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PEN BRANCH STREAM CORRIDOR AND DELTA WETLANDS CHANGE ASSESSMENT

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PEN BRANCH STREAM CORRIDOR AND DELTA WETLANDS CHANGE ASSESSMENT

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ABSTRACT

Airborne multispectral scanner data from 1987 to 1991 covering the Pen Branch corridor and delta at SRS were utilized to provide a detailed change detection analysis. The multispectral data were georeferenced to a Universal Transverse Mercator projection using finite element registration. Each year was then classified into eleven different landcover categories, and the yearly changes in each landcover category were analyzed. The decrease in operations of K Reactor in 1988 has resulted in drying of the corridor and delta. This has led to the decline of nonpersistent vegetation and the increase of persistent vegetation. Cattails, willow, and bottomland hardwoods, in particular, have grown to dominate the corridor and most of the delta.

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1. INTRODUCTION

Airborne multispectral scanner (MSS) data have been acquired each spring over the Savannah River Site (SRS) near Aiken, South Carolina, by the Remote Sensing Laboratory, operated for the United States Department of Energy by EG&G Energy Measurements, Inc. (EG&G/EM). The data from 1987 through 1991 were used in an analysis of the Pen Branch stream corridor and delta region of the SRS to determine the changes that occurred in the wetland vegetation communities during that time period. To implement the multitemporal analysis, it was necessary to develop and use new techniques and ancillary data to overcome the inherent geometric distortions of the scanner data.

2. SITE DESCRIPTION

The SRS is a 77,700-hectare site located 20 kilometers southeast of Aiken, South Carolina (Figure 1). SRS began operations in 1952 as a nuclear materials production complex consisting at that time of five nuclear reactors and one coal-fired power plant. The site is currently operated by Westinghouse Savannah River Corporation (WSRC) for the Department of Energy.

Six major stream systems drain the SRS: Upper Three Runs Creek, Beaver Dam Creek, Fourmile Branch, Pen Branch, Steel Creek, and Lower Three Runs Creek. Pen Branch has received cooling water discharge from K Reactor since 1954. K Reactor cooling water is released into Indian Grave Branch, which is a tributary of Pen Branch. The water flows approximately 2.5 kilometers in Indian Grave Branch until it reaches Pen Branch, and then flows approximately 8 kilometers to the Savannah River swamp. The flow rate averaged between 10 and 11 cubic meters per second during reactor operations, which is about 10 times greater than the natural stream flow (Ruby *et al.*, 1981). The average yearly temperature of the releases from K Reactor has reached 70°C (Ezra *et al.*, 1986).

Three effects on the wetlands vegetation communities due to reactor operations have been observed: 1) altered flooding cycles, which disrupt the lifecycles of species adapted to natural flooding cycles, 2) increased erosion and sedimentation, which caused formation and expansion of a delta (the Pen Branch delta) into the swamp and burial of plant root systems, and 3) increased water temperatures, which can exceed the thermal tolerance of some wetlands species (Repaske, 1981).

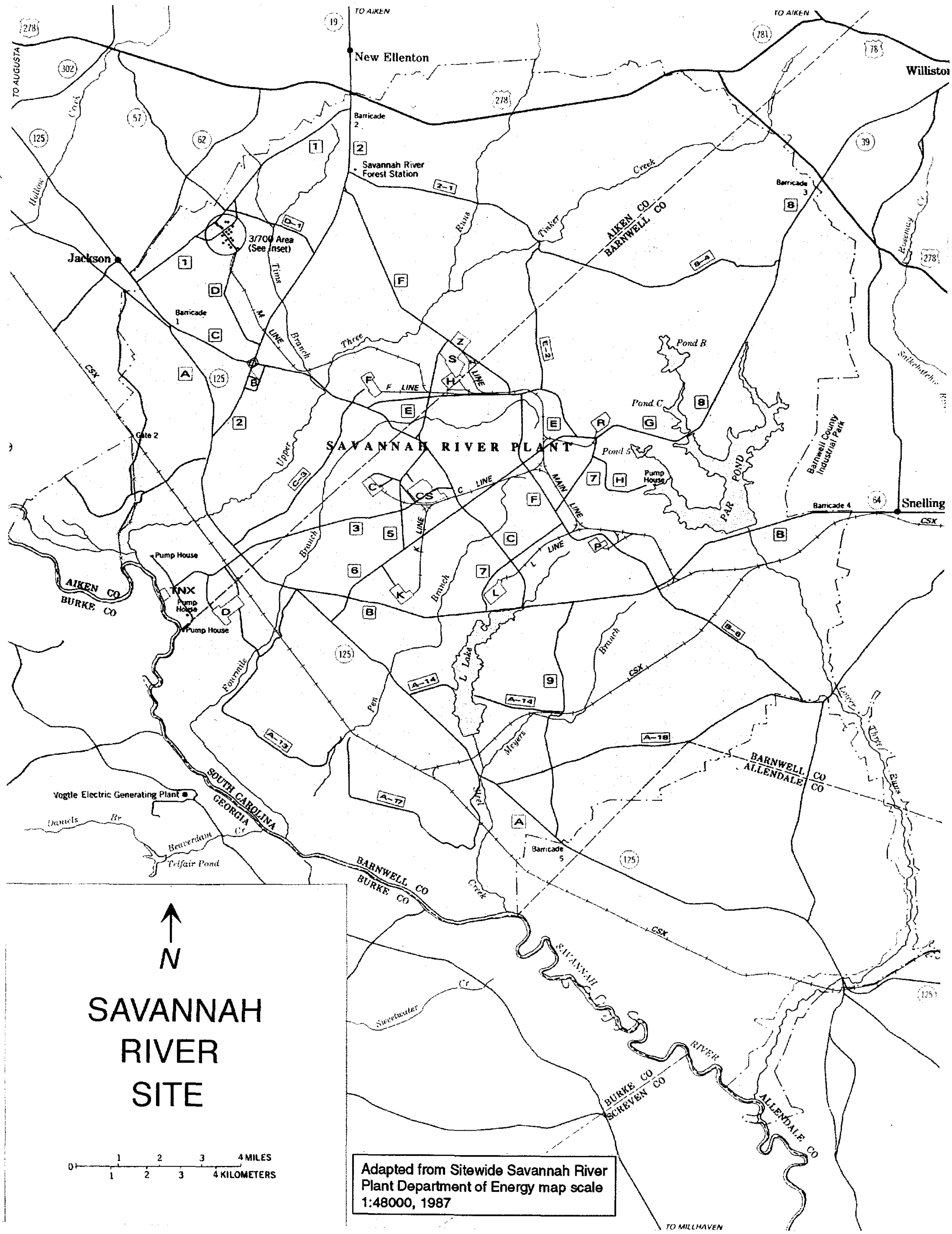

FIGURE 1. ***MAP SHOWING STUDY LOCATION***

3. PREVIOUS STUDIES

Numerous remote sensing studies have been performed on the wetlands vegetation communities of SRS. Several of these studies deal specifically with Pen Branch. To obtain a perspective on the objectives of this study, a few of these studies will be reviewed.

Christensen *et al.* (1984) used historical aerial photography to document change in the Pen Branch delta. Available photography covered 1951, 1955, 1956, 1961, 1966, 1973, 1974, 1979, and 1982. Photography from 1961, 1966, 1973, 1979, and 1982 was interpreted and classified into three damage categories: no apparent damage, partial damage (5–95% canopy loss), and complete damage (95–100% canopy loss). Boundaries of the different damage categories were drawn on the photographs, and the boundaries were then digitized and entered into a raster-based geographic information system (GIS). The study first noted canopy defoliation in the 1961 photography. Over the period from 1961 to 1965, the delta expanded at an average rate of 23 acres/year. In 1965, reductions in reactor power levels resulted in a decrease in discharge temperatures until 1974. From 1965 to 1973, the delta expansion rate declined to 4 acres/year. From 1974 to 1982, after the reactor had returned to normal operations, the delta expansion rate increased to 16 acres/year.

Tinney *et al.* (1986) also used historical aerial photography to document changes in Beaver Dam Creek, Fourmile Branch, Pen Branch, and Steel Creek. This study utilized photography from 1955, 1956, 1961, 1966, 1974, 1984, and 1985. The photography was interpreted stereoscopically into the same three damage classes: no damage, partial canopy loss (5–95% canopy loss), and total canopy loss (95–100% canopy loss). Damage class boundaries were drawn onto clear overlays, which were then optically enlarged to fit a planimetrically accurate base map. The overlays were digitized and entered into a raster-based GIS system, allowing area statistics and summaries for each damage class to be generated. Between 1966 and 1985, the total affected area within the Pen Branch corridor actually decreased by 23.1 hectares (57.1 acres). This value consisted of a decrease in total canopy loss area of 30.6 hectares (75.6 acres) and an increase in partial canopy loss area of 7.5 hectares (18.5 acres). Within the Pen Branch delta from 1966 to 1985, the total affected area increased by 100.4 hectares (248.1 acres). This figure was comprised of a total canopy loss increase of 68.0 hectares (168.0 acres), and a partial canopy loss increase of 32.4 hectares (80.1 acres).

Jensen *et al.* (1987) used airborne multispectral scanner data to monitor wetland change in the Pen Branch delta from 1981 to 1985. MSS data from Daedalus AADS1260 and AADS1268 scanners (described in Section 4.1.6) were used. AADS1260 data were obtained on March 31, 1981 and AADS1268 data were obtained on April 29, 1985. Because not enough ground control points were available to allow image-to-map registration, image-to-image registration was performed using the 1981 data as the base image. Initially, the registration was performed on a 375-hectare (926.6-acre) subset of the MSS flightline using a first-order linear transformation. The resulting root mean square error was greater than 5.0, which was unacceptable. To solve this problem, the 375-hectare subset was further subdivided into four smaller subsets, and each subset was then individually registered. The four individual root mean square errors ranged from 1.52 to 2.63. The two different dates of data were then classified, and the resulting classifications compared for change. It was found that 12.4 hectares (30.6 acres) of deciduous swamp forest had changed to transition deciduous swamp forest, which is characterized by a much more sparse, open canopy; 3.64 hectares (9.0 acres) of deciduous swamp forest changed to emergent marsh; 9.30 hectares (23.0 acres) of deciduous swamp forest to open water; 2.42 hectares (6.0 acres) of transition deciduous swamp forest to emergent marsh; and 1.21 hectares (3.0 acres) of transition deciduous swamp forest to open water. In general, as the canopy became more open, emergent marsh invaded and open water became more prevalent.

Christensen *et al.* (1988) utilized aircraft MSS data to analyze the deltas of Beaver Dam Creek, Fourmile Branch, Pen Branch, and Steel Creek. Daedalus AADS1260 data were collected on March 31, 1981; May 25, 1983; April 6, 1984; and AADS1268 data were collected on April 29, 1985. Because available maps for the SRS had very few control points within the swamp, the 1981 imagery was used as a base, and the 1983, 1984, and 1985 data were registered to it. A first-order linear transformation was used to register subsets of the data. The first attempt, with subsets of 512×240 pixels, was unsatisfactory because the linear transformation could not deal with the non-linear distortions within such a large image. Because of this, the data were further subset to a size of 320×240 pixels. With the reduction in size, a reasonable registration accuracy was obtained. The study noted that Pen Branch was the most difficult to register due to its complex shape. Because of the difficulty in image-to-image registration, only classification results for the Steel Creek delta were provided. The dominant change found was the replacement of persistent emergent marsh by shrub/scrub, due to the lowering of water depths in portions of the delta. Shrub/scrub was also found to be replacing nonpersistent emergent marsh.

Mackey (1990) utilized SPOT HRV three-band multispectral satellite data to analyze trends in Pen Branch from 1987 to 1989. Eleven dates of SPOT imagery were classified in this study: April 9, April 24, May 4, August 22, and October 22, 1987; April 17, May 2, May 18, and October 25, 1988; and January 28, and May 17, 1989. The satellite data were analyzed in conjunction with coincident aerial photography, hydrological data regarding Savannah River and K Reactor flow rates, and ground photographs and observations acquired within the Pen Branch delta. Three main wetland cover types were found to dominate the delta: open water, non-persistent emergent marsh, and persistent marsh. By taking into consideration the ancillary ground data, this study was able to explain the vegetation trends in the delta. Because K Reactor operated at half power during 1987, resulting in lower temperature releases into the delta, Ludwigia expanded into the shallow water and mudflat areas, and cattails expanded into the "tail" of the delta. With K Reactor being shut down in mid-April 1988, open water areas declined accordingly. As the delta continued to dry into 1989, it became more difficult to differentiate between Ludwigia and cattail beds, and portions of the lower stream corridor began to resemble "old field" sites. The study predicted that as the delta continues to dry, it will develop into more persistent wetland communities accompanied by invasion of shrub/scrub species.

Mackey (1993) used SPOT satellite data from 1987 to 1992 to monitor change in the lower portions of the Pen Branch corridor and the delta. SPOT HRV data from April 24, 1987, May 2, 1988, May 17, 1989, May 11, 1990, May 2, 1991, and May 5, 1992 were used in the study. In 1987 Ludwigia expanded into the mudflat and shallow water areas, and cattails expanded in the "tail" portion of the delta. K Reactor was shut down in 1988, resulting in a decrease in the amount of deep/open water. With the drying of the delta from 1988 through 1990, it became more difficult to differentiate between Ludwigia and cattails. This was attributed to the presence in the spring of dead brown biomass from the previous summer's growth. Also during this period, portions of the corridor began to take the form of "old field" sites. After 1990, the majority of the delta became dominated by cattails and by shrub/scrub species such as willow and button bush.

4. METHODOLOGY

The previous studies used aerial photography, airborne multispectral scanner (MSS) data that were registered with linear transformations, and SPOT satellite imagery (both multispectral and panchromatic). Each of these techniques or data sources has inherent limitations. With aerial photography, results from interpretation can be interpreter-specific, and some geometric distortion can be created as the interpretations are transferred to the base map. Aerial photographs also have limited spectral response due to the nature of the film itself. In the study by Christensen *et al.* (1988), airborne MSS data provided more spectral sensitivity than photographic film, but only limited size areas could be registered together because of the registration techniques used. Finally, in the Mackey (1990) study, the use of SPOT satellite data solved the inherent geometry distortions common in aircraft MSS data, but spatial resolution is comparatively low, especially for dealing with wetland species. SPOT satellite data also have limited spectral sensitivity.

The objective of this study was to document the changes that occurred from 1987 to 1991 for the entire Pen Branch corridor and delta. To meet these objectives, numerous types and sources of data were used. It was also necessary to develop and use techniques allowing the exploitation of the advantages of airborne MSS data to identify wetland species types.

4.1 Data

4.1.1 Phenology Photography – Ground Truthing

This photography consisted of ground photographs taken at two Pen Branch locations: the Pen Branch boardwalk and the Pen Branch tail region (Figure 2). These photographs were taken periodically during the year, and immediately prior to, during, and after airborne MSS data acquisitions. These photographs provide valuable historical documentation of the vegetation conditions leading up to and during the period of scanner acquisitions. The specific dates of phenology photography are shown in Table 1. A summary of phenology trends is presented in Mackey (1990) and Mackey (1993).

4.1.2 Aerial Photography – Classification Labelling

Vertical and oblique aerial photography has been acquired by EG&G/EM on an annual basis since the early 1980s, in conjunction with airborne MSS acquisitions. Aerial photography alone has also been acquired at other times during the year. This photography is available in small and large scale formats, using both color and color infrared films. The large scale photography was invaluable for photographic interpretation of MSS classification results. The specific dates of the aerial photography used for classification labelling are shown in Table 2.

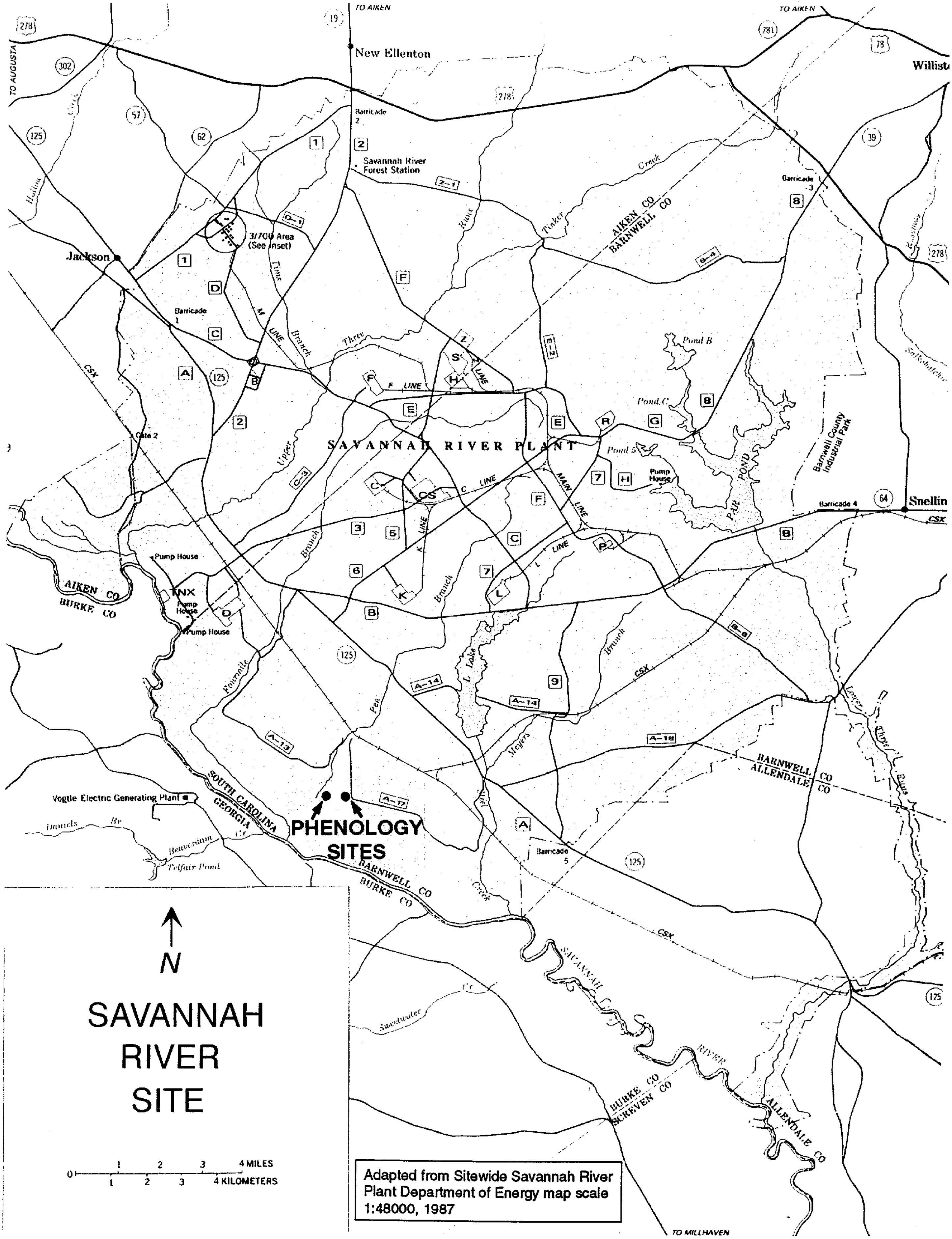

FIGURE 2. *MAP SHOWING PHENOLOGY PHOTOGRAPHY LOCATIONS*

Table 1. Phenology Ground Photography Dates				
1987	**1988**	**1989**	**1990**	**1991**
4 March	10 March	3 April	15 March	18 March
17 March	14 April	12 April	28 March	22 March
3 April	9 May	1 June	12 April	12 April
17 April			19 April	26 April
4 May			4 May	20 May
22 May			22 May	

Table 2. Ground Truth Aerial Photography Dates				
Year	**Date**	**Format**	**Film Type**	**Altitude (feet)**
1987	3 March	Vertical	Color	450, 600, 700, 2,000
	18 April	Vertical	Color, Color IR	8,400
	20 April	Vertical	Color, Color IR	8,400
	21 April	Vertical	Color, Color IR	10,400
1988	23 March	Oblique	Color	500
	29 April	Vertical	Color, Color IR	4000, 8,000, 10,000
	7 May	Vertical	Color, Color IR	4,000, 8,000
	18 May	Vertical	Color, Color IR	10,000
1989	13 April	Vertical	Color, Color IR	10,000
	27 April	Vertical	Color, Color IR	3,800
	2 May	Oblique	Color	200, 500
1990	12 April	Vertical	Color	2,000, 10,000
	16 April	Vertical	Color	10,000
	26 April	Oblique	Color	300, 400, 800, 2,600
1991	18 April	Vertical	Color	10,000
	22 April	Vertical	Color	10,000
	24 April	Vertical	Color	10,000
	2 May	Vertical	Color	10,000
	4 June	Oblique	Color	200
	8 June	Oblique	Color	200, 400
	10 June	Oblique	Color	400
	11 June	Oblique	Color	1,000

4.1.3 Hydrology Data

United States Geologic Survey (USGS) hydrology data, in the form of Savannah River flow rates and Pen Branch flow rates, were utilized in this study. The Savannah River flow rates were recorded at the Jackson gauge station (station number 02197320). During periods of extreme flooding, this gauge station cannot record data at levels exceeding 22,000 cubic feet per second. To obtain estimates for flow rates at this station during extreme flood conditions, flow rates from the 301 Bridge gauge station, located down-river, were used in a regression analysis to estimate flow rates at the Jackson gauge station when flow rates exceeded 22,000 cubic feet per second. The Pen Branch flow rates were recorded at the SRS Road A13.2 gauge station (station number 02197348). All flow rates were recorded as a daily mean.

4.1.4 Digital Map Data

USGS Digital Line Graph (DLG) data from the 1:24,000 and 1:100,000 scale topographic map series were used in the image registration process.

4.1.5 Aerial Photography – Registration

Two sets of aerial photographs were digitized and registered during the course of this study. These consisted of three color infrared photographs acquired by EG&G/EM in 1988, and six historical black and white infrared photographs acquired from SRS for 1966. The dates and flight parameters of this photography are shown in Table 3.

Table 3. Registration Aerial Photography Dates

Year	Date	Format	Film Type	Altitude (feet)
1966	4 May	Vertical	Black & White IR	10,890
1988	29 April	Vertical	Color IR	10,000

4.1.6 Daedalus AADS1268 Multispectral Scanner Data

The scanner data used in this study were acquired with a Daedalus AADS1268 Multispectral Scanner. The scanner contains four detector packages with a total of eleven discrete elements. Reflected and/or emitted electromagnetic energy enters the scanner from below and strikes a rotating "axe-blade" mirror, which reflects it into the detector housing. There, a prism and a series of dichroic filters spectrally decompose the energy onto the detectors.

Channels 1−8 are generated by a single silicon detector array, which is contained in an integrated circuit-like package. Channels 9 and 10 are each generated by a single Indium Antimonide (InSb) detector housed inside dewars filled with liquid nitrogen to increase their sensitivity. A Mercury Cadmium Telluride (MCT) detector generates channels 11 and 12, and also resides inside a dewar. Electromagnetic energy striking the detectors produces a photovoltaic effect proportional to the number of photons striking at a given instant. The signal is amplified and converted into an 8-bit digital value, which is then recorded onto a high-density digital tape (HDDT). The scanner has selectable scan rates (up to 100 scan lines per second), which are necessary to assure contiguous coverage from different altitudes and relative ground speeds. A schematic of the scanner is shown in Figure 3.

The nominal spectral bands for the AADS1268 are as follow:

Channel	Wavelength (micrometers)
1	0.42−0.45
2	0.45−0.51
3	0.51−0.59
4	0.58−0.62
5	0.61−0.66
6	0.65−0.73
7	0.71−0.82
8	0.81−0.95
9	1.60−1.80
10	2.10−2.40
11	8.20−10.50
12	8.20−10.50

The dates and flight parameters for the scanner acquisitions used in this study are shown in Table 4.

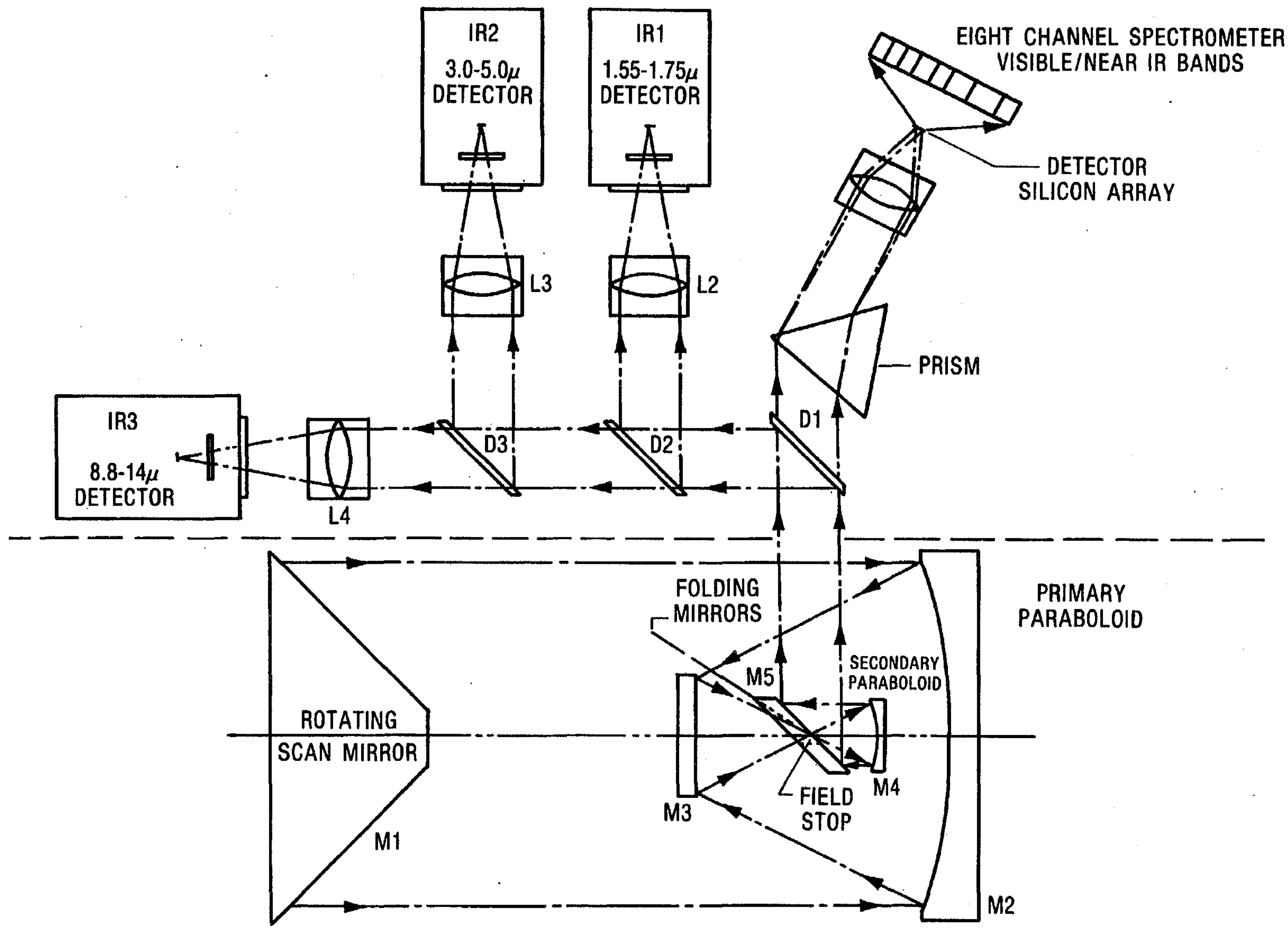

FIGURE 3. *SCHEMATIC DIAGRAM OF DAEDALUS AADS1268 MULTISPECTRAL SCANNER*

Table 4. Multispectral Scanner Data Acquisition Dates			
Year	**Date**	**Time**	**Altitude (feet)**
1987	21 April	1412	10,300
1988	29 April	1410	10,000
1989	13 April	1409	10,000
1990	16 April	1040	10,000
1991	2 May	1321	10,000

4.2 Scanner Data Registration

To detect change over time for a given area, a technique referred to as multitemporal analysis was performed. This consists of co-registering several different dates of imagery, so that the different dates overlie one another. Once the digital data have been registered, they can be classified and the different dates can be compared to determine where changes have occurred over time.

Previous studies, including Christensen *et al.* (1988), have discussed the difficulties in locating sufficient control points for airborne MSS data registration when using maps, especially in a predominantly swamp environment. Because aerial photographs inherently have less geometric distortion than airborne MSS data, they can be more easily registered with a limited number of control points. Due to the limited number of available control points in the DLG data located within the study area, aerial photographs were used as an intermediate map base for registering the airborne MSS data to the DLG data.

The map base chosen for this study was the Universal Transverse Mercator (UTM) projection, Zone 17. USGS DLG data for the entire SRS were available as ARC/INFO coverages (Environmental Systems Research Institute Incorporated, 1989). The 1:24,000 and 1:100,000 scale coverages were subset over the Pen Branch corridor and delta area, and were converted from vector format to raster format, with a grid cell size of 20 feet by 20 feet. The resulting raster image had a dimension of 3,020 lines by 1,896 samples.

Three color infrared aerial photographs from 1988 were digitized using a Perkin-Elmer Model 1010G Microdensitometer System. The photographs were scanned with a sampling size of 80 microns. The scanned photograph data were then entered into the Interactive Digital Image Manipulation System (IDIMS) image processing system (ESL Incorporated, 1989), and converted to IDIMS 8-bit format data.

Each photograph was registered to the DLG data using the TRNSFORM and REGISTER functions in the IDIMS package. The number of control points used and the average residuals for each photograph are shown in Table 5. Each photograph was registered using the appropriate coefficients. Cubic convolution was used for the resampling to provide the visually sharpest possible image for registering the MSS data. The three registered photographs were then mosaiced together using the IDIMS function MOSAIC. The three registered and mosaiced photographs are shown in Figure 4.

To register the airborne MSS data, many more control points are necessary than are available in the DLG data. The detail present in the photograph mosaic provides many more opportunities for control point selection for the MSS data. By registering the photographs to the DLG data, the photograph mosaic assumes the same coordinate system as the DLG data, and provides more opportunities for selecting control points.

As mentioned previously, simple linear transformations are usually inadequate for registering airborne MSS data. While a photograph captures an image almost instantaneously, a scanner such as the AADS1268 creates an image continuously, using the forward motion of the aircraft to provide the along-track momentum. Due to the inevitable pitch, roll, and yaw movements of an aircraft while the scanner is operating, severe nonlinear distortions can be entered into different parts of the overall image as it is being created (Richards, 1986). A single set of linear transformation equations cannot account for the many distortions present in a typical flightline of MSS data.

To compensate for the distortions present in MSS data, more complicated and powerful registration techniques are required. One such technique is finite element registration, which is available in the Video Image Communication and Retrieval (VICAR) image processing package (Jet Propulsion Laboratory, 1987). With this technique, the selected control points are used to create a triangulation over the image; each triangle is then registered using a first-order polynomial, resulting in a piecewise linear solution. Each triangle is mathematically forced to be continuous with its surrounding triangles, maintaining continuity throughout the image.

Table 5. 1988 Color Infrared Photography Registration

Photo	Initial Points	Points Used	Sample Residual	Line Residual
1	31	18	1.10 pixels	1.03 pixels
2	28	16	0.80 pixels	0.91 pixels
3	27	15	0.90 pixels	1.28 pixels

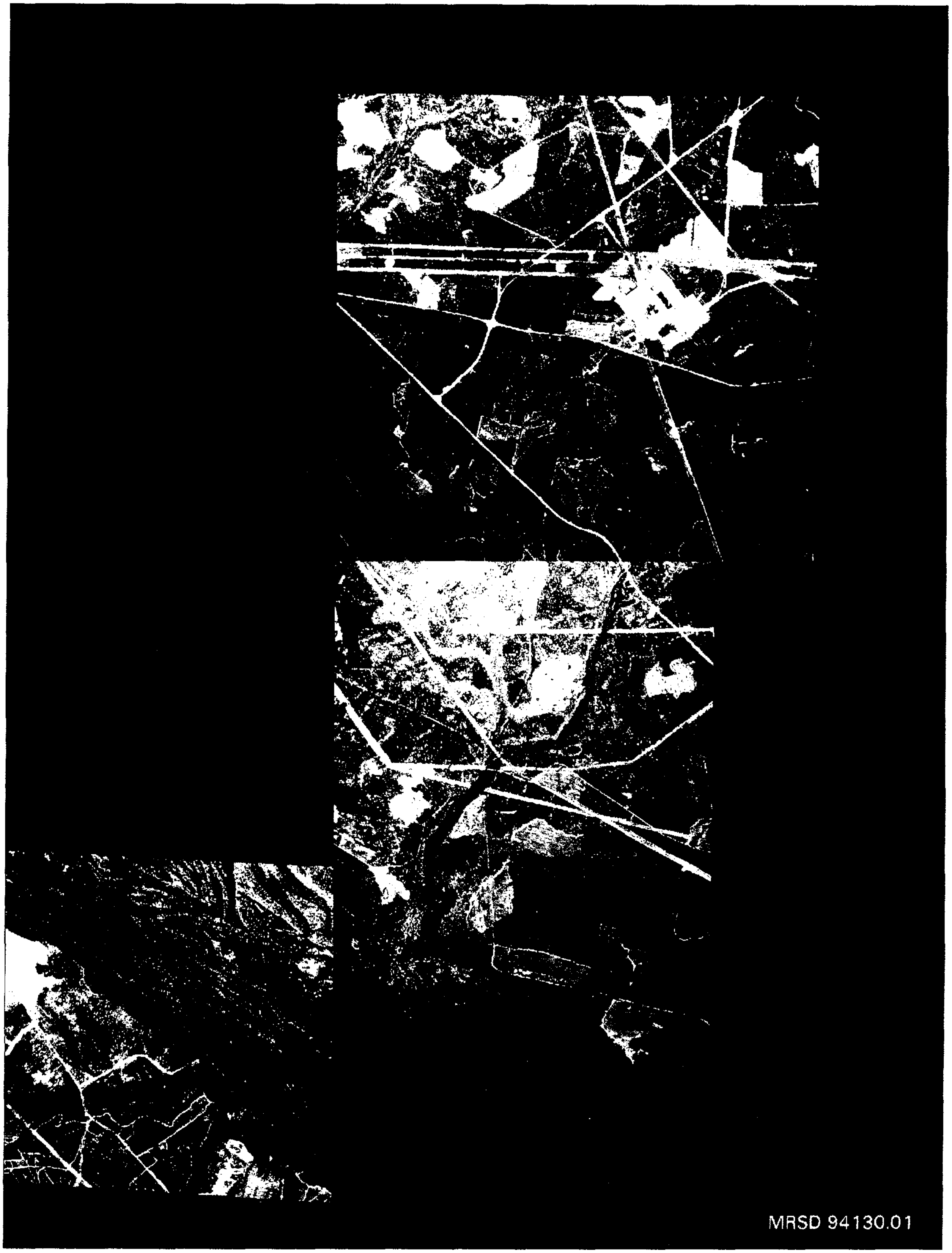

FIGURE 4. *MOSAIC OF GEO-REFERENCED 1988 COLOR INFRARED PHOTOGRAPHS*

Unlike linear transformations, where additional control points can only minimally influence the coefficients of the transformation equations, finite element registration allows additional points to be picked where distortion is greatest, and those additional points actually force the image to match the base image. In this way, the distortion in an entire flightline of MSS data can be iteratively removed by picking additional control points as needed. Of course, there are software limitations in the VICAR package regarding the number of possible control points and image size. Because of this, the control point section for this study was designed to optimize the registration of the Pen Branch corridor and delta at the expense of the rest of the area in the flightline.

Another shortcoming of the VICAR finite element approach is that there is no way to measure the registration accuracy, as is possible with linear transformations. The best approach to assess accuracy in a finite element registration is to visually compare the registered image with the base image over the entire area of interest, and verify that the images adequately line up. In this study many registration iterations were performed until the fit was judged adequate. The number of control points used for the MSS data for each year was for 1987-56, 1988-64, 1989-64, 1990-62, and 1991-46. The resampling option used in this case was nearest-neighbor, in order to preserve the original radiometric integrity of the data. A composite of channel seven (0.71−0.82 micrometers) of the five registered flightlines of MSS data is shown in Figure 5.

4.3 Study Area Delineation

Before image classification could begin, it was necessary to designate the actual analysis area boundaries. This was required for two reasons. First, as described previously, the MSS data registrations were optimized for the immediate Pen Branch corridor and delta areas; misregistration outside these immediate areas could result in erroneous changes being created. Second, because of the classification strategy used, eliminating extraneous areas would optimize the classification performance. The IDIMS unsupervised clustering algorithm ISOCLS was used. This is a divisive clustering algorithm, meaning that the data are regarded initially as one large cluster, and then subsequently divided into more clusters. The algorithm has a limiting maximum possible number of clusters that can be created. Wetland/swamp environments are often characterized by subtle spectral differences between vegetation types, making it difficult to obtain spectrally separable clusters. One way to overcome this difficulty is to have as many clusters

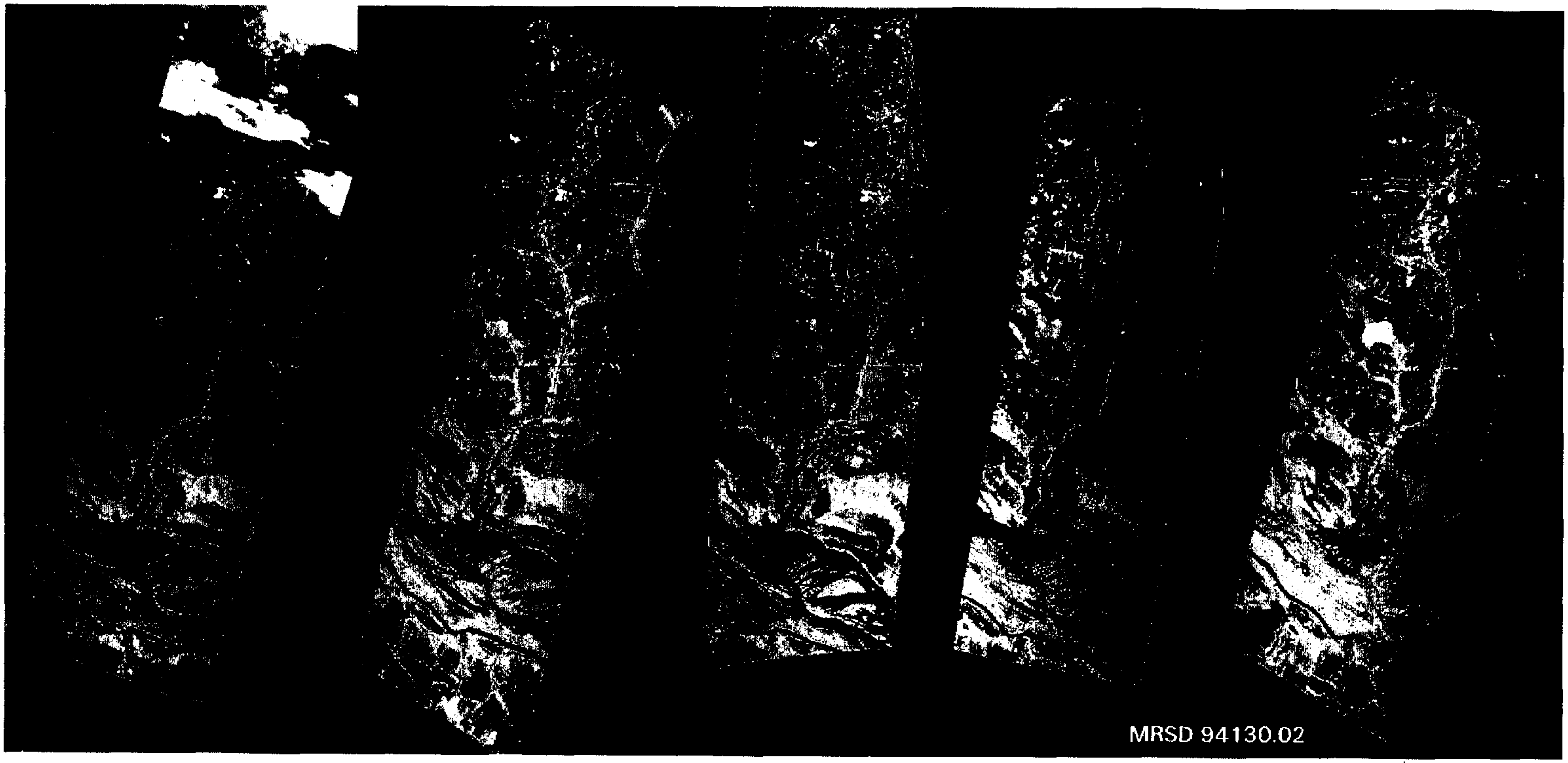

FIGURE 5. *GEO-REFERENCED CHANNEL 7 FLIGHTLINES FOR 1987 TO 1991*

within the different vegetation types as possible. To keep doing this, the areas outside the corridor and delta could be ignored, thereby not using, or "wasting," clusters outside the actual areas of interest.

A digital mask was created to eliminate the areas outside of the corridor and delta. The mask had to indicate the maximum area within the corridor and delta that had been affected during reactor operations. The best source of historical data found was SRS black and white infrared aerial photographs from 1966. Unfortunately, the negatives for this photography were not available. The infrared photography showed the flooded areas exceptionally well. From the previous studies by Tinney *et al.* (1986), this was considered a period of maximum vegetational effects.

To use the 1966 photography to create a mask, it was necessary to register these photographs to the base map as well. Six photographs covered the area of interest and were scanned with the Perkin-Elmer microdensitometer with a sampling size of 80 microns. Again, all six scanned photographs were entered into the IDIMS package, and converted to 8-bit IDIMS format data. The six photographs were registered using the IDIMS functions TRNSFORM and REGISTER. The photographs appeared to contain some distortion, most likely due to their age, which made it difficult to obtain a precise registration fit. The number of control points used and the average residuals for each photograph are shown in Table 6.

The six photographs were registered using the cubic convolution resampling option, again to produce the sharpest possible output image. To create a mask with these registered photographs, it was critical that the corridor and delta boundaries match as well as possible from one photograph to the next when mosaiced together. To accomplish this, the finite element functions were used to tie the corridor and delta boundaries together at the seams of each photograph. When the photographs were subsequently mosaiced together, the boundaries matched almost perfectly. The final mosaic of the six 1966 photographs is shown in Figure 6.

The boundaries of the Pen Branch corridor and delta were digitized from the photograph mosaic to create the mask. This was accomplished by using ARC/INFO to digitize the boundaries while using the Live Link function within the ERDAS image processing package (ERDAS Incorporated, 1990). The mosaic was displayed on the screen, and the boundaries of the corridor were delineated. To obtain the delta polygon, the northern edges, or terraces, of the delta were traced from the photograph mosaic, and an arbitrary rectangle was extended to the Savannah River, containing the entire delta. Because there are no distinct boundaries to the extent of the delta, this large area was used to ensure that all potential impacted areas of the delta were included in the study area.

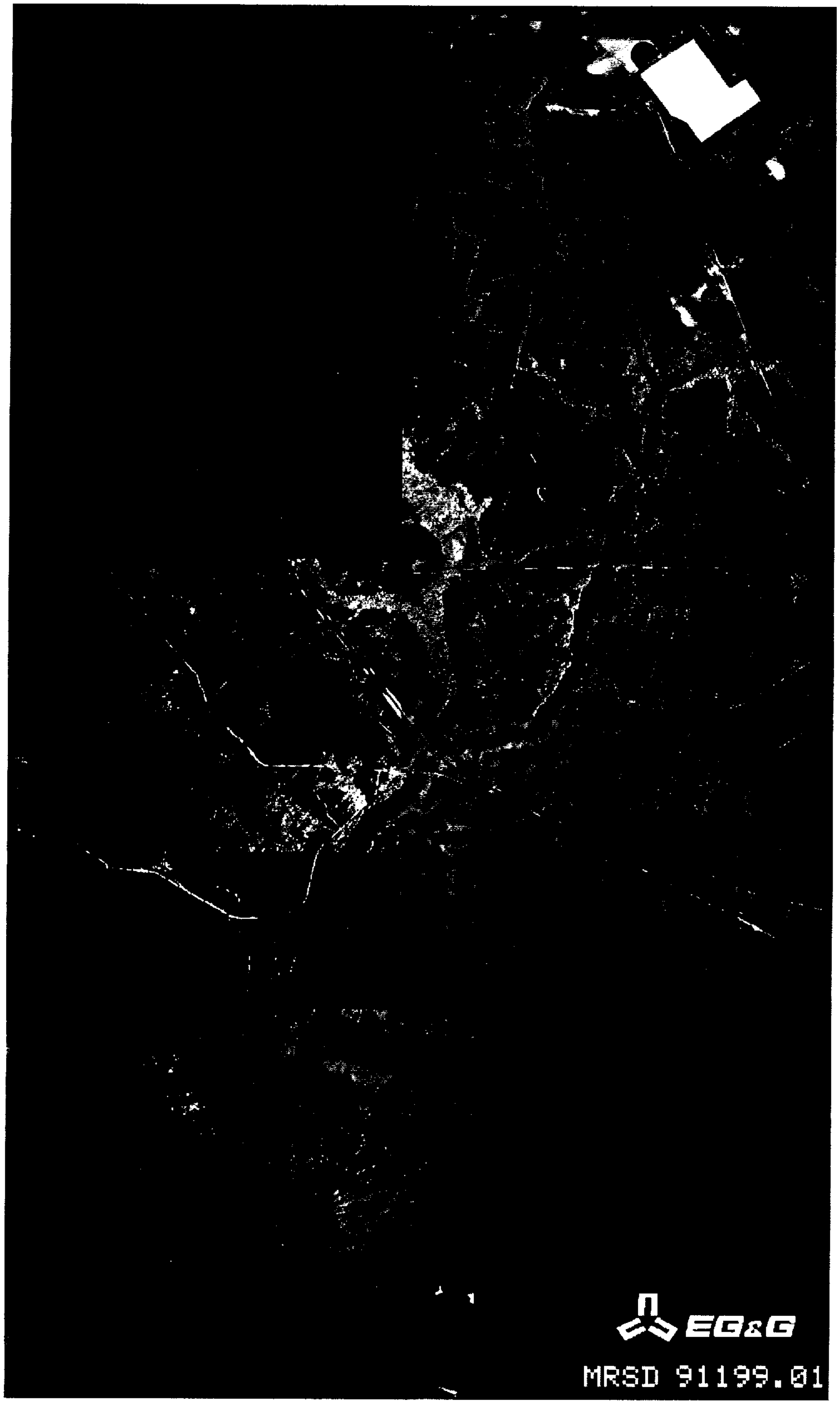

FIGURE 6. *MOSAIC OF GEO-REFERENCED 1966 BLACK AND WHITE INFRARED PHOTOGRAPHS*

Table 6. 1966 Black and White Infrared Photography Registration				
Photo	**Initial Points**	**Points Used**	**Sample Residual**	**Line Residual**
1	21	9	1.90 pixels	1.87 pixels
2	24	9	1.83 pixels	1.83 pixels
3	16	9	1.37 pixels	1.27 pixels
4	15	9	0.67 pixels	1.10 pixels
5	19	7	1.59 pixels	1.72 pixels
6	17	10	1.96 pixels	2.33 pixels

To further optimize the image clustering, the corridor and delta regions were separated into two polygons. This allowed the maximum number of clusters for the different vegetation types in the delta and the corridor. To ensure that the corridor polygon would include the actual corridor despite any misregistration, the original corridor polygon was expanded outward by two pixels (twenty feet per pixel) using the ARC/INFO function BUFFER. However, to allow comparison to the total acreage amount reported in previous studies (Tinney *et al.,* 1986), classification acreages were prepared with the buffer and without the buffer. The final buffered corridor and delta/river polygons are shown in Figures 7 and 8, respectively.

4.4 Classification

The corridor and delta/river polygons were used to subset the MSS data. This resulted in five datasets containing only the corridor, and five datasets containing only the delta/river. Each dataset was classified using the IDIMS function ISOCLS. The first ten channels of each dataset were used in the classification. The thermal channels were not used because daytime thermal imagery normally has a fairly low information content relative to the reflected-energy channels for discriminating vegetation types. As mentioned previously, the ISOCLS algorithm is a divisive clustering algorithm. In addition to producing cluster statistics, this function also produces a cluster map for the entire input image. This cluster map was then labelled and used as the classification. One of the strongest features of this type of clustering algorithm is that it allows the use of masked data without creating clusters contaminated by the mask. The number

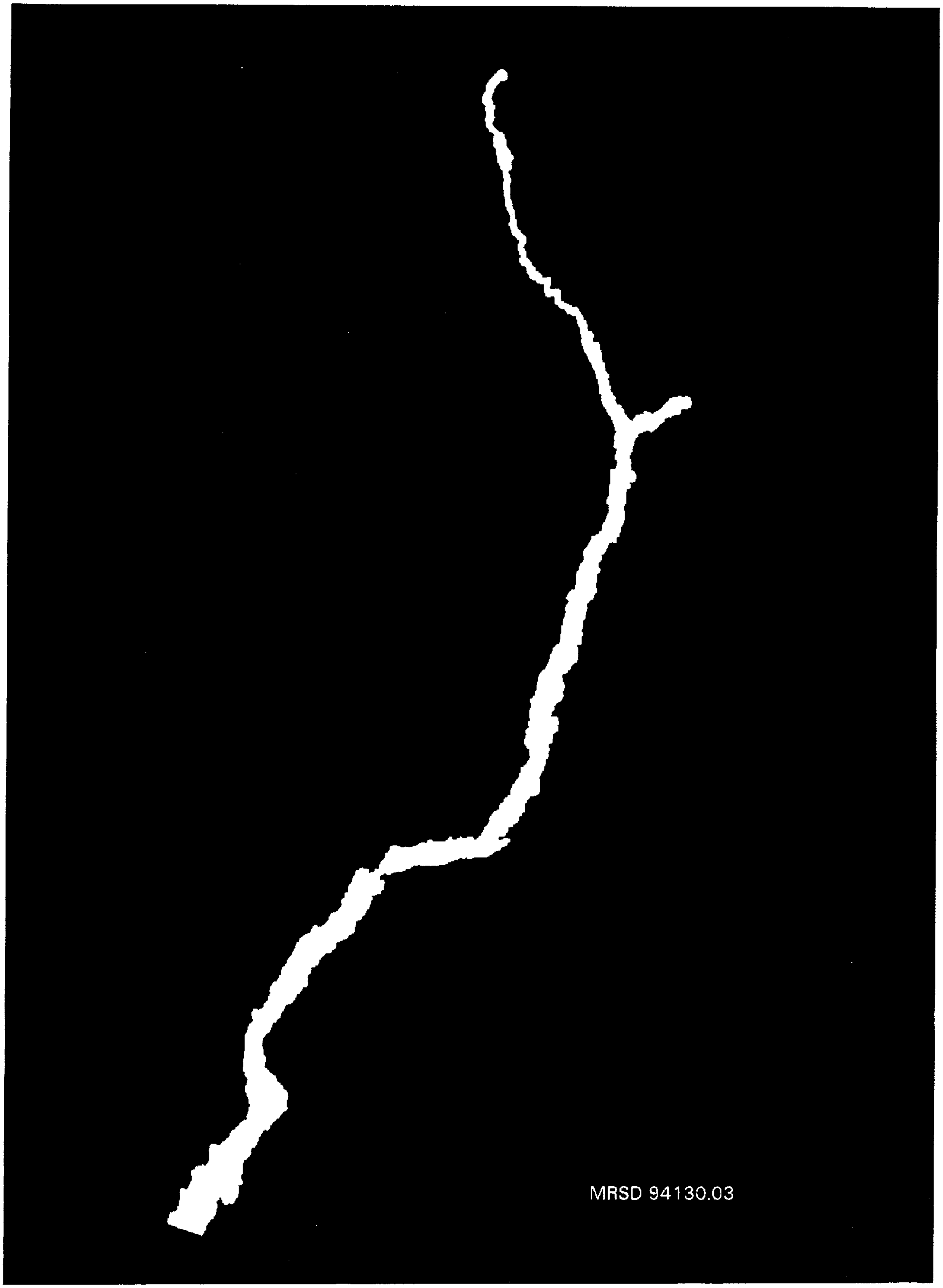

FIGURE 7. ***BUFFERED CORRIDOR POLYGON USED FOR STUDY AREA DELINEATION***

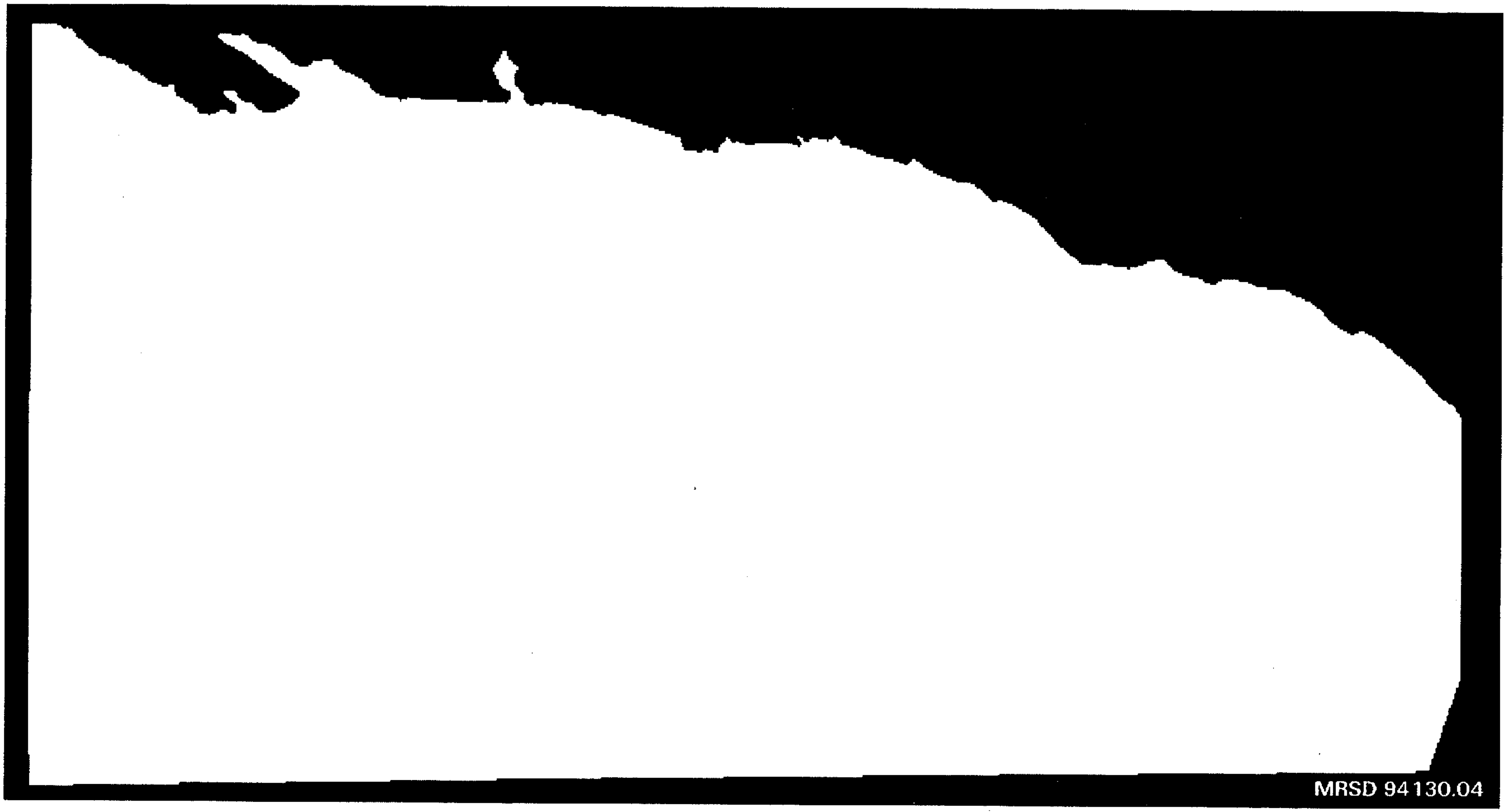

FIGURE 8. *BUFFERED DELTA/RIVER POLYGON USED FOR STUDY AREA DELINEATION*

of clusters obtained for each dataset is shown in Table 7. The accuracy of each classification was visually checked using the low-altitude aerial photography and the ground-based photography, and the confidence in the classification accuracy was judged very high. A more rigorous, quantitative assessment of the classification accuracy will be performed in the follow-up study using 1992, 1993, and 1994 MSS data.

4.5 Cluster Labelling

Cluster labelling involved careful consideration of environmental conditions and interactions present in the Pen Branch imagery. The vegetation types present in the corridor and delta in a given year at the time of scanner acquisition depend on several factors. The reactor flow will affect how much water is in the corridor and in the delta. Without reactor output, the normal flow rate in Pen Branch varies from 30 to 50 cubic feet per second. When the reactor operates at full power, the flow rate can increase by a factor of 10. The flow in the Savannah River will also affect the wetness of the delta; as the flow in the Savannah River exceeds approximately 15,300 cubic feet per second, openings in the natural levee

Table 7. Corridor and Delta Dataset Clustering Results

Year	Number of Clusters
Corridor	
1987	36
1988	51
1989	51
1990	51
1991	51
Delta	
1987	44
1988	51
1989	51
1990	51
1991	51

between the river and the swamp allow floodwaters to enter the delta. The wetness of the corridor and delta will, in turn, influence both the timing of vegetation growth, and the vegetation types that will be favored.

The thermal characteristics of the water flooding the delta will also have a major impact on vegetation development. The effect of flooding by hot water, such as in 1987, is much different than that by cool water, which has been the case since the reactor ceased operations in 1988. The timing of the reactor flows and the river floods relative to vegetation development and the season in which the data are acquired will also affect what is present. Finally, the development of vegetation in a given year may be affected by the presence of dead vegetation or biomass from the previous year (Mackey, 1990, 1993).

As many environmental conditions as possible must be taken into account when labelling the classification clusters. The amount and quality of field data available for this study become especially important. The hydrology data are shown in Figures 9 through 18. The Savannah River flow is shown in Figures 9 through 13, while the Pen Branch flow is shown in Figures 14 through 18. The dates of the scanner acquisitions are shown on each graph. Phenology graphs for the three primary vegetation types are shown in Figures 19 through 28 for 1987 through 1991. Again, the dates of the scanner acquisitions are shown on each graph. These graphs show the relative height of the previous year's dead brown vegetation in relation to the current year's living green vegetation. These graphs are extremely valuable for interpreting what the scanner recorded. In addition to analyzing these sources, the aerial and ground-based photography were used in conjunction with two-dimensional plots (using channels 3 and 7) of the cluster means and standard deviations to identify the individual clusters. The information classes used for this study are shown in Table 8.

5.0 RESULTS

Classification and cluster labelling were carried out for each year. The results for each year are presented in the following sections.

5.1 1987 Classification

Figures 9 and 14 show the Savannah River and Pen Branch flow, respectively, for 1987. These figures show that both the Savannah River and Pen Branch flows were high prior to and during the MSS

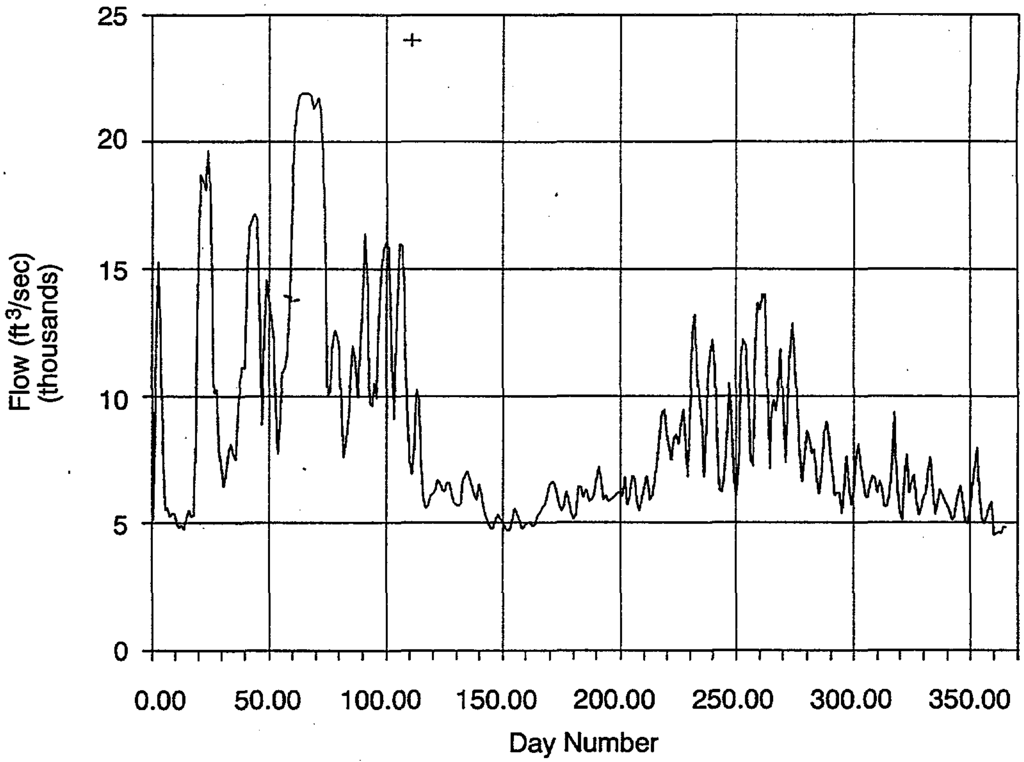

FIGURE 9. ***SAVANNAH RIVER FLOW FOR 1987***

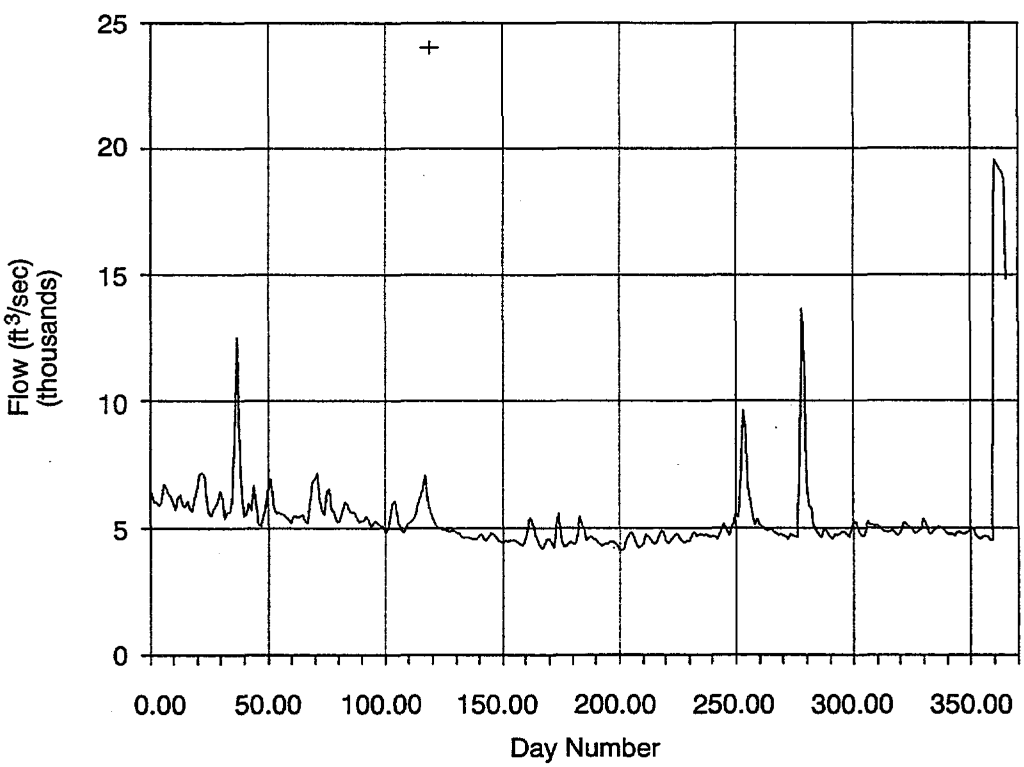

FIGURE 10. ***SAVANNAH RIVER FLOW FOR 1988***

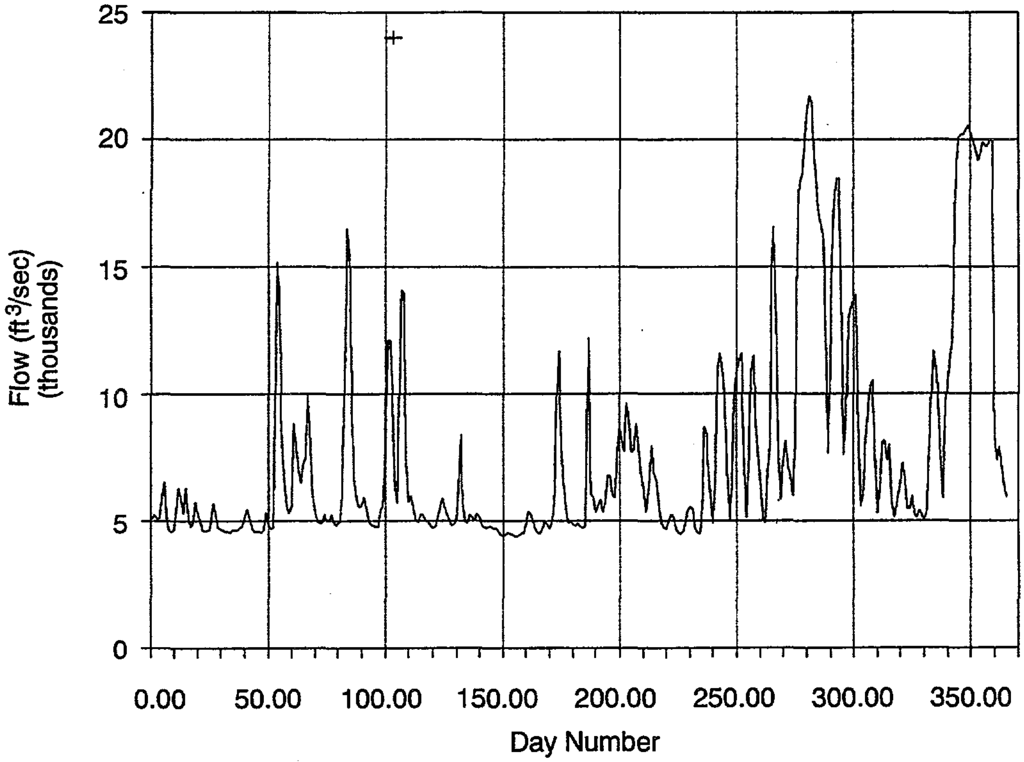

FIGURE 11. ***SAVANNAH RIVER FLOW FOR 1989***

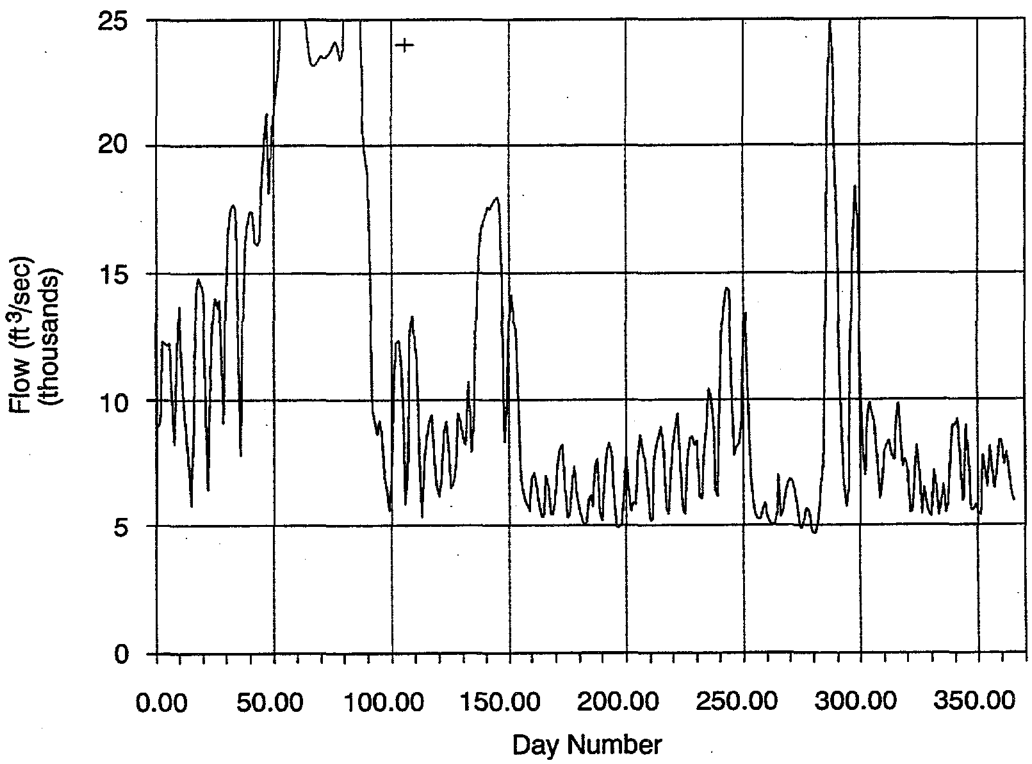

FIGURE 12. ***SAVANNAH RIVER FLOW FOR 1990***

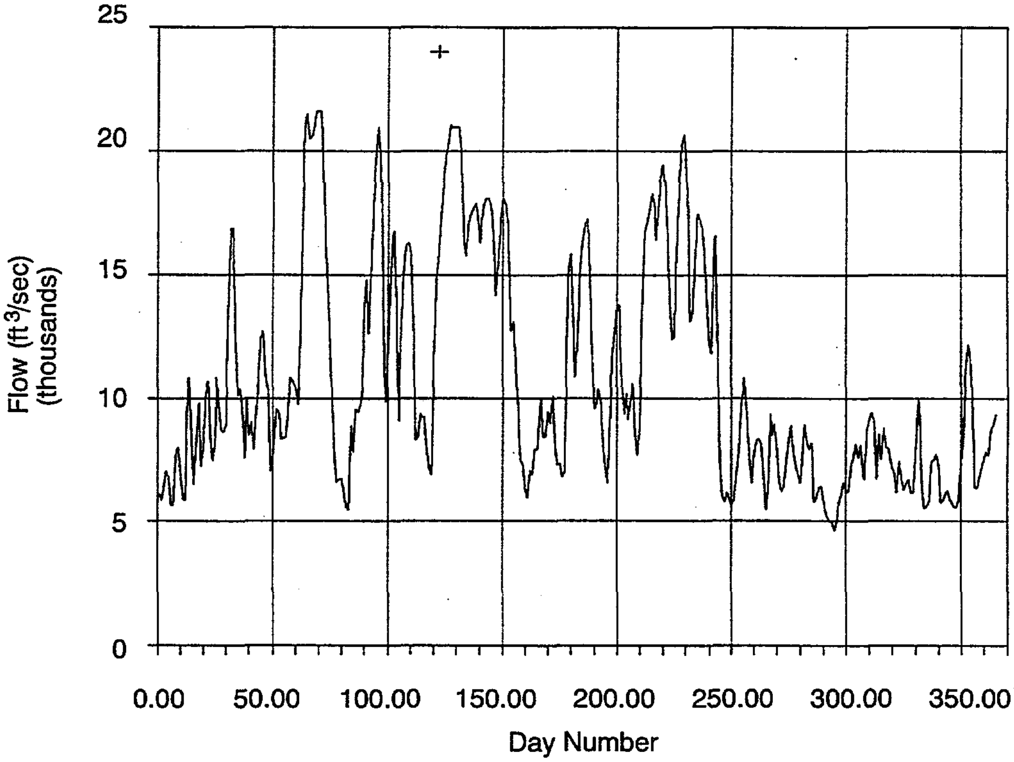

FIGURE 13. ***SAVANNAH RIVER FLOW FOR 1991***

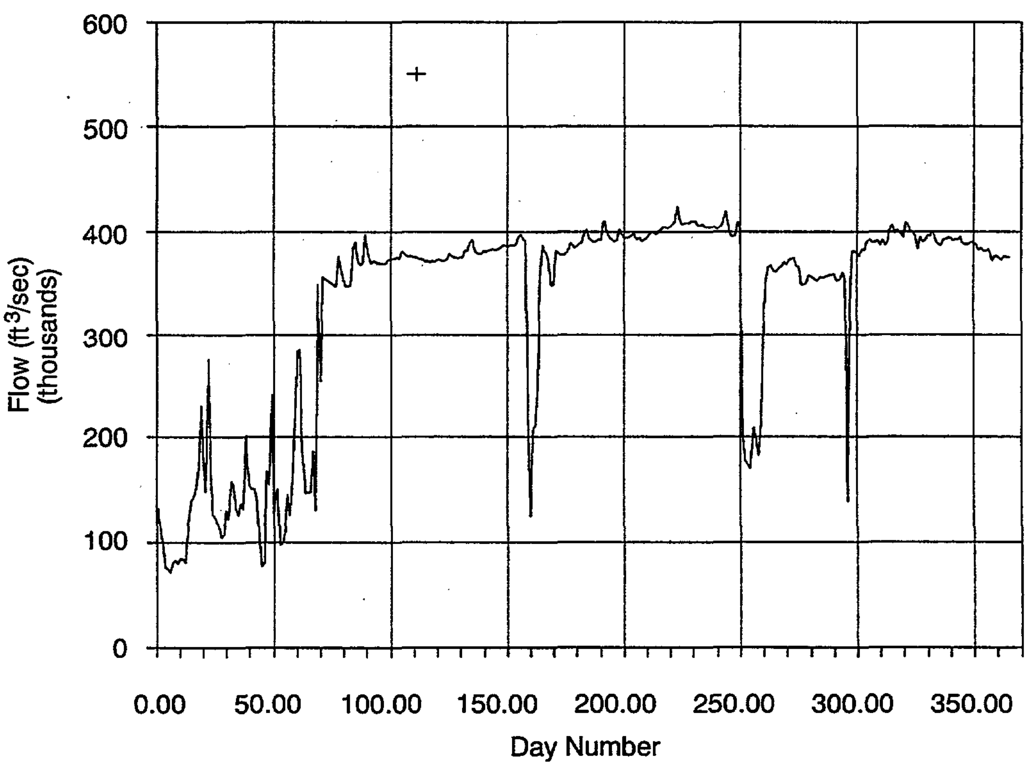

FIGURE 14. ***PEN BRANCH FLOW FOR 1987***

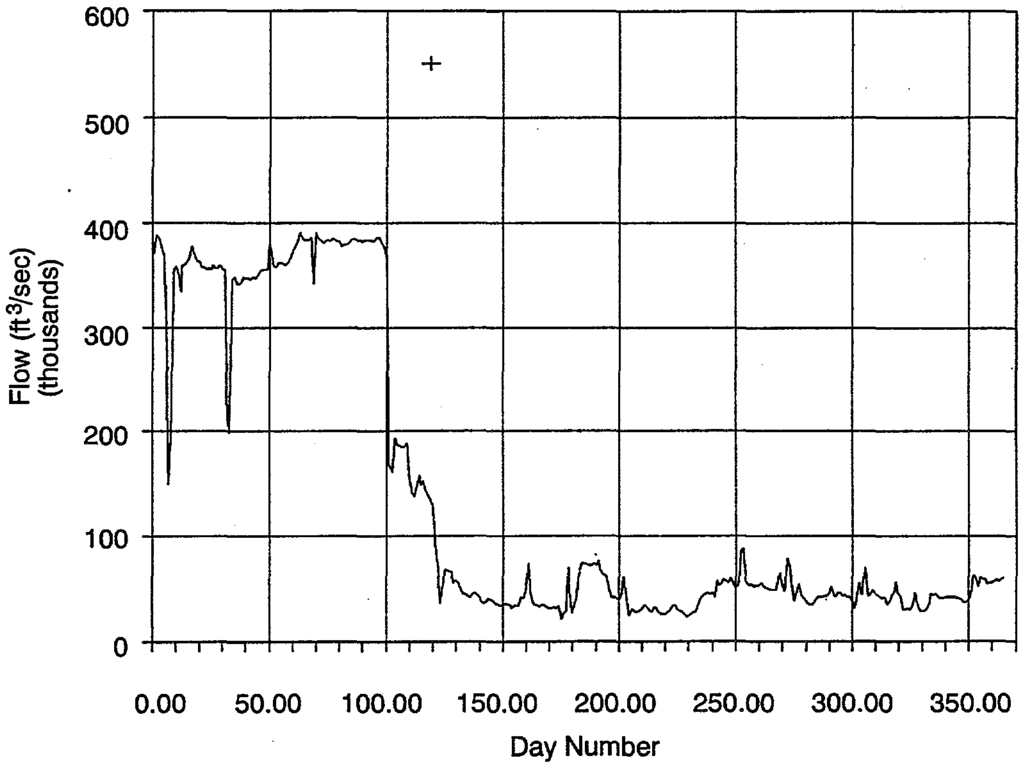

FIGURE 15. ***PEN BRANCH FLOW FOR 1988***

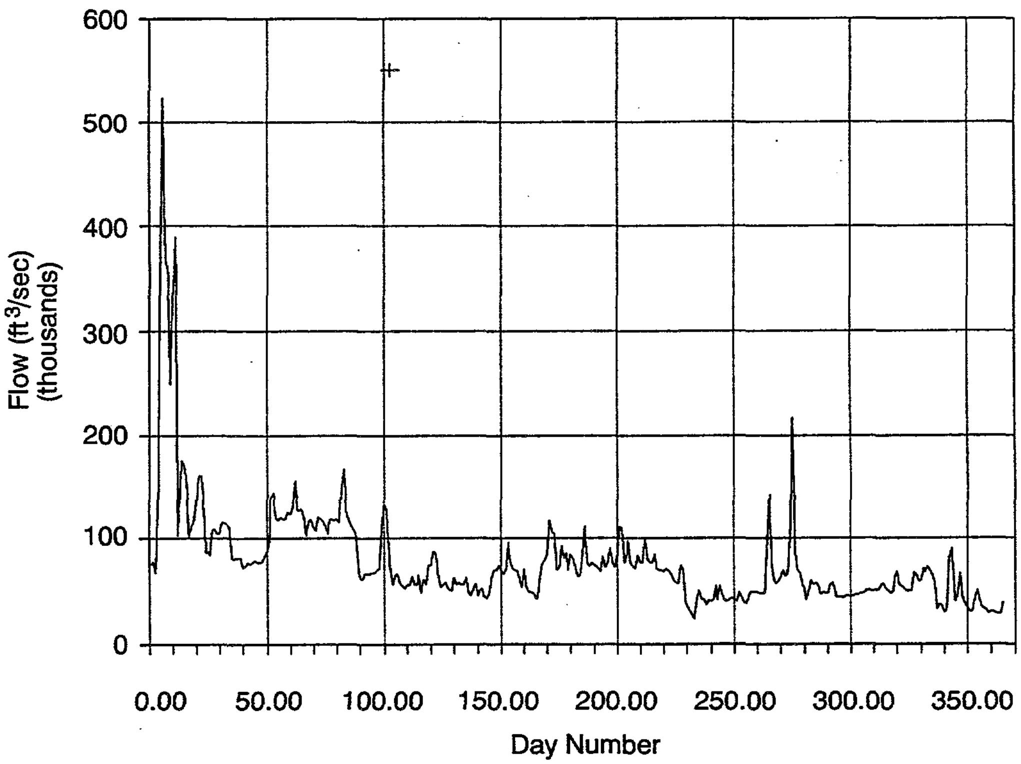

FIGURE 16. ***PEN BRANCH FLOW FOR 1989***

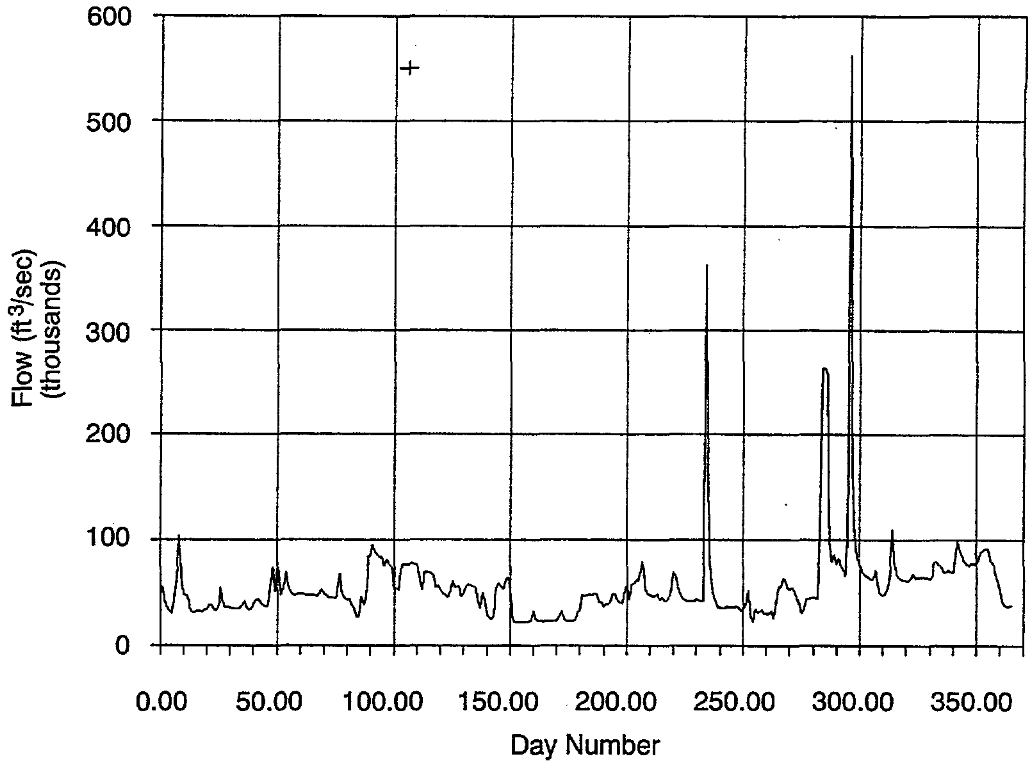

FIGURE 17. ***PEN BRANCH FLOW FOR 1990***

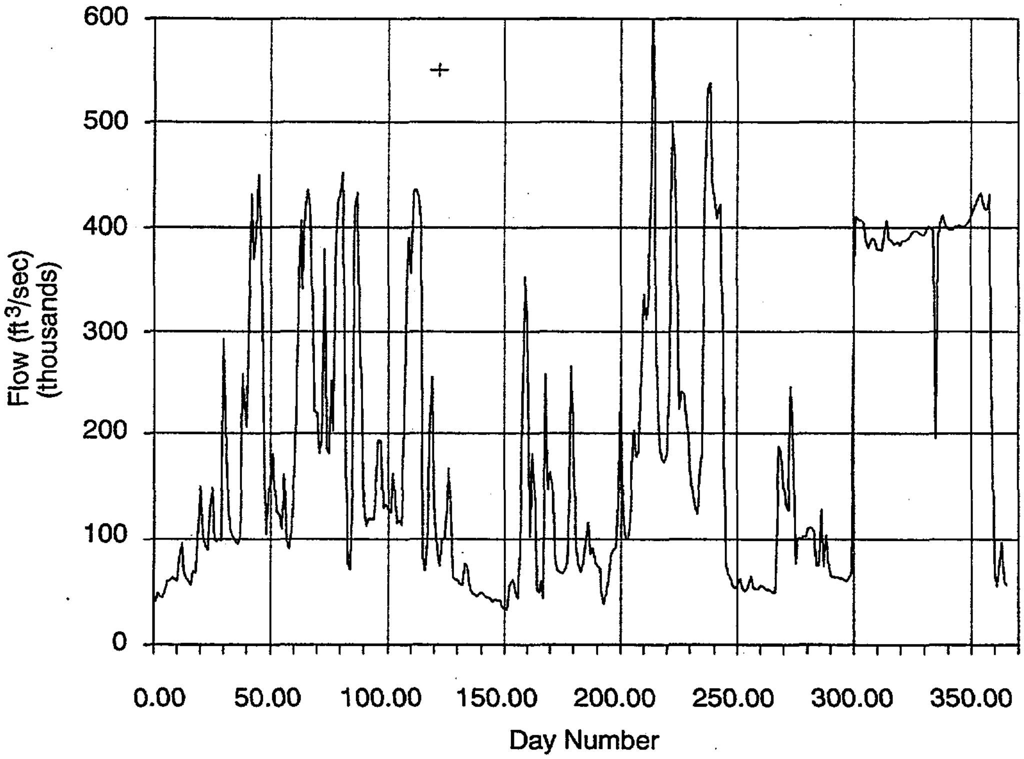

FIGURE 18. ***PEN BRANCH FLOW FOR 1991***

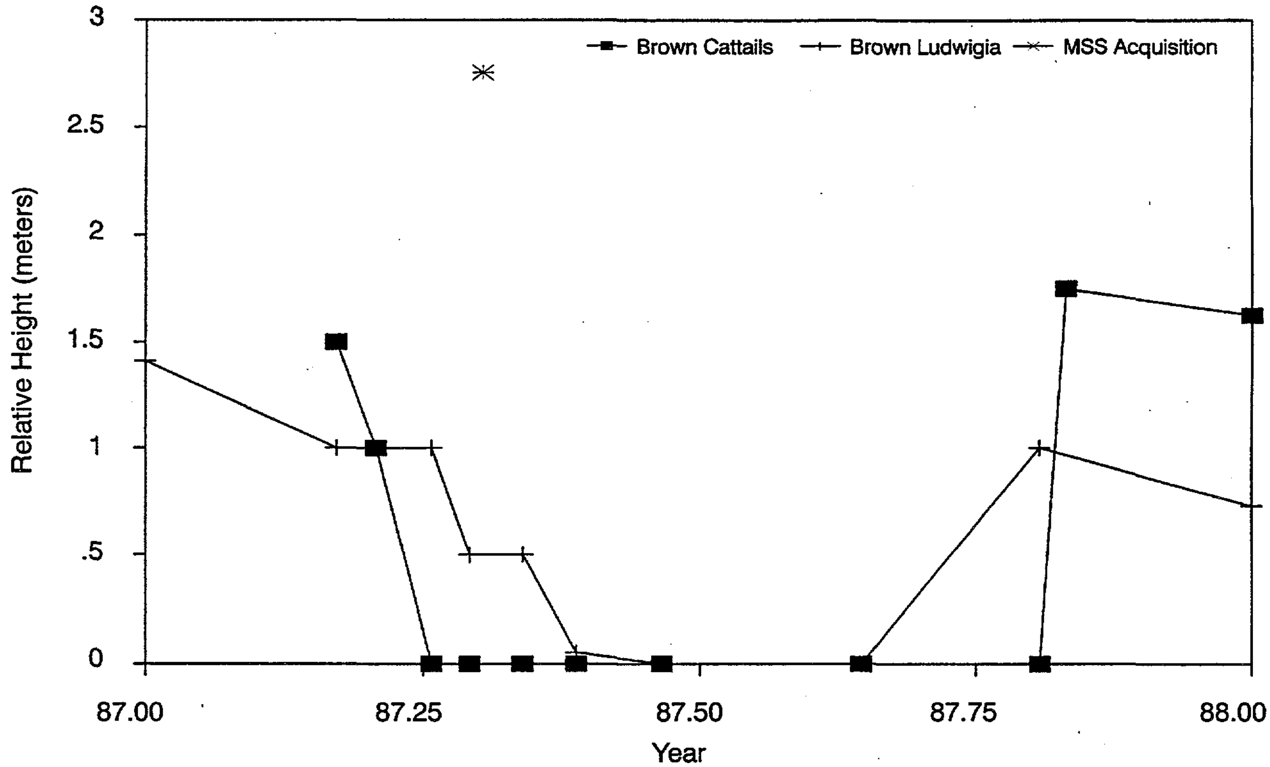

FIGURE 19. ***1987 BROWN PLANT PHENOLOGY GRAPH***

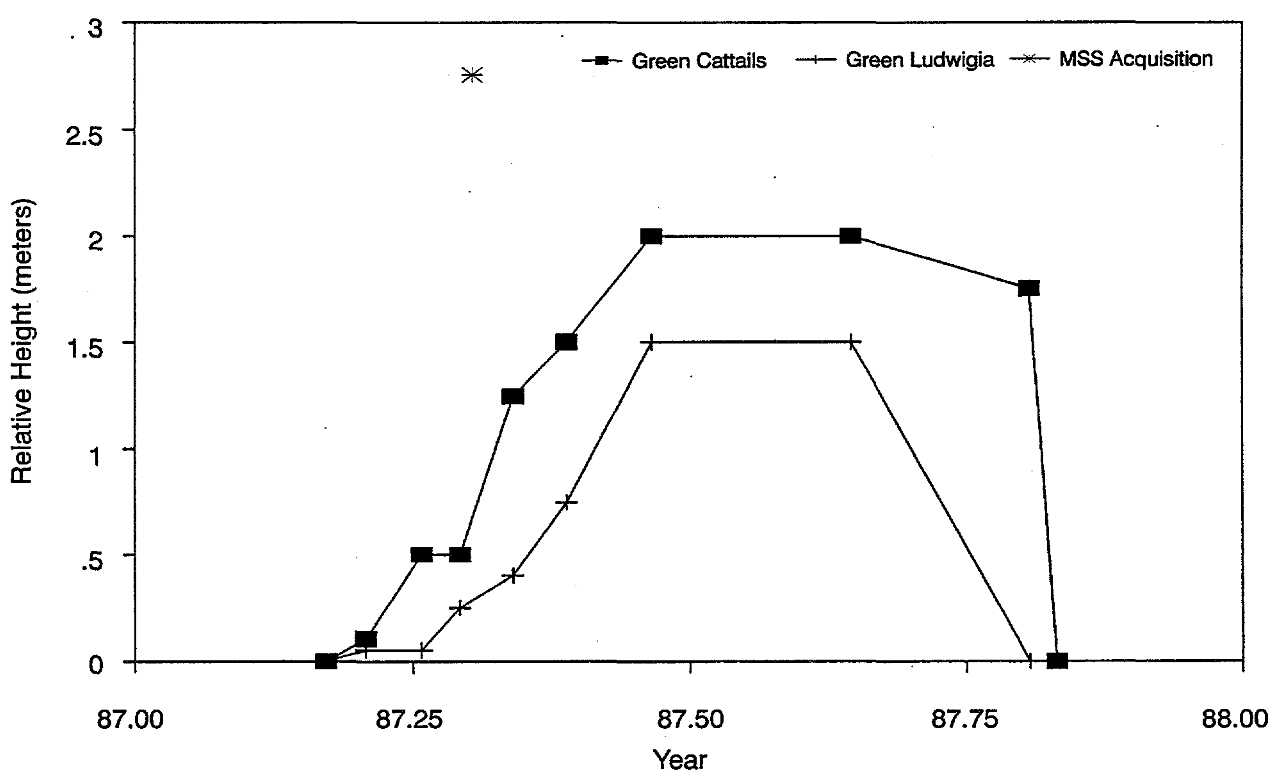

FIGURE 20. ***1987 GREEN PLANT PHENOLOGY GRAPH***

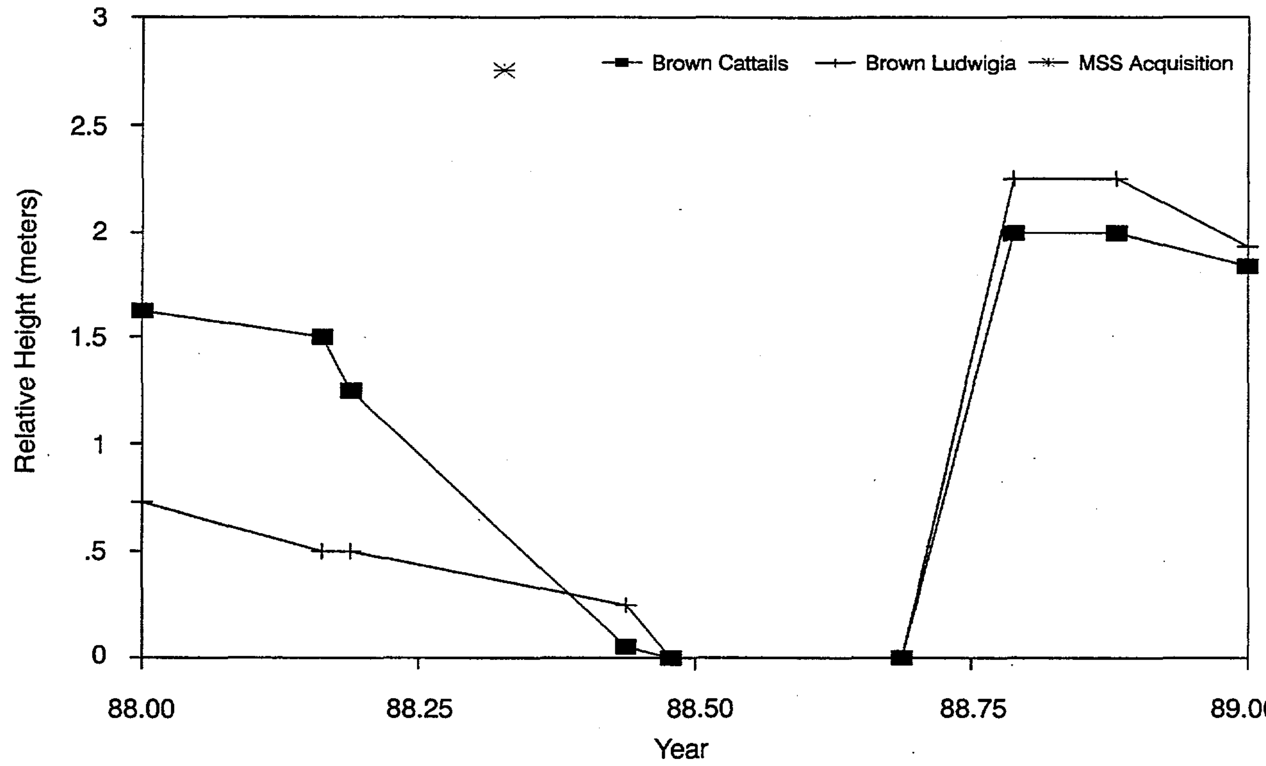

FIGURE 21. ***1988 BROWN PLANT PHENOLOGY GRAPH***

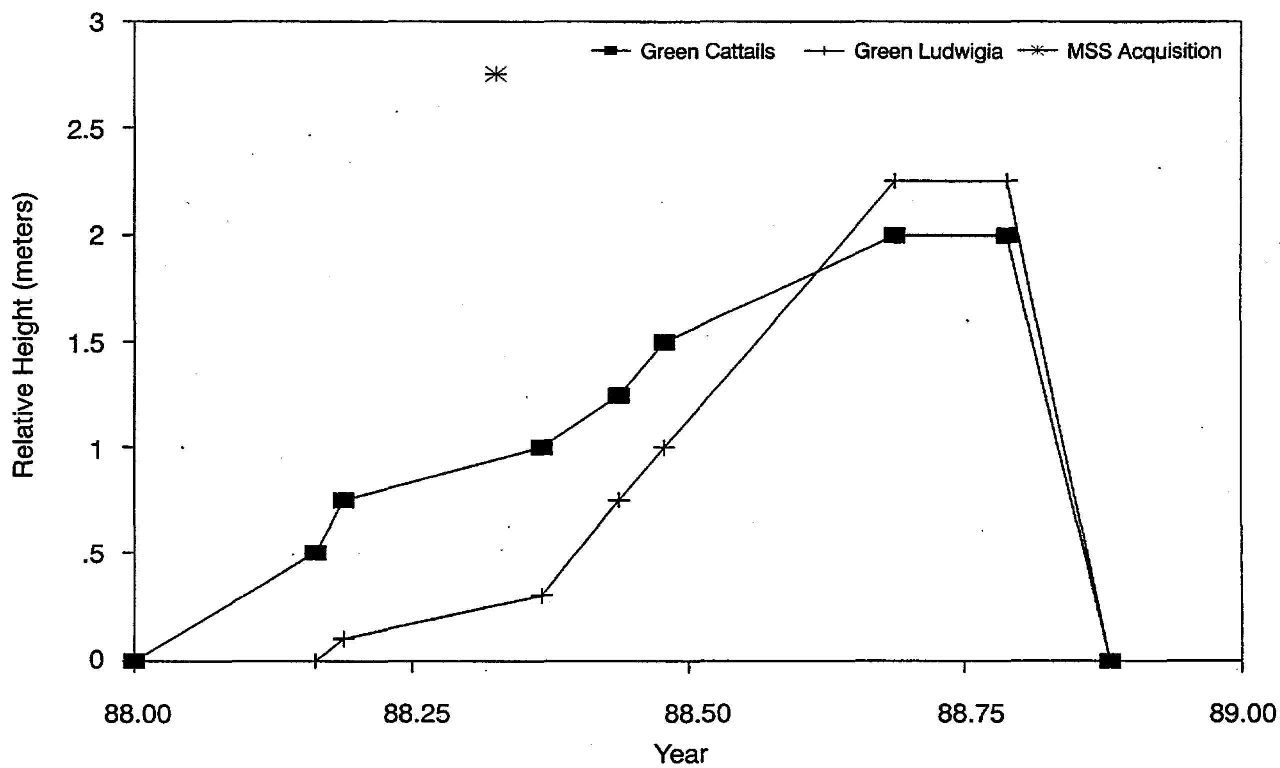

FIGURE 22. ***1988 GREEN PLANT PHENOLOGY GRAPH***

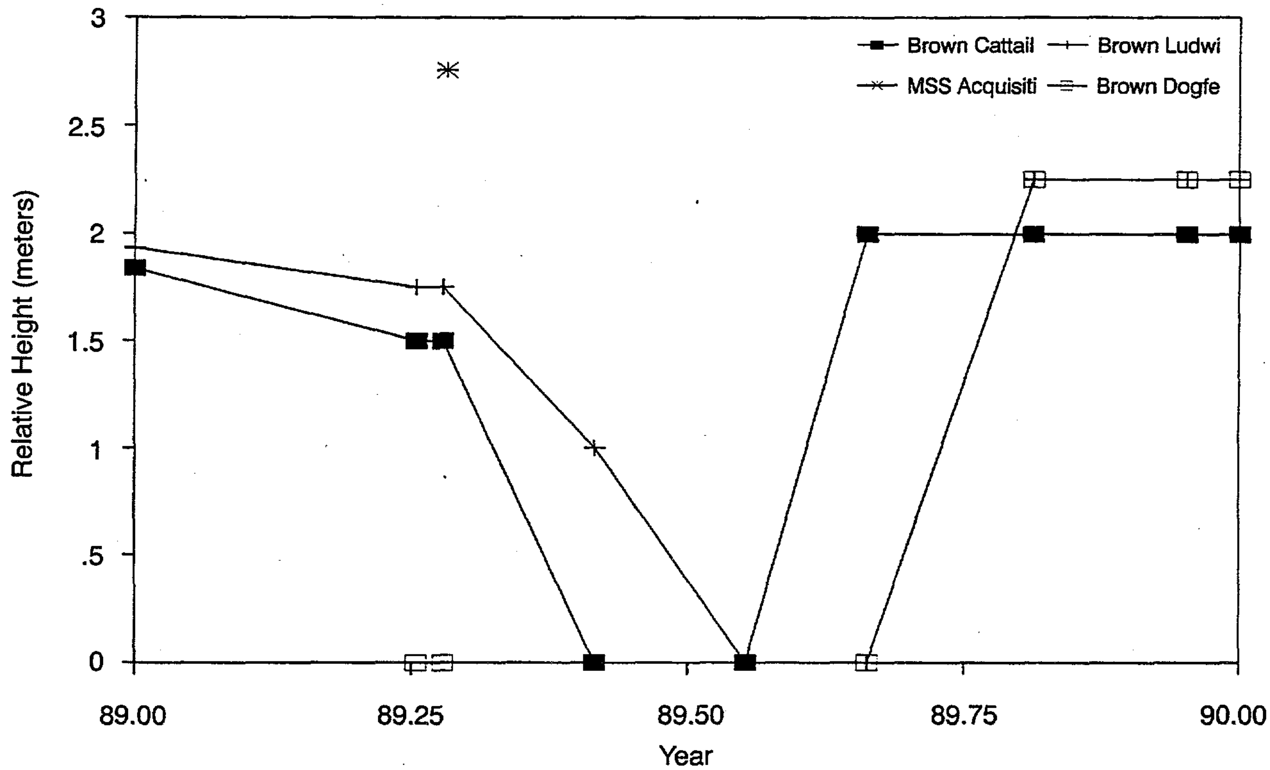

FIGURE 23. ***1989 BROWN PLANT PHENOLOGY GRAPH***

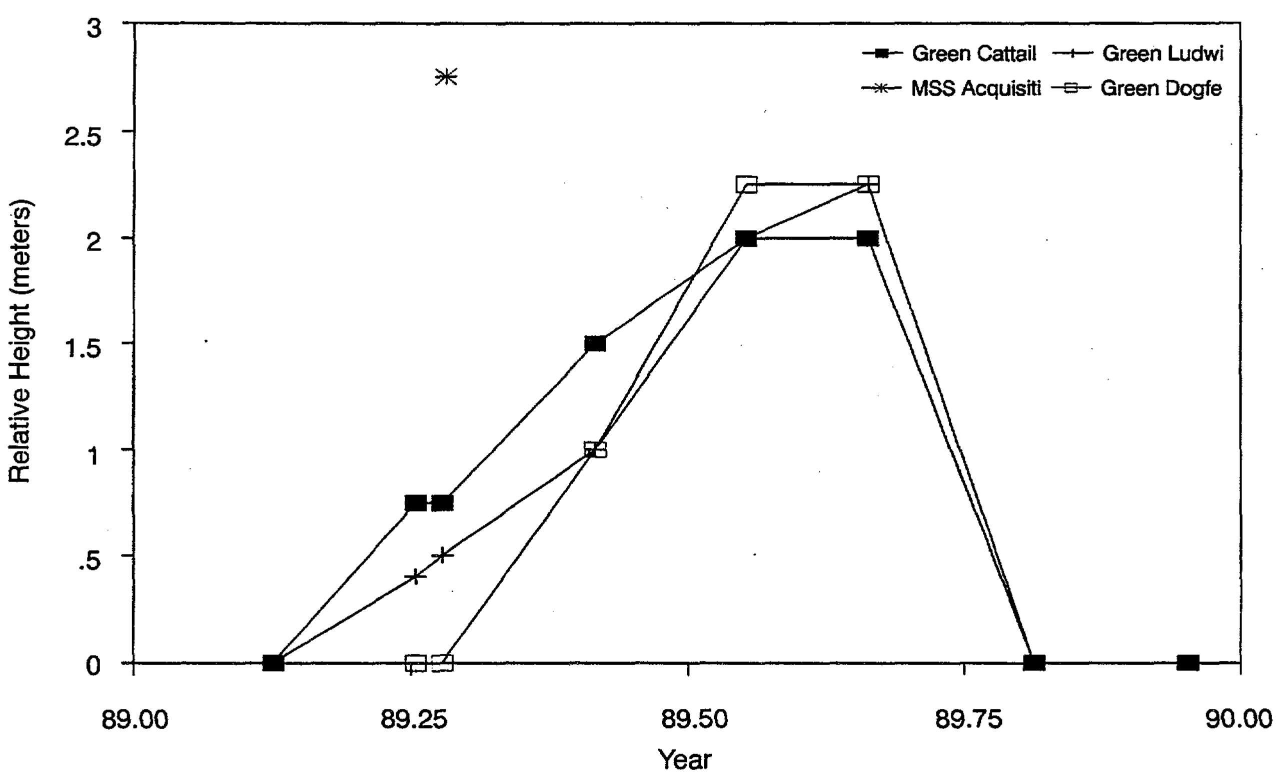

FIGURE 24. ***1989 GREEN PLANT PHENOLOGY GRAPH***

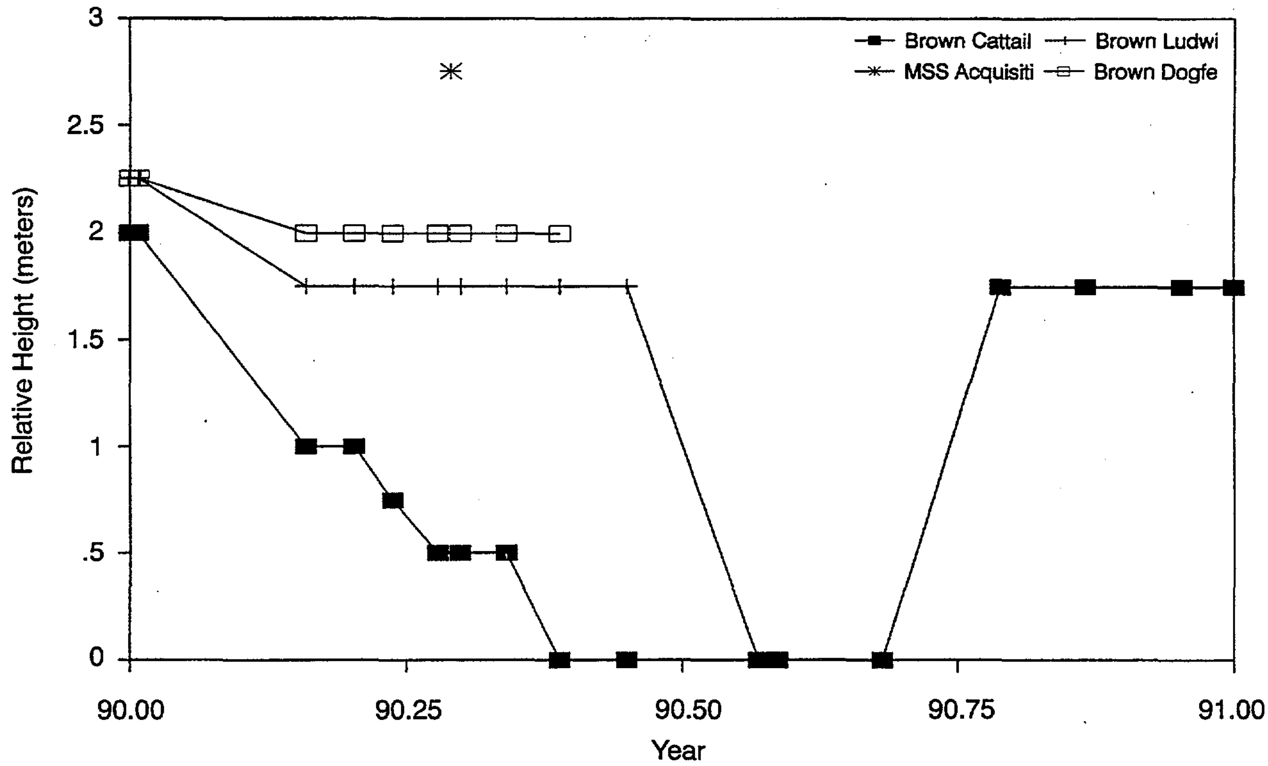

FIGURE 25. ***1990 BROWN PLANT PHENOLOGY GRAPH***

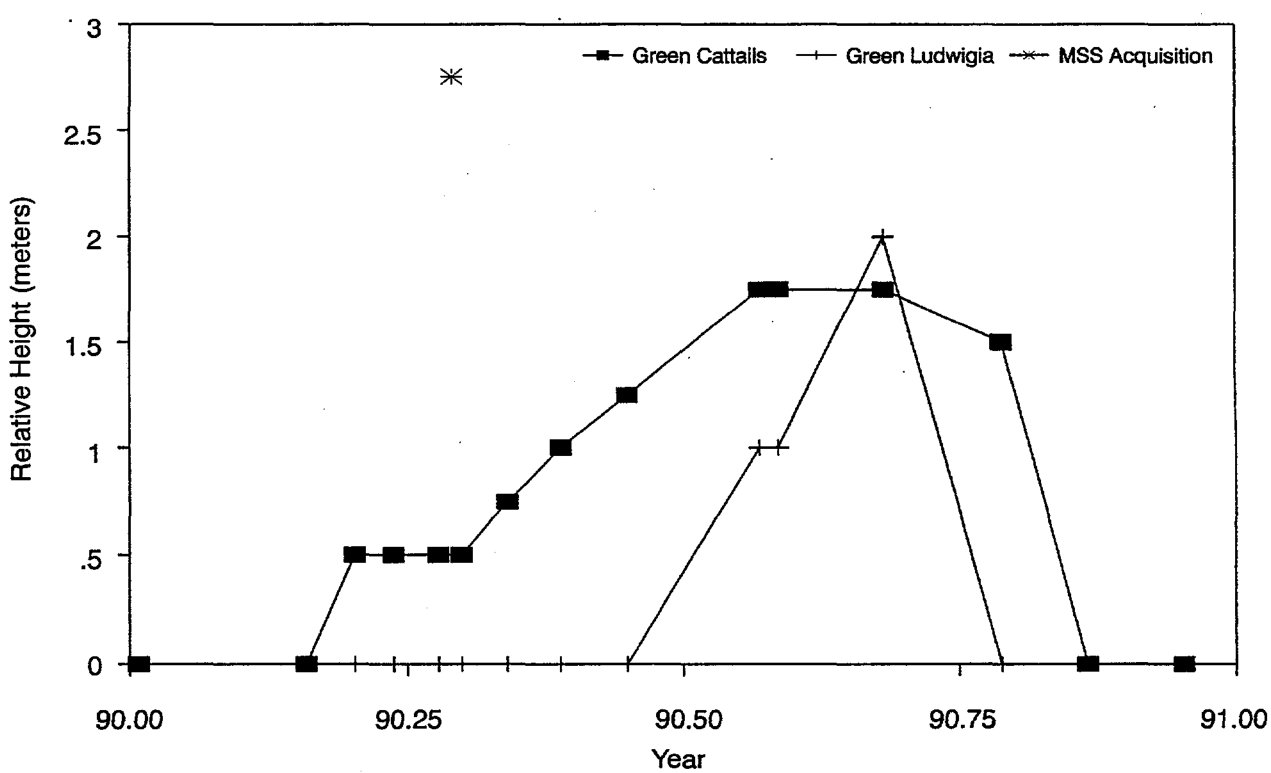

FIGURE 26. ***1990 GREEN PLANT PHENOLOGY GRAPH***

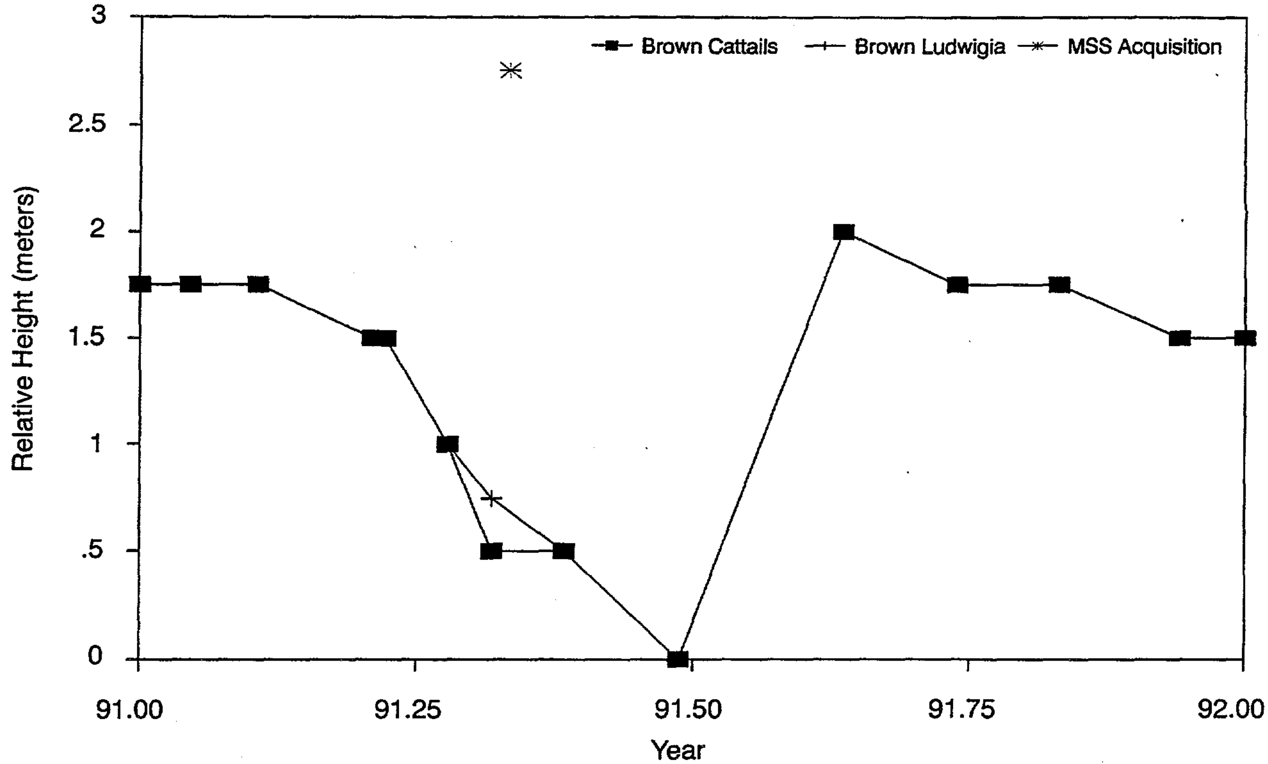

FIGURE 27. ***1991 BROWN PLANT PHENOLOGY GRAPH***

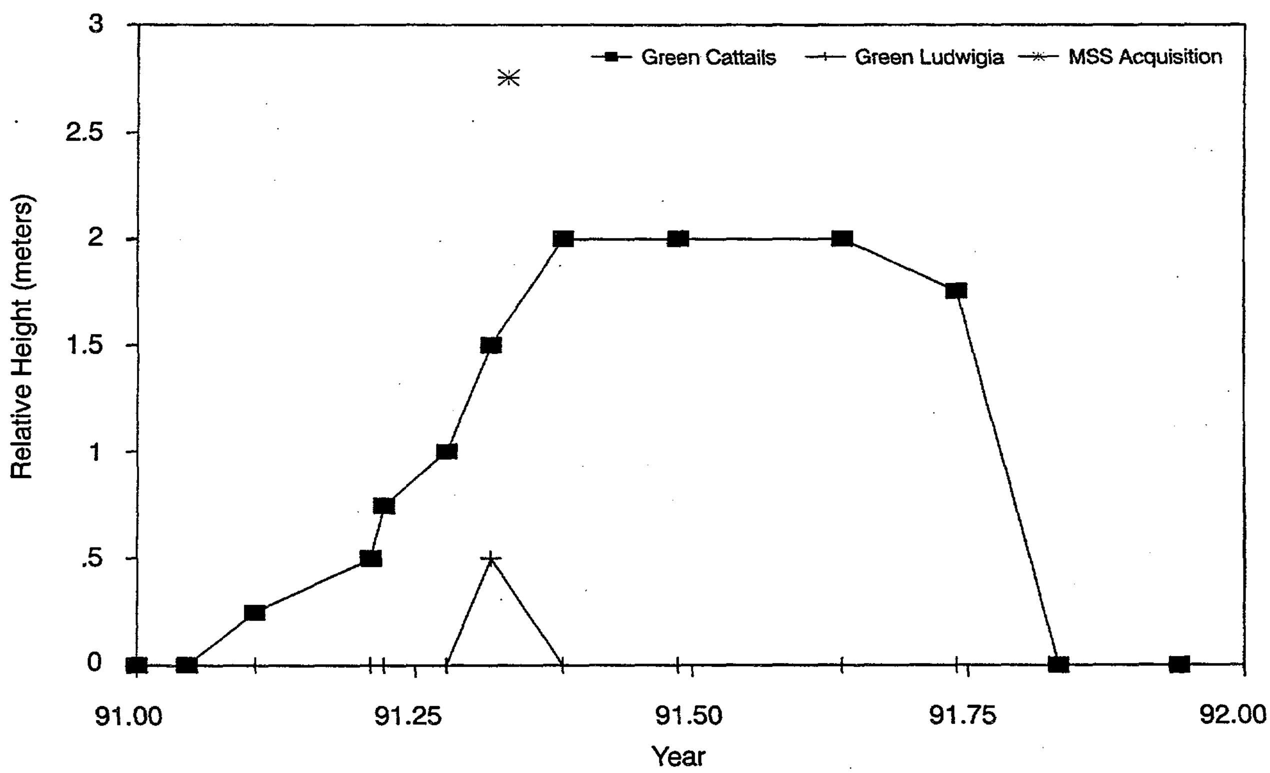

FIGURE 28. ***1991 GREEN PLANT PHENOLOGY GRAPH***

Table 8. Information Classes Used in Imagery Classification
Bottomland Hardwood Forest
Cypress/Tupelo Swamp Forest
Deep Water
Shallow Water
Cattails
Willow
Shrub/Scrub
Ludwigia
Mudflat
Duckweed
Bare Soil

acquisition. Therefore, the corridor and delta should be very wet, with a corresponding effect on vegetation. The corresponding phenology graphs, Figures 19 and 20, show that cattails and Ludwigia were not very well developed at the time of MSS acquisition (see also Mackey, 1990).

As described previously, the delta/river polygon used for image classification contained the entire delta and extended to the Savannah River. To limit this study to only that part of the delta influenced by reactor operations, it was necessary to further subset the delta/river dataset into a smaller dataset containing only the immediate Pen Branch delta. Because the delta was almost uniformly flooded in 1987 due to Savannah River and reactor flow rates, the classified 1987 image was used to create a delta mask that contained only the immediate Pen Branch delta. The delta acreages that are reported in this and the following sections correspond to this subsectioned delta polygon (shown in Figure 29).

The classified 1987 image is shown in Figure 30. The corresponding acreage values for the corridor, delta, and corridor and delta combined, including the buffer, are shown in Tables 9, 10, and 11, respectively, and in Figures 31, 32, and 33, respectively. The acreage values for the corridor and corridor and delta combined, excluding the buffer, are shown in Tables 12 and 13, respectively, and in Figures 34 and 35, respectively. For the corridor, the five largest classes are bottomland hardwood (47%), deep water (25%), willow (11%), shallow water (10%), and mudflat (4%). In the delta, the five largest classes are

FIGURE 29. *SUBSECTIONED DELTA POLYGON*

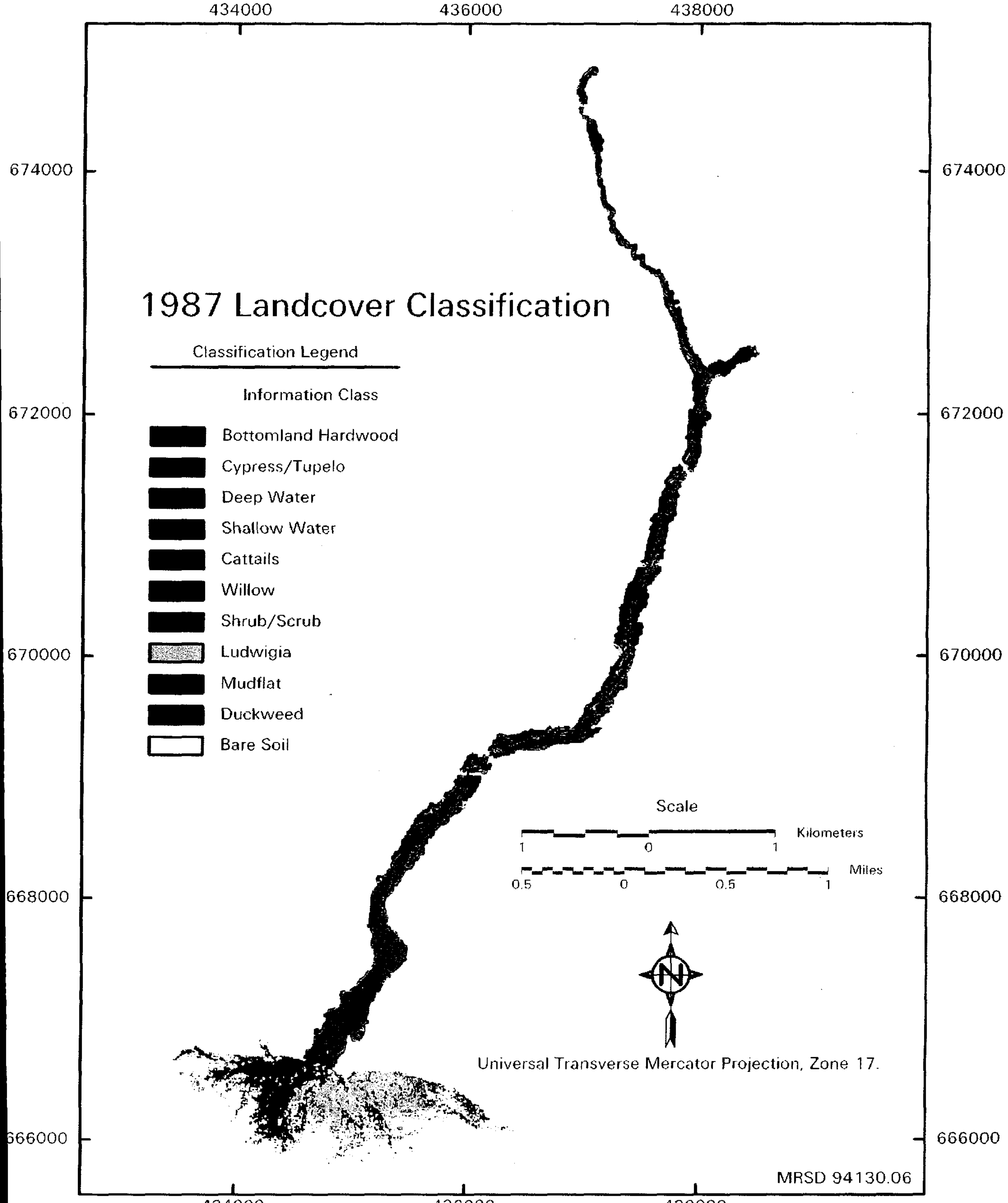

FIGURE 30. ***1987 CLASSIFICATION IMAGE***

Table 9. Corridor Acreages - With Buffer					
Class	**1987**	**1988**	**1989**	**1990**	**1991**
Hardwood	165.40	167.81	181.85	194.42	223.56
Cypress	0	0	0	0	0
Deep Water	87.05	40.39	46.68	52.32	30.45
Shallow Water	35.58	0	0	0	5.58
Cattails	0	0	0	0	1.72
Willow	38.23	29.24	44.95	51.02	62.61
Shrub/Scrub	0	0	20.85	0	0
Ludwigia	0	33.60	25.21	19.76	0
Mudflat	14.84	74.33	26.59	30.08	21.36
Duckweed	1.07	0	0	0	0
Baresoil	6.52	3.33	2.56	1.08	3.41
Total	**348.69**	**348.70**	**348.69**	**348.68**	**348.69**

Table 10. Delta Acreages					
Class	**1987**	**1988**	**1989**	**1990**	**1991**
Hardwood	0	0.10	1.36	0.44	0.89
Cypress	0	16.73	25.39	22.09	0
Deep Water	1.08	21.10	6.82	23.50	8.49
Shallow Water	113.46	74.43	41.46	0	40.86
Cattails	16.17	0	12.64	44.36	97.92
Willow	0	0	0	0	83.99
Shrub/Scrub	7.58	14.40	17.91	19.95	0
Ludwigia	76.02	102.97	128.74	112.12	0
Mudflat	0	0	0	0	0
Duckweed	20.00	4.59	0	0	2.13
Baresoil	0	0	0	0	0
Total	**234.31**	**234.32**	**234.32**	**222.46**	**234.28**

Table 11. Combined Acreages – With Corridor Buffer					
Class	**1987**	**1988**	**1989**	**1990**	**1991**
Hardwood	165.40	167.91	183.21	194.86	224.45
Cypress	0	16.73	25.39	22.09	0
Deep Water	88.13	61.49	53.50	75.82	38.94
Shallow Water	149.04	74.43	41.46	0	46.44
Cattails	16.17	0	12.64	44.36	99.64
Willow	38.23	29.24	44.95	51.02	146.60
Shrub/Scrub	7.58	14.40	38.76	19.95	0
Ludwigia	76.02	136.57	153.95	131.88	0
Mudflat	14.84	74.33	26.59	30.08	21.36
Duckweed	21.07	4.59	0	0	2.13
Baresoil	6.52	3.33	2.56	1.08	3.41
Total	**583.00**	**583.02**	**583.01**	**571.14**	**582.97**

shallow water (48%), Ludwigia (32%), duckweed (9%), cattails (7%), and shrub/scrub (3%). These values are consistent with a very wet corridor and delta, with suppressed vegetation growth.

5.2 1988 Classification

The Savannah River and Pen Branch flow rates are shown in Figures 10 and 15, respectively. The phenology graphs for 1988 are shown in Figures 21 and 22. The flow of the Savannah River was much lower than in 1987, and the reactor output flow was reduced approximately 3 weeks prior to the MSS acquisition, as K Reactor was shut down. The phenology graph shows that at the time of acquisition, the green vegetation component was almost matched by that of the dead brown vegetation from 1987. In this case, the scanner was probably viewing both living and dead vegetation. While the scanner can often differentiate living vegetation types, it is very difficult to distinguish between different dead brown vegetation types.

The 1988 classified image is shown in Figure 36. The corresponding acreage values for the corridor, delta, and corridor and delta combined, including the buffer, are shown in Tables 9, 10, and 11, respectively, and in Figures 31, 32, and 33, respectively. The acreage values for the corridor and corridor and

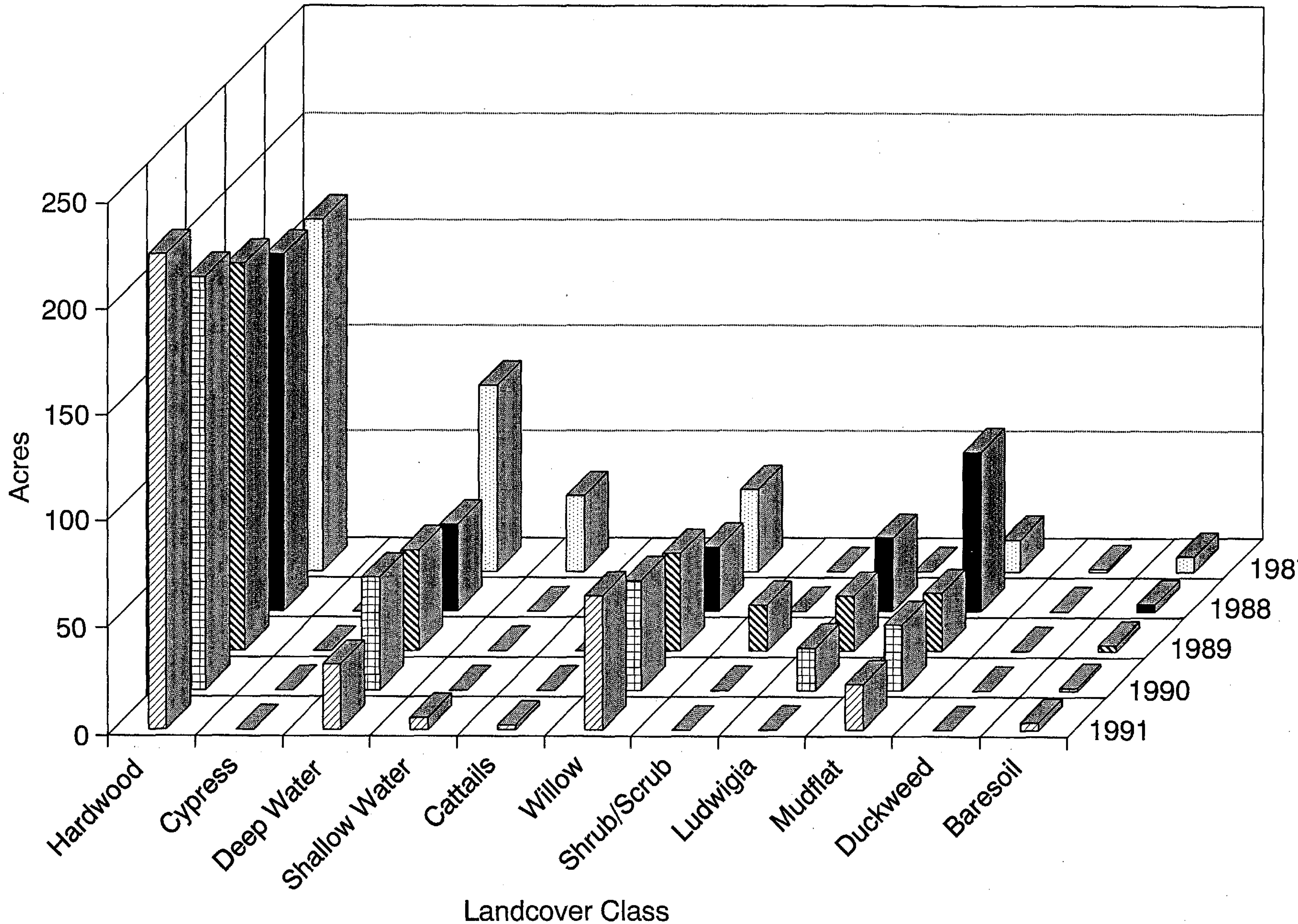

FIGURE 31. *PEN BRANCH CORRIDOR CLASS ACREAGES, INCLUDING BUFFER*

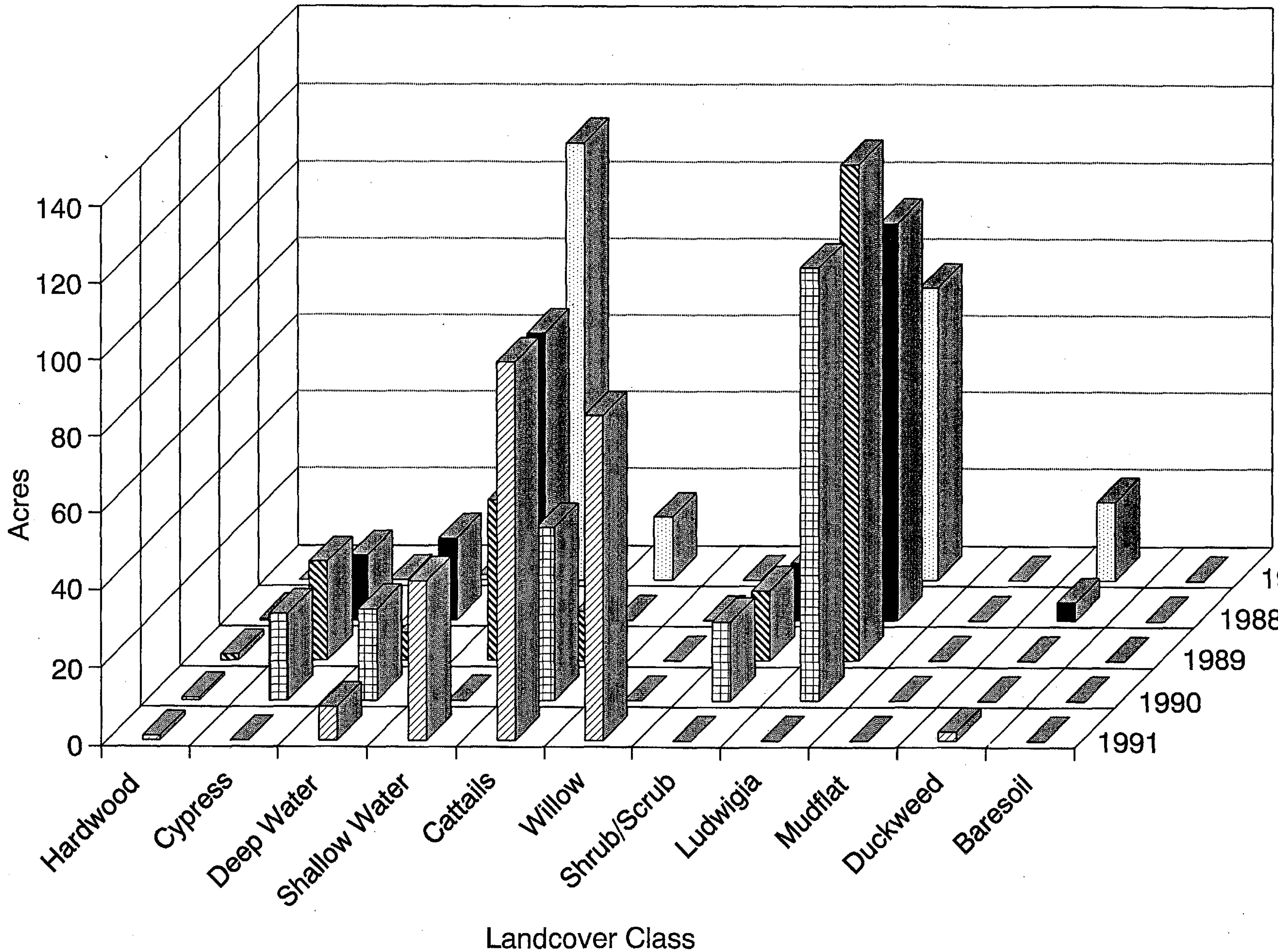

FIGURE 32. *PEN BRANCH DELTA CLASS ACREAGES, INCLUDING BUFFER*

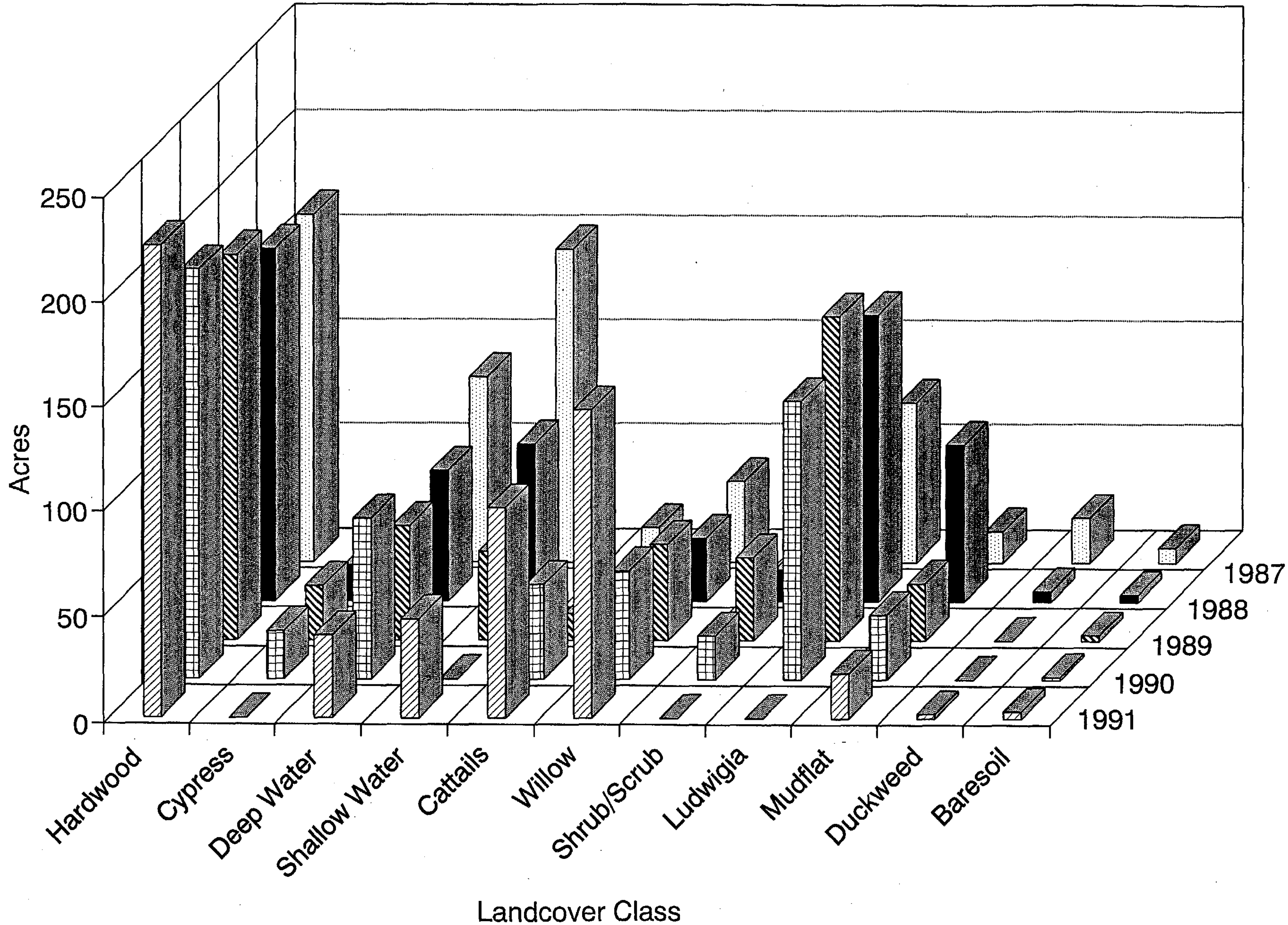

FIGURE 33. ***PEN BRANCH COMBINED CORRIDOR AND DELTA CLASS ACREAGES, INCLUDING BUFFER***

Table 12. Corridor Acreages – Excluding Buffer					
Class	**1987**	**1988**	**1989**	**1990**	**1991**
Hardwood	105.05	107.08	130.27	137.82	161.86
Cypress	0	0	0	0	0
Deep Water	81.72	37.83	41.86	42.64	28.27
Shallow Water	34.04	0	0	0	5.24
Cattails	0	0	0	0	1.65
Willow	33.96	25.91	34.54	46.88	55.10
Shrub/Scrub	0	0	17.82	0	0
Ludwigia	0	32.03	23.84	18.22	0
Mudflat	14.64	69.38	24.64	28.08	20.02
Duckweed	0.95	0	0	0	0
Baresoil	4.03	2.15	1.41	0.74	2.23
Total	**274.39**	**274.38**	**274.38**	**274.38**	**274.37**

Table 13. Combined Acreages – Excluding Corridor Buffer					
Class	**1987**	**1988**	**1989**	**1990**	**1991**
Hardwood	105.05	107.18	131.63	138.26	162.75
Cypress	0	16.73	25.39	22.09	0
Deep Water	82.80	58.93	48.68	66.14	36.76
Shallow Water	147.50	74.43	41.46	0	46.10
Cattails	16.17	0	12.64	44.36	99.57
Willow	33.96	25.91	34.54	46.88	139.09
Shrub/Scrub	7.58	14.40	38.76	19.95	0
Ludwigia	76.02	135.00	152.58	130.34	0
Mudflat	14.64	69.38	24.64	28.08	20.02
Duckweed	20.95	4.59	0	0	2.13
Baresoil	4.03	2.15	1.41	0.74	2.23
Total	**508.70**	**508.70**	**508.70**	**496.84**	**508.65**

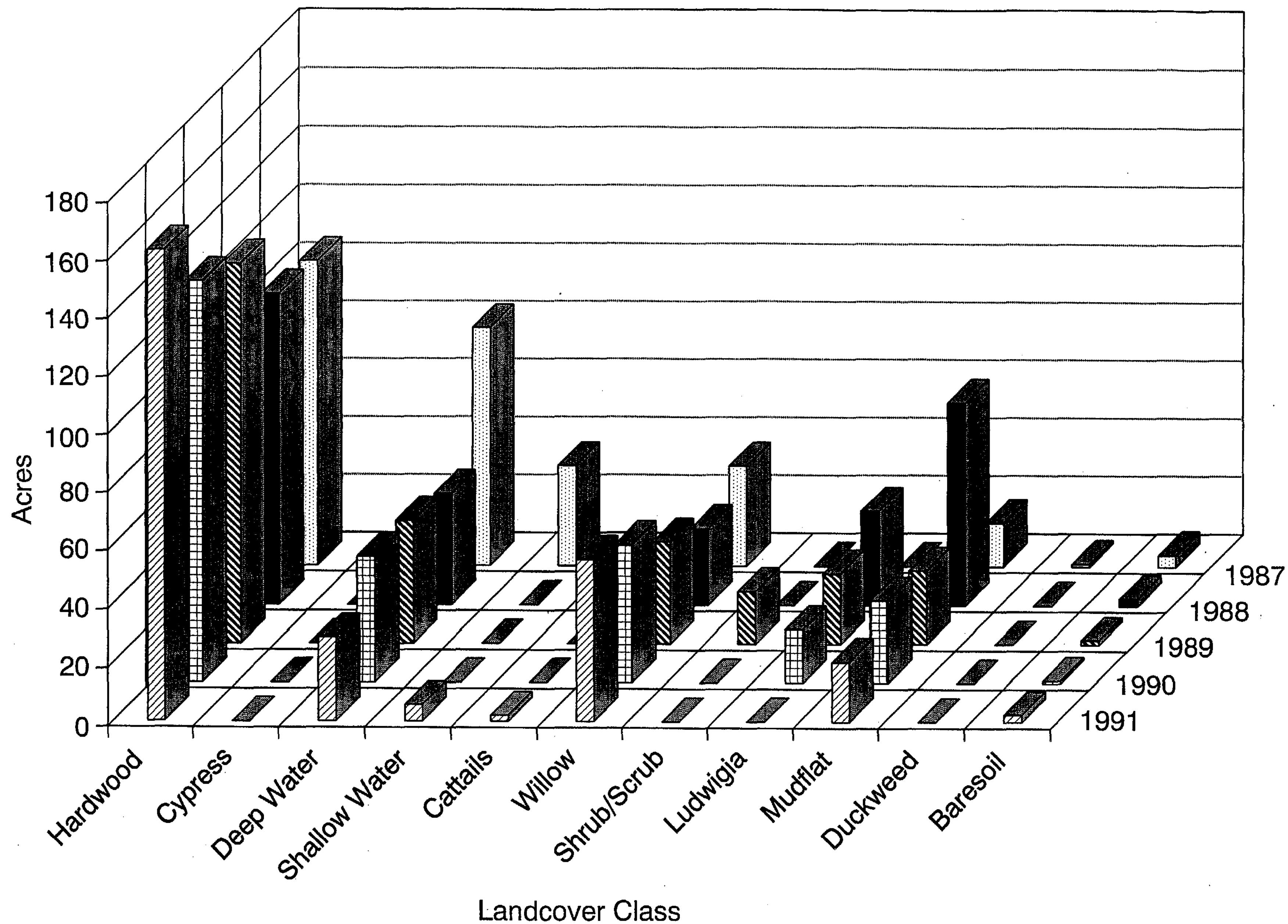

FIGURE 34. ***PEN BRANCH CORRIDOR CLASS ACREAGES, EXCLUDING BUFFER***

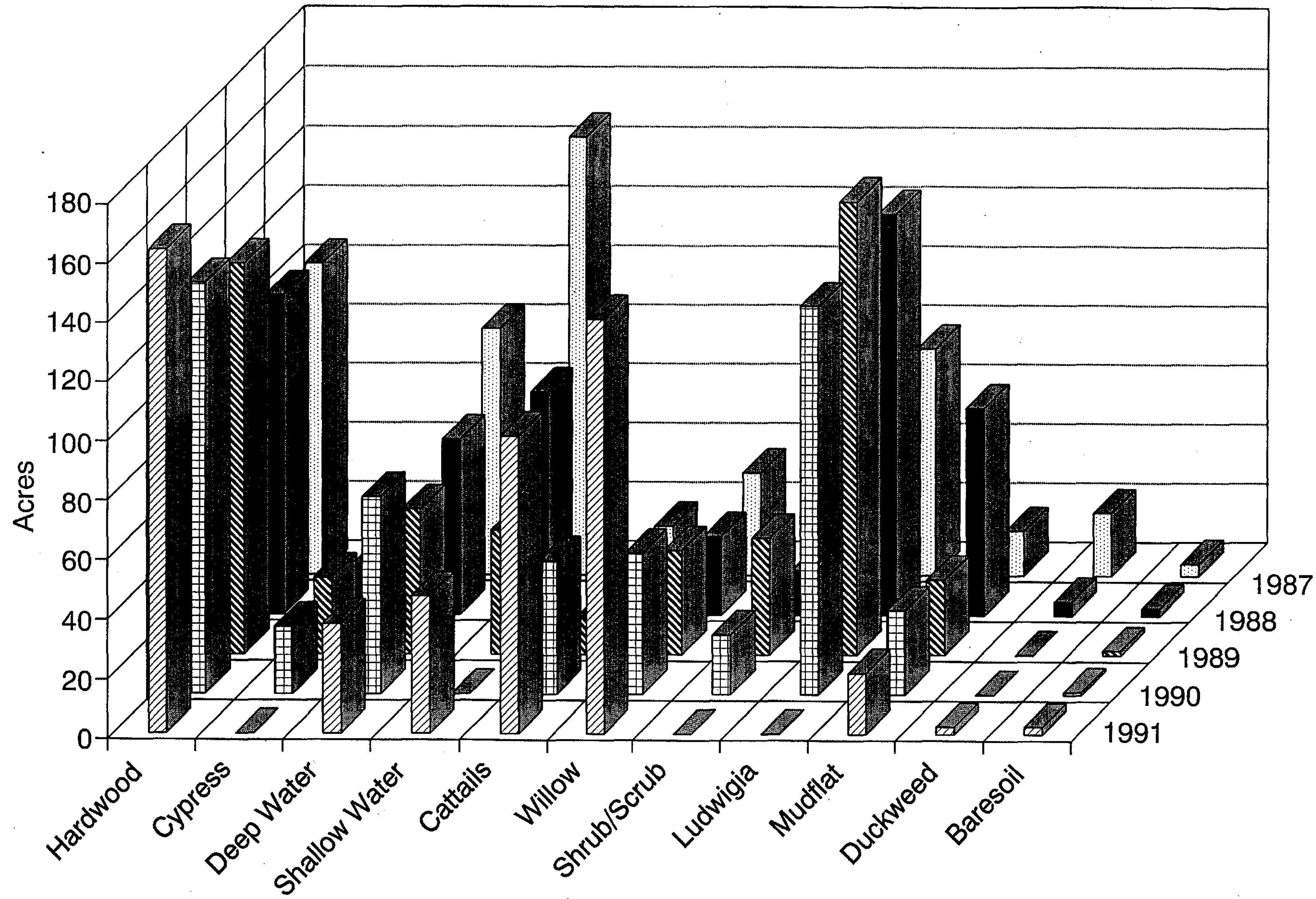

FIGURE 35. ***PEN BRANCH COMBINED CORRIDOR AND DELTA CLASS ACREAGES, EXCLUDING BUFFER***

delta combined, excluding the buffer, are shown in Tables 12 and 13, respectively, and in Figures 34 and 35, respectively. For the corridor, the five largest classes are bottomland hardwood (48%), mudflat (21%), deep water (12%), Ludwigia (10%), and willow (8%). For the delta, the five largest classes are Ludwigia (44%), shallow water (32%), deep water (9%), cypress/tupelo (7%), and shrub/scrub (6%). These values show that the corridor and delta have begun to dry, as evidenced by the decreased amounts of deep and shallow water, but that the vegetation has not really had time to recover by the time of the MSS acquisition.

5.3 1989 Classification

The Savannah River and Pen Branch flow rates for 1989 are shown in Figures 11 and 16, respectively. The phenology graphs for 1989 are shown in Figures 23 and 24. The Savannah River flow for 1989 remained low for the most part, and the Pen Branch flow remained low. As the phenology graph shows, no disruptive flooding occurred to knock down or wash away the dead vegetation from the previous year; as a result, the dead vegetation is almost more dominant than the living vegetation at the time of MSS acquisition. The brown vegetation is primarily Ludwigia from the previous year. Because of the dramatic increase in dryness in the delta and corridor in 1989, there was a transient invasion by another species. The delta and corridor were dry enough to allow dog fennel to develop. Because this was limited to a single year flush of the species, it was not included as a separate vegetation cover type, and is mostly contained within the reported Ludwigia acreage.

The 1989 classified image is shown in Figure 37. The corresponding acreage values for the corridor, delta, and corridor and delta combined, including the buffer, are shown in Tables 9, 10, and 11, respectively, and in Figures 31, 32, and 33, respectively. The acreage values for the corridor and corridor and delta combined, excluding the buffer, are shown in Tables 12 and 13, respectively, and in Figures 34 and 35, respectively. In the corridor, the five largest classes are bottomland hardwood (52%), deep water (13%), willow (13%), mudflat (8%), and Ludwigia (7%). For the delta, the five largest classes are Ludwigia (55%), shallow water (18%), cypress/tupelo (11%), shrub/scrub (8%), and cattails (5%). As mentioned previously, the acreage value reported for Ludwigia in the delta contains a significant proportion of dog fennel. Because of the presence of so much dead vegetation, there is probably some confusion occurring between the dead Ludwigia and dead cattails in the delta (see also Mackey, 1990). These

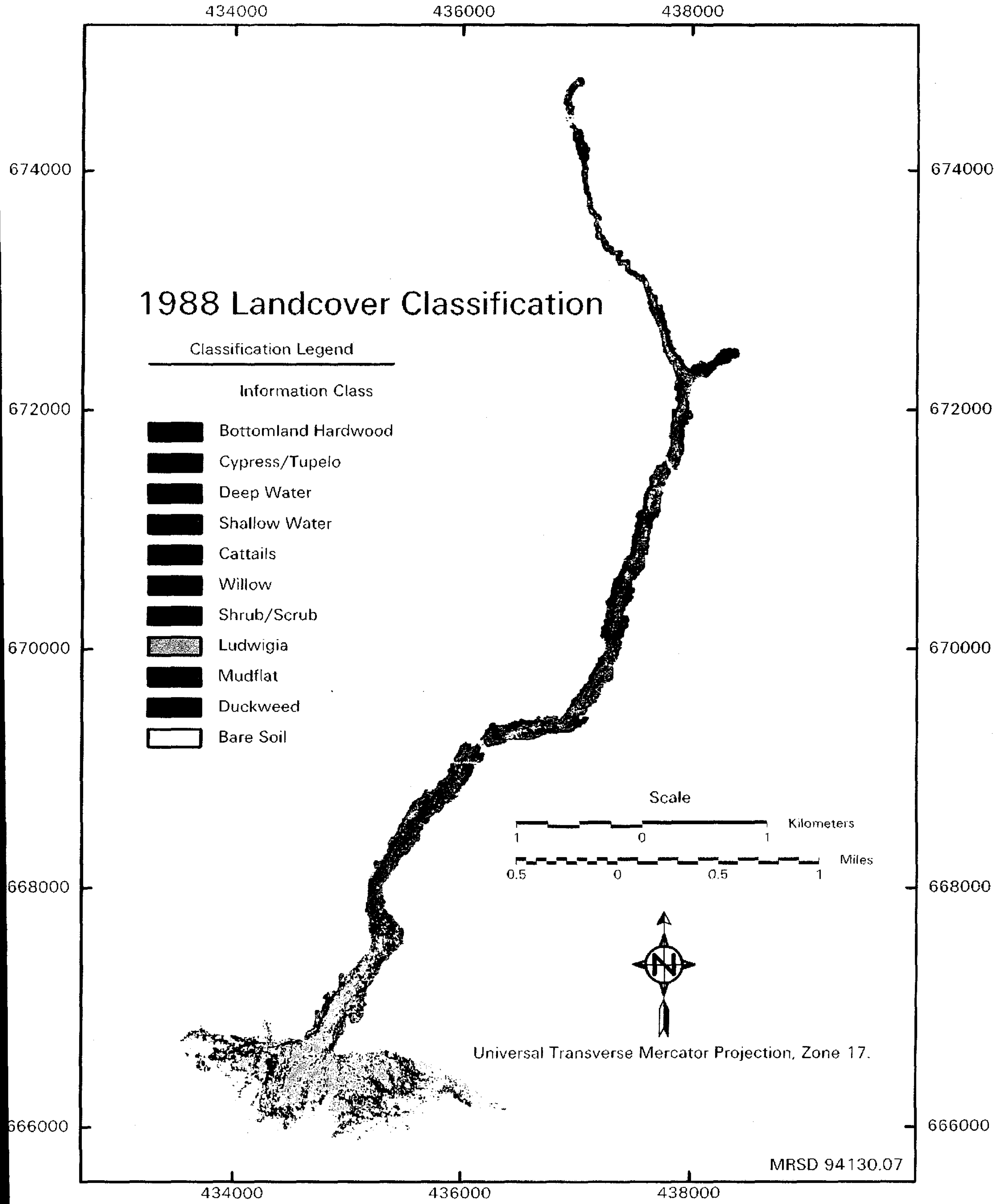

FIGURE 36. ***1988 CLASSIFICATION IMAGE***

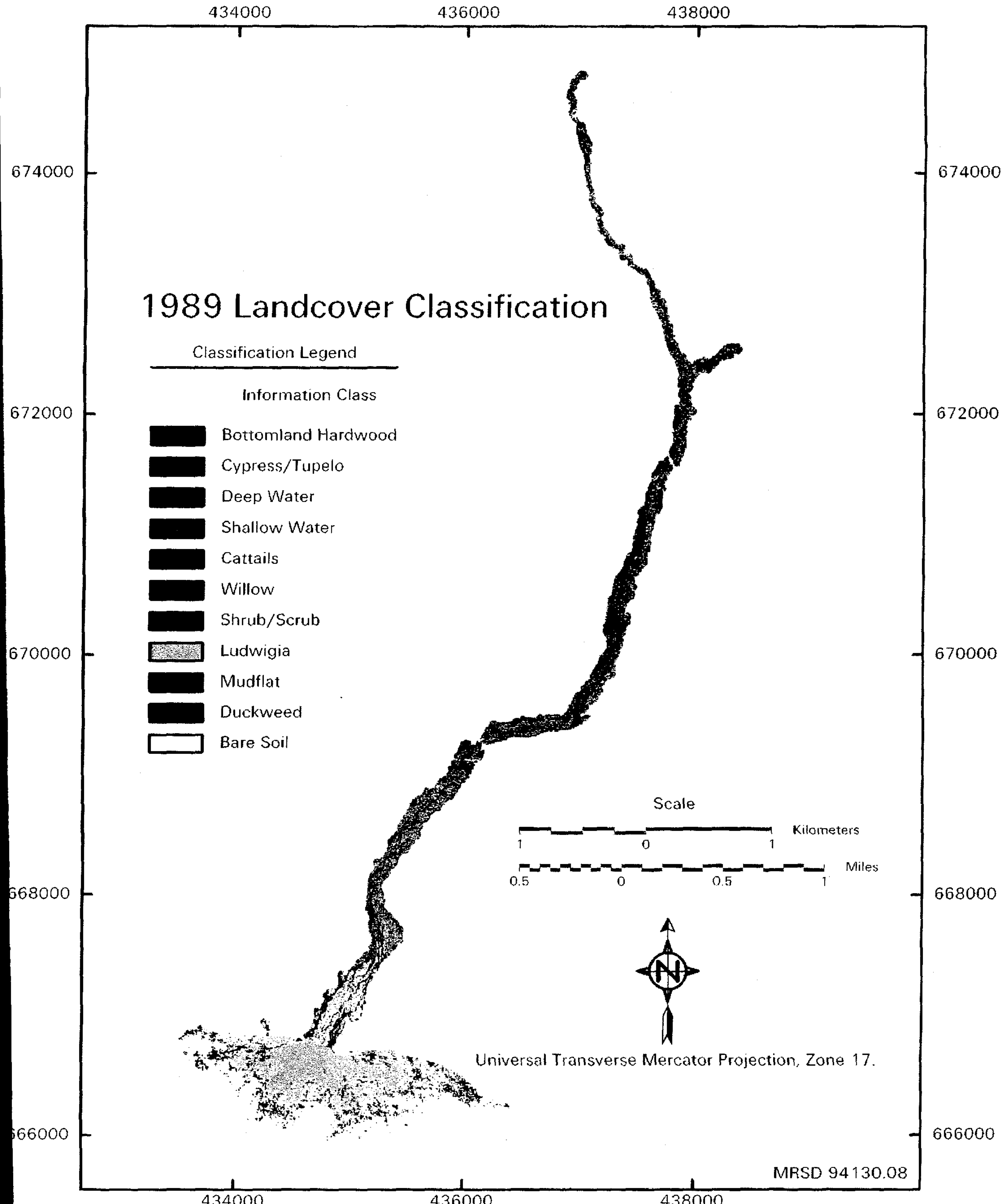

FIGURE 37. ***1989 CLASSIFICATION IMAGE***

acreage values show that as the delta and corridor continued to dry, the non-persistent vegetation began to increase in the delta, while the water and mudflat classes continued to decline.

5.4 1990 Classification

The Savannah River and Pen Branch flow rates are shown in Figures 12 and 17, respectively. The phenology graphs for 1990 are shown in Figures 25 and 26. In 1990, there was increased flow and flooding in the Savannah River throughout the entire spring prior to the MSS acquisition. There was also increased Pen Branch flow approximately one month before the acquisition. However, the phenology graph shows that the increased river flow was, once again, not enough to eliminate the dead brown vegetation from the previous year. The graph shows that the vegetation recorded by the scanner is probably composed mostly of dead vegetation, and most of the live vegetation is cattails. As a result of the invasion by dog fennel in 1989, much of the brown vegetation was probably dead dog fennel from 1989.

The classified image for 1990 is shown in Figure 38. The corresponding acreage values for the corridor, delta, and corridor and delta combined, including the buffer, are shown in Tables 9, 10, and 11, respectively, and in Figures 31, 32, and 33, respectively. The acreage values for the corridor and corridor and delta combined, excluding the buffer, are shown in Tables 12 and 13, respectively, and in Figures 34 and 35, respectively. The five largest classes in the corridor are bottomland hardwood (56%), willow (15%), deep water (15%), mudflat (9%), and Ludwigia (6%). In the delta, the five largest classes are Ludwigia (57%), cattails (10%), deep water (10%), cypress/tupelo (9%), and shrub/scrub (8%). Once again, the Ludwigia acreage undoubtedly contains a significant amount of dead brown dog fennel from 1989. The sensitivity of the MSS data to wetness conditions is shown by the increases in deep water acreages in both the delta and corridor. For the most part, the corridor and delta continue to dry, allowing non-persistent species such as Ludwigia to continue to expand. As the drying has continued, more persistent species have begun to become established as well, such as cattails, willow, and shrub/scrub. The confusion between dead vegetation types continues, however, and the large amount of Ludwigia present in the delta probably has a significant component of dead cattails hidden within it, which can not be spectrally separated due to the confusion.

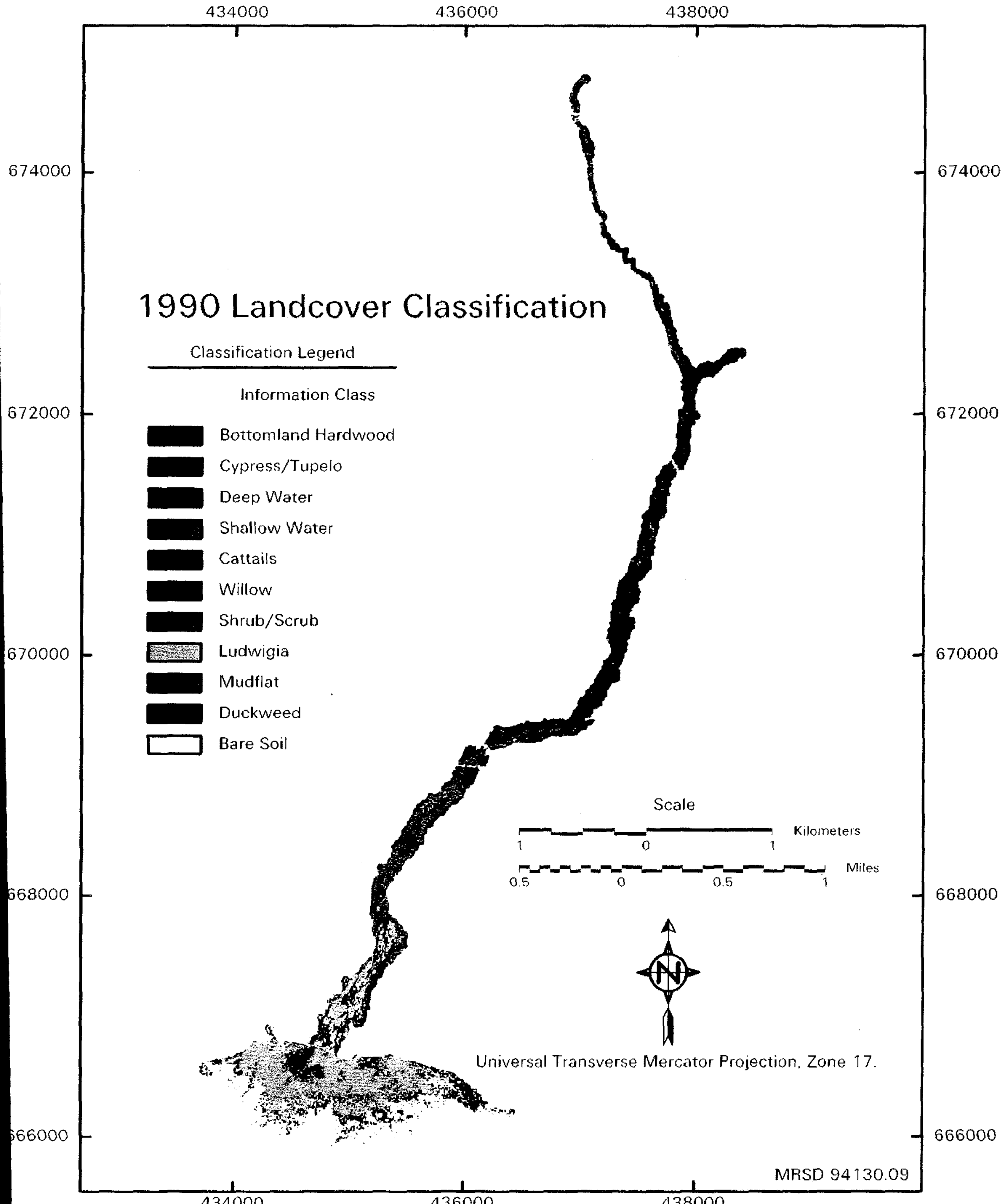

FIGURE 38. ***1990 CLASSIFICATION IMAGE***

5.5 1991 Classification

The Savannah River and Pen Branch flow rates are shown in Figures 13 and 18, respectively. The phenology graphs for 1991 are shown in Figures 27 and 28. The Savannah River flow ranged from low to large floods in the spring of 1991, with fairly high flow immediately prior to the MSS acquisition. Test runs at K Reactor also caused some high reactor output flows during the spring and just prior to the acquisition. The phenology graph shows that cattails replaced former areas occupied by Ludwigia. The dead brown vegetation appears much less prominent for 1991 than for the previous two years, and has about equal components of cattail and Ludwigia.

The classified image for 1991 is shown in Figure 39. The corresponding acreage values for the corridor, delta, and corridor and delta combined, including the buffer, are shown in Tables 9, 10, and 11 respectively, and in Figures 31, 32, and 33, respectively. The acreage values for the corridor and corridor and delta combined, excluding the buffer, are shown in Tables 12 and 13, respectively, and in Figures 34 and 35, respectively. The five largest classes in the corridor are bottomland hardwood (64%), willow (18%), shrub/scrub (10%), deep water (9%), and mudflat (6%). For the delta, the five largest classes are willow (36%), cattails (32%), shallow water (17%), shrub/scrub (9%), and deep water (4%). The increase in water class acreages again shows the MSS sensitivity to the flooding indicated by the flow graphs. In 1991 two major displacements occurred. Ludwigia was extensively replaced by cattails and willow. Expansion of shrub/scrub (primarily willow) occurred in the delta, and willow also expanded in the corridor. The nonpersistent vegetation was replaced by persistent and more permanent vegetation, which had an opportunity to become established due to the decrease in disruptive flooding and thermal discharges.

Tables 9 through 13 illustrate the fluctuation in cypress acreages during the 1987-1991 period. Since cypress should be a successionally mature species, and therefore more stable, these fluctuations are probably due to slight misregistration. These acres occur at the extreme southern edge of the delta polygon. Because the registration effort was concentrated on the corridor and the main portion of the delta, the registration fit is probably not as precise for the 1988, 1989, and 1990 datasets at the southern edge of the delta. This slight shifting caused some of the cypress pixels outside the delta polygon to be included inside the polygon for the years affected. Since the affected acreages account for less than five percent of the total, and occur at the extreme edge of the polygon, they should not impact the overall results of this study.

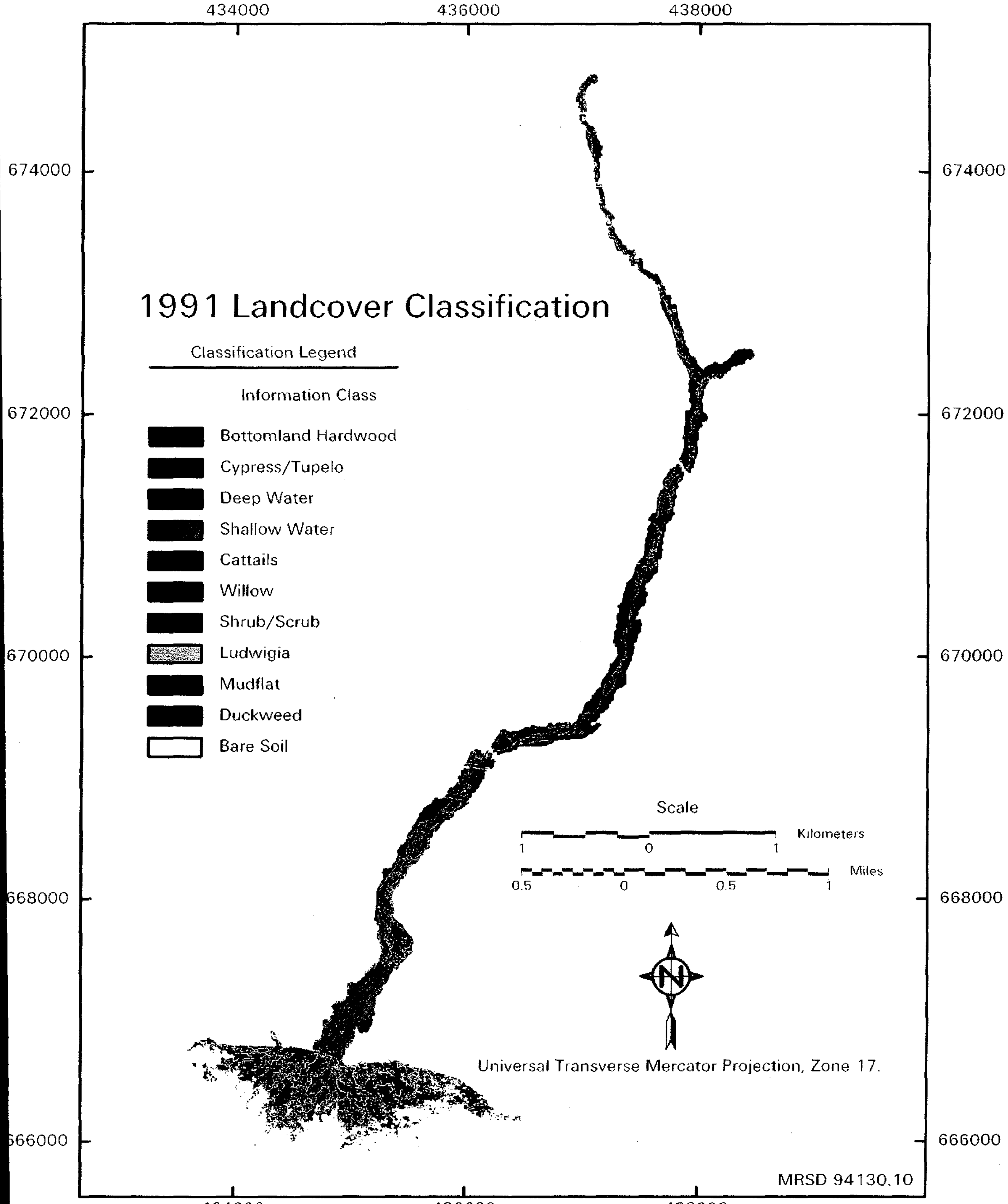

FIGURE 39. ***1991 CLASSIFICATION IMAGE***

5.6 Analysis of Change

The figures and tables in the five previous sections indicate the changes in Pen Branch over the period 1987 to 1991. However, they do not show the specific nature of these changes. The use of geo-referenced scanner data for this study allows the monitoring of each individual pixel over the duration of the study. This type of study allows the change processes occurring in a wetlands environment such as Pen Branch to be monitored in two directions at once. It is possible to examine a class that has increased in size by 1991, such as hardwoods, and determine what information classes the additional acres have come from. This shows what has changed from 1987 to become hardwood in 1991. Likewise, it is possible to examine a class that has decreased in size by 1991, such as shallow water, and determine what information classes those acres have changed to by 1991. This shows what has changed from 1987 shallow water to become something else in 1991.

Tables 14, 15, and 16 show the acreage values for each information class for 1987 and 1991 for the corridor, the delta, and the corridor and delta combined, respectively. These tables represent a change matrix between 1987 and 1991. At the base of each column, the total number of acres for each information class present in 1991 is shown. The entries contained in each column show the 1987 information class that changed to become the 1991 information class in each particular column. For example, Table 14 shows that there were 223.55 acres of bottomland hardwood present in 1991. Of these, 146.01 acres originated as 1987 hardwood, 37.23 acres changed from 1987 deep water, 6.70 acres changed from 1987 shallow water, 27.26 acres changed from 1987 willow, 1.89 acres changed from 1987 mudflat, 0.18 acres changed from 1987 duckweed, and 4.28 acres changed from 1987 baresoil. All of these acres that have changed from 1987 sum up to the 223.55 acres of bottomland hardwood present in 1991. At the end of each row, the total number of acres for each information class present in 1987 is shown. The entries in each row show what the 1987 information class acreages changed to in 1991. For example, the first row of Table 14 shows that there were 165.40 acres of bottomland hardwood in 1987. Of these acres, 146.01 remained bottomland hardwood in 1991, 2.91 acres changed to 1991 deep water, 0.12 acres changed to 1991 shallow water, 13.79 acres changed to 1991 willow, 1.95 acres changed to 1991 mudflat, and 0.59 acres changed to 1991 baresoil. All of these acres that have changed to another information class in 1991 sum up to the 165.40 bottomland hardwood acres that originally were present in 1987. In this way, the columns of the tables show how 1987 information classes have changed to 1991 information classes, and the rows of the tables show how 1991 information classes have changed from 1987 information classes.

Table 14. Acreage Change Matrix for Corridor Only – With Buffer

1987	1991											
Class	Hardwood	Cypress	Deep Water	Shallow Water	Cattail	Willow	Scrub/ Shrub	Ludwigia	Mudflat	Duckweek	Baresoil	**Total**
Hardwood	146.01	0	2.91	0.12	0.03	13.79	0	0	1.95	0	0.59	**165.40**
Cypress	0	0	0	0	0	0	0	0	0	0	0	**0.0**
Deep Water	37.23	0	15.15	1.43	0.41	24.75	0	0	7.04	0	1.04	**87.05**
Shallow Water	6.70	0	7.53	2.53	0.37	12.70	0	0	5.59	0	0.17	**35.59**
Cattail	0	0	0	0	0	0	0	0	0	0	0	**0.0**
Willow	27.26	0	1.84	0.26	0.39	6.46	0	0	1.69	0	0.33	**38.23**
Scrub/Shrub	0	0	0	0	0	0	0	0	0	0	0	**0.0**
Ludwigia	0	0	0	0	0	0	0	0	0	0	0	**0.0**
Mudflat	1.89	0	2.62	0.15	0.46	4.33	0	0	4.36	0	0	**14.81**
Duckweed	0.18	0	0.32	0.04	0.03	0.14	0	0	0.26	0	0.10	**1.07**
Baresoil	4.28	0	0.08	0.06	0.03	0.44	0	0	0.47	0	1.16	**6.52**
Total	**223.55**	**0.0**	**30.45**	**5.59**	**1.72**	**62.61**	**0.0**	**0.0**	**21.36**	**0.0**	**3.39**	

Table 15. Acreage Change Matrix for Delta Only

1987	1991											
Class	Hardwood	Cypress	Deep Water	Shallow Water	Cattail	Willow	Scrub/ Shrub	Ludwigia	Mudflat	Duckweek	Baresoil	**Total**
Hardwood	0	0	0	0	0	0	0	0	0	0	0	**0.0**
Cypress	0	0	0	0	0	0	0	0	0	0	0	**0.0**
Deep Water	0	0	0.19	0.24	0.21	0.43	0	0	0	0.01	0	**1.08**
Shallow Water	0.28	0	3.86	20.55	44.41	43.03	0	0	0	1.32	0	**113.45**
Cattail	0.43	0	1.07	0.98	3.76	9.92	0	0	0	0.01	0.01	**16.18**
Willow	0	0	0	0	0	0	0	0	0	0	0	**0.0**
Scrub/Shrub	0.08	0	0.78	1.17	1.55	3.96	0	0	0	0.04	0	**7.58**
Ludwigia	0.10	0	2.22	13.07	38.66	22.04	0	0	0	0.53	0	**76.02**
Mudflat	0	0	0	0	0	0	0	0	0	0	0	**0.0**
Duckweed	0	0	0.37	4.86	9.94	4.62	0	0	0	0.22	0	**20.01**
Baresoil	0	0	0	0	0	0	0	0	0	0	0	**0.0**
Total	**0.89**	**0.0**	**8.49**	**40.87**	**97.93**	**84.00**	**0.0**	**0.0**	**0.0**	**2.13**	**0.01**	

Table 16. Acreage Change Matrix for Corridor and Delta With Buffer

1987	1991											
Class	Hardwood	Cypress	Deep Water	Shallow Water	Cattail	Willow	Scrub/ Shrub	Ludwigia	Mudflat	Duckweek	Baresoil	**Total**
Hardwood	146.01	0	2.91	0.12	0.03	13.79	0	0	1.95	0	0.59	**165.40**
Cypress	0	0	0	0	0	0	0	0	0	0	0	**0.0**
Deep Water	37.23	0	15.34	1.67	0.62	25.18	0	0	7.04	0.01	1.04	**88.13**
Shallow Water	6.98	0	11.39	23.08	44.78	55.73	0	0	5.59	1.32	0.17	**149.04**
Cattail	0.43	0	1.07	0.98	3.76	9.92	0	0	0	0.01	0.01	**16.18**
Willow	27.26	0	1.84	0.26	0.39	6.46	0	0	1.69	0	0.33	**38.23**
Scrub/Shrub	0.08	0	0.78	1.17	1.55	3.96	0	0	0	0.04	0	**7.58**
Ludwigia	0.10	0	2.22	13.07	38.06	22.04	0	0	0	0.53	0	**76.02**
Mudflat	1.89	0	2.62	1.15	0.46	4.33	0	0	4.36	0	0	**14.81**
Duckweed	0.18	0	0.69	4.90	9.97	4.76	0	0	0.26	0.22	0.1	**21.08**
Baresoil	4.28	0	0.08	0.06	0.03	0.44	0	0	0.47	0	1.16	**6.52**
Total	**224.44**	**0.0**	**38.94**	**46.46**	**99.65**	**146.61**	**0.0**	**0.0**	**21.36**	**2.13**	**3.4**	**–**

Some of the transitions shown in Tables 14, 15, and 16 are undoubtedly caused by sources other than the ecological changes occurring in the study area. For example, Table 16 indicates that 27.26 acres of 1987 willow have changed to 1991 hardwood, which is an expected result. However, the table also indicates that 13.79 acres of 1987 hardwood changed to 1991 willow, which is the reverse of the expected trend. This is probably due to willow becoming more physiologically and spectrally similar to hardwood as it matures, resulting in spectral confusion and some misclassification. Another example is 4.28 acres of 1987 baresoil becoming 1991 hardwood. This is an unlikely situation, as it would probably take longer than the time period in this study to transition from baresoil to hardwood stands. Since the baresoil in this area tends to occur in small patches, this erroneous transition is probably the result of either slight misregistration or spectrally mixed pixels.

In most cases of illogical transitions, the affected acres are almost always fewer than 2 acres, and usually less than 1 acre. Since this is such a small percentage of the total acres involved in this study, these acres are insignificant.

Figures 40 and 41 are graphical representations of Table 16. The colors of the stacked bars correspond to the classification images shown in the previous sections. Figure 40 shows how the acreages present in 1991 changed from other 1987 information classes. For example, the leftmost bar in Figure 40 shows what other 1987 information classes contributed to the 224.44 acres of bottomland hardwood present in 1991. These are the acres of other 1987 classes that changed to 1991 bottomland hardwood. In contrast, Figure 41 shows what the 1987 information classes changed to in 1991. The leftmost bar in Figure 41 shows what the 165.40 acres of bottomland hardwood present in 1987 changed to in other 1991 information classes. Figures 42 and 43 are enlarged portions of Figures 40 and 41, respectively, to show the smaller information classes in more detail.

Figures 40 through 43 show how the information class acreages changed from 1987 to 1991. One final piece of information that these figures do not show is where the changes have occurred. Figures 44 through 53 are change images for bottomland hardwood, deep water, shallow water, cattails, willow, shrub/scrub, Ludwigia, mudflat, duckweed, and baresoil, respectively. These figures show those acres that remained in the same information class from 1987 to 1991 in the same color scheme as the classification images shown in the previous sections. Those acres that changed from the particular information class are shown in pink, while those acres that changed to that particular information class are shown in tan. Thus, these images show where the acres for a particular information class have remained the same, where

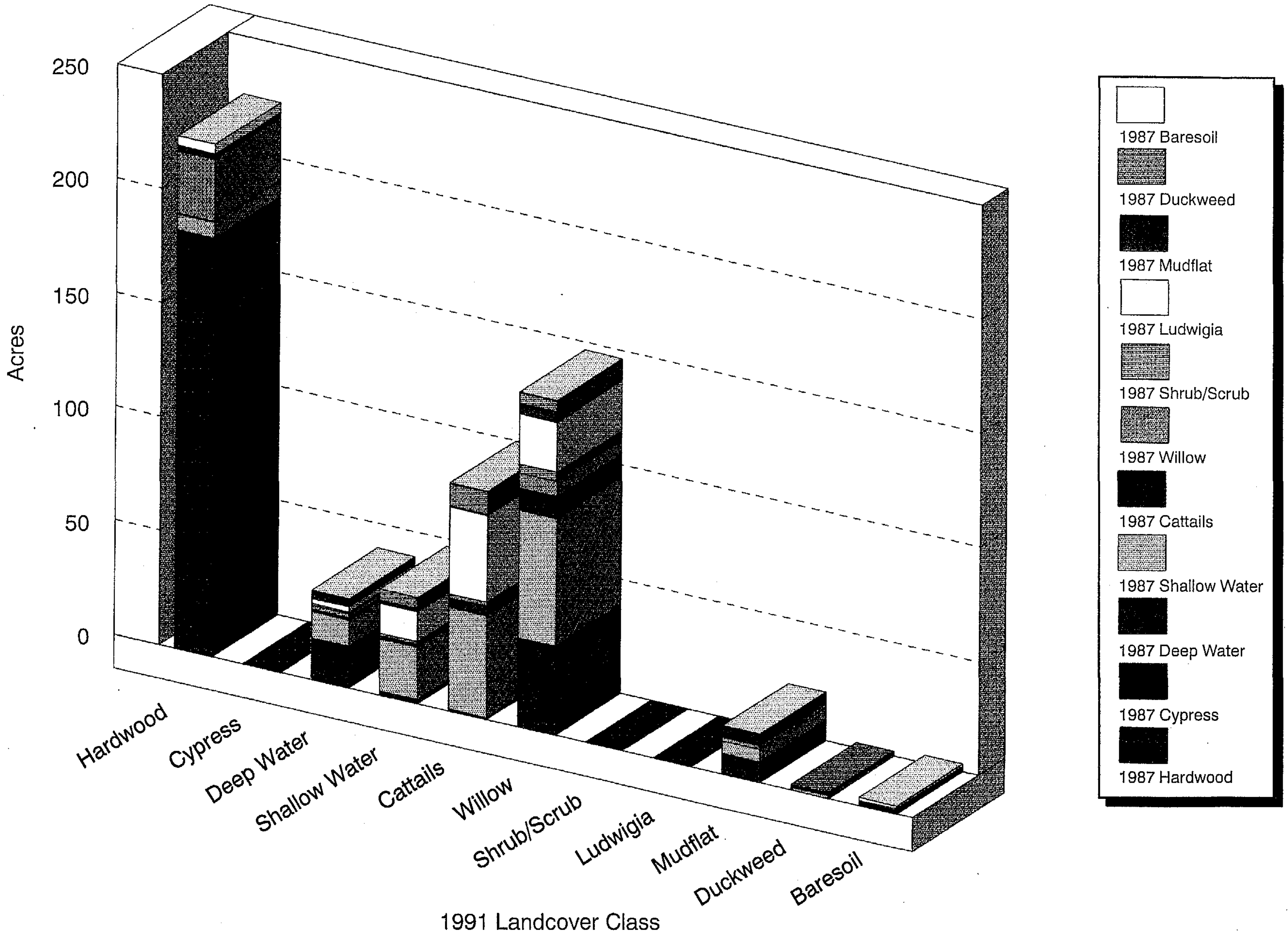

FIGURE 40. ***1991 CLASS FROM 1987 CLASS ANALYSIS OF CHANGE***

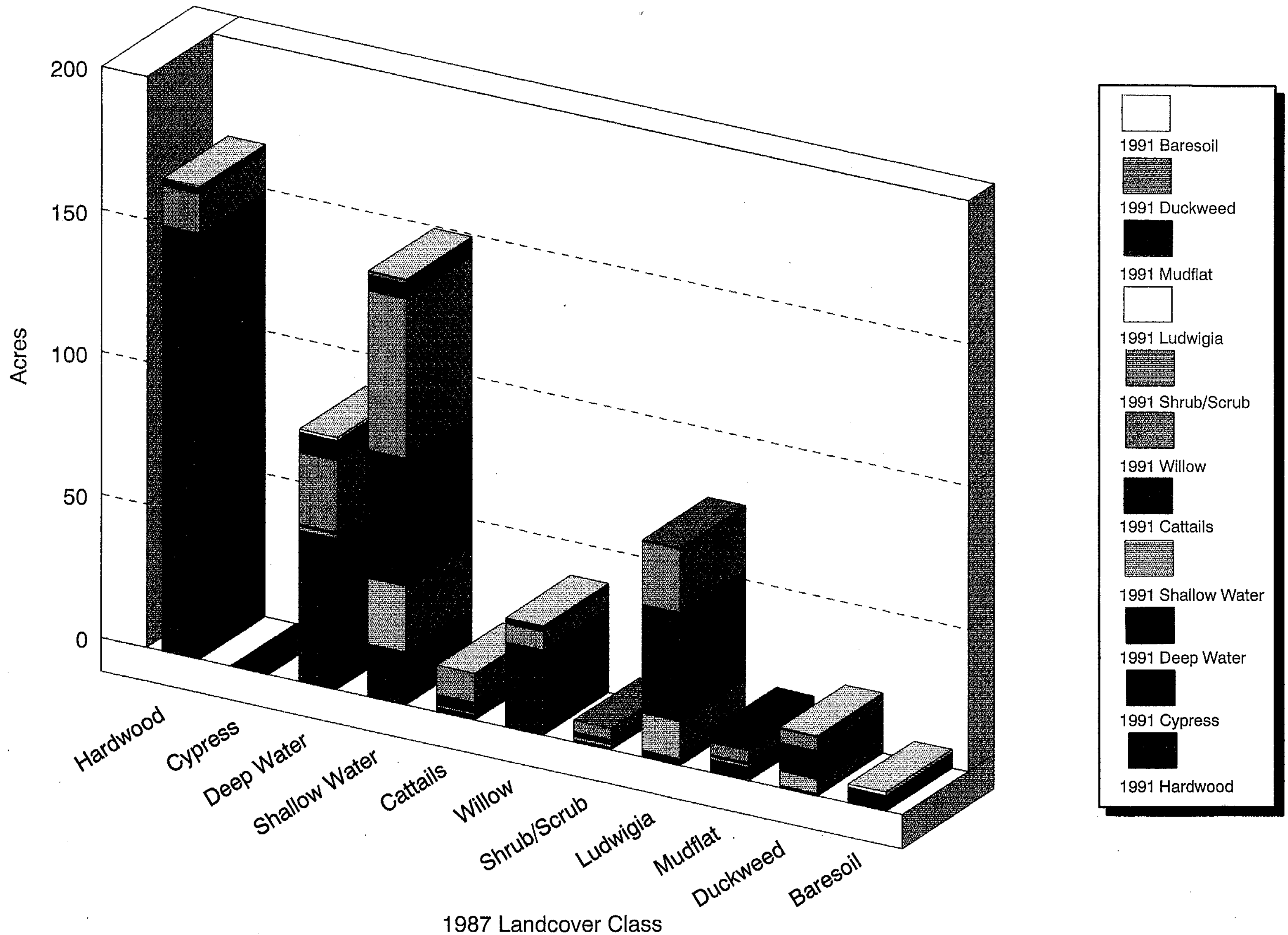

FIGURE 41. ***1987 CLASS TO 1991 CLASS ANALYSIS OF CHANGE***

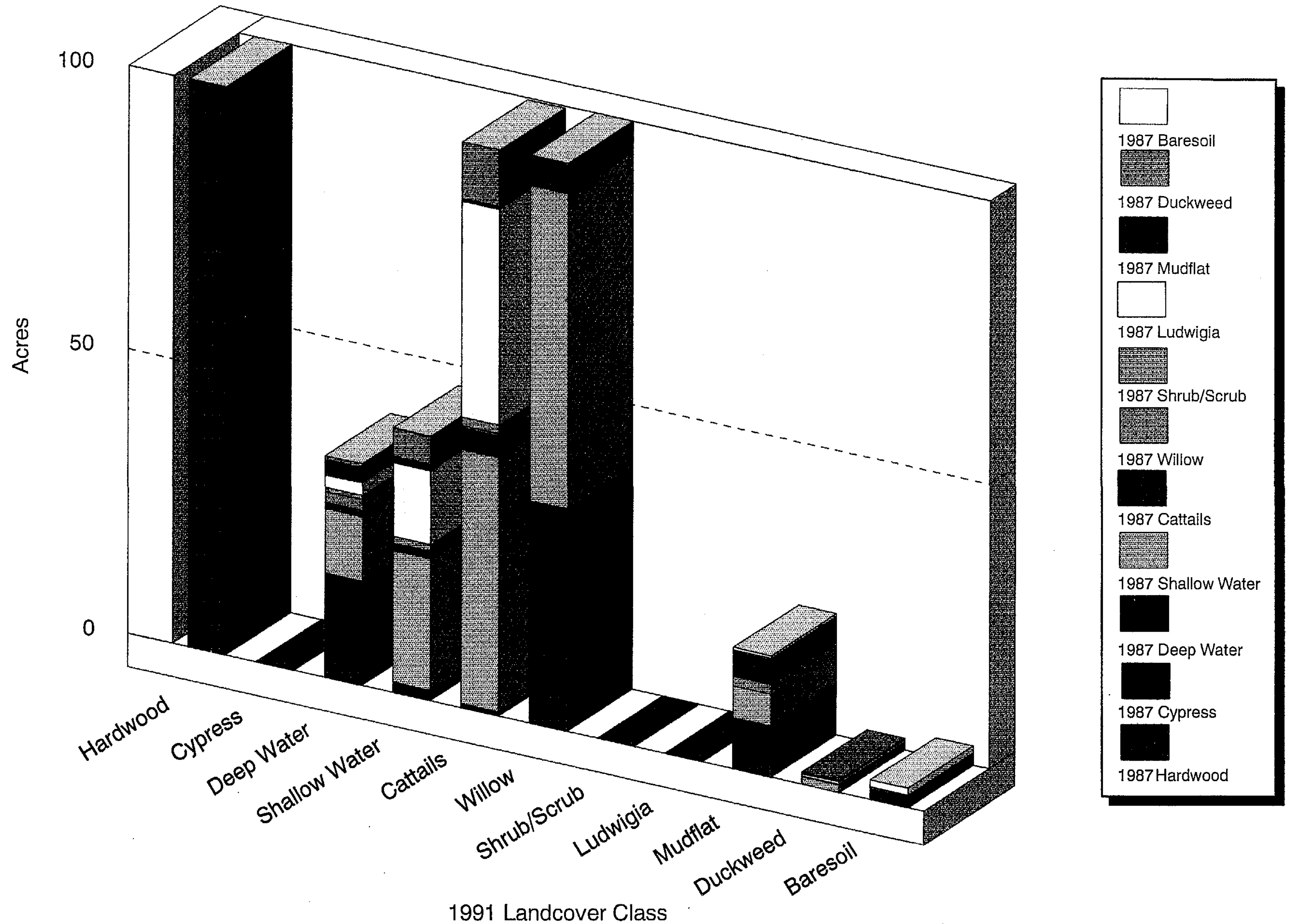

FIGURE 42. ***1991 CLASS FROM 1987 CLASS ANALYSIS OF CHANGE ENLARGED***

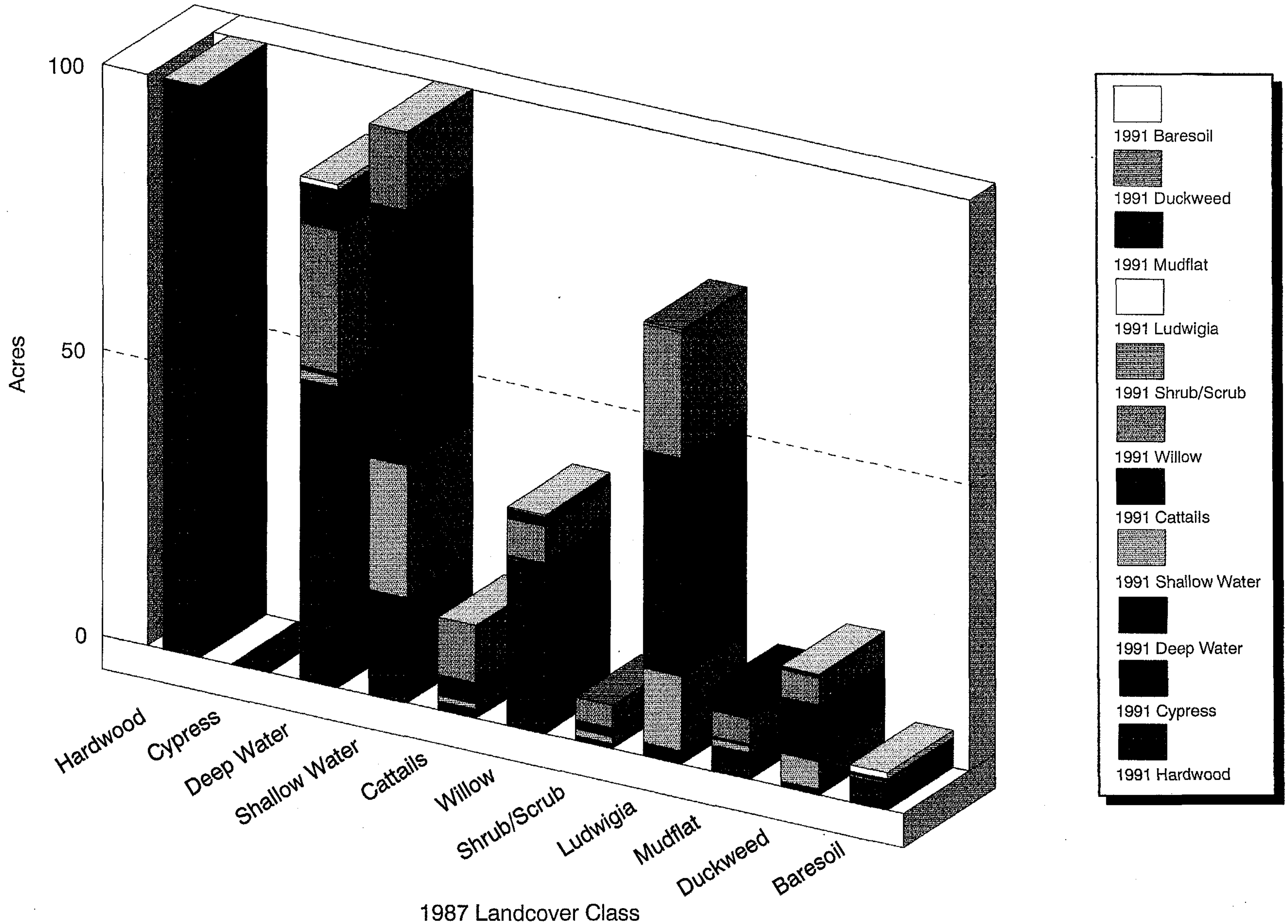

FIGURE 43. ***1987 CLASS TO 1991 CLASS ANALYSIS OF CHANGE ENLARGED***

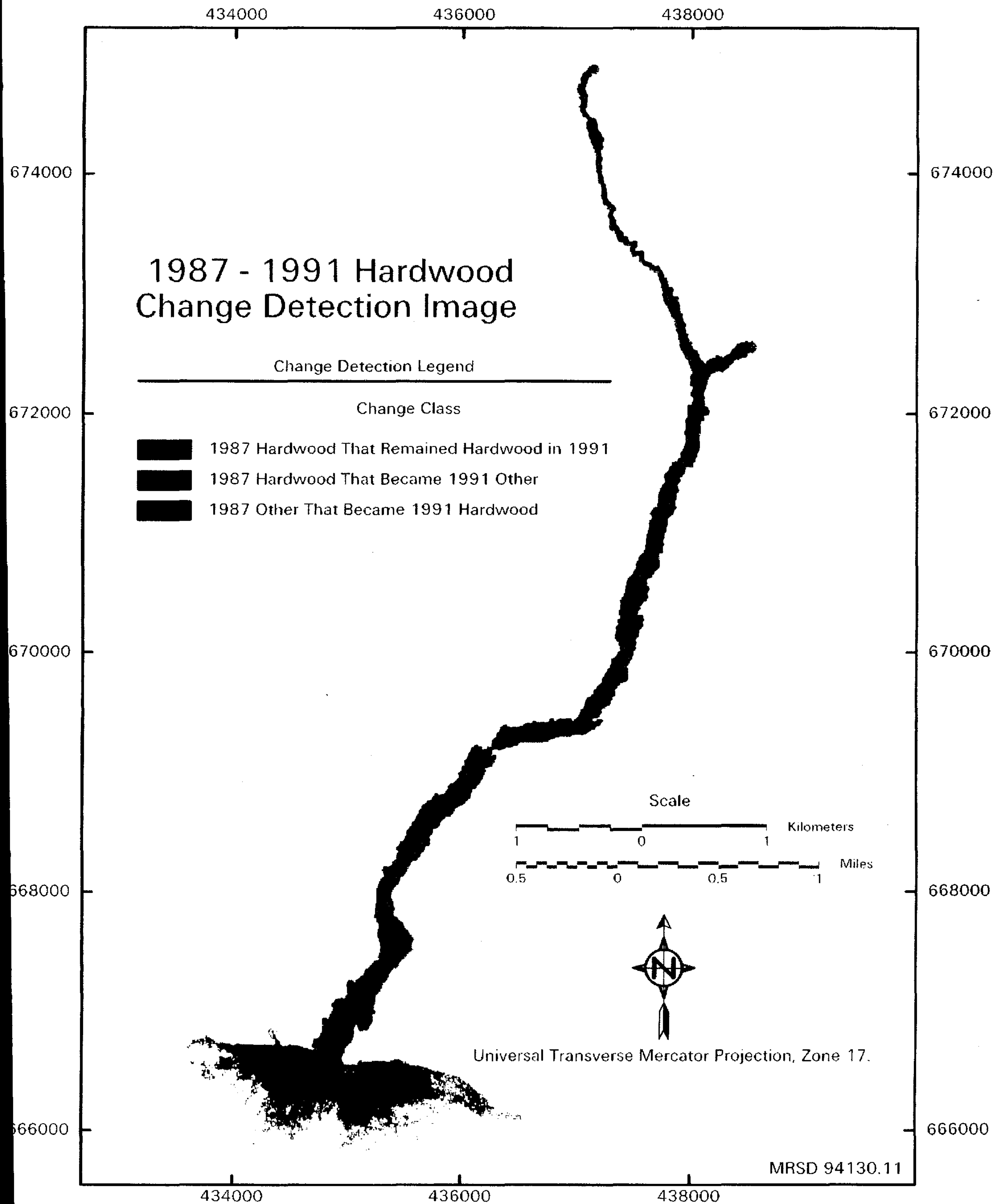

FIGURE 44. ***HARDWOOD CHANGE IMAGE***

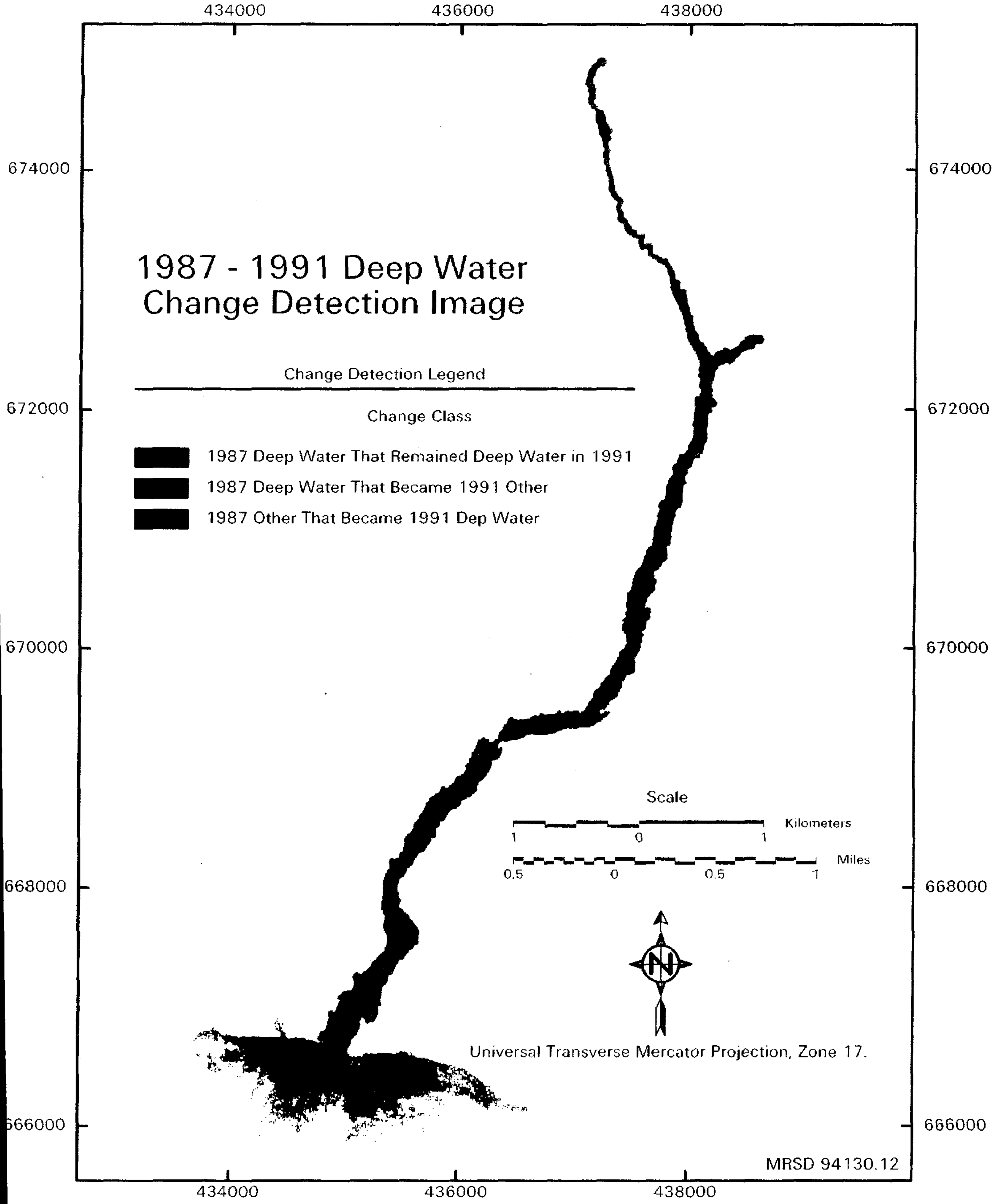

FIGURE 45. ***DEEP WATER CHANGE IMAGE***

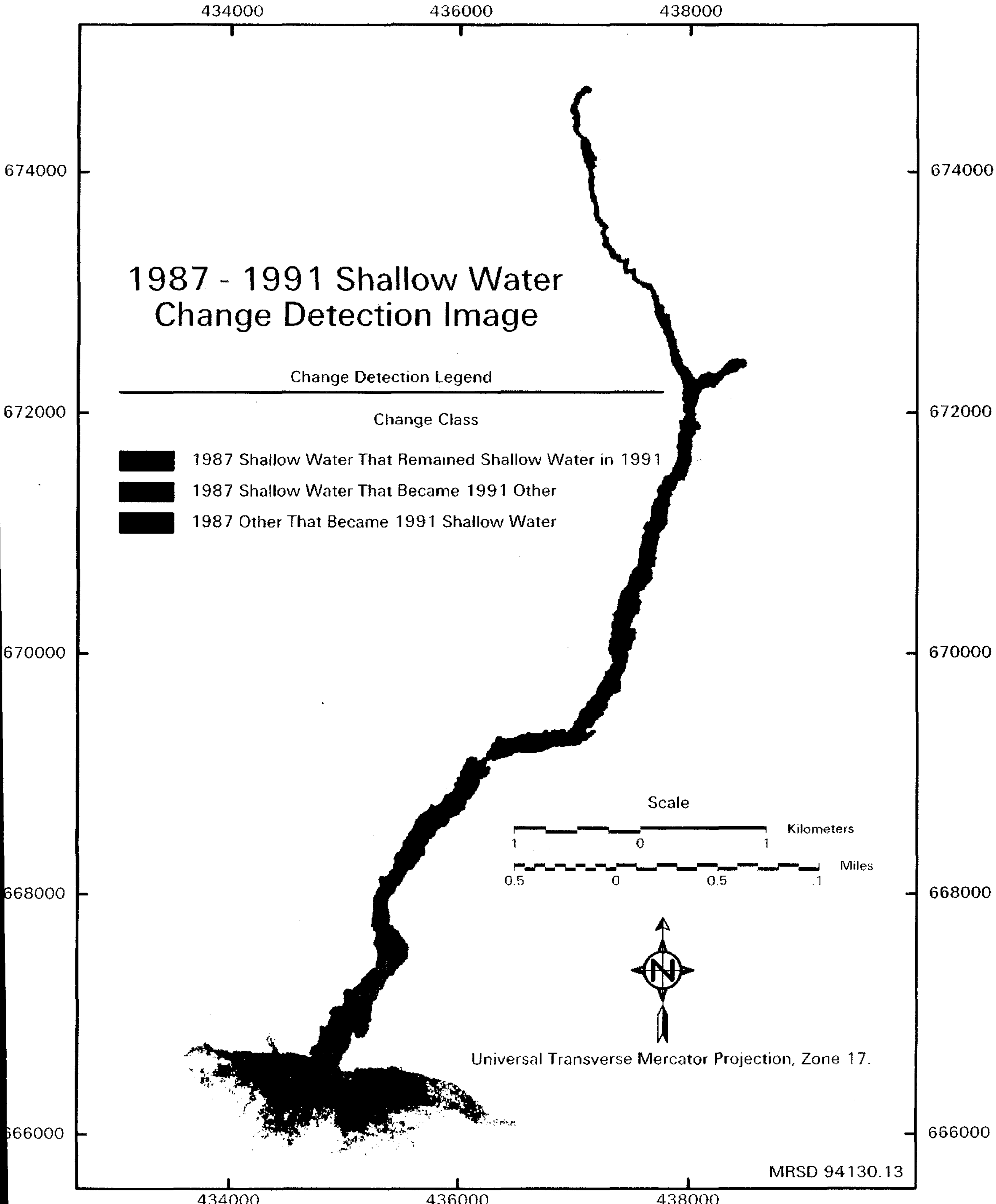

FIGURE 46. ***SHALLOW WATER CHANGE IMAGE***

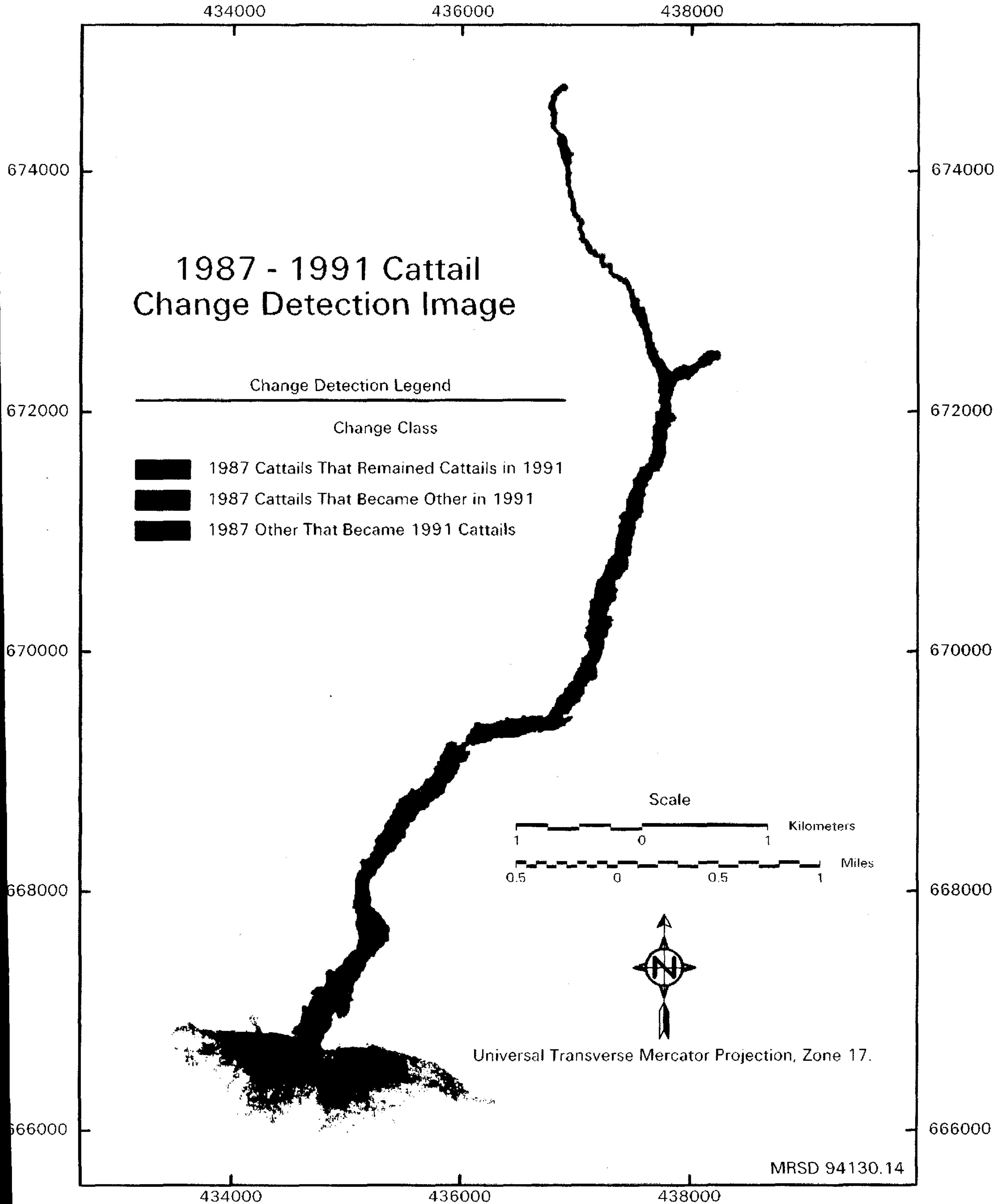

FIGURE 47. ***CATTAILS CHANGE IMAGE***

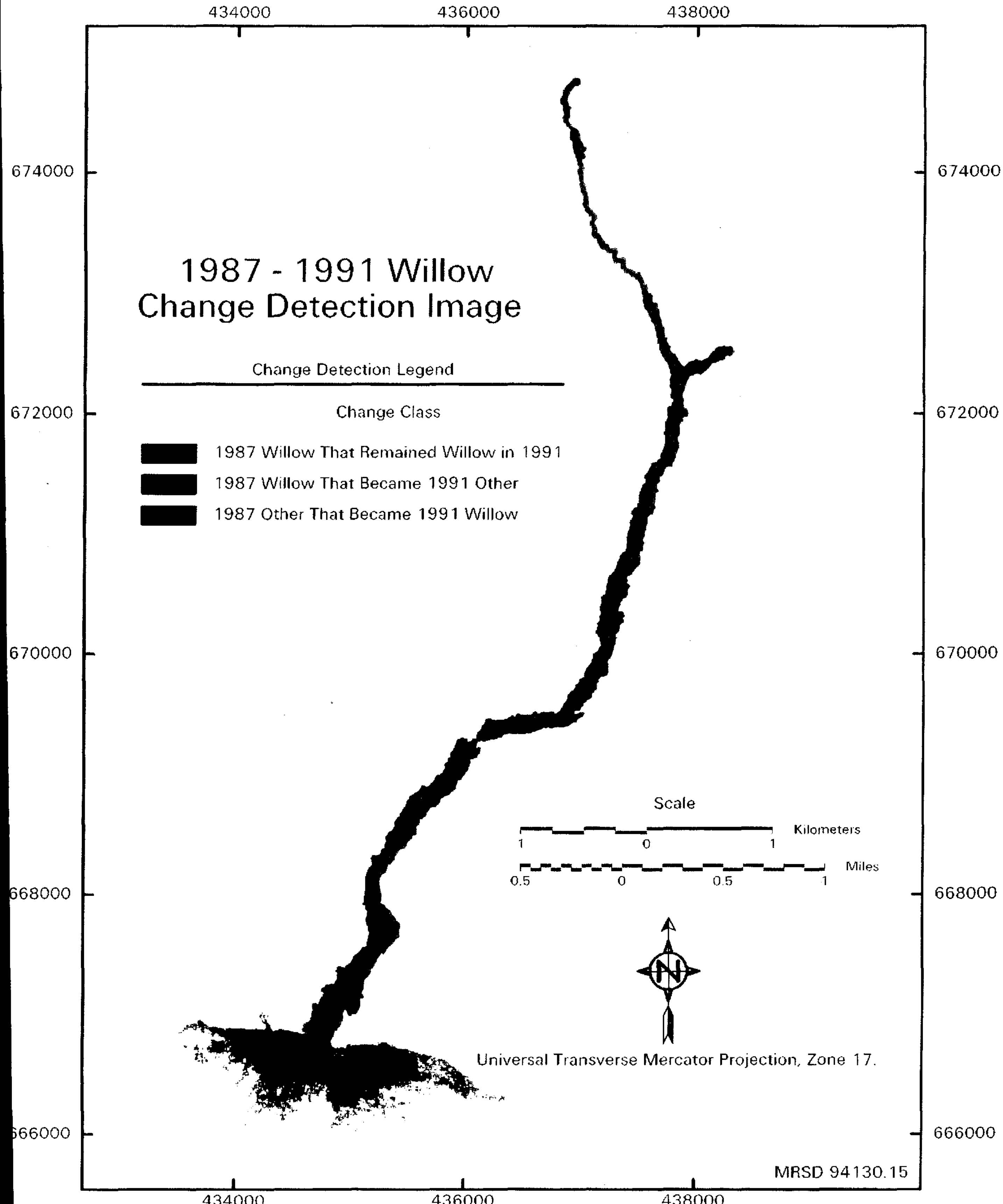

FIGURE 48. ***WILLOW CHANGE IMAGE***

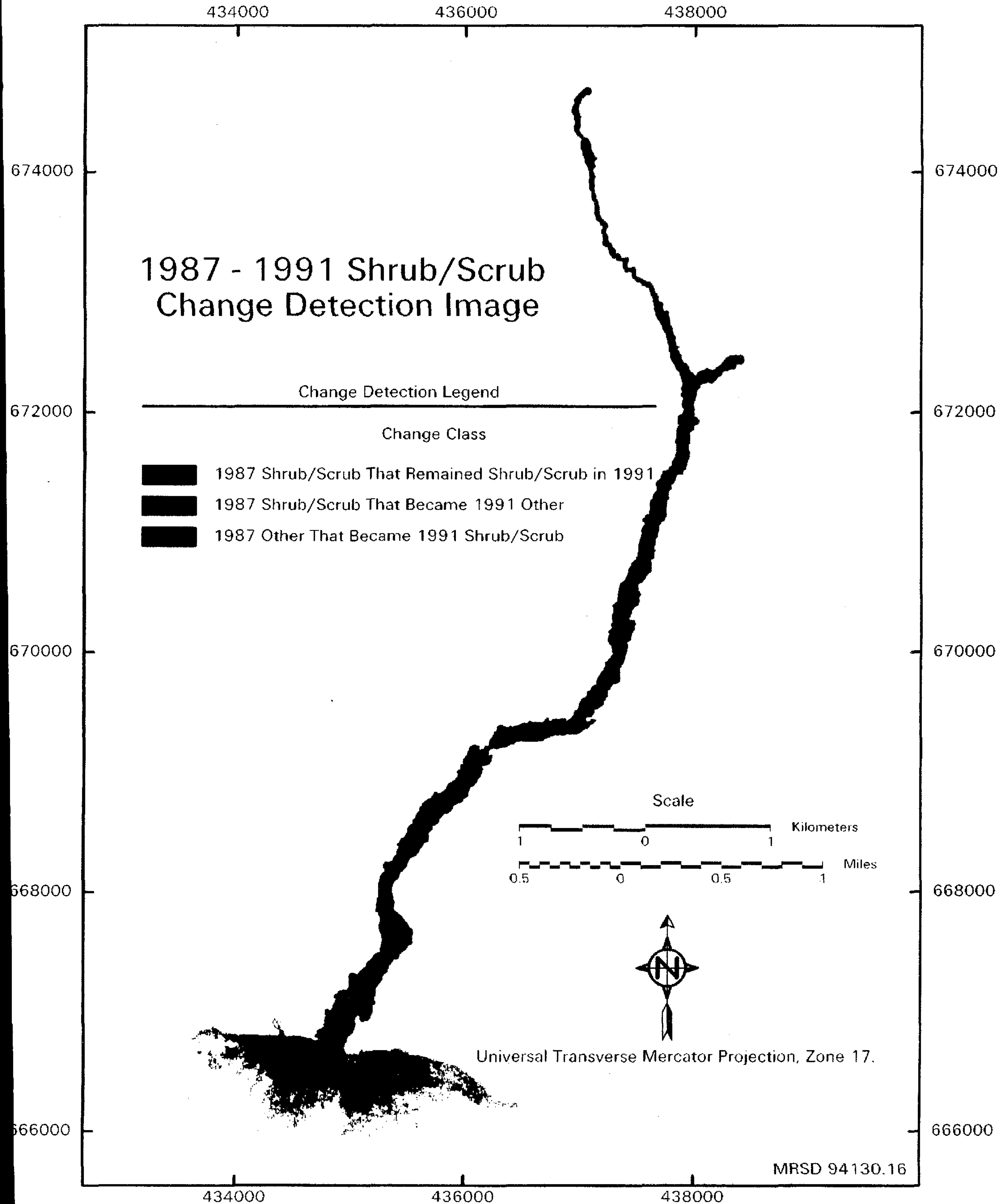

FIGURE 49. ***SHRUB/SCRUB CHANGE IMAGE***

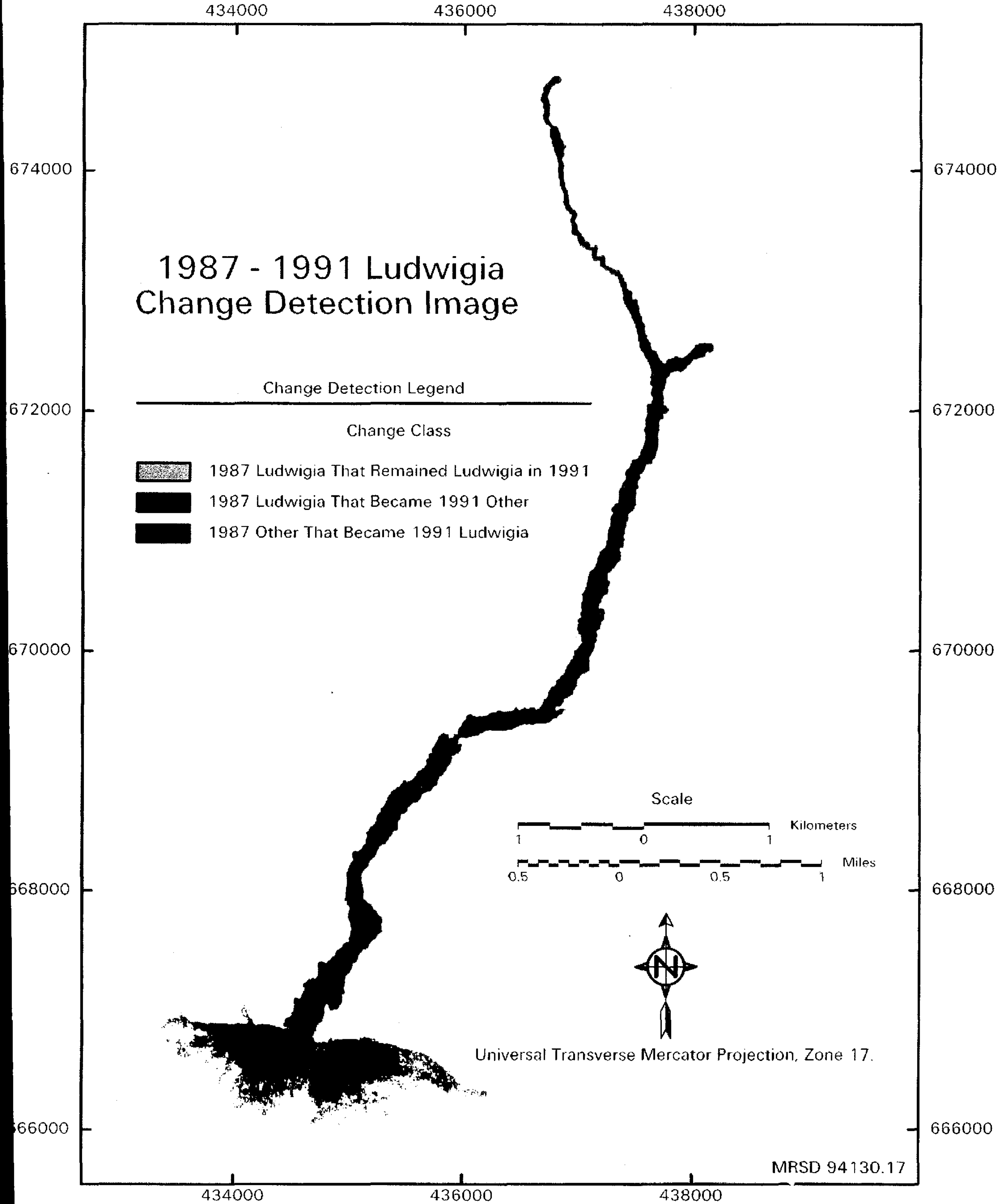

FIGURE 50. ***LUDWIGIA CHANGE IMAGE***

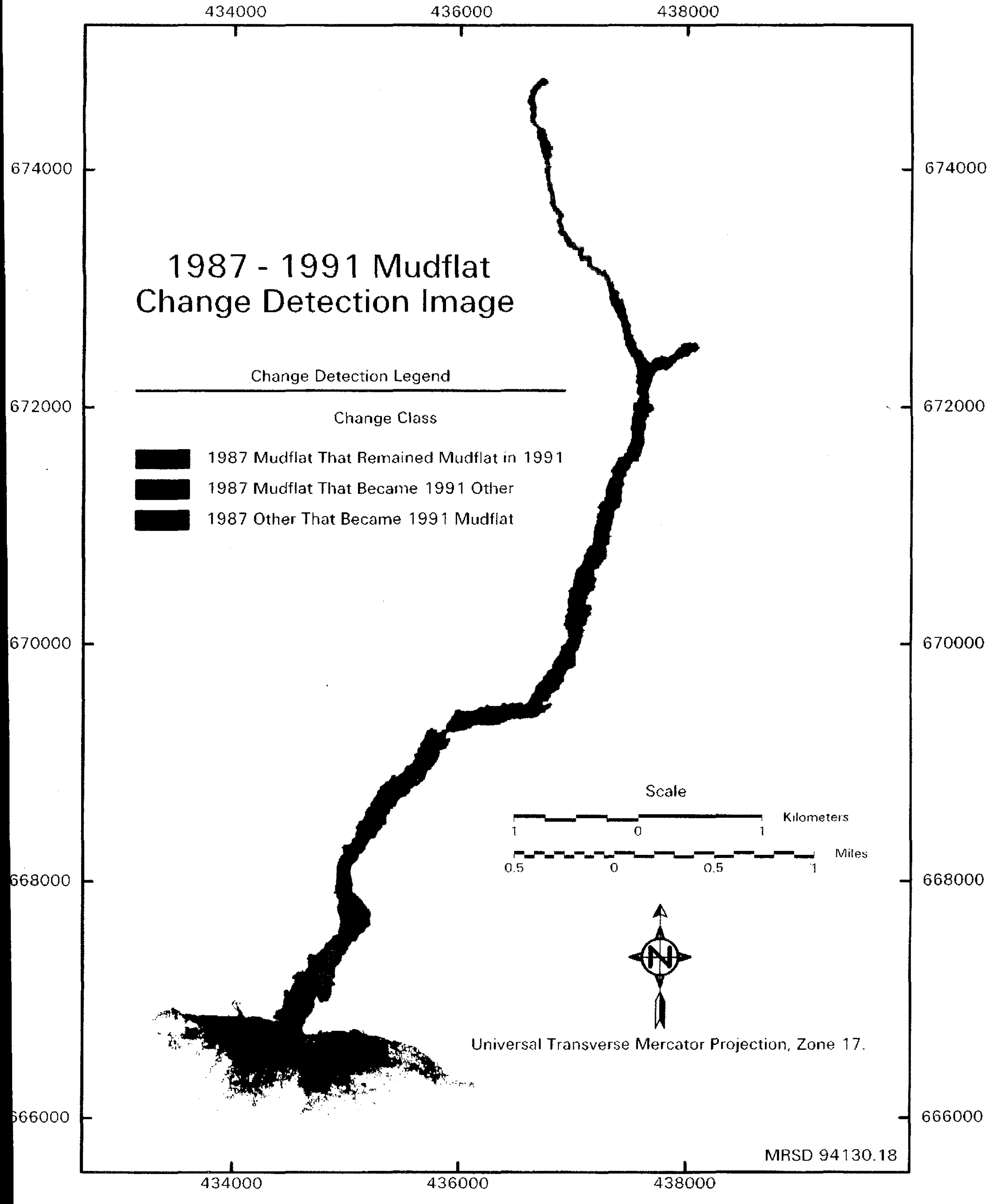

FIGURE 51. ***MUDFLAT CHANGE IMAGE***

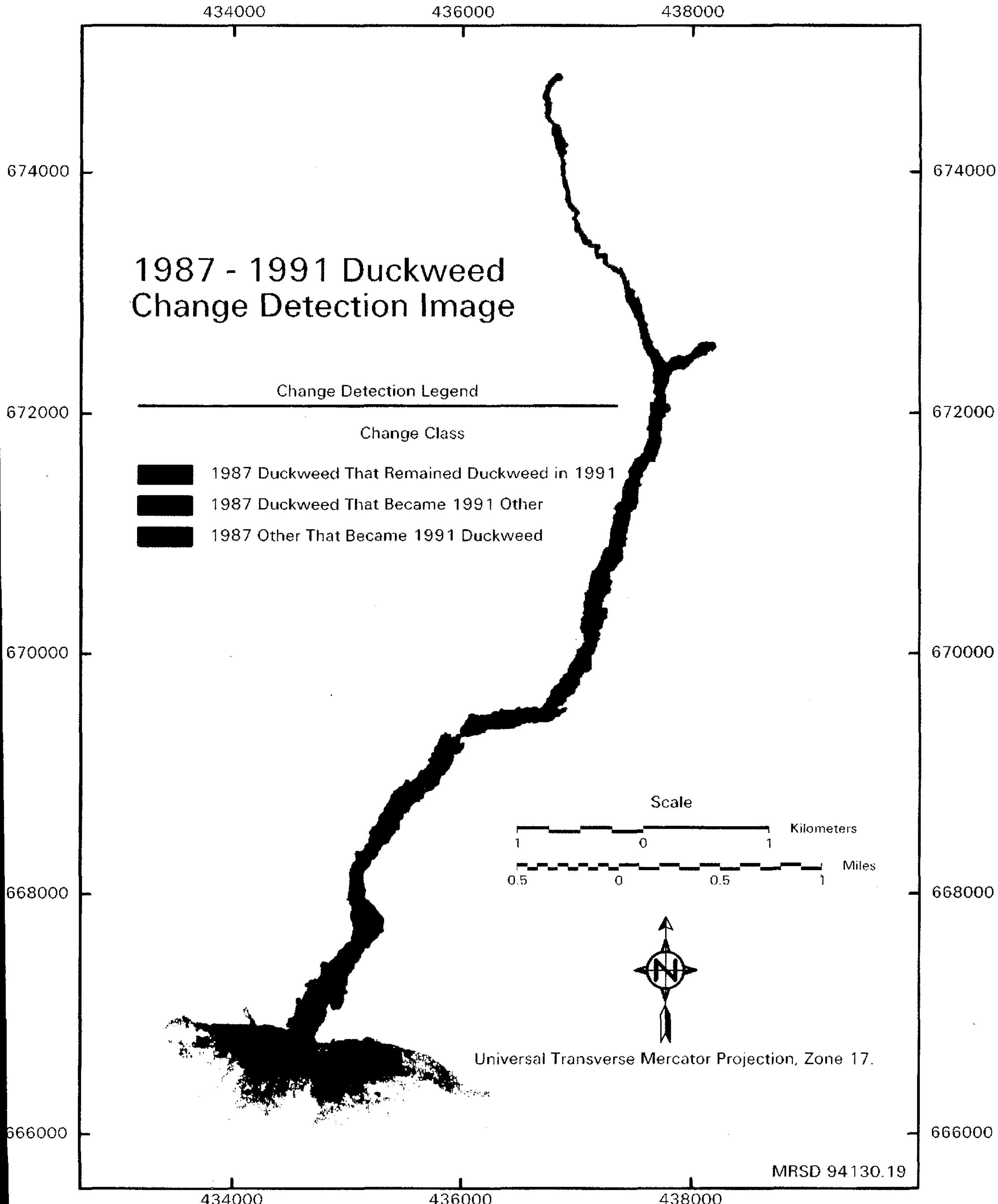

FIGURE 52. ***DUCKWEED CHANGE IMAGE***

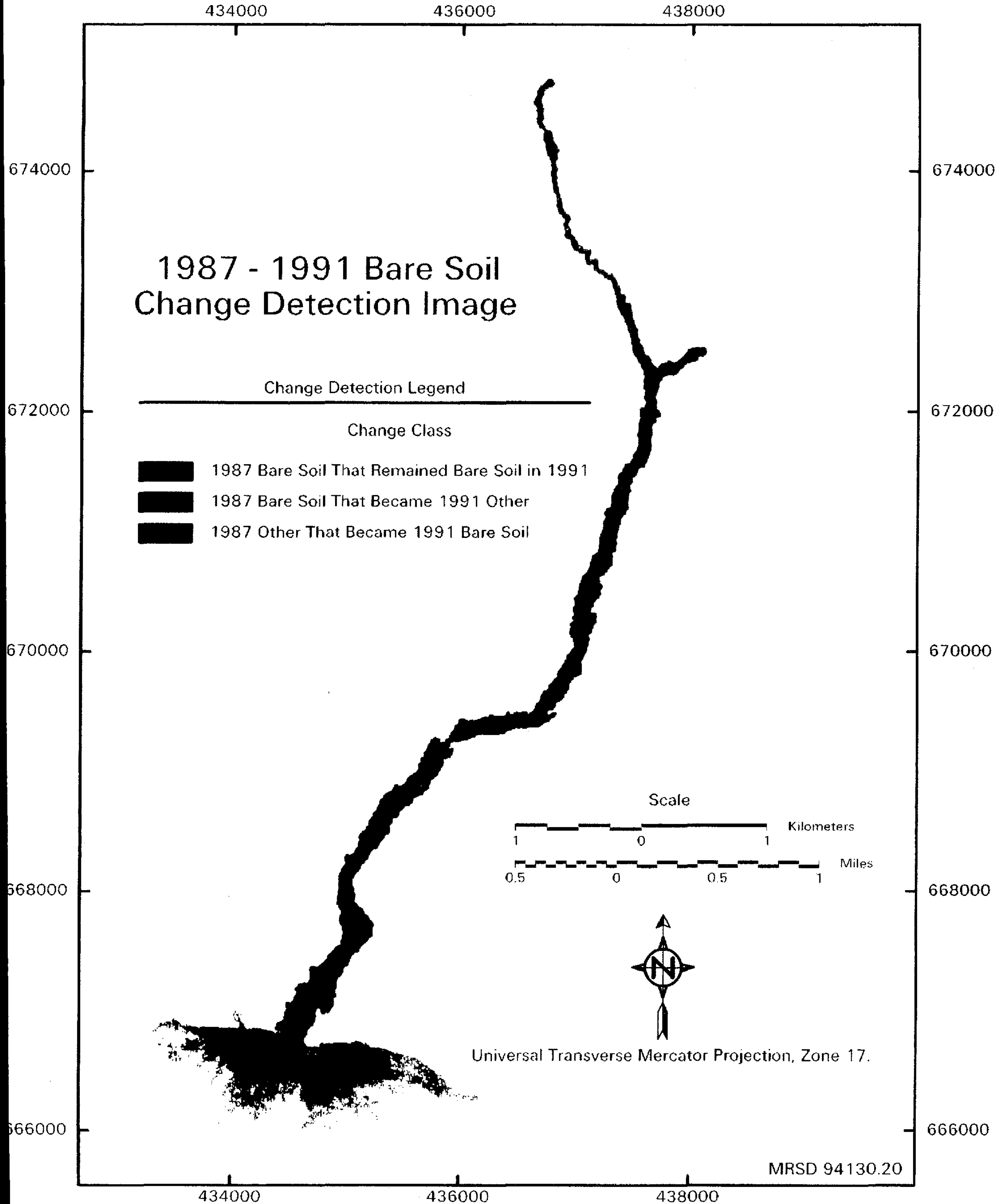

FIGURE 53. ***BARESOIL CHANGE IMAGE***

those acres are that have changed to some other class, and where those acres are that have changed from some other class to a particular information class. Figure 44 shows that bottomland hardwoods remained constant in the upper reaches of the corridor, and by 1991 had advanced down the corridor almost to the delta. Figure 45 reveals that portions of two deep water channels persisted in the corridor to 1991, but that large overall decreases in deep water acres occurred in the middle and lower portions of the corridor. Figure 46 shows that several areas of shallow water remained unchanged in the delta. However, almost all the shallow water acres in the corridor and in the western portion of the delta were eliminated, while new shallow water acres occurred in the eastern portion of the delta by 1991. Figure 47 is the change image for cattails. This figure shows that the cattails that were present in the eastern edge of the delta were eliminated, and that cattails have expanded dramatically across the rest of the delta. Figure 48 indicates that willow has been replaced in the middle corridor, most likely by bottomland hardwood, and has expanded tremendously in the lower corridor and into the delta. Figure 49 shows that shrub/scrub has disappeared from the delta by 1991. Figure 50 shows the expanse of Ludwigia that was present in the delta in 1987. Due to the changing conditions, Ludwigia has been replaced in the delta by 1991. Figure 51 indicates the changes in mudflats in the lower corridor. Some of the 1987 mudflat remained mudflat in 1991, but most of the rest has changed to other classes. Figure 52 is the change image for duckweed. Again due to the changing environment, most of the duckweed present in the delta in 1987 has changed to other classes by 1991. Finally, Figure 53 shows the relatively small amounts of change in baresoil. Because there is so little baresoil relative to the rest of the study area, these changes are insignificant. These Figures 44-53, in conjunction with Figures 40-43, show both how the information class acreages have changed, and where these changes have occurred.

5.7 Discussion

As the previous sections have shown, many interacting factors affect the change process occurring in the Pen Branch corridor and delta. The most notable factor is the reduction in K Reactor operations that began in April 1988. As Figures 14 through 18 show, the average yearly flow rate before reactor shutdown was approximately 400 cubic feet per second, and the flow was nearly continuous. After 1988, the flow rate dropped by approximately a factor of 10, and became much more sporadic. By 1991, the flow rates had increased again and become more frequent, but did not approach the levels of 1987. While the corridor is impacted most directly from the reactor flow rates, the delta is affected by the combination of reactor flow rates and Savannah River flow rates. As Figures 9 through 13 show, the flow rates of the Savannah River are more random and variable than those of K Reactor. When the river flow rate reaches a sufficient level, the water enters and floods the swamp, including the Pen Branch delta. This leads to four flooding scenarios. The reactor can be operating at full capacity while the river rates are high, leading to major flooding within the delta and corridor. The reactor can be shut down during high river flow rates, or the reactor can be operating during low river flow rates; both of these scenarios lead to moderate flooding. And finally, the reactor can be shut down while the river flow rates are low, leading to relatively dry conditions within both the corridor and delta. In addition to the effects due to the volume of water involved, it is also necessary to consider the thermal effects due to the heat of the water flowing from the reactor. Some species are affected primarily by the level of flooding, while other species are most impacted by the thermal effects of the reactor flow.

The classification images show what was present only at the time of data acquisition. This imagery represents only a snapshot in the day-to-day continuous ecological processes in this system. Efforts are made to optimize the timing of imagery acquisition so that vegetation types and conditions can most readily be differentiated. The combined presence of a given year's green vegetation with that of the brown vegetation from the previous year highlights the difficulties associated with vegetation classification in such a complicated ecosystem as Pen Branch. It is necessary to understand what was present in the previous year to fully categorize what is present in the current year. However, what remains from a previous year is impacted by the extent and duration of flooding that occurs previous to imagery acquisition. Thus, a given year's flooding will impact both that year's vegetation development, and what remains of the previous year's vegetation.

With the reduction in K Reactor operations in 1987, the trend within the Pen Branch corridor has been toward drier conditions. At the same time, the level of Savannah River flow has been relatively low, especially in 1988 and 1989. These two years of relative dryness allowed the beginning of a shift from nonpersistent vegetation to more persistent vegetation. The Savannah River flooded extensively again in 1990 and 1991, but with the elimination of thermal influence due to the reduced K Reactor operations, the overall impact on the vegetation types within the delta and corridor was not as great as in the past, and the shift in vegetation types continued.

The techniques used in this study show the number of acres that have changed, which information class acres have changed, and where those acres changed. With the reduction in K Reactor output, and the relative decrease in Savannah River flow, both deep water and shallow water acres have decreased markedly, replaced by the more persistent vegetation types of cattails, willow, and hardwood in the lower portions of the corridor and in the delta. The nonpersistent vegetation types, Ludwigia and duckweed, have been replaced primarily by cattails and willow in the delta. Hardwood has expanded down the corridor, while willow has expanded throughout the delta. Cattails have similarly expanded over the entire delta.

All of these changes indicate that the Pen Branch corridor and delta, with the reduction in K Reactor operations, have begun to recover to a more successionally mature ecosystem. Nonpersistent vegetation types, that required the disruptions caused by thermal flooding to maintain dominance, are being replaced by persistent vegetation types that can compete more effectively in consistent, stable environmental conditions. To determine whether this ecosystem is recovering to its original state, it will be necessary to know what the original conditions of the Pen Branch corridor and delta were before the K Reactor was constructed and operating.

6. CONCLUSIONS

The Pen Branch corridor and delta have undergone substantial change over the period from 1987 to 1991. The primary cause for this change appears to be the decreased operations of the K Reactor, and the subsequent drying of the corridor and delta. As the corridor and delta have dried, the vegetation communities present have changed dramatically. Nonpersistent vegetation has been replaced by more persistent vegetation, and hardwoods and willow have grown to dominate the corridor and much of the delta. At the same time, wet areas such as deep and shallow water have been replaced by drier conditions, such as mudflats and persistent vegetation.

To achieve the results of this study, airborne multispectral data of high spatial and spectral resolution have been used. The usual problems of registering highly distorted airborne data have been overcome by the use of iterative applications of the finite element registration approach, and the use of registered aerial photographs as a map base. By overcoming the registration problems, it has been possible to use all the advantages of the high spatial and spectral resolution of this data, relative to that available from commercial satellites. The level of detail achieved by the classifications in this study were made possible by the spectral bands available with the Daedalus AADS1268 scanner, and by being able to obtain this spectral information at a spatial resolution that is capable of resolving the vegetation types present.

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