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Rural Land Use Mapping by Satellite: A Case Study of Region D COG, North Carolina

One of the most important pieces of data necessary to develop an adequate analytical base for most land use and other natural resource planning is an existing land use map.

The U.S. Department of Housing and Urban Development (HUD), through its "701" comprehensive planning regulations, mandated that all applicants for HUD "701" funds have a substantially completed land use element prior to August 22, 1977. HUD "701" was one of the major sources of planning funds for the Region D Council of Governments. To comply with these regulations and continue to receive funds, Region D developed a regional land use plan for the 1,615,000 acres in its seven-county area in northwestern North Carolina.

Because planning is a relatively new concept in western North Carolina, staff personnel were preoccupied with grantsmanship for local governments and land use and natural resource education programs. It was not feasible to employ additional staff on a short term basis because Region D received only $31,000 of HUD "701" funds. Yet, to comply with the federal regulations, an accurate existing land use map had to be acquired within the budgetary and time constraints.

Selection of a Mapping Technique

Land use and environmental planners at Region D were concerned with three factors in determining the suitability of methods for producing an existing land use map: (1) cost; (2) accuracy; and (3) time frame completion. The Council of Governments was limited by the amount of money available to produce a land use map. Accuracy of mapping was of great importance to ensure the integrity of the land use plan. Moreover, planners at Region D realized that an accurate map was required for programs other than HUD 701 such as "208" water quality planning and industrial site selection. Quick turnaround was necessary because HUD 701 guidelines required that the land use element be substantially completed by August 22, 1977.

Region D is mountainous and heavily forested, with imprecise drainage patterns typical of much of the land in western North Carolina. Manmade features included limited highway networks and sparse population patterns. The physiographic and manmade characteristics of the region greatly influenced the choice of map production techniques because of their effect on cost, accuracy, and time of completion. Three basic options were considered to compile the existing land use map: (1) windshield survey; (2) aerial photography/interpretation; and (3) satellite imagery/computer processing.

Windshield Survey—The cost of a windshield survey was estimated at between $15,000 and $20,000 for the 2821 square miles of surface area within Region D, or approximately 5 to 7 dollars per square mile. The time necessary to complete a quality windshield survey was estimated to be 10 man-months which was much too long for the combination of time and manpower available. The accuracy of a windshield survey was also questionable because of the poor road systems within the region. Many areas that were important from a natural resource standpoint contained no roads at all. A windshield survey was impossible in these areas.

Aerial Photography Interpretation—The latest aerial

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photography of the entire area within Region D was flown in 1964 by the U.S. Soil Conservation Service. This photography was considered outdated for accurate land use analysis. A new flight of the region was estimated to cost approximately $35,000, or more than 12 dollars per square mile. After the photography was processed, it would have to be supplemented with ground cover analysis made by a skilled photo interpreter at additional expense. The total completion time using this method was estimated at one year.

Satellite Imagery/Computer Processing—Imagery from the National Aeronautics and Space Administration's (NASA) LANDSAT Satellite Program was readily available for the entire Region D area. The cost of the imagery, which was available from the Earth Resources Observation System (EROS), a program of the Department of Interior dealing with the inventory and management of remote sensing data, was estimated at $200. Computer processing through a private sub-contractor would add another $63,000, or a total cost of $2.30 per square mile. Accuracy in determining the correct land use and its location would be at least 90 per cent and the completed map would be available within 120 days. However, transportation systems and small isolated acreages of urban development and other land uses were not always distinguishable using the satellite imagery/computer processing system. The imagery would have to be supplemented in these areas with additional information.

Satellite imagery was chosen as the most cost-efficient, accurate, and timely way to obtain an existing land use map. In addition, it was known that end products could include: (1) custom-selected land use categories; (2) color-coded land use maps based on one-acre increments; and (3) area tabulations which would indicate the land area occupied by selected land uses over predetermined spatial limits.

Imagery was requested for the seven county area of Region D from EROS. After screening for clarity, cloud cover, time of year and time of day, an image dated April 16, 1976 was selected for computer processing. Region D contracted with Bendix Corporation's Aerospace Systems Division in Ann Arbor, Michigan to process the required data.

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How the Satellite Works

The Earth Resources Technology Satellite (ERTS), later renamed LANDSAT, was sponsored by NASA and placed into orbit on Sunday, July 23, 1972 from Point Lobos, California. The satellite has been passing over every portion of the earth once every 18 days at an altitude of approximately 570 miles. A second satellite was placed in orbit in January, 1975. As the satellites pass over the earth they perform "remote sensing" (the measurement of certain characteristics of an object without touching it). LANDSAT produces imagery of four of the wavelength bands in the energy spectrum, and records this information on tape drives on board the satellite. At appropriate times, information is transmitted to earth tracking stations throughout the world and recorded. The smallest picture element or "pixel" recorded covers a ground area of 57 x 79 meters, or approximately 1.1 acres.

The satellite senses the amount of energy reflected by different land and water features. Objects with different physical and chemical properties radiate different amounts of energy in the form of electromagnetic wavelengths called "signatures."

Computer Processing

Region D staff was required to provide certain information to Bendix before any computer processing could begin. Two basic work programs had to be completed. In the first work program the local staff defined land use categories that would be the most helpful for land use analysis at the regional scale and would be distinguishable from the satellite images. After consideration of the systems involved and the end products needed, the following categories were derived:

1. *Urban Developed*—Areas with land use of 60 to 80 percent impervious material. May include varying types of buildings, parking lots, etc.
2. *Deciduous*—Areas having primarily deciduous vegetation.
3. *Mixed Vegetation*—Areas of deciduous and evergreen trees.
4. *Open Field/Pasture*—Areas currently in grass cover.
5. *Bare Soil*—Areas recently disturbed through plowing or some other ground disturbing activity.
6. *Mining*—Areas affected by any mining activity.
7. *Water*—Lakes, ponds, and portions of rivers equal to or larger than 1.1 acres.
8. *Unclassified*—Areas not falling into the above seven categories.

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In the second work program, the Region D staff located 40 acre homogeneous plots of each of the requested land use categories. These "training sets" were photographed and located precisely on Standard USGS 7½' quadrangle maps for latitude and longitude coordinates.

The electromagnetic signatures stored on tape in numeric form were then processed by a sophisticated algorithm. The algorithm, a type of multivariate categor-

A LANDSAT map of the mountainous terrain in western North Carolina was made with satellite photos.

Photo courtesy of North Carolina Department of Natural Resources and Community Development

ical analysis, carries out a series of operations: (1) Training—Interprets each training set for a typical electromagnetic signature of the particular land/water use; (2) Analysis—Each pixel is then analyzed for its unique signature and mathematically placed within the land-/water category with a similar signature; and (3) Display/Testing—Each land/water category is assigned a color code and areas are displayed on a television screen for investigation.

Final Products

Region D received a final color coded land use map from Bendix at the end of the 120 day contract period. Final mapping was scaled at 1:126,720 which corresponds to North Carolina Department of Transportation Highway Maintenance Maps.

Land use/area tabulations were also provided. When categorized land use maps were completed, Region D requested that the number of acres in each of the land use categories be produced for each county. This process, called digitization, was employed only for county boundaries. In the future, Region D planners could analyze the digital files again and retrieve land use/area tabulations for any physical or political delineation. Examples of areas that could be analyzed are townships, watersheds, municipalities, and USGS 7½ minute quadrangle maps.

Limitations of the LANDSAT Base

LANDSAT imagery has resolution problems that must be recognized to prevent the information from being used inappropriately. A primary limitation of LANDSAT imagery and the computerized analysis is the satellite's inability to differentiate among urban land uses. Because the reflectivity patterns of commercial, residential, and industrial land cover are similar, the satellite and computer processing system cannot accurately discriminate among these land uses. Consequently, the most accurate method to classify residential, commercial, and industrial land uses is to aggregate them in a general category called urban. Since the predominant construction materials associated with the three urban uses are similar, the limitations of the system are understandable. In addition, low density or heavily forested residential development is also confused with timber land and pasture uses. Another limitation of the processing system is that LANDSAT data must include an uncategorized classification which is composed of land uses that are not discernable by the computer. Since the uncategorized class comprises less than 1 per cent of Region D, this limitation is not significant.

Overcoming the Limitations of LANDSAT

Providing the supplemental data needed to disaggregate the urban category while still preserving the integrity of the LANDSAT base became a real problem. There were two reasonable alternatives to achieve the objective.

The first alternative the Region D staff assessed was the analysis of low altitude aerial photography. Only photos of urban land uses would have to be procured because LANDSAT already covered the rural areas adequately. Estimated costs of aerial photography and interpretation of the urban areas was $5,000. The latest existing aerial photography available had been flown in 1964. The second alternative would utilize windshield surveys of urban land uses along the highway systems. Additional information about urban land uses could be

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acquired from North Carolina Department of Transportation "County Cultural Maps" which depicted all the urban development outside incorporated communities. The "cultural maps" were slightly outdated since most of them were compiled in 1972, but they were good enough for a regional land use plan because of the area's lack of growth. The information from the "cultural maps" and windshield surveys could be incorporated into an existing land use map which would rely on LANDSAT imagery for the natural resource component. The windshield survey costs were estimated to be less than $1,000 for the entire region. Because there was insufficient funding to rephotograph the area and hire a photo interpreter, the windshield survey method was chosen.

It is important to note here that the efficiencies of using LANDSAT data in combination with aerial photographic analysis or windshield surveys could be lost in areas with a substantial amount of acreage in the urban category because much more time would be spent compiling and analyzing the supplemental information. However, Region D municipalities cover less than 1 percent of the total acreage so the method chosen was cost efficient.

The Bendix Corporation has initiated efforts to overcome the problem of resolving urban land uses by analyzing, digitizing, and presenting aerial photography using 1.1 acre "pixels." The process basically involves cleaning the digitized tapes obtained from the satellite in the urban areas and then redigitizing them using information obtained from low altitude aerial photographs (Reed and Enslin 1977). Then, the tapes are processed in the usual fashion. This analysis does add cost to the contracting party.

Presentation of the Supplemental Information

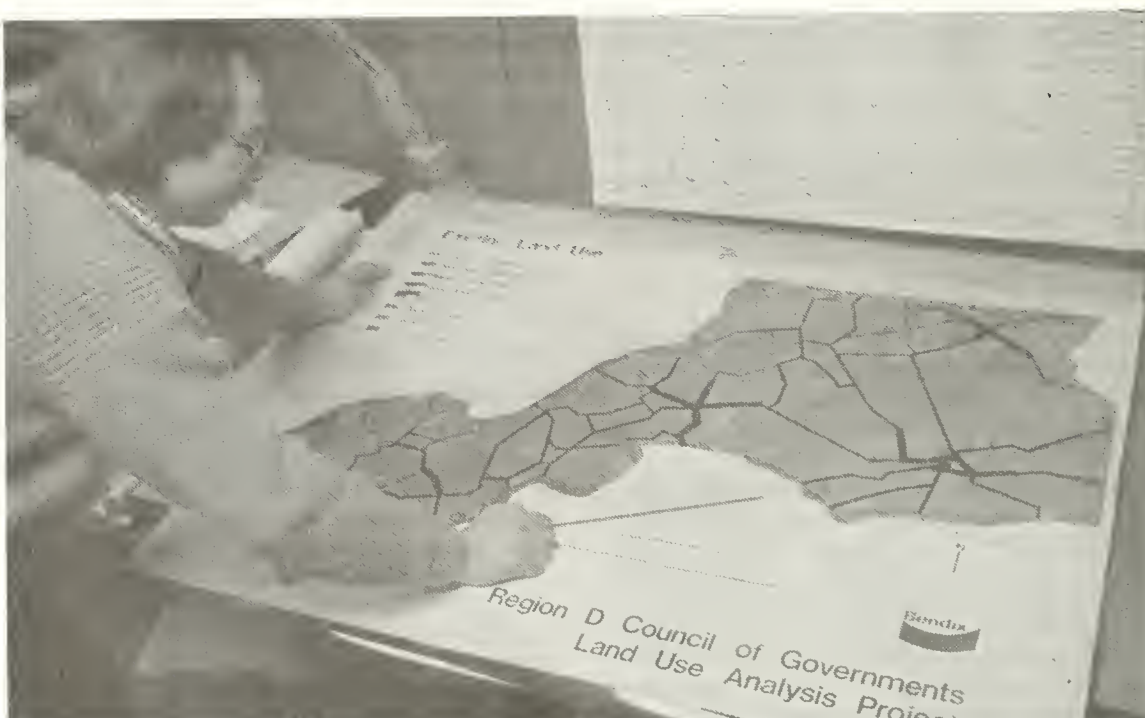
The technique used to present the supplemental urban information on the LANDSAT base was borrowed from an idea used in the "Subregional Overview Project" developed by the Tennessee Valley Authority (TVA), Division of Navigation and Regional Studies (Division of Navigation Development and Regional Studies 1975). The TVA technique basically involved accentuating important features of a base map derived from high altitude photography using diazo overlays. In Region D's case, the base map was provided by the computer enhanced LANDSAT imagery. The overlays were developed rather inexpensively. All that was needed was graphic talent, drafting supplies, and access to a blueprint machine to ensure the availability of important natural resource information and still gain the more specific residential, commercial, and industrial information that would be needed for the land use planning effort.

The advantages of developing the land use map in this manner are: (1) the existing land use map would be as specific as county or regional land use planning would require; (2) important relationships between urban and nonurban uses in remote areas could be shown; and (3) McHargian methodology (McHarg 1969) could be used to develop the plan by providing additional overlays showing environmental and human factors of importance which could easily be understood by the non-technical audiences that would view the plan.

Aerial photo interpretation could have been used to develop the map in the same manner, but not as cheaply. However, the necessity for supplemental urban information would have been less with photography than with LANDSAT imagery.

LANDSAT's Relevance to Water Resources Planning

LANDSAT imagery is potentially valuable in water resources planning as well because the data can be analyzed for any desired spatial limits. Watershed or river basin data are as easy to digitize as state or county data. The number of acres in each land use category such as urban, deciduous forest, cropland, pasture, and mining can be called off the tapes within any designated



The LANDSAT map can be used as a basis for making overlays.

Photo courtesy of Region D Council of Governments spatial limits. If the land use data is combined with soils and slope angle and length information, models can be developed estimating flows, runoff, sedimentation, suspended solids, and other wasteload factors closely related to existing land use.

Soil erodibility, slope angle, and slope length are relatively static and large scale modification of these three factors is normally not feasible, at least on a short term basis. However, land use is constantly changing, which provides a means for controlling and monitoring potential nonpoint sources of pollution. Future waste loads can be estimated by simulating future land use patterns. The Triangle J Council of Governments used LANDSAT data extensively in their "208" study (Rogers *et al.* 1975).

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Computer techniques can also be used to digitize elevation and detailed soils data. Elevation data, used for calculating slope angle and slope length data, is supplied on computer compatible tapes by the National Cartographic Information Center of the United States Geological Survey. This data was initially derived from the 1:250,000 scale topographic map series by the U.S. Department of Defense to avoid negative effects of elevation on radar tracking. Information from detailed soils surveys can also be digitized. The scale and resolution of the LANDSAT data are similar enough to the resolution and scale of digital soils and terrain data to enable the three data sources to be composited for multi-dimensional analysis.

LANDSAT imagery can be very useful at an even larger scale such as the Water Resources Council, Level A and B studies compiled on a statewide and river basin level, respectively. Land cover and water quality factors can be monitored generally but cheaply over these large areas.

Other Uses of LANDSAT Data

LANDSAT data has a variety of other uses especially where large areas have to be monitored frequently. LANDSAT data can be updated every 18 days, provided there is no cloud cover. LANDSAT can be beneficial in mapping fault zones and potential mineral sites. Satellite imagery is especially effective in monitoring floodways, wetlands, snow cover, and forest fires where the spatial limits vary widely over short time spans. As long as knowledge of specific urban uses such as residential, commercial, and industrial are not needed, LANDSAT can also be used to monitor urban change.

Advantages of Using a LANDSAT Base

Using LANDSAT imagery has its greatest advantages in rural areas of significant size. Land use in large regions can be monitored more quickly and cheaply using LANDSAT than with any other technique. The accuracy of LANDSAT is comparable to other methods, except in urban areas. In rural areas, where population density is low and funds for land use mapping are limited, computer processed LANDSAT imagery is an excellent alternative to aerial photographic analysis, especially where natural resource applications are important. If computer simulation of land use information is desired, LANDSAT imagery is extremely valuable because it is already digitized on computer compatible tapes.

The Future of LANDSAT Imagery

As techniques of determining land cover from satellites become more refined, satellite data will become more useful. Already plans are being made to launch a new satellite that will monitor a greater portion of the infrared spectrum, which should provide even more information about land use. The new satellite will also have a thermal scanner on board. Because different types of vegetation emit different levels of heat, even more accurate land use data are expected. More extensive analysis of the infrared spectrum and use of the thermal scanner should improve the urban resolution problem. However, many more improvements will need to be made before satellite imagery can distinguish among urban land uses. As processing technology becomes more refined, even greater resolution will be possible because the pixel size is expected to be smaller, which should make satellite imagery even more accurate. The changes in technology will probably come quickly, and satellite imagery will provide even more information that can lead to more accurate predictions and planning.

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