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Land-Cover Classification Using Digital Processing of Aerial Imagery

The accuracy of classification in an urban area for a hydrological model was approximately 88 percent.

INTRODUCTION

FOLLOWING the passing of the Federal Water Pollution Control Act (P.L. 92-500) in 1972, state and federal agencies in Wisconsin have intensified their interests in both point and non-point sources of water pollution. Until recently the emphasis has been on point sources of water pollution because they are easier to detect, monitor, and treat. Today, however, more research is being conducted on non-point water pollution from such land-cover activities as agricultural fields, urban areas, and construction sites. It is toward these latter two sources that Wisconsin state agencies have directed much of their current interest.

With funds supplied by the International Joint Commission (IJC) on Water Quality in the Great Lakes and the U. S. Environmental Protection Agency (EPA), the Wisconsin Department of Natural Resources (DNR), the Wisconsin Water Resources Center and the Southeast Wisconsin Regional Planning Commission have been investigating the non-point water pollution problem in the Menomonee River watershed in southeastern Wisconsin. The 86,979 acre (35,200 hectare) Menomonee watershed consists of 48 sub-watersheds. These sub-watersheds have land-cover types that range from high density industrial to rural agricultural. The watershed as a whole is steadily becoming more urbanized due to the influence of Milwaukee, Wisconsin. This three-year investigation attempted to develop future forecasts of sediment and pollution discharge into Lake Michigan from non-point sources based upon the analysis of each sub-watershed's current and anticipated physiography, hydrologic, and land-cover data in conjunction with a hydrologic model, LANDRUN. The goal of the project was to predict the sediment and pollution loads into Lake Michigan into the year 2000.

ABSTRACT: *Land-cover information for a hydrological model was provided by digital analysis of aerial photography. A fast method for obtaining land-cover information in two watersheds was tested and found to be cost effective. Thematic representations as well as tabular information was produced. Accuracy of approximately 88 percent was determined for the digitally classified imagery.*

The computer model, LANDRUN, is a hydrologic and overland transport model which describes the runoff of sediment and pollutants from land surfaces under existing and predicted land-cover conditions. The model converts precipitation into quantity and quality of surface runoff, interflow, and groundwater recharge. It also determines

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 46, No. 8, August 1980, pp. 1059-1065.

the amount of pollutants absorbed in the top soil, the quantity of dissolved particles removed in the interflow, and groundwater recharge. The various land-cover types in the Menomonee watershed were aggregated into 11 land-cover categories for which LANDRUN determined a hazard ranking (a logarithmic ranking based on the estimated contribution of pollutants from each land cover) for suspended solids, total phosphorus, and lead loadings. The principal factors which affect non-point source pollution include soil type, slope, percent imperviousness, and type and degree of land management. In urban areas the most significant parameter is the degree of imperviousness.

Since one of the important input parameters in the LANDRUN model is land cover, remote sensing was investigated as a possible method of obtaining land-cover information. The most widely used remote sensing technique is manual photo interpretation of large-scale aerial imagery in conjunction with the ground-based field work.[1] Although sufficiently accurate for land-cover interpretation in urban areas, this method has proven costly and time consuming when implemented on areas larger than a few square miles.[2]

A second method of obtaining land-cover information is by computer assisted interpretation of Landsat tapes which has been investigated by a number of researchers.[3-6] Although this method is faster and inexpensive, it has several drawbacks. One drawback is the 1.43 acre instantaneous field-of-view for a resolution cell of Landsat.[7] This requires the amount of impervious surface to be indirectly inferred by assigning to each land-cover category a predetermined amount of imperviousness. This technique seems to work well in rural areas, but is not as accurate as desired in urban areas.[8]

An additional consideration when satellite imagery is to be used, particularly in Wisconsin, is acquiring cloudless imagery. The ideal season to obtain imagery for mapping land cover within urban areas, especially impervious land cover, is in the early spring or late fall. Unfortunately, this is when the number of cloudless days is at a minimum.[9] Consequently, it may be easier to acquire aerial imagery than cloud-free Landsat imagery of a desired watershed. The goal of this investigation was to develop and test the technique of digital interpretation of aerial photography for land-cover mapping in urban areas.

DIGITIZED PHOTOGRAPHY

Densitometry on multi-emulsion imagery has been described adequately elsewhere;[10-12] thus, only a short review of the salient points will be presented here. Because of the colored dyes present in the imagery, any density measurement on multi-emulsion imagery is wavelength dependent. Any density measurement on the film is an integral density dependent on the concentrations of all three dyes present. Before any correlation is made between ground resources and measurements on the film imagery, the interaction between these dyes is determined. The first step in this calibration procedure is to determine the transformation between density measurements and analytical density of the film layers.[2] Analytical densities are proportional to the concentration of dyes present at each spatial location on the imagery. Next, characteristic curves are generated for the roll of imagery. These curves represent the relationship between analytical density and log exposure.

Once characteristic curves have been generated for a specific roll of imagery, their use in the analysis procedure is relatively straightforward. After the analytical densities have been found for a particular spot on the imagery, the characteristic curves are used to find the three exposures (one for each layer) which are related to the incident energy at that spot on the exposed film. The exposures are then corrected for the change in exposure across the film format due to the lens geometry.[10] These corrected exposures are the values to be correlated with the ground phenomena via digital analysis programs. In the Menomonee River study these values were correlated with land cover.

EXPERIMENT

In order to test this technique, two sub-watersheds were chosen in the Menomonee River watershed, Schoonmaker and Noyes Creeks. Schoonmaker Creek is an older, highly developed residential area of approximately 440.62 acres (178.0 hectares). It is primarily a single-family residential area with some parks, schools, and commercial/retail stores. Noyes Creek covers 1,367.24 acres (553.2 hectares) and is in the early stages of urbanization. This sub-watershed is a mixture of single, multi-family residential, open areas, parks, commercial/retail, industrialized, and agricultural areas. NASA color infrared imagery at a scale of 1:120,000 of Noyes Creek and Kodak Aerochrome MS Aerographic Film 2448 at a scale of 1:38,000 were obtained on 31 July 1974 and 16 November 1976, respectively. Both images were digitized on an Optronics P-1700 scanning microdensitometer. The ground reso-

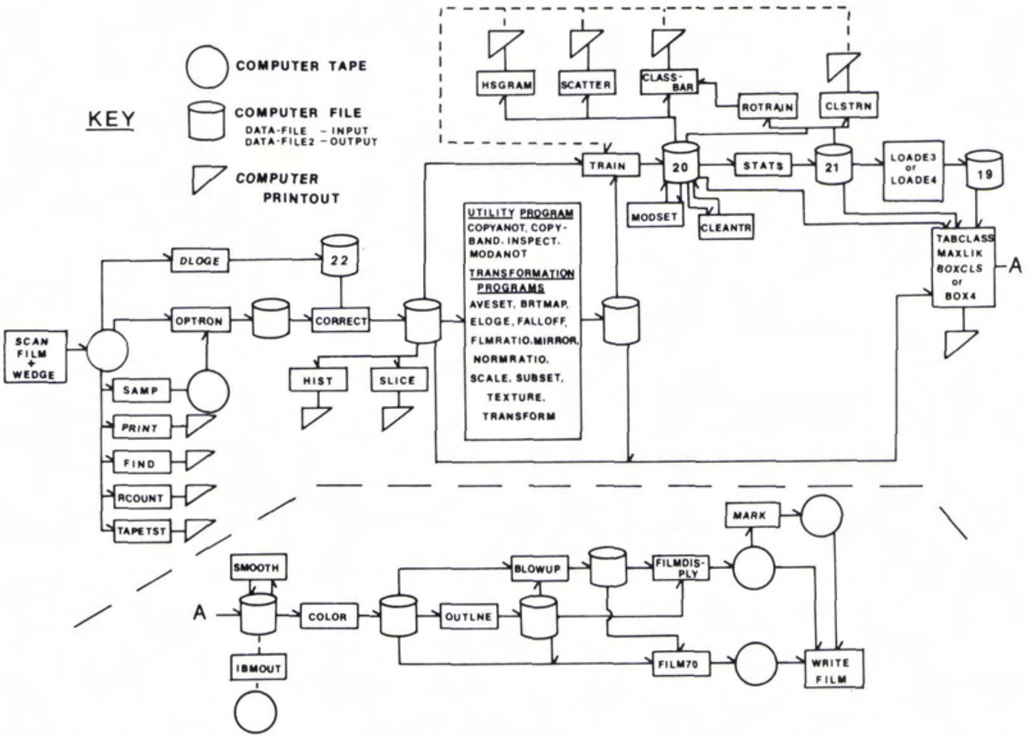

FIG. 1. Block diagram of the digital processing programs at the University of Wisconsin for analysis of remote sensing imagery. The procedure is based on converting an aerial image to a digital format (top far left); creating a computer file; locating and computing statistics for each training area (top middle); and running the elliptical classification program (top far right). If the classification is inaccurate or incomplete, additional training areas can be chosen, etc., until the classification appears correct.

lution was 6.0 metres square (19.7 feet square) and 3.8 metres square (12.48 feet square) for Noyes Creek and Schoonmaker Creek, respectively. The data on the computer tapes for these areas, produced by the Optronics system, were transferred to exposures and placed on disk files on a Univac 1110 computer. Training areas representing the different land-cover categories were chosen from level slices on each sub-watershed's computer file. After the spatial and spectral quality of the training areas were checked, statistics which characterized the land-cover classes were generated. The statistics for each training area consist of a mean vector, covariance matrix, eigenvalues, and eigenvectors. These statistics were used to load a look-up table for an elliptical classifier.[13]

This type of classifier first creates an ellipsoid in spectral space from the statistics derived for each training area. The classifier then determines if the spectral signature of each pixel falls within the various ellipsoids. If a pixel falls into only one ellipsoid, the pixel is classified as that category. If the pixel falls into more than one ellipsoid, a maximum likelihood algorithm is employed to determine the most probable category. Pixels that do not fit into any of the training area ellipses remain unclassified. A schematic of the entire classification procedure is depicted in Figure 1.

RESULTS

The results of the classifications on each sub-watershed after several iterations are shown in Table 1. For the computer classifications, five major land-cover categories were chosen: impervious surfaces—streets, sidewalks, rooftops, etc.; upland hardwood tree cover; vegetative cover; water; and a transition class. This latter class usually contains a combination of the impervious and vegetative surface. This class also represents boundary conditions between land-cover categories.

The transition class presented some problems during the classification procedure. The transition class has a mixture of a large number of spectral signatures. An example illustrating classification ellipses generated from training sets extracted from impervious surfaces, vegetation, and a

TABLE 1. CLASSIFICATIONS FOR SCHOONMAKER AND NOYES CREEKS

Land Cover	Schoonmaker Creek	Noyes Creek
Impervious	63.6%	38.0%
Vegetation	25.4%	50.0%
Forest	0%	3.7%
Transition	10.7%	3.3%
Water	0%	0.05%
Unclassified	0.3%	4.95%
	100%	100%

transition class can be found in Figure 2. It was desired to classify as transition only the pixels which fell into the shaded area on the figure. The method we chose to accomplish this task was to use a two-stage classification procedure. The algorithm in the elliptical classifier was changed to allow a designated number of classes to be checked first; then, if a pixel remained unclassified, the rest of the classes were checked. By designating that the transition class be checked second, only pixels falling in the overlap area, not classified as the other classes, will be classified as transition.

These land-cover categories were chosen because of their compatibility as input parameters into the LANDRUN model. The actual computer classification broke down each of these categories into a number of subcategories. For instance, vegetative land cover really consisted of a number of agricultural crop types, some native plant species, grass, etc. The sub-categories were then integrated into a smaller number of categories to be compatible with the LAND RUN model.

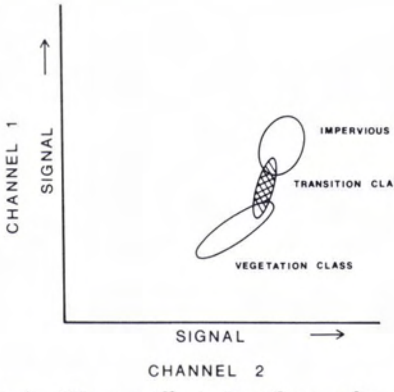

FIG. 2. Diagram illustrating the overlap of spectral signatures between the transition class and the impervious and vegetation classes.

Besides a tabular product, both color slides and prints were produced of the two classified sub-watersheds.

As with any computer classification of land cover, the accuracy of the classification must be checked. The classifications were checked against a ground calibration and visual photo interpretations of the original imagery as well as computer-generated imagery. Large homogeneous areas of a resource such as parking lots, roads, and large stands of trees were easily verified and were virtually all classified correctly. Small patches of vegetation and transition classes were very difficult to check because it was impossible to locate a 4 to 6 metres square classified pixel on the ground. Since a spatial error of a few metres on the ground could lead to significant errors in locating the correct pixels, the ground calibration of transition classes was abandoned.

It was felt that a visual photo interpretation of the original imagery would be a reasonable "ground calibration" of the classified imagery. Even with this technique, locating the classified picture element on the imagery presents problems. In order to locate these pixels, a calibration technique has been devised. Essentially, 350 randomly chosen pixels in the classified scene are picked and marked in a file of the scanned imagery. Of these pixels approximately half fell within the boundaries of each subwatershed. This marked imagery is then made back into a photographic product on the Optronics system and manually photo interpreted using a color additive viewer. The results of the computer classification for those pixels is then compared to the photo interpretation. Figure 3 is a black-and-white copy of the imagery illustrating the marking procedure. In this fashion, we can locate the exact picture element classified by the digital processing and validate, in a statistical sense, the accuracy of the classification. The results of this comparison can be found in Tables 2 and 3. Each table represents a comparison between the number of pixels/land-cover category that were classified by the computer and the photointerpreter. For instance, in Table 2, 45 of 47 pixels classified by the computer as impervious were also classified by the photointerpreter as impervious or 95.78 percent the same; however, of the 55 pixels the photointerpreter classified as impervious, the computer only classified 45 or 81.82 percent the same. Ideally, if there was perfect agreement between the computer and the photointerpreter, Tables 2 and 3 would be diagonal matrices. The im-

FIG. 3. *Black-and-white print of one band of the original Noyes Creek image illustrating* the marking procedure used in verifying the accuracy of the computer classification.

portant number is the total number of pixels classified correctly, which is the total number of pixels classified correctly for all land-cover categories divided by the total number of pixels. As can be seen, the computer classification was very close to the photointerpretation results, with an accuracy of 86.67 percent and 89.40 percent for Noyes and Schoonmaker Creeks, respectively. The problem land-cover categories seem to be in the transition class.

The costs of digital classification are always an important aspect of any classification project. Each scene contained approximate 302,500 picture elements, 1089 hectares (4.20 square miles) and 437 hectares (1.69 square miles) on the ground for Noyes and Schoonmaker Creeks, respectively. The computer costs to calibrate and classify this number of picture elements was approximately $139.00. Since our digital analysis system is an intermixture of interactive and batch use of the computer, the time needed to classify a scene is somewhat long. The estimated total time to classify a scene is 20 hours, which includes the time to digitize the image, classify the scene, and produce the colored thematic products. All expenses, e.g., acquiring the aerial, digitization, etc., are summarized in Table 4. These expenses

TABLE 2. COMPARISON OF MANUAL VS. COMPUTER CLASSIFICATIONS FOR THE AREA WITHIN NOYES CREEK. THE NUMBER OF PIXELS AND THE PERCENTAGE CLASSIFIED CORRECTLY OUT OF 135

	Manual Interpretation					
	Unclassified	Impervious	Vegetation	Forest	Transition	% Similar/Row
Computer Classification						
Unclassified		5	5			
Impervious		45	2			95.8
Vegetation		4	67			94.3
Forest			1	4		80.0
Transition		1	2		1	25.0
% Similar/Column		81.8	89.3	100	100	86.7

TABLE 3. COMPARISON OF MANUAL VS. COMPUTER CLASSIFICATION FOR THE AREA WITHIN SCHOONMAKER CREEK. THE NUMBER OF PIXELS AND THE PERCENTAGE CLASSIFIED CORRECTLY OUT OF 151

	Manual Interpretation				
	Unclassified	Impervious	Vegetation	Transition	% Similar/Row
Computer Classification					
Unclassified		1			
Impervious		81	4		95.2
Vegetation		6	49		89.0
Transition		3	2	5	50.0
% Similar/Column		89.0	89.1	100.0	89.4

represent the actual cost/image as well as personnel time to produce the final classifications.

SUMMARY AND CONCLUSIONS

We believe that this project has demonstrated a cost-effective method of mapping current land cover in an urban area. The technique involves using digitized aerial imagery (either color or color infrared) that has been properly calibrated. The calibrated digital imagery is classified using a two-stage elliptical table look-up algorithm which produces a tabular presentation of different land-cover classes as well as a thematic representation. The accuracy of the classification was checked by ground calibration and photointerpretation of reconstituted images.

In order to effectively use hydrologic transport models such as LANDRUN, accurate, current information on land cover is needed. We believe that remote sensing techniques may be the only practical method of ascertaining such information in a timely fashion. The digital analysis of aerial imagery would seem to be superior to the analysis of Landsat tapes in an urban area because of the better resolution and the versatility in choosing the date of imagery.

TABLE 4. SUMMATION OF EXPENDITURES IN LAND COVER MAPPING IN BOTH NOYES AND SCHOONMAKER CREEKS SUA WATERSHEDS

	Cost		
		per/image	
Item	per/unit	Noyes Crk.	Schoonmaker Crk.
1. Film Acquisition***			
a. Film Cost	$57.75/100′ roll	*	$ 0.15
b. Flight	$100.00/hr.	*	0.85
c. Film Processing	$1.00/ft.	*	0.25
2. Data Conversion & Transformations			
a. Digitization & Photowriting	$35.00/hr.	$12.00	$ 12.00
b. Computer Preclassification	$175.00/hr.**	30.00	30.00
3. Data Classification	$175.00/hr.	$55.00	$ 55.00
4. Classification Representation & Verfication			
a. Color Thematic Maps		$26.00	$ 26.00
b. Manual Photo Interpretation		15.00	15.00
	Subtotals	$138.00	$139.25
Total Cost/image = $139.00 plus 20 man hours			

* Provided by NASA.

** Includes CPU, file and tape I/O, pages printed, cards input, tape mounts, and computer.

*** The Schoonmaker Creek image was obtained as part of another aerial photographic flight. The cost for acquiring the image was determined based on the total acquisition cost for that flight.

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(Received 23 August 1979; revised and accepted 14 January 1980)

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