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DETERMINATION OF TURBIDITY PATTERNS

IN LAKE CHICOT FROM LANDSAT MSS IMAGERY

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## 1.0 INTRODUCTION

Many of our inland lakes are suffering from increasingly higher levels of sediment which degrade their aquatic environment and recreational value. These sediments carry pollutants, and the siltation build-up is continually limiting the usefulness of larger areas of these lakes. Lake Chicot, located in the southeastern corner of Arkansas, is one such lake which is being particularly affected by the influx of large amounts of sediment, caused by increasing amounts of land cultivation, drainage ditches, and levee construction. The dynamics of the total lake system that affect the movement and fate of sediment are not readily apparent on a small scale and time frame. Determining and understanding the properties of the lake and the complete drainage basin are essential for optimum management of future conservation measures and possible remedial actions.

It is difficult to assess the overall magnitude and future impact of the sediment problem without some effective monitoring tool. The launch of the Landsat satellites and their regular overpass over a given area afford a valuable reconnaissance tool in obtaining synoptic information from affected areas. The upwelled radiance data measured by the MSS (multispectral scanner) Landsat system can furnish seasonal and regional turbidity and hydrographic patterns which can be related to when and where the problems are occurring. By examining past Landsat scenes, a historical record of sediment patterns and possible disposition can be obtained.

## 2.0 LANDSAT'S SATELLITE AND MSS IMAGERY SYSTEM

The Landsat satellites are launched in a nearly circular sun-synchronous, north-south orbit with an inclination of 99° and a nominal altitude of 920 km. This permits the satellites to be over the same area at the same local time every 18 days. With a period of 103 minutes, Landsat makes approximately 14 revolutions of the Earth in a day and 251 revolutions in the 18 day cycle. The orbit progresses in the westwardly direction by 159 km per revolution at the equator. An overlap between adjacent ground scenes (14% at the equator) allows some areas to be seen 24 hours later.

The multispectral scanner system consists of 4 distinct ranges or bands as shown in figure 1. The gains on the sensors are set so that all possible ranges of the Earth's upwelled signal are bracketed, resulting in low sensitivities for the water areas. In order to achieve complete ground coverage with the given orbit, there are 6 rows of each of the scanners. This frequently leads to a noticeable difference in every sixth line of Landsat data (called banding) that is caused by different scanner drift rates. The on-board detectors scan in a west to east direction with an instantaneous field-of-view of 79 by 79 meters (because of overlap in the scan direction, there are only 56 meters of new information). A ground area of 185 km is swept by each cycle of the scanners, and a Landsat scene is formed when a ground track of 185 km is recorded.

## 3.0 CORRELATION OF LANDSAT IMAGERY

Turbidity patterns can be readily observed in Landsat's imagery scenes. Since an increase in the suspended and certain dissolved materials in the water increases the backscatter of light, many researchers have used Landsat data to statistically correlate its spectral intensity with water quality parameters in the form of transmittance, secchi depth, turbidity, and suspended solids. By using a minimum number of field samples, algorithms were developed by which many large inland bodies of water were quantified corresponding to their pollutants. Using in situ transmittance measurements (ref. 1), high correlations were found with Landsat spectral data for waters in Gunston Grove, Virginia, a branch of the Potomac River. Studies conducted on Kansas lakes (ref. 2 and 3) were able to correlate secchi depth and suspended solids with the Landsat bands for concentrations of suspended solids less than 80 ppm. Many lakes in Wisconsin were used to correlate Landsat's MSS data with secchi depth (ref. 4) and turbidity (ref. 5) for concentrations of suspended solids less than 40 ppm. Investigations conducted on South Dakota lakes (ref. 6 and 7) were able to relate secchi depth and turbidity with the output of Landsat for low levels of suspended solids. Minnesota lakes (ref. 8) were used to obtain high correlations of turbidity with the radiances measured by Landsat for suspended solids less than 3 ppm. The Great Lakes were the object of several intense studies. Lake Ontario's waters were used to correlate secchi depth, turbidity, and suspended solids (ref. 9) to Landsat's radiances for concentrations of suspended solids less than 95 ppm. Turbidity was related to Landsat's MSS data in Lake Superior (ref. 10) for suspended solids less than 20 ppm. Lake Erie (ref. 11) was used to connect turbidity and suspended solids to the bands of Landsat for suspended solids less than 80 ppm. Examination of the waters in Virginia lakes (ref. 12) found that Landsat data could be associated with suspended solids for concentrations less than 92 ppm. Studies conducted on Nebraska lakes (ref. 13) correlated turbidity and suspended solids with Landsat's radiances for suspended solids less than 184 ppm, although the fitted regressions were subjected to large levels of uncertainty.

Most of the previous investigations were carried out with levels of suspended solids less than 100 ppm which resulted in either band 5 or band 6 of Landsat giving the best correlations. Generally, when levels of suspended solids were greater than 100 ppm, the data became nonlinear and the resulting regression efforts exhibited high levels of uncertainty. This effect is demonstrated in references 3 and 4, where the Landsat radiance data rapidly increased with concentrations of suspended solids less than 100 ppm, and then changed very little for levels greater than 100 ppm. In effect, the radiance signal saturates, that is, the upwelled signal for low wavelengths remain the same no matter how high the sediment loads.

A model of the Landsat's bands as a function of concentrations of suspended sediment is displayed in reference 14 that shows the exponential nature of their signal. This model shows that band 4 reaches a plateau at 10 ppm, band 5 reaches another plateau at 50 ppm, and band 6 reaches yet another plateau at about 150 ppm. Band 7 never reached an upper limit for the model shown which had a boundary of 1000 ppm. Studies were conducted on suspended solids from Lake Chicot in Arkansas and Kerr Lake in Virginia (ref. 15) as a function of wavelength. Results of the studies show the exponential nature of the upwelled radiance signal and demonstrate that larger wavelengths are needed to investigate higher concentrations of suspended solids. Investigations conducted on lakes in Mississippi (refs. 16 and 17), for suspended solids less than 350 ppm, and Lake Chicot in Arkansas (ref. 18), for suspended solids less than 550 ppm, illustrate that the best correlations between high levels of suspended solids and upwelled radiances are obtained for wavelengths between 700 and 900 nanometers.

## 4.0 RESULTS AND DISCUSSION

Due to changes in land use practices, Lake Chicot, in the southeastern corner of Arkansas, has been subjected to increasing sediment loads from rainfall run-off. The lake, located near Greenville, Mississippi, is an old c-shaped, cut-off channel of the Mississippi River that covers approximately 12 km in the east-west direction and 13 km in the north-south diretion. A causeway in the northwestern part of the lake above the town of Lake Village separates the lake into a distinct north and south zone. There are three bayous connected to various parts of the lake and numerous drainage ditches located in the northern section of the lake.

The Lake Chicot Landsat scenes can be quantified for sediment in a limited way by noticing the difference in water patterns on separate bands of Landsat imagery. Patterns that appear in higher wavelength bands that do not appear in lower bands indicate higher loads of sediment. To maximize this difference, bands 5 and 7 of Landsat were chosen as the bands best suited to show a complete range of sediment patterns. The sensitivity curves for bands 5 and 7 are shown in figure 1. Close examination of the sensitivities reveals that band 7 has more response at the lower part of the band than the upper part. In fact, 51% of the response is between 0.8 and 0.9 micron and 89% is between 0.8 and 1.0 micron.

Two Landsat scenes of Lake Chicot were chosen to illustrate the effect of different sediment levels on the bands. Landsat's imagery for September 22, 1974, in figure 2 shows high levels of brightness in the southern zone of the band 5 image while displaying low values in the northern part. Inspection of the band 7 image reveals the same low intensity in both the north and south zone. The brightness levels displayed in band 5 can be directly related to different sediment loads, which are probably less than 100 ppm because of the absence of any signal in band 7. The band 5 imagery for April 14, 1979, shown in figure 3, displays high levels of different brightness in both the north and south zone, but this time band 7 discloses a brighter return in the southern section (this pattern may not be distinguishable on some reproduced pictures, but will be repeated as a sketch in a later figure). Thus, levels of sediment greater than 100 ppm are indicated in the southern part of the lake. Due to the large amounts of sediment present, some of the signal in the southern part of the lake in band 5 have actually saturated, thus, further information on the amount of sediment remaining is not measurable.

In order to detect and delineate instantaneous and long term turbidity patterns of the area, Landsat scenes originating from the launch of the first satellite to present time had to be studied. Because of cloud cover or poor quality of the finished product, only a limited number of scenes were found to be beneficial to the investigation. Of all the imagery surveyed, 20 different dates were selected that cover a period from October 20, 1972 to October 11, 1979, and encompassed all seasons of the year, except the summer months. To properly display sediment patterns observed on the available Landsat scenes, the intensities observed on bands 5 and 7 were divided into 6 different ranges and transformed onto maps of Lake Chicot. This procedure permits an easier and quicker examination of the scenes than is afforded by the original imagery. On some of the scenes band 7 has a uniform pattern of brightness for the entire lake; in this case the sketch will show only one level of brightness. The presentation of the Landsat imagery data will proceed from the most recent to the oldest scene.

## 4.1 LANDSAT IMAGERY FOR OCTOBER 11, 1979

The scene, illustrated in figure 4, reveals in band 5 that the most turbid waters occur in the southern part of the lake, with the highest levels of turbidity occurring in this area above Lake Village. Some interesting patterns of higher reflectivity are easily observable in the northeast part of the lake; these patterns appear in every Landsat image and usually display different features. A small region of lesser brightness is visible at the eastern tip of the lower branch of the lake. Also appearing in this area is a small dark abutment on the northern shore which is probably related to the small bayou connected to the main lake in this section. Just below Lake Village, a small turbid plume flows part way into the lake. The waterway connecting the west part of the lake to the east exhibits the same upwelled signal as the upper part of the lake. Connerly and the other bayous connected to the lake display lower levels of turbidity than the water in the lake. The band 7 view discloses the same intensity in all parts of the lake and waterways, although bright patterns appear in the northeastern and southern tip of the lake. Another bright zone is noticeable on the right side of the causeway where Connerly Bayou joins the lake.

## 4.2 LANDSAT IMAGERY FOR SEPTEMBER 14, 1979

Several levels of turbidity are discernible in both the upper and lower sections of the lake on the band 5 image depicted in figure 5. Higher intensities occur above Lake Village, in the lower section, and in the northeast corner of the upper part. All the bayous joined to the lake reveal lower ranges of brightness than the main lake. Unique bright features are manifest in the upper right area and dark features are visible in the eastern end of the lower section of the lake. A small prominent bright plume is observed entering the lake in the region below the town of Lake Village. The waterway joining the upper left part of the lake to the right displays the same low turbidity level as the area above the causeway at Connerly Bayou. No change in intensity is noticeable between the north and south part of the lake and the related bayous on the band 7 imagery. Bright features are evident in the northeastern and southeastern end of the lake and near the northwestern causeway.

## 4.3 LANDSAT IMAGERY FOR APRIL 14, 1979

In the southern part of the lake a uniform pattern of higher turbidity is revealed on the band 5 scene in figure 6. In fact, this part of the lake is one of the brightest areas in the Landsat scene. Lower turbidity levels are visible in the northern part along with alternating dark and light features in the northeast corner. The bayou that joins the bottom part of the lake from the south shows levels of turbidity as high as the levels in the lake. Connerly Bayou is slightly less turbid while the bayou connected to the southeastern section appears dark. Several turbidity levels are noticeable in the southern section of the band 7 scene, with the higher values being above Lake Village. All the bayous joined to the lake display the same degree of turbidity as in the lake. An interesting feature appears in the northeastern part of the lake that looks like a smoke plume. It starts from the small island and bends to the right and down, dissipates somewhat and then forms a narrow channel that ends in a curve at the eastern tip. The appearance of turbidity patterns in band 7 indicate that the level of sediment is over 100 ppm. Also, the uniform pattern of high intensity displayed in the lower part of the lake in band 5 demonstrates that the signal is saturated, another indicator of high sediment.

## 4.4 LANDSAT IMAGERY FOR MARCH 9, 1979

Band 5 of figure 7 divulges a homogeneous level of high turbidity throughout the lower region of the lake. The bayou joined on the southern shore also displays high turbidity, while Connerly Bayou shows the same intensity as the top part of the lake, and the bayou on the eastern apex appears dark. Different shades of varying intensity are perceptible in the northeastern corner, and the southeastern end of the lake reveal features that give off a darker tone. An interesting dark strip, not observable on other scenes, goes partway up the lower, northwestern shore, starting at the causeway at the Connerly Bayou juncture. The southern part of the lake in band 7 exhibits levels of turbidity that are higher than the northern part of the lake with the highest levels around Lake Village. The two bayous linked to the southeastern zone of the lake display the same level of intensity as the lake, but lower intensities are observed in Connerly Bayou. Features in the northeastern region of the upper lake and the eastern region of the lower lake are just faintly visible in this scene. Concentrations of sediment greater than 100 ppm are indicated in the lower part of the lake, since band 5 appears saturated and band 7 exposes high intensity patterns in this area.

## 4.5 LANDSAT IMAGERY FOR APRIL 28, 1978

A high order of turbidity is revealed in the lower section of the lake on the band 5 scene of figure 8. Lower intensity levels are evident in the bayous leading into the lake and still lower levels exist in the northern part of the lake. Patterns in the northeastern part of the lake display a brighter signal and features on the lower eastern tip appear darker. The level of turbidity exhibited in band 7 of the southern area is only slightly higher than the northern area turbidity. Connerly Bayou and the southernly connected bayous display the same intensity as the lake, while the bayou on the eastern apex shows a bright return. Distinct features in the northeastern region, the eastern tip of the lower zone, and the left part of the causeway at Connerly Bayou are brighter than the adjoining water. Since the water in the southern zone appears saturated in band 5 and more turbid in band 7, sediment loads greater than 100 ppm are indicated.

## 4.6 LANDSAT IMAGERY FOR JUNE 5, 1977

A higher range of constant turbidity is illustrated in the band 5 sketch on figure 9 for the lower section of the lake. The horizontal waterway joining the upper parts of the lake display the same intensity as the northern section. All the bayous leading into the lake exhibit lower levels of turbidity. The same characteristic bright patterns appear in the upper-right region and dark patterns in the lower eastern tip. Band 7 imagery depicts a slightly higher level of turbidity in the southern area than the northern area. Lower intensities are apparent in all the connected bayous, except the one flowing into the lower lake from the south. The distinct features in the northeastern and eastern part of the lake display high levels of intensities. Surface sediment concentrations greater than 100 ppm are implied by the saturation of band 5 and high intensities of band 7 in the lower part of the lake.

## 4.7 LANDSAT IMAGERY FOR APRIL 6, 1977

The degree of intensity observed in the lower section of the lake in the band 5 image on figure 10 is much higher than that observed in the adjoining Mississippi River and a little higher than that observed in the surrounding cultivated land. Only one turbidity level is distinguishable in this section, and the visible part of the bayou leading into the lake from the south has the same level. Part of Connerly Bayou next to the lake displays a high intensity, but the rest of Connerly Bayou to the north and the bayou on the eastern extreme reveals lower intensities. The horizontal waterway between the upper-left and the upper-right part of the lake also shows high intensities. Bright features appear in the northeastern corner and dark features are noticeable on the lower eastern tip. The water in the southern part, depicted in band 7, displays several levels of turbidity, with the highest level being above Lake Village. High intensities are prominent in both Connerly Bayou and the bayou entering the lake on the eastern tip, while the bayou flowing into the lake from the south displays the same level of turbidity as the lake. Both the upper part of the lake and the east-west canal reveal the same degree of turbidity. Brighter shapes appear in the northeastern section, the lower eastern extreme, and below the causeway at the mouth of Connerly Bayou. Sediment levels are probably greater than 100 ppm because of the higher values of turbidity in the southern part of band 7, and also due to signal saturation of band 5 in the same area.

## 4.8 LANDSAT IMAGERY FOR MARCH 1, 1977

Inspection of the band 5 image on figure 11 reveals a greater degree of turbidity in the southern section. Only one level is conspicuous in this area, and the east-west upper waterway displays the same intensity as the lower region of the lake. Connerly Bayou and the bayou leading into the lake from the south manifest the same intensity as the lake, while the bayou at the lower eastern tip produces a lower hue. Brighter features are perceptible in the northeastern area while darker areas occur in the lower eastern zone. Only one level of turbidity is disclosed on the band 7 view. This view discloses that both Connerly Bayou and the bayou entering the lower lake from the south have the same degree of turbidity as the lake, and higher turbidity is evident in the bayou on the lower eastern tip. Different brighter features are prominent in the northeastern corner, the lower eastern tip, and below the causeway where Connerly Bayou joins the lake.

## 4.9 LANDSAT IMAGERY FOR JUNE 13, 1976

The lower section of the lake, as displayed on band 5 in figure 12, exhibits only one level of higher turbidity. All three of the visible bayous show the same intensity of low turbidity, and the east-west canal in the northern region displays a higher intensity. Patterns in the upper right corner are distinguishable by different, brighter contours, whereas features near the causeway and the eastern tip are darker. There is little information on the band 7 sketch except the bright patterns at the causeway, the northeastern section, and the eastern tip. A uniform shade of darker hue is noticeable throughout both the northern and southern zone, and the adjoining bayous show the same shade except for a lighter tone in the bayou on the eastern tip.

## 4.10 LANDSAT IMAGERY FOR APRIL 11, 1976

A high level of turbidity is indicated in the lower part of the lake, as viewed in the band 5 scene in figure 13. This area of the lake displays a uniform shade that is much brighter than the other waters in the image and, also, is as bright as the surrounding land masses, while the northern part of the lake is one of the darkest areas in the scene. Bright features are present in the upper right corner, and the upper east-west waterway also gives off a bright signal. Connerly Bayou and the bayou on the eastern tip appear dark while the bayou entering the lower section from the south appears bright. Band 7 scenery divulges that the southern zone displays a slightly lighter hue than the northern part, implying a concentration of sediment greater than 100 ppm. In addition, the east-west canal, Connerly Bayou, and the southern bayou display a darker intensity. Brighter patterns are observable in the northeastern corner in the lower eastern tip.

## 4.11 LANDSAT IMAGERY FOR APRIL 2, 1976

One of the brightest objects on the image of band 5, depicted in figure 14, is the southern part of the lake. This section, whose waters are of constant intensity, is as bright as most of the adjoining land and considerably brighter than the Mississippi River. The small east-west waterway in the upper area, as well as features in the northeastern corner and the bayou joining the lake on the southern most part, are characterized by bright signals. Connerly Bayou and the bayou on the eastern tip appear darker than the surrounding shapes. A higher turbidity level is also displayed in the band 7 data. In fact, two levels are noticeable with the higher level occurring above Lake Village. The upper east-west canal, Connerly Bayou, and the bayou linked to the lake on the southern most part all display intensities similar to those in the lower region. The bayou and other features on the tip of the lower eastern part of the lake show only faint lighter patterns. Bright patterns are observed in the upper right-hand corner of the lake. Sediment loads greater than 100 ppm are probably in the southern section since band 5 has saturated and turbidity patterns appear in band 7.

### 4.12 LANDSAT IMAGERY FOR FEBRUARY 26, 1976

Again the lower section of the lake, as viewed on band 5 in figure 15, is one of the brightest objects in the image and is also composed of a uniform intensity. The bayou coming into the lake from the south and the upper east-west canal display slightly lower levels of turbidity, while Connerly Bayou and the eastern tip bayou are barely discernible as darker objects. The patterns in the northeastern section, which seem to change for every scene, are brighter than the surrounding areas. Examination of the band 7 scene also reveals higher turbidity levels in the lower part of the lake, where the highest range exists above Lake Village. Lower levels of turbidity are noticeable in the upper east-west canal and the three most prominent bayous leading into the lake. Features of higher but different intensities, are observable in the northeastern corner. Another interesting feature that is conspicuous in only this image is the appearance of two dark objects that look like bayous flowing into the lake in the northeastern corner. Inasmuch as band 5 appears saturated and turbidity patterns appear in band 7, suspended sediment concentrations greater than 100 ppm probably occur in the southern part of the lake.

### 4.13 LANDSAT IMAGERY FOR SEPTEMBER 22, 1974

In relationship to the other water and land in the scene, band 5 data in figure 16 shows the southern part of Lake Chicot to be a distinct, bright object. A much higher level of turbidity is displayed in the southern part of the lake and also in the bayou leading into the lake from the south. Connerly Bayou is not very distinct, but appears to have less intensity, and the bayou on the lower southern tip gives off a darker tone. The east-west upper waterway exhibits a sharp drop on the western end to the lowest levels of turbidity in the lake, possibly caused by a bridge causeway or dike. Brighter but somewhat blurred patterns are noticeable in the upper right-hand corner of the lake, while distinct darker features are observable below the causeway at Connerly Bayou and at the lower eastern extremity. The band 7 image reveals the same turbidity level for both the upper and lower parts of the lake and also the bayous leading into the lake, except for the bayou on the eastern tip, which shows a brighter return. Brighter features are prominent in the northeastern section, the lower eastern tip, and below the causeway at Connerly Bayou. Although band 5 gives off a bright signal in the lower part of the lake, the absence of any higher turbidity patterns in this section on the band 7 image indicates sediment levels less than 100 ppm.

4.14 LANDSAT IMAGERY FOR JUNE 24, 1974

Studying the band 5 imagery, whose sketch is shown in figure 17, discloses that the lower part of the lake is one of the brightest features in the scene. Even the upper part of the lake, though darker than the lower, shows higher signals than are normally observed. Uniform intensities occur throughout the lower section, and the east-west canal and the bayou linked to the south side of the lake show high but lesser turbidity levels. Connerly Bayou and the bayou on the lower eastern tip, as well as features below the causeway and at the lower eastern end, appear darker. Some of the patterns in the northeastern zone actually appear for the first time darker than the surrounding water. The southern section of the image in band 7 also appears more turbid than the northern section. While the bayou on the lower eastern extreme appears brighter, the east-way canal, Connerly Bayou, and the bayou leading into the lake from the south appear less turbid. Bright features are conspicuous on the lower eastern tip and below the causeway where Connerly Bayou joins the lake. Once more, the smoke plume feature shows up in band 7; a bright plume that originates in the upper right corner which bends down and remains next to the shore and finally curls back at the end of the lake.

Indications that sediment loads are greater than 100 ppm are given by the saturated signal in band 5 and turbidity patterns in band 7.

### 4.15 LANDSAT IMAGERY FOR MAY 19, 1974

Only one level of higher intensity is observable in the southern section of the lake for the band 5 scene on figure 18, although several divisions of lower turbidity are visible in the northern region. The east-west waterway is slightly less turbid than the southern region and all the bayous leading into the lake display a dark hue. Some bright features appear in the northeast corner while dark patterns are discernible on the eastern, lower tip and below the right-hand side of the causeway. No change in turbidity is perceptible on band 7 image between the two parts of the lake. On this image, Connerly and the bayou flowing into the lake from the south disclose dark outlines, whereas the bayou on the lower eastern tip appears bright. Higher reflective signals are observable on the lower eastern tip, the northeastern corner, and below the right side of the causeway.

### 4.16 LANDSAT IMAGERY FOR JANUARY 31, 1974

The lower part of Lake Chicot for the band 5 image sketched on figure 19 is the most prominent shape observed in the scene. Its signal is much higher than the signal from the Mississippi River and other waters and also higher than the signal from most of the surrounding land. Higher intensities are also visible in Connerly Bayou and the southern connected bayou, however, a dark shade is discernible in the bayou on the lower eastern end. The east-west waterway connecting the eastern part of the lake to the western part is only slightly less turbid than the southern section of the lake. Many different intensity patterns are perceptible in the northeastern zone and some dark patterns occur below the causeway and the lower eastern extremity. Two distinct, higher turbidity levels can be detected in the lower region of the lake on the band 7 view, with the largest values occurring above Lake Village. The bayous display intensities only slightly less than those of the lower lake and the east-west canal returns a signal that is as dark as the northern part of the lake. A bright plume appears in the northeast corner, follows a course to the southeast and dissipates, only to be followed by another plume-like feature. Concentrations of suspended material greater than 100 ppm are substantiated by the fact that turbidity patterns appear in band 7 and band 5 is saturated.

## 4.17 LANDSAT IMAGERY FOR MAY 24, 1973

This scene, as viewed on band 5 in figure 20, is unique in that the northern part of the lake is almost as bright as the southern section. Only one turbidity level is visible in the southern part and the intensity in the upper east-west canal has the same level as the lower part of the lake. While the bayou joining the lower part of the southern section has a bright signal, the other bayous exhibit dark characteristics. The distinct features in the upper right-hand corner display contours that are darker than the lake. Also showing darker shapes are the areas below the right part of the causeway and the eastern tip of the lower lake. An interesting feature exposed in this image is a small, ribbon-like shape that runs southward from the mouth of the bayou on the lower eastern end. Band 7 reveals that the southern section and the east-west canal are slightly more turbid than the northern part of the lake. Connerly Bayou appears darker, but the two bayous flowing into the lower southern region manifest a bright signal. Features in the northeastern corner, the lower southern end, and below the causeway display high intensities. Since turbidity patterns appear in the southern zone, the sediment loads must be near 100 ppm.

## 4.18 LANDSAT IMAGERY FOR MARCH 31, 1973

The southern part of Lake Chicot is the most conspicuous and one of the brightest objects of the band 5 image displayed in figure 21. There is a small bright plume at the entrance of the bayou joining the lake from the south. Although the north part is several shades darker than the south part, it is still brighter than most of the surrounding scenes. Connerly Bayou and the bayou on the lower eastern tip reveal darker features, while the bayou entering the lake from the south is very bright, as is the east-west canal. Somewhat darker features are seen in the northeast area and also in the lower eastern extreme. The scene disclosed on band 7 shows several higher turbidity ranges in the lower section of the lake with the larger values occurring above Lake Village. All of the three bayous leading into the lake have the same degree of turbidity as the southern part of the lake, whereas the east-west canal is slightly darker. No features are visible in the lower eastern tip, but a long, curving plume is prominent in the upper eastern corner. Since turbidity patterns appear in the southern section of band 7 and the same area of band 5 is saturated, sediment loads greater than 100 ppm are indicated.

### 4.19 LANDSAT IMAGERY FOR DECEMBER 31, 1972

High sediment loads are evident in the southern region of the lake since the return signal in band 5 of figure 22 is much more intense than the Mississippi River and many of the surrounding land masses. The bayou flowing into the lake from the south exhibits intensities as high as the lake, while Connerly Bayou is a shade darker and the bayou on the lower eastern tip is just barely visible as a darker object. The east-west canal is divided into a bright part on the west and a darker region on the east. Bright features are noticeable in the northeastern region and dark features are displayed in the lower eastern end. A unique feature for this data is the bright shape in the northwestern part of the lake that looks like an extension of the land into the lake. Band 7 shows the lower part of the lake to be slightly more turbid than the northern section. This band also disclosed that Connerly Bayou and the bayou on the south side have the same intensity as the lake, while the area of the bayou on the lower eastern tip is bright. The east-west canal appears darker and bright patterns are distinguishable in the lower eastern tip, the northeastern corner, and below the causeway at Connerly Bayou. Due to the appearance in the southern section of patterns in band 7 and the saturated condition in band 5, suspended loads greater than 100 ppm are indicated.

## 4.20 LANDSAT IMAGERY FOR OCTOBER 20, 1972

The lake in the band 5 scene in figure 23 is darker than the Mississippi River and most of the surrounding land. Higher levels of turbidity are viewed in the southern zone where the larger values are encountered below the causeway at Connerly Bayou. All the bayous display a darker signal except for the bayou joining the lake on the southside, which exhibits a slightly brigher signal. Patterns of all intensities are visible in both the northeastern corner and the lower eastern extreme. There is no difference in turbidity between the top and bottom section of the lake as revealed in the band 7 data. This band shows that the east-west canal as well as Connerly Bayou and the bayou on the southern end to be of lower turbidity. The bayou on the lower eastern tip appears bright as does other features in this area, as well as features in the northeastern corner and below the causeway at Connerly Bayou. The turbidity level for this date is probably much less than 100 ppm because of the weak signals from both bands 5 and 7.

## 5.0 CONCLUSIONS

A historical review of suitable Landsat imagery over Lake Chicot has provided an insight into the distribution, possible origins, and the seasonal variations of turbidity in the lake. Differences in and between bands 5 and 7 of Landsat indicate different levels of sediment concentration which can be used to survey surface sediment distributions. Distinct sediment patterns only appear on band 7 when the suspended loads are greater than 100 ppm, and, in addition, the upwelled signals are exponential in nature, resulting in saturation of band 5 and not capable of detecting higher levels.

Examination of the Landsat scenes reveals a distinct separation of the lake into a north and south zone by the causeway in the northwestern part of the lake. Frequently, in both bands 5 and 7, the brightest part of the lake is just below the causeway while at the same time the darkest part of the lake is just above the causeway. The band 5 data always displays a bright signal below the causeway and if sediment concentrations are above 100 ppm, the band 7 data will also appear bright. The highest levels of sediment, as detected by band 7, occur in the south section during the first half of the year, with a higher range occurring above Lake Village during the first four months of the year. Higher intensities are also observed in the upper east-west waterway during the first six months of the year. Comparison of the reflectivity of Lake Chicot with the adjacent Mississippi River and the surrounding land, many of which are under cultivation, afford another calibration tool for sediment quantification. Frequently, the southern part of the lake is very easy to detect in the band 5 imagery, being the brightest object in the scene, and at other times the intensity is lower, being at the same level as the Mississippi River. Observations of band 5 have also shown that the north part of the lake will appear bright for high sediment loads, though not nearly as intense as the southern region, and, conversely, will be one of the darkest objects in the scene for low sediment loads.

The most prominent of the bayous connected to the lake displays intensity differences with the lake and also between the bands. Generally, Connerly Bayou is darker than the lake in band 5 and has the same intensity in band 7. The bayou flowing into the lower part of the lake from the south displays the same shade as the lake for both bands 5 and 7. The bayou flowing into the lower eastern end from the north has less intensity than the lake in band 5 and more intensity in band 7. On several scenes, drainage ditches are noticed on the north shore of the upper zone of the lake.

Unique patterns appear in the northeastern corner and lower eastern end that seem to increase and decrease in intensity and size. These patterns appear darker than the lake in band 5 and lighter than the lake in band 7, and tend to be darker in band 5 during the first half of the year, and more distinct in band 7. The patterns do not seem to be seasonal and will sometimes appear as a narrow, ribbon-like plume that covers much of the northeastern section. One of the features in the lower eastern end, which looks like a sandbar that forms at the mouth of a bayou, always occurs in band 5 and usually occurs on the band 7 image in the spring.

There have been some interesting features that have appeared only occasionally on the scenes. A bright plume has been observed to flow into the lake from an area below Lake Village and other bright plumes have been perceptible at the mouth of Connerly and the bayou flowing into the lake from the south. In the northwestern region a dark strip has been noticed that goes partway up the eastern shore from the causeway. At the top of the north zone, a bright half-moon shape infringes partway into the lake which possibly could be the result of flooding. A small, dark ribbon-like string appears on one band 5 scene in the lower eastern end, and on another scene the band 7 image displays two dark plumes entering the lake in the lower northeastern section.

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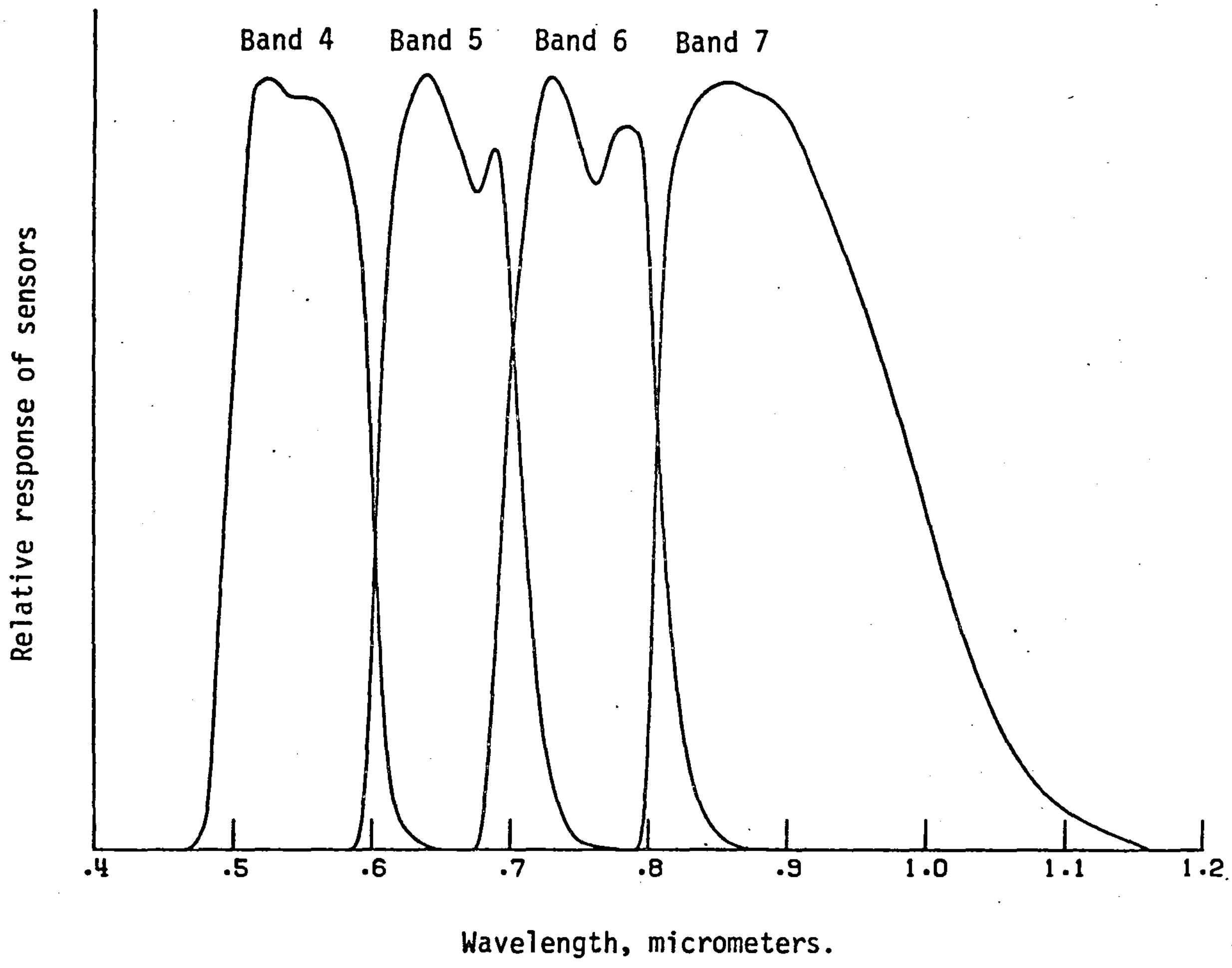
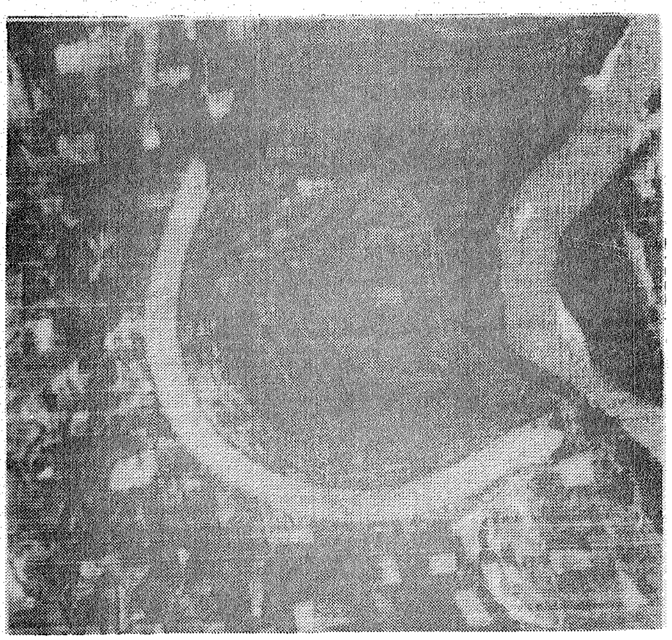



Figure 1.- Instrument sensitivity curves for Landsat's MSS sensors.



(a) Band 5

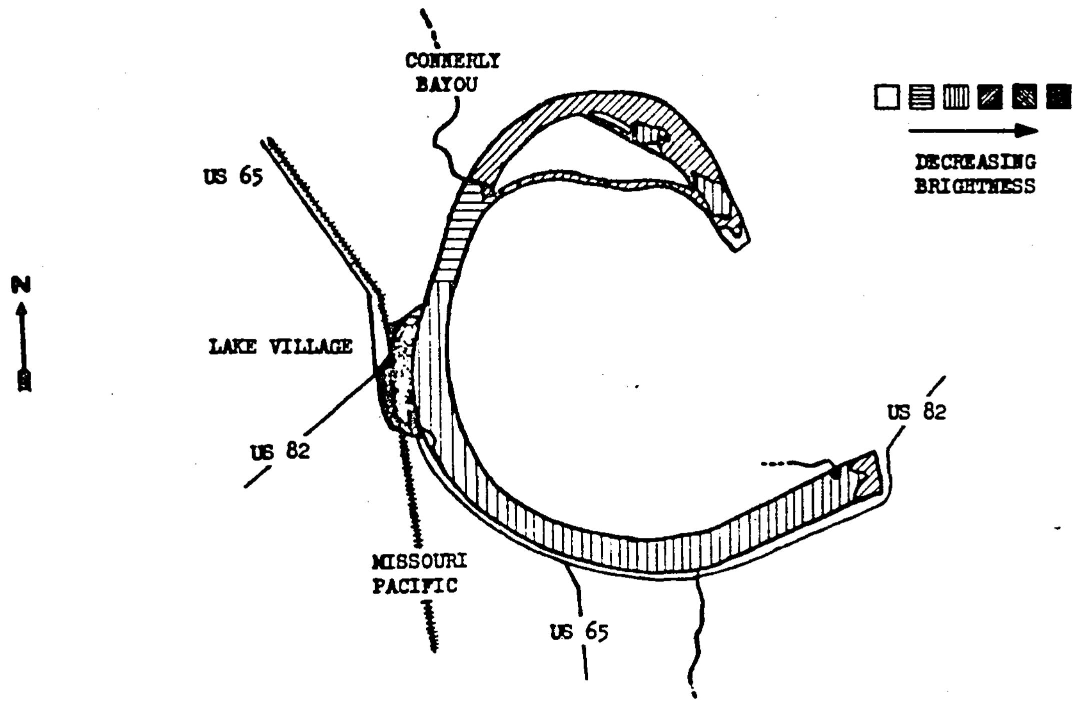
(b) Band 7

Figure 2.- Landsat images of Lake Chicot for September 22, 1974.

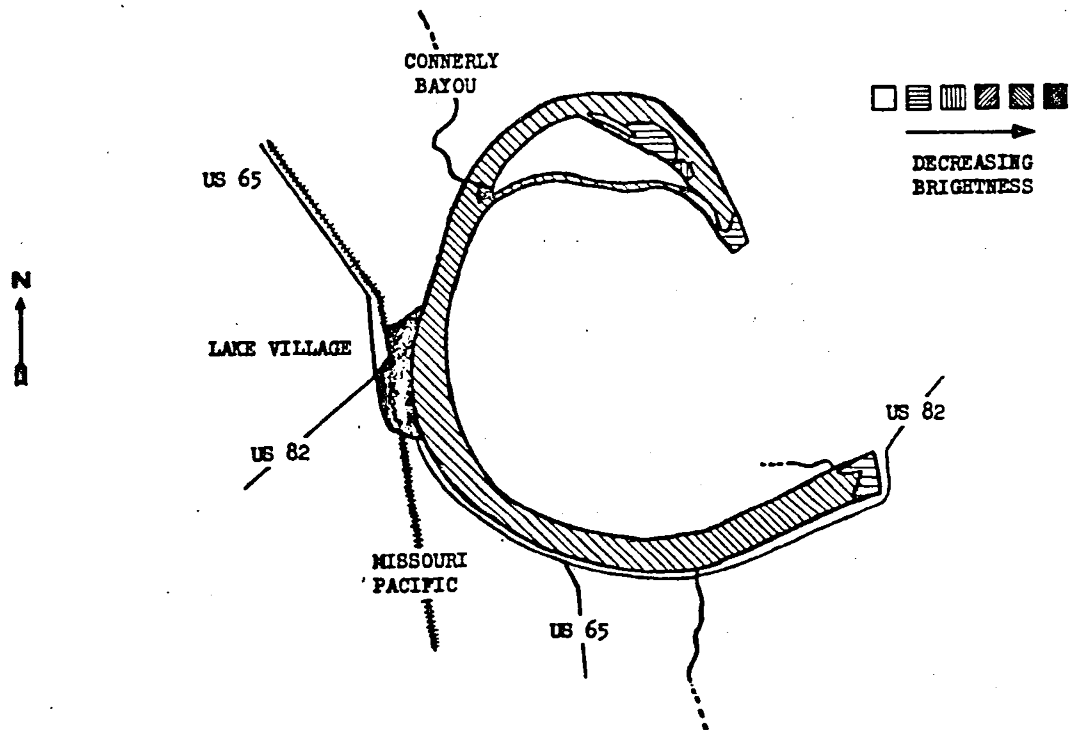
(a) Band 5

(b) Band 7

Figure 3.- Landsat images of Lake Chicot for April 14, 1979.




(a) Band 5




(b) Band 7

Figure 4.- Sketch of Landsat images of Lake Chicot for October 11, 1979.

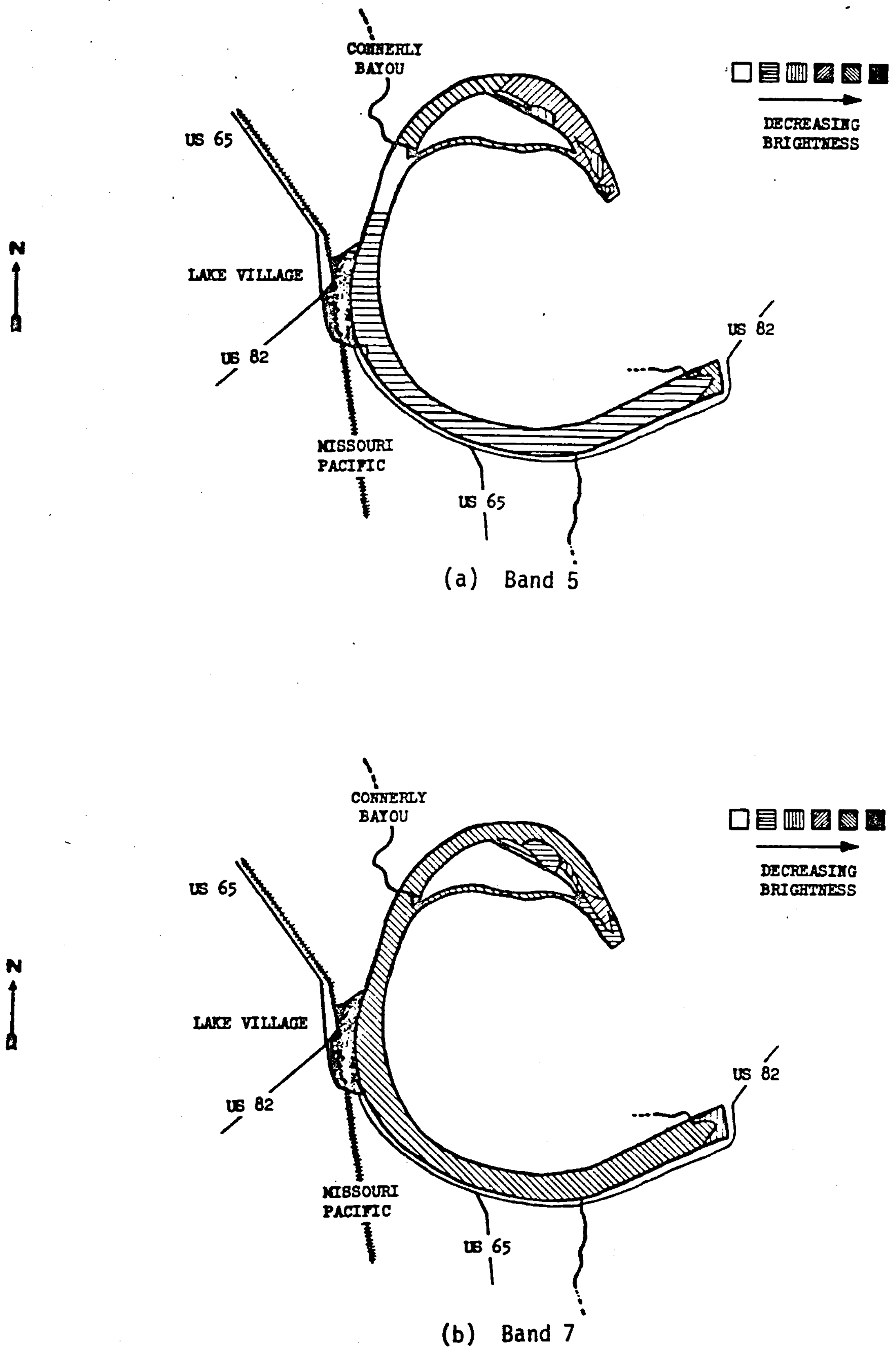
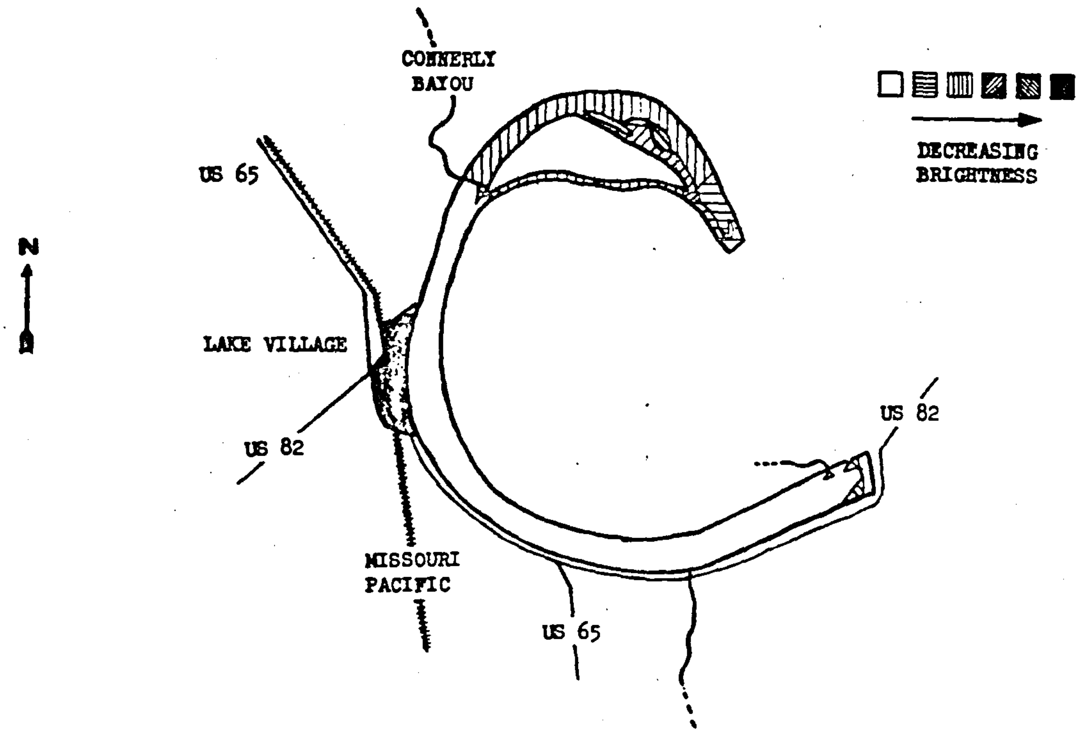
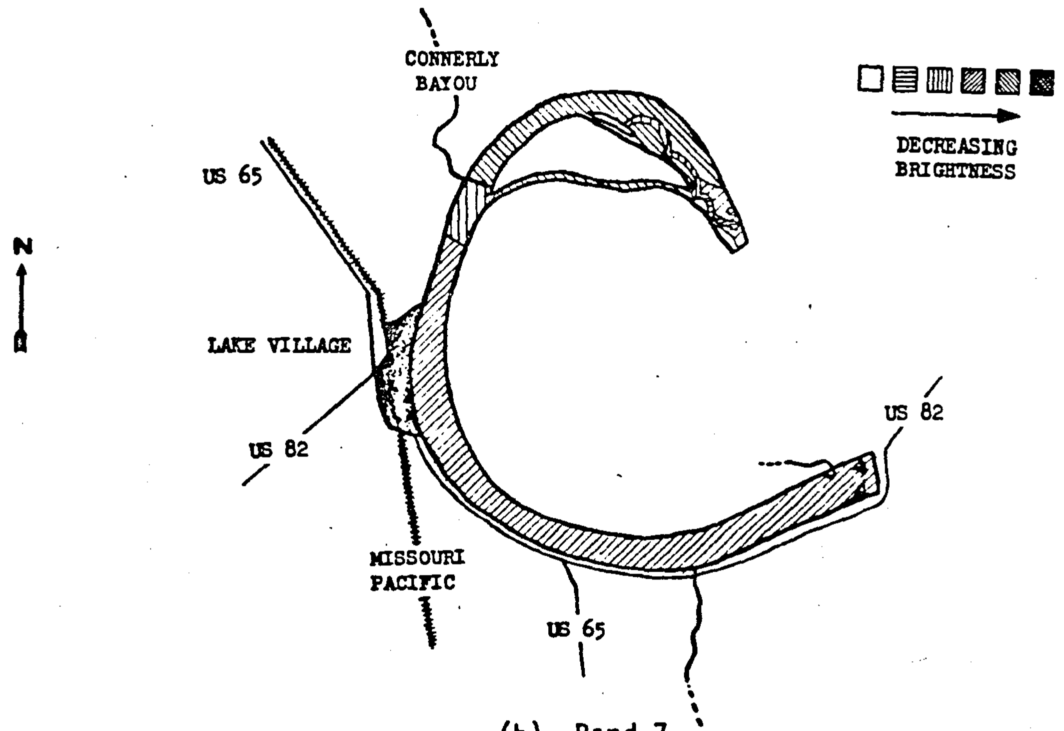



Figure 5.- Sketch of Landsat images of Lake Chicot for September 14, 1979.

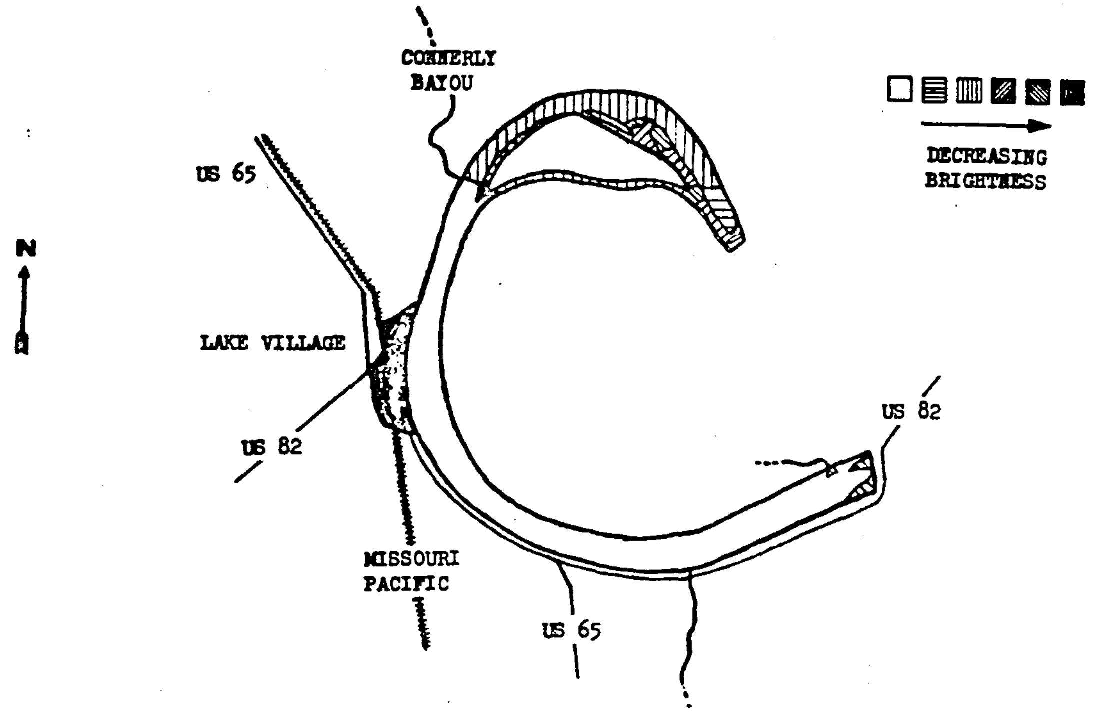



(a) Band 5

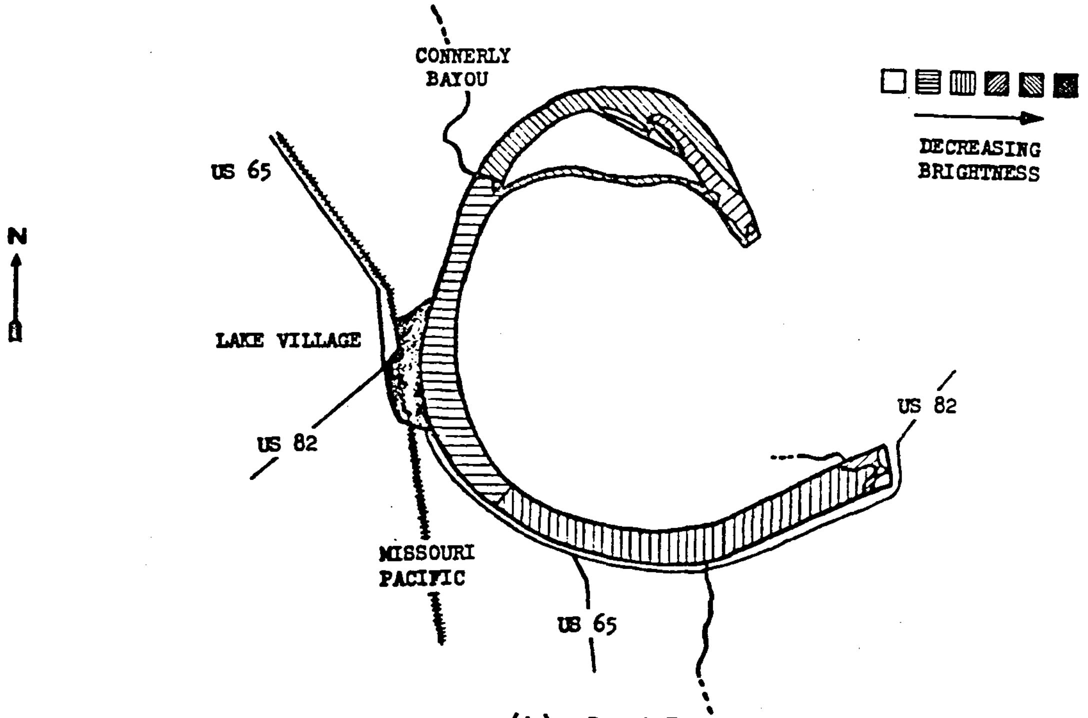



(b) Band 7

Figure 6.- Sketch of Landsat images of Lake Chicot for April 14, 1979.

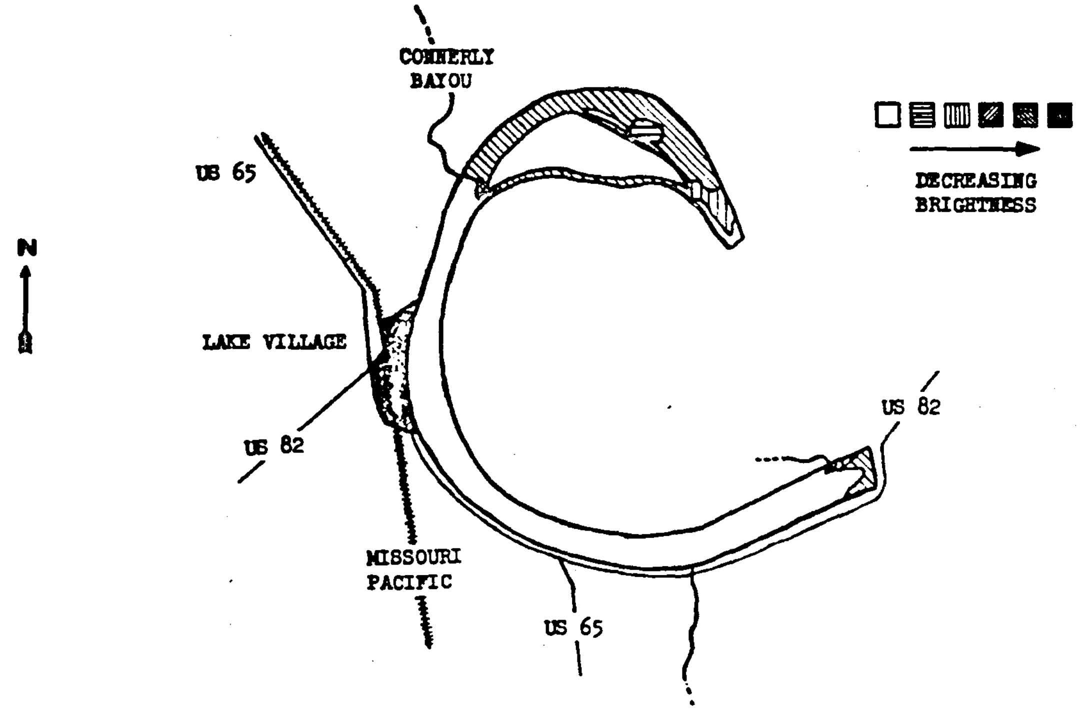



(a) Band 5

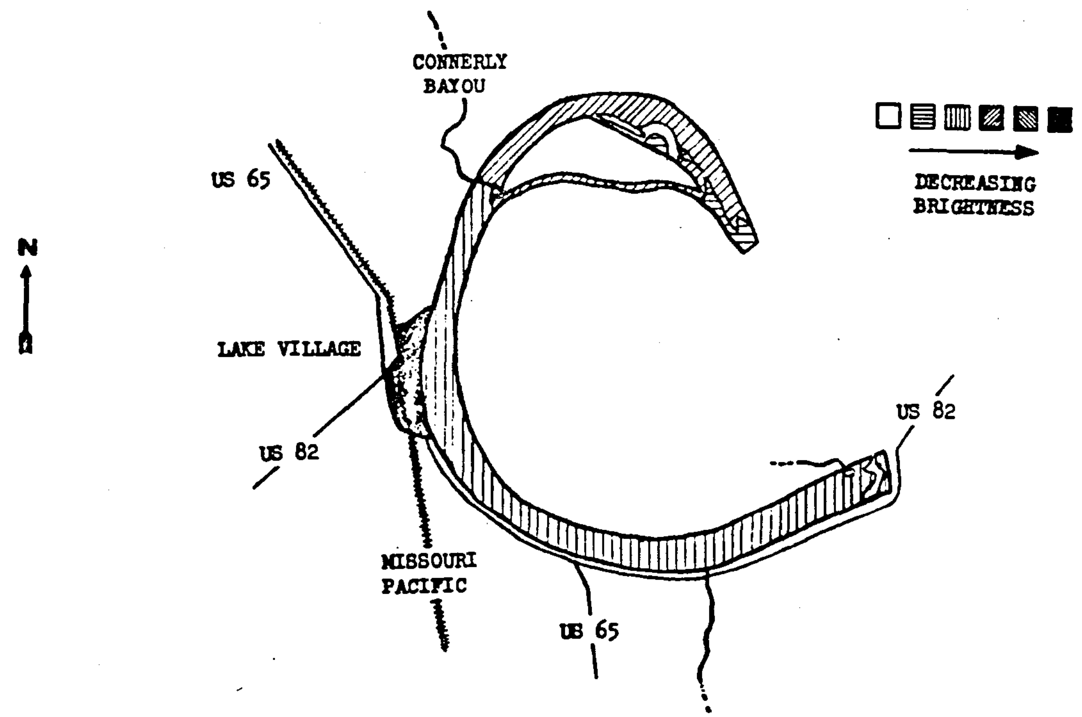



(b) Band 7

Figure 7.- Sketch of Landsat images of Lake Chicot for March 9, 1979.

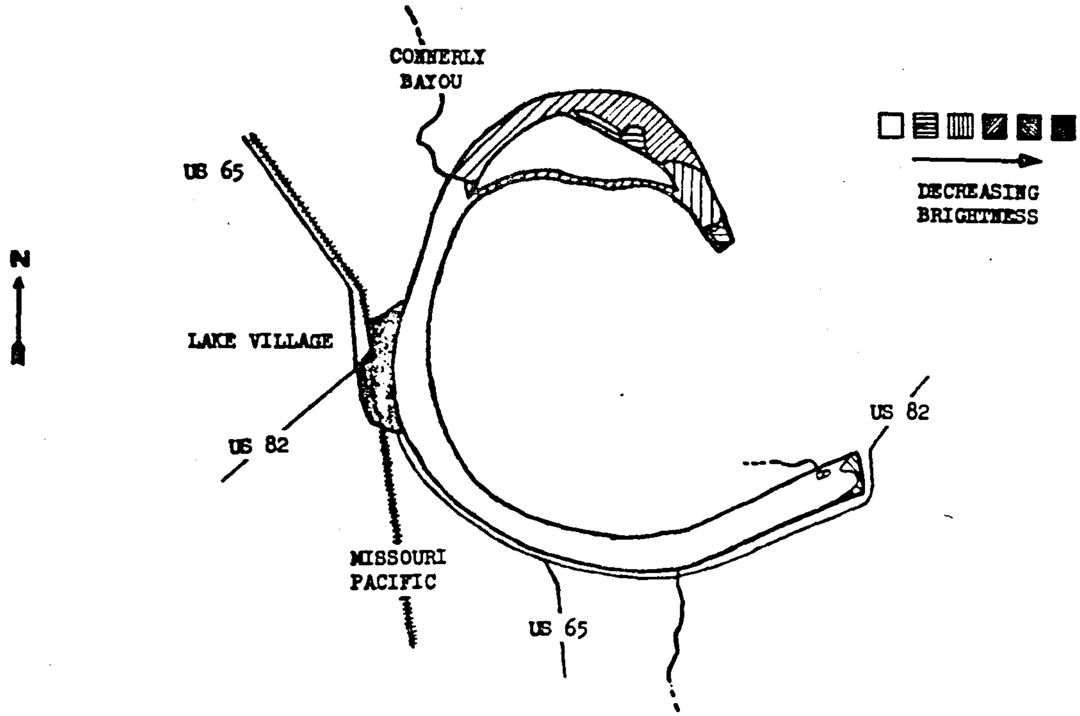



(a) Band 5

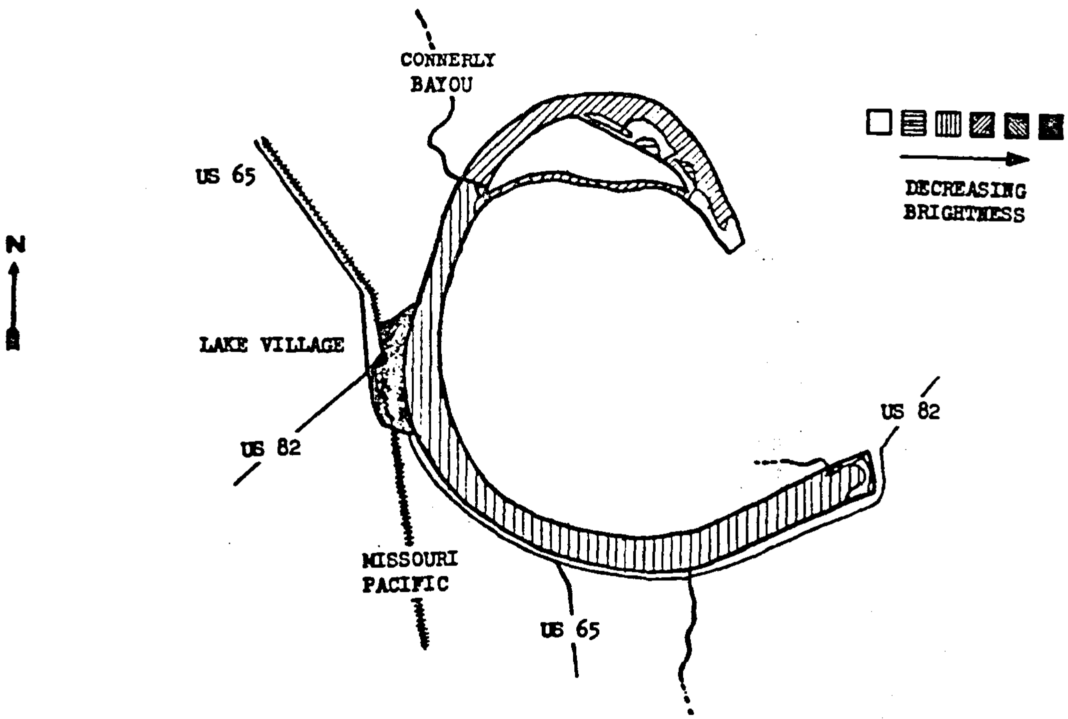



(b) Band 7

Figure 8.- Sketch of Landsat images of Lake Chicot for April 28, 1978.

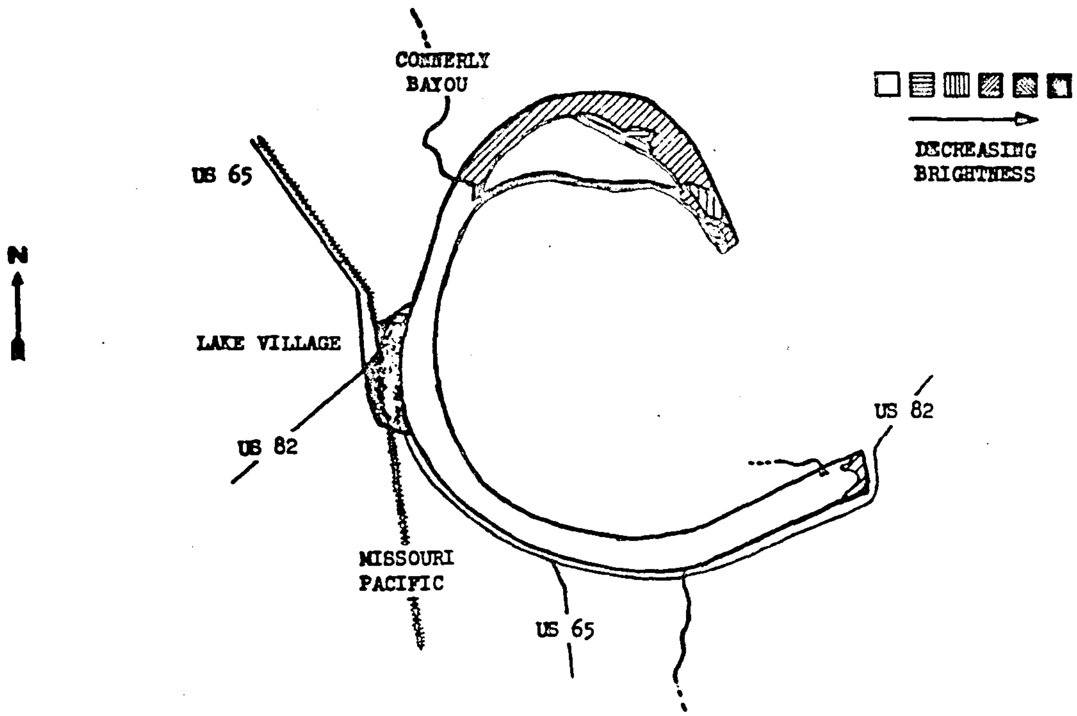



(a) Band 5

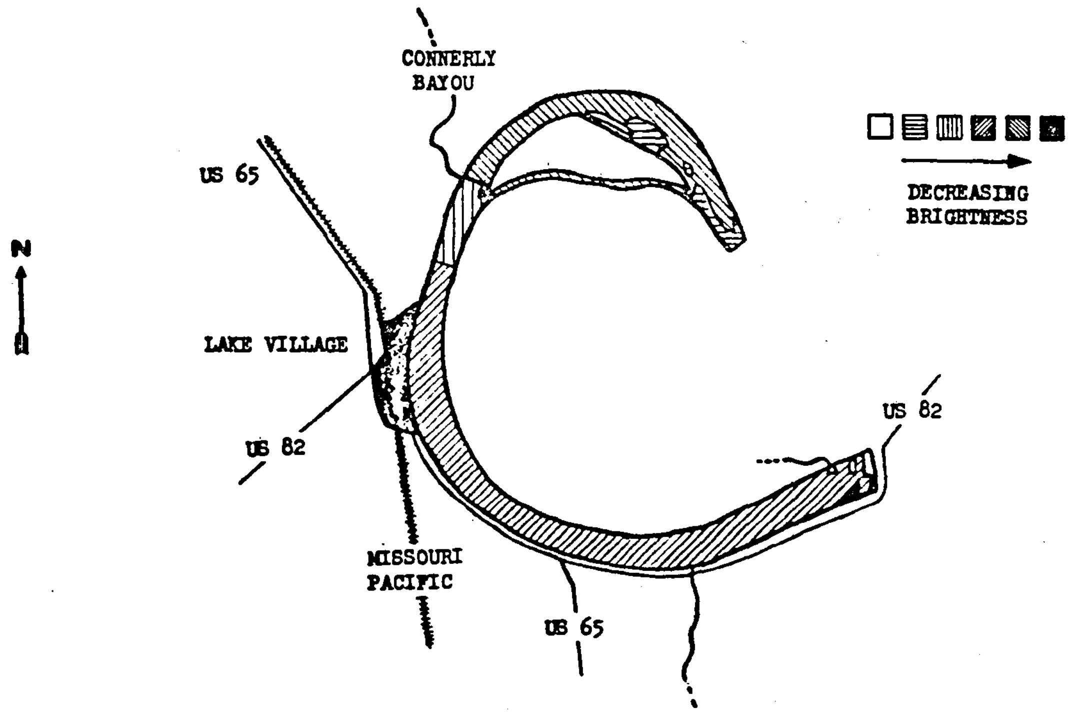



(b) Band 7

Figure 9.- Sketch of Landsat images of Lake Chicot for June 5, 1977.

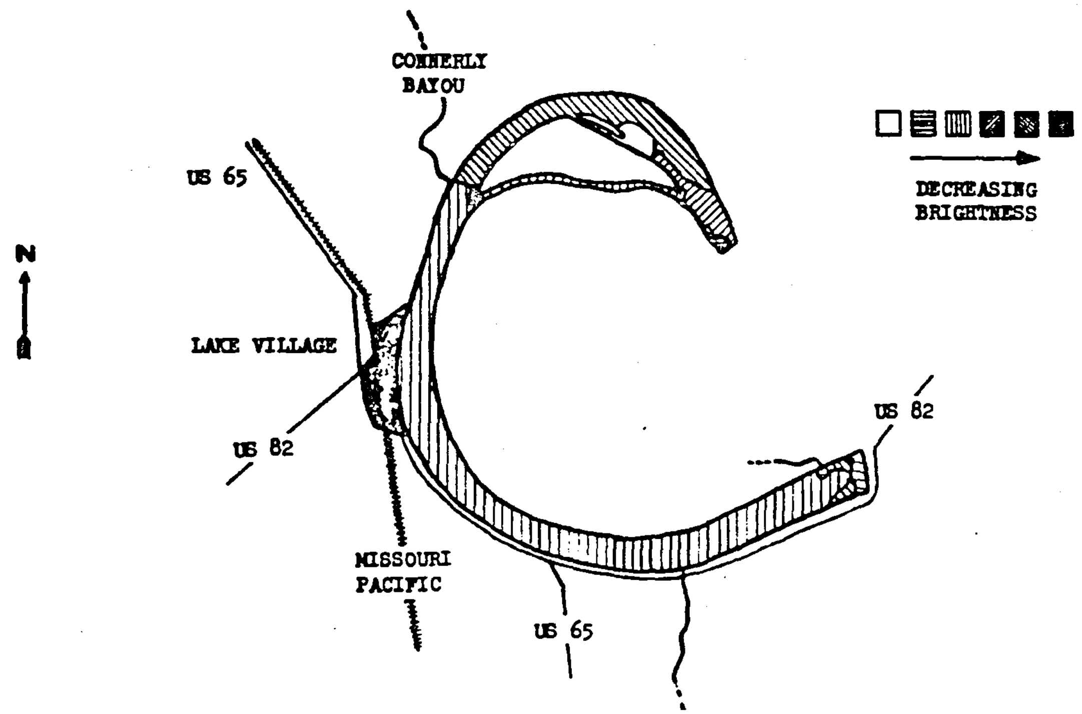



(a) Band 5

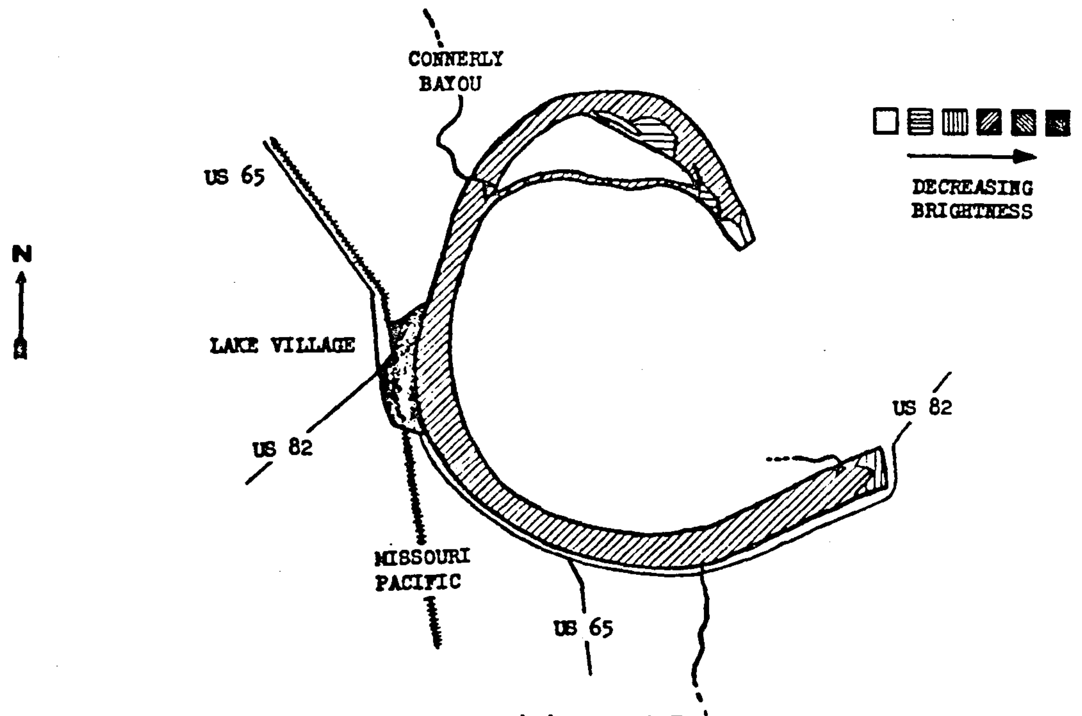



(b) Band 7

Figure 10.- Sketch of Landsat images of Lake Chicot for April 6, 1977.

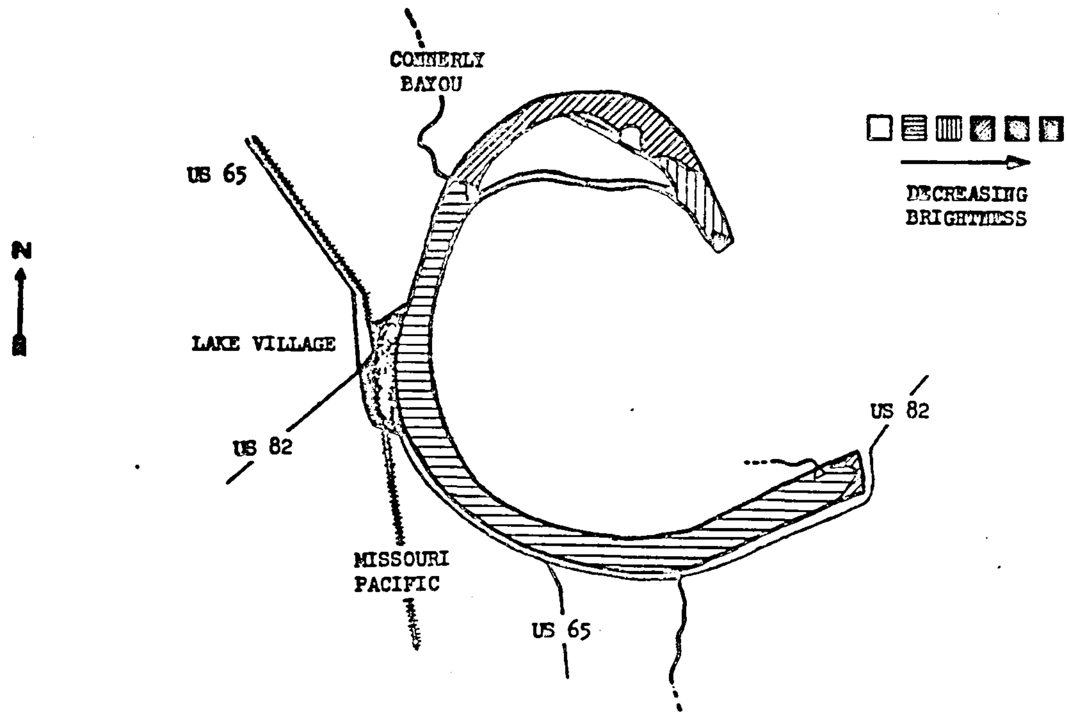



(a) Band 5

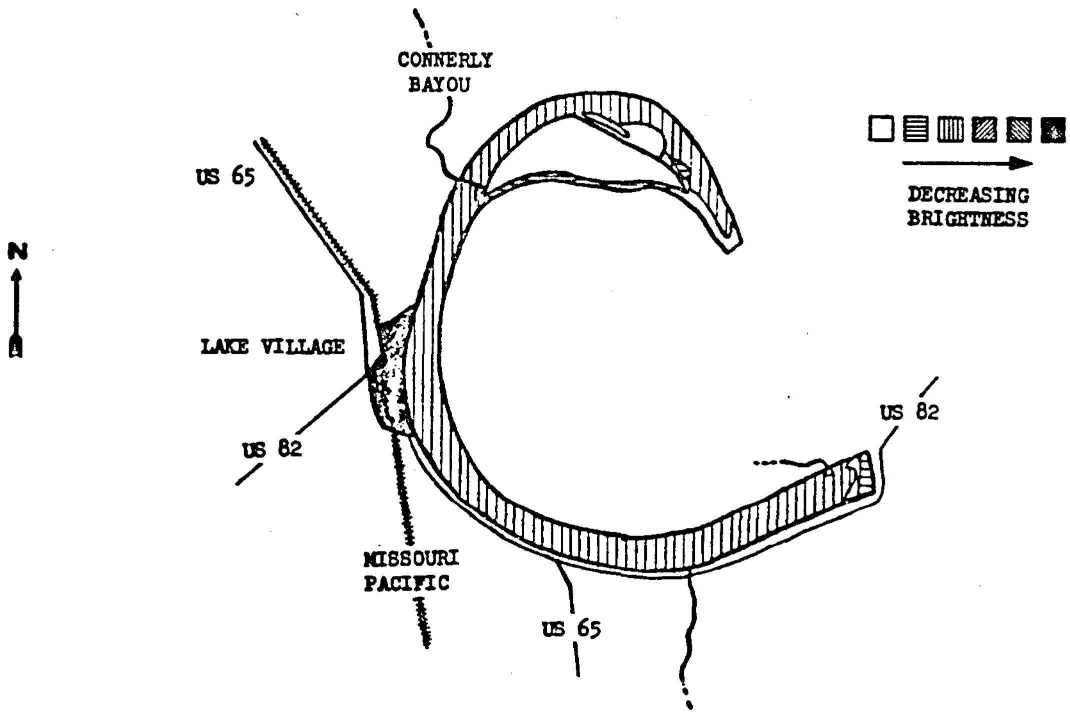



(b) Band 7

Figure 11.- Sketch of Landsat images of Lake Chicot for March 1, 1977.

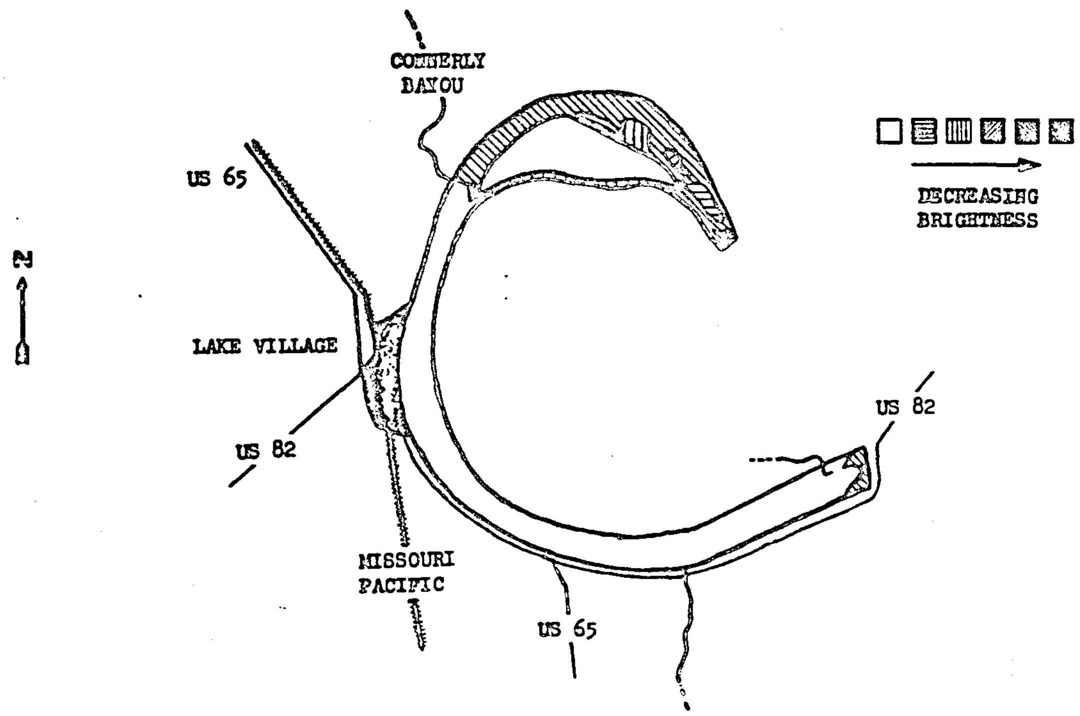



(a) Band 5

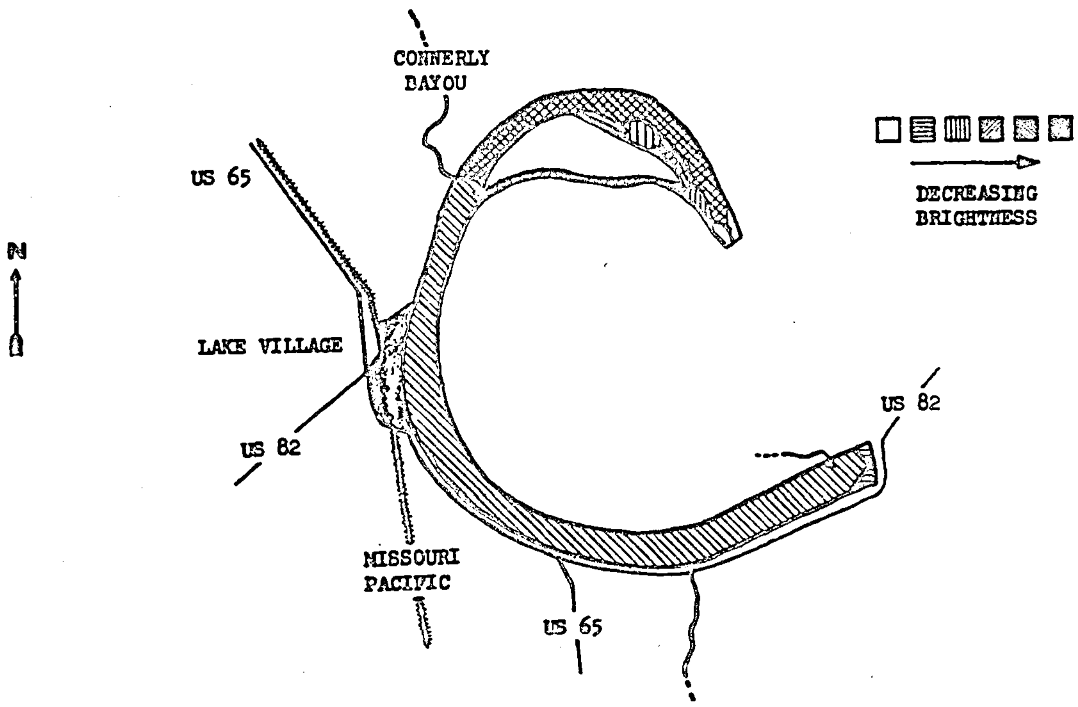



(b) Band 7

Figure 12.- Sketch of Landsat images of Lake Chicot for June 13, 1976.

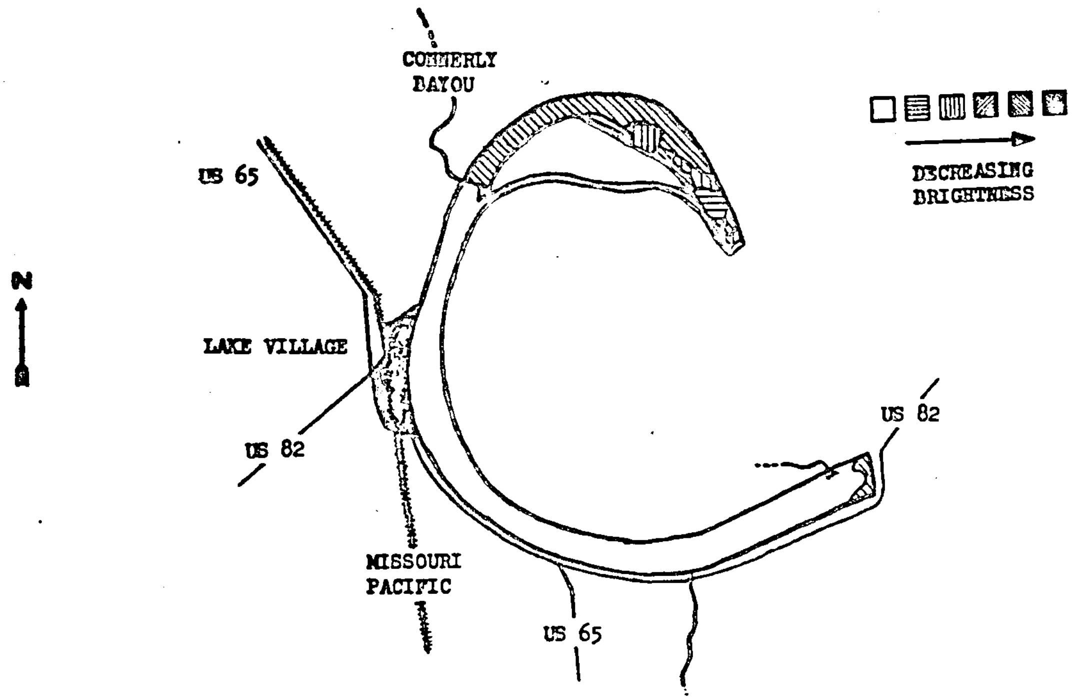



(a) Band 5

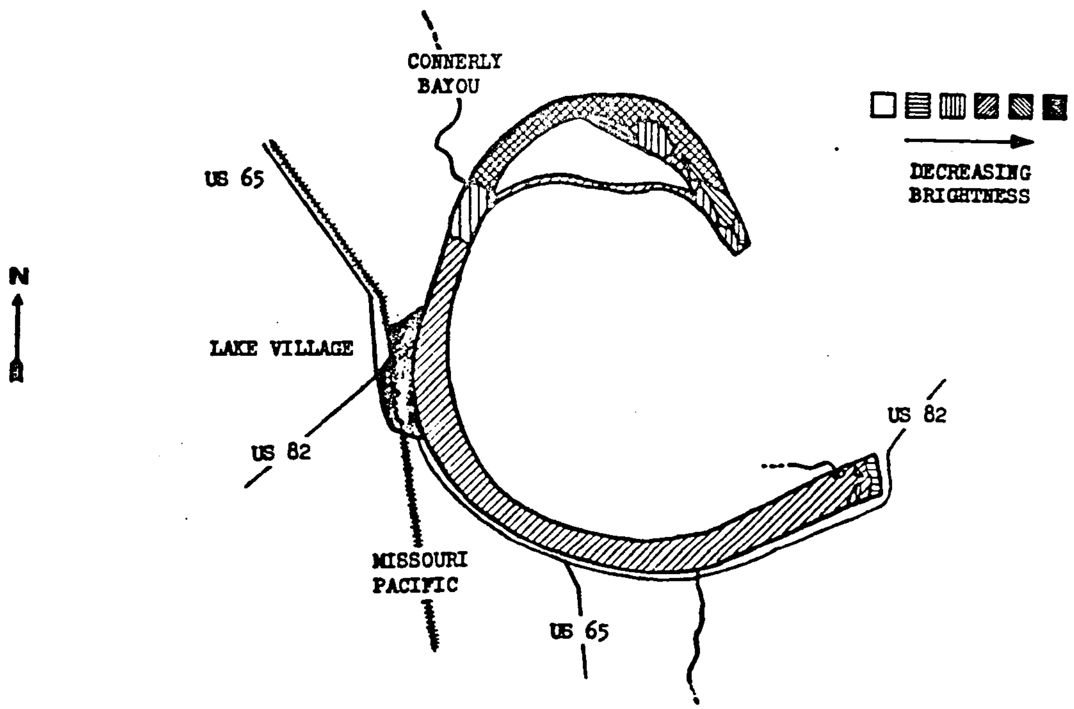



(b) Band 7

Figure 13.- Sketch of Landsat images of Lake Chicot for April 11, 1976.

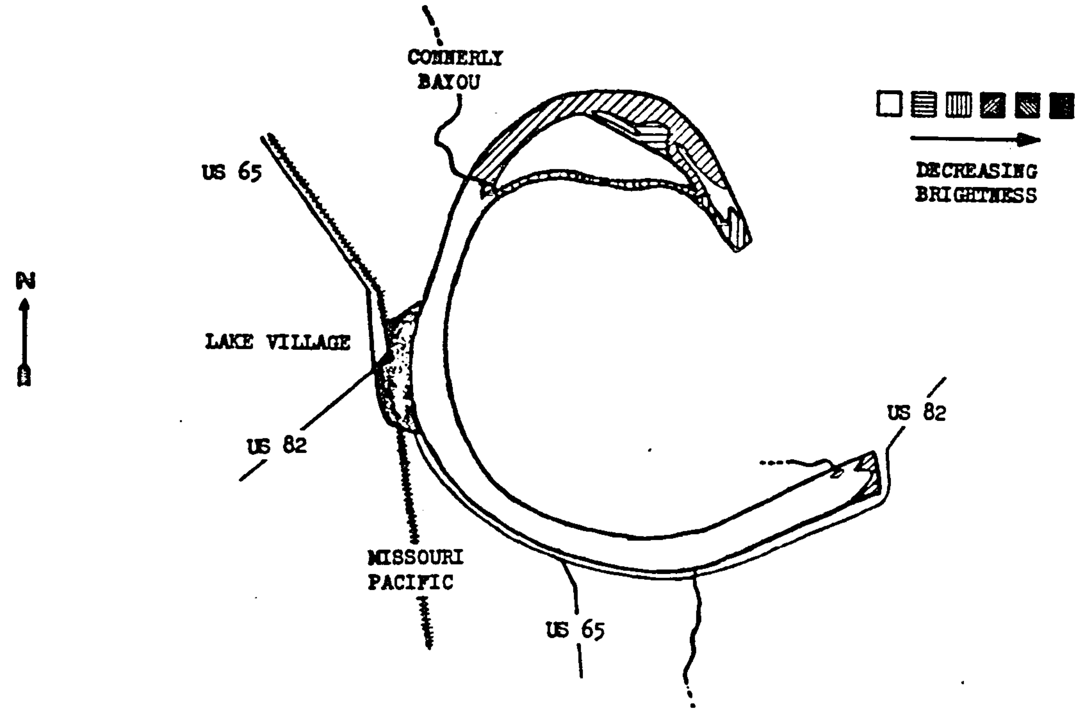



(a) Band 5

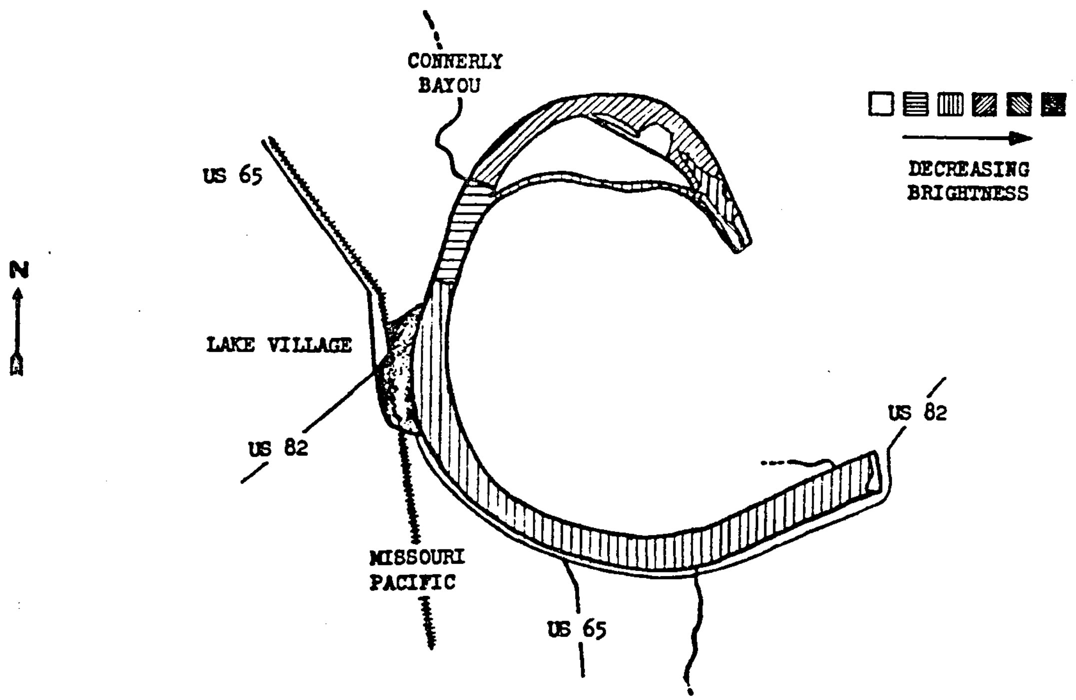



(b) Band 7

Figure 14.- Sketch of Landsat images of Lake Chicot for April 2, 1976.

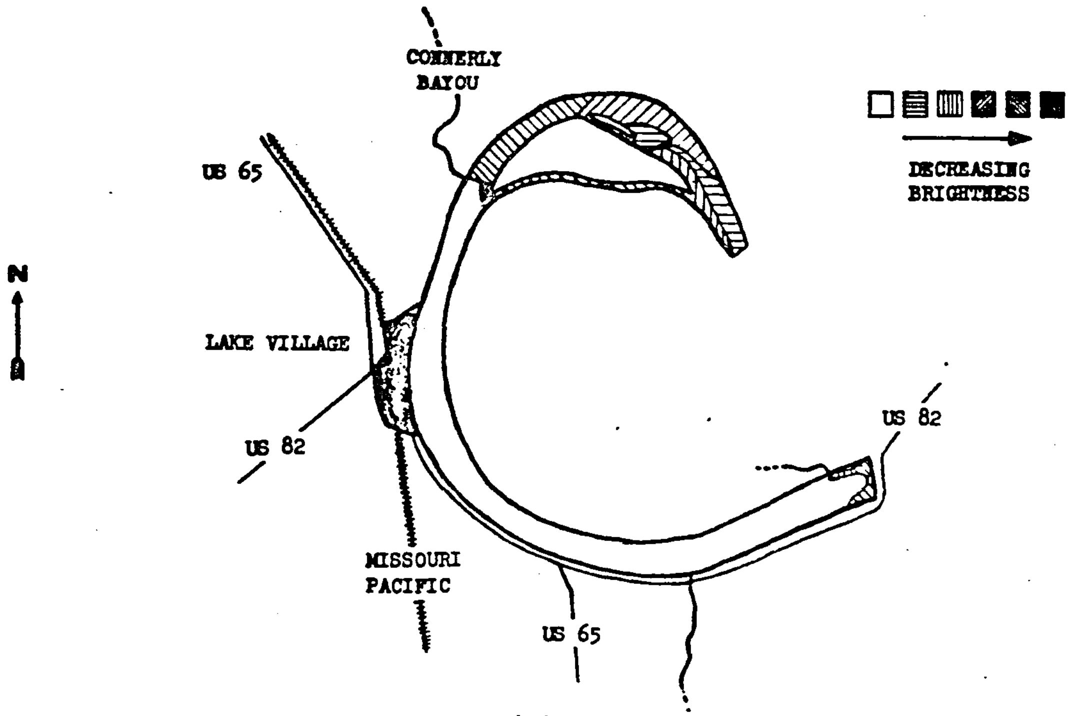



(a) Band 5

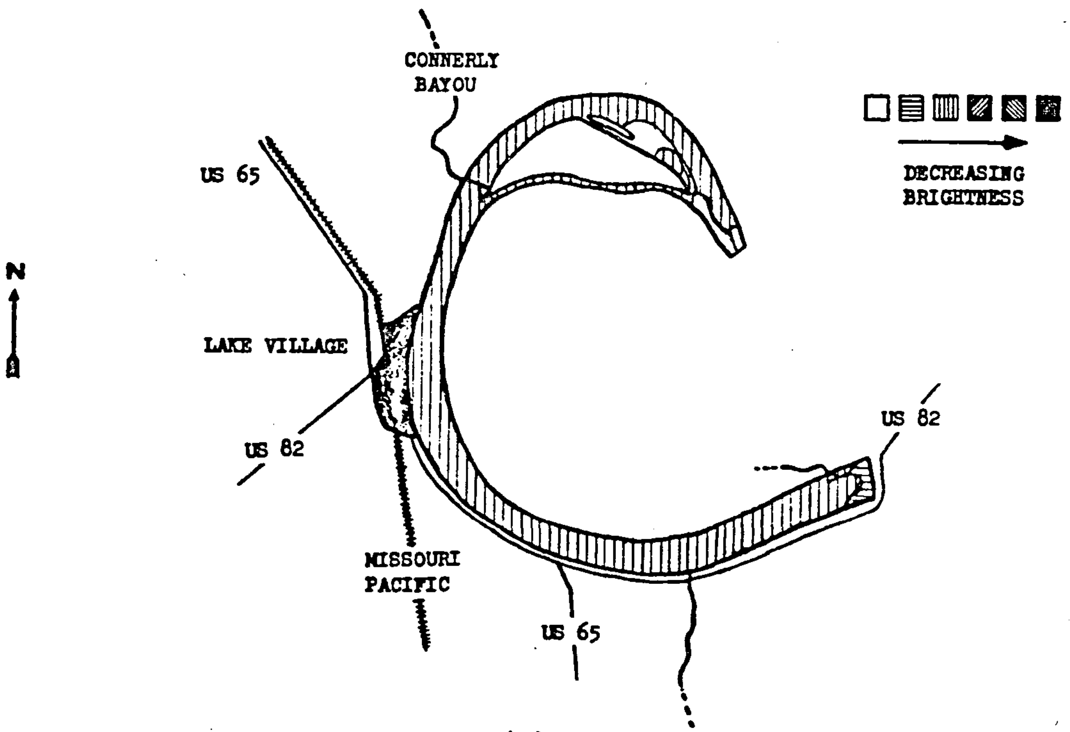



(b) Band 7

Figure 15.- Sketch of Landsat images of Lake Chicot for February 26, 1976.

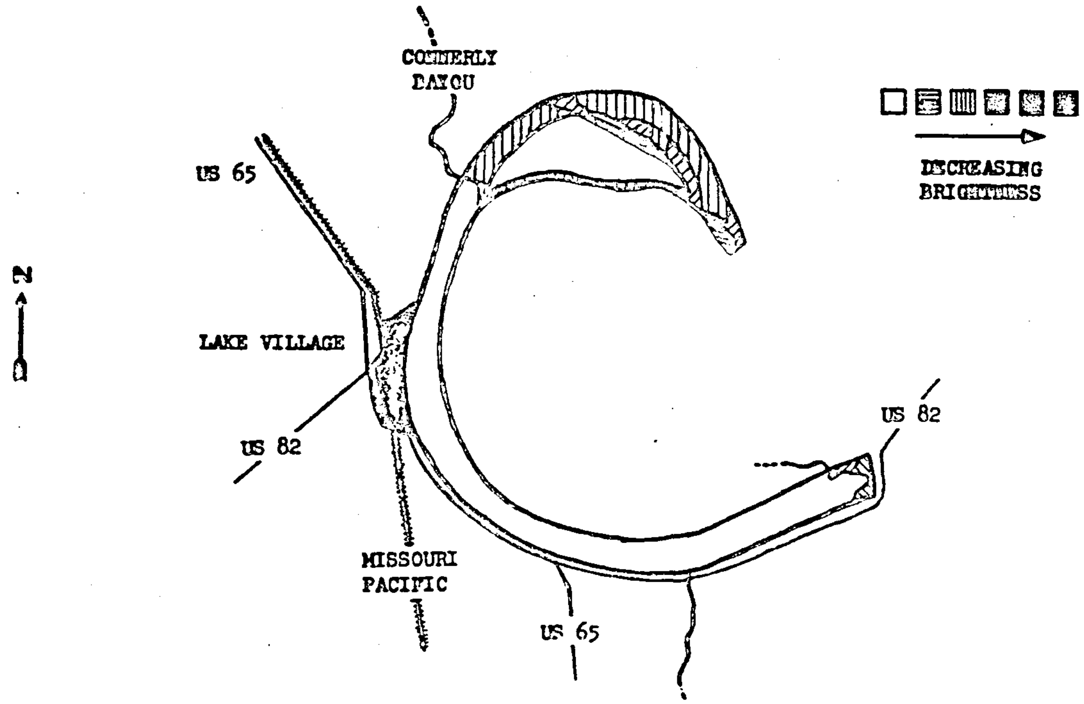



(a) Band 5

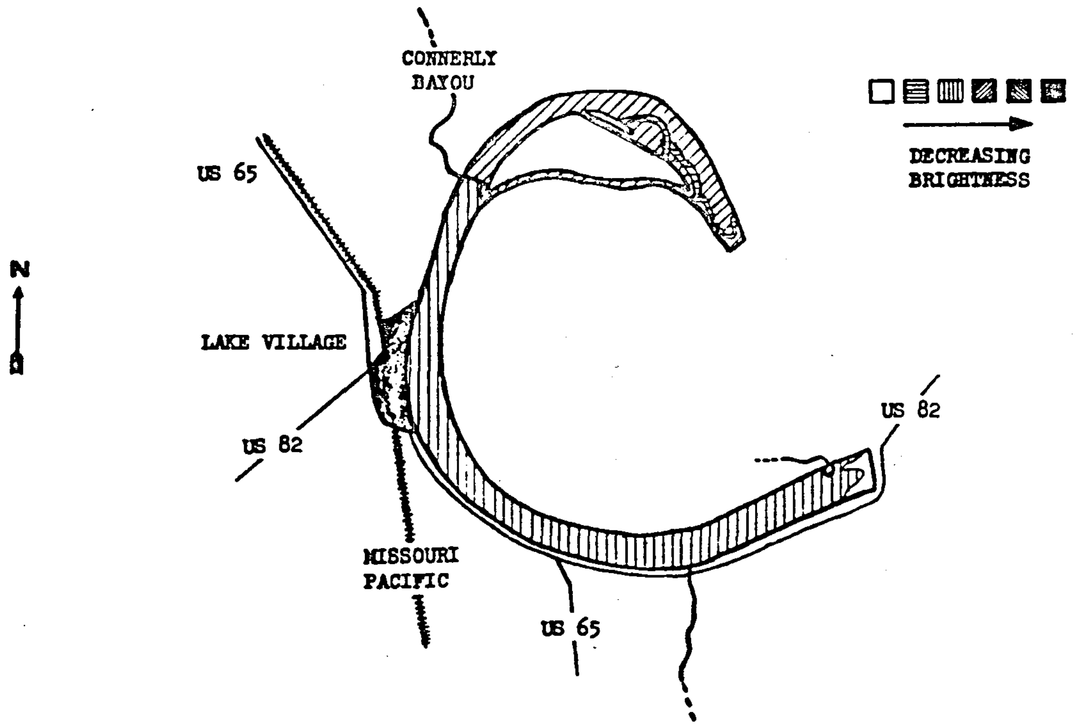



(b) Band 7

Figure 16.- Sketch of Landsat images of Lake Chicot for September 22, 1974.

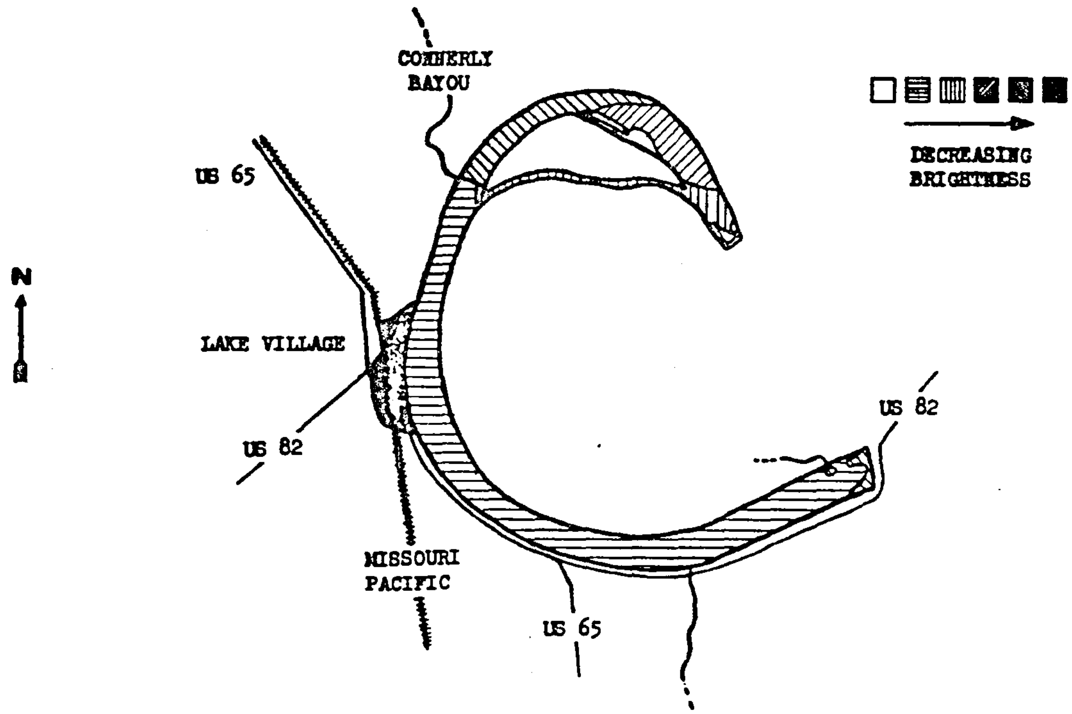



(a) Band 5

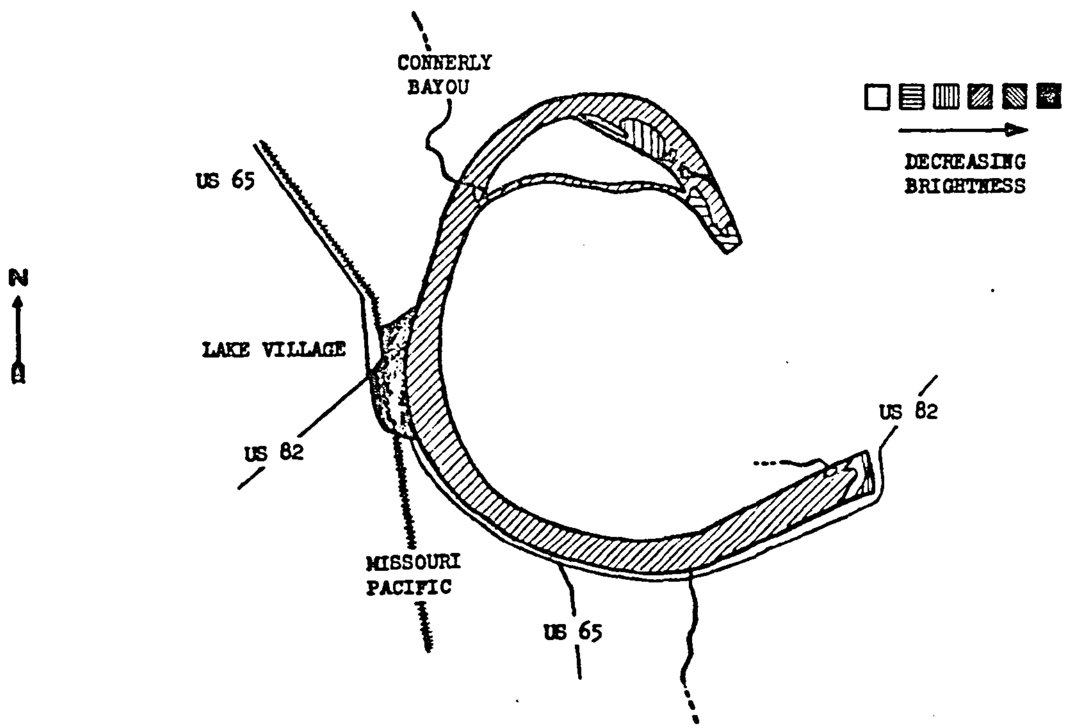



(b) Band 7

Figure 17.- Sketch of Landsat images of Lake Chicot for June 24, 1974.

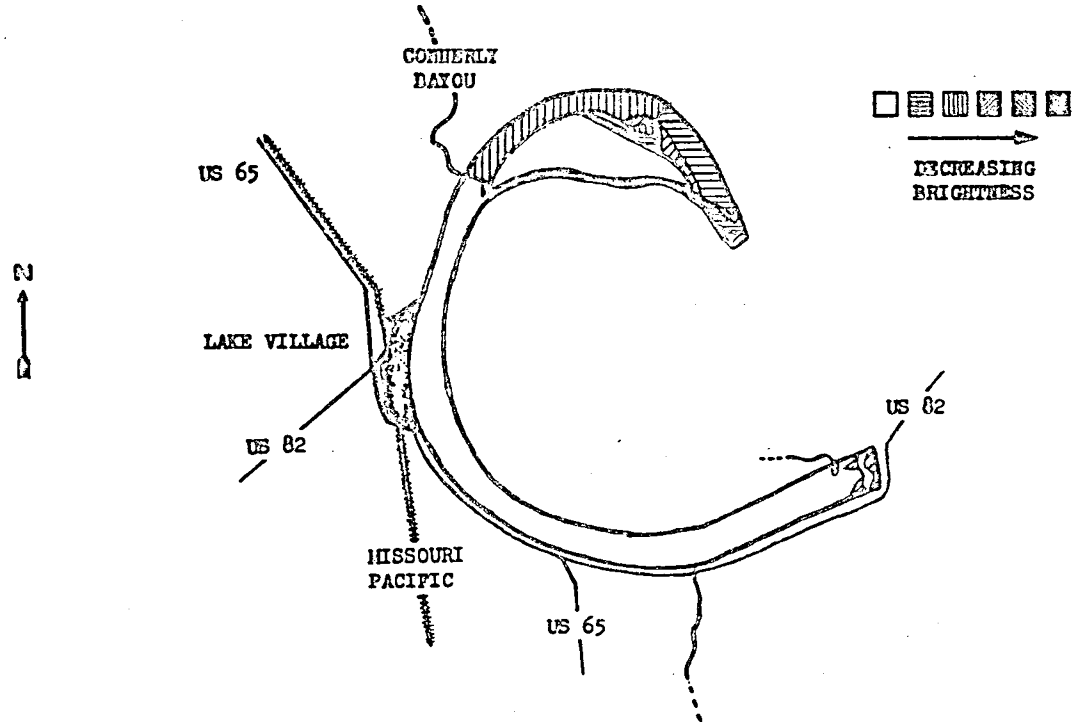



(a) Band 5

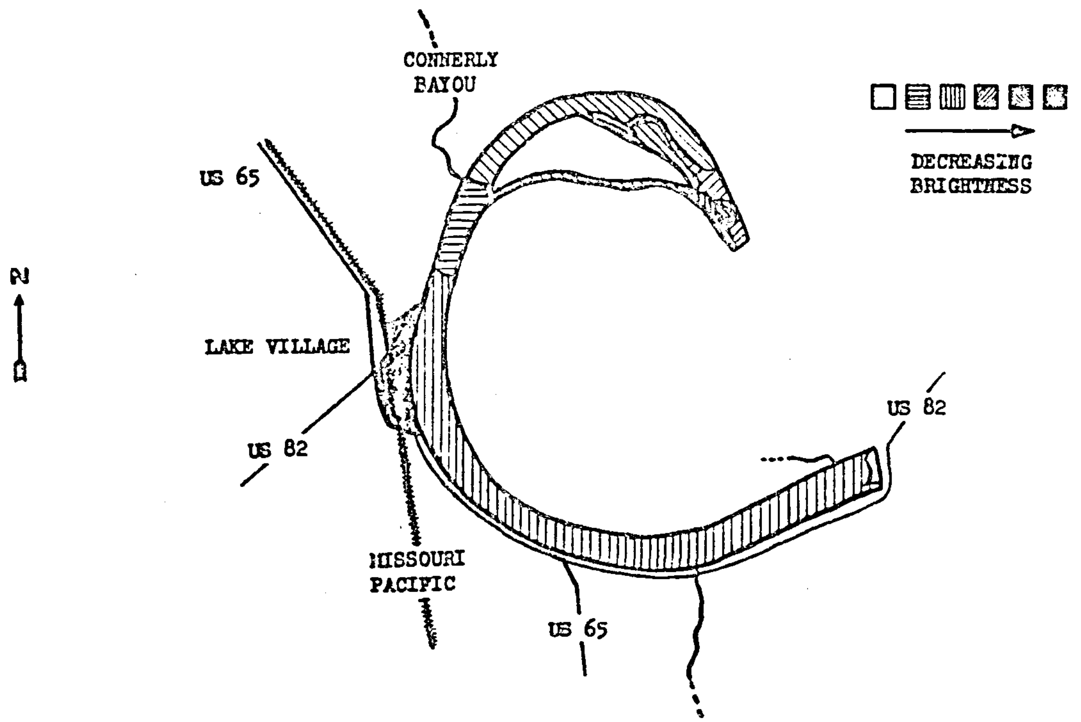



(b) Band 7

Figure 18.- Sketch of Landsat images of Lake Chicot for May 19, 1974.

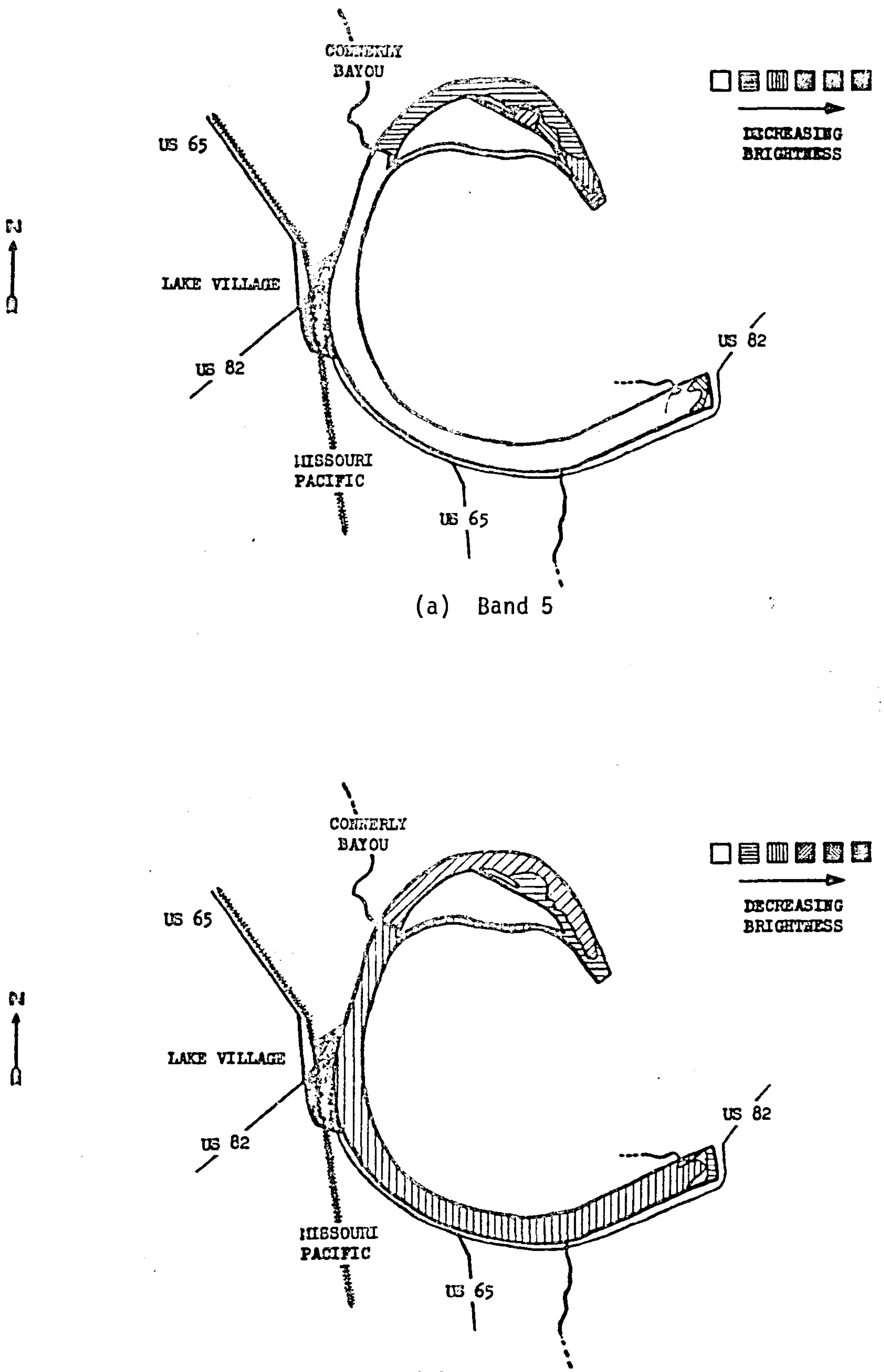



(a) Band 5




(b) Band 7

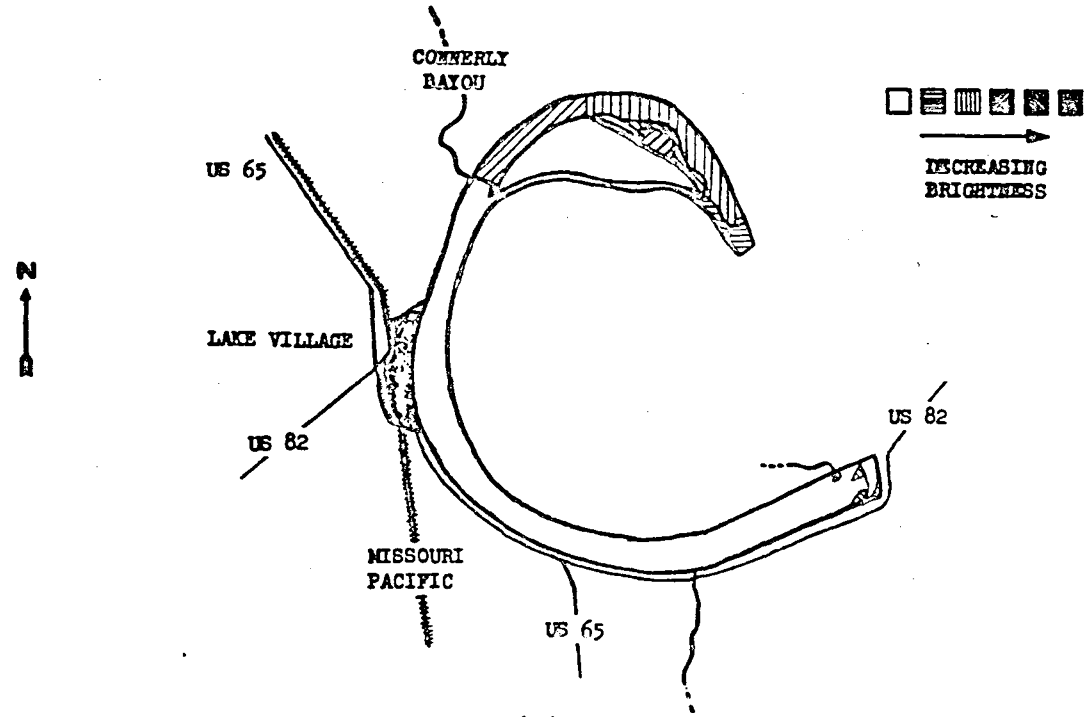
Figure 19.- Sketch of Landsat images of Lake Chicot for January 31, 1974.



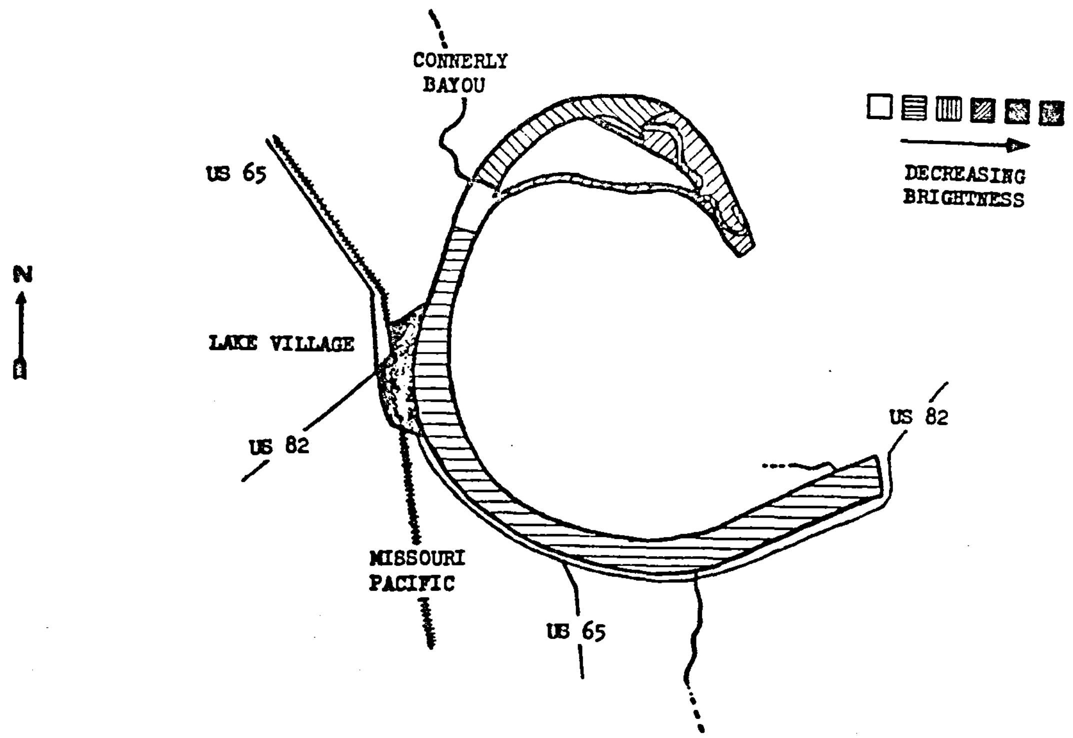

(a) Band 5

(b) Band 7

Figure 20.- Sketch of Landsat images of Lake Chicot for May 24, 1973.

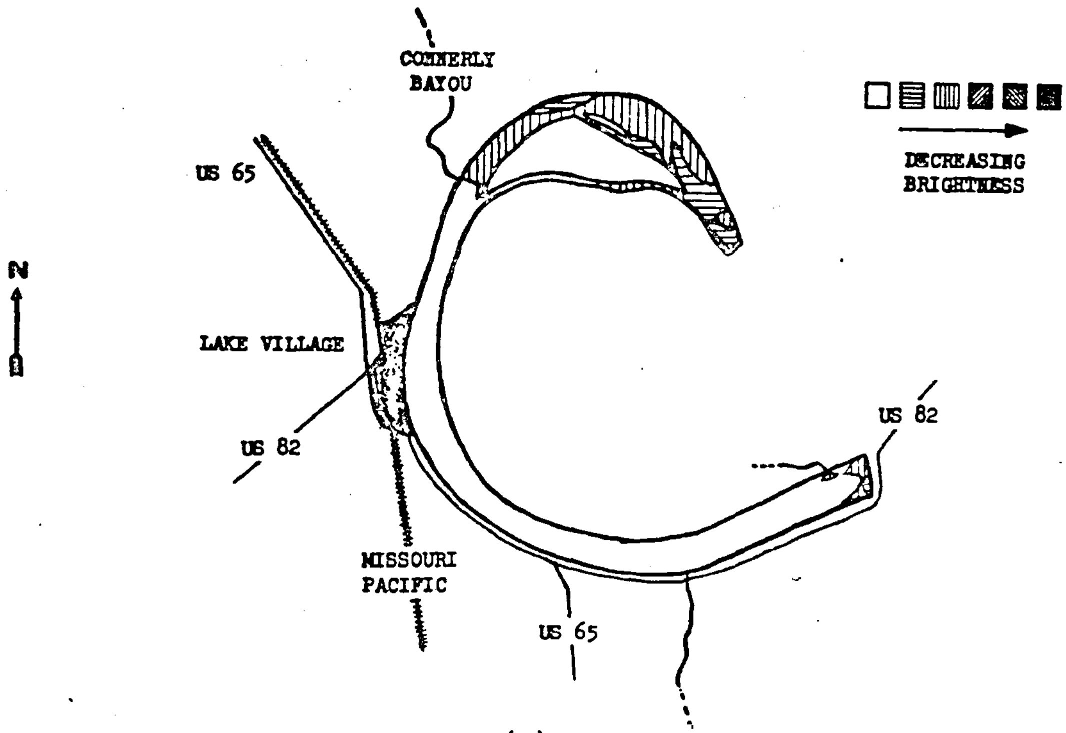



(a) Band 5

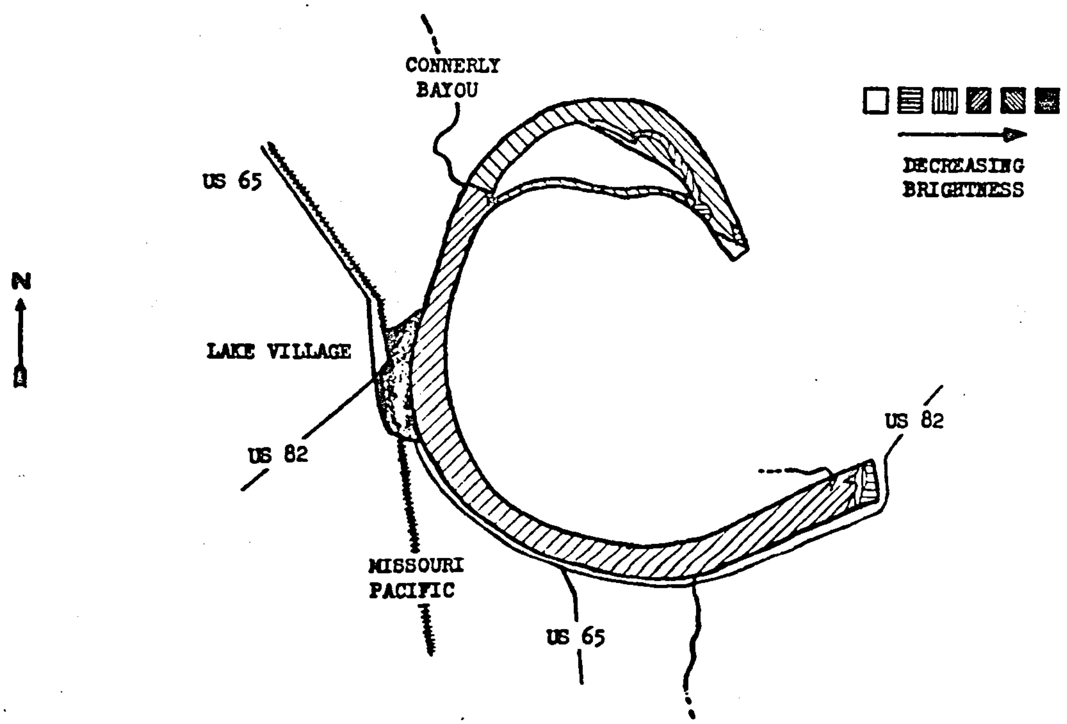



(b) Band 7

Figure 21.- Sketch of Landsat images of Lake Chicot for March 31, 1973.

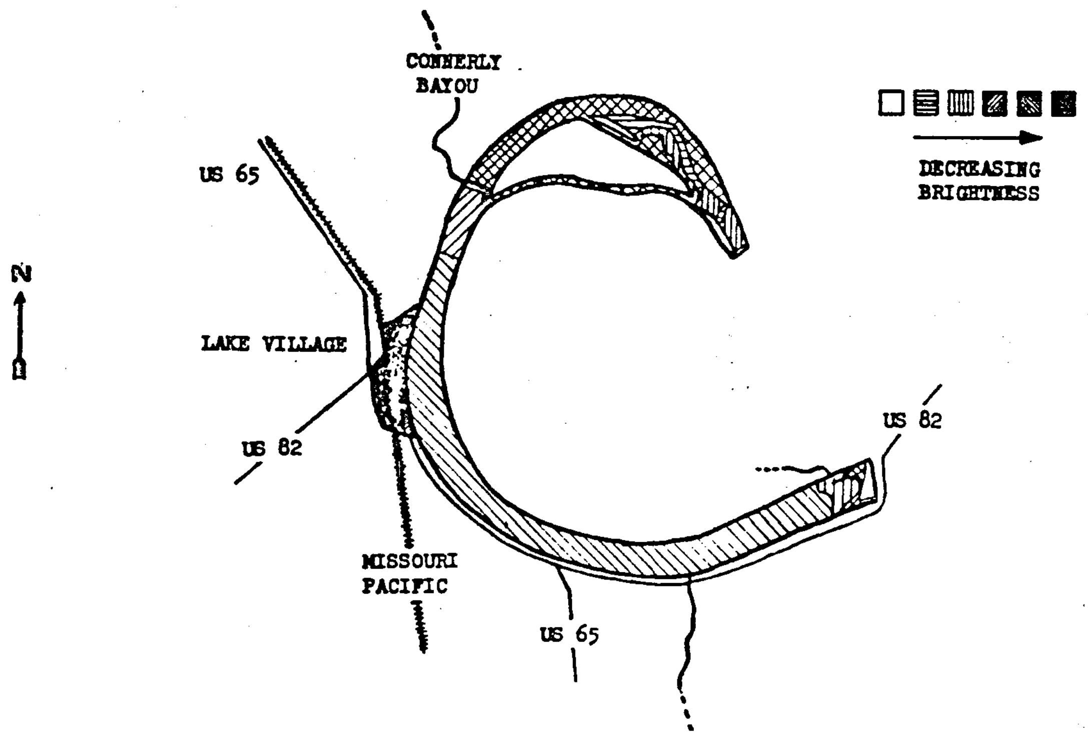



(a) Band 5

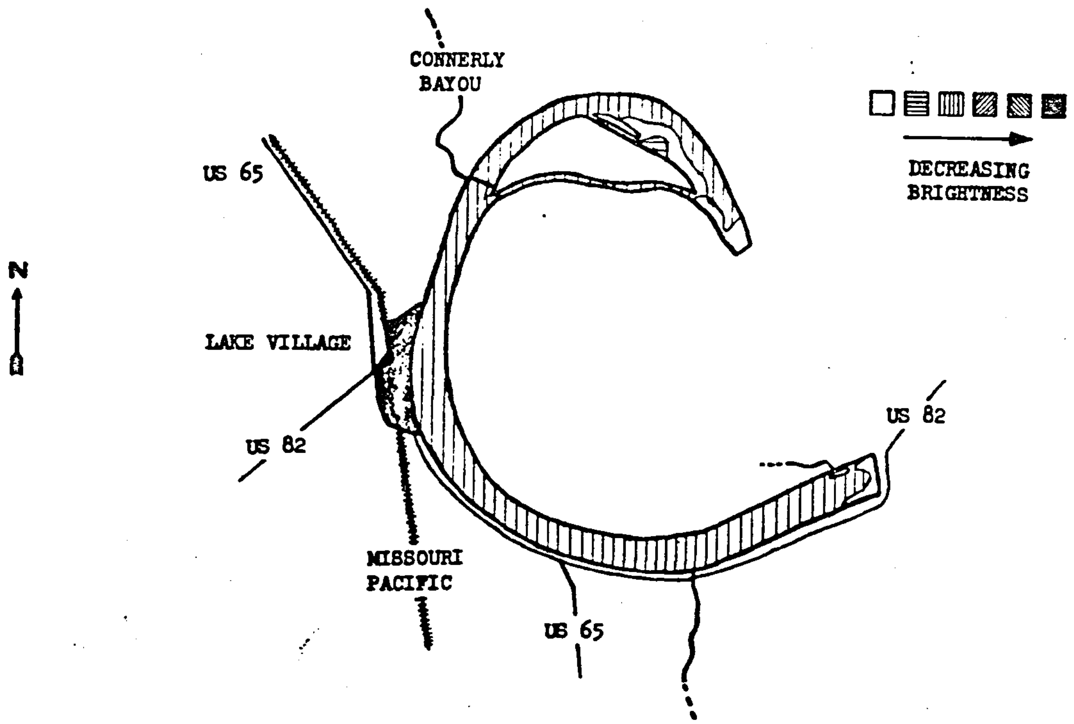



(b) Band 7

Figure 22.- Sketch of Landsat images of Lake Chicot for December 31, 1972.




(a) Band 5




(b) Band 7

Figure 23.- Sketch of Landsat images of Lake Chicot for October 20, 1972.

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15. Supplementary Notes

Langley Technical Monitor: Dr. Charles H. Whitlock

16. Abstract

A historical analysis of all the applicable Landsat imagery was conducted on the turbidity patterns of Lake Chicot, located in the Southeastern corner of Arkansas. By examining the seasonal and regional turbidity patterns, a record of sediment dynamics and possible disposition can be obtained. Sketches were generated from the suitable imagery, displaying different intensities of brightness observed in bands 5 and 7 of Landsat's multispectral scanner data. Differences in and between bands 5 and 7 indicate variances in the levels of surface sediment concentrations. High sediment loads are revealed when distinct patterns appear in the band 7 imagery. Additionally, the upwelled signal is exponential in nature and saturates in band 5 at low wavelengths for large concentrations of suspended solids.

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