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16. Abstract

ERTS-1 computer compatible tapes (CCTs) were used as a basis to generate land-use maps in lake watersheds in southeastern Michigan. These maps, generated on a repetitive basis, provide information essential to governmental agencies concerned with planning and control of lake eutrophication. The ERTS mapping products included geometrically correct land-use map overlays at 1:250,000 and 1:48,000 scale and area measurement printouts. The printouts provide, within the watershed boundaries and by land-use category, a quantitative measure of the amount of land, in sq kilometers and acres. This quantitative measure of land use in watersheds is essential to the development and application of deterministic models, which compute nutrient flows into lakes and establish lake eutrophication rates.

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Introduction

National, state, and local government agencies, as well as conservationists, environmentalists, and private citizens, are becoming increasingly alarmed over the loss in water quality in many of our public lakes. Much of this loss is a direct result of pollution generated by man and the increased nutrient runoffs into the lakes resulting from urbanization in the watersheds. It is now realized that our water resources are not inexhaustible and that land development in the watersheds must be planned if the conflict between utilization of our water resources and maintenance of the quality of our lives is to be resolved.

In response to this problem, the Environmental Protection Agency (EPA) and the Michigan Department of Natural Resources (DNR) have initiated programs in Michigan and the Great Lakes to determine how land-use policies and practices in watersheds affect lake water quality. A common requirement of these programs and programs of other governmental agencies, concerned with the maintenance and control of water quality, is the development of a knowledge of the interrelationships between the water quality parameters (turbidity, chlorophyll concentrations, etc.) and land-use parameters (land-use categories and coverage, etc.).

To obtain this information the EPA in collaboration with the Michigan DNR is sponsoring a modeling study of water quality in Saginaw Bay (Lake Huron), Fig. 1. This bay is heavily enriched by drainage from 6,000 square miles of urban and agricultural land. The program goal is to develop a deterministic model capable of predicting water quality in the bay resulting from existing and potential land-use policies. Accurate water and land-use parameters are essential in the development and application of this model. Similar procedures will be applied by the Michigan DNR to lake watersheds throughout the state to assess the degree of eutrophication in the lakes and to establish their potential for further enrichment and pollution resulting from land-use development. This information will form the basis for modifying the state's land-use practices as needed to control lake nutrient and sediment inputs to a tolerable level.

AUTOMATED LAND-USE MAPPING

While many factors influence lake eutrophication rates, a dominating factor is the use of land within a narrow zone only several hundred meters wide adjacent to and surrounding the lake. During periods of rain or thaw, this zone discharges nutrients directly to the lake by means of surface runoff or storm drainage. The amount of nutrients discharged is a function of land use within the zone, area covered by each land-use category, and terrain topography. Fertilized lawns (tended grass) and paved streets discharge more nutrients, especially phosphorus, than do rangeland (untended grass) and forested land.

To establish nutrient flows into the lakes and to determine lake eutrophication rates, accurate information on land use within the watershed and area covered by each land-use category is essential.

Utilizing conventional techniques, the watershed land-use information would be extracted from land-use maps. One difficulty with this procedure is that in high growth areas, land-use information on the maps is generally out of date by the time the map is printed. Present techniques for generating land-use maps based on the use of aerial photography and photometric mapmaking are mostly manual, expensive, and time-consuming. Also, in the early development of deterministic models concurrent measurements of water quality and land-use factors are essential. Since lake eutrophication in high growth areas is subject to rapid change, the likelihood of having a land-use map of the area concurrent with water quality measurements is very remote.

Previous studies (Ref 1 and 2) have already shown that water properties (turbidity, total particulate solids, etc.) can be derived directly from aircraft and spacecraft data. Dr. James Scherz has shown (Ref 2) that lake eutrophication, based on turbidity or suspended solids, correlates well with lake reflectance measurements in ERTS Band 5. This study evaluated the suitability of using ERTS computer compatible tape (CCT) data as a basis for deriving watershed land use.

Test Site

The data for this study are the lakes and watersheds selected from the second CCT of ERTS scene 1265-15474, acquired on 14 April 1973, and correspond to a ground coverage of approximately 1.6×10^3 square kilometers (625 square miles) in southeastern Michigan. This test area used by the ERTS-1 Inland Lakes Investigation (MMC 598) is shown on the map in Fig. 1. It is located mainly within Oakland County, Michigan, on the northwestern outskirts of Detroit. Historically, this is a glacial outwash area characterized by low hills, morainic soils, and numerous "kettle" lakes, many without any discrete inlet or outlet. At present these lakes are surrounded by urban and suburban developments grading into farmlands and some undeveloped land toward the northwest. Urbanization has been rapid: the county's population has doubled during every decade since 1940. Fortunately, county authorities in recent years have prepared detailed thematic maps (based on aerial and ground surveys) of topography, vegetation, and land use. These graphically show the impact of urbanization on the area, although much development had occurred since the last maps were developed. The maps provide an excellent base for updating efforts and made possible a direct comparison of ERTS and conventional mapping techniques.

With respect to its effect on water quality, a watershed may be defined in different ways. In the largest sense it includes the whole drainage basin within which all elevation gradients slope toward a lake. The basin would include, by definition, all other lakes "upstream" that discharge seepage, even rarely, to the lake in question. However, by a more functional definition that better applies to lakes in the study area, the watershed is that part of the drainage basin immediately adjacent to the lake. During periods of rain or thaw this area discharges drainage directly to the lake via surface runoff or storm drains. In these cases the major sources of nutrients are paved surfaces, septic tanks, fertilized lawns, and eroded soils. Waste waters that arrive at the lake after slow percolation through soil or vegetation are generally less enriched, at least by phosphorus (Ref 3).

Therefore, in mapping watersheds of lakes with diffuse sources of nutrients, emphasis should be given to the narrow zone of land adjacent to and extending back from the water. This zone is defined by this study as being approximately 125 meters wide, or the effective width of two ERTS picture elements. Ordinarily, this zone includes the first rank of waterfront lots, houses, and roads, as well as launching ramps and docking facilities. If warranted, larger areas such as housing developments served by storm drains could be included in the analysis to compute total nutrient flows.

Data Processing

The need for a faster and more economical means of generating watershed land-use information has led Bendix into evaluating computer target "spectral recognition" techniques as a basis for automatic target classification and mapping (Ref 4). These classification techniques have been under continued development at Bendix for the past 8 to 10 years, primarily using aircraft multispectral scanner data and, more recently, using ERTS/MSS and Skylab/EREP-S192 data.

The elements of the Bendix data center used to process data for this study include a Digital Equipment Corporation PDP-11/15 computer with 32K words of core memory, two 1.5M-word disk packs, two nine-track 800-bits-per-inch tape transports, a line printer, a card reader, and a teletype unit. Other units are a color moving-window computer-refreshed display, a glow-modulator film recorder, and a computer-controlled Gerber plotter.

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

Locate Training Areas

The first step in the development of the Oakland County land-use map was to locate the CCT coordinates, in terms of resolution element number and scan-line count number, of those areas that best typified the land-use target categories of interest, the "training areas."

While recognizing that many factors influence the quality of land drainage, we chose the six general types of land-use categories which are listed below in order of their potential to discharge nutrients, especially phosphorus. The codes following the category names correspond to those proposed by Anderson, et al. (Ref 5). While other target categories or combinations thereof might have been chosen as well, the ones listed account for most of the watershed use that affects water quality in the study area. Water categories (deep and shallow) were included to complete the land-use map.

- Urban, 01. Large commercial areas, major roadways, high density residential areas, and many isolated shopping centers.
- Extractive Earth, 01-04. Strip mines, gravel pits, construction sites, and other areas of disturbed or bare earth.
- Tended Grass, 01-09. Golf courses, cemeteries, sod farms, and other areas of cultivated grass which are very green in Michigan in April.
- Wetlands (nonforested) 06-01. Marshes, bogs, swamps, and low brushy areas.
- Rangeland (untended grass), 03-01. Natural grasslands, pasture land, dry savannahs, and old fields. Natural grassy areas (rangeland) are normally brownish in Michigan in April. Unharvested crops would probably be included, while plowed fields would be classified as extractive land.
- Forested Land (trees), 04-03. Mixed hardwood (deciduous) forest. There were no sizable evergreen forests in the study area.
- Shallow Water, 05. Bottom visible in some ERTS band. In most of the study lakes, shallow water ranged up to 4 meters deep.
- Deep Water, 05. Waters where bottom contours are not visible in any ERTS band (i.e., over 4 meters).

- Unclassified. This category includes all targets that do not exceed the probability thresholds established by the investigator.

The training areas were located by simply viewing the CCT data on the color-coded moving window display. Once the target of interest was located on the display, a computer-generated gray-scale image of the target scene was produced and used to perform detailed editing by scan-line count and resolution element number.

Develop Target Characteristics

Inputting the training area coordinates (boundaries) to the computer permitted the ERTS spectral measurements within these boundaries to be extracted (edited) from the CCTs and placed into computer disk files. One file was established for each different land-use category. The data in each file were then processed to obtain a numerical descriptor to represent the spectral characteristics of each land-use category. The descriptors included the mean signal and standard deviation for each band and the covariance matrix taken about the origin.

Evaluate Target Characteristics and Classification Techniques

Once the numerical descriptions which define the spectral characteristics of each target category were determined, the "canonical analysis" program (Ref 6) was applied. This program derives, for each target category, a set of "canonical coefficients." In the decision processing phase these coefficients are used by the computer to form a linear combination of the ERTS measurements to produce a "canonical variable" whose amplitude is associated with the probability of the unknown measurement being from the target sought.

In decision processing, the probability of an ERTS measurement arising from each one of the different land-use categories of interest is computed for each ERTS spatial resolution element, and a decision based on these computations is reached. If all probabilities are below a threshold level specified by the operator, the computer is permitted to decide that the target viewed is unknown (an undefined land-use category).

Before producing decision data on a large amount of ERTS data, a number of tests were applied to evaluate the computer's capability of performing the desired target classification. The tests included generating classification accuracy tables and viewing the results of processed data on a TV monitor.

The classification accuracy table provided a quantitative measure of the interpretation accuracy. In this step the canonical coefficients were used in the decision processing, but the data processed were limited to those that are well known, i.e., the training data that were previously edited and stored on the disk file. Processing these data and keeping an accurate record of decisions permitted the computer printout shown in Table 1 to be developed. In the table, training set one, tended grass, was classified as tended grass 97% of the time and as rangeland 3% of the time. Also, target group four, urban areas, as shown in the table, was confused somewhat with extractive (bare earth/concrete), rangeland, and wetlands.

Produce Decision Data Products

When we were satisfied with the classification accuracy of the decision processing, the canonical coefficients were placed into the computer disk file and used to process that portion of the CCT covering the study area. This first step in the decision processing resulted in a new or classified CCT, wherein each ERTS spatial element is represented by a code designating one of the eight land-use categories. This first step also results in the computer-generated area measurement table shown in Table 2.

Area Measurement Table - The area measurement table is the first real data product useful for predicting nutrient flows into lakes. This table provides the amount of land that falls within a particular category in terms of square kilometers, acres, and as a percentage of the total area processed.

It can be noted in Table 2 that forest land (trees), for example, comprised 11% (65,732 acres) of the total 625-square-nautical-mile (581,206-acre) area processed. Total surface water (shallow plus deep) covers 10,099 acres. It is also noted that approximately 12% of the area remained unclassified. Most of this unclassified area was determined to be automobile assembly plants (heavy industrial) which were characterized by large areas of dark roofs and parking areas. Obtaining similar printouts from additional ERTS overflights would provide additional land-use categories and establish the dynamics of land use within the watershed.

The computer classified the Oakland County study area of the ERTS tape into the nine categories of Table 2 at a rate of approximately 130 acres per second. This rate will increase by more than 10 times when hardware under development is used to perform the target classification function presently accomplished by software algorithms.

Decision Map Overlays - To produce land-use classifications that will directly relate to a map, the decision (classified) CCT was submitted to a second stage of processing. In this stage, a new tape was generated that had data corrected for earth rotation and whose format was compatible with the Gerber plotter. This tape, when played back by the computer, caused a geometrically corrected map of a specified target class to be drawn on film at a map scale specified by the operator. The operator had an option of obtaining either boundary line drawings enclosing a select land-use category or boundary line drawings that are filled in. The film, when removed from the plotter and photographically processed, provided transparent overlays which were used directly, as those in Fig. 2 through 9, or processed further to produce color-coded land-use overlays. Color-coding permitted multiple overlays to be used simultaneously over the base map.

Fig. 2 shows a map overlay of the boundary lines enclosing deep and shallow water, i.e., total surface water. In the same figure the water overlay is also shown on an AMS 1:250,000 map. Boundaries drawn at this scale appear accurate and smooth. The smoothed effect is partly due to the fact that the equivalent map distance of the line (333 feet) used to describe the boundaries is larger than the width of an ERTS element (240 feet). The relatively large lake and the island appearing in the lower center of the overlay are

Orchard Lake and Apple Island. The lake is approximately 1.5 miles wide. This illustration of Orchard Lake should be compared with that produced in Fig. 6 at a scale of 1:48,000. In Fig. 6, and individual ERTS element (240 x 240 feet) shows as a small rectangular box which creates a stair-step appearing boundary line when describing rounded boundaries.

In Fig. 3, 4, and 5, the filled-in versions of six land-use categories are shown overlaying the AMS 1:250,000 map. These overlays appear very accurate, as shown by the ability of the water category in Fig. 3 to fall within the lake outlines on the maps. Note the small fringe of wetlands surrounding Apple Island on the right side of the same figure. The wetlands category mapped in this figure includes marshes, bogs, swamps, and low brushy areas. Tended grass areas with standing water do not appear to be misplaced into this group.

Extractive earth and forested land categories are mapped in Fig. 4. Extractive earth, which includes gravel pits, construction sites, and other areas of bare earth, is one of the highest lake nutrient sources. Close analysis of Fig. 9 shows that some large asphalt parking areas are also classified into the extractive category, perhaps due to a coating of earth or salt which has modified the reflectance characteristic of the asphalt. The forested land category mapped on the right side of Fig. 4 is almost exclusively mixed hardwood (deciduous) forest. Some older subdivisions with numerous large trees are also mapped into this category. Trees are shown covering Apple Island as they should in Fig. 4 and 7.

Tended grass and urban areas are shown mapped at the 1:250,000 scale in Fig. 5. Tended grass during April in Michigan occurs in areas which are highly watered and fertilized, such as golf courses and cemeteries. Rangeland (untended grass), which is mapped but not included in the paper, is brownish at this time of year. The large golf course on the lower west side of Orchard Lake is easily observed in Fig. 5. It can be seen more clearly at a larger scale in Fig. 8. The heavy fertilization used on golf courses can be major sources of phosphorus in the lakes. The urban category shown on the right side of Fig. 5 includes all large commercial areas, major roadways, high density residential areas, and many isolated shopping centers. The major portion of this category is centered over Pontiac, Michigan. The paved surfaces, septic tanks, and fertilized lawns from this target class are also a major source of lake nutrients.

Fig. 6 through 9, which were discussed previously, show four of the land-use categories as boundary line drawings at a scale of 1:48, 000. The overlays in this case are placed on vegetation and land-use maps compiled by the Oakland County Planning Commission. This scale is much more suitable for detailed analysis of land use in small lake watersheds. An individual ERTS ground element at this scale appears as a small rectangular box of approximately 1/16 x 1/32 inch. This element, as noted previously, produces the "stair-step" boundaries shown in Fig. 6 when describing target categories which normally have rounded boundaries. The stair-step appearance, if distracting, can be smoothed as shown in Fig. 6.

As noted previously, the effective watershed of many lakes, with respect to nutrient enrichment, is a narrow zone adjacent to and surrounding the lake and is about two ERTS elements wide. At the 1:48, 000 scale, it would not be difficult to manually count the classified picture elements of each target category within this zone. For Orchard Lake there would be 250 elements in the zone. A count of classified elements would provide immediately the area covered by each target category within the zone and would provide a basis for an estimate of nutrient flow into the lakes. Computer software is under development which will permit an investigator to interact with the data and to obtain an automatic tabulation of target category areas as in Fig. 2 for any desired zone of interest.

Summary

This study shows that watershed land use can be automatically mapped from ERTS data.

Automatic processing of ERTS tapes produced geometrically correct map overlays showing land use at scales of 1:250, 000 and 1:48, 000. At the 1:250, 000 scale, boundary

lines appear smooth and mapping errors are equal to or less than the width of the line (333 feet) used to describe the boundaries. The 1:48, 000 scale overlay was found best suited for study of land use in the watersheds of lakes 2, 000 acres in size or smaller. An ERTS element at this map scale (1/16 x 1/8 inch) produces a rough stair-step appearance when plotting target boundaries which are normally rounded, e.g., lakes. Computer smoothing would greatly improve the appearance of these overlays.

The automatic spectral processing techniques were found to be very fast. Each resolution element within an ERTS CCT is placed into one of 16 target categories within a few microseconds. The complete CCT (25 by 100 mile area) can be interpreted within minutes, followed immediately by a printout giving area covered by each target class in square kilometers and acres. The area printout tables provide information essential to the computation of nutrient flows into the lakes. A technique which will permit the investigator to interact with the data and obtain area printouts by target category within irregular shaped watershed boundaries is essential. Further research is needed to establish the nutrient loads to be expected in runoff from different land-use categories in a given area.

It is estimated that watershed land-use maps at the 1:48, 000 and 1:250, 000 scales can be produced from ERTS CCTs at a tenth of the cost of conventional mapping techniques. Since these maps can be produced quickly and economically, it is now feasible to monitor changes in watershed land use in a timely enough manner to alert planners to conditions that might result in intolerably high nutrient flows and increased rates of lake eutrophication.

References

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Table 1 Classification accuracy table.

Classification Table: 11:02:50

Rejection Level = 0.000000 Percent
Group Biases: Group Bias
4 0.40000

TNG Set	0	1	2	3	4	5	6	7	8
1	0.000	96.552	0.000	0.000	0.000	0.000	0.000	0.000	3.448
2	0.000	0.000	96.552	0.000	0.000	3.448	0.000	0.000	0.000
3	0.000	0.000	0.000	100.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.769	0.000	0.769	90.000	5.385	0.000	0.000	3.077
5	0.000	0.000	4.706	0.000	1.176	91.765	0.000	0.000	2.353
6	0.000	0.000	0.000	0.000	0.000	0.000	98.182	1.818	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100.000	0.000
8	0.000	1.562	1.562	0.000	0.000	3.125	0.000	0.000	93.750

Program Run Time = 00:00:36

0 Unclassified
1 Tended Grass
2 Forest Land
3 Extractive Earth
4 Urban
5 Wetlands
6 Deep Water
7 Shallow Water
8 Rangeland (Untended Grass)

Table 2 Automatic tabulation of category areas.

ERTS Scene ID - 1265-15474
Date of scene - 14 Apr 73
Center of scene - N43-17/W082-42
Sun coordinates - EL49 degrees
AZ138 degrees

Spacecraft Heading - 191 degrees
Tape Number - 2
Starting Scan Line = 1700
Ending Scan Line = 2340

Category	Percent of Total	Sq. Km.	Acres
Unclassified	12.17	286.30	70,747.48
Tended grass	9.20	216.38	53,468.36
Forest land	11.31	266.01	65,732.55
Extractive earth	1.83	43.03	10,632.10
Urban	15.94	374.83	92,621.77
Wetlands	10.10	237.50	58,688.14
Water, deep	1.01	23.79	5,879.11
Water, shallow	0.73	17.08	4,220.16
Rangeland	37.72	887.14	219,216.36
Totals	100.00	2,352.06	581.206.06

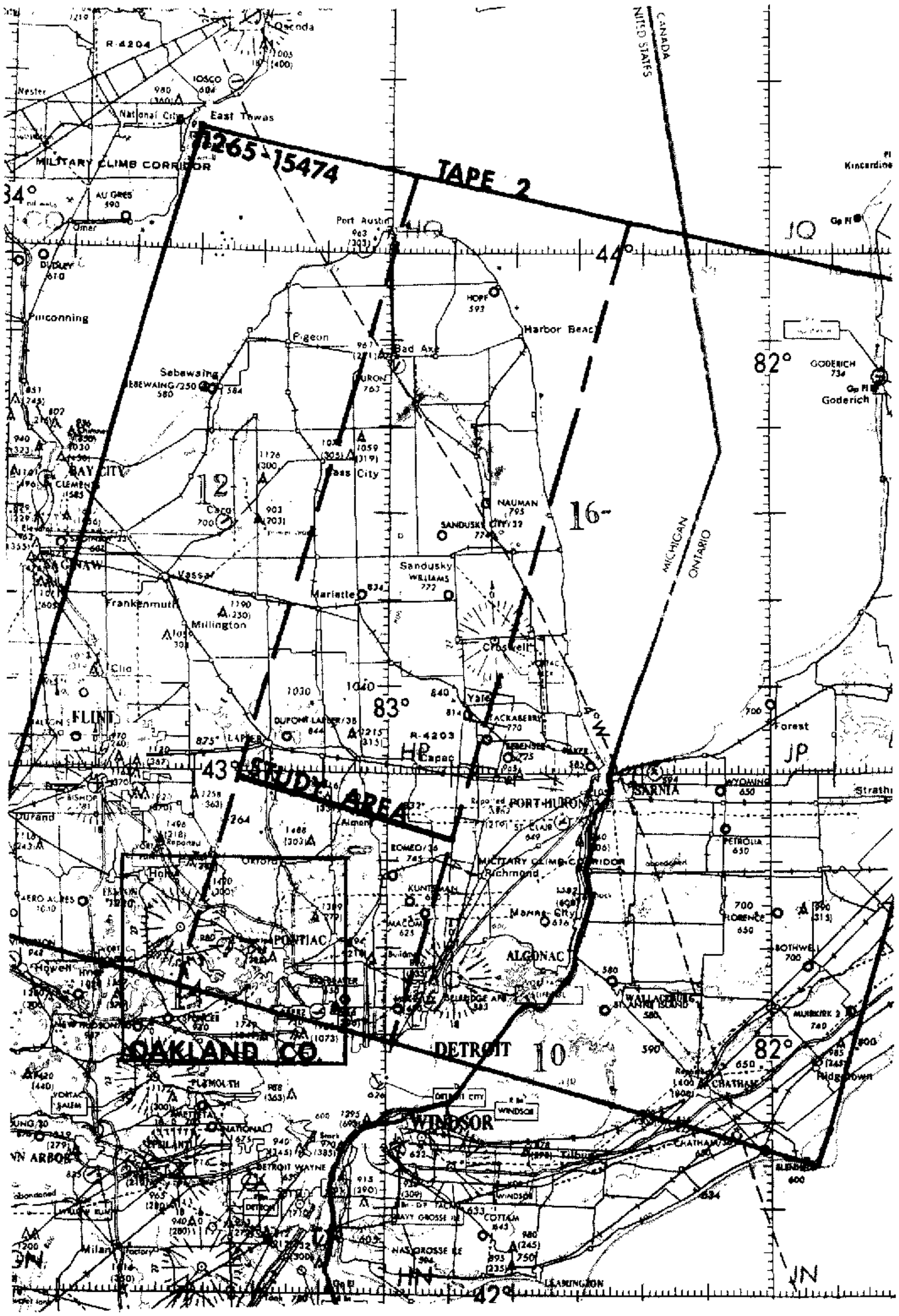
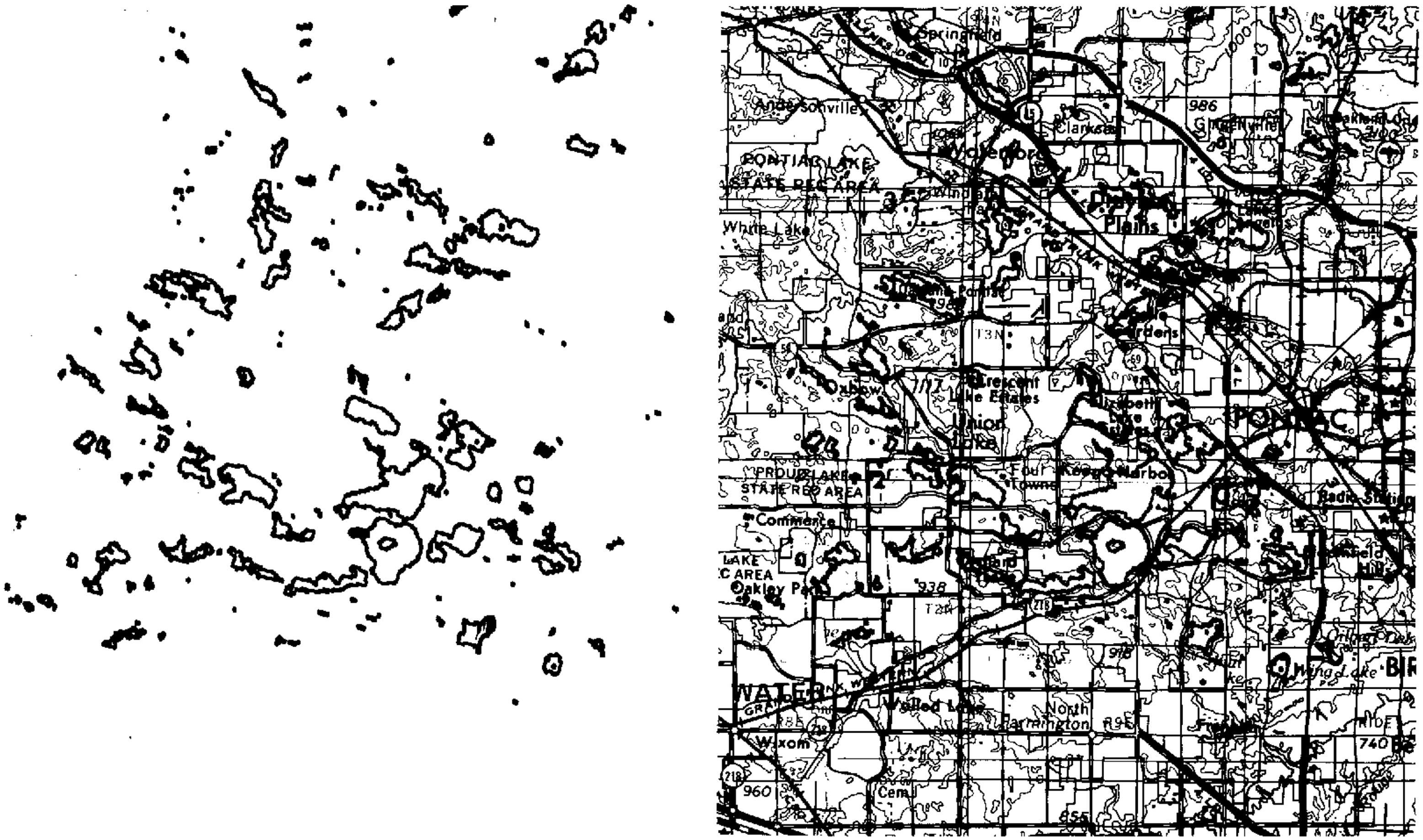


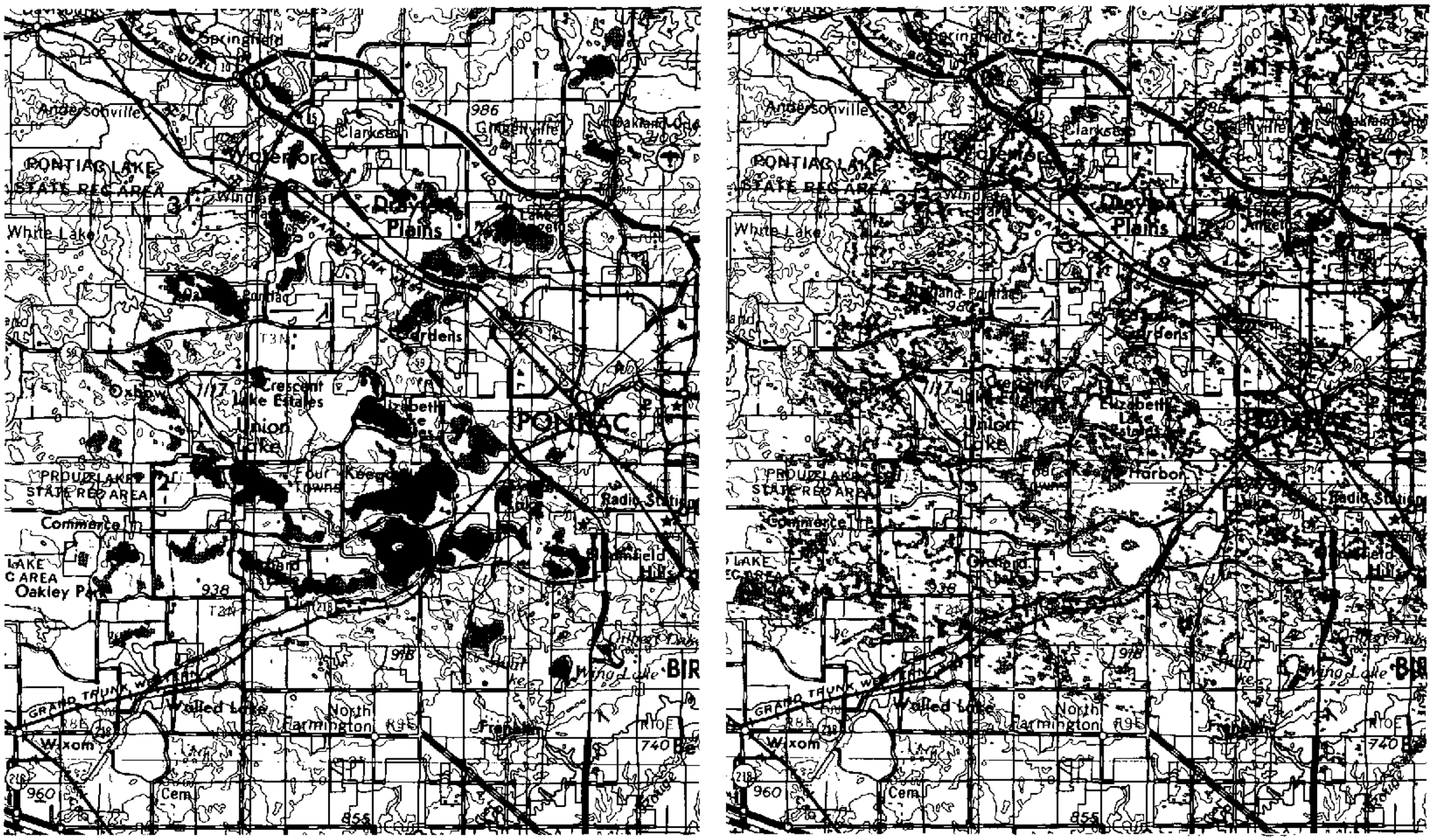
Fig. 1 The study area (scale 1:1, 250, 000).



Plotter Overlay of Water Boundaries

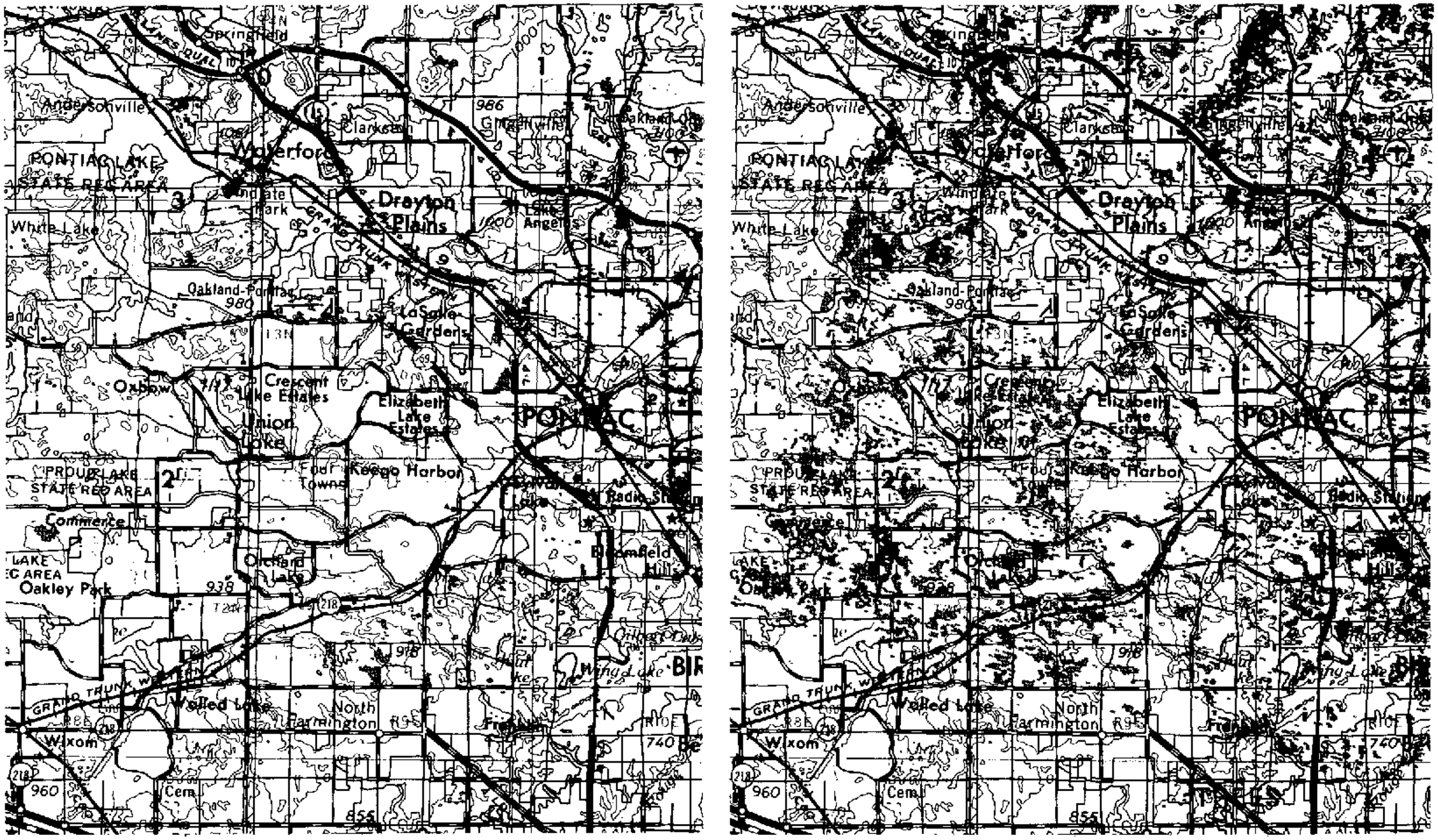
Plotter Overlay on AMS 1:250,000 Base Map

Fig. 2 Computer-generated map of water boundaries from ERTS tapes.



Water (Deep and Shallow) Wetlands

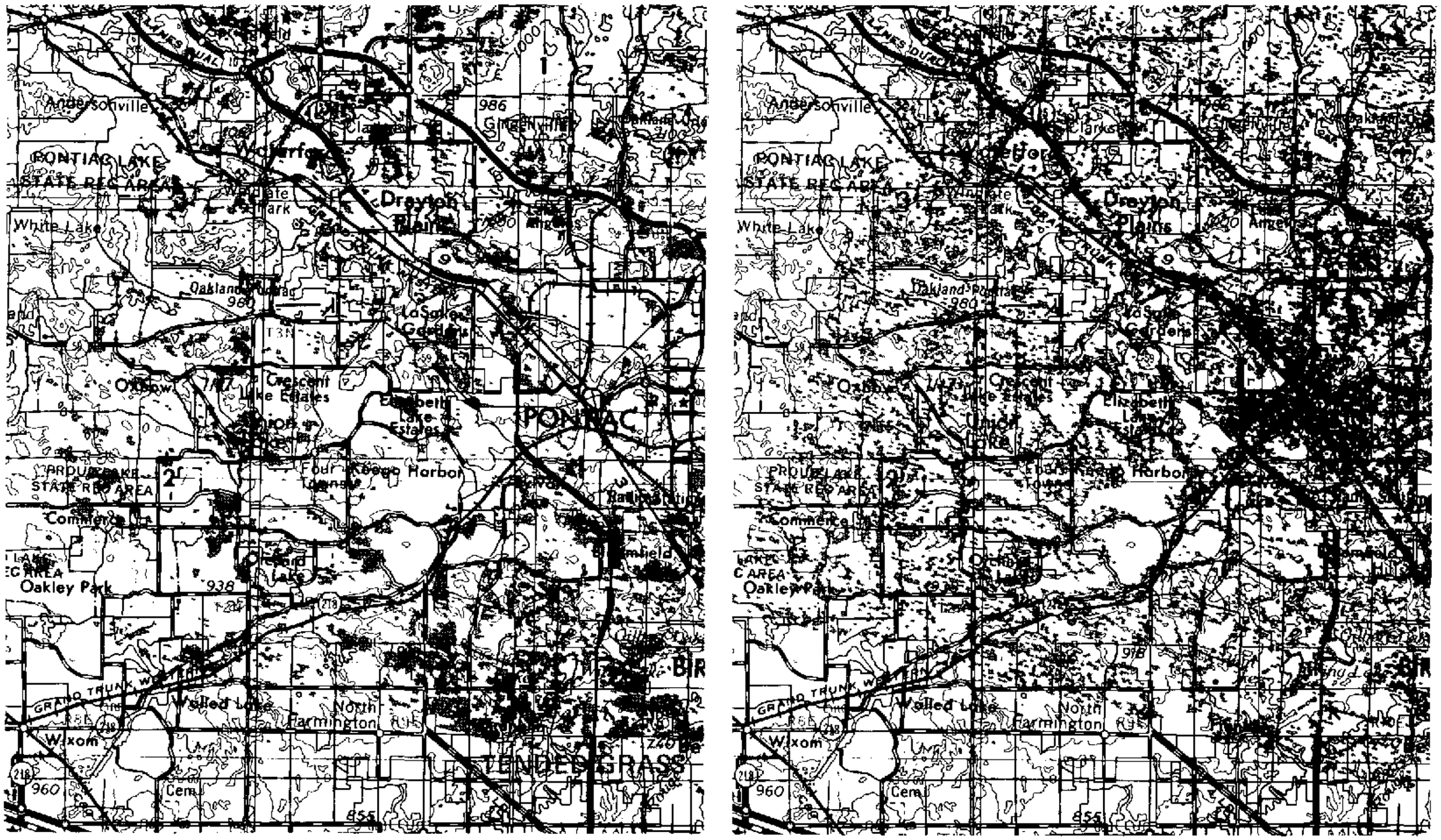
Fig. 3 Computer-generated overlays on AMS 1:250,000 scale map.



Extractive (Bare) Earth

Forested Land

Fig. 4 Computer-generated overlays on AMS 1:250,000 scale map.



Tended Grass Urban

Fig. 5 Computer-generated overlays on AMS 1:250,000 scale map.

Unsmoothed on Vegetation Map

Smoothed on Land-Use Map

Fig. 6 Computer-generated map of water boundaries on Oakland County 1:48, 000 scale maps.

Fig. 7 ERTS computer-generated overlay of forested land boundaries on Oakland County vegetation map (scale 1:48, 000). Map symbols E, K, M denote deciduous forest.

Fig. 8 ERTS computer-generated overlay of tended grass boundaries on Oakland County land-use map (scale 1:48, 000). Boundaries show recreational and conservation map categories.

Fig. 9 ERTS computer-generated overlay of extractive earth boundaries on Oakland County land-use map (scale 1:48, 000).