COMPUTER MAPPING OF LANDSAT DATA FOR ENVIRONMENTAL APPLICATIONS

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16. Abstract

LANDSAT CCTs were used as a basis for inventoring land cover within the Triangle J Council of Government's 1,750 square mile 208 study area. Ten land cover categories were interpreted for the study area at a detail of 0.44 hectares (1.1 acres) and included 3 urban density categories, 4 forest types, agricultural-managed lands, bare soil-construction sites, and water. The resulting products included color-coded overlays for each of the 10 categories for a 1:96,000 scale base map, a color composite map of the same categories and scale, and a computer tape containing 54 quadrangles (7.5 minute) where each 50 meter grid cell was coded as to the ten land cover types. This taped data is being aggregated into 4 hectar (about 10 acres) grid cells and merged with soils and slope data to compute sediment and nutrient flows in the drainage areas. The complete inventory was accomplished within a period of 60 days at a cost of less than one cent per acre, a significant improvement in dollars and time over previously reported efforts.

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COMPUTER MAPPING OF LANDSAT DATA FOR ENVIRONMENTAL APPLICATIONS

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ABSTRACT

As part of the national effort to deal with water pollution, Section 208 of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) provides regional planning agencies with the opportunity and funding to undertake regional water quality planning. A common requirement of the 208 program is to develop a capability of predicting water quality in the rivers and lakes resulting from existing and potential land-use patterns. To achieve this capability, the Triangle J Council of Governments is developing deterministic models capable of predicting sediment and nutrient flow into the waterways. An essential input to these models is an accurate inventory of land-cover within the watersheds of the region.

The needed inventory was obtained by Triangle J for its 1,750 square mile (1,120,000 acres) 208 study area through the computer processing of LANDSAT computer compatible tapes (CCTs). Ten land cover categories were interpreted for the study area at a detail of 0.44 hectares (1.1 acres) and included 3 urban density categories,

4 forest types, agricultural-managed lands, bare soil-construction sites, and water. The resulting products included color-coded overlays for each of the 10 categories for a 1:96,000 scale (1 inch = 8000 feet) base map, a color composite map of the same categories and scale, and a computer tape containing 54 quadrangles (7.5 minute) where each 50 meter grid cell was coded as to the ten land cover types. This taped data is being aggregated by Triangle J into 4 hectar (about 10 acres) grid cells and merged with soils and slope data to compute sediment and nutrient flows in the drainage areas.

The complete 208 inventory was accomplished within a period of 60 days at a cost of less than one cent per acre, a significant improvement in dollars and time over previously reported efforts.

BACKGROUND

It has become increasingly apparent to federal, state, and local agencies that the control of water pollution by single-step, short-ranged programs is not an approach that will produce noticeable results. Regulations which focus primarily on the end of a sewage discharge pipe do not address the many faceted and complex interactions which, in effect, result in polluted water. Billions of dollars have been expended solely for expensive treatment facilities without making an effort to understand overall causes and effects of water pollution or to look toward less expensive methods for controlling its impacts. Agriculture, silviculture, mining, construction, urbanization, and natural processes all contribute in different ways to pollution loads in lakes and streams. The use of the land, the environmental processes which are occurring, and the capacities of streams and rivers to withstand pollution are interactive forces. Planning for the utilization of valuable resources must focus on a range of causes, effects, and solutions to have meaningful impact on water quality.

The Federal Water Pollution Control Act Amendments of 1972 initiated a coordinative approach to the problem of water pollution. Under provisions of Section 208 of this Act (Ref. 1) federal, state, and areawide programs were established with financial backing from the Environmental Protection Agency. This 208 areawide water quality management planning effort, for the first time enabled sub-state regional agencies such as Triangle J to plan for improved water quality while concurrently addressing the land-use, environmental, managerial, and financial aspects which are directly related to solving the problem. Such a planning process deals with point sources of pollution and, perhaps more importantly, with non-point pollution. These non-point sources include storm-water runoff from agricultural areas, urban runoff, erosion from construction site, and leachates from septic tanks.

The Triangle J Council of Governments, in May of 1974, was the first regional planning agency to be granted EPA funds to conduct a water quality management program. As part of this pilot project, Triangle J spend eight months developing a comprehensive work plan for its program of study (Ref. 2). This work plan has since provided guidance for other agencies who have become involved in 208 water quality planning (Ref. 3). Of primary importance in the plan was the development and evaluation of relationships between water quality and land resources and use within the region. To accomplish this goal it was essential that Triangle J obtain a uniform base map of existing resources and a data base which could be used to relate existing and future land use to storm-water quality problems, and environmental impacts.

While many factors influence water quality, a dominating one is the use of land adjacent to and surrounding the lakes and rivers, the "drainage areas." During periods of rain or thaw, sediment and nutrients are washed directly into nearby water bodies. Each land-use category has its own special characteristic (Ref. 4) which is important in the calculation of the quantity and quality of storm-water runoff. For example, urban lawns and streets discharge more nutrients, especially phosphorus, than do rangeland and forested land. Cropland is often tilled in the spring when rainfall is frequent and absorbs much of the water, but erosion in the form of sediments, containing pesticides and fertilizer, are washed into nearby streams. This differs from what happens in a center city area where virtually all of the ground is covered by pavement and buildings and little or none of the water is absorbed into the earth. Instead, the water flows rapidly into storm sewers, carrying with it dirt from streets and buildings. In order to quantify the water quality impacts resulting from storm-water runoff from various land-uses Triangle J established six water quality monitoring stations and eleven water quality sampling stations. The monitoring stations continuously measure dissolved oxygen, water temperature, conductivity, and pH and are placed downstream from major population centers. The sampling stations are designed to take samples only during storm-water runoff events and measure biochemical oxygen demand, chemical oxygen demand, total organic carbon, total and suspended solids, and levels of nitrogen and phosphorus compounds. These sampling stations are located in such a manner that they measure storm-water quality from a specified land-use category in particular drainage areas. Land-use categories being monitored are: single family residential, multi-family residential, central business district, commercial, developed rural, and undeveloped rural. The remaining sampling stations sample large drainage areas with several land-use categories.

Water quality data from the monitoring and sampling stations are being used to develop pollution coefficients (Ref. 4) for particular land-use categories. Triangle J's approach requires a land-use and topographic map to delineate drainage areas throughout the region based on relatively homogeneous land-use. The pollution coefficients for the dominant land-use category along with other pertinent data (soils, slope, rainfall data, etc) is then used by the 'Storm-water Management Model' (Ref. 5) to estimate sediment and nutrient flow from the area.

The inventory of present land-use together with population projections was also required by Triangle J to form a basis for developing maps of anticipated land-use patterns. This analysis will use a 'Residential Allocation Model' (Ref. 6). By programming various constraints such as urban density, soil suitability, slope, and critical environmental areas, projected population will be allocated to undeveloped and developed areas in a series of alternative land use patterns. Anticipated storm-water runoff problems can be assessed for each drainage area and projected land-use category by applying the associated pollution coefficient. This analysis together with other detailed work with point sources will aid Triangle J in identifying critical areas where alternatives will have to be developed to minimize any deleterious impact on water quality. This may involve redirecting growth to other areas where the impact may not be as severe, or changing the character of the growth to minimize any harmful impact on water quality. The water quality plan will, in effect, contain a significant land-use planning element. The 208 water quality planning program will provide a rational basis for determining land use policy, especially as the policies may relate to water quality.

The land use inventory, as noted, is essential in the Triangle J 208 work plan. To accomplish the 208 effort Triangle J was faced with the requirement of having to inventory its relatively large study area, 1,750 square miles, within a short period of time; less than three months, with only a modest sum of money, under ten thousand dollars. Other 208 regions are most likely faced with this same dilemma.

The region had orthophoto 7.5 minute quadrangle maps prepared for the area in 1973 by the U.S. Geological Survey. The 208 area was included in parts of 40 to 50 of these quadrangles. The effort required to manually transform the land-use data from the quads into a uniform set of map overlays and into digitally coded tapes (for merging with other data) was determined to be too time consuming and expensive. For these reasons, Triangle J decided that the traditional techniques for land-use inventory - based on interpretation of aerial photographs or orthophoto quads and field inspections - were impractical on a regional level. To obtain the needed inventory Triangle J turned to LANDSAT data and computer assisted interpretation techniques.

TRIANGLE J 208 STUDY AREA

The Triangle J region is located in the eastern portion of the North Carolina Piedmont physiographic province. The designated 208 area is the central core of the region encompassing three counties (Orange, Durham, and Wake) and portions of two others (Chatham and Johnston) in the six-county region. The 208 area shown in the LANDSAT image of Figure 1 covers 1,750 square miles (over 1,120,000 acres). Three major population centers (Raleigh, Durham, and Chapel Hill) and fourteen other municipalities provide a variety of employment and residential opportunities within this area. The 208 area is within the watersheds of the Neuse and Cape Fear Rivers but because many of area's 5,000 miles of streams are headwater streams, water is not abundant and the small amount that is available is highly valued. Presently, there are only a few medium sized water supply reservoirs and numerous ponds. Two major reservoirs with a total surface area exceeding 74,000 acres are proposed for the area. Population in the 208 area increased 37% from 1950 to its 1970 level of 428,000. Conservative estimates indicate an anticipated population in the 208 area beyond 761,000 by the year 2000.

COMPUTER ASSISTED INTERPRETATION

To prepare for the LANDSAT data processing effort the 208 staff evaluated LANDSAT Band 5 images acquired October 25, 1973, February 10, 1974, February 14, 1975 in order to select the scene with least cloud cover, best resolution, and best coverage of the study area. These images were at a scale of 1:250,000 (1" = 3.9 miles). The selected image, that of October 25, 1973 shown in Figure 1, was ordered in the 9 track computer compatible tape (CCT) form. In addition to being the best scene, the date closely corresponded to that on the orthophoto 7.5 minute quadrangle maps acquired on the area in February 1973.

Bendix Data Center

The elements of the Bendix Data Center used to process the LANDSAT CCTs are shown in Figure 2 and include: a Bendix Datagrid® Digitizer System 100 for digitizing geographical or map data, a Bendix Multispectral Data Analysis System (M-DAS) for the analysis of LANDSAT computer-compatible tapes (CCTs), and an Optronics P-1500 model 30D film recorder for the production of land cover overlays and images from the LANDSAT tapes. A Cal Comp Plotter and a Gerber Series 40 Plotting Table can also be used for producing the overlays (Ref. 7). The nucleus of the M-DAS is a Digital Equipment Corporation PDP-11/35 computer with 28K words of core memory, one 1.5M-word disc pack, two nine-track 800 or 1600 bpi tape transports, and a DECwriter unit. Other units are an Ampex FR-2000 14-track tape recorder, a bit synchronizer and tape deskew drawers which can reproduce up to 13 tape channels of multispectral data from high-density tape recordings, a high-speed hard-wired special-purpose computer for processing multispectral data, a 9 1/2 in. drum recorder for recording imagery on film, and a color moving-window computer-refreshed display. M-DAS is the result of an evolutionary program initiated by Bendix in 1967 and is dedicated to the processing of remote sensing data.

Processing Steps

The data processing steps used and the results achieved in transforming LANDSAT CCTs into the desired land-use maps and data are briefly summarized in the following paragraphs.

Establish Map Categories

The first step in the development of the Triangle J land-use map was to locate and designate to the computer a number of LANDSAT picture elements or "pixels" that best typified each land-water category which was to be mapped, the "training areas." These areas of known characteristics were established by the Triangle J staff using the orthophoto quadrangle maps and their personal knowledge of the area. These training areas, about 16 hectares (40 acres) or more in size, were located on the LANDSAT CCTs by viewing the CCT data on the M-DAS TV monitor. The coordinates of the training areas were designated to the computer by placing a cursor over the desired area and assigning a training area designation, category code, color code and name. Several training areas, typically 20 to 50 pixels in size, were picked for each category, with each pixel corresponding to a ground coverage of 57 x 79 m. The color code was used in later playback of the tapes when the computer-categorized data are displayed in the designated colors.

Develop Processing Coefficients

The LANDSAT spectral measurements within the training area boundaries were edited by the computer from the CCT and processed to obtain a numerical descriptor (computer-processing coefficients) to represent the spectral characteristics of each land cover category. The descriptors (Ref. 8) included the mean signal and standard deviation for each of the four LANDSAT bands and the covariance matrix taken about the mean. The descriptors were then used to generate a set of processing coefficients for each category. In multivariate categorical processing (Ref. 8) the coefficients are used by the computer to form a linear combination of the LANDSAT measurements for each pixel. The variable produced has an amplitude which is associated with the probability that the unknown pixel measurements belong to each of the particular land cover categories sought. In categorical processing, the probability of a LANDSAT pixel arising from each one of the different land cover categories of interest is computed for each pixel and a decision, based on these computations, is reached. If all the probabilities are below a threshold level specified by the operator, the computer will decide that the category viewed is unknown, or "uncategorized".

Evaluate Selection of Training Areas and Processing Coefficients

Before producing categorized data for the entire 208 study area, a number of tests were applied to evaluate the computer's ability to perform the desired interpretation. The tests included generating categorization-accuracy tables and viewing the processed imagery on the M-DAS TV monitor. Selection of training areas, generation of accuracy tables, and evaluation of processing results through use of computer printouts and the TV monitor were iterative operations. The land cover categories listed below, approximately in order of their potential for discharging sediment and nutrients, resulted from the LANDSAT categorical processing.

- Urban-High Density Developed - Developed areas with high concentrations of impermeable surface and no vegetation, such as central business district and high density industrial, commercial, and residential areas.

- Urban-Medium Density Developed - Developed areas with medium concentrations of impermeable surface and limited vegetation includes low density commercial and low density single and multi-family residential areas.

- Urban-Rural and Low Density Developed - Developed areas with very low concentrations of impermeable cover and 30% to 40% vegetation, including single family residential and rural development.

- Agricultural-Managed Lands - Active cropland, tended pasture land, and managed areas with grass type cover such as golf courses and major highway interchanges.

- Bare Soil-Construction Areas - Areas with bare soil exposed such as plowed or working agricultural fields and areas undergoing construction. Would also include sand and gravel pits, bedrock quarries, and extractive sites.

- Upland Hardwoods - Forests dominated by oaks and hickories found in areas which have been relatively undisturbed for over 100 years.

- Pine Forest - Forests dominated by pine trees found in areas which have been cleared for use within the last 60 to 80 years.

- Mixed Forest - Forests with varying mixes of deciduous and evergreen trees in areas in successional transition from pine to hardwood.

- Bottomland Hardwood - Forests dominated by hardwoods including sycamore, birch, maple, and oak located in low-lying areas which are subject to periodic flooding.

- Lakes and Ponds (Water) - Various categories of depth and sediment concentration were combined.

- Uncategorized - Small areas which were not represented in the above ten categories. Less than 1.0% of the study area.

Generate Categorized LANDSAT Tapes

When satisfied with the categorization accuracy achieved on the land-water categories, the processing coefficients were placed into the computer disk file and used to process that portion of the LANDSAT CCTs covering the 208 study area. This step in the categorization processing resulted in new or 'categorized' CCTs, where each LANDSAT pixel was represented by a code designating one of the 11 land-water categories.

Geometric Processing

LANDSAT data in addition to categorical processing was submitted to geometrical processing in order to produce map overlays and coded taped data that were geometrically corrected and corresponded to a specified geographical area and scale. Geometrical processing included (1) establishing an earth to LANDSAT coordinate transformation, (2) developing a LANDSAT data file of a specified area, (3) rotating the orientation of the LANDSAT data to north-south, (4) removing the skew in the LANDSAT data due to earth's rotation, and (5) resampling the LANDSAT pixel to a desired cell size. Geometrical processing could have been accomplished before or after the categorical processing. For the Triangle J area the data was corrected after categorization.

The earth (latitude; longitude) to LANDSAT (pixel number) coordinate transformation was needed to locate the desired 208 area within the LANDSAT categorized CCT, and to establish the location and direction of the line used to scan the CCT data from west to east. The first step in developing the transformation was to digitize 25 carefully selected ground control points (GCPs) from the USGS 7.5 minute quad maps of the region. The GCPs were digitized using the Bendix Digitizer shown at the top of Figure 2. The criteria for selecting these GCPs was that they could be easily and accurately identified on the LANDSAT CCT data when viewed on the TV monitor. The second step consisted of converting the latitude and longitude of these GCPs to LANDSAT pixel coordinates by using a theoretical transformation derived from known and assumed spacecraft parameters including: heading, scan rate, altitude, and a knowledge of earth rotation parameters. The LANDSAT GCP coordinates and transformation matrices thus obtained were approximate, based on the use of the nominal spacecraft parameters. This transformation matrix was accurate enough to locate and display on the TV monitor the area containing the GCP. The exact GCP location was designated to the M-DAS computer by using a cursor. Once the operator had designated each of the GCPs on the M-DAS monitor an improved set of coefficients for the transformation matrix was computed. After an accurate LANDSAT to earth transformation matrix was obtained it was used to produce geometrical correct map overlays and coded tapes for the 208 study area. The error in transforming from earth coordinate to LANDSAT coordinates was found to be less than 1.0 pixel (rms).

Produce Categorized Map Overlays

The LANDSAT to earth transformation matrix and the categorized CCTs were used by M-DAS to drive a high speed Optronics film recorder (Type P-1500) to produce a geometrically corrected film negative for each of the 11 land cover categories. Inputs to the filming program included; transformation matrix, earth coordinates of corners of rectangle containing the 208 area, categorized LANDSAT tape, desired film scale, and filming aperture. A film scale of 1:576,000 (one sixth of the final map scale) was chosen with a film aperture of 50 x 50 microns. The M-DAS filming program located the categorized data on the study area and corrected it for earth rotation (skew) and scale to produce the desired film for each land-water category. The run time for this step was approximately 30 minutes per category (film). The negatives were photographically enlarged and printed as black and clear positives on mylar at a scale of 1:96,000. Examples of the transparent overlays over a portion of the Triangle J base map near Durham is shown in Figures 3, 4, and 5. On close observation a single LANDSAT pixel can be observed at this scale. The black and clear overlays were color coded by a Cromalin process to produce color Cromalin overlays, one per category, and to produce a color composite map of the study area. The color coding permitted multiple overlays to be used simultaneously over the Triangle J base map.

Produce Rescanned-Resampled Tape

Triangle J Council of Governments is tied into the Triangle Universities Computation Center and has the capacity to aggregate 50m x 50m land-use coded taped data into Statewide Planning and Land Use Management System (PLUM) grid cells (Ref. 9) for direct comparison with soils and slope data for the 208 area which are already coded on the basis of 4 hectare grid cells. Data aggregations are also possible on an area-wide, county, municipal, census tract, or watershed basis. To produce LANDSAT data that can be related directly to the PLUM cells the categorized tapes were submitted to a second stage of processing which produced a rescanned-resampled tape. A data file on this new tape was established for each of the 54-7.5 minute quads required to cover the 208 study area. Each quad file was identified on the tape by the quad name, an ID number, and the earth coordinates of its corners. The data in each file scanned the quad one line at a time from west to east (designated as a 'record') progressing a line at a time from the north to the south end of the quad. A data cell within the file covered a 50m x 50m square, had a north-south grid orientation, and was coded to designate one of the 11 land cover categories.

Inputs to the M-DAS rescanned-resampled tape program included the name and ID number for the quads, earth location of corners of quads, the earth to LANDSAT transformation matrix, and the categorized tape. The M-DAS program with help from the transformation matrix located the quads and established the location and direction of the line used to scan the categorized CCT data from west to east. When the categorization data was being scanned it was also resampled, using a nearest neighbor method, to produce the desired 50m x 50m grid cell.

The original categorized tape was transformed into the new land-cover map files at a rate of one 7.5 minute quad file every 2 minutes for a total run time of about 1.6 hrs.

FIELD VERIFICATION OF DATA

Field checks and close analysis of LANDSAT map and data products revealed the following:

1) Within an 80 acre site east of Raleigh which was under development in October, 1973, LANDSAT correctly identified areas; as Urban-High Density Developed where apartments and parking lots had been constructed, as Agriculture-Managed where construction had been completed and grass was planted, and as Bare Soil-Construction where land had been cleared for additional apartments.

2) At the North Carolina State University's Agricultural Research farm, two acres of Urban-Low Density Developed (three research buildings and lawn area) were correctly categorized from the surrounding cropland area of 150 acres.

3) Numerous farm ponds and construction sites with exposed soil were distinguished which were at the limits of LANDSAT resolution, 1.1 acres.

4) Distinctions between forest types were assessed to be particularly good for Upland Hardwood, Pine Forest, and Mixed Forest. Bottomland Hardwood, characteristically variable from site to site, was the least exclusive category, on occasions being classed as Mixed Forest and as Upland Hardwood. Checks on aerial photography of sites with known forest cover indicated that separations for the four forest types were extremely useful for the 208 applications.

5) Distinctions between levels of high, medium and low density urban development were particularly accurate when checked against aerial photography. Some areas of known low density, older residential development with thick tree cover were categorized as a forest type. Such areas however were easily recognized and corrected by staff members familiar with the region.

6) The amount of area uncategorized was very small. In the Chapel Hill 7 1/2' quad area only 1.5% of the total acreage was uncategorized. For the overall test area 1.0% or less was uncategorized.

7) The overall categorization accuracy was estimated by the Triangle J Staff to be better than 90%.

SUMMARY

The land-cover overlays and maps produced from LANDSAT are providing information on existing land-use and resources throughout the 208 study area. The overlays are being used to delineate drainage areas of a predominant land cover type. The information on cover type is also being combined with other pertinent data (soils, rainfall, topography, etc) to develop estimates of sediment and nutrients flows from the drainage area. The LANDSAT inventory of present land-cover together with population projects is providing a basis for developing maps of anticipated land-use patterns required to evaluate impact on water quality which may result from these patterns.

The overlays of forest types have been particularly useful for defining wildlife habitat and vegetational resources in the region. The extent and distribution of these forest types indicates the general availability of wildlife habitat, possible existence of rare and endangered species, and locations of unique or natural areas. A knowledge of the location and area covered by the four forest types is also a significant factor in planning potential control of storm-water run-off, which is significantly less from forested areas.

LANDSAT data and computer assisted interpretation was found to be a rapid cost-effective procedure for inventorying land-cover on a regional bais. The entire 208 inventory which include acquisition of ground truth, LANDSAT tapes, computer processing and production of overlays and coded tapes was completed within a period of 2 months at a cost of about 0.6 cents per acre, a significant improvement in time and cost over conventional photo interpretation and mapping techniques.

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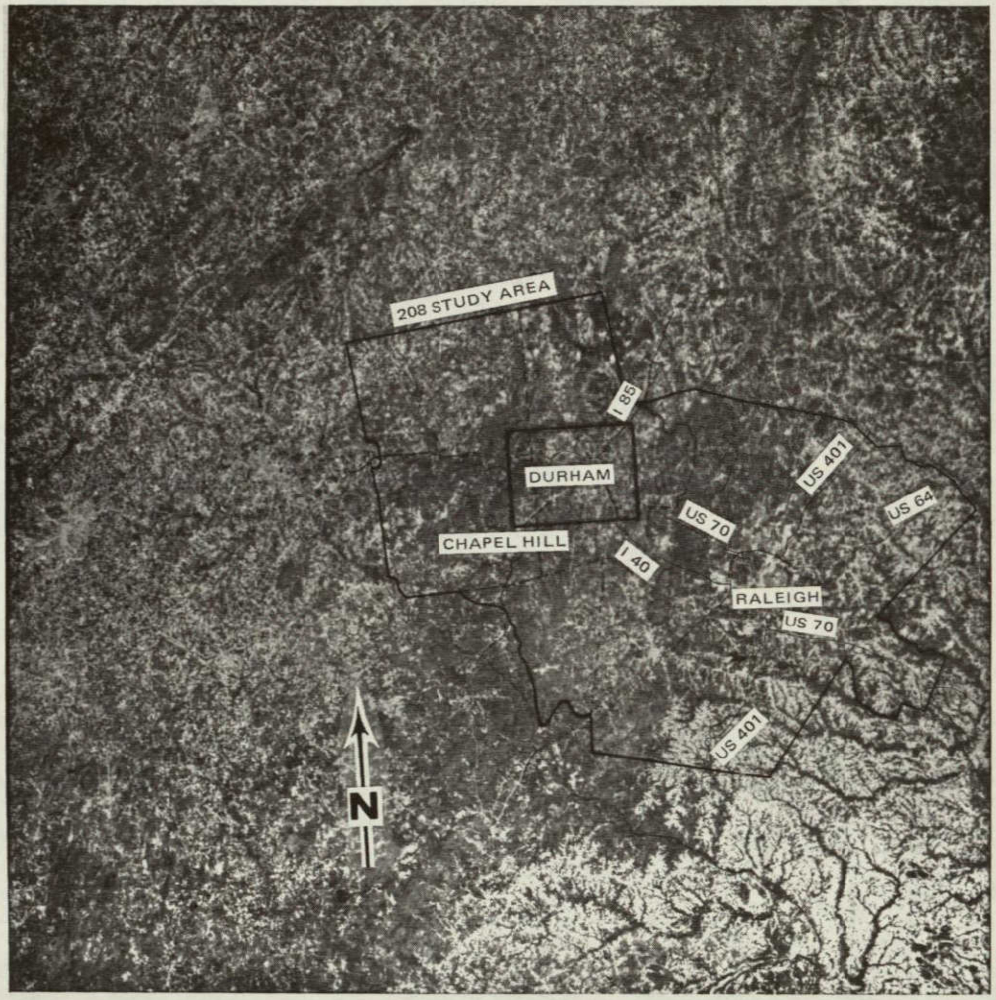


Figure 1. LANDSAT Band 5 Image (E-1459-15235) of 25 October 1973 Showing the 1, 750 Square Mile Triangle J 208 Study Area. Small 8 by 10 mi Area Around Durham is Shown Processed in the Following Figures 3, 4, and 5.

Datagrid Digitizer

Multispectral-Data Analysis System (M-DAS)

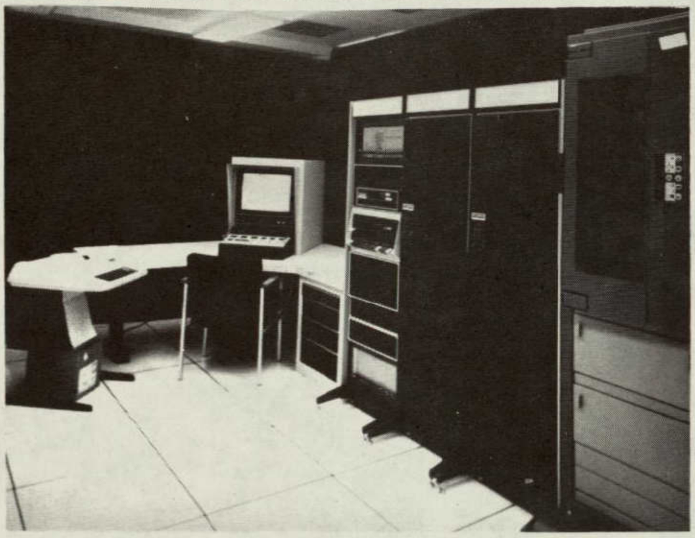
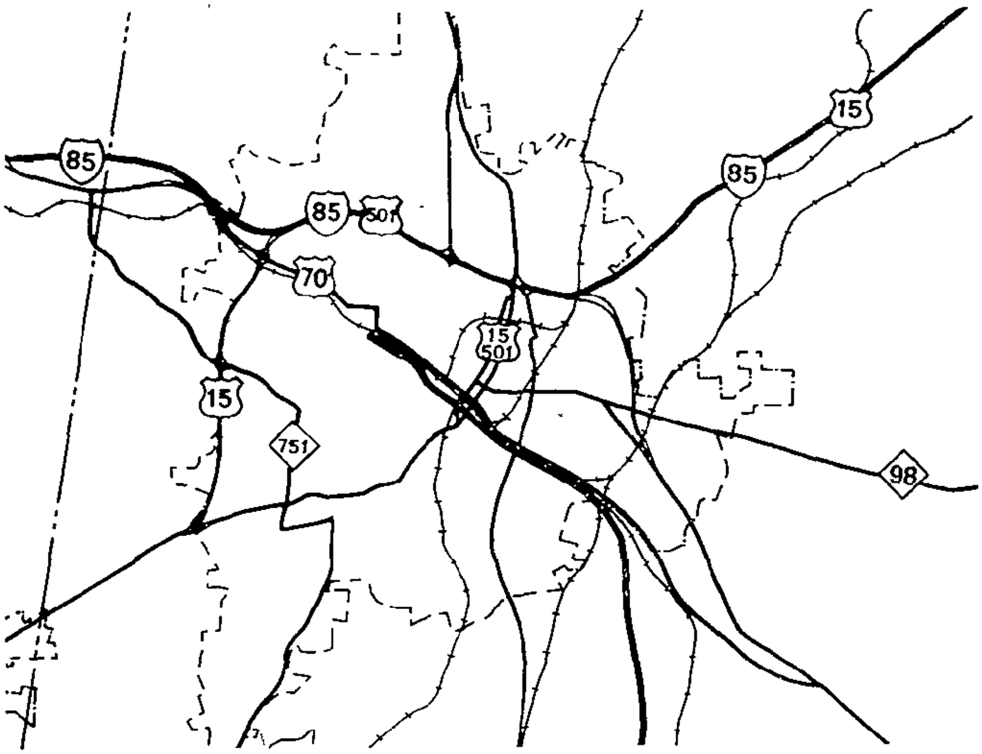


Figure 2. Computer Generation of Land-Use Maps from LANDSAT Data. The Datagrid is Used to Digitize Ground Control Points and Boundaries of Areas for Which Area Tables are Required. M-DAS Transforms the Datagrid and LANDSAT Computer Tapes into Area Tables, Categorized Map Overlays, Color-Categorized Imagery, and Rescanned-Resampled Tapes.

Base Map Original Scale 1:96,000



High Density Developed Category over Base Map. (Central Business District, Commercial, and High Density Residential)

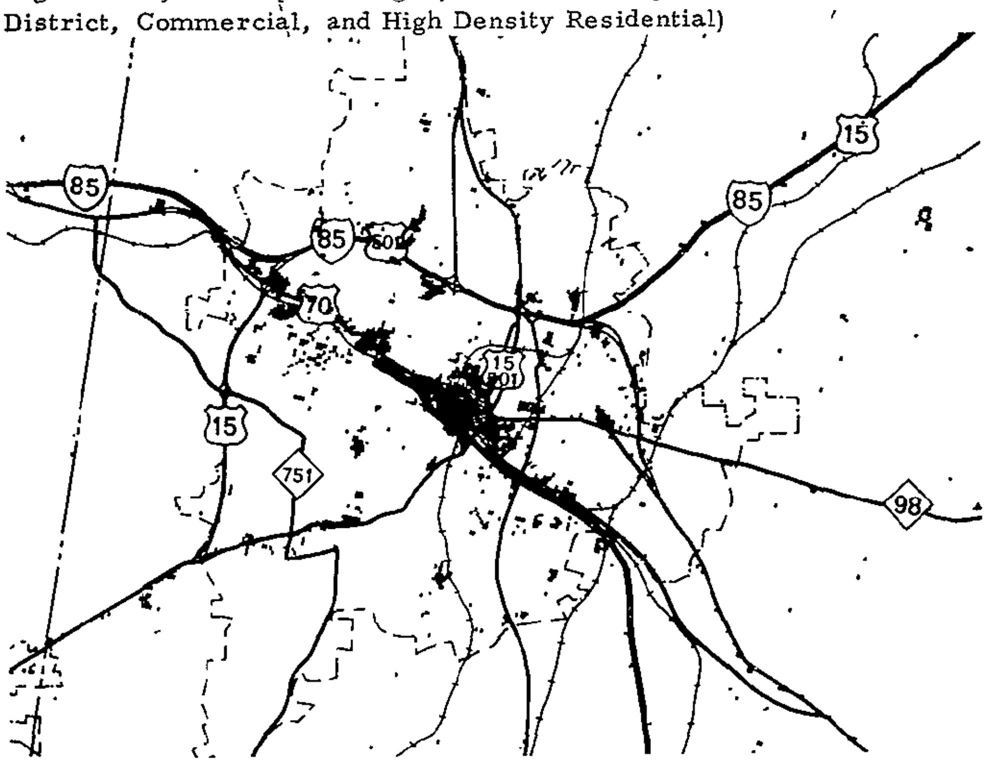


Figure 3. Example of Urban Land Cover as Mapped from LANDSAT Categorized Tapes. View of 8 mi by 10 mi Area Centered on Durham N. C.

Medium Density Developed Category Over Base Map(Less Dense Commercial and Residential Areas)

Low Density Developed Category Over Base Map(Single Family Residential and Developed Rural)

Figure 4. Additional Urban Land Cover Categories Mapped from LANDSAT Around Durham N. C.

Pine Forest

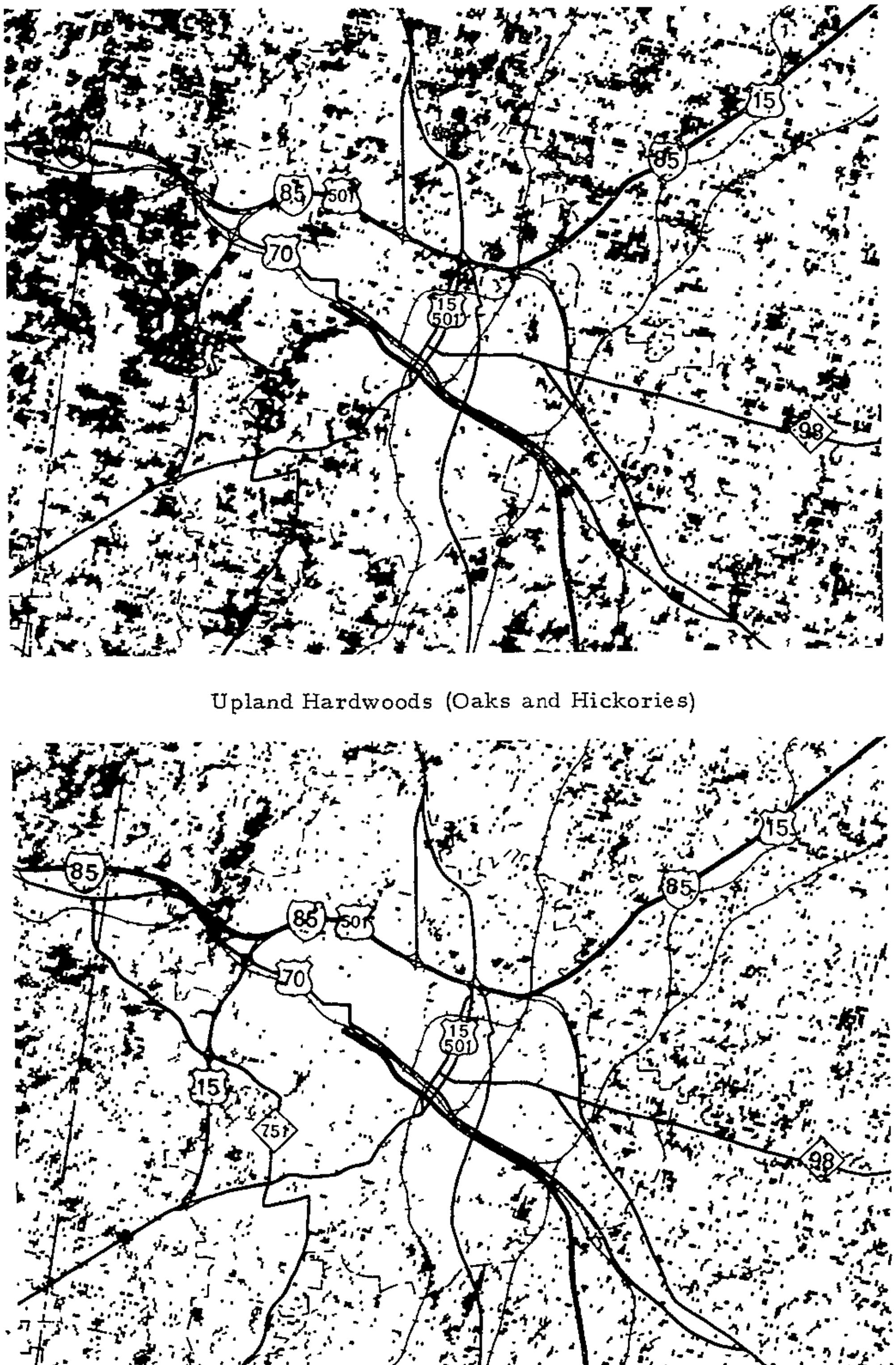


Figure 5. Two of Four Forest Cover Categories Mapped From LANDSAT Around Durham N. C.