APPLICATION OF LANDSAT IMAGES TO WETLAND STUDY AND LAND USE CLASSIFICATION IN WEST TENNESSEE

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Original photography may be purchased from:
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Sioux Falls, SD

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FINAL REPORT
PART I

NOTICE

The intention of this report is to provide information and instruction for the uninitiated or potential user of remote sensing data. It is directed towards an audience involved in local, state, and regional activities or governments who have had little or no exposure to the potential uses of such data.

Information is given on basic equipment and methods for analysis of photographic data obtained from Landsat as well as high and low altitude aircraft. In addition, instructions are provided for utilizing such equipment and methods to explore a specific application. This application involves a study to determine land use classifications for a selected watershed in West Tennessee with special emphasis on determining wetland boundaries, and thereby provide resource information to appropriate agencies for management and preservation programs.

ABSTRACT

The Obion-Forked Deer River Basin in northwest Tennessee is confronted with several acute land use problems which contribute to excessive erosion, sedimentation, pollution, and hydrologic runoff. In order to assist with resource planning in this basin, the objective of this study was to demonstrate the application and utilization of Landsat data in imagery form for determining land use of selected watershed areas within the basin, with special emphasis on determining wetland boundaries.

Densitometric analysis was performed to allow the numerical classification of objects observed in the imagery on the basis of measurements of optical densities. Relative light transmission measurements were taken on four types of scene elements in each of three Landsat black and white bands in order to determine which classifications could be distinguished. The analysis of band 6 determined forest and agricultural classifications to be significantly different, but the urban and wetlands classifications were not. Both bands 4 and 5 showed a significant difference existed between the combined classification of wetlands-agriculture and urban areas. Therefore, the combination of band 6 with either band 4 or 5 would permit the separation of the urban from the wetland classification.

In order to enhance the urban areas as well as the wetland boundaries, the Landsat black and white bands were

combined in a multispectral additive color viewer. Several combinations of filters and light intensities were used to obtain maximum discrimination between points of interest. The best results for enhancing wetland boundaries and urban areas were achieved by using a color composite (i.e. a blue, green, and red filter on bands 4, 5, and 6 respectively).

Using the Tennessee Land Use Classification System, Level I classifications were determined on a 1:250,000 scale Landsat color composite and on 1:130,000 high altitude color infrared photography for a specified watershed. Level II classifications were done on 1:24,000 scale photography. Areas were calculated for the various classifications at each scale. The percentage of difference or error was calculated between the low altitude control data and each of the other scales in order to indicate their level of accuracy.

Differences in acreage between the Landsat imagery and the low altitude imagery related primarily to resolution limitations of the Landsat data and not to an inability to differentiate between classifications. Use of the additive color viewer demonstrated that the desired classifications could be separated. From this study, it was concluded that Landsat data in imagery form can be used effectively to determine wetland boundaries, and can therefore be used to periodically measure remaining acreages and types of wetlands, thereby providing needed resource information for management and preservation programs.

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INTRODUCTION

The aggregate demand for uses of land and water for different purposes has increased the pressures on water and related land resources. In order to facilitate coordinated conservation measures, watershed planning agencies require adequate resource information, especially on current land use.

The objective of this study was to demonstrate the application and utilization of Landsat data for determining land use of selected watershed areas in west Tennessee, with special emphasis on determining wetland boundaries. Three methods of analysis were used to meet this objective.

Densitometric analysis was performed to allow numerical classification of objects observed in the imagery on the basis of measurements of optical densities. Manual mapping and classification techniques were employed not only for the Landsat imagery, but also for high and low altitude photography. Classification boundaries and area calculations were examined as possible sources of error which would decrease the accuracy of classifications from Landsat and high altitude imagery as compared to low altitude control data. In addition, multispectral analysis of the Landsat imagery provided the capability of altering the color of image presentations in order to enhance particular relationships.

CHAPTER I

DISCUSSION OF WETLANDS AND THEIR VALUE

Of primary importance in the study of watershed areas are the determination of wetland boundaries and the classification of wetlands vegetation. The term "wetlands" refers to land where an excess of water is the dominant factor determining the nature of soil development and the type of plant and animal communities living at the soil surface. More specifically, wetland is defined as land where the water table is at, near, or above the land surface long enough each year to promote the formation of hydric soils and to support the growth of hydrophytes as long as other environmental conditions are favorable (Cowardin et al., 1976). These wetlands are referred to by such names as marshes, swamps, bogs, wet meadows, potholes, sloughs, and river overflow lands (Figure 1). Shallow lakes and ponds, usually with emergent vegetation as a conspicuous feature, are included in the definition, but the permanent waters of streams, reservoirs, and deep lakes are not included (Shaw and Fredine, 1956).

Value of Wetlands

The values of natural wetlands include the storage of ground water, the stabilization of runoff, and the reduction or prevention of erosion. They aid in water purification

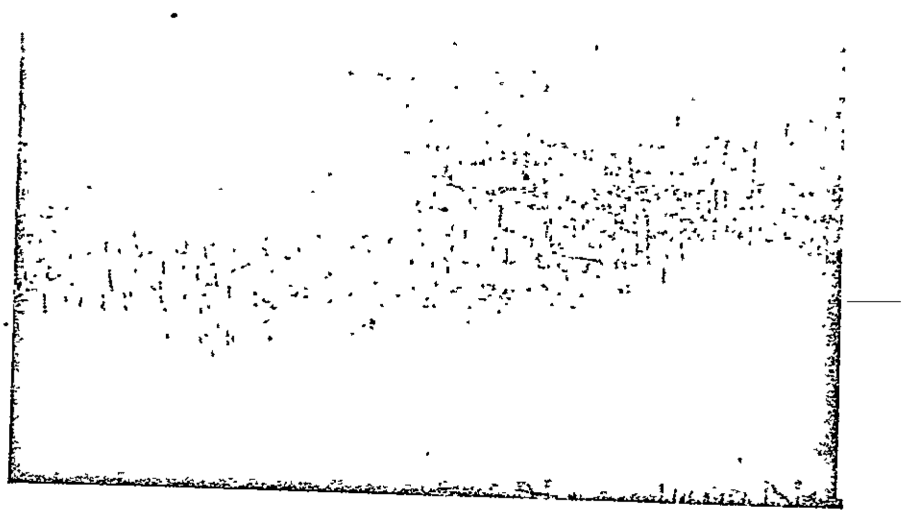


Figure 1. North Fork-Forked Deer River Wetlands, West Tennessee.

Source: U. S. Department of Agriculture, Soil Conservation Service, Nashville, Tennessee.

by trapping, filtering, and storing sediment and other pollutants and by recycling nutrients. They function as nursery areas for numerous aquatic animal species and are critical habitat for a wide variety of plant and animal species. Wetlands produce economically important crops of fur, fish, wildlife, timber, wild rice, wild hay, wild cranberries, and other products. Many return profits through fees for trapping, fishing, and hunting privileges (Davis, 1976).

Wetland Exploitation

Over the history of man's expansion, wetlands have not been understood for their true values, but have been viewed instead as wastelands that must be "improved" for the betterment of mankind. The general American creed during the first 150 years of our country was that our vast natural resources were virtually unlimited and should be exploited for the betterment of the country and for personal gain. By the middle of the Nineteenth Century, unoccupied public domain was diminished to the point that eyes turned toward swamp and overflow lands.

The Swamp Acts of 1849, 1850, and 1860 paved the way for transferring nearly 65 million acres of wetlands in 15 states from Federal to State administration for the purpose of expediting their drainage. Nearly all of these lands are now in private ownership, and their value as wetlands is usually only a minor consideration. Agricultural drainage and flood control were the forces primarily responsible for drainage or otherwise destroying at least 45 million of the original 127 million acres of natural wetlands by the middle 1950's. Other activities such as canal construction, drainage for mosquito control, industrial expansion, and highway building have also greatly reduced the values of some wetlands (Shaw and Fredine, 1956).

Cooperative Planning

Government agencies engaged in conflicting programs of wetland destruction and wetland preservation need to work together to develop unified wetland-use programs that are both acceptable to the landowner and beneficial to the nation. Various kinds and degrees of management may be required to insure desired stages of productivity of existing wetlands. Management involves manipulation of plant species and densities through measures such as water depth control, burning, grazing, and mowing. Offsite measures are often essential to control wind and water erosion, to minimize sedimentation, to maintain optimum salinity, and to divert pollutants. On the other hand, many wetlands, if desired, could be used as prime cropland for the production of food and fiber. Long-term needs must be assessed for the protection of environmental resources for the enjoyment and well-being of future generations to reach a balance with projected needs for food and fiber (Davis, 1976).

Wetlands Inventory Data

To achieve and maintain such a balance, wetlands inventory data is needed for analysis by such agencies as the Corps of Engineers, Forest Service, Bureau of Land Management, Soil Conservation Service, and many others. The most general, and in some ways most important, use of wetlands inventory data is associated with periodically measuring remaining acreages and types of wetlands and determining drainage trends. These data are needed to correlate with declining wildlife populations, increased flood runoff, lowered water tables, and other related environmental declines. With these facts in hand, private citizens, planners, and law makers can become more knowledgeable of the general values of wetlands and the need to preserve them (Stegman, 1976).

According to Anderson et al. (1975), the most appropriate means of identifying wetlands and wetland boundaries is provided by vegetation types and detectable surface water or soil moisture interpreted from remote sensor data. In as much as vegetation responds to changes in moisture conditions, remote sensor data acquired over a period of time allows the detection of fluctuations in wetland conditions.

CHAPTER II

SITE SELECTION

The U. S. Department of Agriculture[1] is currently conducting a survey on water and land resources of the combined drainage areas of the Obion and Forked Deer Rivers in northwest Tennessee. This survey, for which the U. S. Soil Conservation Service in Tennessee has responsibility for overall leadership, is to be used as a basis for the development of coordinated programs for planning the use of water and related land resources of the basin as they contribute to the objectives of national economic development and environmental quality (USDA, 1975).

The Obion-Forked Deer River Basin is approximately 3,019,000 acres (1,221,759 hectares) in size and contains parts of 14 counties in northwest Tennessee (Figure 2). The basin area includes 50 incorporated towns of which the largest is Jackson with a population of over 40,000. Dyersburg, Humbolt, Union City, Milan, and Martin are other major towns with populations over 5000. The topography of the region is abrupt and hilly in the extreme eastern part and slopes gradually westward through the less hilly and undulating areas to the low flat plains near the Mississippi River. The

[1]Includes the Soil Conservation Service, Economic Research Service, and Forest Service.

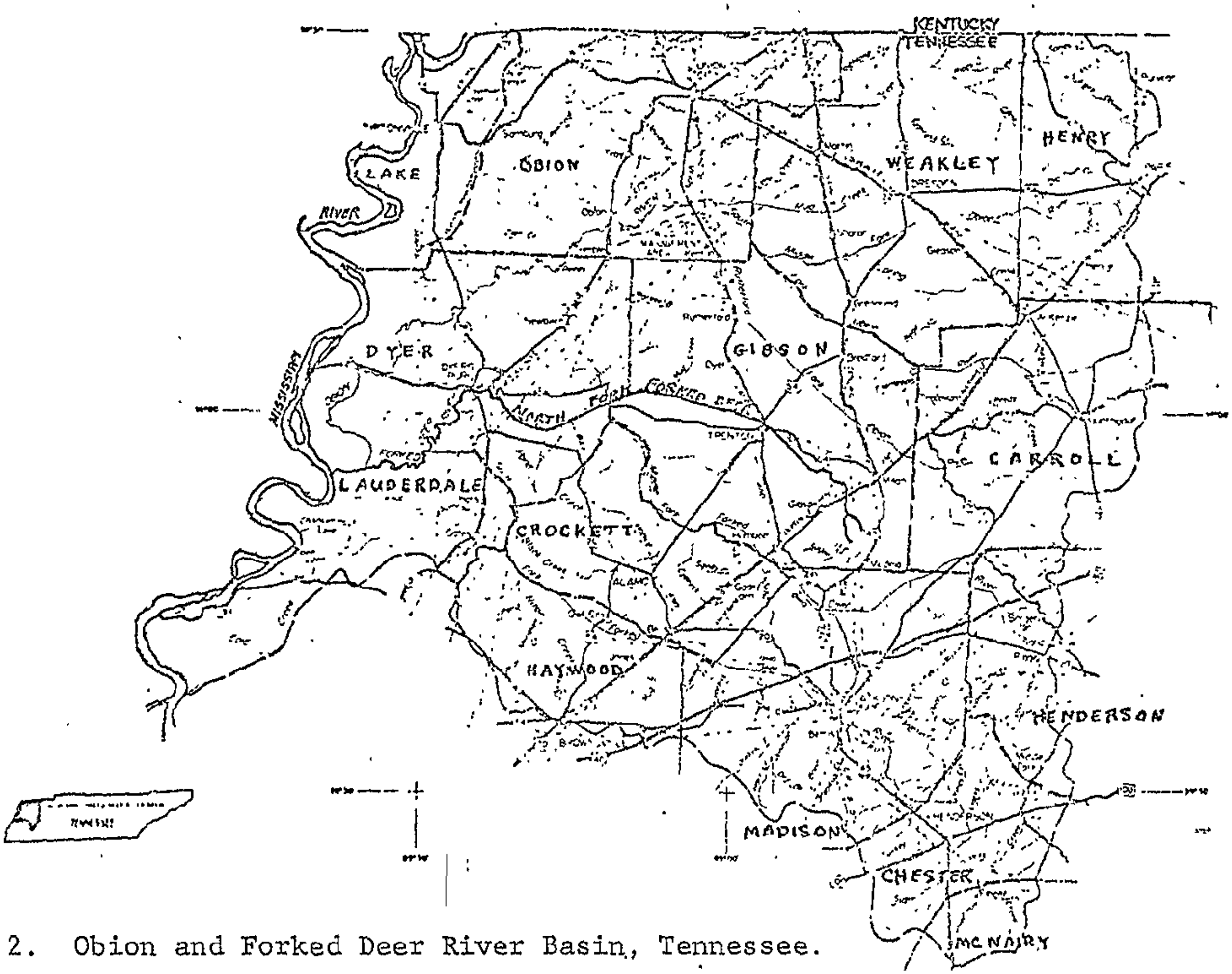


Figure 2. Obion and Forked Deer River Basin, Tennessee.

Source: U. S. Department of Agriculture, Soil Conservation Service.

highest elevation, 550 feet (168 meters) above sea level, is in the eastern part, while the lowest point is at the confluence of the Obion-Forked Deer and Mississippi Rivers where the elevation is 225 feet (69 meters) above sea level.

The Obion-Forked River Basin is confronted with several acute land use problems which contribute to excessive erosion, sedimentation, pollution, and hydrologic runoff. As this is one of the largest and most important agricultural areas in the state,[2] the condition of the land is important, not only to the citizens residing within the area itself, but also to the entire state, region, and nation (USDA, 1975).

These river systems have a profusion of tributaries of which the major ones are the North, Middle, South, and Rutherford Forks of the Obion River and the North, Middle, and South Forks of the Forked Deer River. This study will be limited to the North Fork-Forked Deer River (Figure 3). The Soil Conservation Service received authorization to study this area for planning under Public Law 566, Small Watershed Act (as amended) (USDA-SCS, 1976).

[2]According to the 1969 Census of Agriculture, while the 14-county area represents only 16% of the state, farm sales from the area accounted for over 23% of the state's total. Crop and livestock sales were $27.21 per acre of all land in farms compared to the state average of $15.36 per acre. Based on the 1972 Forest Survey, timber sales for the basin were $7.84 net return per acre of forest land compared to the state average of $5.51 per acre.

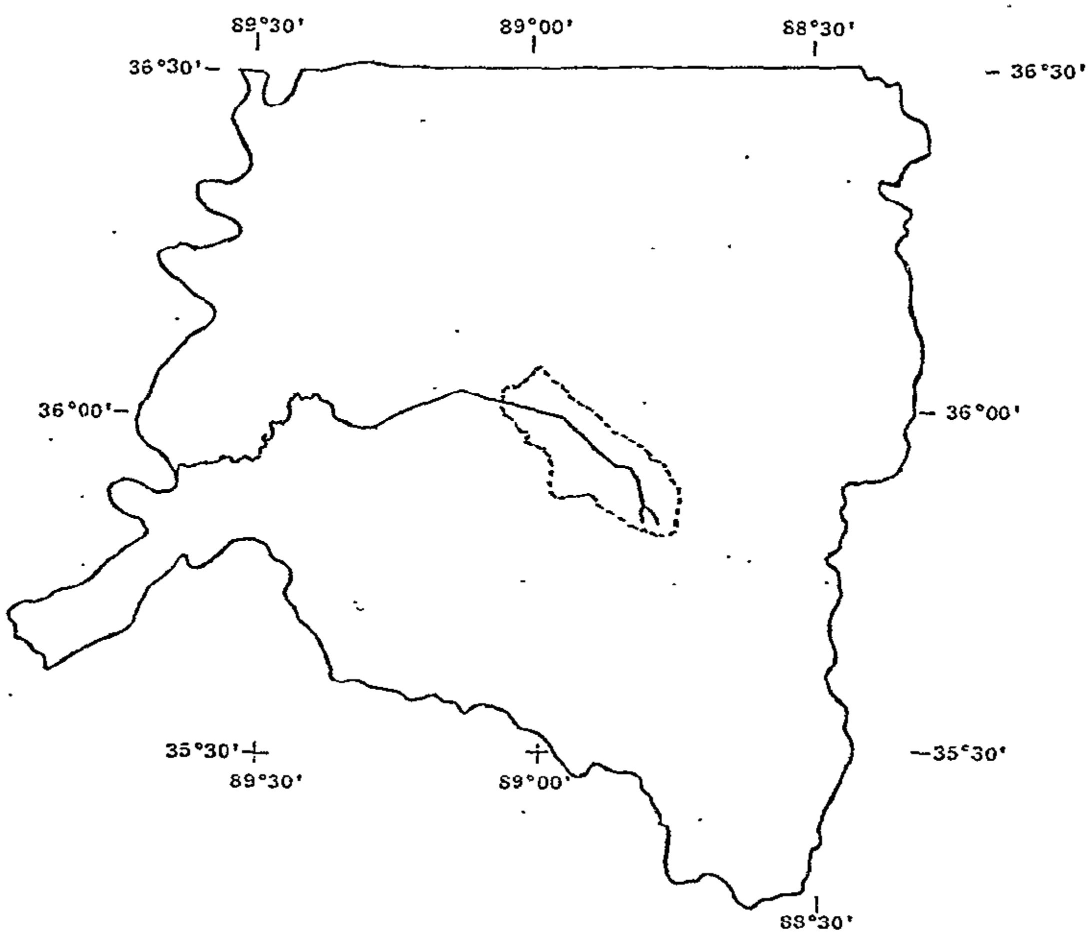


Figure 3. North Fork-Forked Deer River Watershed shown in dotted line within Obion-Forked Deer River Basin.

CHAPTER III

DATA ACQUISITION

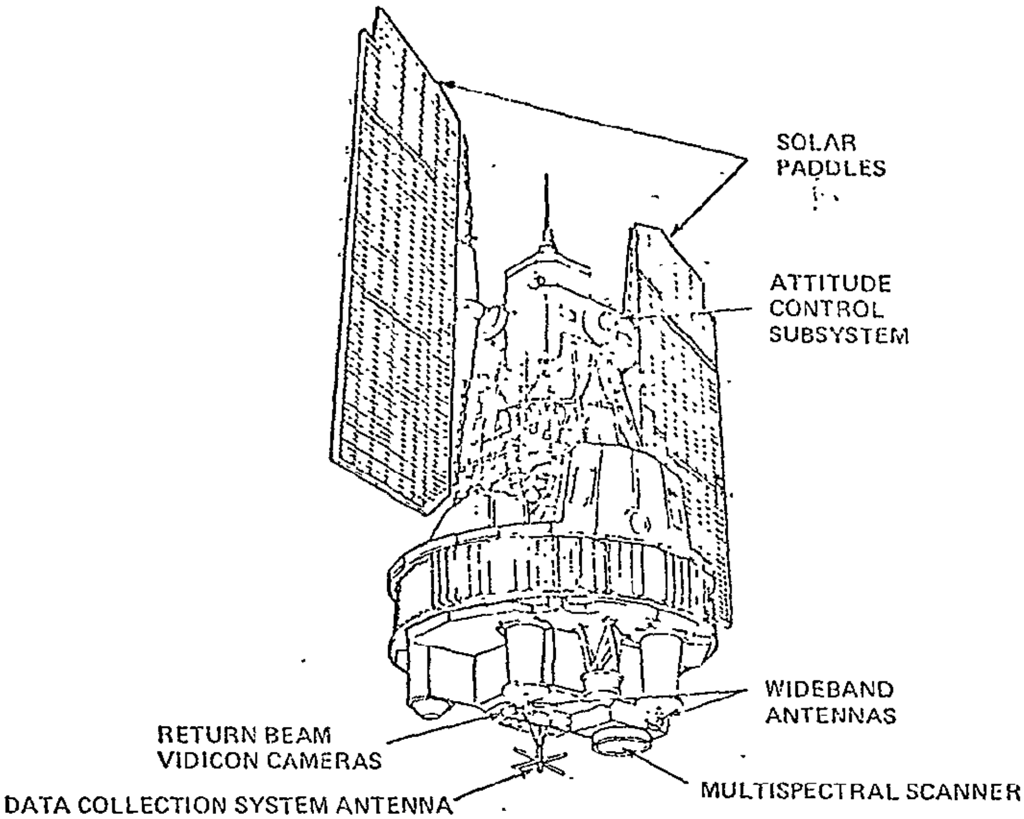
Landsat Data

The NASA Earth Resources Technology Satellite (ERTS, now renamed Landsat) is in polar orbit around the Earth at an altitude of 570 statute miles (920 km) (Figure 4a). The satellite images each locale in the United States every 18 days with each frame of photography covering an area 115 x 115 statute miles (185 km). The main characteristic of data gathering by satellite is the excellent synoptic coverage of large areas. This not only permits valuable interpretation of regional and local land use patterns and resource characteristics, but also pinpoints high priority sites for examination by large scale imagery and field investigation.

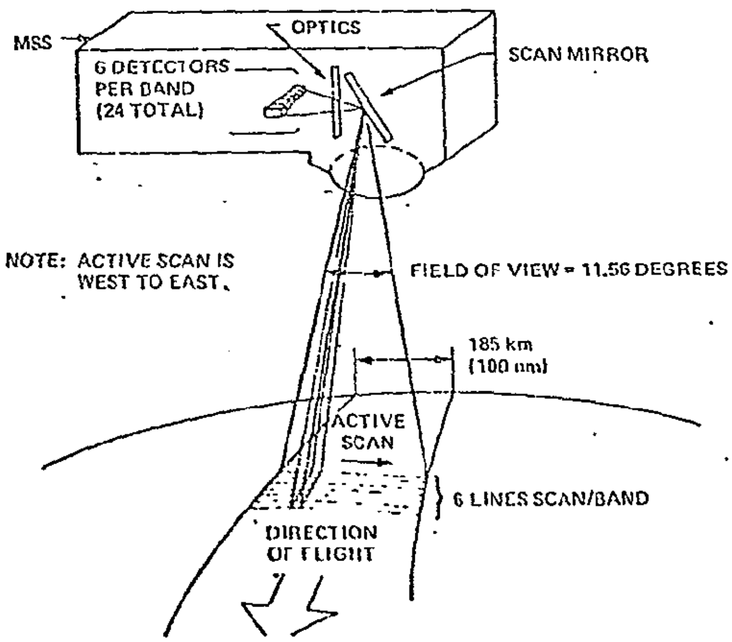
The multispectral scanner (Figure 4b) aboard Landsat images the Earth in four different wavelength bands; in effect viewing the Earth through four different color filters. These four bands emphasize the following characteristics which are useful in identifying wetland boundaries and for determining land use classifications.

1. Band 4, the green band, 0.5 to 0.6 micrometers, emphasizes the movement of sediment laden water and delineates areas of shallow water, such as shoals, reefs, etc.;

2. Band 5, the red band, 0.6 to 0.7 micrometers, emphasizes the cultural features;



a) LANDSAT Observatory Configuration



b) Multispectral Scanner Ground Scan Pattern

Figure 4. Landsat satellite system.

Source: General Electric Company, Earth Resources Technology Satellite Reference Manual.

3. Band 6, the near-infrared band, 0.7 to 0.8 micrometers, emphasizes vegetation, the boundary between land and water, and landforms; and

4. Band 7, the second near-infrared band, 0.8 to 1.1 micrometers, provides the best penetration of atmospheric haze and also emphasizes vegetation, the boundary between land and water, and landforms (USDI, 1975).

Important features of the Earth's surface can be emphasized by using unique combinations of bands and filters in the photographic printing process. Thus color composite photos are created by exposing three of the black and white photos (bands) through color filters onto color film. However, the color photo produced does not look like normal color photography. Healthy vegetation appears bright red rather than green; clear water appears black; sediment-laden water is powder blue in color; and mixtures of concrete, asphalt, and roof-tops (cities) appear blue or blue-gray. If a single black and white photo is used for analysis, the one taken through the red filter gives the best general view of the Earth's surface (USDI, 1975).

In order to obtain information on the Landsat imagery available for the designated area of west Tennessee, a computerized geographic search was requested from the Earth Resources Observation System (EROS) Data Center in Sioux Falls, South Dakota. This request was for images taken in April to June, 1975 and from October to December, 1975 in order to closely correlate the dates of these images with those of available underflights. The computer listing contained the available images over or close to the study site with details on the characteristics (quality, cloud cover, date acquired, band availability, latitude and longitude coordinates, etc.) of each image.

From the available listing, image number 8139416053, dated August 21, was chosen for study. Black and white transparencies were obtained in all four bands at a nominal scale of 1:3,369,000 with 2.2 inch (5.58 cm) format. In addition, a 7.3 inch (18.5 cm) color composite print at 1:1,000,000 nominal scale and a 29.2 inch (74.2 cm) color composite print at 1:250,000 nominal scale were obtained (Figure 5).

Skylab Data

Recent studies by the U. S. Geological Survey have shown the utility of Skylab photographic and multispectral sensor data for the classification and mapping of wetlands (Coker et al., 1974; Alsid, 1974). However, upon obtaining a computer search of Skylab images of west Tennessee from the EROS Data Center, it was discovered that none were available for this particular study site.

NASA High Altitude Data

NASA high altitude aerial photography is generally available on 9 x 9 inch (23 cm) film format at approximate scales of 1:120,000 or 1:130,000. The University of Tennessee Space Institute (UTSI) acquired data on high altitude flights (1:130,000 nominal scale) over west

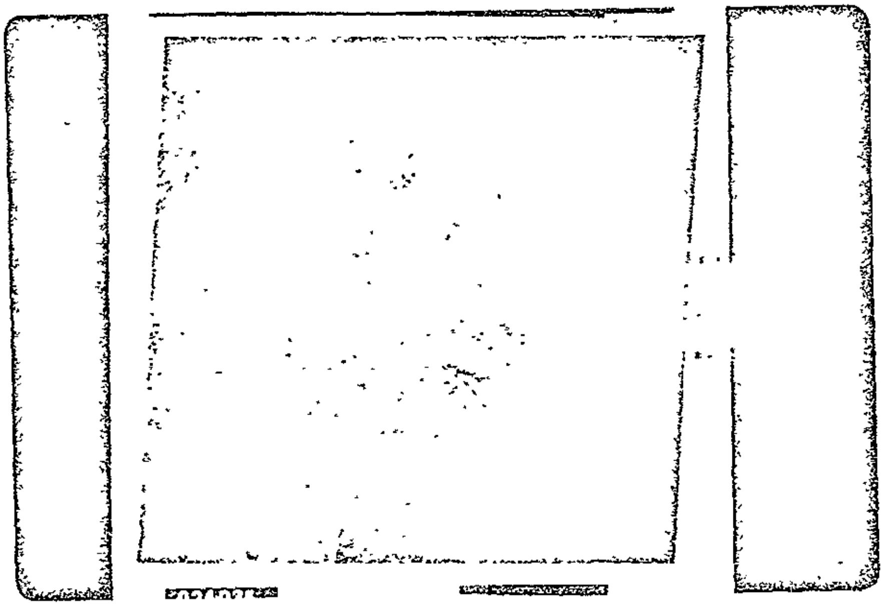


Figure 5. Reproduction of Landsat image number 8139416053.

Source: EROS Data Center, Sioux Falls, South Dakota.

Tennessee from the EROS Data Center for November, 1975. On this flight, RC-10 cameras were used with a focal length of 6 inches and Kodak Aerochrome color infrared film type 2443. Image numbers 9288 and 9302 were chosen from this flight to cover the North Fork-Forked Deer River Watershed (Figure 6).

Low Altitude Underflights

Selective underflights by conventional aircraft can be used to support and supplement the broad data-acquisition capability of synoptic satellite coverage. An identification of a delineated area on a satellite image, if not possible in one step, can be performed through multistage sampling using higher-resolution aerial photographs and ground truth information.

Aerial photographs were acquired by UTSI on the priority areas in west Tennessee as designated by the Soil Conservation Service. The flight mission of October 3, 1975 over the North Fork-Forked Deer River was flown by Surdex Corporation under contract to UTSI. The flight was in a twin-engine Aero Commander plane with a Zeiss RMK 6-inch focal length camera loaded with Kodak Aerochrome color infrared film type 2443. The resulting images were at a scale of 1:24,000 (Figure 7).

Ground Truth Data

Ground truth on both land use and wetlands vegetation was gathered for limited areas of the North Fork Watershed.

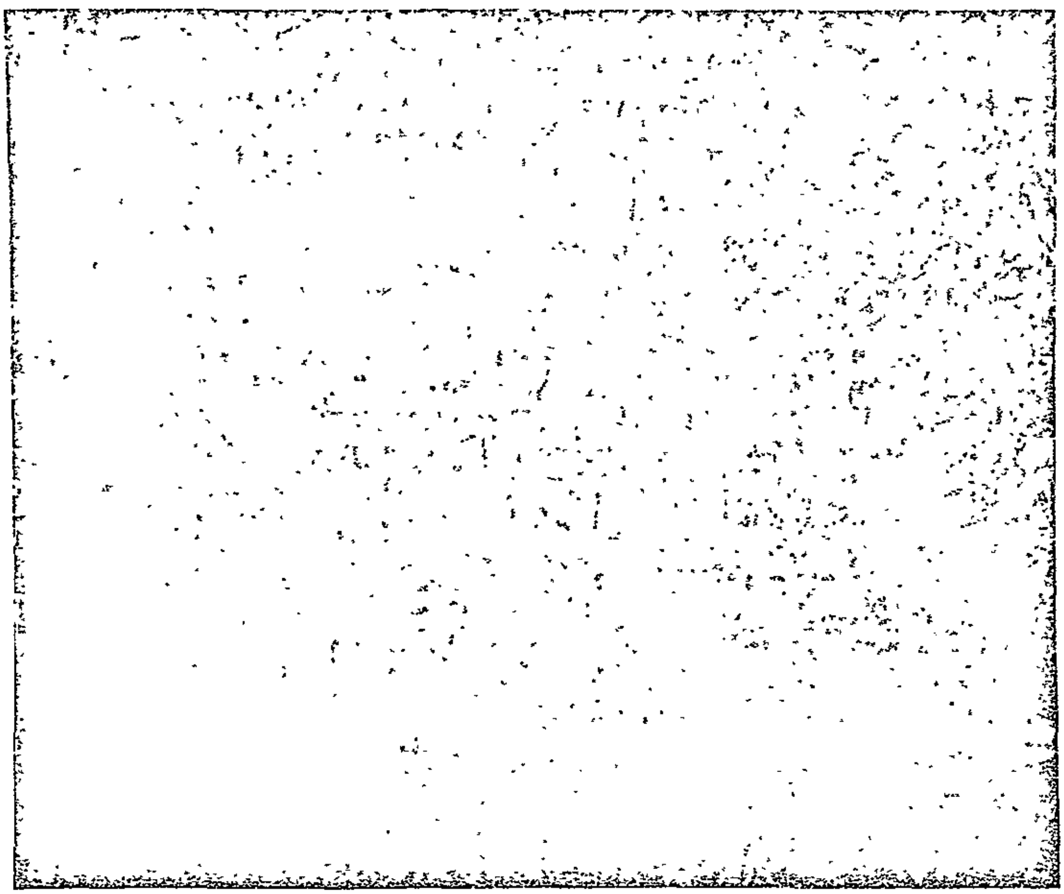


Figure 6. Reproduction of NASA high altitude image number 9288.

Source: EROS Data Center, Sioux Falls, South Dakota.

Figure 7. Reproduction of 1:24,000 scale image over Trenton, Tennessee.

Source: The University of Tennessee Space Institute, Tullahoma, Tennessee.

For land use in the North Fork, UTSI personnel gathered data on October 15-17, 1975 and SCS personnel on December 1-3, 1975. On November 11-13, 1975, SCS personnel did extensive vegetation ground truthing of the wetlands area in the North Fork.

Principles of Positive Transparency Reversal Color Film

Kodak Aerochrome infrared film 2443 was designed for aerial photography and is useful for camouflage detection, agricultural and forestry work, and remote sensing applications where infrared discrimination is required. It has an ESTAR base with "false color" reversal emulsion. False color films differ from ordinary color films in that the three layers are sensitive to green, red, and infrared radiation instead of the usual blue, green, and red used for normal rendition in the visible spectrum. With these films, a yellow filter (such as Kodak Wratten Filter No. 12) is normally used over the camera lens to absorb the blue radiation to which all three layers are sensitive (Kodak, 1971).

As in any color reversal film, energy in a certain band will make the color or dye associated with that band disappear, and the resulting color of the scene will be determined by the dyes in the unexposed or remaining bands. Therefore, when the film is processed as recommended, the green-sensitive layer is developed to a yellow positive image, the red-sensitive layer to a magenta positive image, and the infrared-sensitive layer to a cyan positive image. The colors blue, green, and red appear in the final transparency, but with false rendition; the blue has resulted from green exposures, green from red exposures, and red from infrared exposures (Figure 8).

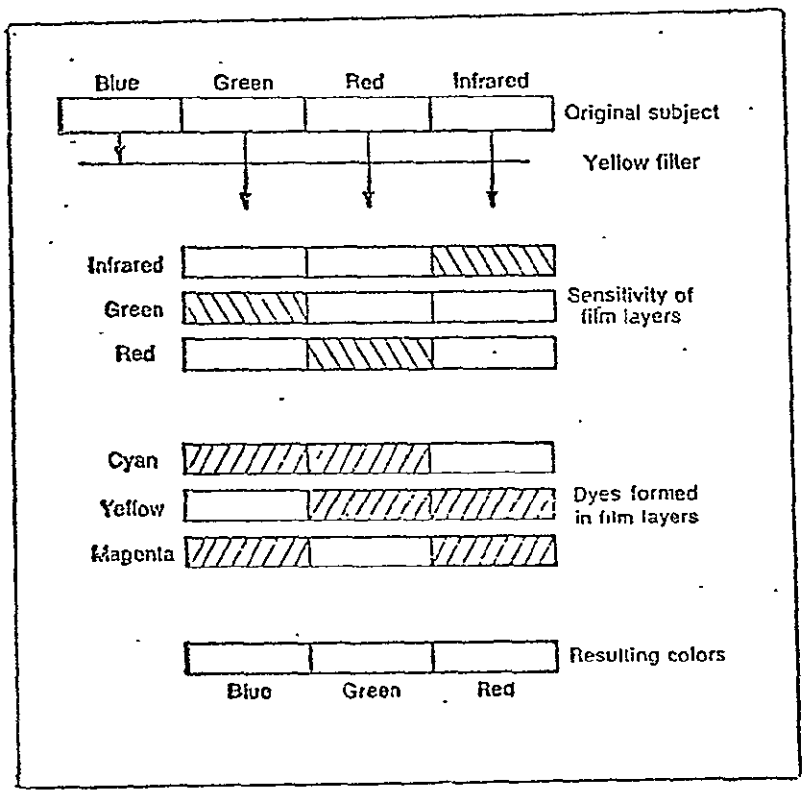


Figure 8. Schematic illustration of positive transparency reversal color film principles.

Source: Kodak Company, Rochester, New York.

CHAPTER IV

EQUIPMENT AND FACILITIES FOR DATA ANALYSIS

The loss of detail in imagery obtained from very high altitudes causes the interpreter to rely on color and brightness factors associated with overall ground scene characteristics rather than on the ability to observe and measure fine detail. Image scanning devices can measure the amount of light coming through a transparency of an aerial image and are capable of recording color and brightness factors of the ground scene in terms of the color and optical density factors of the transparency. This type of image analysis is possible with the analog/digital automatic analysis and classification system available in the UTSI Remote Sensing Laboratory.

Light Table and Accessories

A light table and accessories are used to uniformly backlight photographic transparencies and position them relative to a vidicon camera for input into an image analysis system.

Television Camera

The Sierra television input camera uses a standard black and white vidicon tube with associated circuitry which is specially designed for inputing photographic data into an image analysis system. The vidicon tube converts optical density into electrical signals proportional to the amount of light received by the camera from each point on the image. These electrical signals can be recorded digitally for use in numerical classification methods. The vidicon camera operates in a scanning mode with the rate being 30 complete image sweeps, of frames, per second. A bellows lens assembly on the camera provides a wide range of optical magnification with little associated vignetting or other types of distortion.

Image Analyzer

An Interpretations Systems Incorporated (ISI) VP-8 image analyzer accepts video image input and is the primary tool for studying the image. It is a solid state, compact instrument designed to aid in data extraction for a variety of image analysis applications. The analyzer permits a flexible and highly "user-oriented" sequence of quantitative measurements to be taken from imaged data. Processing of the input signals is accomplished by operator control of the VP-8.

The analyzer is capable of generating a horizontal and vertical cursor line pair onto a monitor screen with the intersection point of these movable cursors determining the image point whose output signal is digitized and read on the digital meter. The measured value of the output voltage from the scanning camera varies with the amount of light coming through a transparency to the vidicon tube. This amount of light depends not only on the light output of the light table on which the transparency is placed and the lens aperture setting, but also on the optical density of the transparency itself. A discussion of the resolution capability of the VP-8 image analyzer system may be found by Rhudy (1974).

Television Monitor

The Sony ISI television monitor is a standard color television set modified to allow representation of the relative optical densities of the image in color-coded form. The analyzer-processed camera signals, rather than the color television signals, control the red, blue, and green color guns. The television monitor's output pattern is synchronized to the vidicon tube scanning pattern. However, the color gun outputs are determined by the camera voltage output level as keyed to various density levels of the image. When the output voltage corresponding to a point on the image being scanned is within a specified range, the color assigned to that voltage range will be displayed on the monitor screen. Thus, the original scene can be reproduced with colors corresponding directly to the various brightness levels of the image. This process of density slicing by color coding is useful for rapid analysis of the relative brightness levels or optical transparency variations of an image (Rhudy, 1974).

XYZ Monitor

Variations in electrical output signals may also be examined on a cathode ray tube display which shows the optical density factors of an entire image in terms of CRT beam deflections. Vertical deflections of a CRT beam cause scanlines to deviate from their normal XY patterns in proportion to scene brightness variations. This produces a pseudo-three dimensional image on the XYZ monitor which is useful for analyzing images for overall brightness variations (Rhudy, 1974).

Data Processing Facility

The data processing facility is built around a Cal Data 1 computer operated from a Digital Equipment Corporation (DEC) DecWriter II console. An ISI TVD-8 video digitizer interfaced to the computer system converts a video picture to digital format. Data can be output on a Versatec 20-inch electrostatic graphics plotter as well as on the console.

Calibration of Equipment

The image to be analyzed is placed on the light table with the VP-8 function control set to Video Only. The camera is set at the desired height above the light table with the desired f/stop lens setting. Contrast and brightness controls on the TV monitor are adjusted for proper image display.

Calibration of monitor geometry and isometric mode are usually performed with the initial set-up of the equipment and should not have to be repeated. Calibration procedures which are specific to a particular image to be analyzed must be performed each time the equipment is used. The input camera should remain on in order to "warm up" for a minimum of 30 minutes before image calibration is performed.

Image Calibration--Point/Level

1. Set the VP-8 Function Control to Slice Video.

2. Beginning in the counter-clockwise position, slowly turn the Base Level control until only one small spot on the TV monitor screen appears dark. This locates the brightest point in the image.

3. Using the Cursor controls, position the crosshairs over this point.

4. Set the Digital Meter to Point.

5. A variable scale factor adjustment (Video Gain Control) on the digital meter permits settings from 0 to 1000 to correspond to the signal produced by a chosen reference point on the transparency being scanned. Adjust the scale factor as desired and record the digital readout.

6. Replace the lens cap to block out all light entering the camera lens. Adjust the LVL/PT CAL control on the VP-8 to give a digital readout of 0.000. The VP-8 is now calibrated to read out the relative brightness of any point in the image.

7. Set the VP-8 Function Control to Video Only.

Image Calibration--Area

1. Place an opaque object of known dimensions such as a square piece of paper on the light table. The square

should be roughly the size of the image to be analyzed and should be of known area.

2. Turn all Band Intensity, Video Intensity, and Relative Band Size controls fully counter-clockwise.

3. Set the VP-8 Function Control to Slice Video.

4. Slowly turn the Base Level control clockwise until the entire square appears bright on the screen.

5. Set the Digital Meter switch to Area.

6. Adjust the Area Cal control to give a digital meter readout which corresponds to the area of the calibration square. The VP-8 is now calibrated to measure areas (ISI, 1972).

Operator Functions

Once the primary calibration operations have been performed as required, the user can proceed to the following sequence of VP-8 operator functions.

Digital Readout

The adjustable crosshairs can be positioned to any point on the image as viewed on the monitor. A digital readout of the X and Y coordinates and the brightness of the image at this point is provided on a built-in digital display. When an intensity reading is made between two settings having a large density transition, a few seconds are required for the readings "to settle." This normally occurs when moving from a light to dark area or vice versa.

Color Coding

Data input from the vidicon can be separated into areas of uniform image brightness with the results displayed on the color monitor. As many as eight distinct bands can be displayed simultaneously. Each level is independently controlled, permitting complete flexibility in selecting band levels. In addition, a band size multiplier control can be used to increase or decrease the size of all bands simultaneously. Each band has a separate control for varying the intensity of the displayed band on the monitor. A digital readout of the area of the image falling in each band can be provided.

Isometric Projection of Data

Data can be displayed in an isometric projection mode. Data values are used to create a three dimensional model of image brightness. This model can be tilted and rotated to allow viewing from any perspective and the degree of model relief can be varied.

Multispectral Viewer

In addition to the facilities of the UTSI Remote Sensing Laboratory, an I^2S multispectral viewer (Figure 9) at the NASA Data Analysis Laboratory in Huntsville, Alabama was available for use in this study.

A multispectral additive viewer is an instrument for use in the interpretation of multiband "black and white" photography. Using two or more spatially identical photos, the device produces a single color presentation by projecting the image of one photo on top of the other, each photo being

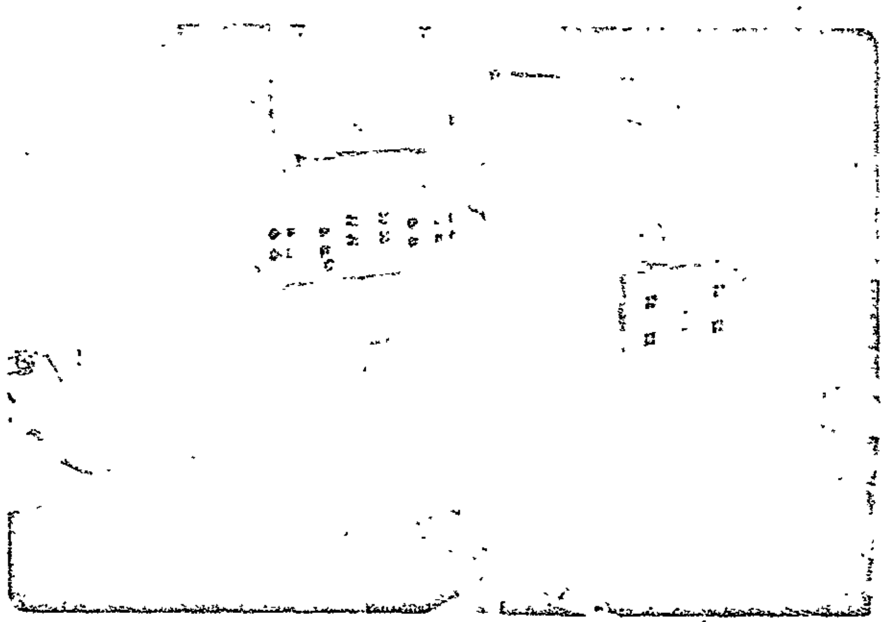


Figure 9. I^2S multispectral viewer, NASA Data Analysis Lab, NASA-MSFC, Huntsville, Alabama.

illuminated by a different light source. In addition, the multispectral additive color viewer provides the capability of altering the color of the presentation in order to enhance particular relationships.

The primary purpose of the additive color viewer is to present to the photo interpreter a composite multispectral image of the scene in good registration. Four well-matched projection lenses are individually focusable in order to project each multispectral band at its maximum resolution. Any shift in the focus of one projection lens relative to the others causes a change in the scale of the imagery. Hence, both focus and scale adjustments are essential in multispectral viewing.

When separate film chips or rolls are viewed additively, provision is included in the projector to rotate and translate each multispectral image in X and Y on the viewer screen. X and Y displacements are accomplished by moving either the projection lenses or the photos in the film gate relative to each other. The former method is usually employed for X,Y motion since the film is held flat with a platen arrangement which accommodates a small amount or rotation.

Control of the color space in terms of hue, brightness, and degree of saturation is essential for interpretation of additive color imagery. A choice of three filters (red, green, and blue) per multispectral channel are provided, as well as open gate. Open gate brightness is usually set as high as possible in order to exploit the full scene brightness range of the composite screen image. Since the densities of the same image on each record add when viewed as a registered composite, inadequate brightness in the projector produces a loss of information in the shadows (Wenderoth et al., 1974).

The following procedure is used to examine multispectral imagery:

1. Place the 70 mm film chips in the film plane of the viewer and bring down the platen to maintain the film in the plane.

2. Remove filters from each projection system and set the lamps to full brightness and full saturation.

3. Turn on each projection system (record) one at a time and adjust lenses to give good focus.

4. Turn on record #1 and record #2, inserting a red filter into record #1 and a green filter into record #2.

5. Fine focus record #1 for the red filter.

6. Using the X,Y adjustments, register record #2 with respect to record #1. This process sometimes requires some small scale changes. Alter the scale of #2 and refocus the image. The images should display no color fringing in any portion of the format.

7. Decrease the brightness of record #1, then #2, and recheck that no misregistrations are present.

8. Turn off record #2 and turn on #3, inserting a green filter into it. Record #1 should not be changed either in X,Y or focus since this image is the one to which all others will be registered.

9. Repeat steps 6 and 7 for record #3.

10. Turn off record #3, turn on #4 using a green filter. Repeat steps 6 and 7.

11. Select those bands which are believed will produce the best multispectral imagery. Using three bands, the least significant of the set should contain the blue filter. Often a change in the viewing filters will enhance some object groups better than others.

12. Alter the brightness and saturation of each record in turn, until the maximum visual color difference is displayed between the background and the objects of interest. Often a small change in brightness or saturation level will expand the color difference between the objects for better discrimination.

13. Photograph the viewer screen presentations for documentation and reference using a color negative film such as Kodacolor X or a color reversal film such as high-speed Ektachrome (Wenderoth et al., 1974).

CHAPTER V

DENSITOMETRIC METHODS OF INTERPRETATION

The Landsat image was obtained in 2.2 inch (5.58 cm) format (1:3,369,000 scale) to permit use of the multispectral viewer. However, in order to effectively use the analog/digital automatic analysis and classification facility at UTSI, all bands of this image were enlarged to 7.3 inch (18.5 cm) format (1:1,000,000 scale). Further enlargement was attempted, but the loss of resolution was too great.

Since band 6 and band 7, the near infrared bands (0.7 to 0.8 and 0.8 to 1.1 micrometers respectively), emphasize vegetation and the boundary between land and water, either is useful for distinguishing wetland boundaries. Band 6 was placed over the central portion of the light table with the lens ring (lower edge) of the vidicon camera set at 3.6 inches (9.14 cm) above the light table surface. A vidicon lens aperture opening of f/9 was used. After allowing the camera to "warm up," the VP-8 image analyzer was calibrated according to the procedures given in Chapter IV for Point/Level readings.

The brightest point in the image was found by turning the Base Level Control until only one small spot on the TV monitor appeared dark. The crosshairs were positioned over this spot which had a density reading of 550. Since the video gain control permits settings on the digital meter from 0 to 1000, 550 was selected as the top setting. The camera lens cap was replaced to give zero light transmission and the LVL/PT CAL control on the VP-8 was adjusted to give a dark level digital readout of 0.000. Thus, the image analyzer was calibrated to read out the relative brightness of any point in the image.

By manually reading the analyzer digital meter and recording the values, twenty repetitions of relative light transmission measurements were taken on each of four types of scene elements. The mean value for each of the scene elements was wetlands (45.45), urban (53.00), forest (158.30), and agriculture (373.95). An analysis of variance test determined that a significant difference existed between the classifications at a 95% confidence level. Duncan's New Multiple Range test was applied to determine which of the classifications were significantly different. Only the wetlands and urban areas were not significantly different from each other. Therefore, these two classifications could not be separated (Table I).

By assuming a normal distribution of the data, the width of the classification ranges could be compared with the mean values plus or minus two standard deviations. This confidence limit of plus or minus two standard deviations would contain approximately 95% of the data points of each data set. The mean and standard deviation were calculated for each type of scene element so that the scene elements could be classified numerically with measured transmission

Table 1. Analysis of Variance Table and Duncan's New Multiple Range Test for Landsat Band 6

Analysis of Variance Table

Source of Variation	df	SS	MS	F
Between groups	3	1406531.85	468843.95	461.65
Within groups	76	77183.70	1015.58	
Total	79	1483715.55		

$F_{.05\ (3,76)} = 2.74$ There is a significant difference in the classifications.

Duncan's New Multiple Range Test

Wetlands	Urban	Forest	Agriculture
45.45	53.00	158.30	373.95

No significant difference exists between wetlands and urban at the .05 level of significance.

values from 10 to 95 for urban, 22 to 69 for wetlands, 95 to 221 for forest, and 274 to 474 for agriculture.

Scanning of the image scene elements was accomplished by moving the cursor intersection point over each separate area at one-tenth inch intervals. This pattern consisted of several lines spaced so as to avoid too close an approach to scene element edges and to avoid overlapping of data points (Rhudy, 1974). Digital readings were recorded at each interval and classified according to the ranges described above. The resulting data was stored on discs in the Cal Data 1 computer system, a bounds algorithm was employed, and output was on the Versatec printer/plotter in the form of both a map with varying shades of gray (Figure 10) and a map with symbols representing the three classifications.

Density slicing is another capability of the VP-8 analyzer system. The result displayed on the television monitor is the reproduction of the image placed under the vidicon camera with color coding corresponding directly to the various brightness levels of the image. When the output voltage corresponding to a point of the image being scanned is within a certain range, the color assigned to that voltage range will be displayed on the monitor screen. Using this capability of density slicing by color coding, the range from 10 to 95 (urban and wetlands) was coded red, from 95 to 221 (forest) was coded green, and from 274 to 474

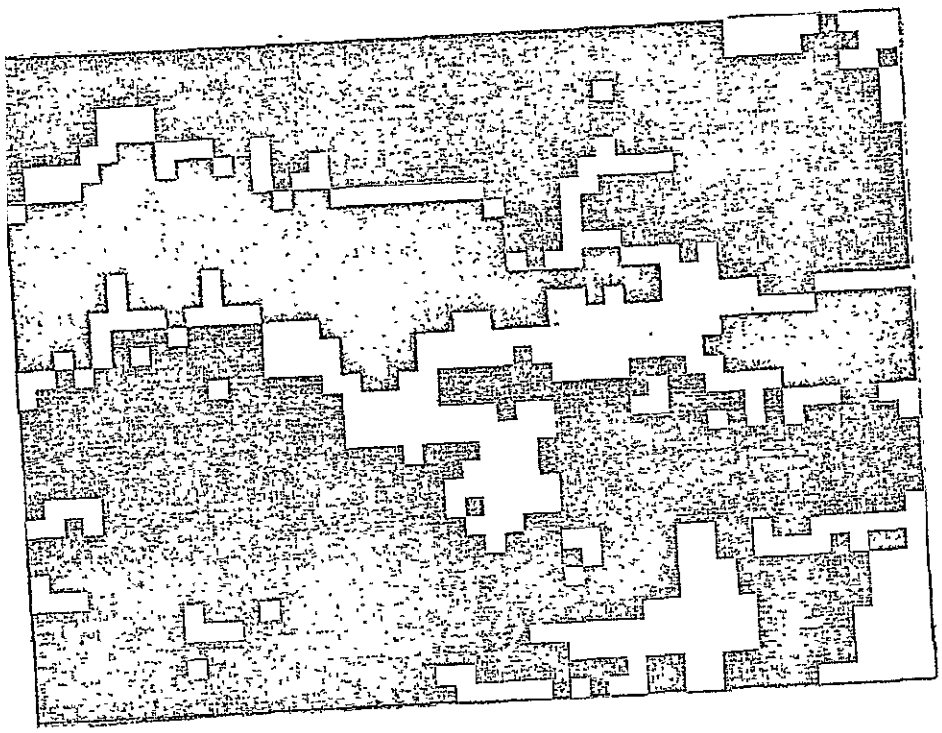


Figure 10. Classification map of three scene elements of a black and white transparency (Landsat band 6) shown in varying shades of gray. Light gray - agriculture; dark gray - wetlands; white - forest.

(agriculture) was coded blue. Color coding of band 6 is shown in Figure 11.

Figure 11. Color coded classification of black and white transparency (Landsat band 6) showing three scene elements. Red - wetlands and urban; green - forest; blue - agriculture.

The XYZ monitor was used to view overall scene brightness variations of band 6. The wetlands boundaries could easily be distinguished in the resulting pseudo-three dimensional display shown in Figure 12.

Twenty repetitions of relative light transmission measurements were also taken on each of bands 4 and 5 of the Landsat image with an analysis of variance table indicating

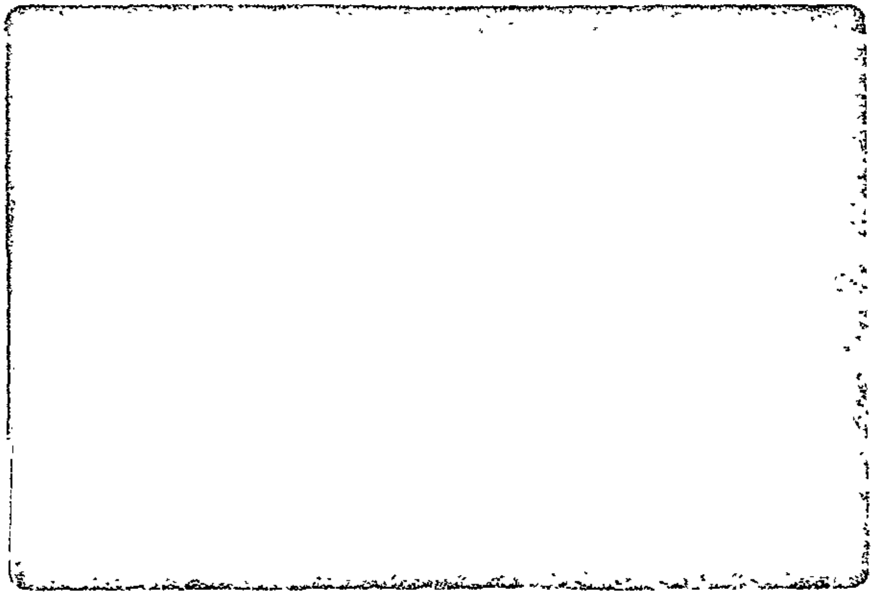


Figure 12. Pseudo-three dimensional display of black and white transparency (Landsat band 6) showing wetland boundaries.

the existance of a significant difference between classifications at the 95% confidence level. As shown in Table 2 for band 5 and Table 3 for band 4, Duncan's New Multiple Range test indicated that the forest and urban classifications were significantly different, but the wetlands and agriculture classifications were not significantly different from each other on either of these bands. Visual observation of these bands caused some doubt that the forest and urban categories were actually different enough to separate, and a t-test was applied to compare each pair of classifications. Although the results of the t-tests showed that not only were the forest and urban classifications significantly different,

Table 2. Analysis of Variance Table and Duncan's New Multiple Range Test for Landsat Band 5.

Analysis of Variance Table

Source of Variation	df	SS	MS	F
Between groups	3	2163433	721144.33	144.96
Within groups	76	378081	4974.75	
Total	79	2541514		

$F_{.05}(3,76) = 2.74$ ∴ There is a significant difference in the classifications.

Duncan's New Multiple Range Test

Wetlands	Agriculture	Forest	Urban
37.15	47.30	336.45	399.55

No significant difference exists between wetlands and agriculture at the .05 level of significance.

Table 3. Analysis of Variance Table and Duncan's New Multiple Range Test for Landsat Band 4.

Analysis of Variance Table

Source of Variation	df	SS	MS	F
Between groups	3	986914	328971.33	72.26
Within groups	76	346013	4552.80	
Total	79	1332927		

$F_{.05\ (3,76)} = 2.74$ ∴ There is a significant difference in the classifications.

Duncan's New Multiple Range Test

Wetlands	Agriculture	Forest	Urban
42.70	60.20	199.00	315.65

No significant difference exists between wetlands and agriculture at the .05 level of significance.

but also the wetlands and agriculture classifications should be significantly different, the test values were so close that an attempt to separate the classifications using density slicing techniques was not successful.

To summarize the densitometric and statistical analyses which were performed on the Landsat black and white transparencies, the analysis of band 6 determined that a significant difference existed in the light transmission measurement values for three out of the four scene classifications. An error occurred between the urban and wetlands categories. With bands 4 or 5, the ranges of light transmission measurement values overlapped to the extent that the ability to separate wetlands from agriculture and urban from forest was questionable. However, these bands did show a definite significant difference between urban and wetland classifications which were not separable on band 6. Therefore it seemed that a combination of band 6 with band 4 or 5 would permit the distinction of these two categories, and a multispectral additive color viewer was used to achieve this combination.

CHAPTER VI

INTERPRETATION WITH MULTISPECTRAL VIEWER

The Landsat image was obtained in 2.2 inch (5.58 cm) format to permit use of the multispectral viewer. Four black and white images, one for each band, were loaded into the additive color viewer. X and Y displacement was removed by adjusting the projection lenses and the platen arrangement which holds the film. The projection lenses were focused to project each multispectral band at its maximum resolution. Brightness levels were adjusted to obtain the maximum visual color difference between points of interest.

According to Frazier et al. (1975), the primary criteria for delineation of wetland patterns are the extremely dark red shades of bogs, marshes, etc.; the reduced infrared reflectance of plants growing in wet areas; and the black color of organic soils. They stated that these patterns are best seen using band 5 with no filter in combination with band 6 or 7 with a red filter.

Several combinations of filters and light intensities were experimented with in order to enhance the target area. Except for the color composite, the band 5-7 combination did give better enhancement to wetland features than other combinations (Figure 13). However, the color composite using blue, green, and red filters respectively on bands 4, 5, and

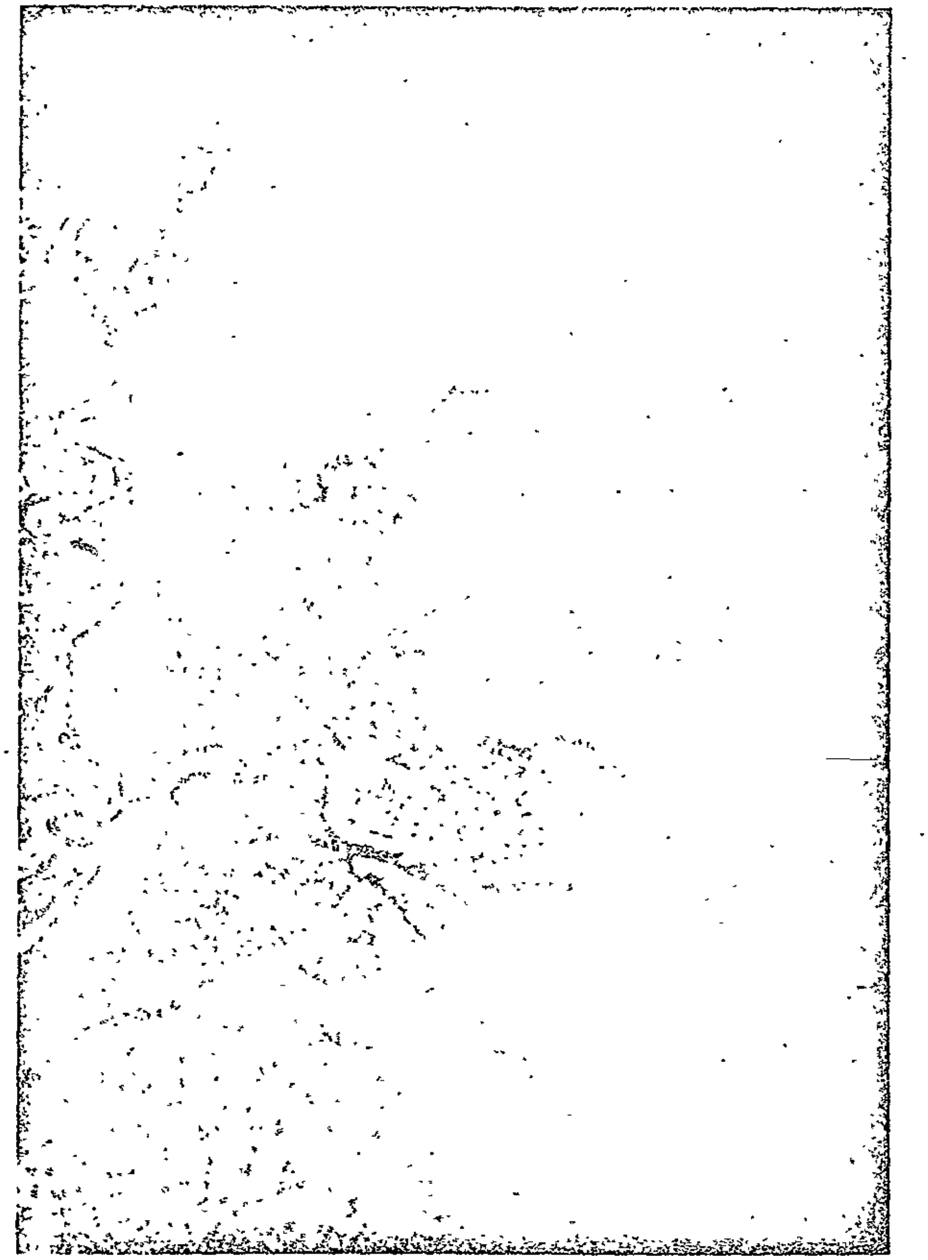


Figure 13. Additive color presentation of Landsat image with no filter on band 5 and a red filter on band 7.

6 provided comparable enhancement of wetland patterns in addition to providing better enhancement of cities (blue or blue-gray in color) (Figure 14). In both the color composite and the band 5-7 combination, forests appeared red although not as dark as the wetlands, and agricultural areas ranged from white to a lighter shade of red than the forests.

Figure 14. Additive color presentation of Landsat image with blue, green, and red filters on bands 4, 5, and 6 respectively.

CHAPTER VII

MAPPING AND CLASSIFICATION TECHNIQUES

Following a procedure similar to that developed by the Geographic Applications Program, U. S. Geological Survey, for a national system of land use classification, the Tennessee State Planning Office developed a compromise Tennessee Land Use Classification System (TSPO, 1975). Using this system (Table 4), the entire North Fork-Forked Deer River Watershed was mapped and classified from a Landsat color composite enlargement (1:250,000 scale) and from high altitude photography (1:130,000 scale). As a basis of comparison, 1:24,000 scale underflights were mapped and classified according to a land use classification system developed by UTSI and SCS personnel (Table 5).

A map was prepared at two scales based on the Landsat color composite. First, it was mapped at its original scale (1:250,000) so as to maintain the quality of resolution. Then, it was placed under a Bausch and Lomb Zoom Transfer Scope and enlarged to a scale of 1:130,000 in order to compare it to the high altitude imagery. At both scales of mapping, only the first four Level I classifications were distinguishable: urban and built-up land, agricultural land, forestland, and wetlands (Figure 15). The North Fork-Forked Deer River appeared only as part of the wetlands since the vegetation is so dense along its banks. Due to the diversity

Table 4. Tennessee Land Use Classification System

Number Code	Classification
1	Urban and Built-up
11	Residential
12	Commercial and Services
13	Industrial
14	Subsurface Extractive
15	Transportation, Communications, and Utilities
16	Mixed (Strip and Cluster)
17	Open and Other
18	Public and Institutional
2	Agricultural Land
21	Cropland and Pasture
22	Orchards and Groves
3	Forestland
31	Deciduous
32	Evergreen
33	Mixed
4	Wetlands
41	Forested
42	Nonforested
6	Water
61	Streams and Waterways
62	Lakes
63	Reservoirs
69	Other
9	Barren Land
95	Surface Extractive
96	Transitional

Table 5. UTSI Land Use Classification System

Letter Code	Classification
	Urban and Built-up
R	Rural Residential (Farmhouses, residences, barn lots, the aggregate area greater than 1 hectare (2.5 acres)
I	Isolated Industrial or Commercial Complexes
P	Small Towns (Urban, suburban, commercial, and industrial areas within the town)
	Agricultural Land
C	Croplands Not Idle
F	Good Grassland and Hayland
G	Fair to Poor Grassland
S	Idle Land (Old cultivated fields, now herbaceous plants, grasses, and brush)
	Forestland
K	Upland Hardwoods
L	Bottomland Hardwoods
M	Conifers
N	Mixed Hardwoods and Conifers
W	Wetlands
1	Rice Cut Grass and Sedge
2	Cattails
3	Open Water and Submerged Aquatics
4	Tree Cover
5	Dead Trees
6	Scattered Trees
	Water
T	Lakes and Ponds

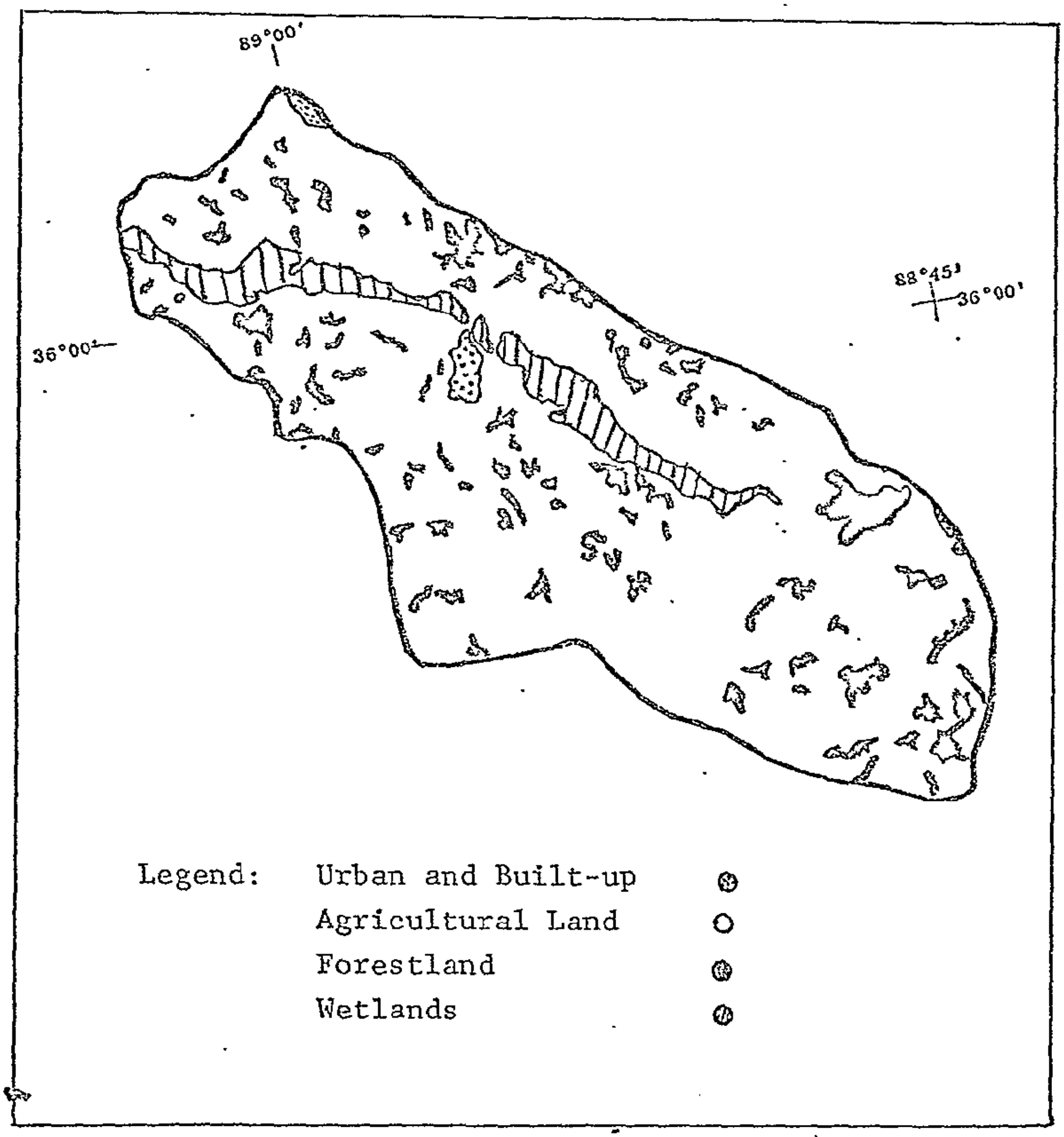


Figure 15. Land use classification of North Fork Watershed mapped from Landsat 1:250,000 scale color composite.

in both type and density of plant cover as well as surface moisture conditions, open or barren land and agricultural land both produce a wide range of color and total energy returns. Since these could not be separated, the agricultural classification also encompasses barren land. Bruns et al. (1976) had similar results in a study in New Hampshire.

High altitude photography of the Watershed was classified without enlargement. The first five Level I classifications could be distinguished (Figure 16). However, the sixth classification, barren land, could not be separated from agricultural land due to the fact that the photography was taken in November when most of the fields were bare. For both high altitude and Landsat imagery, areas that could not be distinguished as urban, forest, wetland, or water, were left in the agricultural classification.

Photo interpretation of the 1:24,000 scale imagery was done, primarily, monoscopically with the aid of a 5-power tube magnifier. Transparencies were viewed with mirror stereoscopes when certain objects required close scrutiny prior to their recognition. Photo interpretation was supplemented with information from 7½-minute USGS quad sheets. Separate map overlays were prepared for each quad in the effective area of the Watershed, showing land use classifications and wetlands vegetation. Final maps were prepared by photographing a base quad sheet in such a way as

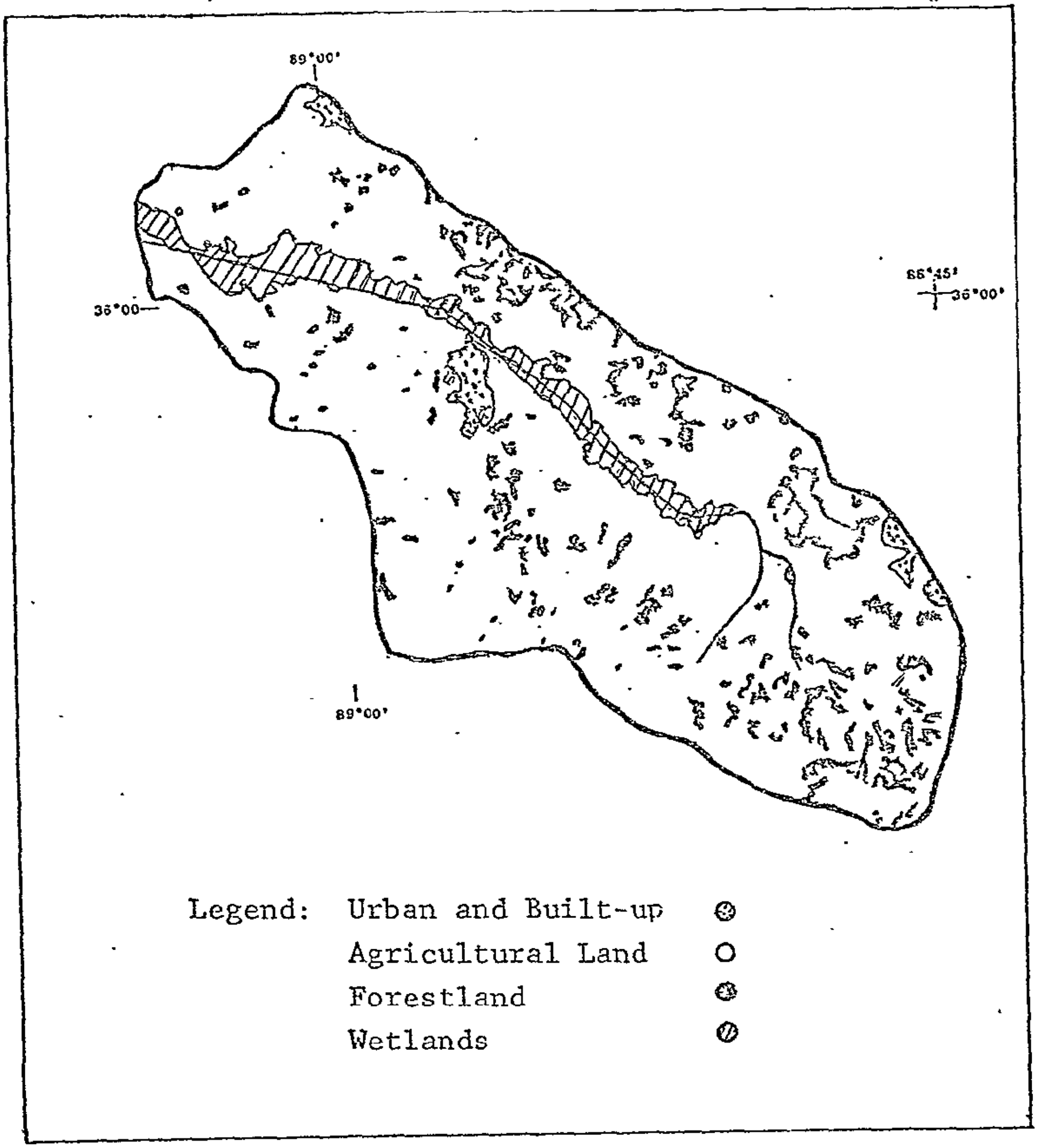


Figure 16. Land use classification of North Fork Watershed mapped from high altitude 1:130,000 scale color infrared image and reduced to 1:250,000 scale after mapping.

to obtain a subdued-tone negative and registering the base map negative containing the classification boundaries and annotations. The combined maps were printed for each quad at a scale of 1:36,000 (In Pocket). Figure 17 shows the wetland vegetation classifications on a section of the 1:24,000 scale Trenton Quad.

Area Calculations

Using the vidicon camera, VP-8 image analyzer, and video display monitor, areas were calculated for each of the various classifications on the 1:250,000 scale Landsat color composite, on the 1:130,000 scale high altitude color infrared photography, and on the 1:24,000 scale low altitude color infrared photography. The equipment was calibrated as discussed in Chapter IV. The square pieces of paper used to calibrate for area calculations of the Landsat and high altitude classification maps were 1/8, 1/4, 1/2, 3/4, and 1 inch. Those used to calibrate for 1:24,000 scale imagery were 2 and 3 inches. By using squares which had size and area corresponding to the scale of the images, the possibility of errors due to fading of boundaries on very small areas was greatly reduced.

Areas were determined by shading-in all similar classification categories on a map and employing density slicing techniques to measure the shaded portions. The equipment permitted the determination of the proportionate

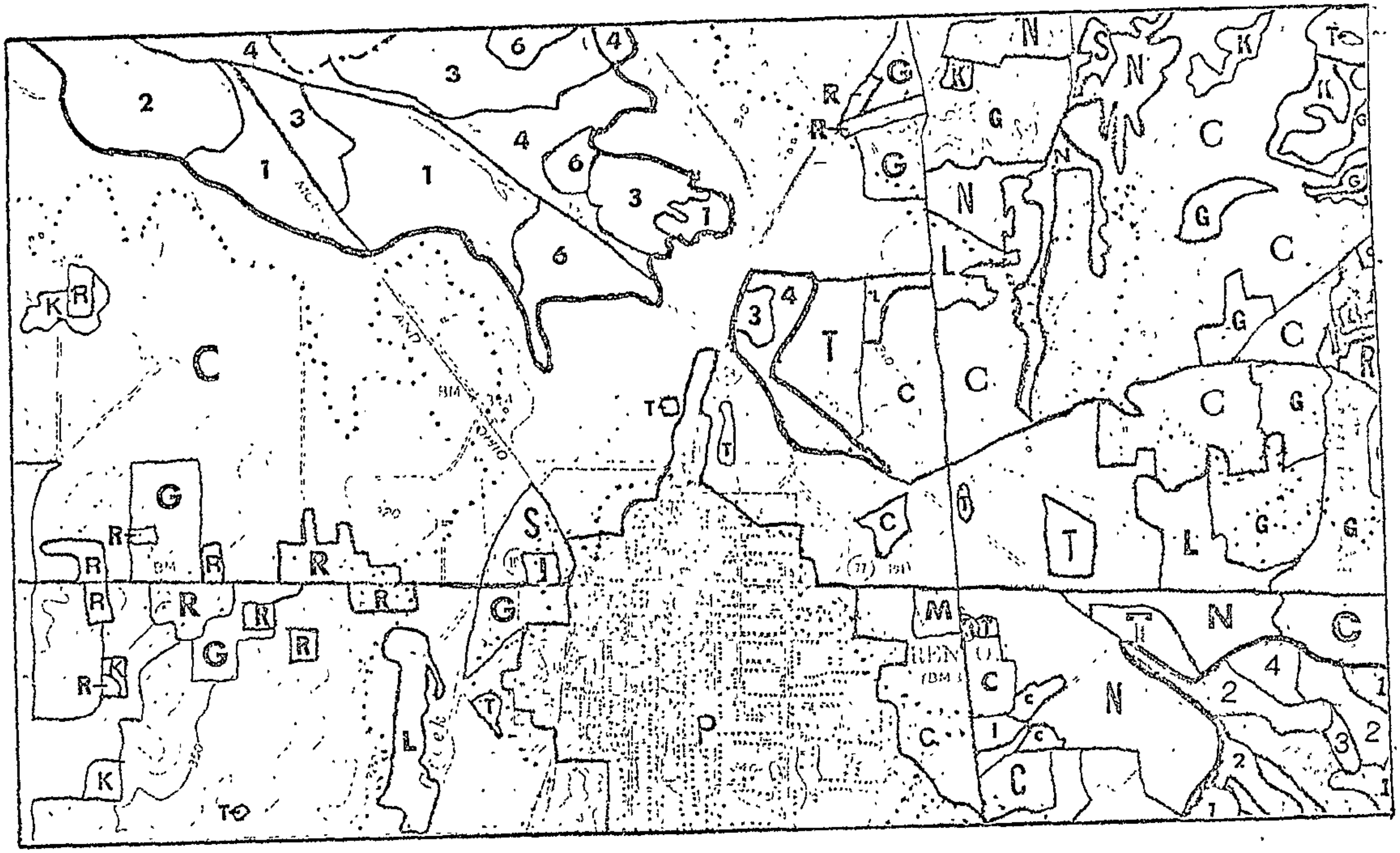


Figure 17. Wetland vegetation classifications on 1:24,000 scale Trenton Quad. (Wetland boundary shown in heavy dark line.)

shading for each specific classification category. Final areas for each classification were calculated by applying the proportions in each category to the total area.

In comparing the area calculations for the various scales of imagery, the 1:24,000 scale photography was used as control. The total area of the North Fork Watershed calculated at this scale was within 2% of the area as determined by boundary planimetry by SCS personnel. The percentage of difference or error was determined between the control data and each of the other scales (Table 6).

For total area, the difference between the 1:130,000 high altitude and 1:24,000 scale imagery was determined to be only 8%. The highest percentages of difference were in the urban and forest classifications. Trenton is the largest city in the North Fork Watershed and is the county seat for Gibson County. Population statistics for Gibson County show that only 9% live in the city. Therefore, the urban category was mostly composed of rural residences, many of which are isolated farmhouses. These rural residences can be identified on 1:130,000 scale high altitude photography. However, many appear only as "dots" which are not sufficiently large to map. The same principle applies to the forest category, much of which is composed of small groups of trees that can be identified on high altitude photography but which are not large enough to map. Therefore, the amounts of area in the urban and forest classifications were considerably reduced. Enlargement of the imagery would have enabled more

Table 6. Area Calculations (hectares) and Percentage of Difference of Landsat and High Altitude Imagery as Compared With Low Altitude Imagery.

Classification	Low Altitude 1:24,000	High Altitude 1:130,000		Landsat 1:130,000		Landsat 1:250,000	
			%		%		%
Urban	1,961	873	-55	938	-52	481	-78
Wetlands	2,100	2,465	17	2,865	36	2,570	22
Forest	4,609	3,423	-26	3,540	-23	3,231	-30
Agriculture	23,454	27,860	19	32,770	40	32,239	37
Total	32,124	34,621	8	40,113	25	38,481	20

of these small residential and forested areas to be mapped, but one purpose of the study was to determine the accuracy of mapping at original scales.

The 17% difference in wetlands acreage between the high altitude and low altitude imagery was attributed to temporal changes in the photography. The low altitude photographs were taken on October 3 and the high altitude on November 12. Rainfall records for this area showed 2.62 inches during the month of September and 2.69 inches in October. However, from November 1-12, 4.49 inches of rainfall were recorded. This additional amount of rain would cause the wetland boundaries to be enlarged.

The 19% difference in agricultural acreage between the high and low altitude imagery was attributed to the fact that urban and forested areas which could not be mapped were left in the agricultural classification. Therefore, this caused a higher percentage of difference than might be expected between these two scales of imagery.

Differences in acreage between the Landsat imagery and the low altitude imagery related primarily to resolution limitations and not to an inability to differentiate between classifications. Use of the additive color viewer has already demonstrated that the four desired classifications could be separated. However, on small scale imagery such as Landsat, boundaries tend to fuse together and can not be seen as clearly.

The Landsat image was mapped at its original scale of 1:250,000 and at an enlarged 1:130,000 scale. At each of these scales, the highest percentage of difference was in the urban category when compared to the low altitude control data. As expected, this percentage was negative for the same reasons that affected the high altitude urban category. Enlargement increased the interpreter's ability to see small urban areas, thereby lowering the percentage of error in this category.

It should be noted that enlargement does not affect the resolution of an image; it only enables the interpreter to see smaller areas more clearly. Enlargement, therefore, would not have as much affect on larger areas. As shown in Table 6, the percentage difference of error between the enlarged Landsat and the original were not significantly different for either the forest or the agricultural classifications.

The total difference between the 1:250,000 scale image enlarged to 1:130,000 scale and the control data was calculated to be 25% whereas the difference using the 1:250,000 image at its original scale was determined to be 20%. These percentages were not considered to be significantly different. It should also be taken into consideration that Landsat imagery as obtained from the EROS Data Center has not been rectified, and therefore some distortions inherent in the imagery may have induced an indeterminant amount of error.

CHAPTER VIII

CONCLUSIONS

Wetland mapping and monitoring presents both an immediate and a long-range problem. In order to begin management and preservation programs, many states urgently need maps showing boundaries and classes of wetlands as baseline information. Longer term repetitive data is also needed to monitor reductions in wetland acreage due to human activities or natural processes.

The objective of this study was to demonstrate the application and utilization of Landsat data for determining land use of selected watershed areas in west Tennessee, concentrating on the determination of wetland boundaries. This study has shown that Landsat data in imagery form can be used effectively to differentiate broad Level I land use classifications including the determination of wetland boundaries. However, low to medium altitude photography is needed to determine vegetation classifications within the wetland boundaries.

When studying Landsat imagery, the following factors should be taken into consideration. Resolution limitations of Landsat imagery sometimes prevent the distinction of a clear boundary line between classifications. Enlargement will increase the ability to see small areas of a classification such as isolated rural residences, but has little effect on large classifications such as agriculture in an area where agriculture is common. Also, Landsat imagery, as obtained from the EROS Data Center, is not rectified photography and some inherent distortions may induce an indeterminant amount of error.

With these considerations in mind, Landsat data in imagery form can be used to determine wetland boundaries and land use classifications. It can therefore be used to periodically measure remaining acreages and types of wetlands and to determine drainage trends, thereby providing needed resource information for management and preservation programs.

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