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Land Use Inventory Through Merging of LANDSAT (Satellite), Aerial Photography, and Map Sources

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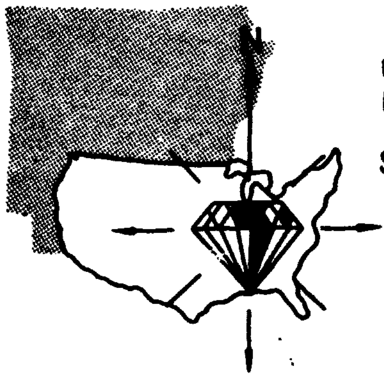

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LAND USE INVENTORY THROUGH MERGING OF LANDSAT (SATELLITE), AERIAL PHOTOGRAPHY, AND MAP SOURCES

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BIOGRAPHICAL SKETCHES

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ABSTRACT

Both photographic and satellite data sources have advantages and limitations with respect to providing all data elements in an accurate cost-effective manner. LANDSAT (Satellite) data processing is the least-cost method of producing general land cover maps and tabular data for large areas, costing about $1.00 to $4.00 per square mile. Some planning needs require detail unobtainable from LANDSAT. Manual interpretation of aerial photography generally provides this detail but is more expensive, about $8 per square mile if photography is available and $11 to $13 per square mile if new photography is needed. A procedure is described which permits the planner to derive land cover categories for a major portion of the region from LANDSAT data and to supplement this source as needed with photo and field interpretations. The blending of these two sources preserves the desired features of low cost and high accuracy. This procedure was found to be cost-effective in the application to regional studies requiring land use information responsive to the needs of both the EPA 208 and HUD 701 studies. These studies required both a high degree of interpretation within the urban areas (e.g., mobile home parks, single family housing, transportation, etc.) which were derived from photography as well as a large area coverage of nonurban categories (e.g., forest, agricultural land, wetland, water, etc.) accurately obtained from LANDSAT.

BACKGROUND

National, state, and local government agencies, as well as conservationists, environmentalists and private citizens have become increasingly alarmed over the degradation in the quality of our nations waters. This degradation is a direct result of mans activities. The pollutant sources may be direct, via contaminated discharges or indirect, via contaminated surface runoff.

It is now realized that our water resources are not inexhaustible and that land development in the watersheds must also be planned if the conflict between utilization of water resources and maintenance of the quality of life is to be resolved. The control of water pollution by single-step, short-ranged programs is not an approach that will produce satisfactory 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 the overall cause and effects of water pollution or to look toward less expensive methods for controlling its impacts. Agriculture, silviculture, mining, construction, urbanization, recreation, 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.

In recognition of the worsening water quality, legislation such as the Federal Water Pollutions Control Act Amendments (FWPCAA) of 1972 Public Law 92-500 and the various Sections (201, 208, 209(a), 303(e), 305(b), and 314) have provided requirements and funding to improve water quality.

Section 208 initiated a coordinative approach for addressing the problems of water pollution. Provisions of this act provide designated planning agencies such as Genesee-Lapeer-Shiawassee (GLS) Region V Planning and Development Commission (GLS Region V) with financial support to develop a comprehensive Water Quality Management Plan (WQMP) (Ref. 1)* for the regions. This 2-year grant requires the region to develop a WQM plan for improving water quality while concurrently addressing key environmental aspects which are directly related to implementing the plan. Environmental factors include the physical environment (e.g., air, water, wildlife habitat), the social environment (e.g., housing, culture), and the economic environment (e.g., per-capita income, employment). The objective of the 208 WQM plan is achievement of water quality consistent with the 1983 water quality goals for swimmable and fishable water.

The 208 planning process requires the division of pollution sources into two groups, "point" and "nonpoint" sources. A point source is a direct discharge to a lake or stream that is easily observed and measured, e.g., end of the municipal sewage discharge pipe. A straightforward control action could shut off the pollutant (e.g., nutrients) input or reduce it to a specified level. A nonpoint source is the entry of pollutants into waterways in a diffuse manner. This source is often difficult to measure and does not lend itself to a straightforward control action. These nonpoint sources include storm-water runoff from agricultural and urban areas.

*References and illustrations can be found at the end of the paper.

erosion from construction sites, leachates from spetic tanks and land fills, and inputs from natural sources such as the atmosphere (wet and dry fall), springs, etc. The EPA has estimated that approximately one-third of the pollution in streams not currently meeting water quality standards comes from nonpoint sources.

Parameters having major effect on quantity and quality of runoff from the nonpoint (land use) source include: intensity and duration of rainfall, characteristics of drainage area (i.e., size, slope, etc.), land use characteristics, and soil texture and slope. Marsh (Ref 2) notes that the efficiency of the flow system or channels that link the drainage areas to the lakes is also an important parameter. Although many factors affect water quality, the dominant one is the use of the land being drained into adjoining waters.

The reasons for this are fundamentally simple. The lake gains its water from an area of land around it called the "watershed", and should the use of this land be radically altered, chances are that the quality of water it yields will be correspondingly altered. As the watershed is developed, forest and other natural vegetated areas are cleared and replaced with surfaces such as pavement, bare earth, and cultivated land which become new sources of nutrients (e.g., phosphorus and nitrogen), salts, and organic debris. Ultimately, these surfaces are flushed by runoff, and the residues of fertilizers, oil, animal excrement, and other foreign substances are carried to the receiving water.

The planner developing a water quality management plan must identify the relevant sources of pollutants (e.g., sewage facilities, atmosphere, land use) quantify their contributions, and recommend the facilities (e.g., new waste treatment plants, etc.) and procedures needed to control or reduce their effects to the degree necessary to achieve published state water quality standards.

A number of models (techniques) have been derived to predict quantity and quality of water resulting from storm runoff. Some of the available techniques have been reviewed by EPA (Ref 1) and others (Ref 3). An important requirement for remote sensing is to provide land cover information to these techniques in a directly usable form. One technique which has been used by the GLS Region V and most other regions during the "preliminary analysis" is one where the area covered by the various land use categories is determined by watershed and multiplied by "areal mass loading factor" (also termed mean total nutrient export factor, loading rate, etc.). This conputation provides potential load (e.g., kilograms per year) to the receiving waterbody in the watershed. Each different land use category has a different loading rate (Ref 3). The approach that would be used by the GLS region for "detail analysis" would include effects of different soil types in the region and more detailed characteristics of the watersheds (e.g., slope). Models of this type require combining land cover with soil type and slope before assigning factors (Ref 1) that account for the loads. An essential input to any of these procedures is the land use data.

The GLS Region V working under the time constraing of the EPA guidelines had 75 days to obtain land use information suitable for estimating pollutants in runoff. To optimize cost outlays, GLS Region V also wished to use the land use information to fulfill HUD 701 study requirements relating to urban planning and desired information suitable for supporting local units of government in their planning efforts. Maps available to the region (e.g., USGS) did not contain land use categories for which loading rates were available nor the detail in urban categories needed to satisfy the HUD requirements. Population growth and urban buildup in the region had made maps showing the urban areas outdated and the urban categories were not identified in terms which could be related to loading rates. Color infrared photography gathered by NASA in May 1975 and black and white photography from June 1975 were available on the region, but the high cost (about $8 per square mile) of interpretation and transforming the information into the desired formats precluded their use except on a very select basis. A "wind shield survey" (i.e., from car) was ruled out due to cost ($5 to $7 per square mile), long survey period (about 3 months) and dubious or unknown accuracy.

None of the available survey methods were really desirable due to either cost, time, or accuracy. GLS Region V was forced to search for another way to map land use patterns. GLS found the solution in recent developments from space and computer technology. A computer technique recently developed by Bendix for merging satellite and photo interpreted data permitted GLS Region V to achieve its mapping criteria: (1) 75-day response, (2) total funding under $20,000, and (3) land use categories responsive to study needs. This multisource procedure has been reported by Reed (Ref 4) and others (Ref 5) and is summarized here.

GLS REGION V

The GLS region is located in the southwestern portion of Michigan's lower peninsula and covers the counties of Genesee, Lapeer, and Shiawassee (Figure 1). These three counties cover approximately 1,840 square miles of predominantly agricultural land. The region consists of 51 townships, 15 cities, and 19 villages in addition to the three counties. The industrial and urban center of the region is the City of Flint. This city constitutes 35 percent of the regional population of 561,025 persons (1970 Census).

PROCESSING

The maps and data graphics required by GLS were produced through the merging of interpretations derived from LANDSAT computer-compatible tapes (CCTs) and aerial photography as shown in Figure 2. Personnel from the Michigan State University Remote Sensing Project provided the photo interpretation and production of plotter maps. Bendix provided the processing of the LANDSAT tapes, digitizing and merging of photo interpretations with LANDSAT data, and production of area tabulations and color maps. The work accomplished in producing these data is summarized in the following.

LANDSAT Data Processing

The Bendix Earth Resources Data Center (ERDC), located in Ann Arbor, Michigan, was used to produce the interpreted land cover data from LANDSAT CCTs. Major elements of the data center include: a Bendix Datagrid® Digitizer System 100 for digitizing graphical data and a Bendix Multispectral Data Analysis System (MDAS) for the analysis of LANDSAT (CCTs).

LANDSAT CCTs acquired on the GLS area were transformed into interpreted land cover data by "supervised categorical" processing. These processing steps have been previously reported (Ref 6, 7, 8) and include: (1) selection of training areas representative of each category to be mapped, (2) computation of categorical coefficients used by computer to represent spectral characteristics of training areas, (3) evaluation of categorization accuracy obtained with coefficients and training areas, (4) generation of geometric correction coefficients required to correct satellite data, and (5) production of categorized tapes. On this "new" tape, a digital code was used to represent the interpreted land cover for each 57 by 79 meter (1.1 acre) picture element (pixel) covering the region. Interpreted categories included: agriculture and open space, forestlands, wetlands, and water (Table 1).

Interpret Photography

Six MSU photointerpreters identified and delineated ten land use/cover categories (Table 1) to a 5-acre level of detail from NASA high-altitude color infrared aerial photography. Orchards and forested wetlands were delineated to a 10-acre level of detail. The photography was taken on May 13, 1975 at scales of 1:60,000 and 1:120,000. The 1:60,000 photos cover about 65% of the region and were used for interpretation wherever possible. The 1:120,000 scale photos, which completely cover the three-county region, were used to interpret areas not covered between the 1:60,000 flight lines. The land cover interpretations were drawn on 1:48,000 scale county base maps (Figure 3) and forwarded to Bendix for digitizing and to GLS Region V as a final map product. The number codes within each interpreted land cover polygon identify one of the cover types listed in Table 1, e.g., Code 7 denotes transportation, Code 5 is commercial services, etc.

Digitize Photo Interpreted Data

The land cover information derived from interpretation of aerial photography and recorded on county maps (Figure 3) was converted to a digital form with the aid of the Bendix Datagrid® Digitizer. This was accomplished by tracing the boundary of each interpreted land cover polygon in either the digitizer "stream" mode (points recorded automatically at preset intervals for irregular polygons) or the "point" mode (points manually recorded by operator) for more regular polygons. The code number identifying land cover designated by each polygon was also recorded as a portion of the digitized boundary information. A digital file was constructed in this manner for each of the region's 51 townships.

This digital polygon township file can now be applied to the Bendix "scan convert" program, which generates cellular files for: viewing on MDAS Color Display; filming; statistical area tabulations; merging with LANDSAT data; and recording on tape. The GLS Region V township files were displayed on the MDAS color monitor to assure that no polygons were missing or coded incorrectly.

Merge LANDSAT/Photo Interpretations

The digital polygon files derived from the photo-interpreted maps were converted to cellular files having the same cell size and orientation as the interpreted LANDSAT pixels (cells). The computer then overlayed these files with the interpreted LANDSAT files of the same area. A new file of the region was produced where the photo interpretations overrode and replaced LANDSAT interpretations, creating a new file which contained 12 categories composed from the two sources. It was from this multisource file that all map and data products were produced for GLS Region V.

Produce Area Tabulations

Area tabulations of land cover were produced for each township (51), watershed (31), and municipality (36) from the multisource digital file. This was accomplished by using the Datagrid* Digitizer to trace the boundary of each area of interest. Each area was then located by the computer in the multisource file and tabulated. The area table lists the amount of land within the boundary falling within a particular category in acres, square kilometers, and as a percentage of total. Table 2 is an example of information derived from tabulations produced for each of the three counties.

Produce Color-Coded Regional Map

Color-coded maps at a scale of 1:96,000 were produced for each of the three counties from the multisource data file. On these maps, color is used as a code to designate the 12 land cover categories. In production of these data, the geometric transformation matrix and the multisource data tape were used by MDAS to drive a high-speed Optronics film recorder to produce a set of geometrically corrected film images for each county. A film scale of one-fourth the final map scale was chosen to allow a complete county to be filmed at one time. Each county was filmed and enlarged 4X and printed with a base map. The three county maps were then mosaicked and mounted for offset printing by GLS Region V. Figure 4, showing Genesee County, is a black and white print of one of the county maps. This county contains the city of Flint and a majority of the industrial activity in the region.

Produce Township Files

Digital township tape files containing 10-acre cells with a north-south grid orientation were produced from the 1.1-acre multisource cells. For the 10-acre cell, only the dominant category within the cell was recorded and priority was assigned based upon the order in which the category was listed in Table 1, i.e., first category highest priority, etc. This task results in tape files for each of the 51 townships, which MSU used to produce plotter maps of the townships and counties.

Generate Plotter Township Maps

The township digital files, containing the merged LANDSAT and photo-derived land use/cover data, were used to produce plotter maps on mylar for each of the 51 townships in the region. The Resource Analysis Program (RAP) was then used to retrieve the land use/cover code for each cell and produce a land use/cover mylar plotter map for each township at a scale of 1:24,000 to directly overlay USGS 7.5 min quads. Figure 5 is an example of one of the township plotter maps. The entire map including the annotations and boundary lines drawn around contiguous cells having the same land use/cover category was generated by a computer-driven Calcomp plotter.

Produce Plotter County Maps

The previously prepared township plotter maps were mosaicked to produce a mylar map of each of the three counties. This was accomplished by photographically reducing each 1:24,000 scale township plotter map by 50%. The resultant prints were then paneled together and registered to a 1:48,000 base map of each county. After the addition of legend and border information to each county map, a final mylar copy was produced photographically.

RESULTS

MSU carefully evaluated the LANDSAT geometric and categorization accuracy. At the township level, 1:24,000 scale maps, a 2° to 3° rotation in LANDSAT data was observed. This was not noticeable on the county and regional maps produced at the 1:48,000 and the 1:96,000 scale, respectively.

Four hundred 10-acre cells in the region were randomly selected by MSU to determine the overall accuracy of the land cover data. The land cover of those selected cells that were categorized from LANDSAT data was verified through photo interpretation whereas cells having photo-derived categories were verified on the ground. The sample survey showed that the land use/cover data are 93.4% accurate at the 0.1 confidence level. Table 3 is a summary of the sample survey.

The area tabulations on a watershed basis were found to be the most convenient format for preliminary analysis of storm water runoff. The digital land cover tape files are the most suitable data format when more detailed analysis is needed and the land cover must be combined with soils, slope, and other data. The digital files can also be easily updated when necessary whenever new photography or other information is available.

Future efforts should include additional categories from LANDSAT, e.g., grassland and barren land. In most cases, LANDSAT can readily categorize cropland into row crops and field crops and a further subdivision to crop types if ground truth is available. Forest can most always be separated into broadleaf trees and evergreen trees.

The multisource technique was particularly cost-effective for GLS Region V, which required both a high degree of interpretation within the urban areas (i.e., mobile home parks, single family housing, transportation, etc.) best derived from photography, and within nonurban areas (forest, wetlands, water, etc.) best obtained by LANDSAT. Table 2 shows that even though 8 out of 12 (67%) of the categories were derived from aerial photography, more than 90% of the total area was categorized by LANDSAT. The nonurban categories, which generally account for a major portion of the planning region, were mapped from LANDSAT data with an accuracy of 93% or better, depending on the category, scene quality, and ground truth availability. This equals or betters the accuracy obtained by manual photo interpretation, but it is achieved at much lower cost.

Both photographic and satellite data sources have advantages and limitations with respect to providing all categories in an accurate cost-effective manner. LANDSAT data processing is the least-cost method of producing general land cover maps and tabular data for large areas, costing about $1.00 to $4.00 per square mile. Some planning needs, such as those of GLS Region V, require detail and/or land cover categories unobtainable from LANDSAT. Manual interpretation of aerial photography generally provides this additional detail, but it is more expensive - about $8 per square mile if photography is available and $11 to $13 per square mile if new photography is needed. To reap the maximum advantage of both systems, the multisource technique demonstrated here permits the planner to derive land cover categories from LANDSAT data for a major portion of the region (at the low cost) and to supplement this source as needed with photo interpretation. The blending of these two sources in this manner preserves the desired features of low cost and high accuracy.

The maps and data graphics will, of course, be used in the usual manner as a tool for spatial analysis in the support of the EPA 208 and HUD 701 programs. Of particular attraction for future work, however, is the possibility of a series of these maps over an extended time frame. This "motion picture," as Lynch calls it (Ref 9), will convey a progressive sequence of development. This sequence would then be analyzed for: (1) the rate of change over the region, (2) the trend and inevitable future change over the region, and (3) the points of conflict within the region.

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3. Omernik, J.M., "The Influence of Land Use on Stream Nutrient Levels," EPA-600/3-76-014, January 1976.

4. Reed, L.E. and Enslin, W.R., "Land Cover Analysis of Region V Genesee, Lapeer and Shiawassee Counties," Bendix Report BSR 4284, July 1977.

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Table 1 Land Use Definitions and Source

Category	Source: Photography	Source: LANDSAT
High to Medium Density Residential - A residential area with a concentration of more than three dwellings per acre. Included in this category are apartment houses, retirement homes, and other multiple unit dwellings.	●	
Low Density Residential - A residential area with a concentration of three or less dwellings per acre with a minimum of five dwellings per group. Included in this category are rural non-farm residents that meet the above requirements.	●	
Mobile Home Parks - A residential area consisting of at least five mobile homes.	●	
Primary Commercial - CBD - The most densely constructed urban portion of a city which normally contains the main commercial service center. By definition, each city has only one Central Business District (CBD).	●	
Commercial, Services and Institutional - This category includes commercial retail establishments; businesses; personal, financial, professional and repair services; establishments and institutional structures such as schools, churches, hospitals, etc. In each case, associated features such as lawns and parking lots were included in the classification.	●	
Industrial - Industrial structures and associated land uses such as stockpiles, wastepiles, and parking lots used in both light and heavy manufacturing activities.	●	
Transportation, Communication, and Utilities - Includes transportation-related land uses such as railroad yards, airports, and air strips. Also included in this category are waste water treatment facilities and electrical substations.	●	
Urban Other - Includes urban land uses other than those listed above. The most commonly delineated features are cemeteries, parks, and outdoor recreation areas including drive-in theaters. Several large parks, covering many square miles, exist within the region. Only the intensively used areas within these parks were classified as "urban other," while the nonintensively used areas were mapped as the appropriate land cover type.	●	
Agriculture and Open Space - Agricultural areas used for growing fruits and berries were mapped in this category and lumped into the agriculture and open space category. It was not known at the time of the interpretation whether LANDSAT data could define the category. It has now been determined that LANDSAT could categorize orchards and bush fruit into the correct category.	●	●
Forestlands - Includes both deciduous and coniferous forest. All areas of woods type vegetation were included.		●
Wetlands - Nonseasonal wetland areas dominated by tree growth were mapped in this category. Some delineations were relatively difficult because on the spring (May) photography, it was often hard to determine whether an area was wet during the spring only, or if it was a nonseasonal wetland. Nonforested wetlands were mapped by LANDSAT data and combined with forested wetlands into the class.	●	●
Open Water - Ponds, lakes, streams, and all areas of open water were included in this category.		●

Table 2 Area Tables Produced from Multisource Data

	Category	Lapeer Co. (Acres)	Genesee Co. (Acres)	Shiawassee Co. (Acres)
1.	High-Med Density Res	995.76	13,200.58	1,406.51
2.	Low Density Res	6,727.02	53,707.54	7,625.47
3.	Mobile Home Parks	121.08	1,476.66	302.12
4.	Central Bus. Dist	167.47	891.66	161.81
5.	Primary Commercial	996.89	10,377.38	908.63
6.	Industrial	250.07	3,164.92	686.85
7.	Trans, Commun, UT	297.60	2,721.36	459.41
8.	Urban Others*	803.40	6,770.02	1,181.33
9.	Agric, Open Space	283,612.12	255,682.26	291,719.63
10.	Forestlands	122,349.19	37,506.11	40,468.49
11.	Wetlands	3,788.40	26,013.04	1,348.80
12.	Open Water	3,865.35	4,526.17	783.03
	Subtotals	423,974.34	416,037.69	347,131.28
	Urban (1-8)	10,359.28 (2.4%)	92,310.11 (22.2%)	12,811.33 (3.7%)
	Nonurban (9-12)	413,615.06 (97.6%)	323,727.58 (77.8%)	334,319.95 (96.3%)
	Total	423,974.34	416,037.69	347,131.28

Total Urban (1-8)	115,480.22 (9.7%)
Total Nonurban (9-12)	1,071,662.59 (90.3%)
	1,187,143.31

*Parks, cemeteries, outdoor recreation.

Table 3 LANDSAT Categorization Accuracy (Summary of Sample Survey)

County	Sample Size	No. Correct	% Correct	No. Incorrect	% Incorrect
Shiawassee	129	123	95.3	6	4.7
Genesee	137	129	94.2	8	5.8
Lapeer	141	128	90.8	13	9.2
Total	407	380	93.4	27	6.6

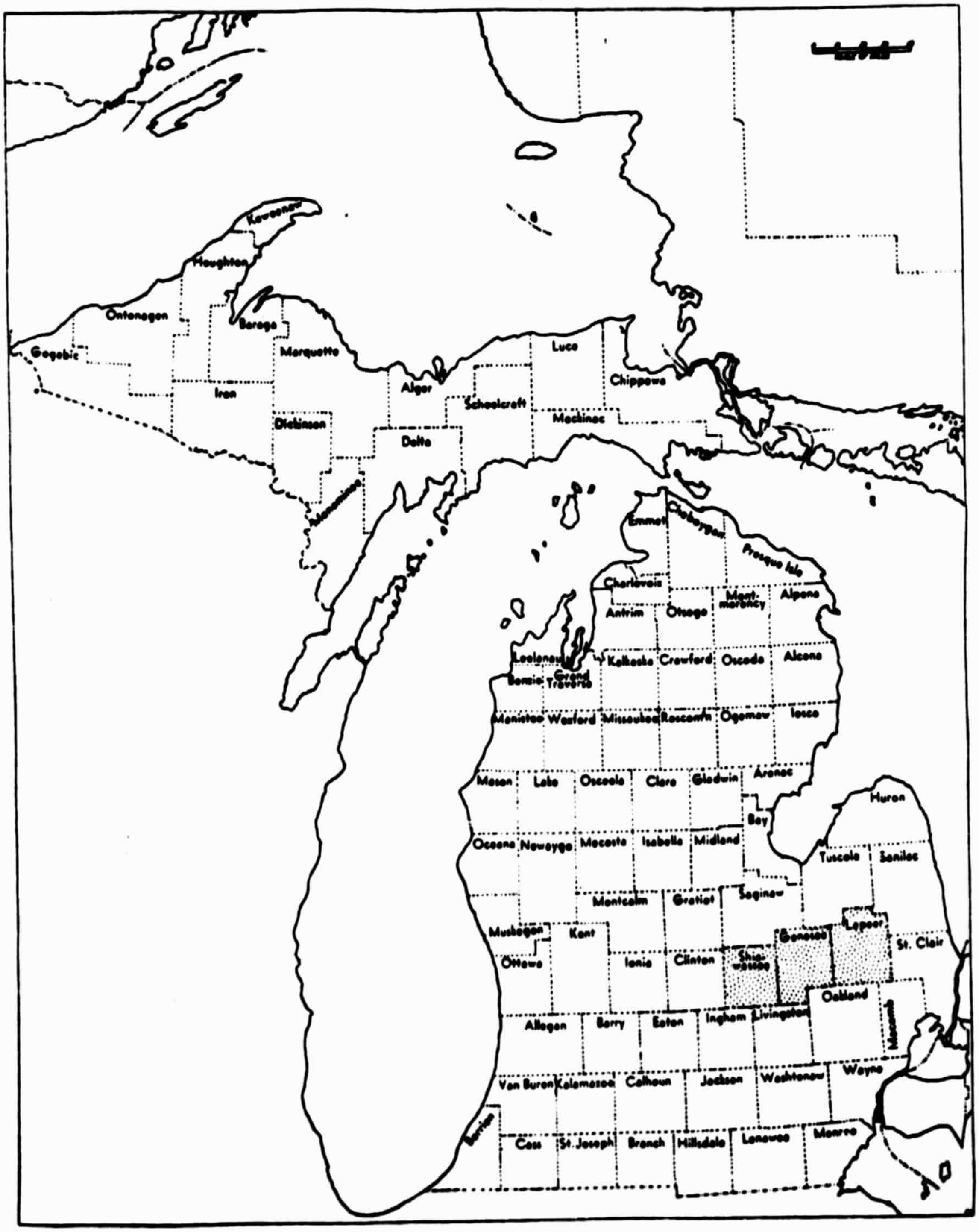

Figure 1 Location of Michigan
GLS Region V

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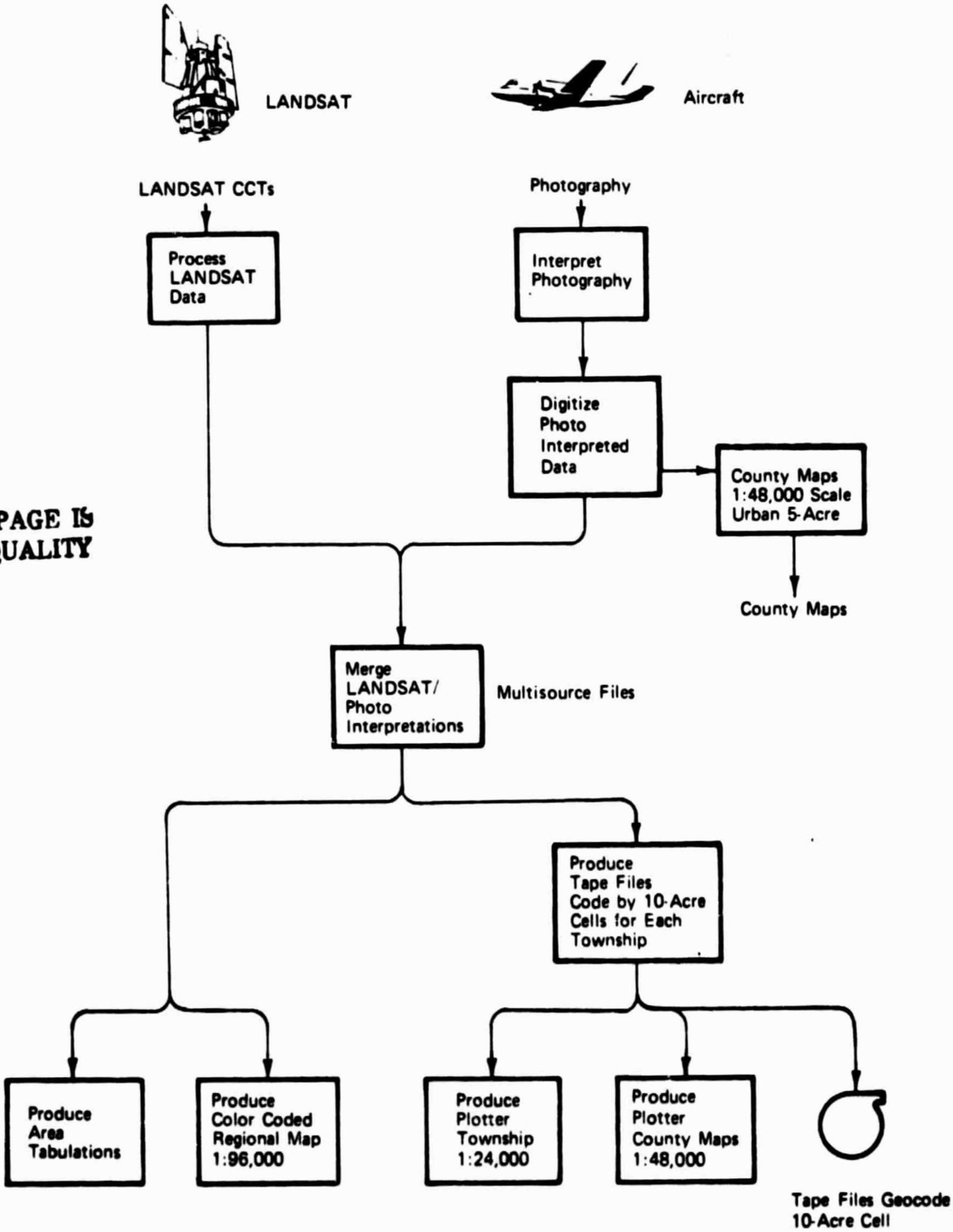

Figure 2 Summary of Processing Steps

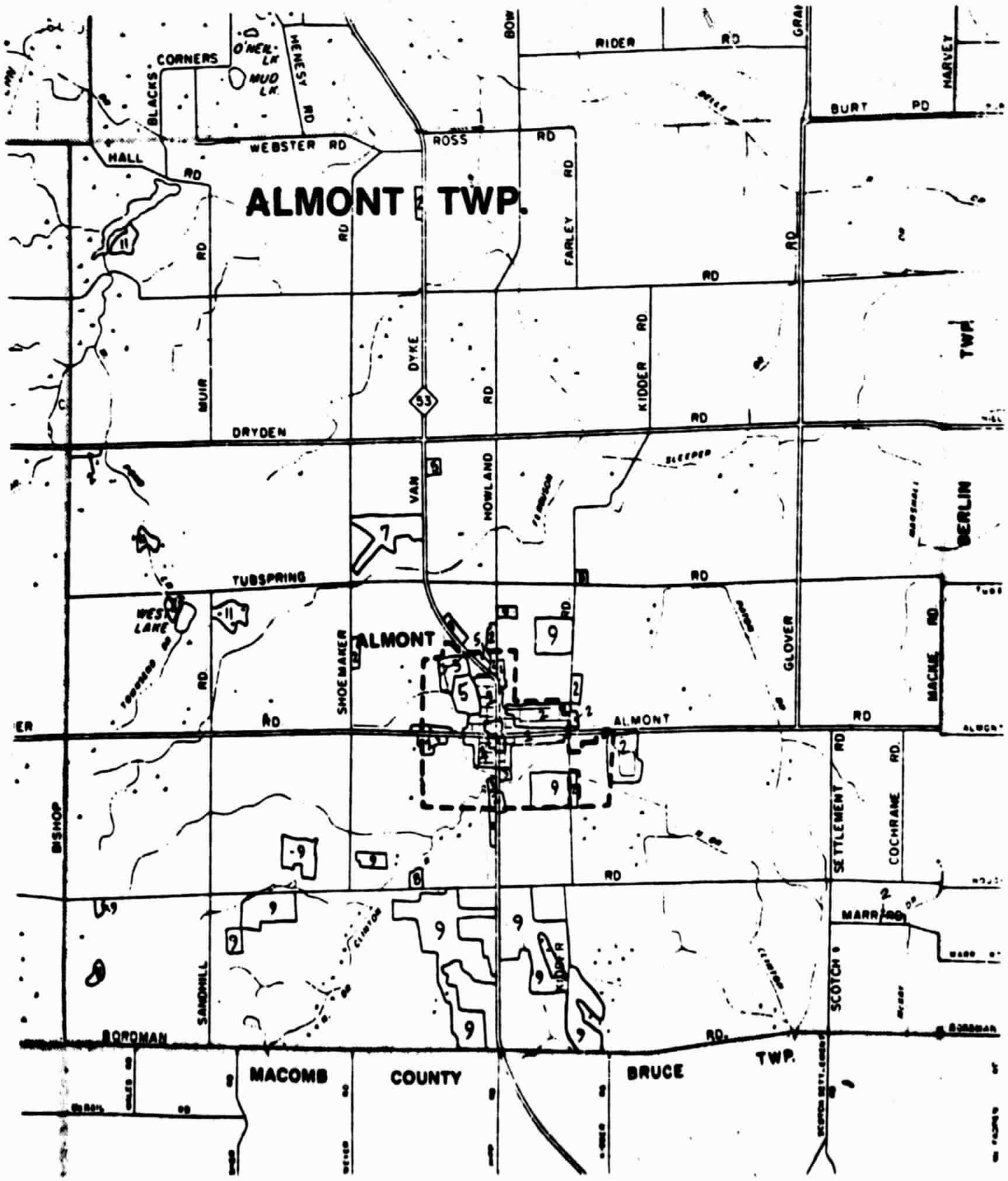

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Figure 3 Portion of County Base Map Showing Interpretations Derived from Aerial Photography

Land Cover – Genesee County

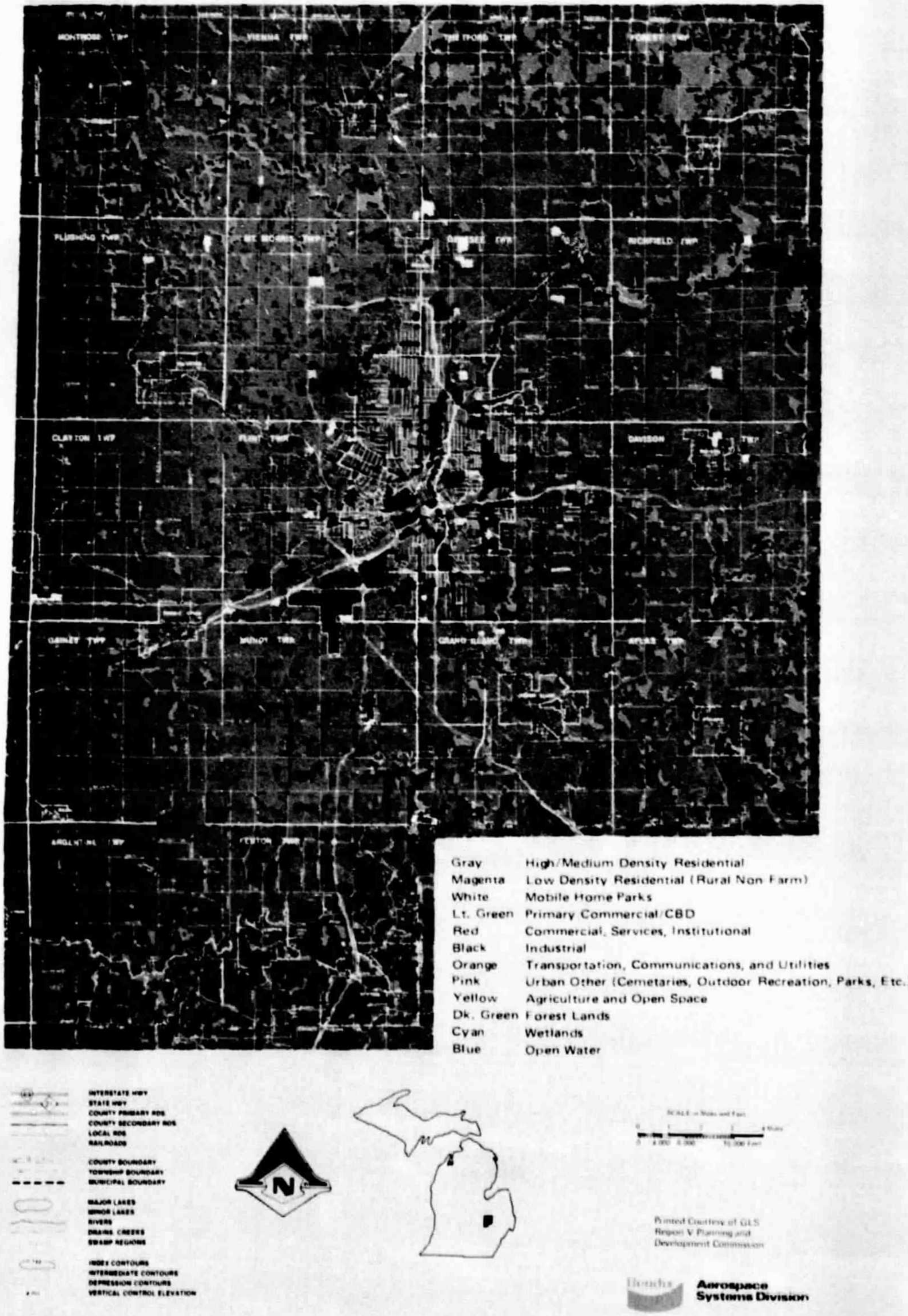

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Figure 4 Black and White Print of Color Map of Genesee County Produced from Multisource Data

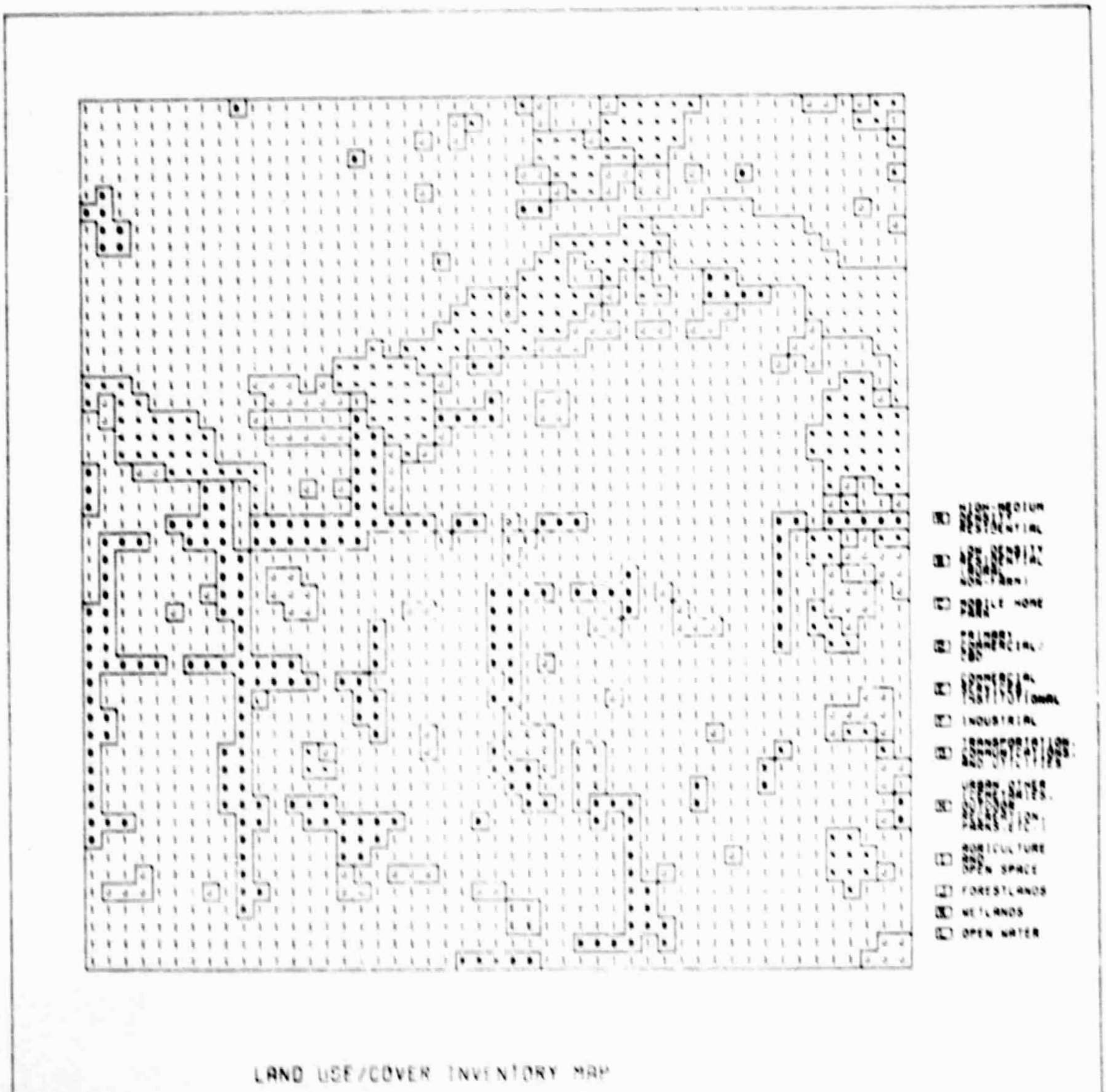

Figure 5 Township Plotter Map (10-Acre Cells)