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AUTOMATIC CLASSIFICATION OF EUTROPHICATION OF INLAND LAKES FROM SPACECRAFT DATA

Robert H. Rogers, Larry E. Reed, and Navin J. Shah
Bendix Aerospace Systems Division
Ann Arbor, Michigan 48107

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V. Elliot Smith
Cranbrook Institute of Science
Bloomfield Hills, Michigan 48013

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16. Abstract

ERTS computer compatible tapes and computer techniques were successfully used to generate and store into data bank an eight category land-use map of Oakland County, Michigan. A software system was demonstrated by which the user can interact with this data bank to obtain, within any zone of interest, the area covered, in sq. kilometers, by each land-use category. The usefulness of ERTS data and the computer techniques for water quality investigations is demonstrated by establishing correlations between watershed land-use and lake water quality, as indicated by a measure of total and fecal coliform bacteria. Example constructed from test lakes in Oakland County indicates that if urbanization in the lakeshore zone occupies 20% or less of the land, water quality, as defined by coliform standard, is well maintained. Lake zones having over 20% urban category have water which is in a questionable state. If 40% or more of the lakeshore area is urban, it is very likely that the water is unsafe for human contact.

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Robert H. Rogers, Larry E. Reed, and Navin J. Shah
Bendix Aerospace Systems Division
Ann Arbor, Michigan 48107

V. Elliot Smith
Cranbrook Institute of Science
Bloomfield Hills, Michigan 48103

ABSTRACT

Spacecraft data and computer techniques can be used to rapidly map and store onto digital tapes watershed land-use information. Software is now available by which this land-use information can be rapidly and economically extracted from the tapes and related to coliform counts and other lake contaminants, e.g., phosphorus. These tools are basic elements for determining those land-use factors and sources of nutrients that accelerate eutrophication in lakes and reservoirs.

1. 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 inexhaustable 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.

Governmental agencies who establish land-use policies and set priorities for pollution control measures, i.e., sanitary sewer lines, storm drains, etc., must make decisions based on an understanding of how these policies and controls affect water quality. Unfortunately, little is known about the inter-relationships between the water quality parameters (i.e., total and fecal coliform bacteria count, phosphorus concentration, etc.) and land-use parameters (land-use categories and extent of coverage, etc). This study utilizes ERTS data to demonstrate the computer software and techniques for obtaining and correlating the required land-use information with one such water quality parameter, coliform bacteria.

The coliform count is widely accepted by state and county health agencies as a standard measure of contamination of lake water because of human micro-organisms. For many years, health officials have relied on fecal coliform counts, in particular, to indicate the possible presence of human pathogens, since direct testing for these pathogens is far more difficult.

While the total coliform count is recognized as only a general measure of bacterial populations in water, the fecal count is a very specific indicator of wastes from warm-blooded animals. It is known that approximately 95% of total coliforms in feces of birds and animals are fecal coliforms, and that virtually all of the coliforms on uncontaminated soils and plants are non-fecal (1968: USDI).

The area selected for study; Oakland County, Michigan; has adopted the following coliform standards for primary contact recreational waters: total coliforms, 2000/100 ml; fecal coliforms, 100/100 ml. Local sampling and testing is carried out by the Oakland County Health Department (OCHD). Like many other county health agencies, the OCHD has used the coliform standard to indicate the extent and sources of human pollution in lakes, as well as to determine the safety of swimming areas.

The OCHD has carried out a broad Lake Surveillance Program since 1971. During the past two summers they have measured (using the membrane filter method) total and fecal coliforms in some 12, 780 water samples from 138 lakes throughout the county. OCHD findings during 1972 indicated that coliform levels (averaged over 10 samples) on 123 of 138 lakes were within safe limits according to state health standards. However, the significant contamination found in many more of these lakes is an indication of the bacterial (and nutrient) enrichment that is occurring in some areas.

Although coliform data is obtained annually on many lakes by state and county health departments, little or no attempt has been made to relate this large body of data to watershed land-use factors. Detailed cause-effect studies have previously been beyond the resources of most health departments. Prior interpretations of coliform counts have been obtained by manual techniques limited to consideration of only a few land-use factors. Consequently, no detailed explanations have been reported to explain observed differences in coliform counts in lakes and how these differences relate to watershed land use. This information, however, is vital in establishing land-use policies and setting priorities for pollution control measures. To provide the basis for obtaining this data, this study sets forth and achieves the following two goals:

- Develop and demonstrate the utility of a computerized technique for economically mapping and storing watershed land-use information.
- Establish and demonstrate, by example, a flexible software system by which watershed land-use information can be extracted from the data storage and correlated to coliform counts and other water contaminants, e.g., phosphorus.

Achieving these objectives would, therefore, provide the tools needed to efficiently correlate a large body of coliform data with a wide range of land-use factors, a necessary step towards improving our understanding of coliform levels observed in lakes and how man's use of land affects these levels.

2. TEST SITE

The study objectives were achieved by developing computer techniques for deriving the required watershed land-use information from ERTS computer-compatible tapes (CCT).

The data for the 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 is shown on the map in Figure 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 and morainic soils, with over 400 "kettle" lakes, many without any discrete inlet or outlet. These lakes provide choice test sites for a study of bacterial contamination in natural waters. 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. All lakes in the county are highly valued for recreational and residential uses. Increasingly heavy public use makes it vital that microbial pollution be monitored constantly during summer months.

3. AUTOMATED LAND-USE MAPPING

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 1). 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 Digital Equipment Corporation 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 the results achieved in transforming ERTS CCTs into watershed land-use maps are briefly summarized in the following paragraphs.

Selecting Training Areas

The first step in the development of the Oakland County land-use map was to locate and designate to the computer those areas that best typified the land-use 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 natural and human sources of nutrients, especially phosphorus and fecal coliform. The codes following the category names correspond to those proposed by Anderson et al. (Ref 2). 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 (rangelend) are normally brownish in Michigan in April. Unharvested crops would probably be included and plowed fields would be classified as extractive land.
- Forested Land (trees), 04-03. Mixed hardwood (deciduous) forest. There were no sizeable 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. The area coordinates were designated to the computer by simply placing a rectangular cursor over the desired area.

Evaluating Training Areas

The ERTS spectral measurements within the training area boundaries were edited by the computer from the CCT and processed to obtain a numerical description (Ref 3) to represent the "spectral characteristics" (computer processing coefficients) of each land-use category. To test the computer's capability to use these spectral characteristics, they were first applied to classify data from known areas. The processed results were viewed on the TV monitor, and output in the form of accuracy tables as shown in Table 1.

Produce Categorized Data Tape

When we were satisfied with the classification accuracy, the processing 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 classification 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 tape was used by this study to generate categorized map overlays and as a medium to store the interpreted land-use information on the study area. Computer-generated area measurement tables were also edited from this tape to determine land use in zones (regular polygon) encompassing the test lakes.

Categorized Map Overlays

To produce land-use classifications that will directly relate to a map, the 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 scale specified by the operator. The operator had an option of obtaining either drawings of boundary lines or drawings with the boundary lines filled in. The film, when removed from the plotter and photographically processed, provided transparent overlays which were used directly to overlay maps and aerial photographs, as illustrated in Figures 2 through 7, or processed further to produce color-coded land-use overlays. Color-coding permitted multiple overlays to be used simultaneously over the base map.

Figure 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 relatively large lake with an island appearing in the lower center of the overlay is Orchard Lake and the island is Apple Island. The lake above Orchard Lake is Cass Lake. Orchard Lake is approximately 1.5 miles wide. This illustration of Orchard and Cass Lakes should be compared with that produced in Figure 3 at a scale of 1:48,000. In Figure 3, an individual ERTS element classified as water would be outlined as a small rectangular box 57 x 79 m (4,532 m^2) to designate a lake.

In Figure 4 the filled-in versions of four categories are shown overlying the AMS 1:250,000 map.

Figures 5 and 6 show the forested land and tended grass 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 Commision. 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 on the map as a small rectangular box of approximately 1/16 by 1/32 inch. 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 varies from two to ten ERTS elements in width. 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.

Categorized boundary line overlays were also generated to match the scale (1:40,000) of aerial photography, as shown in Figure 7. This permitted a detailed analysis of mapping accuracy (geometric and classification) achieved by ERTS.

Close examination of the aerial photograph and overlays in Figure 7 show that water boundaries are accurately outlined and some older subdivision, with numerous large trees, are mapped into the forested land category. Trees are also shown covering Apple Island, as they should be shown. Tended grass during April in Michigan occurs in areas which are highly watered and fertilized, such as golf courses and cemeteries. Rangeland (untended grass) is brownish at this time of year. The large golf course on the lower west side of Orchard Lake is clearly outlined in the tended grass boundaries of Figure 7. It is also observed, however, that some low density residential areas with large green lawns are classified as tended grass areas rather than as urban areas.

4. RELATING LAND USE TO WATER QUALITY

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 4).

Therefore, in mapping watersheds of lakes with diffuse sources of nutrients, emphasis is given to the narrow zone of land adjacent to and extending back from the water. This zone is defined by this study as being between 125 and 725 meters wide, or the effective width of two to ten 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.

Computer-generated area measurement tables were produced from the categorized data tape to determine land-use in zones (regular polygons) encompassing the test lakes. To accomplish this step, the categorized data tape was used to produce printouts, as the one in Figure 8 showing Cass Lake. In this case, the symbols on the printout designate land-use categories. These printouts were used to locate the coordinates (scan line number and resolution element number) of a regular polygon(s) which defined the boundary of the lakeshore zone of interest. Inputting these coordinates in turn to the computer yielded, immediately, the desired area measurement table, as shown in Figure 8. The table quantifies the land-use in the lake zone of interest. These tables were rapidly produced for each test lake of interest.

The area measurement tables provided for each test lake the amount of land that falls within each land-use category in terms of square kilometers, acres, and as a percentage of the area processed. A summary of the results extracted from area measurement tables of seven test lakes is shown on the left side of Table 2. On the right side of the same table range and average values are listed for total and fecal coliform counts. The average and range was computed from coliform data obtained from samples near each of the lake swimming beaches. The number of beaches (or samples used) and water rating, as determined by OCHID based on the coliform data, is also shown in Table 2.

5. SUMMARY

Spacecraft data and computer techniques can be used to rapidly map and store onto digital tapes watershed land-use information. Software is now available by which this land-use information can be extracted from the tapes and related to coliform counts and other water contaminants, e.g., phosphorus.

The brief example constructed from seven test lakes in Oakland County, Michigan indicates that if urbanization (urban category) in the lakeshore zone occupies 20 percent or less of the land, water quality, as defined by coliform standard, is well maintained. Lake zones having over 20 percent urban category have water which is in a questionable state, and should be monitored frequently by health departments. If 40 percent or more of the lakeshore area is urban, it is very likely that the water is unsafe for human contact.

6. REFERENCES

1. Rogers, R. H., and Reed, L. E., "Automated Land-Use Mapping from Spacecraft Data," Proceedings of the 40th Annual Meeting of the American Society of Photogrammetry, St. Louis, Mo., March 1974.

2. Anderson, J., Hardy, E., and Roach, J., "A Land-Use Classification System for Use with Remote Sensor Data," Geological Survey Circular 671, Washington, D.C., 1972.

3. Dye, R. H., Hanson, D. S., and Crawford, C. L., "Signature Data Processing Study," Bendix Report BSR 2949, NAS 9-9848, August 1970.

4. Weibel, S. R., "Urban Drainage As a Factor in Eutrophication," Eutrophication: Cause, Consequences, Correctives, National Academy of Sciences, Washington, D.C., pp. 383-403, 1967.

TABLE I. CLASSIFICATION ACCURACY TABLE

Classification Table: 11:02:50

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

	TNG Set	1	2	3	4	5	6	7	8
1	Tended Grass	96.552	0.000	0.000	0.000	0.000	0.000	0.000	3.448
2	Forest Land	0.000	96.552	0.000	0.000	3.448	0.000	0.000	0.000
3	Extractive Earth	0.000	0.000	100.000	0.000	0.000	0.000	0.000	0.000
4	Urban	0.769	0.000	0.769	90.000	5.385	0.000	0.000	3.077
5	Wetlands	0.000	4.706	0.000	1.176	91.765	0.000	0.000	2.353
6	Deep Water	0.000	0.000	0.000	0.000	0.000	98.182	1.818	0.000
7	Shallow Water	0.000	0.000	0.000	0.000	0.000	0.000	100.000	0.000
8	Rangeland	1.562	1.562	0.000	0.000	3.125	0.000	0.000	93.750

TABLE II. CORRELATION OF LAND-USE AND WATER QUALITY DATA

Lakes	Area Covered by Water sq. km.	Approximate Percentage of Lakeshore Land in Target Categories							Water Quality Data *				Number of Swimming Areas and Water Rating*		
		Urban	Tended Grass	Bare Earth	Forested Land	Rangeland	Wetlands	Other	Total Coliform Range	Total Coliform Avg.	Fecal Coliform Range	Fecal Coliform Avg.	Safe	Questionable	Unsafe
Harris, Osmun, Terry	.01	43.0	1.0	2.0	3.0	17.0	12.0	22.0	1200-3972	2330	31-210	82	0	6	7
Sylvan	1.35	34.0	3.0	1.0	5.0	13.0	16.0	28.0	538-2371	1051	17-117	44	6	2	1
Elizabeth	1.2	32.0	7.0	0	7.0	25.0	12.0	17.0	333-2333	617	10-33	17	15	1	1
Cass	3.96	23.0	7.0	1.0	9.0	21.0	15.0	24.0	400-2200	736	15-105	34	10	0	2
Orion	.95	21.0	2.0	2.0	8.0	16.0	29.0	22.0	710-1197	851	16-55	33	6	2	0
Pine	1.28	20.0	13.0	0	20.0	24.0	12.0	11.0	491-834	630	13-27	17	10	0	0
Voorheis	0.63	9.0	4.0	1.0	16.0	29.0	24.0	17.0	481-489	485	20-25	23	2	0	0

*As established by the Oakland County Health Department

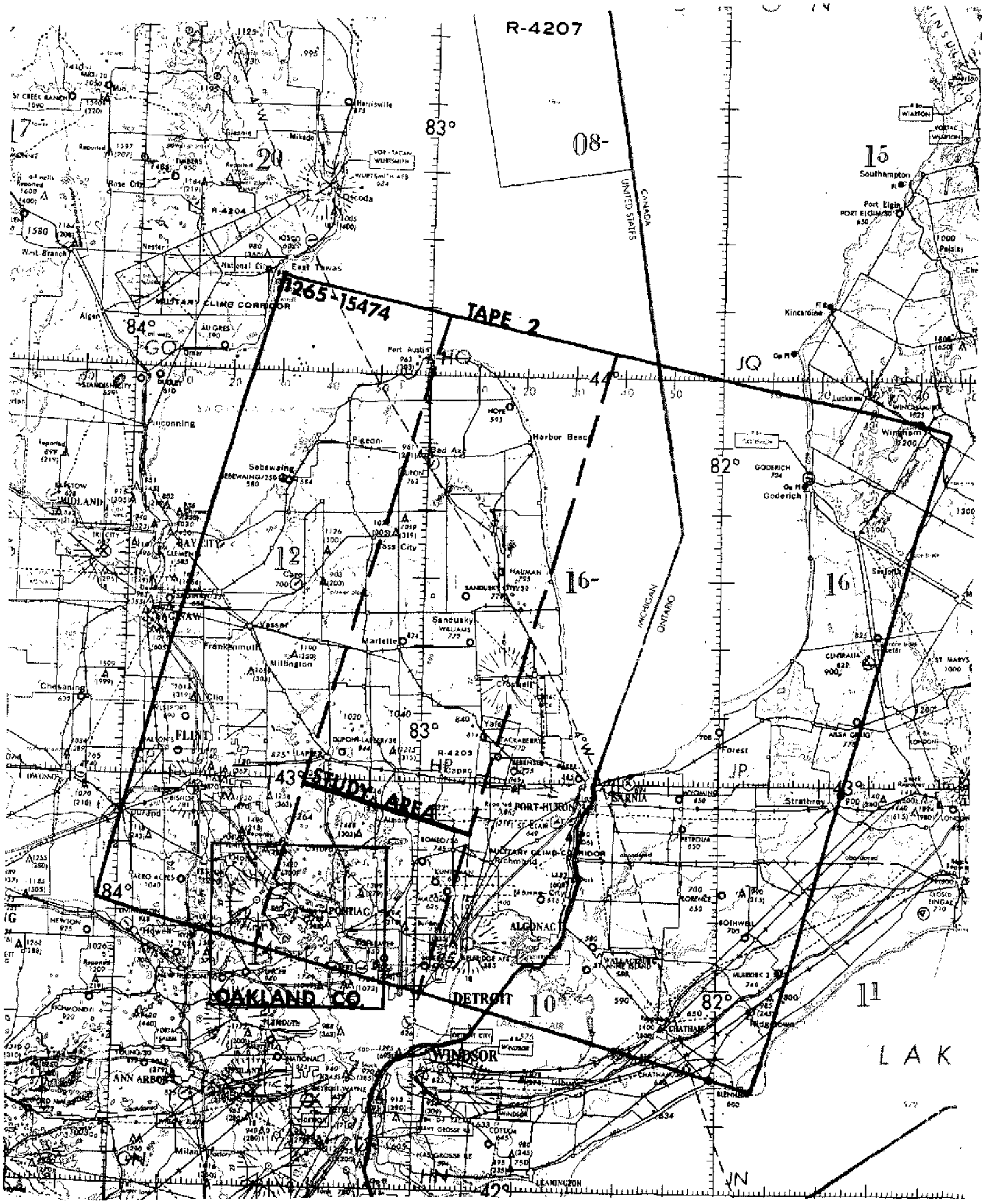
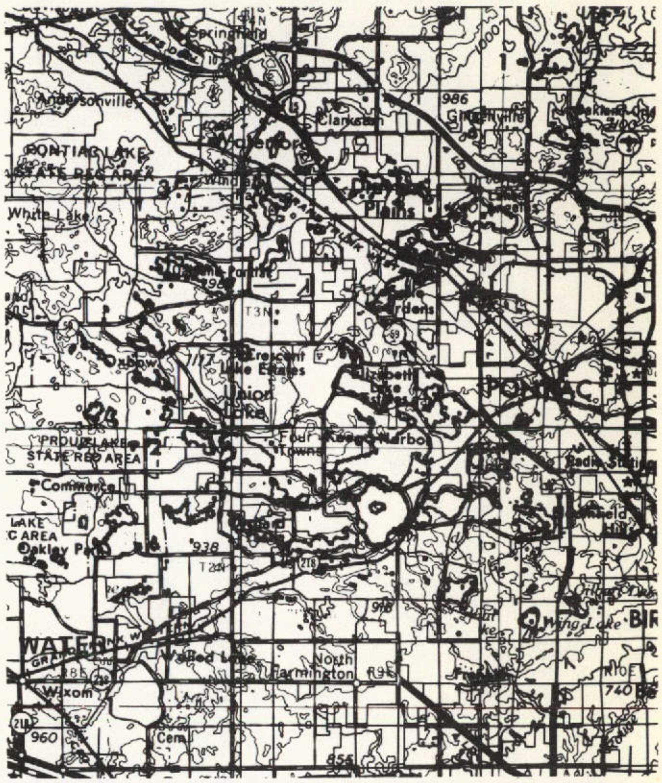


FIGURE 1. THE STUDY AREA (SCALE 1:1, 250, 000).

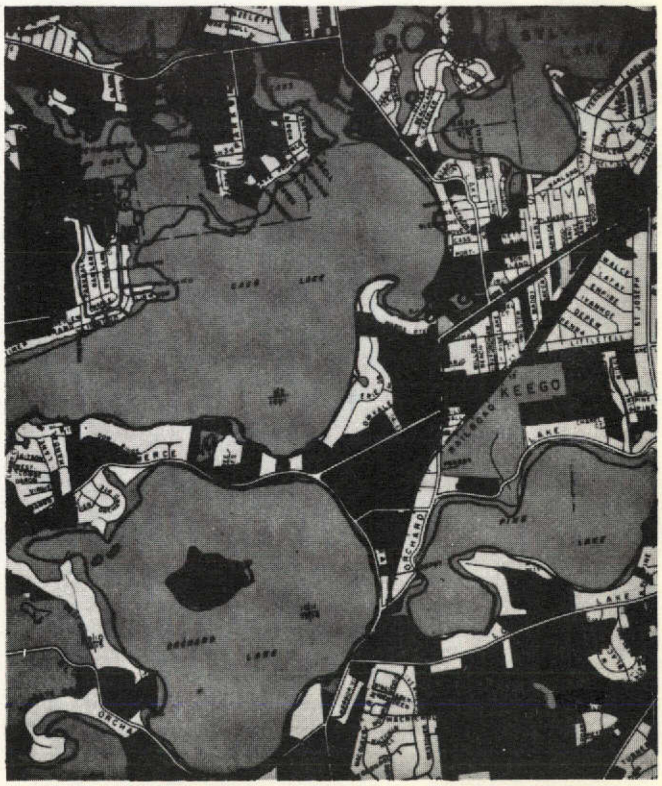
Plotter Overlay of Water Boundaries



Plotter Overlay on AMS 1:250, 000 Base Map

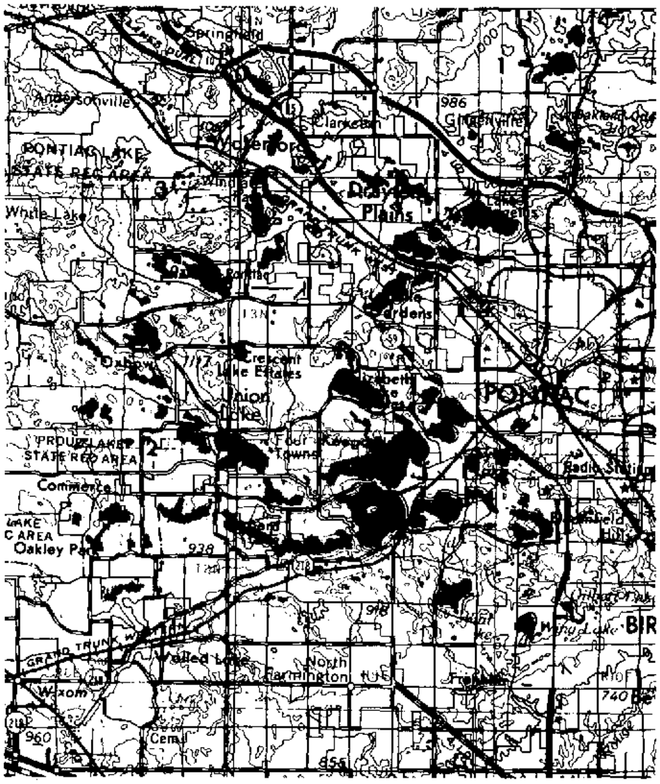
FIGURE 2. COMPUTER-GENERATED MAP OF WATER BOUNDARIES FROM ERTS TAPES.

Unsmoothed on Vegetation Map

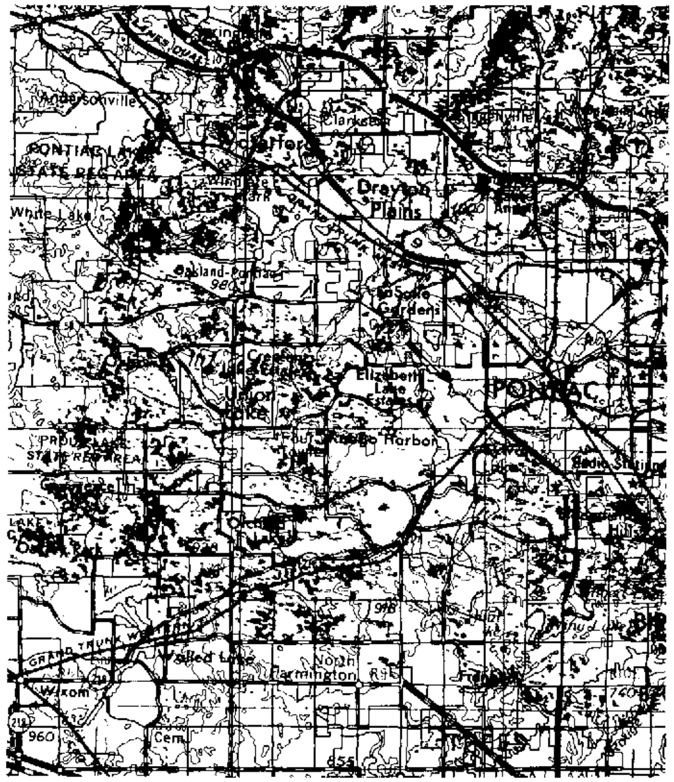


Smoothed on Land-Use Map

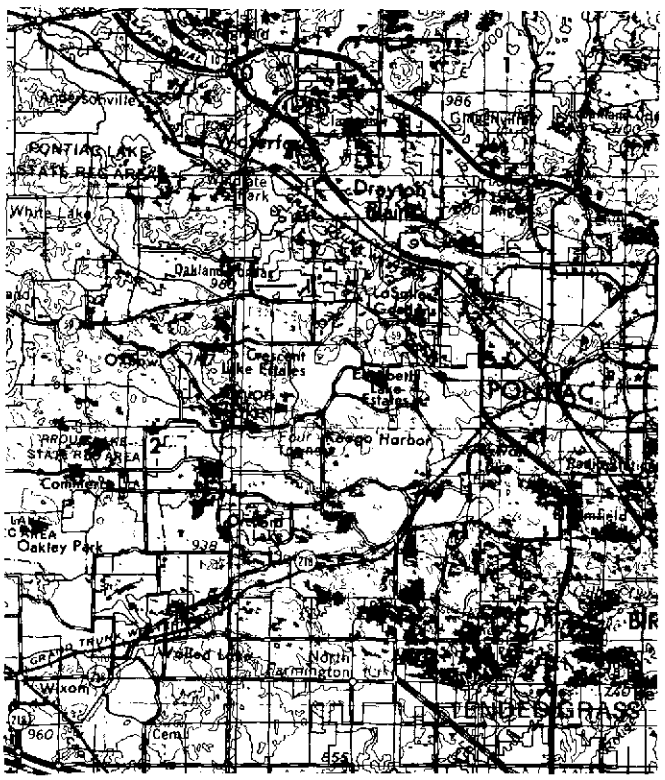
FIGURE 3. COMPUTER-GENERATED MAP OF
WATER BOUNDARIES ON OAKLAND COUNTY 1:48, 000 SCALE MAPS.



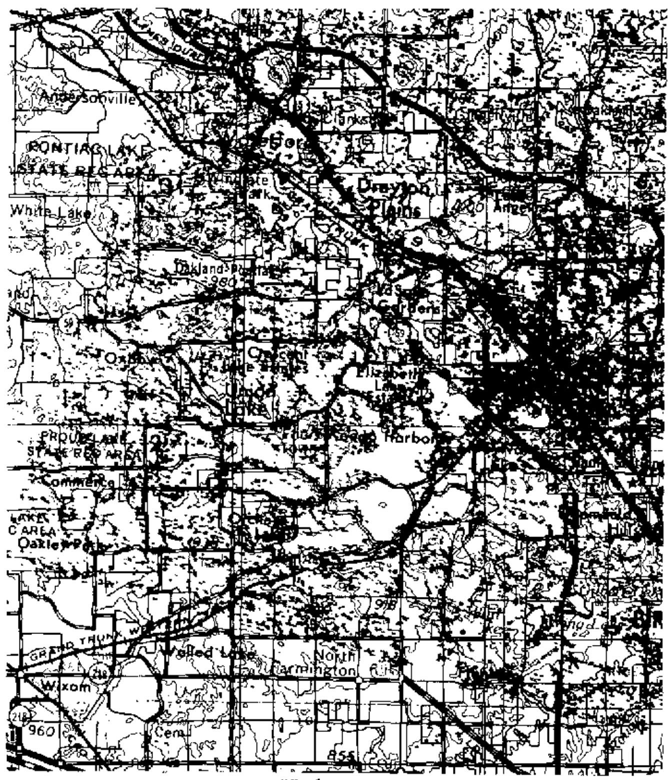
Water (Deep and Shallow)



Forested Land



Tended Grass



Urban

FIGURE 4. COMPUTER-GENERATED OVERLAYS ON AMS 1:250,000 SCALE MAP.

FIGURE 5. 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.

FIGURE 6. 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.

Aerial Photograph

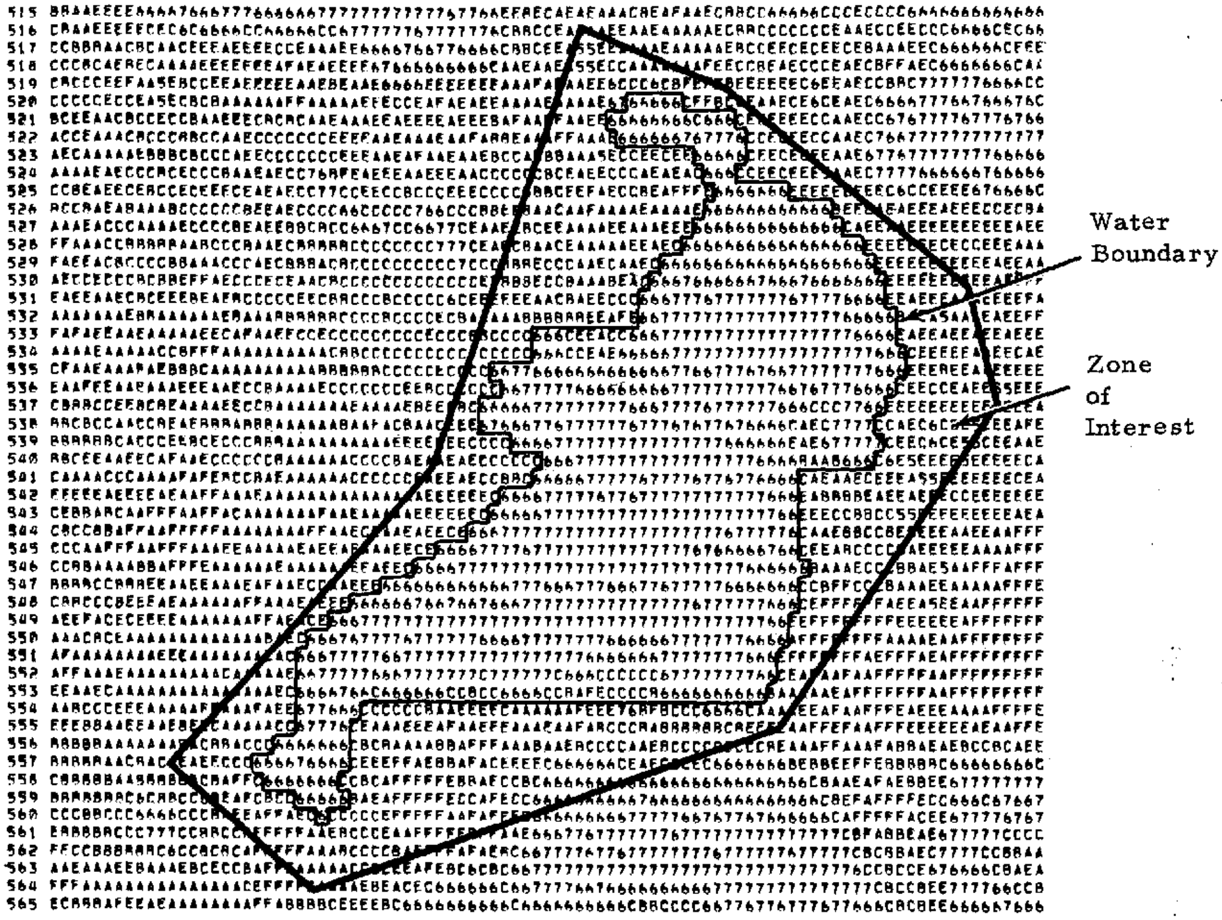
Water Boundaries

Tended Grass Boundaries

Forested Land Boundaries

FIGURE 7. COMPUTER-GENERATED BOUNDARIES FROM ERTS TAPES OVERLAYING AERIAL PHOTOGRAPH.

Categorized Printout of Cass Lake Area Used to Designate Area of Interest to Computer for Land-Use Tabulation



Computer Tabulation of Land Use within Polygon Around Cass Lake

Symbol	Category	Percent of Total	Acres	Sq. Km.
O	Unclassified	13.36	281.71	1.14
F	Tended Grass	3.55	74.90	0.30
B	Forest Land	4.72	99.49	0.40
5	Extractive Earth	0.53	11.18	0.05
E	Urban	12.51	263.82	1.07
C	Wetlands	7.90	166.57	0.67
7	Water Deep	24.87	524.29	2.12
6	Water, Shallow	21.58	454.98	1.84
A	Rangeland	10.98	231.40	0.94
	Totals	100.00	2108.35	8.53

FIGURE 8. EDITING LAND USE FROM POLYGON AROUND CASS LAKE.