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MULTISPECTRAL REMOTE SENSING OF INLAND WETLANDS IN SOUTH CAROLINA: SELECTING THE APPROPRIATE SENSOR

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I. INTRODUCTION

Wetlands are important natural resources that assimilate pollutants, absorb floodwaters, and serve as breeding, nursery, and feeding grounds for many species of fish and wildlife. Information concerning wetland distribution and condition is essential for effective protection and management (Roller, 1977; Carter, 1982). This study describes the use of various types of multispectral remote sensor data to characterize nontidal (inland) wetlands located in South Carolina.

II. THE STUDY AREA

The Savannah River watershed encompasses an area of 27,000 square kilometers. Forested and nonforested wetland comprise a large portion of the drainage basin. Approximately 3020 hectares of Savannah River floodplain wetlands border the Savannah River Plant (SRP) located near Aiken, South Carolina (Figure 1). Cooling water from SRP operations is released to onsite streams that drain into the Savannah River swamp forest. Some of the heat carried by the streams is dissipated in the creek floodplains and SRP river swamp wetlands, altering normal vegetation communities. This research summarizes the utility of remote sensing for mapping both local (SRP) and regional wetlands including:

* Thermally affected areas of the SRP swamp, using multispectral scanner (MSS) imagery and large scale aerial photography;

* The SRP river swamp, using aircraft MSS and Landsat thematic mapper imagery, and

* The Savannah River watershed, using Landsat MSS imagery.

III. THERMAL DELTA WETLAND MAPS

A. USING AIRCRAFT MSS IMAGERY

Four SRP streams have carried cooling water to the SAvannah River Swamp System (SRSS) adjacent to SRP; Beaver Dam Creek, Four Mile Creek, Pen Branch, and Steel Creek (Figure 1). Where each creek enters the swamp, the wetland forest has been replaced by sedimentation deltas, open water and marsh-type vegetation. Remote sensing wetland mapping has been completed for each of the deltas; however, this study will only report on Steel Creek delta. The delta was formed between 1954 and 1968 while Steel Creek received cooling water discharges. The stream has not received thermal effluent since 1968, and the delta area has been revegetating.

Black and white and color aerial photography of Steel Creek delta was not optimal for mapping the numerous and highly intermixed wetland vegetation types. However, high resolution aircraft (MSS) imagery was available (Figure 2), and used to classify the wetland vegetation types according to the Cowardin wetland classification system (Cowardin et al., 1979). The MSS imagery was collected on 31 March 1981 at 1220 meters above ground level (AGL) using a Daedalus sensor system with an IFOV of 2.5 milliradians. The MSS data had a resolution of 2.8 x 2.8 meters per picture element (pixel). Eleven spectral measurements were obtained for each pixel (Table 1).

Table 1. Daedalus DS-1260 MSS Specifications

Band	**Wavelength Interval**	**Spectral Region**
1	0.38 - 0.42um	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

Scientists familiar with swamp vegetation assisted in the supervised classification of the Steel Creek delta and in the collection of *in situ* transect data to assess the mapping accuracy of the following wetland categories: Persistent Emergent Marsh (PE), Nonpersistent Emergent Marsh (NPE), Scrub/Shrub (SS), Mixed Deciduous Bottomland Forest (MDBF) and Mixed Deciduous Swamp Forest (MDSF). The results are summarized in Table 2 and the classification map is presented in Figure 3. The optimum channels for this study area, the spectral characteristics of the various Cowardin wetland classes and where they clustered in n-dimensional feature space are discussed in Jensen et al. (1984).

Table 2.
Per Meter Evaluation of Remote Sensing Classification Along Steel Creek Delta Transects A and B[1]

Ground Truth Class	Multispectral Classification PE	NPE	SS	MDSF	MDUF	W	U	Total[2]	%
PE	343	20	49	--	--	--	--	412	83
NPE	30	137	10	--	--	--	--	177	77
SS	20	20	254	20	--	--	--	314	81
MDSF	--	--	--	127	10	--	10	147	86
MDUF	--	--	--	20	117	--	--	137	85
W	--	10	--	--	--	128	--	138	93
U	--	--	--	--	--	--	--	--	--
Total[3]	393	187	313	167	127	128	10	1325	83

[1]Transect A and B were 1021 and 304 meters in long.

[2]Total meters in each category as verified by in situ observation.

[3]Total meters in each category on the remote sensing derived map.

The overall absolute classification accuracy was 83.5 percent along the two transects. Such accuracy was comparable with Thomson's (1970) study of tree islands and saw grass in the Florida Everglades which were mapped with 80-90 percent accuracy using MSS data and the study by Sellman et al (1974) which achieved approximately 94 percent accuracy for emergent plant species in Michigan using aircraft MSS data. Thus, the feasibility of using aircraft MSS data to accurately identify and map specific classes of South Carolina non-tidal wetland was demonstrated.

B. CHANGE DETECTION USING AERIAL PHOTOGRAPHY

Although the large scale aerial photography was not useful for mapping the wetland vegetation classes, it was valuable for mapping the delta growth from 1954 to 1968 and subsequent rejuvenation through 1982. The study identified areas on or adjacent to the deltas where indigeneous cypress-tupelo swamp forest canopy had been defoliated from exposure to hot water and sediment. The following classification scheme was adoped for the swamp forest areas:

1) no canopy loss
2) partial canopy loss (0-95%)
3) complete canopy loss (95-100%).

This classification scheme was useful for identifying where damage had occurred or was underway and/or where successional vegetation recovery had taken place since the reactor was placed on stand-by in 1968.

The six dates of original aerial photography (Figure 4) were analyzed at contact scale using stereoscopic photointerpretation techniques. Ecologists from the Savannah River Ecology Laboratory and the Savannah River Laboratory interpreted the imagery independently to locate the percent canopy loss boundaries. However, the final polygon boundaries were jointly selected. The completed canopy loss polygons were then optically enlarged and transferred to a 1:10,000 scale planimetric basemap. Because the Steel Creek delta area is virtually flat, relief displacement adjustments were not necessary.

A geographic information system (GIS) is a structured, digital cartographic data base where all spatial information are stored in near-perfect geographic registration (Borrell, 1982). Steel Creek delta information was placed in a raster-based GIS which facilitated interactive analysis and viewing of the different images on a color CRT. In order to convert the six 1:10,000 scale overlays into a format compabible with a raster-based GIS, each damage class 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 developed by the authors. The result was six files in near-perfect geometric registration. Each was a matrix of 240 rows by 256 columns with each pixel representing an area on the ground of 13m x 13 m.

Once the six overlays were geometrically registered, delta growth information for each date of imagery was available in the form of color, 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 (Jensen and Toll, 1982). The composite image (Figure 5) and statistics provided a visual impression of both the spatial extent and direction of change as-well-as the changes in acres for each class. A similar procedure was applied to evaluate Steel Creek delta vegetation recovery from 1966 to 1982 (Figure 6).

This change detection information was used to identify the modification rate and spatial distribution of wetland influenced by cooling water effluent. In addition, it provided valuable information on the rate at which canopy-return can take place in a wetland once thermal effluent discharges cease (Figure 7).

IV. WETLAND MAPPING OF THE SRP SWAMP

A. USING HIGH RESOLUTION MSS IMAGERY

The 2.8m x 2.8m aircraft MSS imagery collected for the analysis of the individual deltas could not be geometrically mosaicked together to produce an accurate planimetric map of the entire swamp adjacent to the Savannah River Plant. For this reason, an additional overflight was made on 31 March 1981 at twice the flying height AGL, 2440 meters, using the same sensor system. In this manner it was possible to encompass the entire swamp in a single flightline, eliminating the need for mosaicking.

This resulted in a data set of eleven spectral channels at 5.6m x 5.6m spatial resolution. New training data were extracted in exactly the same areas as for the 1220m AGL dataset. When introduced to a transformed divergence equation, exactly the same sequence of spectral channels (features) were selected for classification. The resultant SRP Swamp Vegetation Map is shown in Figure 7.

The lower spatial resolution did not decrease the spectral contrast between the various wetland vegetation types found in the swamp. The SRP swamp map had approximately the same accuracy (80%) as the delta maps when compared with in situ transects sampled in Pen Branch and Steel Creek deltas.

B. USING THEMATIC MAPPER IMAGERY

Because swamp vegetation could still be separated spectrally using aircraft MSS data, even after a two-fold decrease in spatial resolution, the possibility of using Landsat Thematic Mapper (TM) data was investigated. TM data has a spatial resolution of 30 x 30 m and with six spectral bands should be able to accurately discriminate various wetland classes, making the collection of expensive aircraft MSS data unnecessary.

Due to the mechanical failure onboard the Landsat 4 satellite, the only date of TM imagery available for analysis was a 28 August 1982 image (Figure 8). Analysis of this imagery demonstrated that at this late date in the growing season some of the wetland vegetation types reflect approximately the same amount of energy throughout the visible and near-infrared wavelengths. Only bands 4 and 5 provided any significant separation between the various wetland classes. Conversely, the upland agriculture, water, and urban/bare soil land cover were easily distinguished. These results suggest that TM data should be obtained in the Spring or Fall of the year in Southeastern environments if the data is to be used for wetland mapping.

V. WETLAND MAPPING OF THE SAVANNAH RIVER WATERSHED

To compare site wetlands information to regional wetlands inventories in the Savannah River watershed, a sensor was needed which could provide reasonable spatial resolution (e.g., a one acre minimum mapping unit), yet adequately discriminate wetland from all other land cover classes. Three Landsat MSS images obtained in the spring of 1977 provided the necessary information; February 22, 1977 (Path 18 Row 37), March 13, 1977 (Path 19 Row 36), and March 13, 1977 (Path 19 Row 37). These data were resampled to 80m x 80m pixels, digitally mosaicked, and rectified to a Universal Transverse Mercator (UTM) projection.

The boundaries of the nine USGS hydrologic units encompassing the Savannah River Watershed were also registered to the UTM projection. This represented a GIS system which encompassed more than 27,000 square kilometers in Georgia, South Carolina, and North Carolina.

The Savannah River watershed map was produced using a supervised classification procedure (Figure 9). The acreage of each land cover type was extracted and evaluated by USGS hydrologic unit. Although Landsat MSS data cannot provide the detailed type of wetland information necessary for the delta studies, it can be used for regional assessments of wetland and other land cover in the Southeastern United States if early spring imagery is analyzed.

ACKNOWLEDGEMENTS

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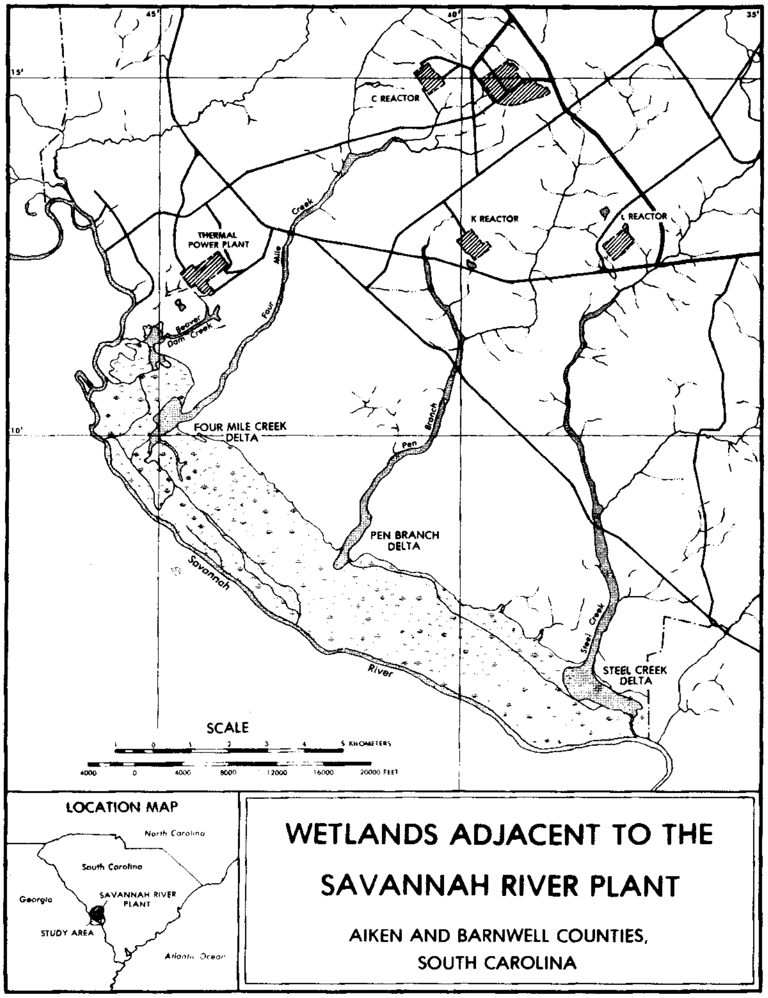
C REACTOR
K REACTOR
L REACTOR
THERMAL POWER PLANT
Four Mile Creek
Beaver Dam Creek
FOUR MILE CREEK DELTA
Pen Branch
PEN BRANCH DELTA
Steel Creek
STEEL CREEK DELTA
Savannah
River
SCALE
LOCATION MAP
STUDY AREA
WETLANDS ADJACENT TO THE
SAVANNAH RIVER PLANT
AIKEN AND BARNWELL COUNTIES,
SOUTH CAROLINA

Figure 1

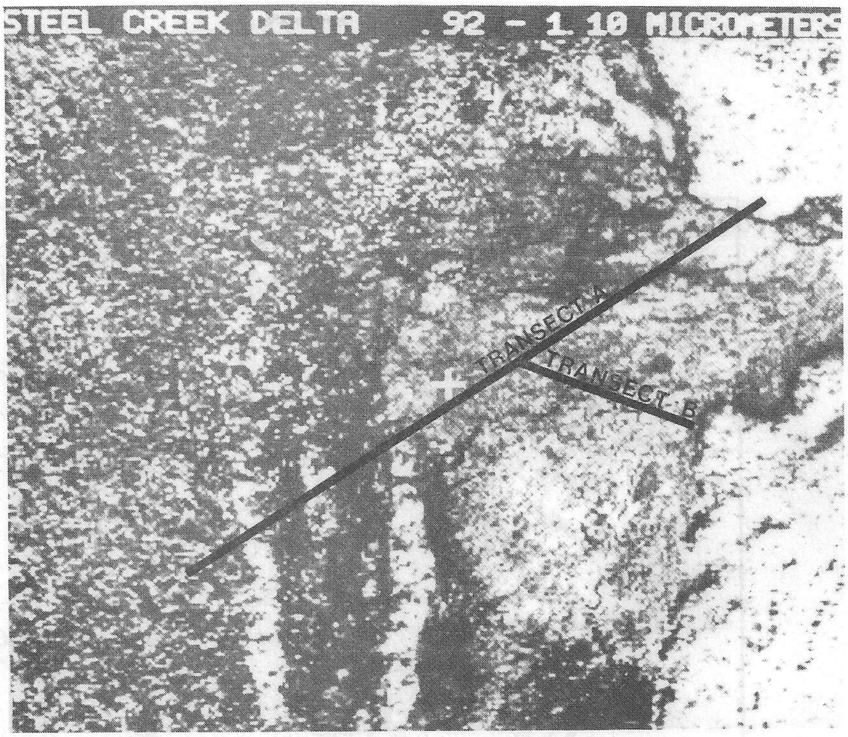

Figure 2

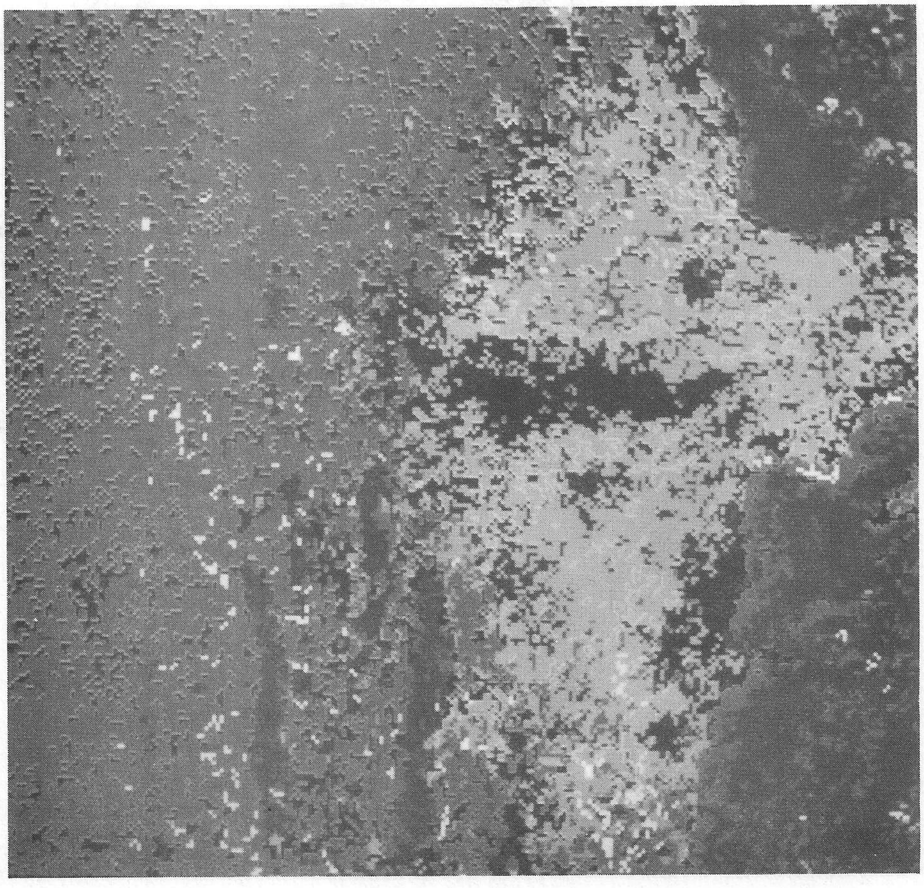

Figure 3

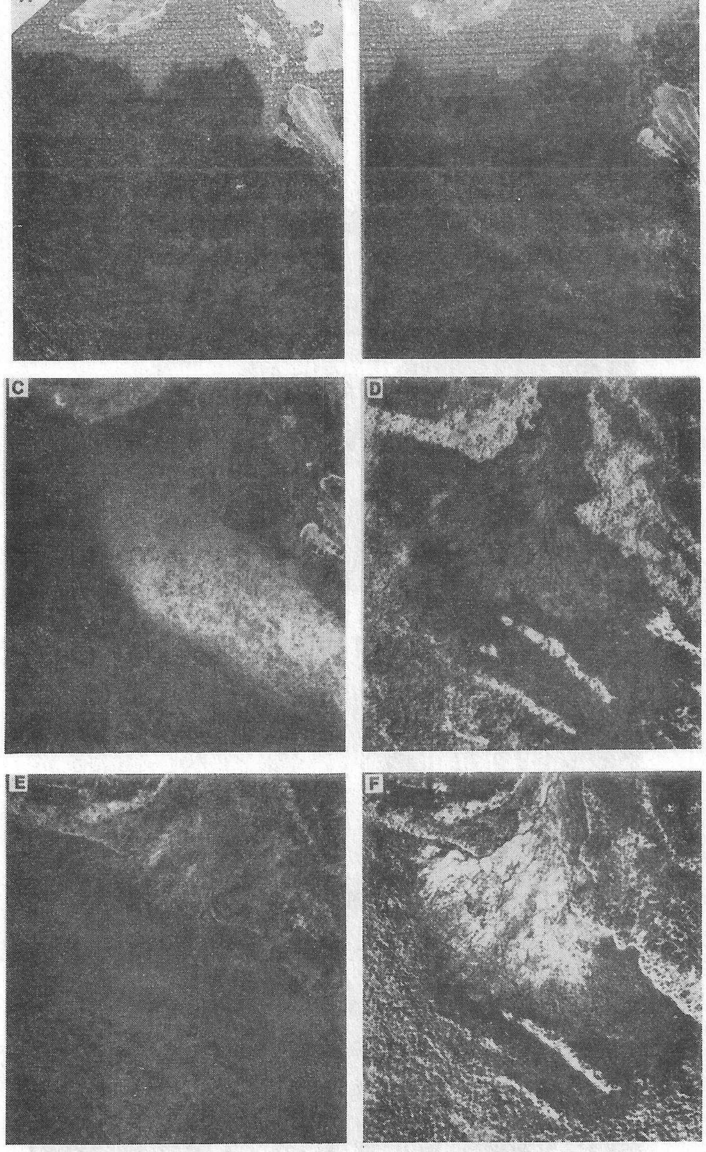

Figure 4. **The original photography used for canopy loss assessments: A = 1951, B = 1956, C = 1961, D = 1966, E = 1974, and F = 1982.**

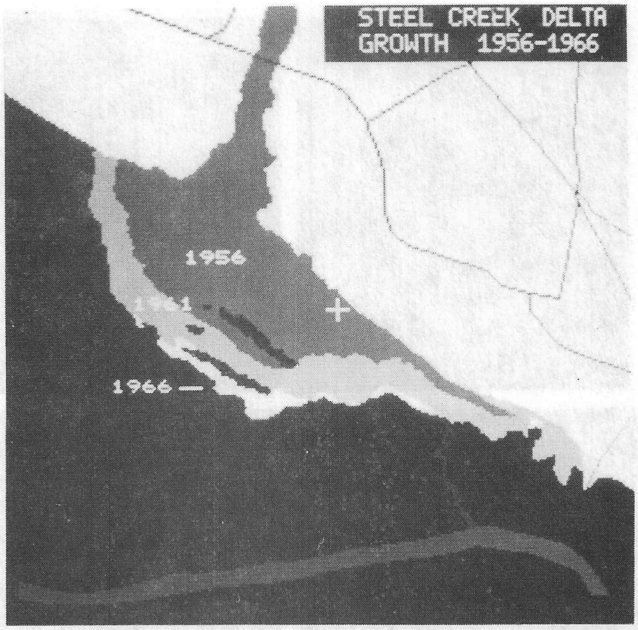

Figure 5

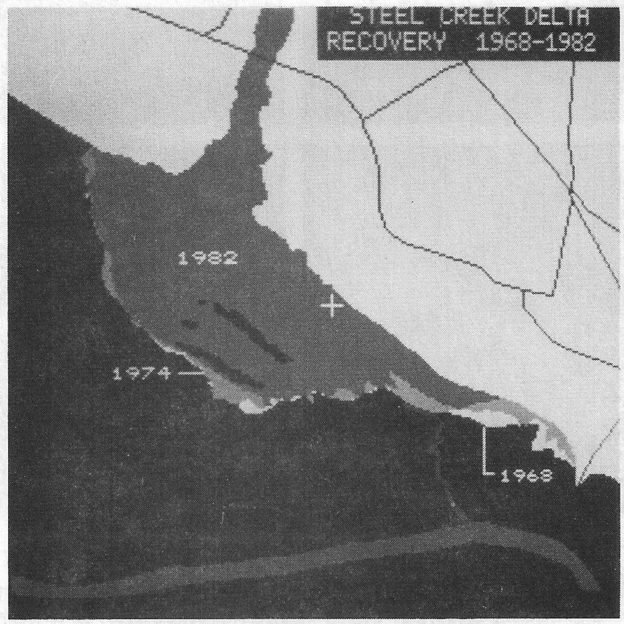

Figure 6

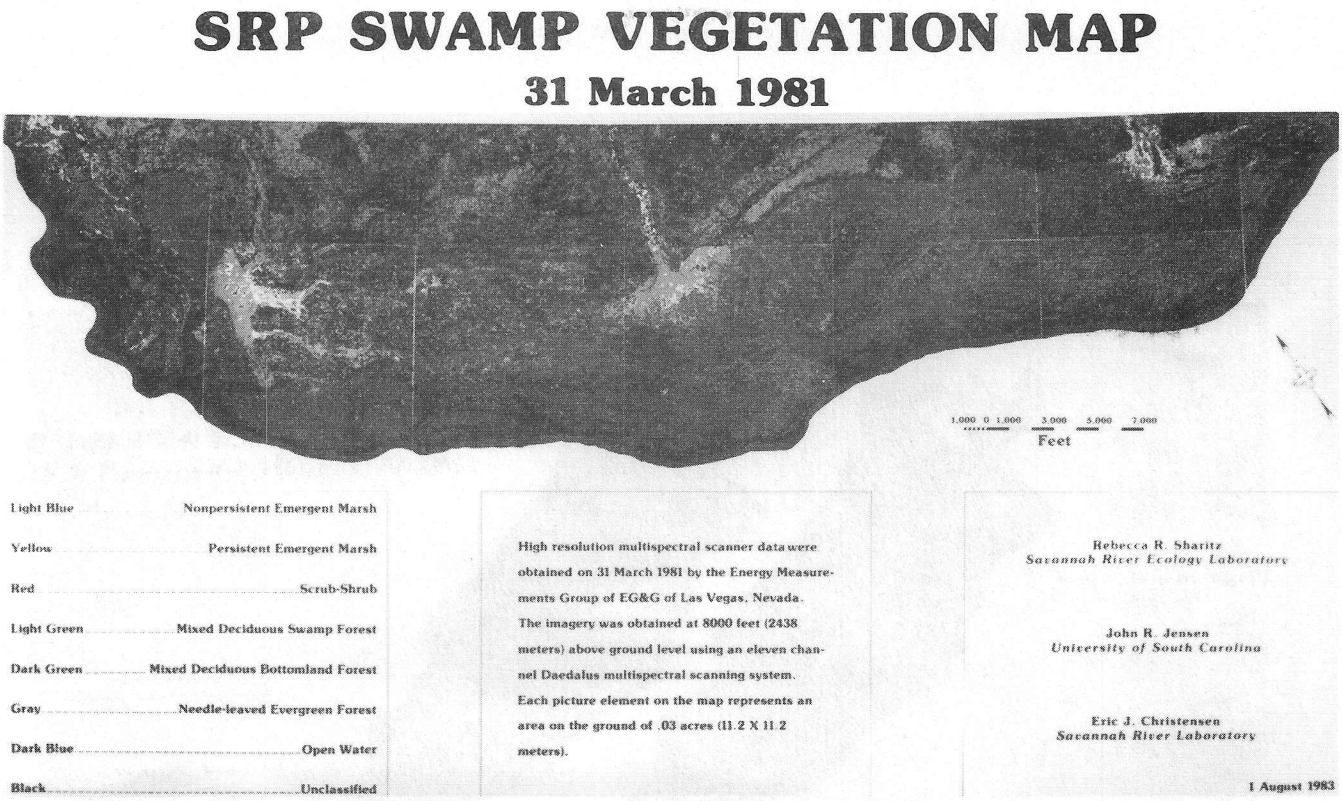

Figure 7

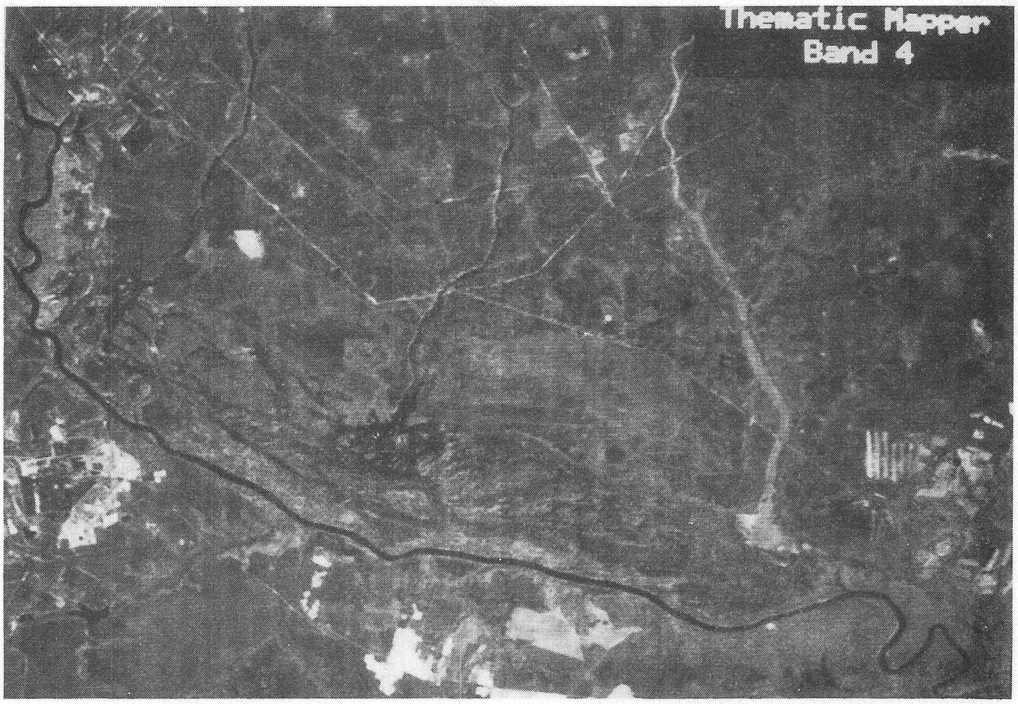

Figure 8

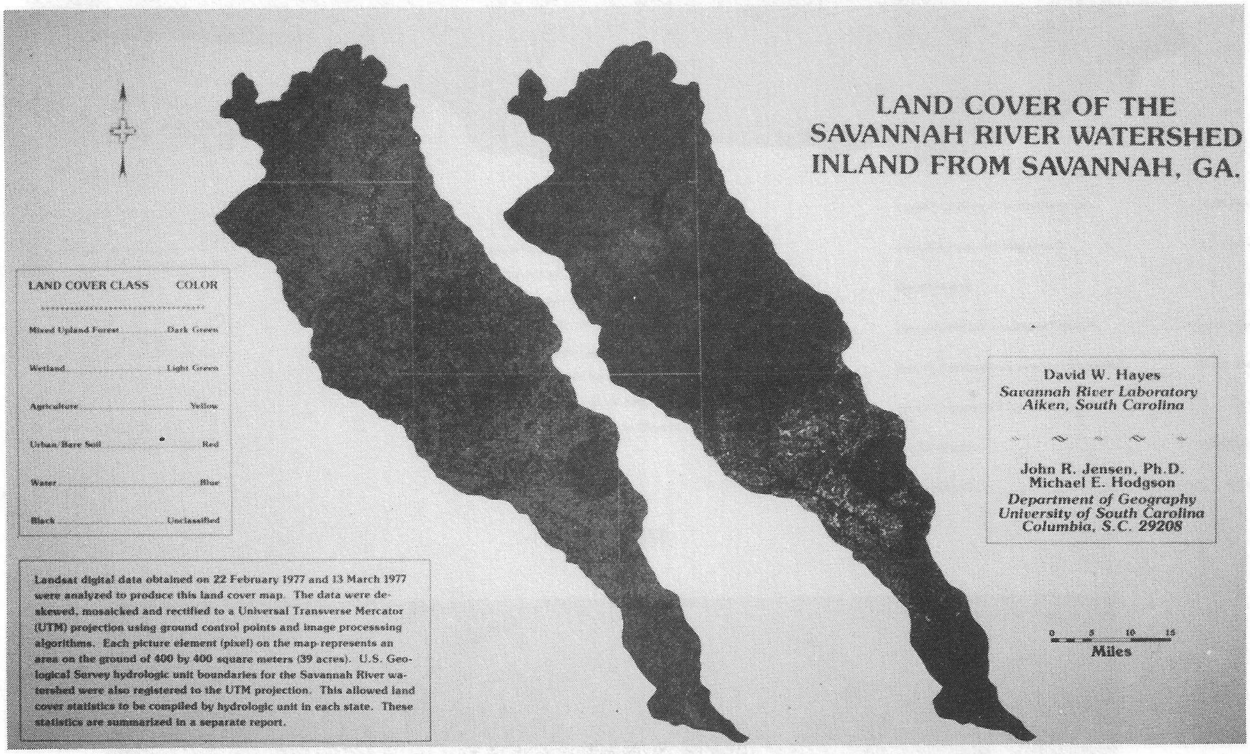
LAND COVER OF THE
SAVANNAH RIVER WATERSHED
INLAND FROM SAVANNAH, GA.
LAND COVER CLASS COLOR
Mixed Upland Forest Dark Green
Wetland Light Green
Agriculture Yellow
Urban/Bare Soil Red
Water Blue
Black Unclassified
Landsat digital data obtained on 22 February 1977 and 13 March 1977 were analyzed to produce this land cover map. The data were deskewed, mosaicked and rectified to a Universal Transverse Mercator (UTM) projection using ground control points and image processing algorithms. Each picture element (pixel) on the map represents an area on the ground of 400 by 400 square meters (39 acres). U.S. Geological Survey hydrologic unit boundaries for the Savannah River watershed were also registered to the UTM projection. This allowed land cover statistics to be compiled by hydrologic unit in each state. These statistics are summarized in a separate report.
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Figure 9