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Classification of Landsat Data for Hydrologic Application, Everglades National Park

The margins of Shark River Slough were accurately defined for the first time, both spatially and temporally, for various hydrologic conditions.

Introduction

Everglades National Park is confronted with unique hydrologic problems which have been created by water modification and control projects throughout south Florida. An extensive network of canals and levees has altered the natural overland sheet flow of surface waters which once entered the National Park. Presently, the park is dependent on freshwater supplies originating from both precipitation and congressionally mandated surface water inflows through control structures. These controlled water deliveries must be furnished in sufficient quantity and at appropriate rates to achieve ecosystem maintenance and preservation.

An understanding of the flow characteristics and surface water distribution within the park required new techniques and approaches because classical hydraulic flow control sections employed in more conventional systems were absent (Rosendahl and Rose, 1980). Remotely sensed Landsat data provided a means whereby both spatial and temporal components of the overland sheet flow in Everglades National Park could be applied to assist with establishing relationships between water deliveries through the control structures and the associated impacts on the park ecosystem.

Abstract: *The hydrologic balance of Everglades National Park has been altered by water modification and control projects. The ability to monitor the spatial and temporal areas of inundation in the Shark River Slough, the main artery for surface water movement, is mandatory for ecosystem maintenance and preservation. Digital image processing techniques were used to analyze Landsat data of the Shark River Slough. Landsat analysis resulted in multispectral classification and mapping of the expansion and contraction of the slough's margins throughout wet and dry seasons in south Florida. These investigations will assist in the formulation of a sound water management program for Everglades National Park.*

Remote sensing provides the capability of furnishing multivariate hydrologic data throughout the park and adjacent vicinity. Higer (1975) suggested that remotely sensed data from Landsat could be input into ecological models providing information to predict ecological conditions in the Everglades. Subsequent research by Anderson and Higer (1980) concluded that remote sensing techniques could be applied to determine water depths and associated water volume coefficients in an area adjacent to Everglades National Park. Rose and Rosendahl (1979) applied Landsat multispectral data, high flight color infrared aerial pho-

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tography, and an interactive processing system to classify the hydrobiological zones (those vegetative areas which directly influence the rate of overland sheet flow) in the Shark River Slough. The classification defined the spectral response of each hydrobiological zone through spectral reflectance plots and generated hydrographic maps for each hydrobiological zone throughout the Shark Slough. Earlier vegetation analysis of the Florida Everglades utilizing a multispectral scanner aboard an aircraft was conducted by Higer *et al.* (1970). Their research isolated spectral bands which could be utilized to differentiate various vegetation and water units. Their study emphasized that multispectral scanning techniques would definitely have transfer value to other hydrologic situations.

The purpose of this research was to utilize Landsat multispectral data to monitor the spatial and temporal aspects of water inundation in the Shark River Slough in Everglades National Park. Landsat images of the Shark River Slough were analyzed using an interactive digital image processing system while being correlated with hydrologic field data. Remotely sensed multispectral data from Landsat provided a means whereby hydrologic conditions throughout the park could be analyzed. The scale of the Landsat imagery combined with the vast acreage of the slough (245,427 acres) and Landsat's repetitive coverage of various hydrologic conditions in Everglades National Park necessitated the application of satellite imagery and remote sensing techniques to define the changing margins of the slough. Through the classification of the wetland conditions utilizing Landsat data and an interactive processing system, the margins of the slough were accurately defined for the first time, both spatially and temporally, for various hydrologic conditions. The knowledge gained through these investigations should help in managing upstream surface water deliveries to the park, enable hydrologic analysis for wetland ecological studies to be formulated, and assist in understanding freshwater contributions to downstream estuarine ecosystems.

Setting

The Shark River Slough, containing 245,427 acres of wetlands, is the largest natural drainageway within Everglades National Park. Surface water flows over this very gently sloping topographic surface in a southwesterly direction, originating from the flow control structures at the park's northern boundary, from uncontrolled flow originating in northeast Shark Slough, and from precipitation (see cover). The combination of these surface water inflows and rainfall determine the inundation of Shark Slough upon which the wildlife and plant species depend. Water level, distribution, and recession rates within the slough are little understood but are essential to maintaining the Everglades and downstream estuarine ecosystems. The slough contains 76 hydrologic monitoring stations, including satellite telemetry stations, continuous recording devices, and staff gauges to monitor overland sheet flow (Figure 1). Field data were collected at these monitoring stations during the 1978 and 1979 Landsat overflights of the Florida Everglades. Regression equations were utilized to predict water levels at these 76 stations for the 1974 Landsat overflight (acceptable confidence level around the regression line was ±0.20 feet (Probst and Rosendahl, 1981)).

FIG. 1. Point location of hydrologic monitoring stations, Shark River Slough (transect stations are indicated).

The ecological balance of the Shark Slough is dependent on management policies north and east of the boundaries of Everglades National Park from which surface water flows originate. In 1970, the 91st Congress enacted into law a minimum annual water inflow of 260,000 acre-feet to Shark Slough. This water enters the park through the four S-12 control structures, maintained by the U.S. Army Corps of Engineers. Presently, it has not been determined what correlation exists between water discharged through the structures and spatial/temporal impact it has upon various regions in the park.

Methodology

Shark River Slough water levels vary greatly throughout the year due to both natural and man-controlled surface inflows. In an attempt to delineate and monitor the expanding and contracting margins of the Shark River Slough, cloud free Landsat scenes acquired during both the wet and dry seasons were evaluated. Four Landsat scenes, representative of a wide range of hydrologic conditions within the slough, were selected for analysis and interpretation procedures. The 19 October 1974 Landsat scene (I.D. 1818-15120) recorded conditions during maximum inundation;

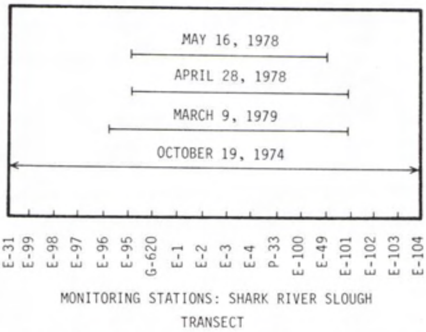

FIG. 2. Inundation in the Shark River Slough along the monitoring transect corresponding to Landsat scenes.

the 16 May 1978 image (I.D. 21210-14475) represented water conditions during minimum inundation. Landsat scenes taken on 9 March 1979 (I.D. 30369-15122) and 28 April 1978 (I.D. 21192-14470) were representative of intermediate flow conditions.

Field studies throughout the extensive ground control network were conducted during the time of each Landsat overpass. Water levels, precipitation, and specific conductance levels were monitored and recorded at the 76 hydrology stations. Water depth cross sections were prepared for a 20 mile transect which transcended the slough's margins and were perpendicular to the overland sheet flow. These transects were of prime importance toward determining the exact location of the slough's margins along these transects for each of the four selected Landsat dates (Figure 2). The graphs depict an expanding and contracting slough margin varying from a maximum width of 17 miles on 19 October 1974 to a minimum width of 8 miles on 16 May 1978 (Table 1).

This hydrologic analysis utilizing Landsat imagery required the extraction of geographically identical subscenes encompassing the Shark River Slough from each of the four Landsat computer compatible tapes (Plates 1 and 2). These 32 by 32 mile subscenes were geometrically registered to a base map for correlation with hydrologic data from the 76 monitoring stations within the slough. The geometric correction process employed a first order transformation of the Landsat data which was accurate to within ±100 metres (Table 2).

TABLE 1. VARIATIONS IN THE SEASONAL EXTENT OF THE SHARK RIVER SLOUGH MARGINS FOR THE MONITORING TRANSECT

Landsat Scene	Width of Shark River Slough (miles)
16 May 1978	8
28 April 1978	9
9 March 1979	10
19 October 1974	17

TABLE 2. GEOGRAPHIC COORDINATE CONVERSION: PIXEL ACCURACIES

	Residual Means	
Landsat Scene	*x* Axis Accuracy	*y* Axis Accuracy
16 May 1978	1.20	0.75
28 April 1978	0.74	0.49
9 March 1979	0.91	0.61
19 October 1974	0.94	0.71
(Based on pixel cell of 100 × 100 m)		

Once each image had been geometrically corrected and the study area defined, contrast stretching routines were employed. This procedure was an iterative approach resetting the upper and lower bounds of the gray scale levels on each band. The contrast stretch eliminated data determined non-essential to the classification of the study area.

The contrast stretch is a visual enhancement technique. The normal distribution of gray levels is inclusive of values from 0 to 255 (Figure 3). During the contrast stretch the pertinent data essential to classification are accounted for, and nonessential data are eliminated through the narrowing of the upper and/or lower gray scale limits for each multispectral channel. The stretch is then applied to spread the significant data from 0 to 255 levels, thereby improving the clarity and quality of the scene (Figure 4).

The objective of the image analysis procedure for the four Landsat scenes was to differentiate inundated and non-inundated areas within the Shark River Slough. The characteristically low spectral response of water in MSS band 7 combined with the lighter tones associated with the contrasting dry lands rendered the land/water interface quite distinguishable. However, within the inundated area of Shark River Slough, the diffuse shallow water is heavily vegetated with sawgrass stands, open marsh vegetation, and hardwood hammocks. Due to the characteristic integration of

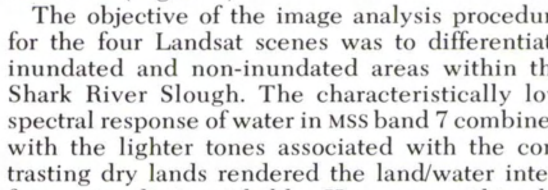

FIG. 3. Normal distribution of radiance values (raw data) prior to contrast stretching.

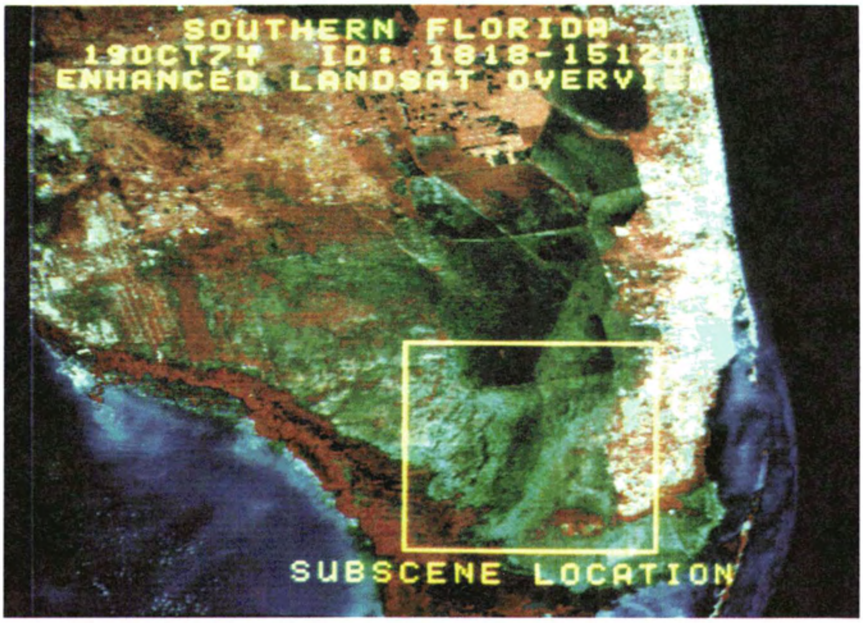

PLATE 1. Shark River Slough subscene location.

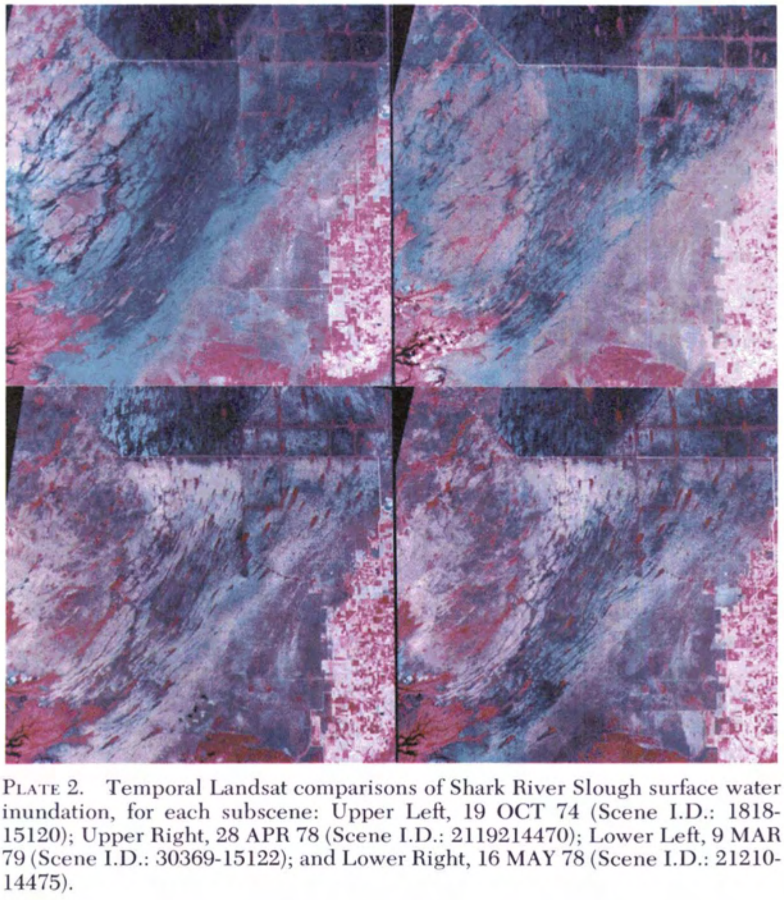

PLATE 2. Temporal Landsat comparisons of Shark River Slough surface water inundation, for each subscene: Upper Left, 19 OCT 74 (Scene I.D.: 1818-15120); Upper Right, 28 APR 78 (Scene I.D.: 2119214470); Lower Left, 9 MAR 79 (Scene I.D.: 30369-15122); and Lower Right, 16 MAY 78 (Scene I.D.: 21210-14475).

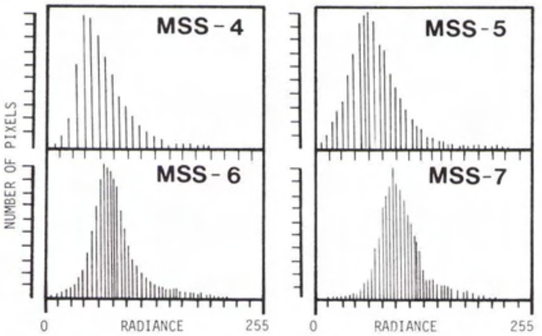

FIG. 4. Distribution of Landsat data following contrast stretch.

spectral response over 1.1 acres with Landsat data, the signatures varied depending upon the respective contributions of water and vegetation.

For each of the five selected Landsat subscenes, Band 7 data were analyzed by means of digital image processing techniques in order to define the area of inundation within the Shark River Slough. A density-slicing technique was used as a dichotomous classification approach. Density slicing proved to be an effective way to classify inundated areas in a marsh system during high water periods. This procedure was initiated following analysis of the histograms by specifying the spectral value which potentially represented the interface between land and water. For the Landsat scenes depicting high water stages, the histograms were distinctively bimodal, with data indicative of either inundated areas or dry land (Figure 5). The digital value of each Band 7 pixel within the subscene was then classified into either the inundated or non-inundated spectral class. Because hydrologic field data corresponding to the date of each Landsat scene were established along transects within the slough, this classification procedure was carried out in an interactive manner. Iterative attempts were made for each Landsat subscene until suitable results were generated which most closely agreed with ground-based water level data.

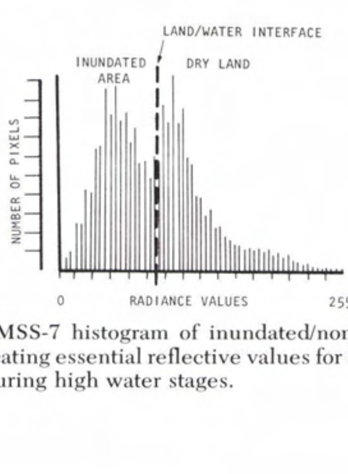

FIG. 5. MSS-7 histogram of inundated/non-inundated area indicating essential reflective values for Shark River Slough during high water stages.

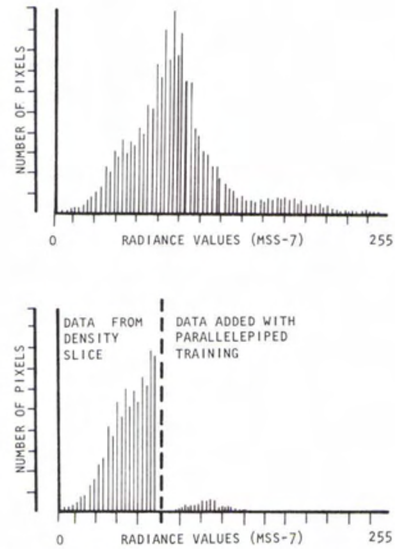

FIG. 6. (a) 28 April 1979 contrast stretch histogram prior to classification. (b) 28 April 1979 histogram depicting radiance values essential for classification utilizing density slicing and parallelepiped approaches.

During low water level periods (dry season classification results) the Band 7 density slicing approach encountered some difficulty. Shallow water depths associated with lower water levels during the dry season made the vegetation/water interface more difficult to discern. There was a predominant vegetative spectral response and a unimodal histogram for reflectance values associated with lower water levels in the inundated areas. This problem was counteracted by initially applying the density slicing procedure which enabled the most pronounced inundated areas to be accounted for and classified accordingly. Subsequent to this procedure, a parallelepiped classification technique was employed on all unclassified data to supplement the classification results from the initial density slicing approach. That is, the inundated area containing the predominant vegetation signature was defined in four-dimensional spectral space (as opposed to the one-dimensional density slicing approach) and the results added to those obtained by the initial density slice. The parallelepiped classification approach utilized a split screen format on the Image-100 Cathode Ray Tube (CRT). Through the combination of these two approaches (density slicing and parallelepiped), the inundated areas of the Shark River Slough were classified for the shallow water conditions encountered during the dry season (Figure 6).

DISCUSSION OF RESULTS

These investigations have determined that Landsat digital data can accurately monitor hydrological conditions in a freshwater marsh ecosystem. The ability to monitor the spatial and temporal components of the wetland conditions provided greater insight into relationships between water deliveries to Everglades National Park and the interactions of sheet surface water movement throughout the slough. Landsat data can be applied to delineate the expansion/contraction of the slough's margins throughout wet and dry seasons.

Through the application of Landsat data the resource manager can also better assess the nature of water distribution throughout a freshwater marsh, such as the Shark River Slough. Water inundation studies conducted during this research generated highly reliable and accurate classifications of the inundated areas in the slough. Analysis of field data at the monitoring stations established slough boundaries along the transect which coincided precisely with the inundation margins determined from the four Landsat scenes.

Through the generation of these Landsat "inundation masks," the spatial and temporal components of the Shark River Slough's expanding and contracting margins were determined for the first time (Figure 7). The inundation mask prepared from the 19 October 1974 scene represented the maximum surface water extent. The mask depicted continuous surface waters across the northern park boundary along the Tamiami Trail (U.S. 41) from S-12A through L-67 extension canal which continued until they encountered L-30N on

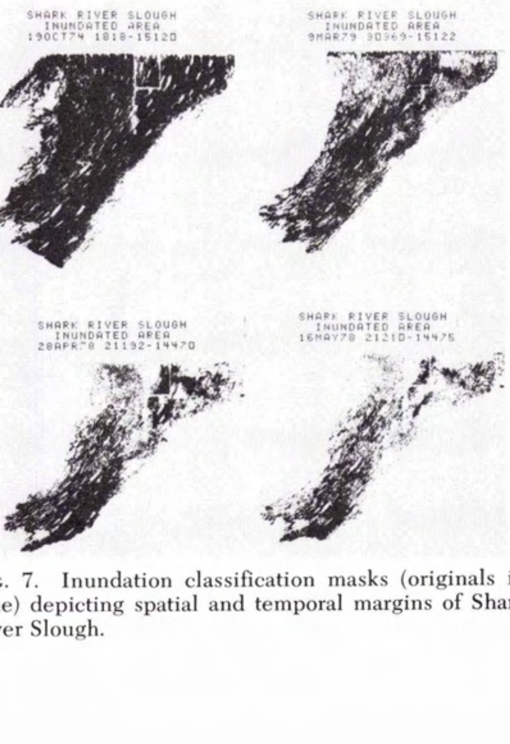

Fig. 7. Inundation classification masks (originals in blue) depicting spatial and temporal margins of Shark River Slough.

the eastern portion of the Northeast Shark Slough region. The eastern inundation boundary for surface waters in the Shark Slough coincided with a rock ridge which outcrops in a northwesterly direction and forms the easternmost boundary of the Shark Slough. Likewise, the westernmost boundary of the slough is restricted by higher land, and the patterns delineated through the classification reflect the location of this physiographic zone. The other Landsat inundation masks prepared demonstrated that the slough's margins began to contract with the onset of the dry season. The easternmost boundary displayed uniform recession rate and paralleled the same general pattern delineated by the classifier for the maximum period of inundation. The western boundary also contracted in a similar manner.

As the area of inundation continued to decrease in total aerial extent for the 16 May 1978 Landsat scene, significant deviations in boundary locations became apparent. The eastern boundary displayed a large projection of surface waters directly south of the L-67 extension canal. This feature displayed the influence L-67 extension had on water conditions in the Shark Slough and northeast Shark Slough during the dry season. The waters which flowed from the canal into the slough created an extension on the anticipated recession boundary. The waters which entered the slough at this point then flowed east-northeast into northeast Shark Slough and west-southwest into the Shark Slough proper. The contribution of the waters from L-67 extension into northeast Shark Slough served to connect the limited surface waters in northeast Shark Slough with those in the Shark Slough proper.

The impact of controlled water delivers into the Shark Slough became apparent on the 16 May 1978, 9 March 1979, and 28 April 1978 Landsat inundation masks during the dry season. Continuous surface waters existed from the S-12 control structures to the estuaries. However, overland sheet flow was interrupted in the northeast Shark Slough because of the presence of the Tamiami Trail (U.S. 41) and associated canal. Surface water existed only where major culverts link the canal to the northeast Shark Slough.

The Landsat inundation masks provided a quantitative analysis of the aerial extent of surface flows during the wet and dry seasons. The analysis procedure determined the area inundated in the Shark Slough for each Landsat scene. A total of 245,427 acres were inundated during 19 October 1974 representing maximum surface water coverage (Table 3). In contrast, the minimum inundation for the Shark Slough totaled 90,402 acres on the 16 May 1978 scene. Therefore, a net change of 63 percent, or 155,025 acres, occurred between the extent of surface water inundation in the Shark

Table 3. Inundated Areas of Surface Water in Shark River Slough as Determined from Landsat Data

Date	Acres Inundated
16 May 1978	90,402
28 April 1978	123,426
9 March 1979	143,241
19 October 1974	245,427

Slough from "wet" season to dry season as determined through the Landsat classification results.

Summary

The application of Landsat imagery for hydrologic applications in a wetlands area, such as the Shark River Slough in Everglades National Park, is definitely a viable tool for resource management. The ability to monitor the dynamic hydrologic conditions, both spatially and temporally, has immense ramifications. Water control and modification programs in south Florida have interrupted the natural hydrologic regime of the park and made the monitoring of hydrologic parameters mandatory. This investigation is of significance to both ecosystem maintenance and preservation by providing greater insight into the interaction of hydrologic inputs and their impacts on the marsh ecosystems in Everglades National Park.

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