Relief displacement adjustments in the aerial photography were not necessary because the Steel Creek delta area is relatively flat.

The Steel Creek delta information was placed in a raster-based geographic information system (GIS) which facilitated interactive analysis and viewing of the different images on a color CRT. A geographic information system is a structured cartographic data base where all spatial information are stored in near-perfect geographic registration (Marble *et al.*, 1985). To convert the six Steel Creek, 1:10,000-scale overlays into a format compatible with a raster GIS, each polygon on the 1:10,000-scale overlays was digitized and given a code. These polygons were then transformed into raster-based data structure using a polygon-to-raster conversion program. This resulted in six files in near-perfect geometric registration. Each file was a matrix of 240 rows by 256 columns with each pixel representing an area on the ground of 15 m by 15 m.

Once the six Steel Creek overlays were geometrically registered, delta growth information for each date of imagery was available in the form of computer cartographic products and/or statistical summaries. In addition, digital change detection based on the use of boolean logic between dates was performed to identify changes in one or more land-cover classes through time. A composite image provided a visual impression of both the spatial extent and the direction of delta growth (Plate 5A). A similar procedure was applied to evaluate Steel Creek delta vegetation recovery from 1968 to 1982 (Plate 5B).

This use of change detection information helped identify the modification rate and spatial distribution of wetlands influenced by cooling water effluent. In addition, the Steel Creek study provided information on the rate at which canopy return took place in a wetland once thermal effluent discharge ended.

REGIONAL WETLAND MAPPING USING LANDSAT MSS AND TM DATA

As indicated earlier, in addition to detailed wetland mapping of the SRP Savannah River floodplain from high resolution remote sensing (MSS) data, regional mapping of the Savannah River watershed can be performed using satellite sensors. Both Landsat (MSS) and Thematic Mapper imagery were evaluated for their potential for wetland mapping.

Previous research demonstrated that the Landsat MSS data are useful for spectral discrimination of large vegetated wetlands (Gilmer *et al.*, 1980; Gammon and Carter, 1979; Butera, 1983). Therefore, Landsat MSS data with their relatively coarse spatial resolution (approximately 0.5 hectare) and four channel spectral resolution were used to produce a simple Level 1 wetland inventory of the entire Savannah River watershed.

Three Landsat MSS images obtained in the spring of 1977 were used: 22 February (Path 18, Row 37), 13 March (Path 19, Row 36), and 13 March (Path 19, Row 37). These data were resampled to 80-m by 80-m pixels, digitally mosaicked, and rectified to a Universal Transverse Mercator (UTM) projection. The boundaries of the nine U.S. Geological Survey hydrologic units comprising the Savannah River watershed were also registered to the UTM projection, creating a GIS of approximately 27,000 square kilometres in Georgia, South Carolina, and North Carolina.

The Savannah River watershed map was produced using a supervised classification procedure (Plate 1). The hectares of each land-cover type were extracted by USGS Hydrologic Unit (Table 1). Although Landsat MSS data could not provide the detailed type of wetland information necessary for individual delta studies on the SRP because of the close spatial mix of many different wetland types, it was suitable for regional Level 1 assessments of inland wetland and other land cover in the Savannah River watershed.

The use of Thematic Mapper satellite imagery for regional wetland mapping was also evaluated. TM data have a spatial resolution of 30 by 30 m for six of the seven spectral bands. Some researchers have suggested that the Thematic Mapper imagery has improved the quality of wetland information (Quattrochi, 1983; Dottavio and Dottavio, 1984). Unfortunately, due to the mechanical failure onboard Thematic Mapper (Landsat 4), and the sporadic data collection of Landsat 5, the only date of TM imagery

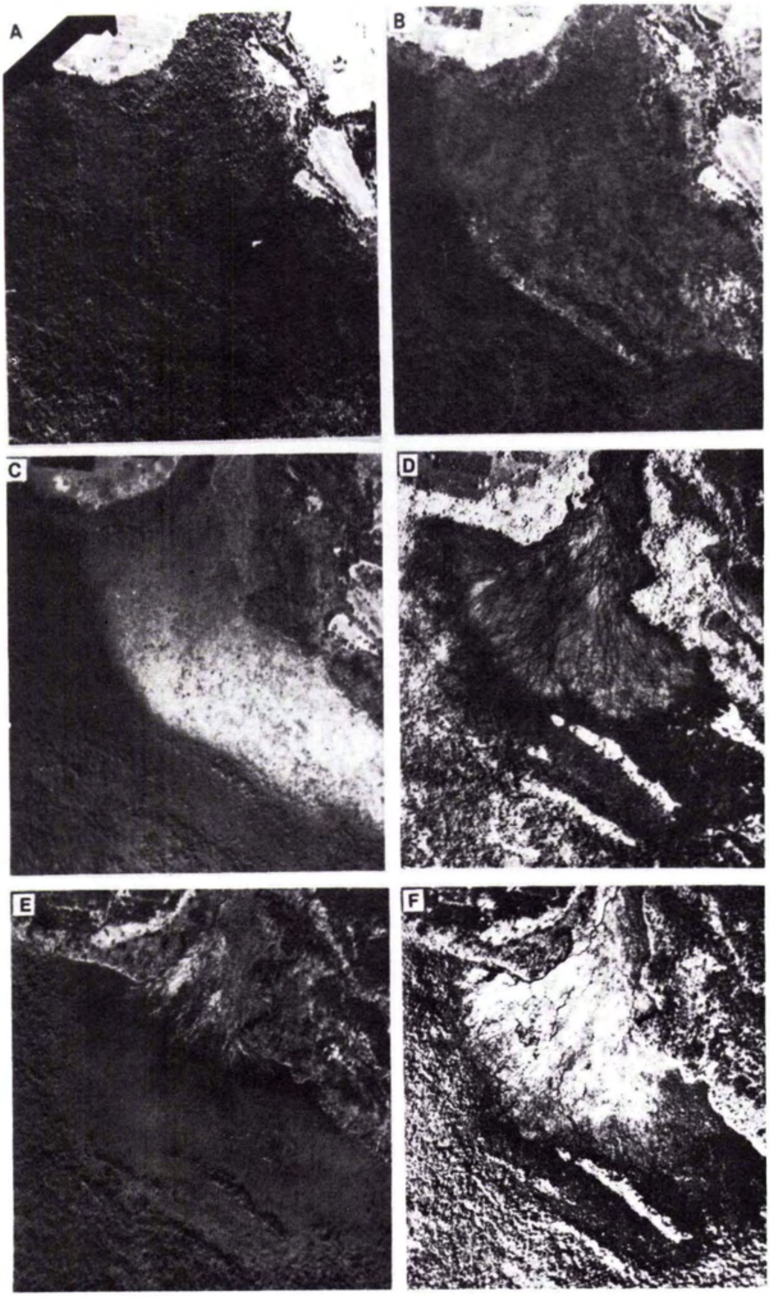


FIG.6. Six dates of aerial photography used to document the growth and subsequent recovery of Mixed Deciduous Swamp Forest (MDSF) canopy density on the Steel Creek Delta. The dates of photography are (A) 4 April 1951, panchromatic; (B) 21 March 1956, panchromatic; (C) 15 March 1961, panchromatic; (D) 5 May 1966, near-infrared; (F) 13 February 1974, panchromatic; and (F) 20 February 1982, natural color.

available for analysis for the Savannah River region was the 28 August 1982 image. Analysis of this imagery demonstrated that, at this late date in the growing season, only Bands 4 and 5 provided separation between the various wetland classes. Unfortunately, these and other bands did not allow

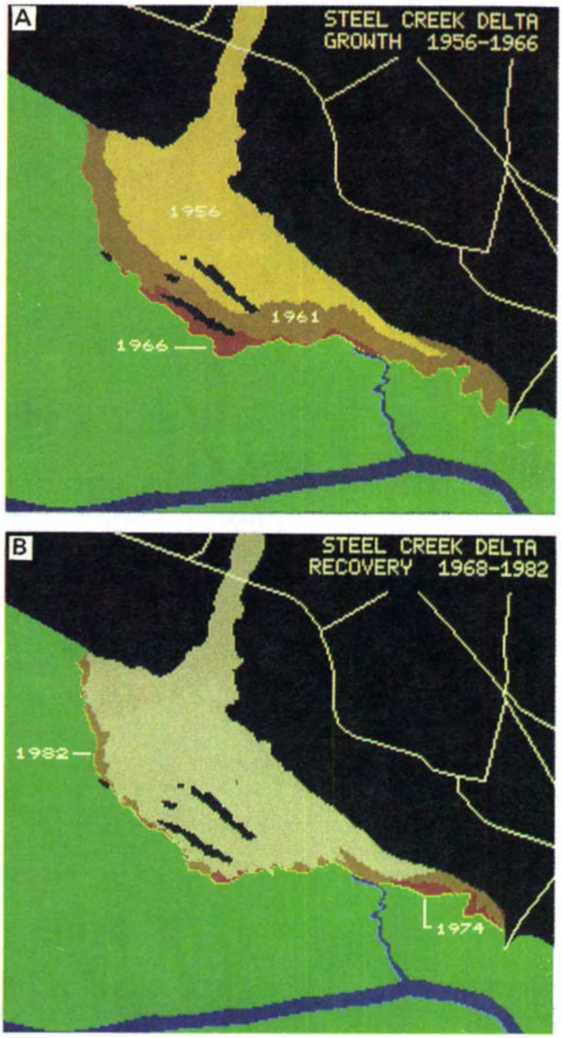


PLATE 5. (A) Steel Creek delta growth from 1951 to 1956 (yellow), 1956 to 1961 (tan), and 1961 to 1966 (red). The unaffected Cypress-Tupelo Mixed Deciduous Swamp Forest (MDSF) is in green. The Savannah River is in blue. (B) Recover of canopy density from 1968 to 1974 (red) and from 1974 to 1982 (tan). The portion of the delta that has not regained canopy density is shown in gray.

differentiation between pine and cypress-tupelo, a serious limitation. Conversely, the upland agriculture, water, and urban/bare soil land cover were easily distinguished. These results suggest that Landsat TM data should be obtained in the spring of the year in the southeast, if the data are to be used for wetland mapping.

SUMMARY

The collection and analysis of various types of multispectral remotely sensed data provide detailed wetland information for an area along the Savannah River in South Carolina. Information on the temperature and spatial distribution of thermal effluent entering the wetland was collected using predawn thermal infrared imagery. Detailed wetland vegetation maps were produced using high resolution daytime visible and near-infrared aircraft MSS data. Thermal infrared data obtained at the same time proved of value when relating vegetation type to surface water temperature. The historic changes in the wetlands of the deltas was best documented using multiple date, large-scale aerial photography. Finally, regional wetlands were best mapped using Landsat MSS data.

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