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Final Report

AN ERTS-1 INVESTIGATION FOR LAKE ONTARIO AND ITS BASIN

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16. Abstract

This report documents a binational study of the techniques for applying ERTS and other types of remote sensor data to terrestrial hydrology. The study site was Lake Ontario's 34,000-square-mile local drainage basin. Methods of manual, semi-automatic, and automatic (computer) data processing were evaluated, as were the requirements for spatial physiographic and limnological information. The coupling of specially processed ERTS data with simulation models of the watershed precipitation/runoff process provides potential for water resources management. Optimal and full use of the data requires a mix of data processing and analysis techniques, including single band editing, two band ratios, and multiband combinations. A combination of maximum likelihood ratio and near-IR/Red band ratio processing was found to be particularly useful.

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PREFACE

The year-long data collection phase of the International Field Year for the Great Lakes (IFYGL) commenced in April 1972. The joint U.S.-Canadian IFYGL program was planned to provide information concerning fundamental hydrologic and limnologic processes of Lake Ontario and its local drainage basin.* As part of this program, scientists from the Environmental Research Institute of Michigan (ERIM), the University of Guelph, and the Ontario Ministry of the Environment joined in a study of Lake Ontario basin data obtained from the NASA Earth Resources Technology Satellite (ERTS-1) now known as LANDSAT-1, and supporting aircraft. This report documents the results of that IFYGL effort.

This report is comprised of three major sections. Section 1 introduces the objectives and results of this investigation. Section 2 concerns detailed hydrologic and physiographic information obtained from portions of the local Lake Ontario drainage basin. Section 3 describes the techniques used in processing and evaluating the ERTS-1 data. Although those concerned with the management of water resources may find Section 2 of greatest interest, the technical discussion of Section 3 provides important insights concerning the capabilities and limitations of the several systems and processing techniques employed.

Personnel of the Environmental Research Institute of Michigan had responsibility for the overall direction and coordination of this program. Fabian C. Polcyn and Allen Falconer were Principal Investigators. Frederick J. Thomson, as Project Manager, coordinated data processing and reporting, and Thomas W. Wagner assumed primary responsibility for program design and interpretation of the results. Diana L. Rebel conducted the innovative digital computer analysis; Bette C. Salmon and William Pillars prepared and processed analog ERTS-1 data.

The collection of ground data and field checking of processed results by co-investigators in the Canadian portion of the Lake Ontario basin were essential to the program. Their cooperation and involvement was generously provided despite the lack of program funds to specifically support their activities. In particular, the work and good counsel of Drs. Allen Falconer and Richard Protz of the University of Guelph

*The lead agency for the U.S. portion of IFYGL is the National Oceanic and Atmospheric Administration, under Dr. Eugene Aubert, U.S. Director.

contributed greatly to the success of the program. Darryl Tighe and Rick Savage also assisted in this University of Guelph effort. Helpful comments, ground truth, and data evaluation were kindly supplied by Robert Ostry, under the direction of Ron Hore, of the River Basin Research Branch, Ontario Ministry of the Environment.

Finally, the interest and forebearance of the IFYGL Terrestrial Water Balance Panel, under the joint chairmanship of Ben DeCooke (U.S.) and D.F. Witherspoon (Canada) is acknowledged.

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1
INTRODUCTION

The NASA launch of the Earth Resources Technology Satellite (ERTS-1) on 23 July 1972, allowed scientists and administrators for the first time to "see" and record very large portions of the earth's surface in a very short interval of time. But with this new type of data came questions of how best to obtain and use information contained in it. By and large these questions must be answered on a discipline-by-discipline basis. This report documents the experience gained from application of satellite data to a growing need for synoptic water resources information. The primary focus of this investigation was the obtaining of land-use and physiographic information useful in the evaluation of terrestrial water balances. The site for this study was the 90,000 km^2 (34,000 mi^2) Lake Ontario basin (Figure 1). The efforts described here were part of the International Field Year for the Great Lakes (IFYGL) program, an official International Hydrological Decade project [1], and were sponsored by the U.S. National Aeronautics and Space Administration (NASA).

1.1 BACKGROUND TO HYDROLOGY —THE NEED FOR TOOLS

Hydrology, like all natural and physical sciences, is concerned with interrelationships of measurement of mass, space, and time [2]. Progress in this water science has been coincident with the ability to make and compare measurements. In the mid-17th Century Pierre Perrault measured rainfall, evaporation, and the capillarity of the drainage basin of the River Seine and was able to show quantitatively that the amount of precipitation over the basin was more than sufficient to account for the flow of the Seine. This event discredited a centuries-old idea that rivers sprang forth from vast underground reservoirs, and marked the beginning of modern hydrology as a science [3].

Until the tools to make the measurements are available, ideas and theories concerning hydrology remain qualitative and speculative, and decisions based on them are imprecise and prone to error. Recent well-publicized water quality and coastal zone problems in all of the Great Lakes have warned of the growing need for better information, based on better tools, for managing this, the largest and most important body of fresh water in the world.

Two sophisticated new tools are currently being developed which can contribute to management of the Great Lakes system. One is remote sensing technology and its associated data transmission and processing techniques; the other is the quantitative synthesis of large amounts of data with hydrologic models.

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FIGURE 1. LAKE ONTARIO DRAINAGE BASIN

1.2 HYDROLOGIC REMOTE SENSING—THE CHALLANGE

To date, the tools used to collect water data have been mainly concerned with point measurements of mass (or volume) over time. While accurate for the locations which are monitored, the spatial extent and variability of hydrologic phenomena are not sufficiently sampled. This spatial uncertainty greatly limits the accuracy of water balance estimates and makes the development of complete models of real-world hydrologic interactions unrealistic. For example, in a recent report on evaporation, S. Dyck states "The high accuracy gained at the measuring point is again lost in the transfer of measured values to the larger regions . . . Hydrological data from remote areas are lacking for establishing global, continental, or regional water balance models" [4].

Furthermore, the need for accurate estimates of regional water supplies is increasing. The combination of growing population, rising water consumption per individual, and rising volume of domestic and industrial wastes for disposal is outstripping the availability of water supplies.

Applications of aircraft remote sensor data to water and energy balances were discussed in a paper by Malila and Wagner [5]. Remote sensing provides an accurate and timely method of extensive spatial sampling. Modern sensors, mounted in aircraft or satellites, provide vast amounts of data in a short time. Indeed, the determination and extraction of hydrologically useful information from these large amounts of data represent the principal challenge to their use. For this reason computer processing techniques have been developed to aid in the data handling and information extraction. The computer acts as a filter to reduce or eliminate data not of interest, and provides useful information in the form of statistical summaries and image displays of the data.

1.3 OBJECTIVES OF THIS PROGRAM

The specific objectives of this investigation were the following:

(1) Using state-of-the-art digital processing techniques, to develop and demonstrate the mapping of hydrologically significant land-use classes for an IFYGL representative watershed—the East and Middle Oakville Creek basin (200 km^2).

(2) Using prototype high speed data processing techniques, to map the near-surface turbidity patterns of Lake Ontario (19,500 km^2).

(3) Using prototype high-speed data processing techniques, to map the surface water and major terrain classes (urban areas, forests, etc.) for the entire Lake Ontario local drainage basin (90,000 km^2).

(4) To visually interpret enhanced and unenhanced images for regional physiographic information—including soils, structural geology, land use, and changing snow and ice conditions.

A general objective of the program was to provide information useful in the evaluation of the terrestrial water balance of the Lake Ontario basin for the International Field Year, April 1972 through March 1973. The terrestrial water balance describes the precipitation input as being equal to the sum of the basin outputs and changes in storage [6], and defines the hydrologic nature of the basin in volumetric terms for given time intervals. The simplified equation is:

$$P = E + R = \Delta S$$

where P = precipitation
E = evaporation (including transpiration)
R = runoff (both surface and subsurface)
ΔS = the net change in water storage

Each of these terms, in reality, is comprised of a number of subterms which are considered in accounting for the various hydrologic processes. While satellite remote sensing cannot directly supply quantitative evaluation of these terms, a great deal can be learned about them by obtaining better land-use, surface cover, physiographic, and water quality information. In other words, the general objective was to provide quantitative spatial information which would aid in the computation of water balances for the basin area.

1.4 SUMMARY OF RESULTS

The results consist of two different types of information—hydrological information and technical data handling information. The technical results are related to a need to devise and implement new procedures for analyzing, editing, and displaying Earth Resources Technology Satellite data. Hydrological information includes land use, physiographic data, and near-surface water turbidity patterns in Lake Ontario.

The terrain analysis results include generalized surface cover maps and areal statistics for the Lake Ontario basin and the East and Middle Oakville Creek drainage basin. For the large area survey six major surface classes were separately mapped and a number of others interpreted from specially processed imagery.

The detailed land-use mapping of the East and Middle Oakville Creek basin comprised eleven terrain categories. In this largely rural basin four natural vegetation classes, four agricultural vegetation classes, and three non-vegetation classes were mapped. Each of these classes was chosen because of its unique influence on the terrestrial hydrology of the basin, particularly the partitioning of rainfall between infiltration, surface storage, runoff, and transpiration. For example, the four agricultural vegetation classes were based on differences in the percentage of green herbaceous cover rather than on the more usual classifications of crop species.

The enhanced images of the large-scale turbidity patterns in Lake Ontario provide new information on surface currents and indicate the sources and extents of water pollution. The extent of the Niagara plume and the existence of large water circulation spirals off Braddock Point and elsewhere were clearly identified and attest to the dynamic nature of this large lake system.

Human interpretation of a large number of machine-enhanced images provided a wealth of information concerning regional physiography. These included the mapping of drainage channels, organic soils, land use, surface geology, and changing water patterns and snow and ice conditions in the winter season.

The technical results of this program are related to the need to define and develop new procedures for extracting useful information from the ERTS-1 multispecteal scanner (MSS) data. The investigation achieved the following technical results:

(1) Conversion of ERTS-1 computer compatible tape data into both analog and digital formats for rapid computer data processing.

(2) Preprocessing to allow extension of quantitative feature recognition criteria (signatures) to ERTS-1 data collected on several different dates and over the entire basin.

(3) Spatial editing to designate the irregular boundaries of natural watersheds.

(4) Development of flexible routines which allow optimal processing of digital data.

(5) Analysis of available information using four different types of processing: level slicing, ratioing, color-additive, and spectrum matching (maximum likelihood ratio) techniques.

These technical results are described in Section 3 of this report.

1.5 CONCLUSIONS AND RECOMMENDATIONS

Remote sensor data obtained from earch orbiting satellites can be processed and interpreted to provide highly useful new hydrologic information for basin areas of varying sizes. This information is largely inferential and related to the spatial area and distribution of terrain features and water patterns. In particular, the ability to quantitatively determine land uses and their changes results in the applicability of these data to models of the hydrologic process. Time-dependent changes, such as changing patterns of snow and ice cover, are readily available from repetitive satellite coverage and are of great significance for evaluating water balances. The usefulness of ERTS-1 data results less from a high degree of image detail than from a spectral resolution that allows detailed identification of a variety of hydrologically significant terrain features. The main strength of ERTS is its ability to record and transmit large-area terrain data quickly and repetitively.

Judicious selection of ERTS-1 spectral bands and processing techniques is seen as the key to effective use of the data. The principal expense in obtaining quantitative information from ERTS data is computer equipment and processing time. Elimination of redundant spectral data and the use of rapid routines on special-purpose computing facilities may provide the margin between the impractical and the cost-effective application of ERTS data.

In general, satellite remote sensing complements and extends the data received from existing hydrological networks, but does not replace them. Indeed the full utilization of ERTS-1 data for hydrology requires the availability of some surface information and aircraft remote sensor data as well.

Further efforts are required before these data can be made generally useful to the managers of our water resources. Recommendations for further development of satellite data in this regard include:

(1) Further development of data handling and processing techniques to obtain accurate areal statistics of surface features for large areas. Signature extension, high-speed processing, and accurate editing are the key advances in this area.

(2) Testing and evaluation of the applicability of the remote sensor data to mathematical models of the terrestrial water balance and hydrologic processes. While existing models may accept or be modified to accept these remote sensor inputs, new models must ultimately be developed to optimize their use.

(3) Further fundamental research concerning the relationship between remote sensor data and the hydrologic parameters of interest. The relationship between such important factors as soil moisture, water depth, runoff, and evaporation, and the recorded remote sensor data is largely inferential and not well known. These factors must be further quantified and confident limits established.

(4) Education of and cooperation with water resources personnel to further define specific information requirements and to publicize the availability of water resources information from existing remote sensor data.

(5) Evaluation of the "mix" of data handling and processing techniques to determine the most useful and cost-effective combinations of information available for hydrology from remote sensor data.

2
LAKE ONTARIO AND ITS BASIN

2.1 ERTS AND THE GREAT LAKES

The Great Lakes cover some 246,000 km^2 (95,000 m^2) and contain about 20% of the fresh water in all the lakes and rivers of the world. The Lakes are a major natural resource of North America and are vital to the economies of both the United States and Canada. They serve more than 35 million residents in their watersheds.

In recent years the quality of the Great Lakes' waters has declined as industrial, commercial, municipal, agricultural, and recreational users increasingly conflict over their use. This vast reservoir of fresh water is neither inexhaustible nor unspoilable. There is the need for better monitoring of the Great Lakes and a better knowledge of the consequences involved in their expanding use.

In considering the role of ERTS-1 and other remote sensor systems in supplying information for managing the Great Lakes, the right questions must be asked of the data. ERTS provides two basic types of information: images which show the location and distribution of features and computer compatible tapes from which statistical tabulations of features can be obtained. The information may be used for estimating or predicting water supply or for assessing water demand by various users. Each approach has certain sets of information requirements: one dealing with the natural ability of the basin to supply water, the other with man's increasing demands on that supply. Water supply is often described in terms of the hydrologic cycle and the monthly or yearly water balance of a basin. Water demand must be examined on an industry-by-industry basis. In projecting total water demand we need to know the present and future requirements of hydroelectric power facilities, irrigation for agriculture, municipal waste treatment, minimum flows for navigation, and recreation requirements.

In this investigation we were concerned with water supply. Accordingly, we attempted to observe and map vegetative, land-use, physiographic, and sediment conditions which affect or indicate the location and nature of basin runoff. ERTS data provides a precise picture of the prevailing conditions and physical features which help determine the flow of runoff to the Great Lakes. However, some conditions are not recorded by remote sensors. For these we continue to rely on conventional ground survey or monitoring systems. Thus, remote sensing is a tool which can contribute new information to our knowledge of hydrology and limnology; it cannot, however, supply all of the information required.

2.1.1 SIGNIFICANT CATEGORIES

What land-use categories are of greatest significance for predicting the hydrologic behavior of a watershed or basin? A number of studies have documented the changes in water yield and timing of flows caused by major changes in land use. The first experimental study in which a planned land-use change was carried out in order to observe the effects on streamflow was conducted at Wagon Wheel Gap, Colorado, starting in 1910 [7]. After clear-felling of the forest on the experimental watershed, streamflow increased 17 percent above that predicted from flows in an unchanged control valley. Since that time numerous studies have shown that streamflow response is proportional to the reduction in forest cover [8].

Direct estimation of plant water-use as a component in the water balance became possible in 1948 when both Penman in Britain and Thornthwaite in the U.S. published evidence that evapotranspiration from a complete canopy of green vegetation can be predicted directly from climatic factors [9].

Until recently it was believed that the amount of water required by crops to promote maximum growth varied considerably. Recent research now indicates that irrigation of a given area, for example, requires the same amount of water almost irrespective of the crop being grown. Thus it is largely the climatic, vegetative cover, and adaphic conditions which represent the major variables in evapotranspiration [10]. In other words, knowledge of vegetation cover and condition are more important for predicting evaporative losses from a watershed where soil moisture is not limiting than is the species or structure of the vegetation communities themselves. Even the physical interception of rainfall by vegetation before it reaches the ground is largely independent of the biological character of the foliage and depends primarily on the intensity and amount of rainfall [11].

Forest vegetation affects both the interception of snowfall and subsequent rates of snowmelt. A general observation by Pereira is that snowpack under closed stands of conifers melts some two weeks later than snow lying in adjacent open areas. Forest also tends to reduce soil erosion and flood risks by stabilizing the surface and reducing stormflow intensities [12].

For much of North America, agricultural land use has the greatest impact on watershed hydrology. The main effect of crops is on the interception of rainfall and its partitioning between infiltration in the soil and overland flow. In particular, seasonal cycles of plowing, cultivating, and harvesting different crops expose the bare soil at different times to desicating solar radiation and physical erosion by rainfall. Also, evapotranspiration rates are directly affected by the density and condition of the vegetative cover, as mentioned above. Thus tillage and cultivation practices become more important to watershed hydrologic conditions than the types of crops planted. Years of studies by the U.S. Department of Agriculture's Agricultural Research and Soil Conservation Services and the Bureau of Reclamation have shown that conservation treatments can reduce runoff by 25 to 40 percent [13].

The effects of urban land use are well documented [14]. Urbanization causes local but severe changes in the hydrologic cycle. In particular, the removal of vegetation and its replacement by a terrain surface impervious to water infiltration greatly increases and accelerates surface runoff. According to Leapold, "of all land use changes affecting the hydrology of an area, urbanization is by far the most forceful."

2.1.2 HYDROLOGIC MODELS

The only practical use of information is as an aid to decision-making. Remote sensor data is only useful within the context of an information system which allows better decisions to be made. To properly utilize the products of remote sensing technology, the data should be part of the water management decision-making process. Increasingly, this process involves the use of mathematical models to simulate and better predict the complex events of basin hydrology. The purpose of model development is to investigate the response or behavior of a hydrologic system and permit extension of the observed data to future or alternative situations [15].

A number of models have been developed to simulate hydrologic systems. The well-known Stanford watershed model predicts streamflow from small watersheds where surface runoff is a large proportion of the total runoff [16]. On a regional basis Witherspoon [15] has developed a model of Lake Ontario where the basin water balance provides an estimate of volumetric relationships between precipitation, evaporation, and runoff. The Ontario Ministry of the Environment is presently testing models of the IHD (International Hydrological Decade) representative basins in the Lake Ontario local watershed [17] and, in cooperation with the University of Guelph, is exploring the use of ERIM-processed ERTS-1 data.

Most computer models have been designed to use sparse hydrological and meteorological data and not synoptic remote sensor data. In the short-term, some existing models and remote sensor data may be modified to be generally compatible, and to hopefully give better results than would the use of the models without the remote sensor data. In the long-term, however, new models must be constructed to optimize the use of remote sensor data along with the more traditional inputs, and to date this has not been done. For illustrative purposes we considered the use of remote sensor data with several existing physical models developed by the U.S. Department of Agriculture (USDA).

Two physical models were of interest: the USDAHL-70 Model of Watershed Hydrology [18] and the Rainfall Erosion Losses Model [19, 20]. It was our objective to explore the potential of remotely sensed data used with models of this type.

2.1.2.1 USDAHL-70 Model

This mathematical model of watershed hydrology, under study in the USDA Hydrograph Laboratory, is designed to serve the purposes of agricultural watershed engineering. The objective is to mathematically define "what actually happens during the runoff process as a basis for planning the engineering structures and procedures that will control the times, routes, and amounts of water flow." It is designed in terms of input information traditionally available to the analyst; in other words, information exclusive of remote sensor data. Inputs include: (1) a continuous record of rainfall; (2) U.S. Weather Bureau temperature and storm reports; and (3) the physical characteristics of the watershed. It is this last factor which remote sensor data may improve.

Several physical characteristics of watersheds are required. Some of these characteristics, such as soil texture and land capability classes, are assumed to remain constant during the simulation period; others, such as soil moisture, change continuously. Of the 34 input parameters required for operating the model, eight are directly related to the identity, areal coverage, or distribution of surface features. These include watershed acreage, number of hydrologic response units or categories used to characterize the watershed, number of crops (for agricultural watersheds), changes in crop distribution, percent areal distribution of soil zones, estimates of evapotranspiration rates, crop identification, and crop phenology (growth indices). Other parameters may be partially indicated by synoptic coverage of the watershed, including percent of overland flow which "cascades" to either succeeding zones or the "channel" or "alluvium," basal area of vegetation, and information on surface routing of flow.

If we were to use the ERTS-1 land-use information for the East and Middle Oakville basin (described in the next section) as inputs to this model we would be limited to watershed area (20,727.4 ha), number of hydrologic response units (11), and percent areal distribution of these units. However, with some modification of requirements for specific crop identification and crop growth indices (substituting 18-day updates of percent herbaceous cover), these kinds of ERTS-1 data may improve model outputs of runoff, evapotranspiration, evaporation from soil, and loss to percolation. From these continuous data, monthly, seasonal, or yearly water balances are computed. Thus the periodic updating of watershed land use may represent a more important application of remote sensor data for this model than the establishment of initial watershed conditions.

2.1.2.2 Universal Soil Loss Equation

Soil losses vary considerably from year to year, but reasonable average annual values can be predicted from a series of related equations developed by the USDA Soil Conservation Service [19, 20]. While not designed for use with remotely sensed data, accurate acreages of the various land uses which comprise the area of interest are required for the soil loss prediction. These equations are designed to provide the agriculturalist with an estimate of field soil losses which occur under different cropping and cultivation regimes. In addition, engineers can roughly estimate the sediment load contributed to stream channels by direct overland flow. The equations relate empirically established coefficients for various land use and physical factors to soil erosion, and were used in a recent study to determine regional soil losses from construction sites [21]. A simplified version of this equation is given below:

$$A = RCKLS$$

where A is computed soil loss per acre per year in tons
R is the average annual rainfall erosion index
C is the ratio of soil loss under specific surface cover and cropping conditions to the corresponding loss from tilled and continuously fallow land
K is a soil erodibility factor
LS is the slope length (L) and slope gradient (S) factor

For illustrative purposes we attempted to make rough estimates of the soil losses which occur for eleven land-use classes in the East and Middle Oakville basin. A number of assumptions concerning average soil series and topography have been made for the computations shown in Table 1. For our purposes we assume no soil losses from areas of marsh, swamp, water, and impervious surfaces. All other land-use classes are listed in Table 1. The assumptions include the conifers as growing on steep slopes along the Niagara Escarpment and the soils as being clay loam for the agricultural areas and loam for the wooded areas. These results are not be be interpreted as definitive, but are merely illustrative of an approach to the use of ERTS-1 data in estimating soil losses.

2.1.2.3 Development of Simulation Models

In hydrology many models have been constructed to simulate certain physical processes of the hydrologic cycle within watersheds or basins. These are based on principles of conservation of mass, conservation of energy or a combination of both. They are designed to optimize the use of sparse, largely point-sample data of water fluxes over some period of time. Indeed, most physical models require "calibration"—an empirical adjusting of equation coefficients so that the model outputs "fit" as nearly as possible a period-of-flow record. To date, no models have been designed to optimize the synoptic spatial input of remote sensor data. However it is clear that such spatial data, if made available on an extensive and periodic basis, could be useful for hydrologic modeling purposes.

Remote sensor data can serve several functions in modeling efforts which are currently limited or ignored due to lack of appropriate data. These functions include:

TABLE 1. SOIL EROSION LOSSES FOR THE EAST AND MIDDLE OAKVILLE CREEK BASIN USING THE UNIVERSAL SOIL LOSS EQUATION AND ERTS-1 DATA

Land Use	R	C	K	L(ft)	S(%)	LS	Acres	Soil Loss (tons)
Hardwoods	75	0.010	0.37	250	14	3.7	11954	12,274
Conifers	75	0.006	0.37	400	35	22.5	344	1,289
Bare soil	75	1.000	0.43	500	6	1.5	5548	268,384
10-60% Green herbaceous cover	75	0.500	0.43	500	6	1.5	19641	475,067
60-80% Green herbaceous cover	75	0.500	0.43	500	6	1.5	3387	8,192
> 80% Green herbaceous cover	75	0.500	0.43	500	6	1.5	6714	1,624
Quarries	75	1.000	0.25	150	40	17.6	35	11,451

Total Annual Loss = 778,281

(1) compartmentalization of watersheds into distinctive soil, vegetation, land use, geological, and climatic zones;

(2) precise areal measurement of zones of differing hydrologic characteristics;

(3) monitoring of major dynamic watershed changes to periodically update the physical watershed data;

(4) integrating quantitative radiance data to obtain radiation measurements useful in energy balance studies of entire watersheds.

2.1.3 EXAMPLE: EAST AND MIDDLE OAKVILLE CREEK BASIN

A representative basin is an instrumented natural watershed which is thought to be characteristic of the hydrogeological conditions of other, less well studied, areas [22]. As part of the IFYGL research program the Ontario Ministry of the Environment designated the East and Middle Oakville Creek basin as one of several representative basins selected for intensive study. This basin is located in the western portion of the Lake Ontario basin, in the center of a triangle formed by the cities of Hamilton, Toronto, and Guelph, Ontario. The elliptical basin has an area of approximately 200 km^2 (76 mi^2) and is five miles northwest of the city of Oakville and the Lake Ontario shore. It is characteristic of an area of relatively level agriculture land on soils derived from the Queenstone shale (Ordivician). The boundaries of the Oakville basin extend between approximately $79^{o}45'$ W and $80^{o}01'$ W longitude and $43^{o}28'$ N and $43^{o}38'$ N latitude. The elevation in the basin ranges from 1275 feet above sea level at its western edge to 475 feet above sea level at its southeastern tip. The topography is one of moderate slopes with increased surface undulations in the most elevated areas. Sharp relief is provided by the Niagara Escarpment which runs through the western portion of the basin in a north-south direction. Four views of the East and Middle Oakville basin are shown in Figure 2. A further description of the basin is available in Logan [23].

One of our objectives was to establish a terrain land-use classification system and apply it to this representative basin within the much larger Lake Ontario drainage basin. This required obtaining a basin land-use map and areal statistics for the irregular watershed, using optimal digital data processing routines. The procedure used is described in section 3.2.4 of this report.

Based on the effects of land use on watershed hydrology (Section 2.1.1), we devised a set of land-use categories, derivable from ERTS-1 data, which seemed to have hydrologic significance. These categories were represented by three different groups: non-vegetative, herbaceous upland vegetation, and non-herbaceous and lowland vegetation. The classification is shown in Table 2.

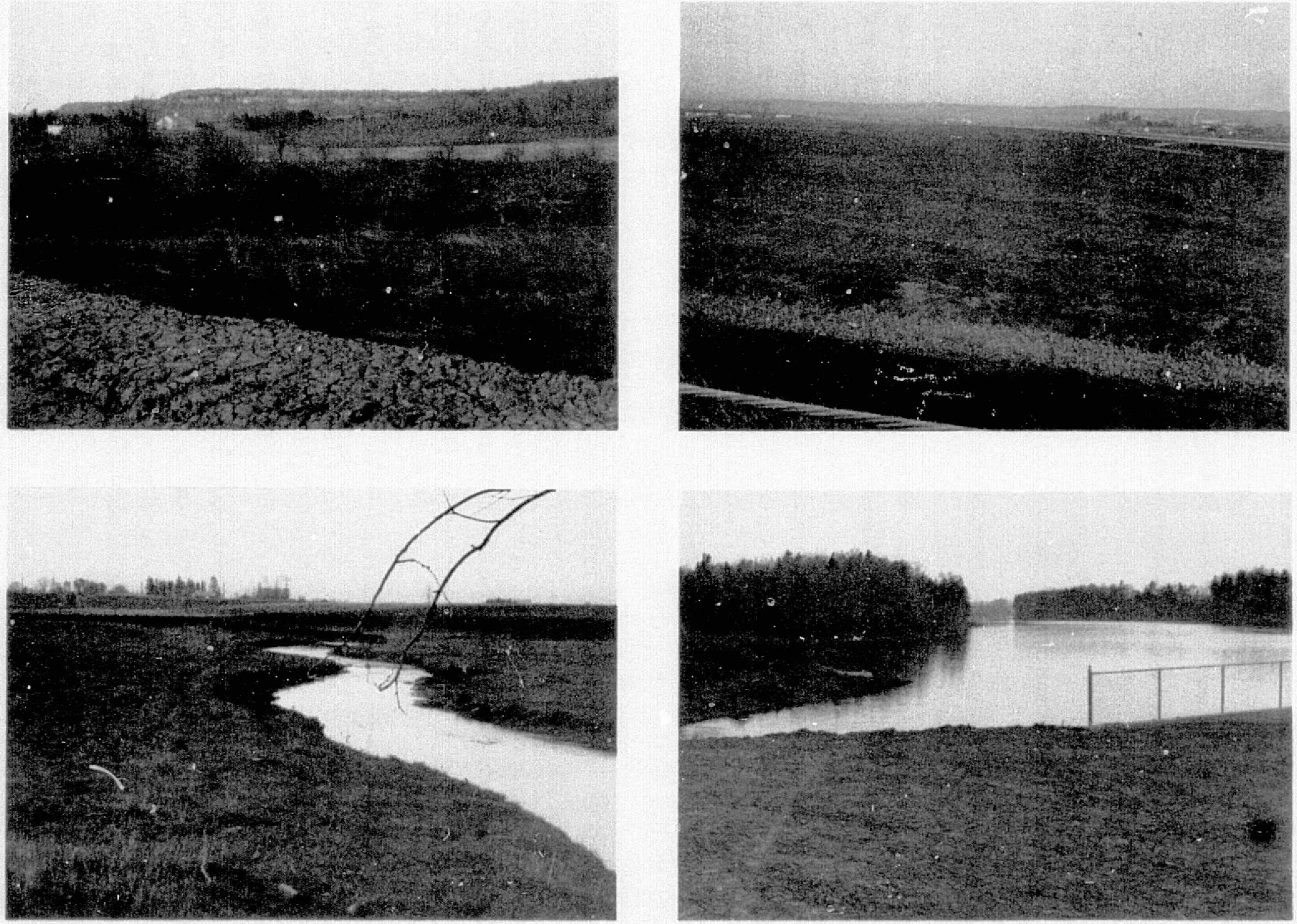

FIGURE 2. FOUR VIEWS OF THE OAKVILLE REPRESENTATIVE BASIN, ONTARIO, CANADA

TABLE 2. WATERSHED LAND-USE CATEGORIES
USED IN RECOGNITION PROCESSING OF THE
EAST AND MIDDLE OAKVILLE CREEKS BASIN

Non-Vegetative:	Standing Water (lakes and ponds)
	Quarries
	Impervious Surfaces (urban)
Non-Herbaceous and Lowland Herbaceous Vegetation:	Hardwoods
	Conifers
	Shrub Swamp
	Marsh
Upland Herbaceous Vegetation:	Bare Soil (<10% cover)
	10-60% Cover
	60-80% Cover
	>80% Cover

Figure 3 shows the land-use map of the East and Middle Oakville Creek representative basin using this classification system. The procedures for obtaining this map are described in Section 3.2.4; statistics for the land use classes are given in Table 3. From this table it may be noted that both the non-vegetative and the non-herbaceous and lowland vegetation categories refer to specific types of terrain surfaces, and in the latter case, to specific dominant vegetation types. However, for the herbaceous upland vegetation category the percentage cover of the surface was deemed more important than the specific crop type. The application of these categories to a rainfall-erosion losses model is discussed in Section 2.1.2.2.

At one time the Oakville Basin was principally forest, with pine the dominant species [24]. Now, however, the area is largely agricultural with sparse distribution of improved and unimproved forested areas [23]. The largest concentration of forests exists in the western quarter of the basin along the Niagara Escarpment.

The total area of the basin, according to the recognition map, is 80.03 mi^2. This is a little over 5% greater than the 76 mi^2 basin area given by Logan. Drainage basin boundaries, however, are not emenable to specific delineation due to uncertainties in the direction of ground water flow.

The accuracy of the recognition map was determined by personnel from the University of Guelph using a combination of field reconnaissance and photointerpretation of high altitude infrared photography taken in June 1972. The high altitude NASA RB-57 photos generally provided the most accurate information for checking the map. However, the temporal lag between June and August presented problems when a verification of the herbaceous classes was attempted. Many fields appeared as bare soil on the photos, since crops had not yet appeared.

Verification of specific points (pixels) on the recognition map was done on pixels selected randomly throughout the basin. For all categories except marsh these data points were from rectangular or L-shaped areas consisting of at least eight pixels. Most marsh areas were not this large. Table 4 lists the pixels which were field checked and the results of that check.

In addition to verifying selected points, several transects across the basin were followed via roadways in order to compare bands of land use on the recognition map and in the field. The classified pixels so observed were found to be accurately identified.

The classification of hardwood and mixed conifer-hardwood areas was generally accurate. In general the few identified errors occurring in hardwood classification appeared to be due to confusion with dense green agricultural crops which had similar tone, but different texture, on the infrared photos. One hardwood signature, representing less dense hardwoods, was similar enough to the agricultural signatures in the 10-60% and 60-80% cover classes that some

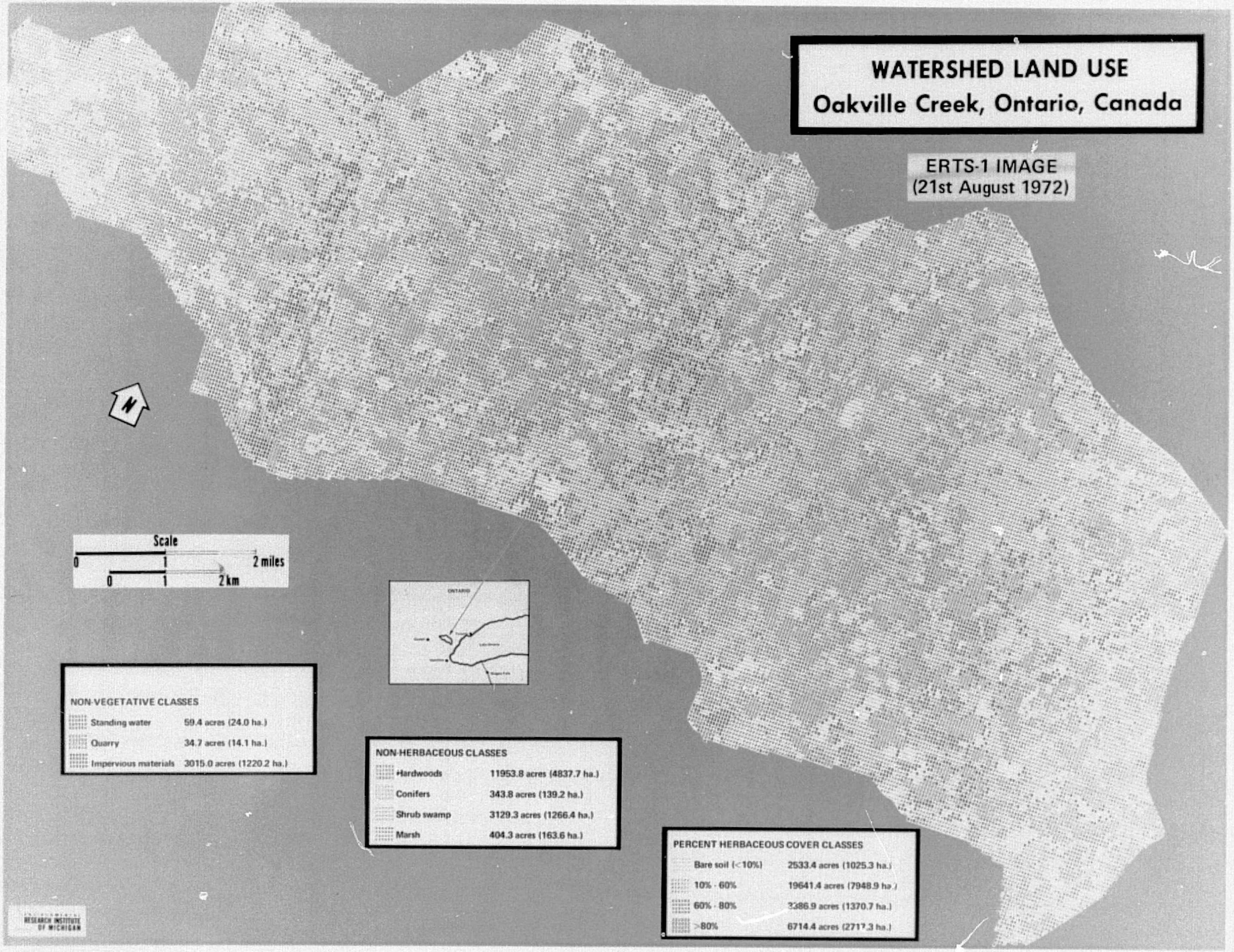
WATERSHED LAND USE
Oakville Creek, Ontario, Canada
ERTS-1 IMAGE
(21st August 1972)
N
Scale
0 1 2 miles
0 1 2 km
ONTARIO
NON-VEGETATIVE CLASSES
Standing water 59.4 acres (24.0 ha.)
Quarry 34.7 acres (14.1 ha.)
Impervious materials 3015.0 acres (1220.2 ha.)
NON-HERBACEOUS CLASSES
Hardwoods 11953.8 acres (4837.7 ha.)
Conifers 343.8 acres (139.2 ha.)
Shrub swamp 3129.3 acres (1266.4 ha.)
Marsh 404.3 acres (163.6 ha.)
PERCENT HERBACEOUS COVER CLASSES
Bare soil (<10%) 2533.4 acres (1025.3 ha.)
10% - 60% 19641.4 acres (7948.9 ha.)
60% - 80% 3386.9 acres (1370.7 ha.)
>80% 6714.4 acres (2717.3 ha.)
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TABLE 3. STATISTICS FOR THE ELEVEN LAND-USE CLASSES OBTAINED FROM RECOGNITION PROCESSING OF THE OAKVILLE BASIN. Data from ERTS observation 1029-15345, obtained 21 August 1972.

Class	Area Acres	Area Hectares	Percent of Total Basin
Standing Water	59.4	24.0	0.1
Hardwood Forest	11953.8	4837.7	23.3
(Hardwood-1)	(10248.0)	(4147.4)	(20.0)
(Hardwood-2)	(1705.8)	(690.3)	(3.3)
Conifer Forest	343.8	139.2	0.7
(Pine)	(56.0)	(22.7)	(0.1)
(Mixed Conifer-Hardwood)	(287.8)	(116.5)	(0.6)
Shrub Swamp	3129.3	1266.4	6.1
Marsh	404.3	163.6	0.8
Quarry	34.7	14.0	0.1
(Sand and Gravel)	(28.0)	(11.33)	(0.06)
(Limestone)	(6.72)	(2.7)	(0.01)
Impervious Material	3015.0	1220.2	5.9
0-10% Green Herbaceous Cover	2533.4	1025.3	5.0
10-60% Green Herbaceous Cover	19641.4	7948.9	38.4
60-80% Green Herbaceous Cover	3386.9	1370.7	6.6
>80% Green Herbaceous Cover	6714.4	2716.3	13.1
TOTAL	51216.4	20726.3	100.1

TABLE 4. RESULTS OF A FIELD CHECK OF SPECIFIC DATA POINTS ON THE DIGITAL RECOGNITION MAP OF THE OAKVILLE BASIN

Check Point	Map Classification	Land Use in Field
1	hardwoods	crop
2	hardwoods	hardwoods
3	hardwoods	hardwoods
4	hardwoods	hardwoods
5	hardwoods	hay/pasture
6	hardwoods	hardwoods
7	hardwoods	crop
8	hardwoods	hardwoods
9	hardwoods	hardwoods
10	hardwoods	hardwoods
11	mixed conifer-hardwood/pine	creek-grass and shrub pine
12	mixed conifer-hardwood/pine	pine
13	mixed conifer-hardwood/pine	pine
14	mixed conifer-hardwood/pine	pine
15	mixed conifer-hardwood/pine	pine
16	mixed conifer-hardwood/pine	pine
17	mixed conifer-hardwood/pine	mixed conifer-hardwood
18	mixed conifer-hardwood/pine	cedar/balsam/softwood
19	mixed conifer-hardwood/pine	cedar/balsam/softwood
20	mixed conifer-hardwood/pine	mixed conifer-hardwood
21	water	water
22	water	water
23	shrub swamp	cedar swamp
24	shrub swamp	cedar/shrub swamp
25	shrub swamp	cedar/shrub swamp
26	shrub swamp	cedar/shrub swamp
27	shrub swamp	cedar/shrub swamp
28	shrub swamp	cedar/shrub swamp
29	shrub swamp	cedar bog
30	marsh	marsh-grass vegetation
31	marsh	marsh-shrub vegetation
32	marsh	marsh depression in field
33	quarry	quarry
34	quarry	quarry
35	impervious	bare fields
36	impervious	bare fields
37	impervious	bare fields
38	impervious	bare fields
39	impervious	bare fields
40	impervious	bare fields
41	80-100 percent cover	corn
42	80-100 percent cover	corn
43	80-100 percent cover	corn
44	80-100 percent cover	corn

misclassification may have occurred. In classification of mixed conifer-hardwood forest, there was a tendency to include stands of swamp-cedar, balsam fir, and some other species of coniferous vegetation.

There was little difficulty in correctly identifying distinct water bodies, cedar-swamps, and marsh areas. However, several small water bodies appearing on the June aerial photography were not recorded on the ERTS map. Many of these ponds may have become dry by mid-August.

Large highways and building complexes were readily and correctly recognized as impervious. However, there was also a significant amount of misclassification in this category. The greatest misclassification occurred with impervious materials. Photointerpretation revealed that many areas classified by the computer as impervious were bare soil in June of 1972. Field checking in mid-August, 1974, two years after data collection (21 August 1972), showed a number of these areas to be supporting mature crops, so it is unlikely that impervious surfaces existed in these locations in 1972. If the ERTS data collection occurred after harvest, however, it could be concluded that the classification of impervious surfaces included some bare soil. Indeed, at one location excavation of the top soil (i.e., stock piling) had recently taken place. The occurrence of several areas classified as bare soil surrounded by areas identified as impervious material also support the conclusion that some bare soil was classified as impervious material.

While recognition of specific agricultural crops was not attempted certain crops fell into various percent cover classes. The 10-60% cover class was composed of cut hay/pasture; corn and grains were in the 80-100% cover category according to the ground observations. The accuracy of determining the percent herbaceous cover appeared to be good, with the exception of the classification of some bare soil as impervious material. This inaccuracy was the result of the method used to delineate impervious material, not from the method used for recognition of the percent cover classes. Except for the impervious area, an overall accuracy of 94% is indicated.

2.2 REGIONAL PHYSIOGRAPHY

There are a number of applications of ERTS-1 data to hydrology where spatial geometry and pattern are more important than measurement or determination of area. In these applications non-quantitative image enhancement and human interpretation are sufficient to obtain useful information. In general the information obtained is limited to large-scale variations in image patterns related to major physiographic features or to the quality of relatively large water bodies. Often the features are related to major linear patterns, such as drainage channels or fault traces, which may be traced on ERTS-1 imagery because of its regional scale. Researchers at the University of Guelph have documented a number of these regional hydrologic applications using portions of the Canadian side of the Lake Ontario basin for their test sites.

Included here is a description of some of the geological and hydrological studies using ERTS-1 data undertaken by personnel at the University of Guelph in cooperation with ERIM. Color image-enhancement techniques are described in Section 3.2.3. Greater detail is available from reports by A. Falconer, et al. [25, 26, 27].

2.2.1 DRAINAGE CHANNEL MAPPING

A study by Bruce and Howarth [28] has shown that ERTS-1 imagery offers little detail in the way of actual drainage channels. However, some of the more dominant networks may be inferred owing to the relationship of surface moisture conditions and vegetation types with flood plains and streams. Figure 4 shows a comparison of drainage networks in the western portion of the Lake Ontario basin, mapped from 1:250,000 topographic maps and from ERTS-1 imagery.

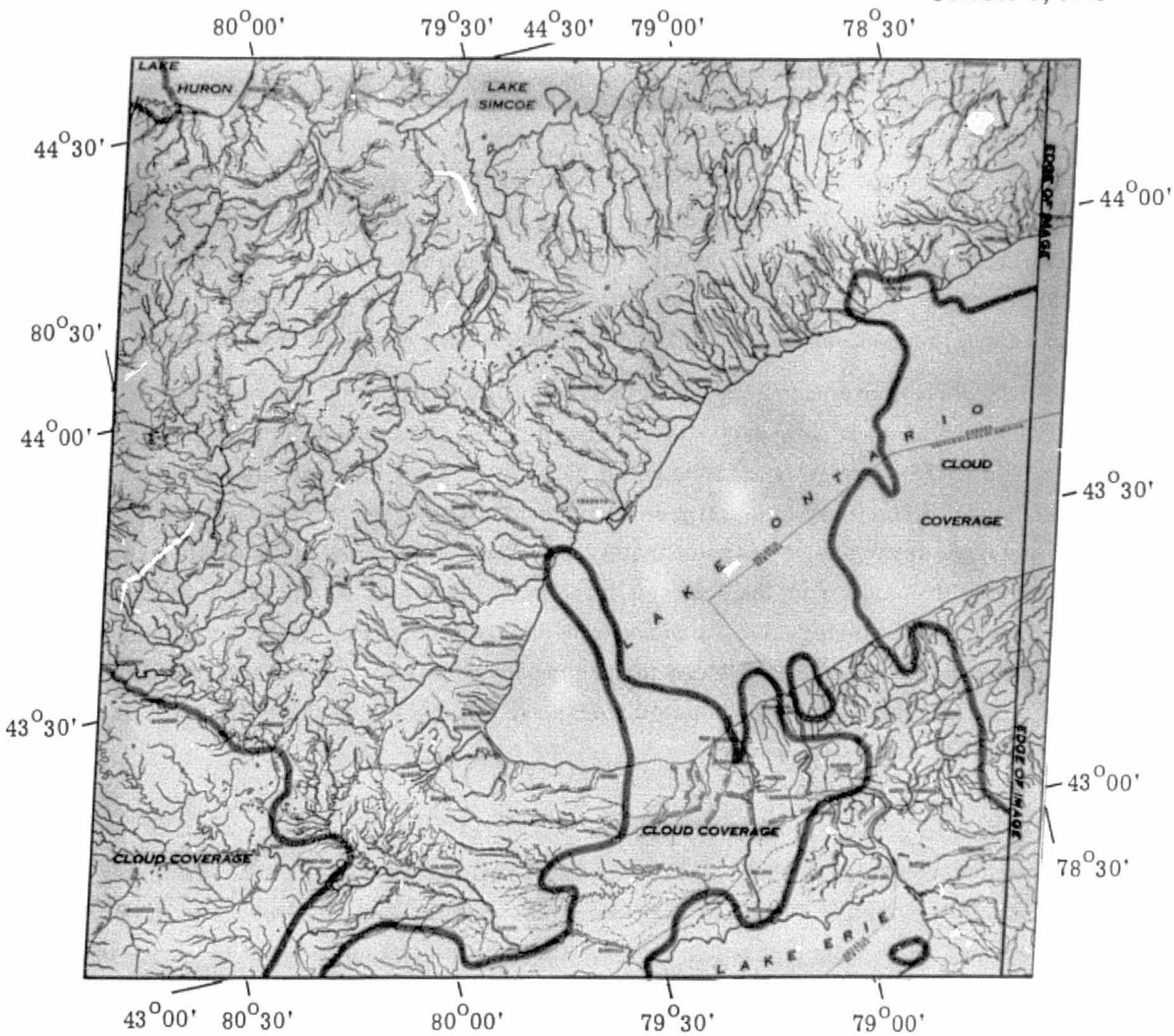
The ERTS-derived drainage network is indicated by dark lines. These are superimposed on lighter lines which show map-derived drainage patterns. The extent of cloud coverage on the 9 October 1973 ERTS-1 image is also indicated. The ERTS imagery provides patterns which are similar to, but which vary in detail from the previously mapped drainage patterns. A majority of the large streams have been accurately identified. There are more small stream systems interpreted than appear on the 1:250,000 base map. This may be due to a variety of factors, including the small size or high density of the minor stream networks. However, linear features such as windbreaks or other man-induced features could be mistaken for drainage channels. A number of other interpreted images indicating drainage channels at different times of the year were produced with ERTS-1 imagery.

2.2.2 ORGANIC SOILS

The location and extent of major areas of organic soils in the Lake Simcoe-Kawartha Lakes region of Ontario is shown in Figure 5. Organic soils are often indicative of areas of poor natural drainage and seasonally high water tables. These areas often represent locations of sediment accumulation from neighboring higher areas, and when adequately drained are important for special types of agriculture; in their natural state they are important for wildlife.

Nine-inch color composites of ERTS imagery were used to identify and map organic soil areas. Organic areas were interpreted as being "greyish-brown" on the color transparencies and these were enlarged and transferred to a 1:250,000 base map using a transfer scope. The results show the general similarities and detailed differences between areas conventionally mapped as organic and those interpreted as organic from ERTS-1 imagery.

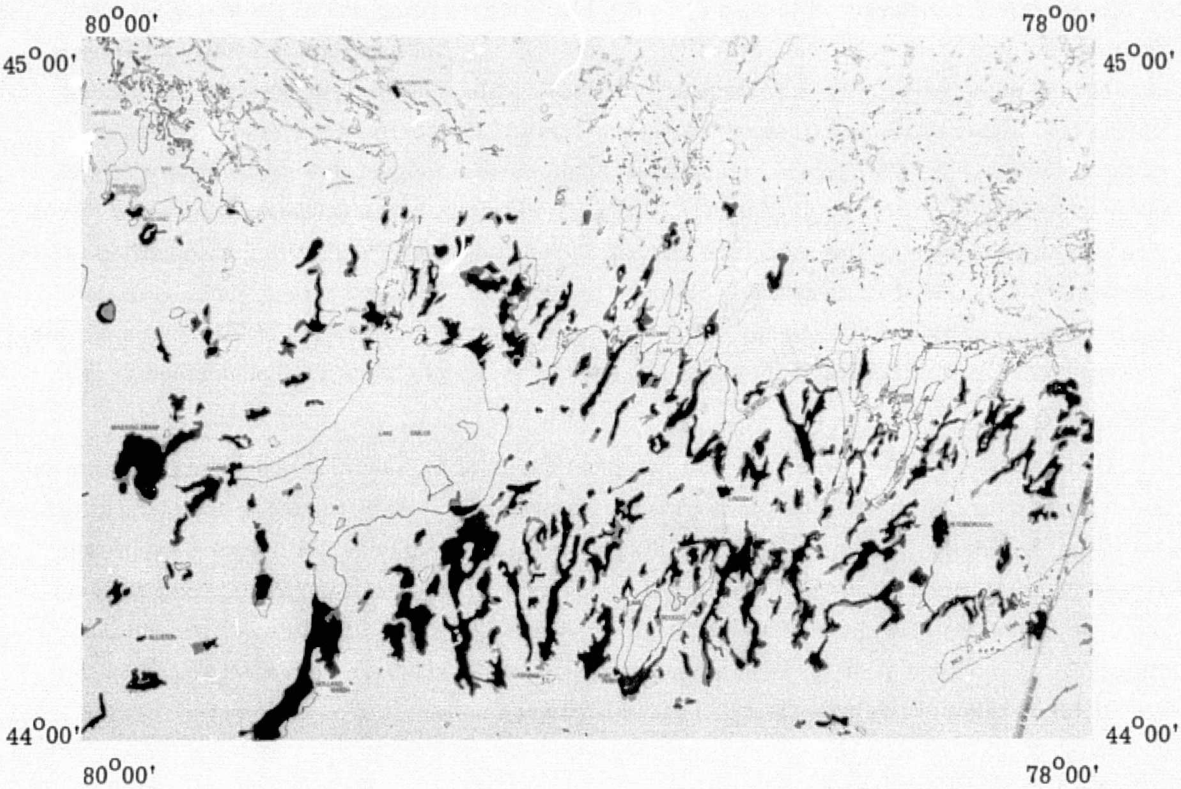
E 1443-15332,15334 Band 5
October 9, 1973



0 5 10 15 20 miles
0 10 20 30 kilometers

Based on N.T.S. 1:250,000 Series
Topographical Maps
30L&M,31D, 40I&P,41A

FIGURE 4. TORONTO-CENTERED REGION HYDROGRAPHY. The ERTS-derived drainage network is indicated by dark lines; lighter lines show map-derived drainage patterns.



N

AREAS OF ORGANIC SOILS AS DETERMINED FROM ERTS-1 IMAGERY

AREAS OF HYDROGRAPHY EVIDENT ON ERTS-1 IMAGERY

AREAS OF ORGANIC SOILS ACCORDING TO THE BASE MAP

1: CORRELATING WITH AREAS ON THE BASE MAP

2: APPARENT ORGANIC SOILS AREAS WITH NO BASE MAP CORRELATION

0 5 10 15 20 miles

0 10 20 30 kilometers

FIGURE 5. ORGANIC SOIL AREAS IDENTIFIED FOR LAKE SIMCOE – KAWARTHA LAKES AREA, ONTARIO, CANADA, USING ERTS OBSERVATION 1443-15332 OF 9 OCTOBER 1973. These areas are compared with Canada Land Inventory Soil Capability for Agriculture Map 31D "Lake Simco" (1957).

2.2.3 LAND USE AND GEOLOGY

In Section 2.1 differences in land use were identified as being one of the major terrain factors affecting local watershed hydrology. Land-use information and the relative distribution of land uses are equally important on a regional scale. Simple enhancement and color-coding techniques were used to show four major terrain classes for the Belleville area of Ontario in Figure 6. This figure compares a single green band (0.5-0.6 μm) image with the color-coded image of forest (green), agricultural land (pink), urban (magenta) and water (blue). The land uses of most of the scene are identified from these four categories; unidentified (white) areas are principally cattail marsh. Although the land uses of much larger portions of the basin were prepared in this manner, Figure 6 shows only a small portion of that image mosaic. The spectral characteristics of these land-use categories and others are documented in Section 3.2.

Geologically, the Precambrian Canadian Shield area of the northern Lake Ontario basin is most interesting. In this region physiographic features are closely related to the underlying geological structure. From the ERTS-1 imagery many linear geological features having surface expression were identified and mapped [29]. Many of these linears were known fracture patterns and faults, but in several cases new evidence of unmapped faults was obtained (see Figure 7). Geological structures in other portions of the basin were not as evident as in the Shield due to thick overlying veneers of glacial tills and soils.

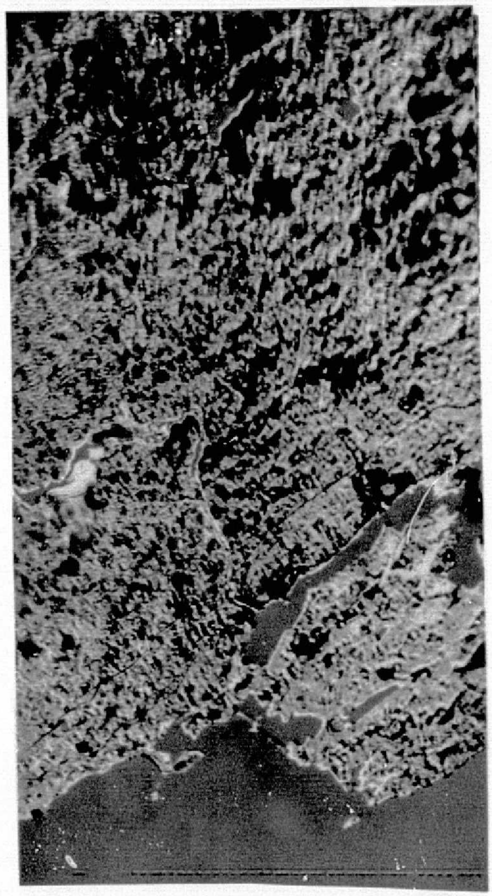
2.2.4 WATER QUALITY

Recent studies of Wezernak [30] and Bukata [31] have shown the value of machine processed imagery in detecting and identifying reflectance parameters related to water quality. Included in this section are illustrations of general quality and movement rather than precise measurements of suspended concentrations of either organic or inorganic particles.

Of the four spectral bands recorded by ERTS-1, the 0.5-0.6 μm wavelength band is generally most useful for observing patterns within Lake Ontario, in contrast to reported optimum results with longer wavelength bands for small water-bodies [32]. In this green spectral region incident solar radiation penetrates to its greatest depths and suspended materials scatter back some of the radiation. Thus, the synoptic patterns of Lake Ontario recorded in ERTS Band 4 indicate relative turbidity integrated to a depth of several meters or more; were turbidity increases, the depth of light penetration decreases. Other, longer-wavelength ERTS-1 bands record only near-surface phenomena.

Figures 8 and 9 compare the use of image enhancement techniques to provide discrimination of Lake Ontario water patterns. Note the differentiation of the counter-clockwise Archimedes spiral located off Braddock Point in New York State. Figure 9 shows the large-scale water

(a) Unenhanced MSS Band 4 Image



(b) Color Coded Land-Use Image

FIGURE 6. COMPARISON OF UNENHANCED AND ENHANCED IMAGES OF THE BELLEVILLE AREA OF ONTARIO. Color code: Green - Forest and Swamp; Pink - Agricultural; Magenta - Urban and Highway; Blue - Water; White - Cattail Marsh.

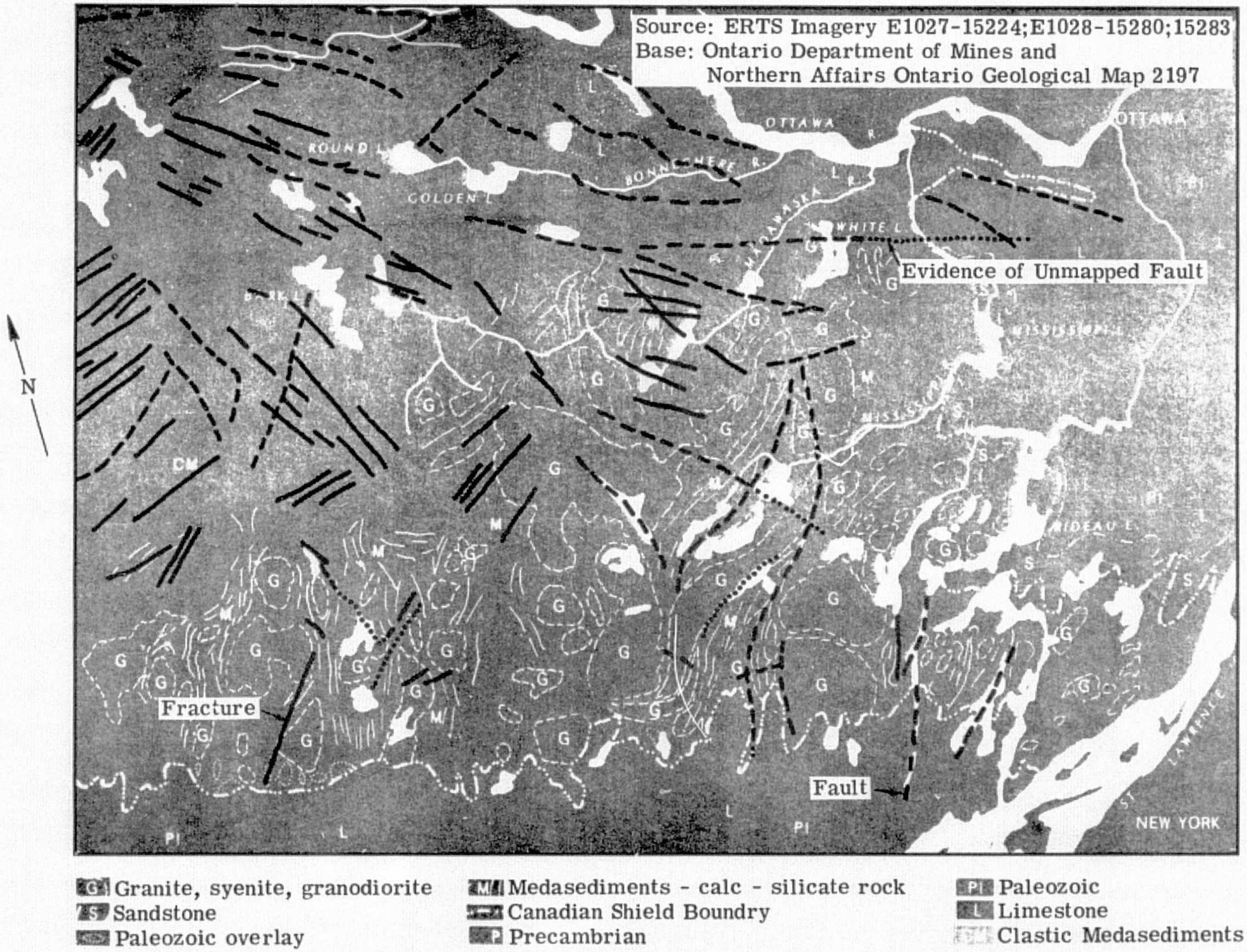
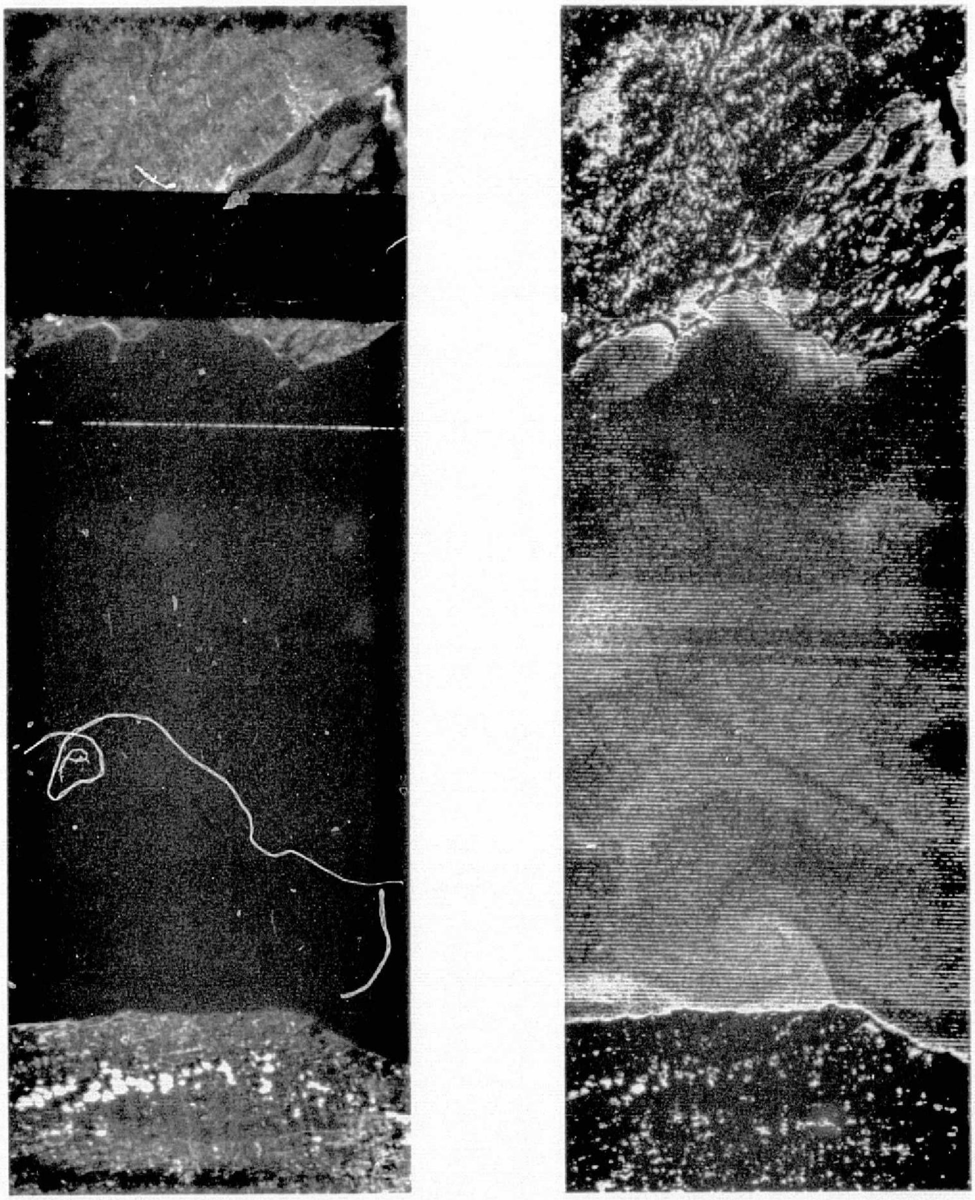


FIGURE 7. SURFACE LINEAR FEATURES RELATED TO GEOLOGIC STRUCTURE OF THE PRECAMBRIAN CANADIAN SHIELD. From figure prepared by Department of Geography, University of Guelph.



(a) Original Image (0.5-0.6μm)

(b) Enhanced Image (level slice)

FIGURE 8. ERTS-1 IMAGES SHOWING ENHANCEMENT OF WATER PATTERNS IN CENTRAL LAKE ONTARIO BETWEEN BRADDOCK POINT, NEW YORK, AND PRESQUILE BAY, ONTARIO FOR 20 AUGUST 1972. Note coastline areas of low and high turbidity and the Archimides spiral off Braddock Point.

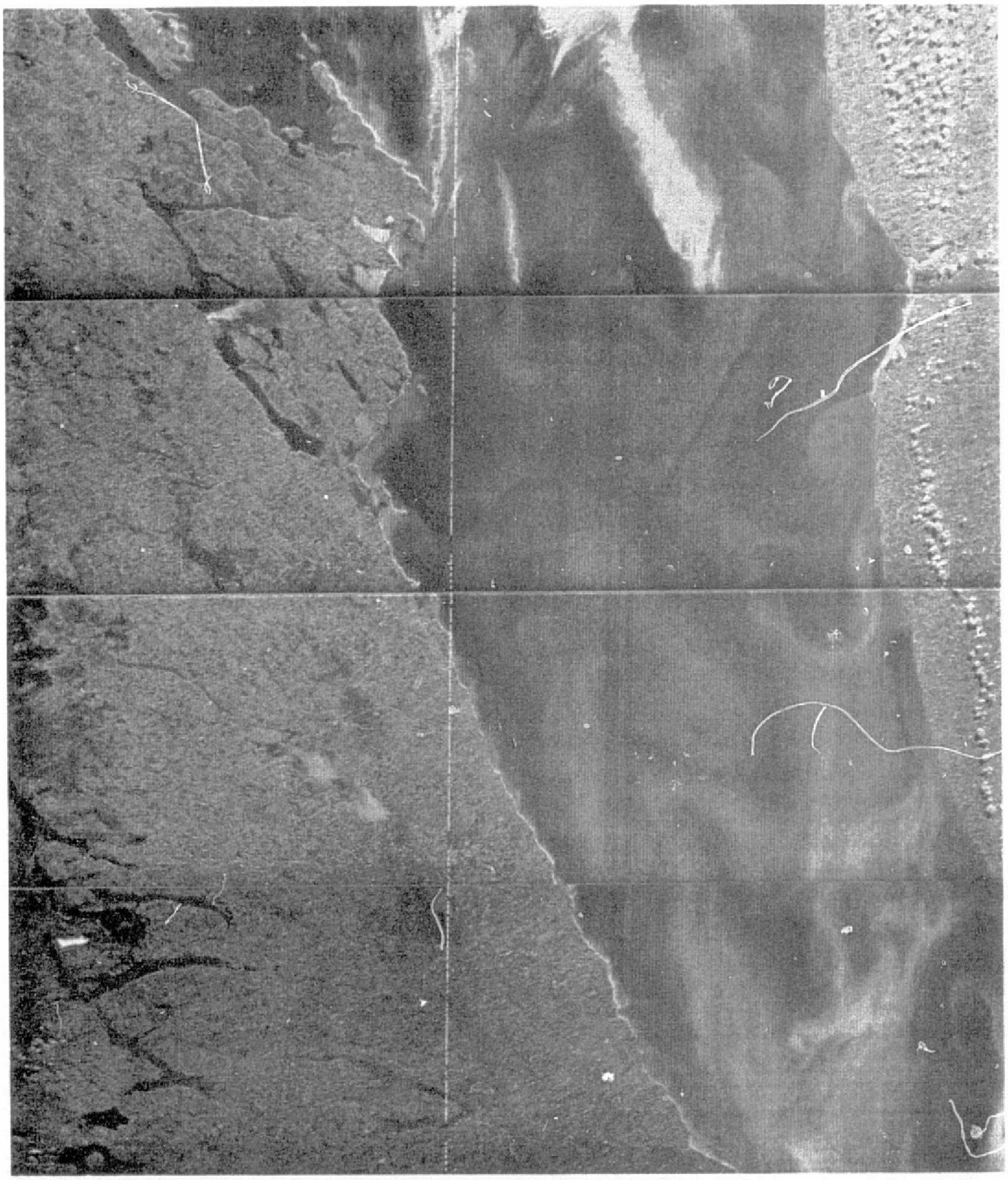


FIGURE 9. ENHANCED ERTS-1 MOSAIC SHOWING NEAR-SURFACE PATTERNS IN CENTRAL LAKE ONTARIO, 20 AUGUST 1972

movement patterns which were occurring at the time of the ERTS pass over central Lake Ontario. While clouds obscure portions of the right-hand side of the image, the Niagara Plume is clearly evident on the left. Also evident are the variable turbidity patterns occurring in several of the smaller Canadian lakes which appear in the upper portion of the image. Indeed, Rice Lake appears to be highly affected by surficial sediments, as do a number of other smaller lakes in the Canadian Shield area (not shown).

For some years aerial observations have been a useful part of the study of nearshore currents and tributary outfalls [33]. The distribution of turbidity patterns and sometimes the movement of dye tracers as viewed from the air suggest current patterns not evident in drogue or fixed-current meter studies. ERTS-1 imagery provides synoptic observations of large lakes systems which could not previously be obtained. The fact that portions of large lake systems function somewhat independently of each other make these synoptic data useful. For example, pollution in the western end of Lake Ontario and along certain shorelines may reach serious levels, while further offshore the water quality may remain good. Thus, these satellite-recorded patterns help to determine the ability of Lake Ontario to disperse or assimilate the waste and erosion products of man's activities.

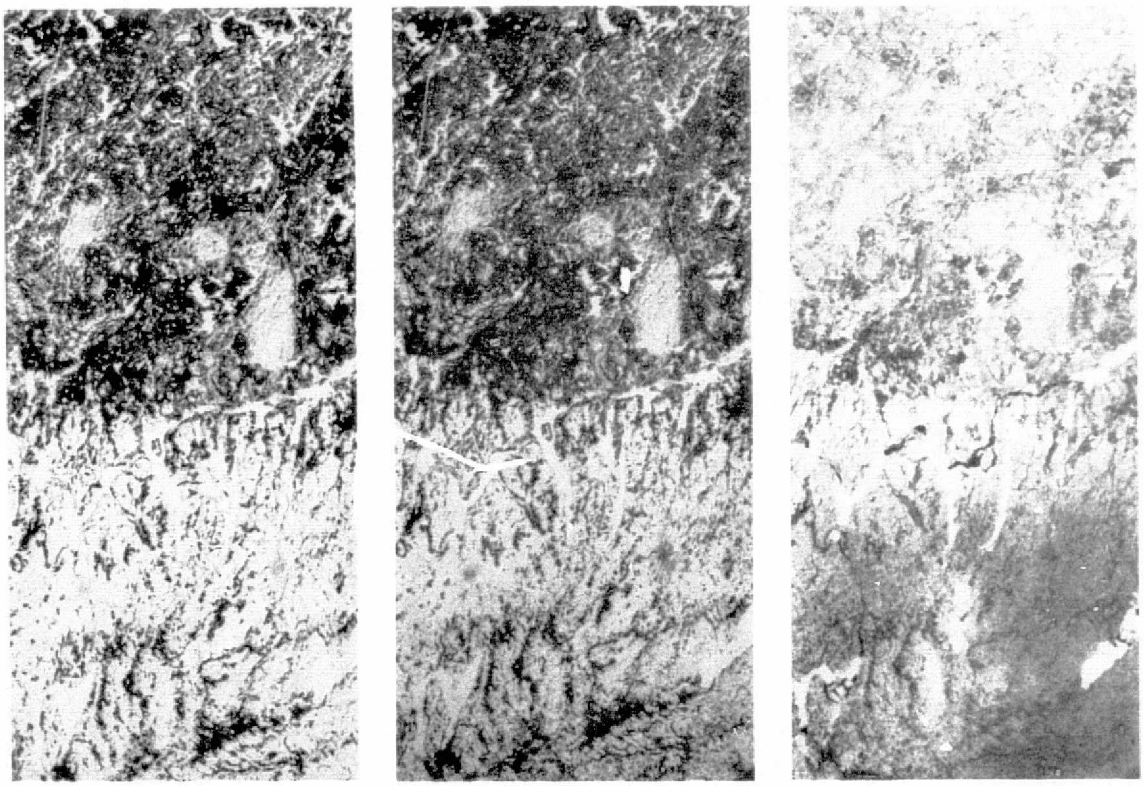
2.2.5 CHANGING SNOW AND ICE CONDITIONS

The storage of precipitation in the form of snow represents an important but difficult-to-measure parameter in the water balance of a large terrestrial area. Also, the timing of ice formation and break-up on rivers and lakes affect both the water flow and the energy balance. A number of ERTS-1 investigators have reported the successful application of satellite data to the monitoring of these winter conditions [34].

Figure 10 illustrates several of these effects for a 7800 km^2 area in the Lake Ontario basin, north of the city of Oshawa. The figure is a sequence of images of the same area obtained by ERTS-1 on three different dates. Snow and ice cover most of the area on both 29 January and 17 February 1973, although in the images the boreal forest areas in the upper portions appear differently than the lower, largely agricultural, areas. Clouds obscured the area during the next ERTS pass (6 March), but by 24 March it is apparent that most of the snow had melted from the agricultural areas and the ice on some of the major lakes was starting to break up. In particular, dark areas in Lake Scugog (lower left) and Rice Lake (lower right) indicate open water surrounded by ice (white).

2.3 THE LAKE ONTARIO BASIN

The primary capability of the ERTS-1 system is its ability to provide accurate synoptic information for very large areas in a short period of time. The information may be spatial



29 January 1973 | 17 February 1973 | 24 March 1973

FIGURE 10. CHANGING SNOW AND ICE CONDITIONS FOR SEQUENTIAL ERTS-1 IMAGERY. Bowmanville, Ontario (0.6 - 0.7μm).

and thematic, or it may be statistical. Statistical data include numerical tabulations such as total acreage or percent of herbaceous cover. However, in dealing with ERTS data for large areas there are certain constraints related to temporal variations and data handling which are not generally significant for small-area study sites. These constraints are illustrated in the processed results for the Lake Ontario drainage basin. In this section the physical characteristics of the drainage basin are briefly described and the thematic mapping of major terrain classes illustrated.

2.3.1 BASIN DESCRIPTION

Lake Ontario, with its basin, is located between 42^{o} and 45^{o} N latitude and 74^{o} and 80^{o} W longitude. Lake Ontario is the smallest of the Great Lakes in surface area and is the furthest downstream; its land basin area (70,450 km^2) is about 3.6 times the lake area (19,425 km^2) [35]. The lake connects with the upper lakes by the Niagara River and Welland Canal, through which it receives about 80% of its water supply. Its outlet is the St. Lawrence River which extends 530 miles to the Gulf of St. Lawrence and the North Atlantic Ocean. Figure 1 is an annotated ERTS-1 image mosaic showing Lake Ontario and its local basin.

The lake surface has an average elevation of 244.6 feet above mean sea level and fluctuates about 6.6 feet between extremes. Since 1960 the lake has been regulated by international agreement to as near a four foot range as possible. The lake is roughly elliptical in shape and has a maximum length of about 193 miles and maximum width of 53 miles. The greatest depth is 802 feet in the eastern end, while the average depth is 283 feet.

The formation of Lake Ontario was a result of the effects of the great Laurentian ice-sheet which covered the northern half of North America as late as 14,000 years ago. The physiography of the basin reflects this glacial origin. The land surface gradually rises from the shoreline of the lake to the basin boundary. Areas near the lake were covered with water following glaciation, resulting in beaches, wavecut cliffs, and deltas. Most of the southern and western portions of the basin show typical glacially-formed landscape features: rolling moraines, drumlins, eskers, and level or undulating till and outwash plains. On the east and northeast numerous outcrops of the PreCambrian Shield are exposed. The Shield includes the Adirondack Plateau which rises to 3,800 feet in the east. In the south the Allegheny Plateau is deeply indented by the long narrow valleys of the Finger Lakes in New York State.

2.3.2 SPATIAL EDITING

In utilizing ERTS-1 data for large area studies a primary consideration is the quality and timeliness of the original data. Cloud-free coverage is required if information is to be obtained for the entire region. In humid temperate or tropical climates completely cloud-free data is seldom available, so cloud and cloud-shadowed areas must be recognized and accounted for in some manner. Also, since the boundaries of natural basins are irregular in shape, methods for spatial editing of the data to include only areas inside the boundaries must be considered. While the approaches devised for this study were not entirely satisfactory, their limitations are not inherent in the system. Further research will improve these initial techniques and reduce the errors they introduced. A major step is the new ERIM-MIDAS processor (not used here).

ERTS-1 data from four successive days are required for complete coverage of the Lake Ontario basin. Data processed for this study were obtained from nearly cloud-free passes on 19-21 August 1972. Complete cloud cover obscured the extreme eastern end of the basin on 18 August and consequently this area was not included in the data processing.

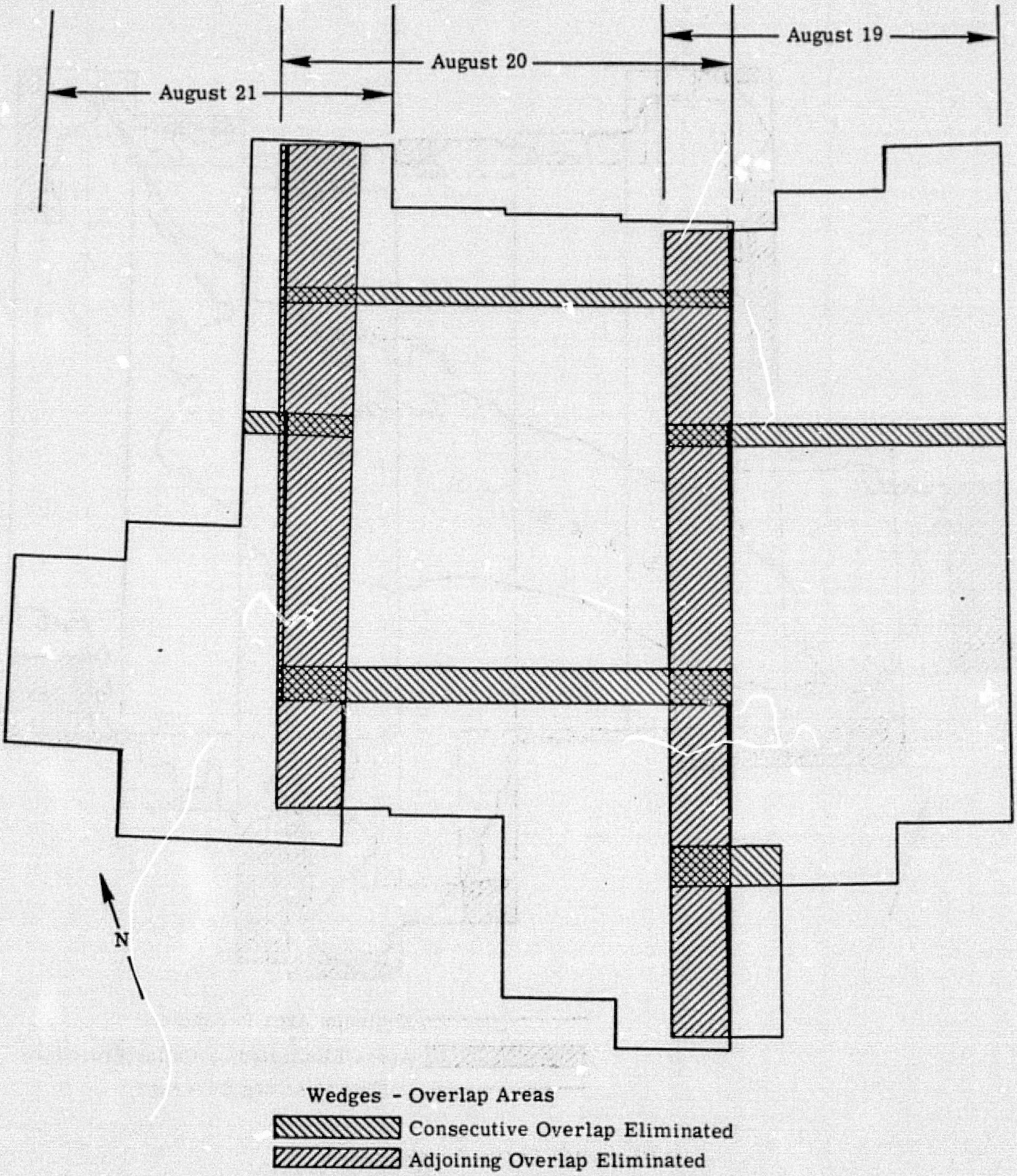
An approximation to the outline of the basin was first made using manual tape-editing techniques. (All of the digital data were converted to analog format for high-speed processing.) Data from the basin comprised a series of tape segments which, when used to produce images, represented most of the 90,000 km^2 basin area. Figure 11a diagrams the series of parallel imagery strips which approximate the basin. These tape segments were further edited using a video gating procedure to eliminate data from outside the basin perimeter and to reduce overlapping data recorded on successive frames (Figure 11b).

It may be seen that the data editing process resulted in errors of area omission and commission. In other words, some portions of the basin were not recorded due to extensive cloud cover over the extreme eastern portion of the basin (Black River area) and small clouds on the remaining data. Errors of commission resulted primarily from an inability to duplicate the irregular outline of the basin using a straight-line electronic gating procedure. Also, slight overlap of data was introduced due to non-parallel tracking of the satellite orbit from one day to the next (Table 5).

Most of the editing and cloud-obscuring effects occurred for land portions of the basin. If one assumes that the proportions of land uses in these areas are similar to those of the imaged basin, then quantitative estimates of the area of land-use classes will be considerably more accurate than the above error estimates would indicate.

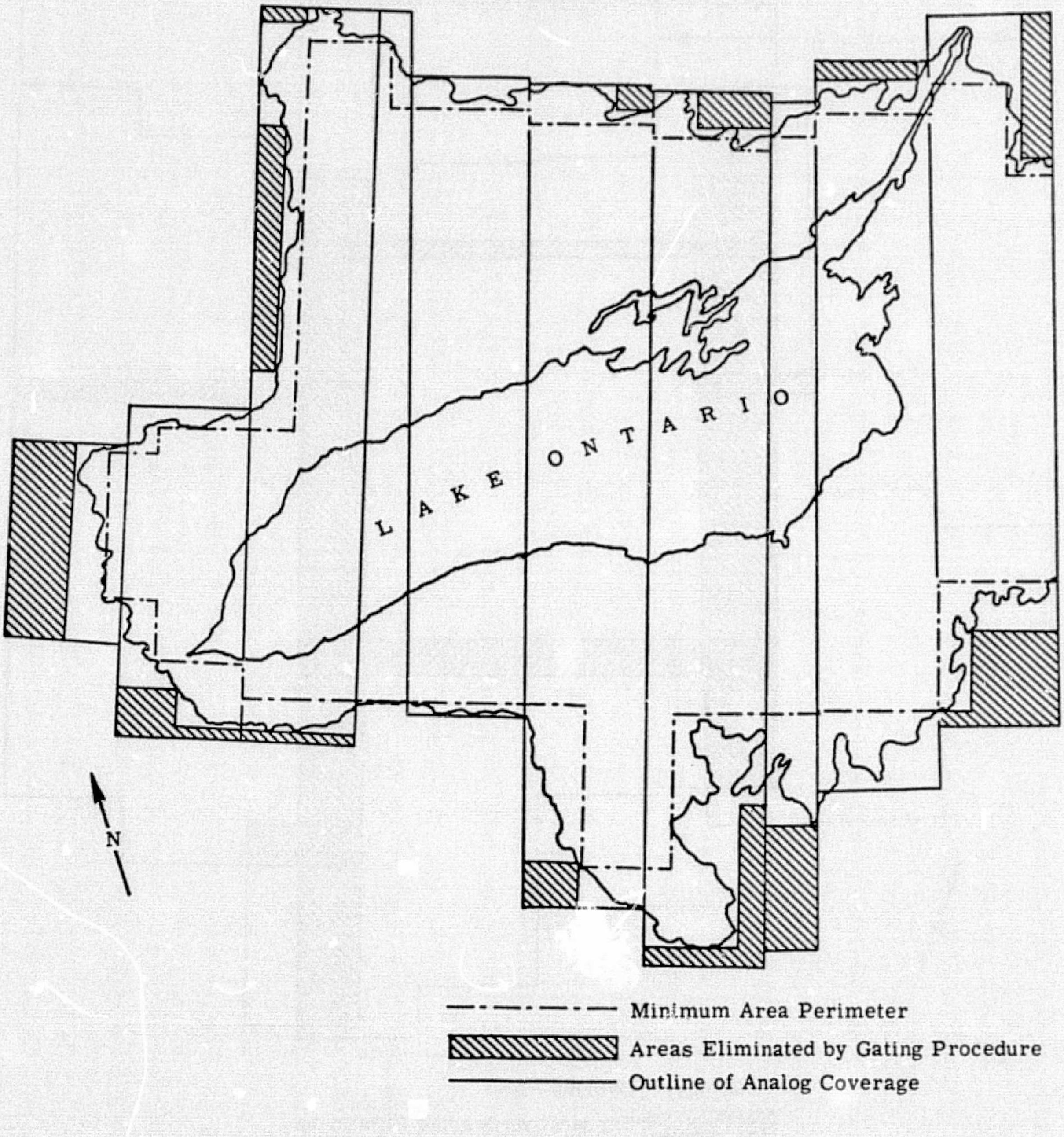
2.3.3. LAND-USE IMAGES

Figure 12 a shows the outline of that portion of the Lake Ontario local drainage basin which was used for rapid analog data processing. It shows the entire basin except those areas which were obscured by clouds during the 18-21 August 1972 data collection period. This image has been dark level corrected to account for the day-to-day atmospheric and calibration level changes which occur with ERTS-1 data.



(a) Areas of Overlap

FIGURE 11. EDITED ERTS-1 COVERAGE OF THE LAKE ONTARIO BASIN (Continued)

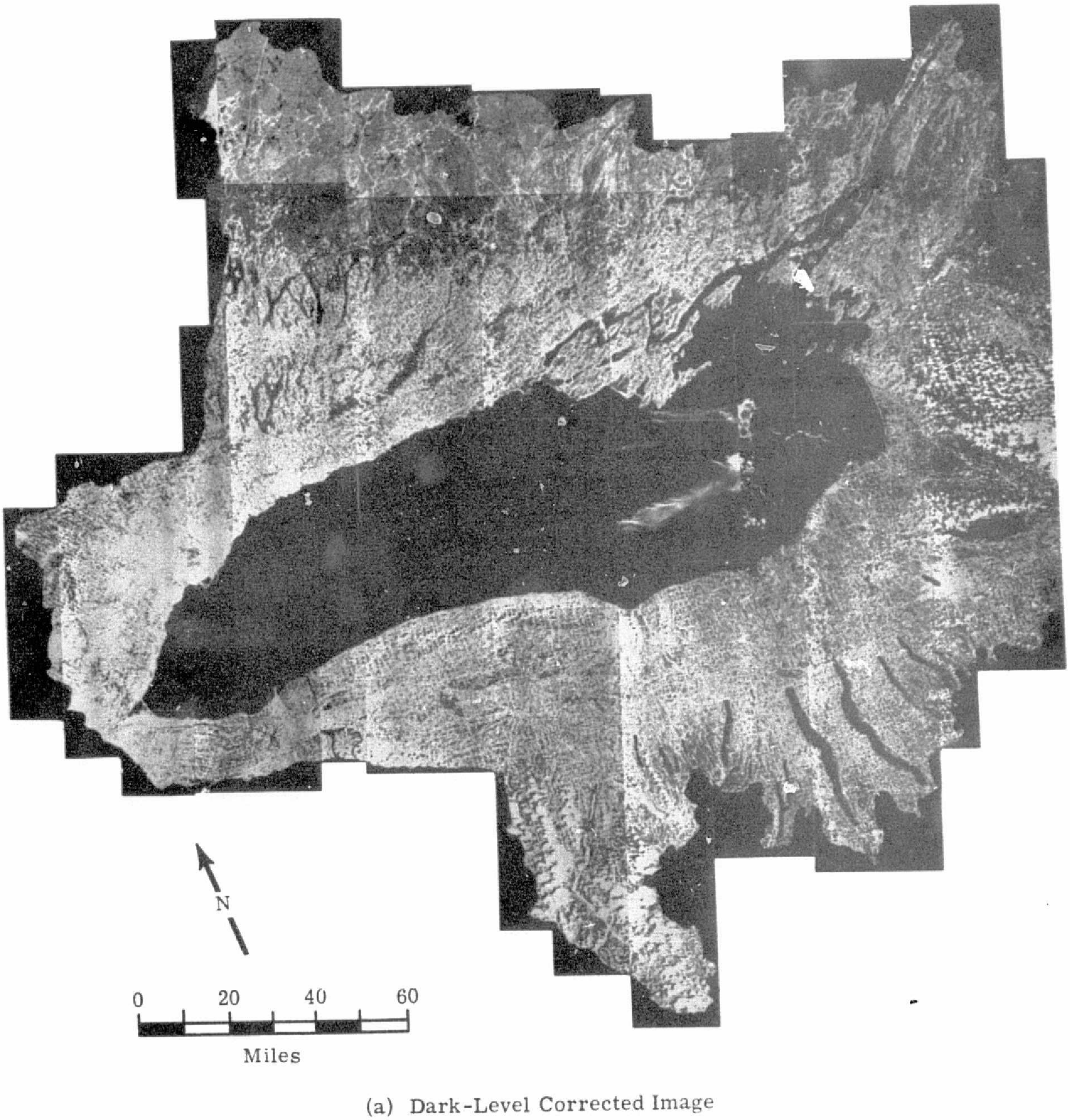


(b) Perimeter Editing Approximation

FIGURE 11. EDITED ERTS-1 COVERAGE OF THE LAKE ONTARIO BASIN (Concluded)

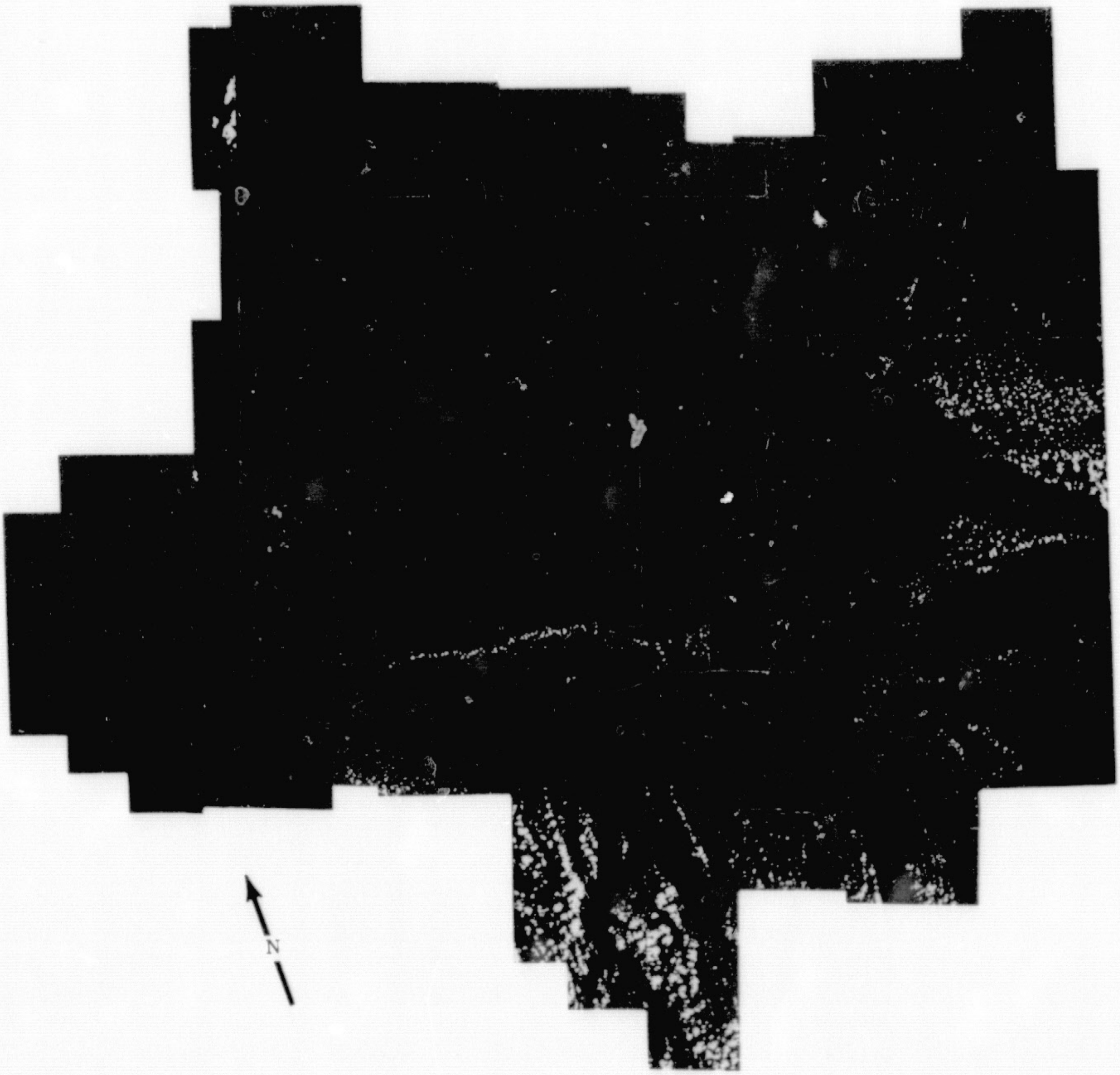
TABLE 5. BASIN AREA AND EDITING ERRORS FOR THE ANALOG PROCESSING OF THE LAKE ONTARIO BASIN DATA

Total Basin	Area (km^2)	% Error (of total basin)
Total Basin	89,900	-
Errors of Omission (total)	11,155	12.4
Eastern Basin (Day 1, 18 August)	6,930	7.7
Cloud & Shadow Obscured	1,528	1.7
Underlap of Segments	2,697	3.0 (estimated)
Errors of Commission (total)	10,878	12.1
Perimeter Editing	9,709	10.8
Overlap of Segments	1,169	1.3 (estimated)



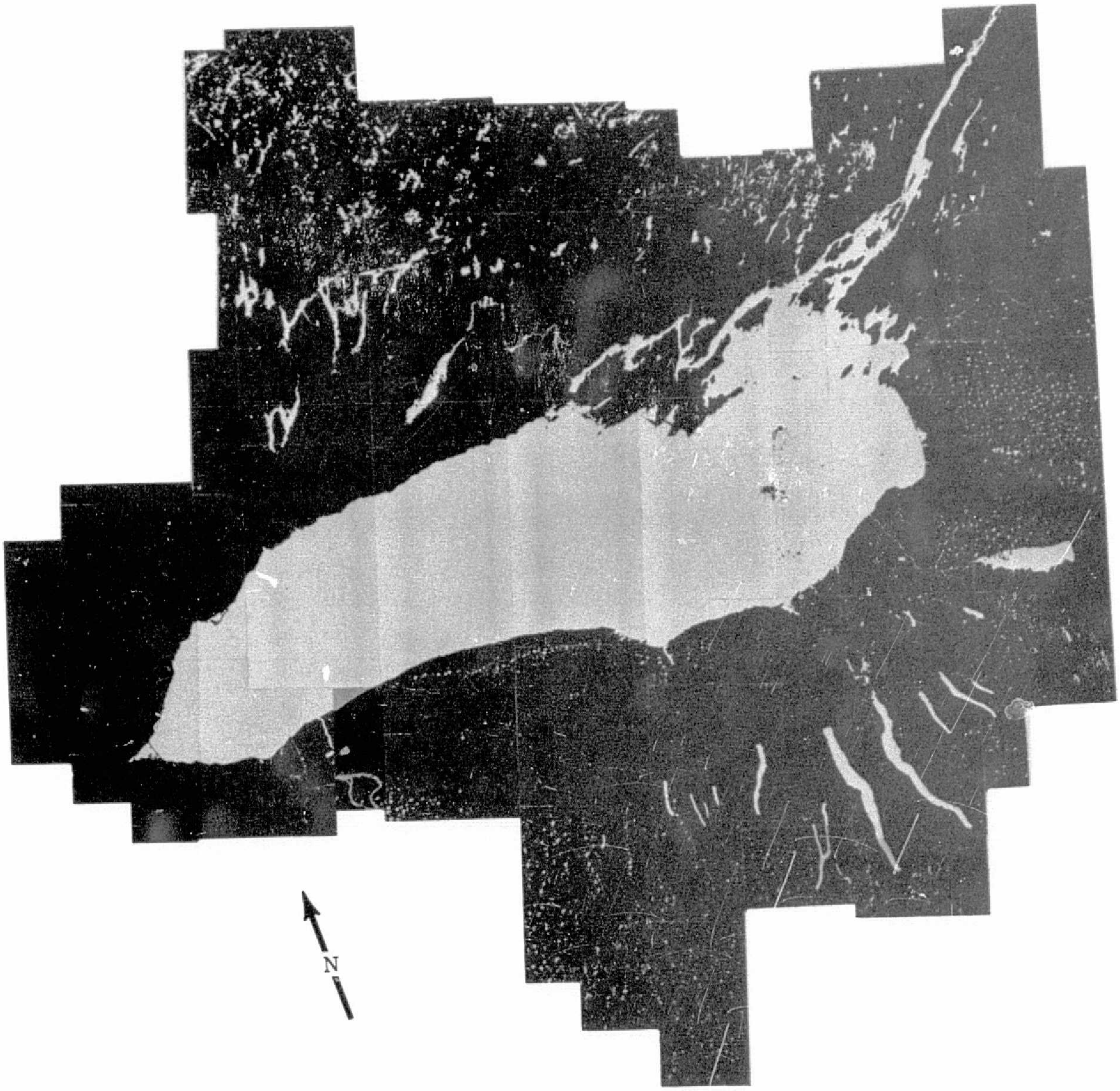
(a) Dark-Level Corrected Image

FIGURE 12. ANALOG IMAGES OF LAKE ONTARIO BASIN (Continued)



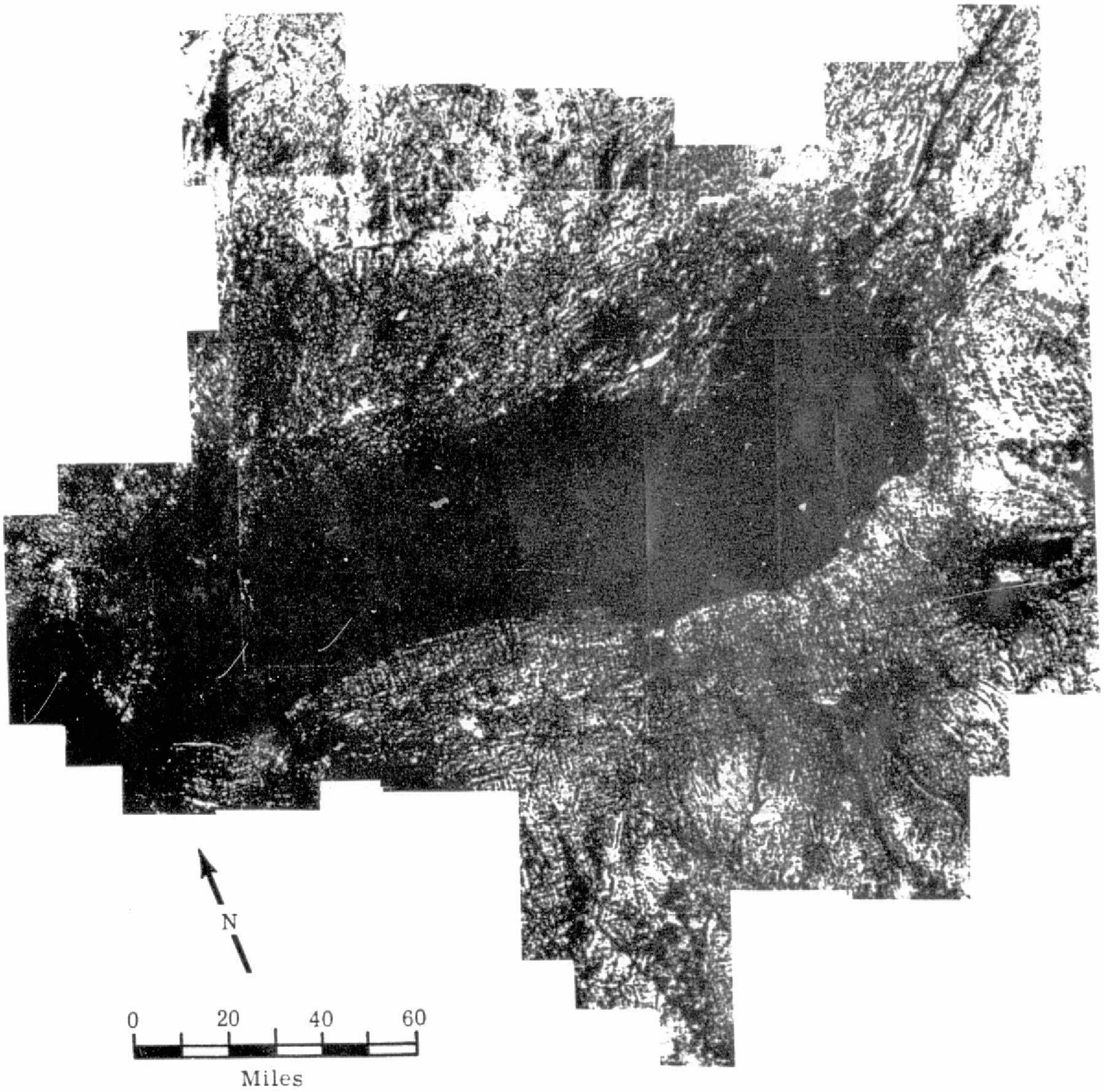
(b) Cloud Distribution (White)

FIGURE 12. ANALOG IMAGES OF LAKE ONTARIO BASIN (Continued)



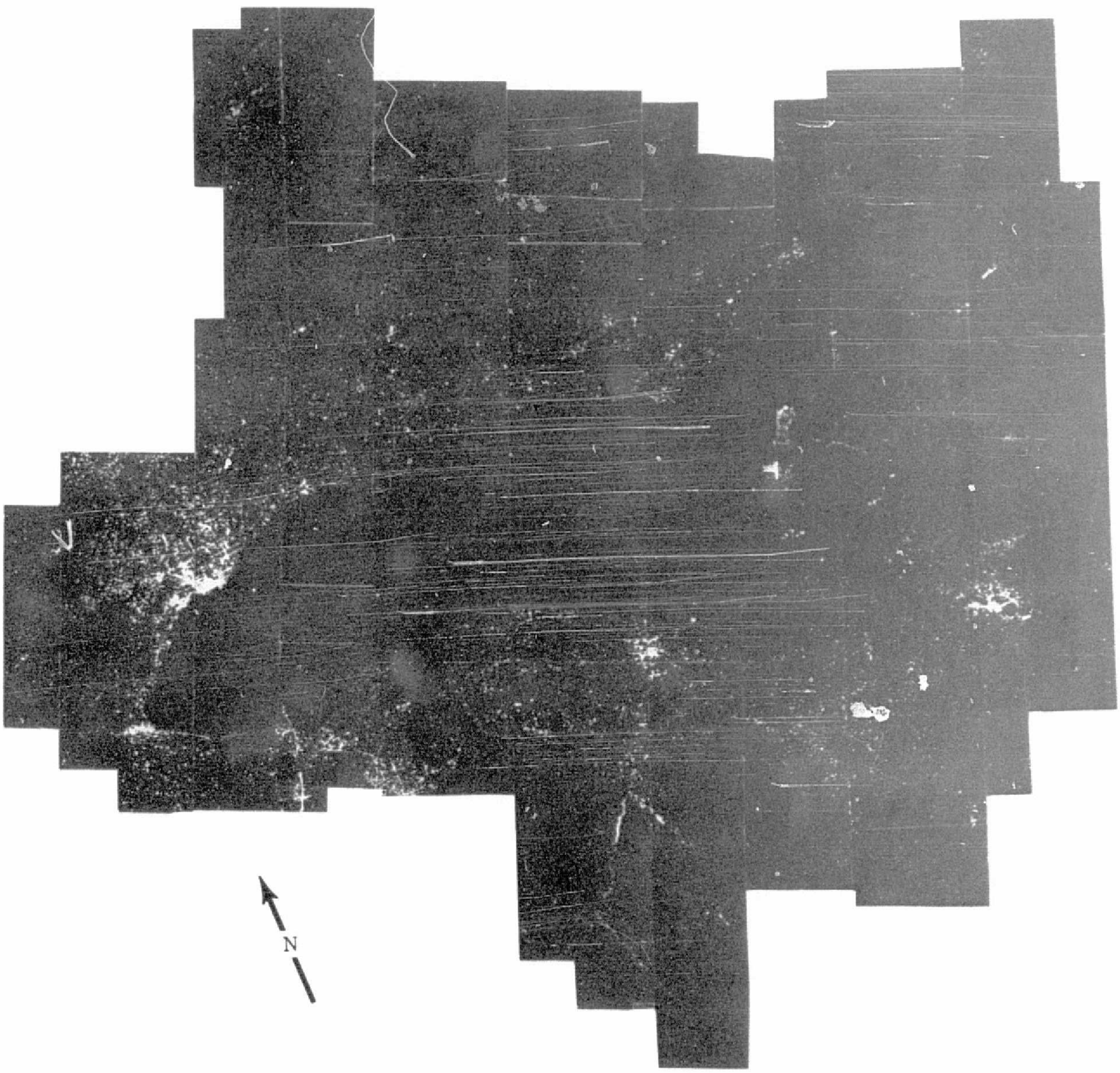
(c) Distribution of Surface Water (White)

FIGURE 12. ANALOG IMAGES OF LAKE ONTARIO BASIN (Continued)



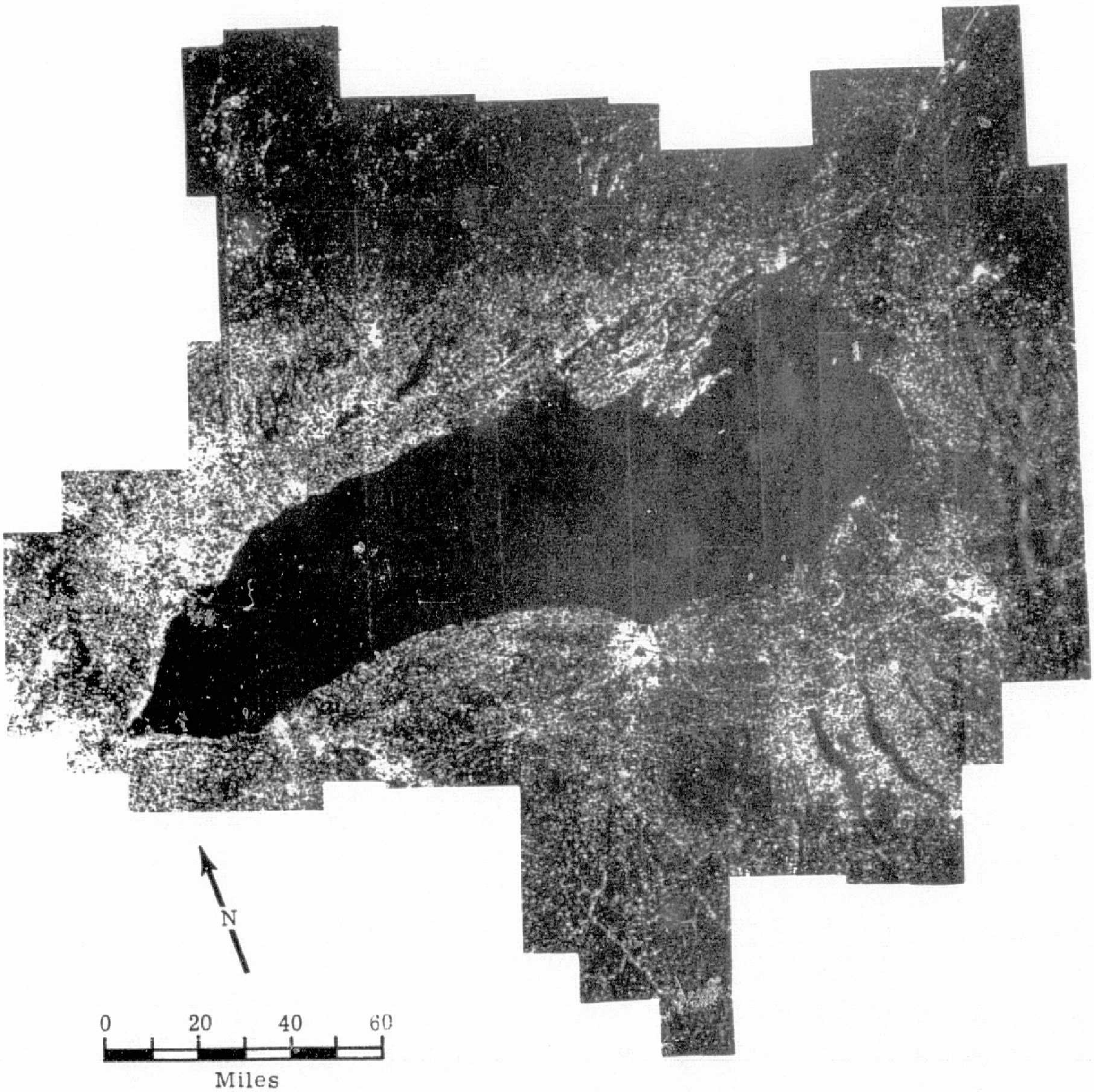
(d) Forest and Swamp Areas (White)

FIGURE 12. ANALOG IMAGES OF LAKE ONTARIO BASIN (Continued)



(e) Impervious Surfaces (Urban Centers and Bare Areas)

FIGURE 12. ANALOG IMAGES OF LAKE ONTARIO BASIN (Continued)



(f) Suburban and Bare Field Areas

FIGURE 12. ANALOG IMAGES OF LAKE ONTARIO BASIN (Concluded)

Because clouds were present in the scene, the first objective was to indicate their location and areal extent (Figure 12b). Clouds are indicated as white; non-obscured areas are black. From this image it can be seen that only a small proportion of the area was covered by small cumulus clouds.

Classification images of four major land-use categories, exclusive of clouds, have been produced and mosaicked. These are: (1) surface water; (2) forest and swamp vegetation; (3) urban areas; and (4) suburban and bare areas. Other images were also produced, but these show largely agricultural areas of unknown identity and are not reproduced here.

Figure 12c shows surface water for the processed portion of the basin. (All areas classified as water are white.) In this image, in addition to Lake Ontario and its outlet, the St. Lawrence River, the numerous lakes associated with the Canadian Shield in the north and the Finger Lakes country in the south are readily identified. However, the many small white dots in the eastern and southern portion of the image are cloud shadows, not water bodies. (Compare Figure 12b with Figure 12c.) Although some of the detail has been lost in the photo-reduction of this image from its original 47 × 45 cm size, narrow and extensive surface water features such as the Niagara River, the Kent River, and the Oswego River are clearly evident.

A major land-use category shown for the edited basin is forest and swamp (Figure 12d). Most of the forested areas occur as 20 to 80 acre farm woodlots and as natural forest growth in areas unsuitable for agriculture. The latter includes tree growth along the steep Niagara Escarpment in the western end of the basin and boreal forest of the Canadian Shield (northern and eastern portion of the basin). While the northern boreal forest area is extensive, examination of the imagery shows that it is not continuous, and many areas of bare rock outcrops and lakes break up this sparsely populated region. Extensive swamp areas such as the Big Swamp in Prince Edward County, south of Belleville, are also indicated.

Figure 12e shows the distribution of impervious materials over the basin. The major area of impervious materials is located at the commercial center of the city of Toronto. Certain linear features on the image have been identified with individual streets and highways. The Toronto International Airport, oil refineries, and a large automotive assembly plant (the Ford-Oakville Plant) are also identifiable in the Toronto area. Other urban centers identified are Hamilton (lower left), Rochester (lower center), Syracuse (lower right), and the northern extension of the Buffalo metropolitan area. Several small incorrectly identified areas occur over the eastern end of the lake and are produced by the occurrence of hazy cloud cover. Numerous isolated spots of recognition outside the urban centers are quarries, gravel pits, bare fields, and other areas where rapid surface runoff is expected.

Figure 12f shows the location of semi-impervious suburban and bare areas. The recognition (white) occurs in irregular rings around the major urban centers identified as impervious in

Figure 12e. In addition, many small spots located in largely agricultural areas correspond to bare areas or areas having relatively little vegetative cover. Several of these small recognition spots were found to be disturbed surfaces resulting from construction activities.

2.3.4 LAND USE STATISTICS

In addition to prints of the recognition of the several land-use classes illustrated in Figure 12, the analog computer gave a count related to the total number of scene elements recognized. The percent of the total area in each land-use class was then the total number of counts divided by the recognition counts for that class. By using topographic maps, an areal determination of the total area processed was made. Table 6 lists both the percentage of the total area processed for several classes and the corresponding area of each class. As mentioned previously, portions of the Lake Ontario basin were obscured by clouds and were not processed. In addition, there were several editing constraints as discussed in Section 2.3.2. These factors made direct determination of the areas of terrain classes for the entire Lake Ontario basin impossible. However, we calculated areas of several terrain classes on a percentage basis. These are also given in Table 6. Our calculations were based on published data for the total area of the basin and on the assumption that, except for water and impervious surfaces, the areas outside the processed part of the basin had the same proportions of land use as did the processed portion.

3
REMOTE SENSOR DATA AND PROCESSING

Applications of remote sensing technology to hydrology require a knowledge of the sensor data collection characteristics, the various methods of data processing and interpretation, and the concepts of radiation physics which allow useful interpretation of the data products. The following section is concerned with some technical aspects of this IFYGL remote sensing program.

3.1 THE ERTS-1 SYSTEM

The Earth Resources Technology Satellite-1 is the first orbiting satellite devoted to the collection of earth resources data. These data are available at nominal cost to anyone who has a desire to use them. However, the ERTS-1 data products are the outputs of a sophisticated sensor and data-transmission technology. Appreciation of their information potential requires some understanding of the manner in which the data are collected, stored, and subsequently played back.

TABLE 6. AREA ESTIMATES OF LAND-USE CLASSES FOR THE LAKE ONTARIO BASIN. Figures are based on the analog recognition of ERTS-1 data of 19-21 August 1972.

	Area Recorded (km^2)		Entire Basin (km^2)
Surface Water	20,267	(23.7%)	20,267
Forest and Swamp	11,557	(13.5%)	13,932
Impervious (Urban)	1,484	(1.7%)	1,484
Suburban and Bare	1,881	(2.2%)	2,432
Clouds	1,454	(1.7%)	-
Other (Agriculture and Idle)	48,871	(57.1%)	51,317
TOTAL	85,514	(100%)	89,873

Detailed information concerning the mechanics and operation of ERTS-1 is available in the ERTS Data Users Handbook [36]. Included here is a brief summary of those aspects of the system which determine data characteristics and affect data processing requirements. In particular, it is important to be aware of the large amounts of quantitative data which are obtained by ERTS. This large volume of data makes some form of machine processing desirable for a variety of applications. For hydrological purposes, different processing procedures provide a wealth of information, but the processing procedures must be geared to specific information requirements. Four approaches to data processing are discussed in Section 3.2 in order of increasing complexity and sophistication.

3.1.1 SATELLITE ORBIT AND COVERAGE

ERTS-1 was launched into near-polar sun-synchronous orbit on 23 July 1972. The circular 920 km orbit allows completion of 14 revolutions of the earth per day, with the same pass repeated once every 18 days. This means that the same geographical coverage (within 32 km) is obtained at nearly the same local time (9:30 a.m.) every 18 days, irrespective of weather or terrain conditions. A typical ground coverage path is oriented in a direction approximately 10° west of due south as the satellite proceeds from north to south on its data collection (sunlit) leg of the orbit.

The primary observation system of the ERTS-1 is a multispectral scanner (MSS). Using an oscillating mirror, the MSS records a 185-km wide swath perpendicular to the ground path of the satellite. Solar energy reflected from the earth is recorded by four sensor arrays of six detectors each--one array for each spectral band. The detector outputs are sampled, encoded to six bits, and transmitted to earth in a continuous data stream of 15 megabits per second. At the NASA Ground Data Handling System facility the data are processed into images and computer compatible tapes (CCT's). The ERTS images utilized for this IFYGL-Lake Ontario investigation were obtained during the period 19 August 1972 to 17 June 1974. Computer processing and analysis of CCT's were limited to data obtained during the period 19-21 August 1972.

The ERTS-1 required four passes on four consecutive days to record the surface conditions in the 90,000 km^2 Lake Ontario basin. Progressing from east to west, successive passes allow a 75-km (40%) overlapping coverage from one day to the next at latitude 44° N. ERTS-1 data collected from the 19-21 August period were largely cloud-free over all but the very easterly portion of the basin--a condition not achieved again to date. Unfortunately, a 5180 km^2 portion of the eastern end of the basin was entirely obscured by clouds on 18 August 1972 and data from this area were not processed.

3.1.2 ERTS-1 SPECTRAL AND SPATIAL RESOLUTION

The ERTS-1 multispectral scanner system views the earth in four different spectral bands in the visible and near-infrared wavelength range. The shortest wavelength bandpass records light in the 0.5-0.6 μm (green) region. Similarly the other three ERTS bands record light in the 0.6-0.7 μm (red), 0.7-0.8 μm (near IR), and 0.8-1.1 μm (near IR) wavelength regions. These four bands are designated ERTS MSS bands 4 through 7, respectively. In this way the same scene can be displayed in four images, each image recording gray scales which are characteristic of scene features in that spectral band and which may be different from other bands.

The instantaneous-field-of-view, determined by the detector size, subtends a square area on the ground of 79 meters on a side. This ground area is sometimes called a pixel (picture element). Long-track scan fields-of-view are contiguous, rendering a pixel resolution limit of 79 meters in the long-track direction. However, the signals from the detectors are sampled every 9.95 μsec in the cross-track direction, providing a cross-track pixel dimension of 57 meters. Thus the nominal spatial representation of a pixel is a rectangular area of 57 by 79 meters (0.44 hectares).

The ERTS-1 along-track motion at the subsatellite point is 6.47 km/second. ERTS-1 records 261,783 samples of a 1158 km^2 area in one second (more than 7.4 million samples per standard 185 km × 178 km ERTS frame). Thus, while by aerial photographic standards the ground resolution of ERTS is coarse, the system records very large amounts of data from immense geographic areas.

As a result of this rather coarse spatial resolution, an object or feature must have at least twice the dimensions of a pixel to insure its being recorded as a single entity. Because the ERTS multispectral scanner integrates the reflected radiation within each pixel, pixels which contain small features or those that include edges of several features do not represent a single entity. Frequently pixels contain several terrain classes which makes their positive identification difficult. For example, a pixel containing a portion of a road will also record the gravel shoulder, perhaps a grassy median, and some buildings or edges of fields. Therefore roads other than major highways are not identifiable from ERTS data. A square 40-acre field containing a uniform crop will have at least 25 pixels unaffected by heterogeneous boundary pixels, thus insuring resolution of that feature. (For further discussion of the ERTS resolution and pixel boundary characteristics see Malila, et al. [37].)

3.1.3 DATA PRODUCTS

ERTS-1 data products are available in several different formats. These include 70-mm and 9.5-inch black and white image transparencies and prints, false color composite image transparencies and prints, and digital computer compatible tapes (CCT's). Image transparencies and prints show areas of 185 × 178 km and are the most immediately useful products. While further processing is possible using these images (see Section 3.2.3), computer compatible tapes provide the greatest opportunity for quantitative data analysis. After computer processing of the CCT's, the results may be printed out in image format.

3.1.4 SPECTRAL SIGNATURES

Analysis of selected portions of several CCT's were undertaken to determine the characteristics of the ERTS-1 data. Nearly 100 spectral signatures from a variety of water and terrain surfaces in the Lake Ontario basin were analyzed. A signature is a set of values (statistical means, variances, and covariances) which, when taken together, describe the spectral characteristics of selected locations in the recorded scene. The selected locations, comprising several to many pixels, are areas of particular terrain or water features. These locations, known as "training sets," are representative of such terrain features as deciduous forest, gravel quarry, and surface water. Thus, hopefully, the signatures are also representative of these features, and are used to identify scene features from unknown areas. The more unique the several signatures, the easier and more reliable will be the identification. Inevitably some features are so spectrally similar in all ERTS-1 bands that they cannot be differentiated. Dark cloud shadows and surface water areas fall into this class. All analyzed signatures were obtained from either the Rochester, New York or the Oakville, Ontario portions of the basin. A significant characteristic of vegetation signatures is the increase in signal values between ERTS MSS bands 5 and 6, which is probably related to the normal increase in vegetation reflectance between the 0.60 to 0.70 μm (chlorophyll absorption) band and the 0.70 to 0.80 μm (foliar reflectance) band. Non-vegetated terrain classes show no such increase.

If ranges of individual signature values are plotted on graph paper they frequently overlap within an ERTS band. As a result, while quarries and bare soil are distinguishable (characterized by different value ranges) from water and vegetation in MSS-4 and MSS-5, they are identical with vegetation in MSS-6 and MSS-7. Also, surface water, indistinguishable from vegetation in MSS-4 and MSS-5, is distinct from vegetation in MSS-6 and MSS-7. No one spectral band provides unambiguous separation of all terrain classes on the basis of ERTS-1 signal values. Information is required from several of the ERTS bands to positively identify most of these terrain features.

Band correlations were computed to determine the most useful bands for distinguishing vegetation and non-vegetation classes. Mean values for the four ERTS bands were listed as variables 1 through 4 and correlation coefficients were computed for each of the pairwise ERTS band combinations. The 12 signatures used included surface water, bare soil, crop, marsh, pasture, hardwood, conifer, and mixed-forest classes. Table 7 shows these correlations.

TABLE 7. CORRELATION COEFFICIENTS FOR FOUR ERTS MSS BANDS USING TWELVE SPECTRAL SIGNATURES FROM THE OAKVILLE REPRESENTATIVE BASIN

	MSS-4	MSS-5	MSS-6	MSS-7
MSS-4	1.0000			
MSS-5	0.9589	1.0000		
MSS-6	0.2384	0.1806	1.0000	
MSS-7	0.0653	-0.0000	0.9792	1.0000

	MSS 6/5	MSS 7/5	MSS 7/6
MSS 6/5	1.0000	0.9963	0.8993
MSS 7/5		1.0000	0.9175
MSS 7/6			1.0000

The ERTS visible bands (MSS-4 and MSS-5) are highly correlated with a coefficient of 0.9589; the ERTS near-IR bands (MSS-6 and MSS-7) are also highly correlated, with a coefficient of 0.9792. MSS-4 and MSS-5, however, are only slightly correlated with MSS-6 and MSS-7. These facts suggest that for these 12 terrain signatures from this data set, the greatest non-redundant spectral information occurs between the visible and the near-IR bands.

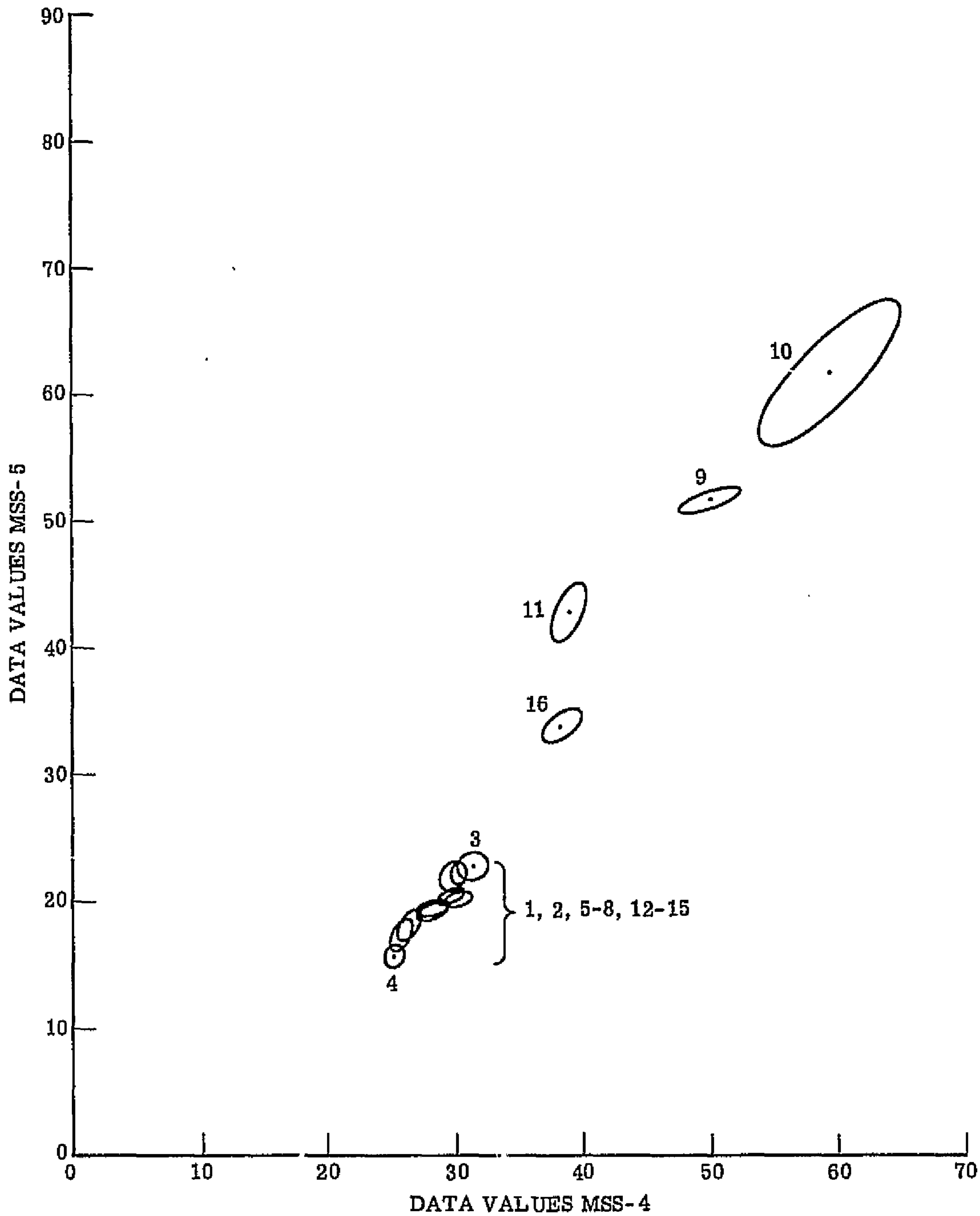
Another way to look at these signature characteristics is in the form of two dimensional graphs which show the relationships of the various terrain features in two spectral bands. Figure 13 shows the distribution of one-standard deviation covariances for a number of terrain classes. The signature classes are listed in Table 8. These figures show the six possible two-band pairs of the ERTS bands. The potential for distinguishing the various features on the basis of ERTS data is suggested by the separation of the ellipses. For example, in Figure 13a the four non-vegetated terrain classes are distinct from the water and vegetation features. Using either MSS-4 or MSS-5, separation of the bare terrain classes from vegetation and water features appears feasible while separation of water, vegetation, and residential areas would be unlikely. In MSS-4 the bare soil and highway have approximately the same values (~40) but MSS-5 separates the two.

The degree to which the signature ellipses occur along a line radiating from the origin of the graph suggests the degree of correlation between bands (i.e., departures from a straight line indicate lack of correlation). Figure 13a shows that the signals for the two visible bands are positively correlated. Figure 13b shows an equally high positive correlation between near-IR bands, but better separation of water and vegetation signatures and worse separation of vegetated and and non-vegetated terrain classes.

Figures 13c through 13f provide greater separation of the various signatures than the previous two-band combinations. The signatures are not arrayed along a straight line from the origin. These four plots show the distribution of signatures for combinations of visible wavelengths (MSS 4 and 5) with near-IR wavelengths (MSS 6 and 7).

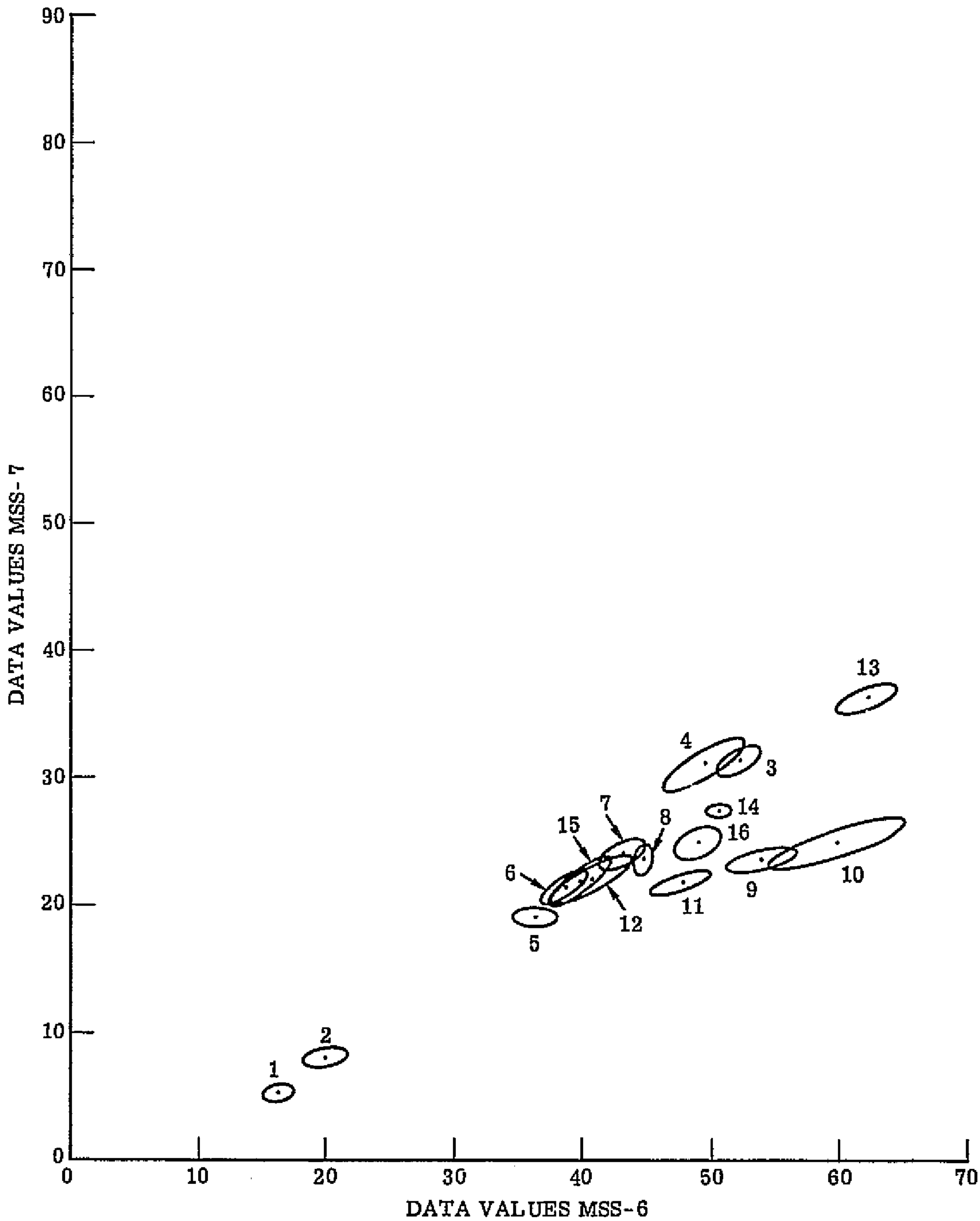
Figures 13 c and 13d are nearly identical, as are Figures 13e and 13f. The major differences are in the range of signature values along the ordinate. ERTS band MSS-6 has a greater total range of values than does ERTS band M SS-7, although the distributions of the various signatures are similar.

We selected bands MSS-5 and MSS-7 as the best two-band combination for separating these signatures. The significance of this selection is discussed in Section 3.2.



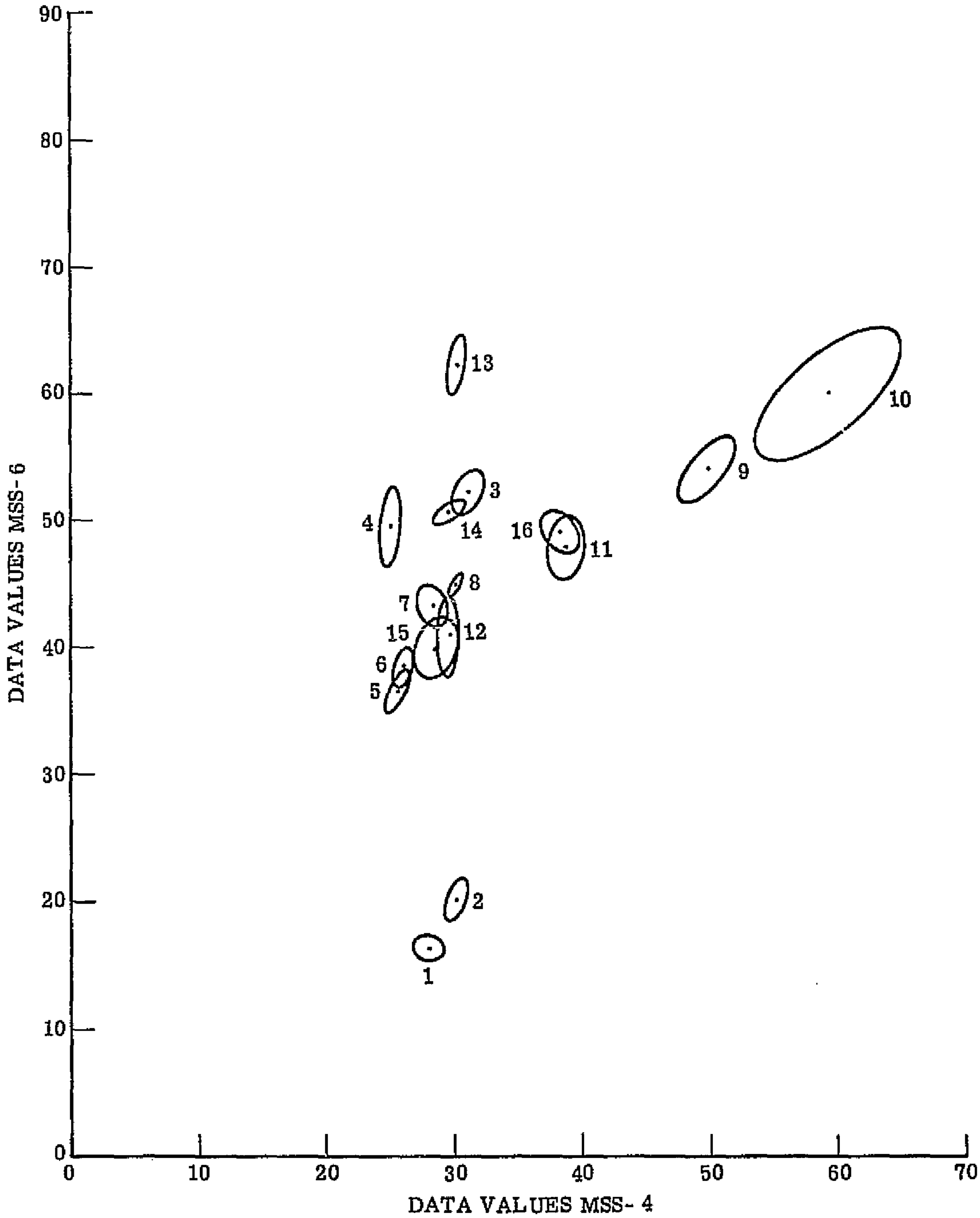
(a) ERTS MSS Bands 4 and 5

FIGURE 13. COMPARISON PLOTS OF REPRESENTATIVE SIGNATURES FROM THE EAST AND MIDDLE OAKVILLE CREEKS BASIN. Refer to Table 8 for identification of signatures. (Continued)



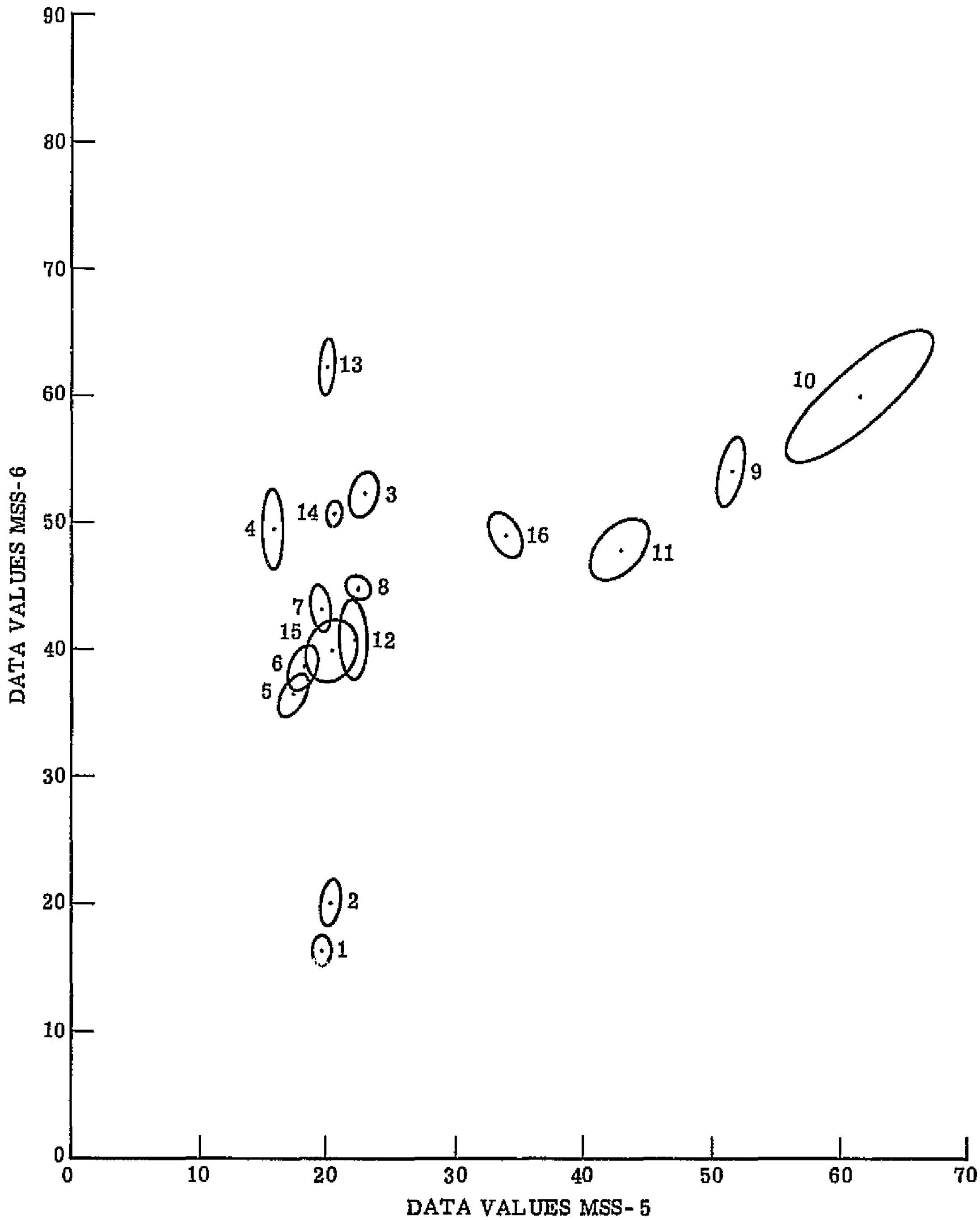
(b) ERTS MSS Bands 6 and 7

FIGURE 13. COMPARISON PLOTS OF REPRESENTATIVE SIGNATURES FROM THE EAST AND MIDDLE OAKVILLE CREEKS BASIN. Refer to Table 8 for identification of signatures. (Continued)



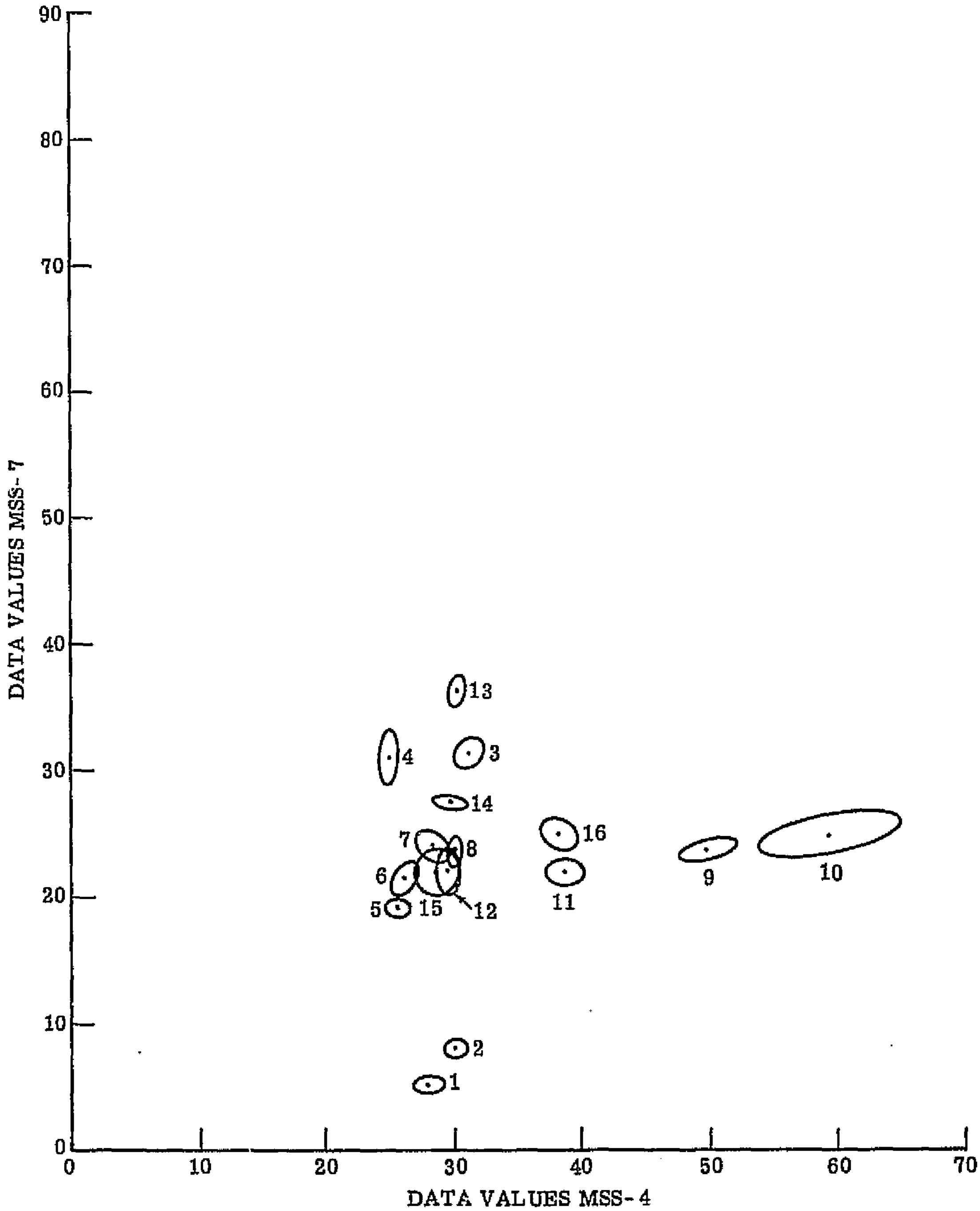
(c) ERTS MSS Bands 4 and 6

FIGURE 13. COMPARISON PLOTS OF REPRESENTATIVE SIGNATURES FROM THE EAST AND MIDDLE OAKVILLE CREEKS BASIN. Refer to Table 8 for identification of signatures. (Continued)



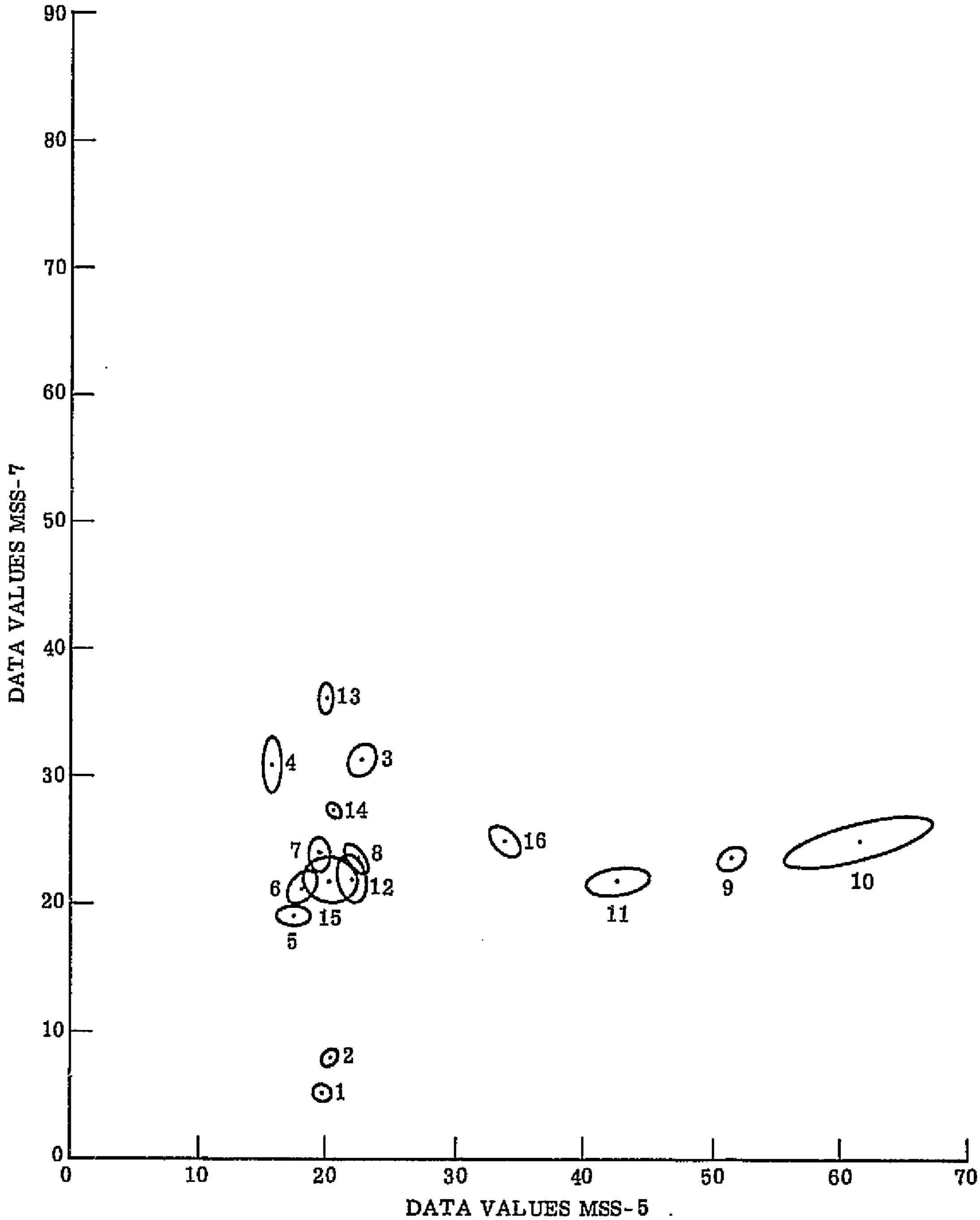
(d) ERTS MSS Bands 5 and 6

FIGURE 13. COMPARISON PLOTS OF REPRESENTATIVE SIGNATURES FROM THE EAST AND MIDDLE OAKVILLE CREEKS BASIN. Refer to Table 8 for identification of signatures. (Continued)



(e) ERTS MSS Bands 4 and 7

FIGURE 13. COMPARISON PLOTS OF REPRESENTATIVE SIGNATURES FROM THE EAST AND MIDDLE OAKVILLE CREEKS BASIN. Refer to Table 8 for identification of signatures. (Continued)



(f) ERTS MSS Bands 5 and 7

FIGURE 13. COMPARISON PLOTS OF REPRESENTATIVE SIGNATURES FROM THE EAST AND MIDDLE OAKVILLE CREEKS BASIN. Refer to Table 8 for identification of signatures. (Concluded)

TABLE 8. SIGNATURES (IN ORDER) FOR THE TWO DIMENSIONAL PLOTS OF FIGURE 13

1. Water-1
2. Water-2
3. Hardwood-1
4. Hardwood-2
5. Pine
6. Mixed Conifer-Hardwood
7. Shrub Swamp
8. Marsh
9. Quarry (sand/gravel)
10. Quarry (limestone)
11. Ploughed Field (<10% cover)
12. Pasture (10-60% cover)
13. Corn (80-100% cover)
14. Agriculture/Idle (60-80% cover)
15. Old Urban
16. Highway

3.1.5 PREPROCESSING

Terrain signatures vary with the season, changes in sensor response, and atmospheric transparency. The changes with sensor response and atmosphere can be significant over regional areas and short time periods. Figure 14 shows a general decrease in average values for the four ERTS bands for the same areas from one day to the next. The training sets were obtained from overlapping ERTS-1 data in the Rochester, New York area. The general decrease in average values indicates that data collected for the same areas on different days may not be comparable. For this reason ERTS-1 data in this project were dark-level corrected.

Dark-level correction is a preprocessing technique whereby those pixels in a data set which show the lowest values in each band are identified. These low values are assumed to represent scene objects having nearly zero radiances. (They may be areas of shadow or perhaps water bodies.) The values recorded by ERTS-1 for the darkest objects are assumed to represent the atmospheric path radiance; these values are then subtracted from all pixels recorded for that region on that day. The result of this relative calibration procedure is that ERTS-1 data may be reliably compared from one day to the next, and the same quantitative feature identification criteria may be applied to all of the data.

3.2 ERTS IMAGE PROCESSING

This section illustrates several kinds of images derived from ERTS data-single spectral band images, two-band images, three-band images, and several types of thematic images. The thematic images illustrate the selective extraction and quantification of physiographic information.

3.2.1 SINGLE BAND IMAGES

The simplest method of portraying the ERTS data is to photograph a cathode ray tube (CRT) image of the data in each spectral band. Each image shows the scene variations for that band in continuous grey tones. Normally playback images are adjusted such that the full dynamic range of the data is recorded over the linear sensitivity range of the photographic film. This approach is required if techniques of film densitometry are used with the transparencies to obtain semi-quantitative information.

Contrast stretching and level slicing are two techniques frequently used with single-band data. Contrast stretching consists of selecting a limited range of data values to play back over the linear sensitivity range of the film. In other words, when only a certain portion of the total range of data values contains the information of interest, the CRT image is adjusted so that only that portion of the range is represented by image tones of dark to light. Data values outside the selected range will appear as either uniformly dark or light and no image contrast information will be available on the image for these areas.

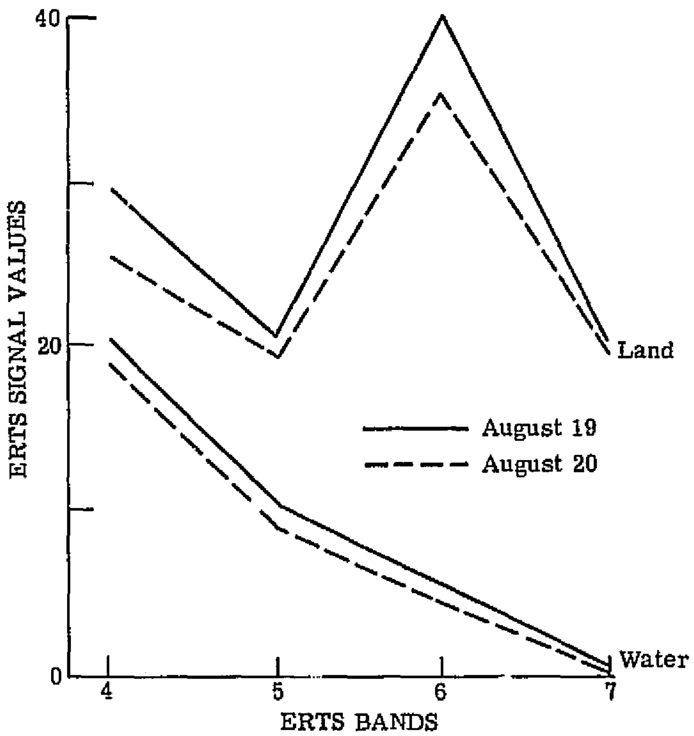


FIGURE 14. ERTS SIGNATURES FOR THE SAME AREA NEAR ROCHESTER, NEW YORK ON 18 AND 19 AUGUST 1972

Water in Lake Ontario is characterized by signal values between 15 and 30 in MSS-4. As a consequence, variations in water quality (optical turbidity) are likewise represented by this limited range. In Figure 15a the CRT was adjusted to enhance the water turbidity patterns evident in MSS-4. Most of the image variation has been lost for the land area.

Figure 15 shows the result of a level slicing technique for the ERTS data values which fall within a selected range. All data values occurring below a threshold were printed out as white; all values above that threshold are black. In this case, all water areas are white while land areas are dark. The use of the level slicing technique requires that features of interest are characterized by unique data values in one spectral band. The number of features for which this assumption holds true is limited and depends to some extent on the time of year and quality of data collection.

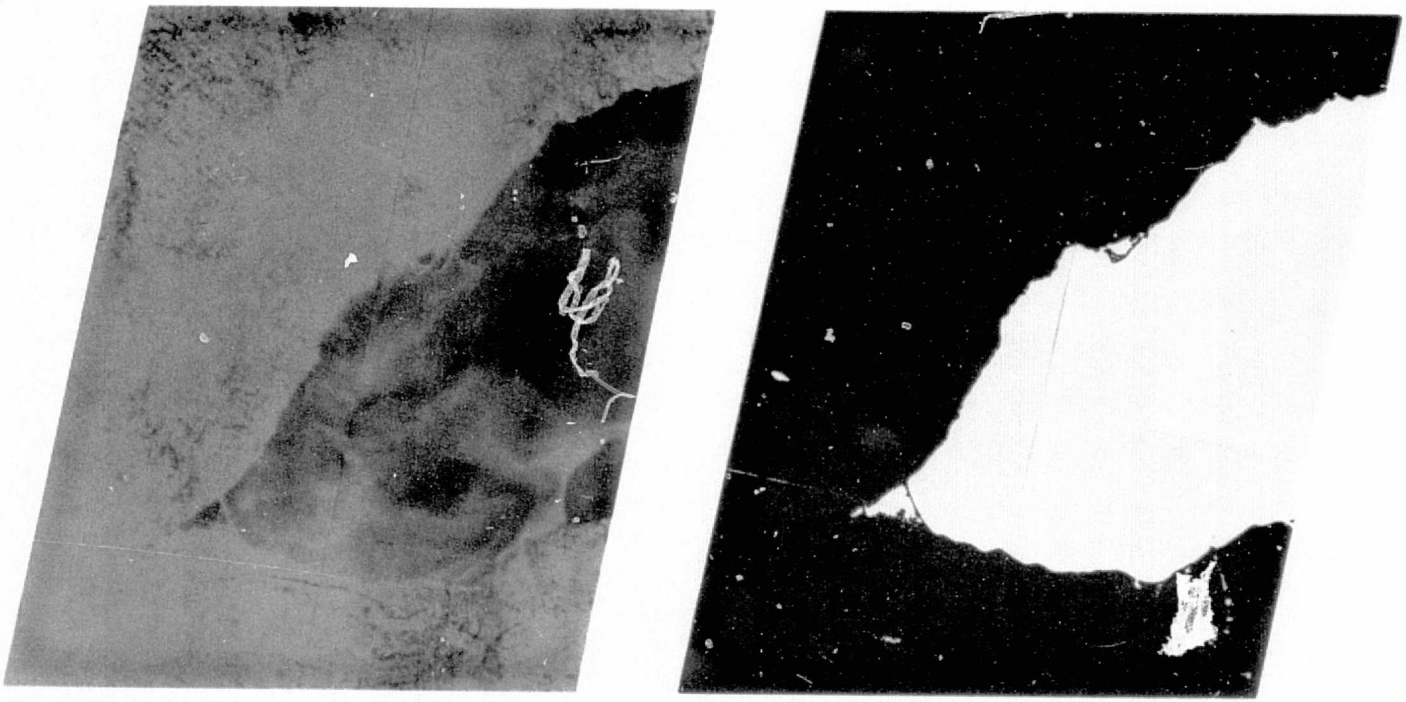
With level slicing, the proportion of the scene and number of pixels classified as falling within the threshold range can be tabulated. As the level-sliced image is displayed, a digital counter keeps an accurate running total of the pixels which are classified, regardless of their location or irregular distribution. This tabulating capability gives computer processing its ability to provide statistical summaries of the area and location of different features with or without the recording of the actual image.

3.2.2 TWO-BAND IMAGES

With two bands of multispectral data, several relatively simple processing procedures were used. Data recorded on magnetic tape may be added, subtracted, or divided to produce new images. An additive image grey scale would be represented by a diagonal line through the origin of a two dimensional plot of signal values in two different bands (Figure 16), with the grey tones increasing linearly from the origin. Subtractive images are similar to additive images, except that the grey scale is oriented along a line perpendicular to the additive image. The numbers are relative and avoid consideration of negative values. The ratio image, represented by Figure 16c, produces a non-linear grey scale along an arc between the two axes. Points of equal values fall on lines radiating from the origin (see Ref. [38]).

In this investigation additive and subtractive images were not produced. Ratio processing was undertaken for both ERTS and aircraft data. Images of the six ratio combinations help to confirm conclusions based on the comparison of limited spectral signatures in Section 3.1.4; that is, that a two-band combination of ERTS MSS bands 5 and 7 provided the best simple separation of a variety of terrain features.

Examples of ERTS-1 images of the Belleville-Picton area illustrate the results of two-band ratio processing for the entire basin. This 92 × 100 km area includes a number of different terrain features, including urban, marsh, swamp, agricultural fields, lakes and forest land.



(a) Contrast Stretching of ERTS MSS-5

(b) Level Slicing of ERTS MSS-7

FIGURE 15. COMPARISON OF SINGLE-BAND IMAGES FOR WESTERN LAKE ONTARIO

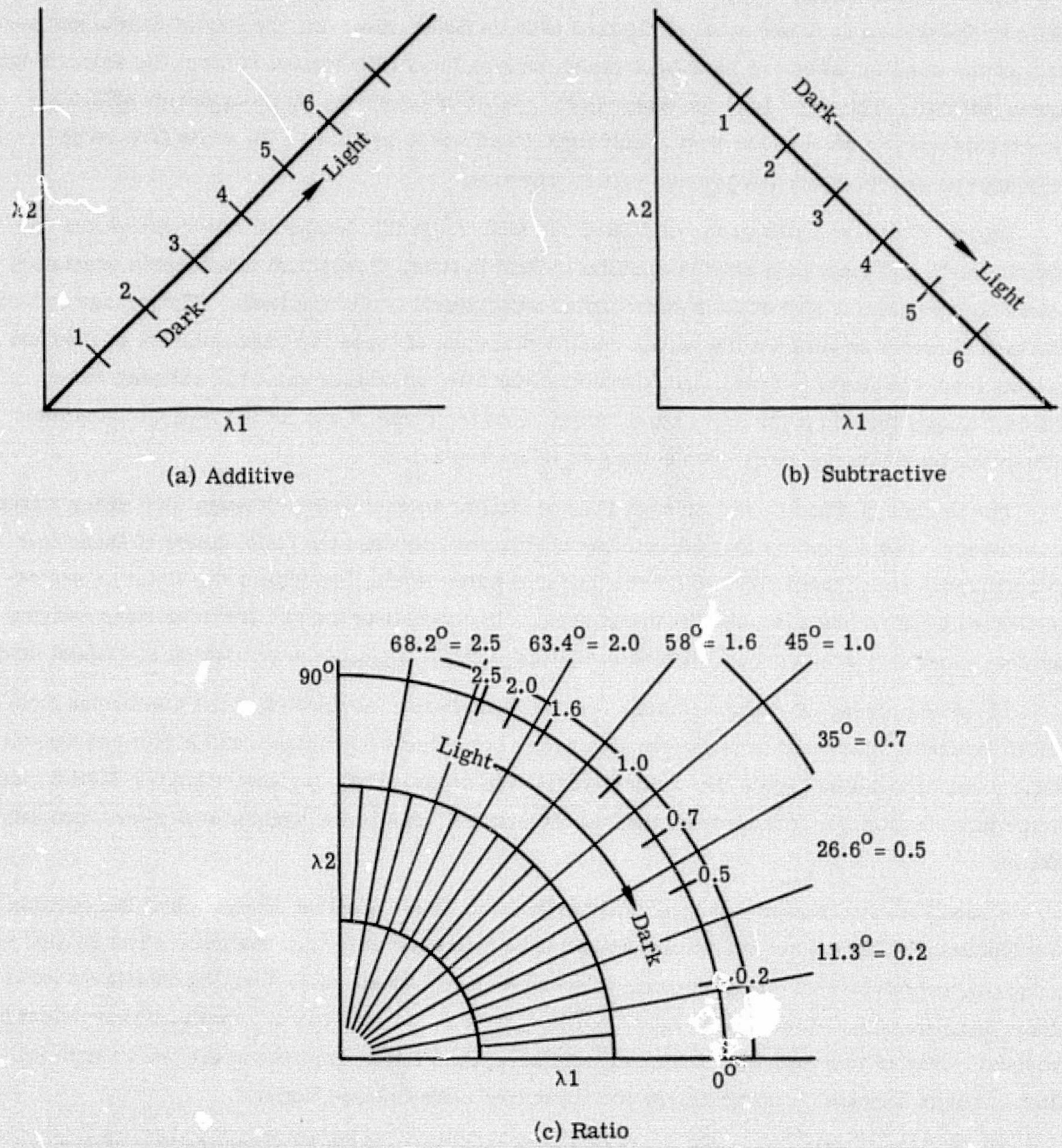


FIGURE 16. COMPARISON OF CONTRAST VARIATIONS ASSOCIATED WITH TWO-BAND PROCESSING

Figure 17a is a ratio image of MSS bands 4 and 5. This ratio image shows the major portion of Lake Ontario as dark and most of the land area as light. However, the Bay of Quinte and several of the smaller lakes are also light-toned, making their differentiation from the adjacent land areas difficult. This light tone for water is the result of relatively large values in MSS-5 indicating turbid water. Most of the very small light-toned areas are bare soil, while five large irregular areas (circled) are lowland cattail marshes.

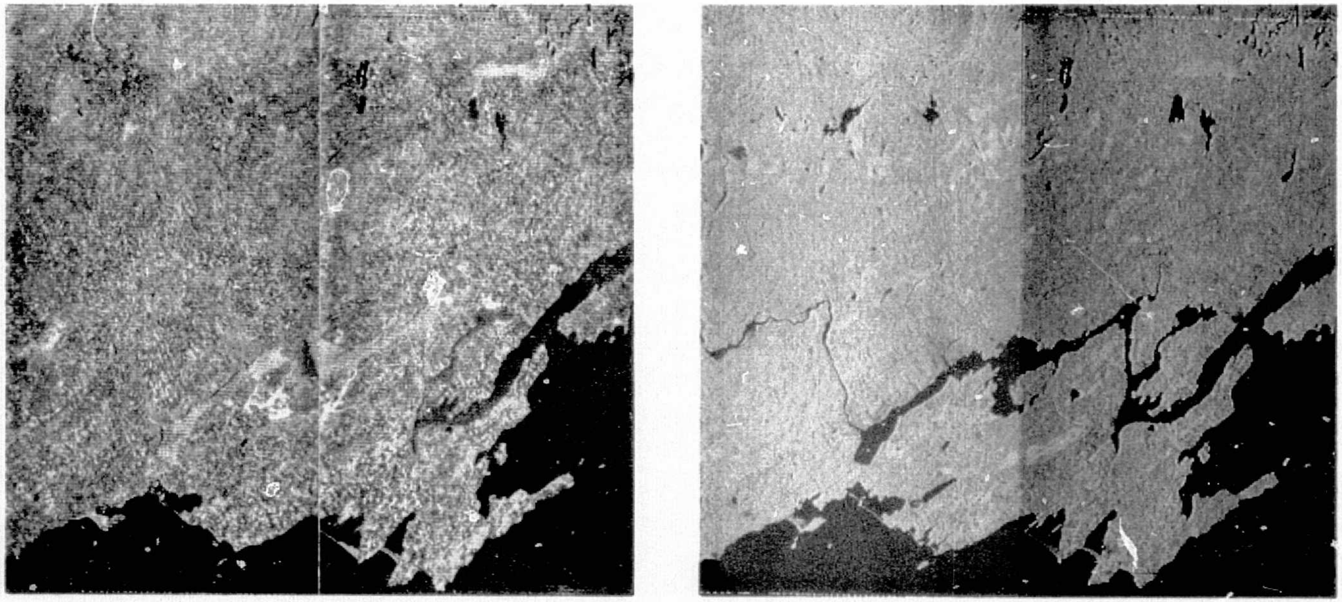
Figure 17b is the ratio image of MSS-6 and MSS-7. In this image all water areas are uniformly dark, and most land area is medium to light in tone. Forest and other green vegetation areas appear slightly lighter than surrounding agricultural and urban lands. This image confirms the high correlation between the values recorded in each of these two bands (0.9792 in the case of data from the Oakville area), and, therefore, the little advantage gained in ratioing them. Table 7 shows the computed correlation coefficients for three of the ERTS ratio combinations. These are based on the signatures discussed in Section 3.1.4.

The images of Figures 17c through 17f are similar to each other although they differ slightly in contrast. Table 7 shows that correlation coefficients between the ratio values of these four combinations range from 0.899 to 0.996. In each, water areas, including Lake Ontario, are represented by dark tones, as are the urban areas. In contrast to the two previous ratio images, natural vegetation areas appear distinctively light against most of the remaining cultivated land.

These visible-to-IR ratioed images are the most easily interpreted of the continuous tone ERTS images. Water and green vegetation areas are clearly identifiable and urban and agricultural areas are distinct from the natural vegetation areas. Ratio images of MSS-7/MSS-5 clearly distinguish four major terrain features: water, natural vegetation, agricultural areas, and urban areas.

A level-slicing routine was implemented with the ERIM Spectral Analysis and Recognition Computer (SPARC) for automatic classification of a number of terrain features. The SPARC is an analog prototype high-speed computing system. It is capable of performing likelihood ratio decision processing with up to 12 spectral bands of data at the rate of more than 10,000 decisions per second. After initial selection of decision criteria, the SPARC requires about one hour to produce a single-feature thematic-image for the entire Lake Ontario basin.

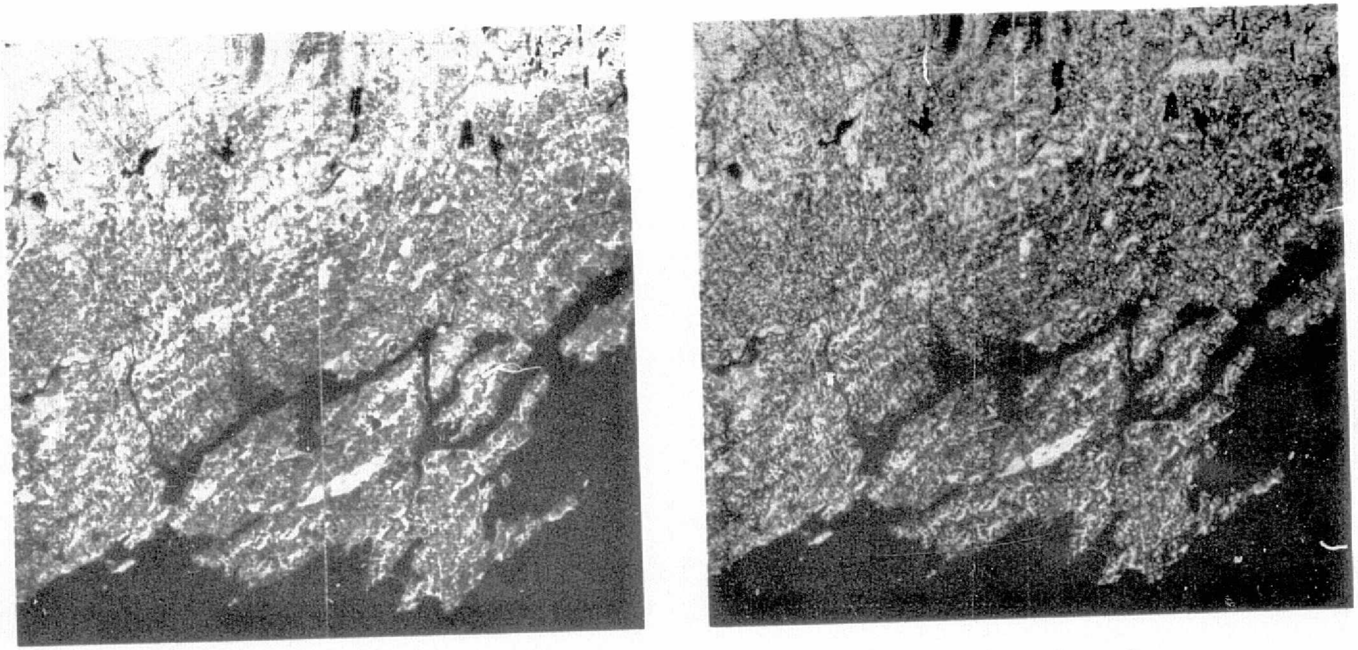
The first step of the decision process was to level slice MSS-7 for recognition of surface water. All subsequent processing was performed on the remaining "non-water" data. Input data to the second step were ratios of ERTS bands MSS-5 and MSS-6, and bands MSS-5 and MSS-7. Analysis of these two ratios indicated coefficients of correlation between these two ratios of 0.996. Subsequently, a number of scene features were classified using a likelihood ratio decision rule. The results obtained using this procedure are shown for the western-most portion of the basin. Figure 18 shows two composite recognition images for a 35 × 65 km area between the



(a) MSS-5/MSS-4

(b) MSS-7/MSS-6

FIGURE 17. COMPARISON OF ERTS RATIO IMAGES OF BELLEVILLE-PICTON AREA OF ONTARIO. Portion of ERTS Frame No. 1028-15290, 20 August 1972. (Continued)

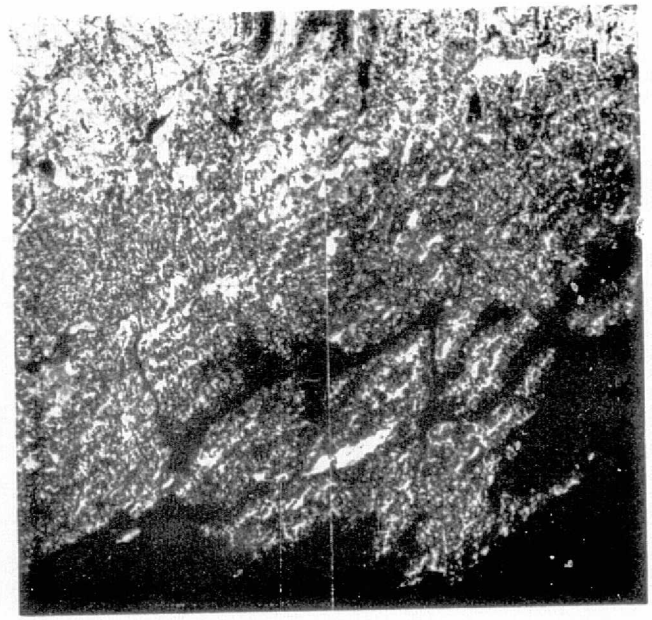


(c) MSS-6/MSS-4

(d) MSS-6/MSS-5

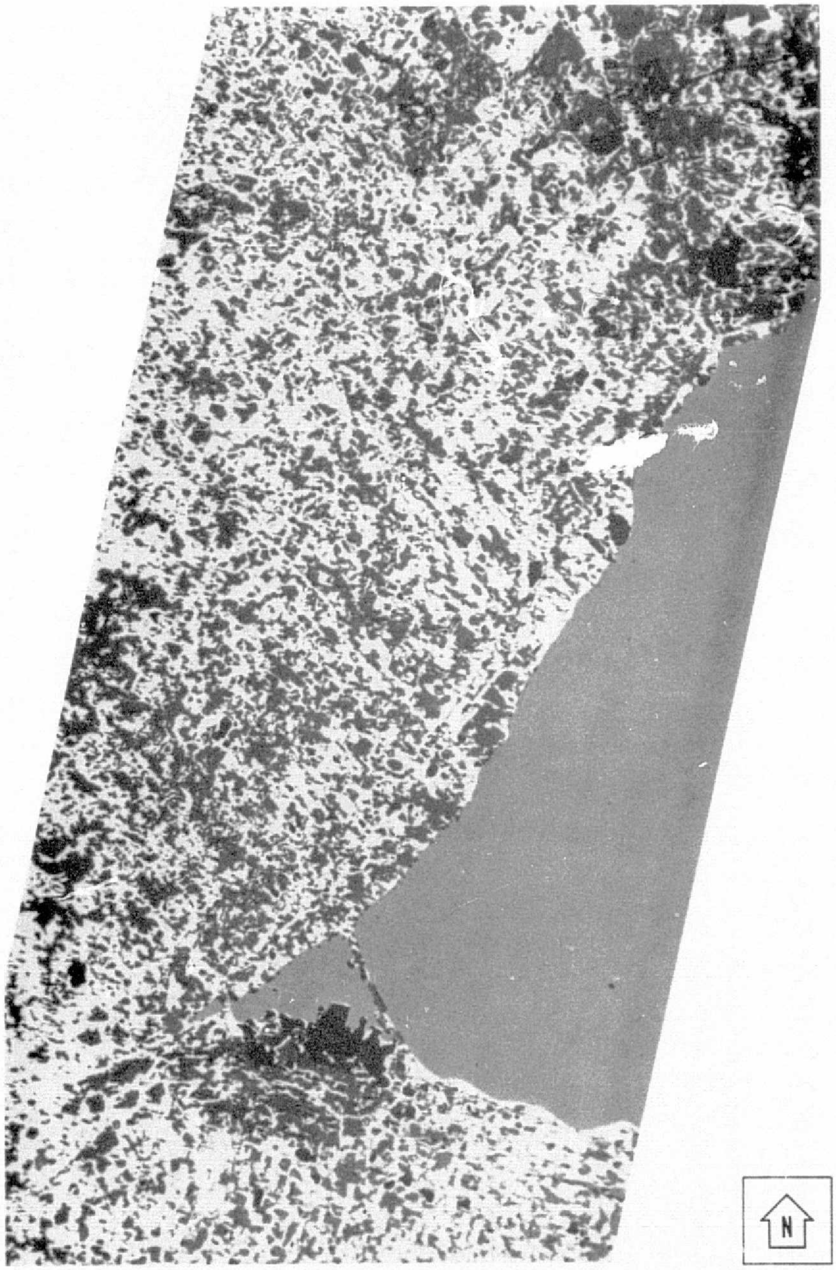
FIGURE 17. COMPARISON OF ERTS RATIO IMAGES OF BELLEVILLE-PICTON AREA OF ONTARIO. Portion of ERTS Frame No. 1028-15290, 20 August 1972. (Continued)

(e) MSS-7/MSS-4



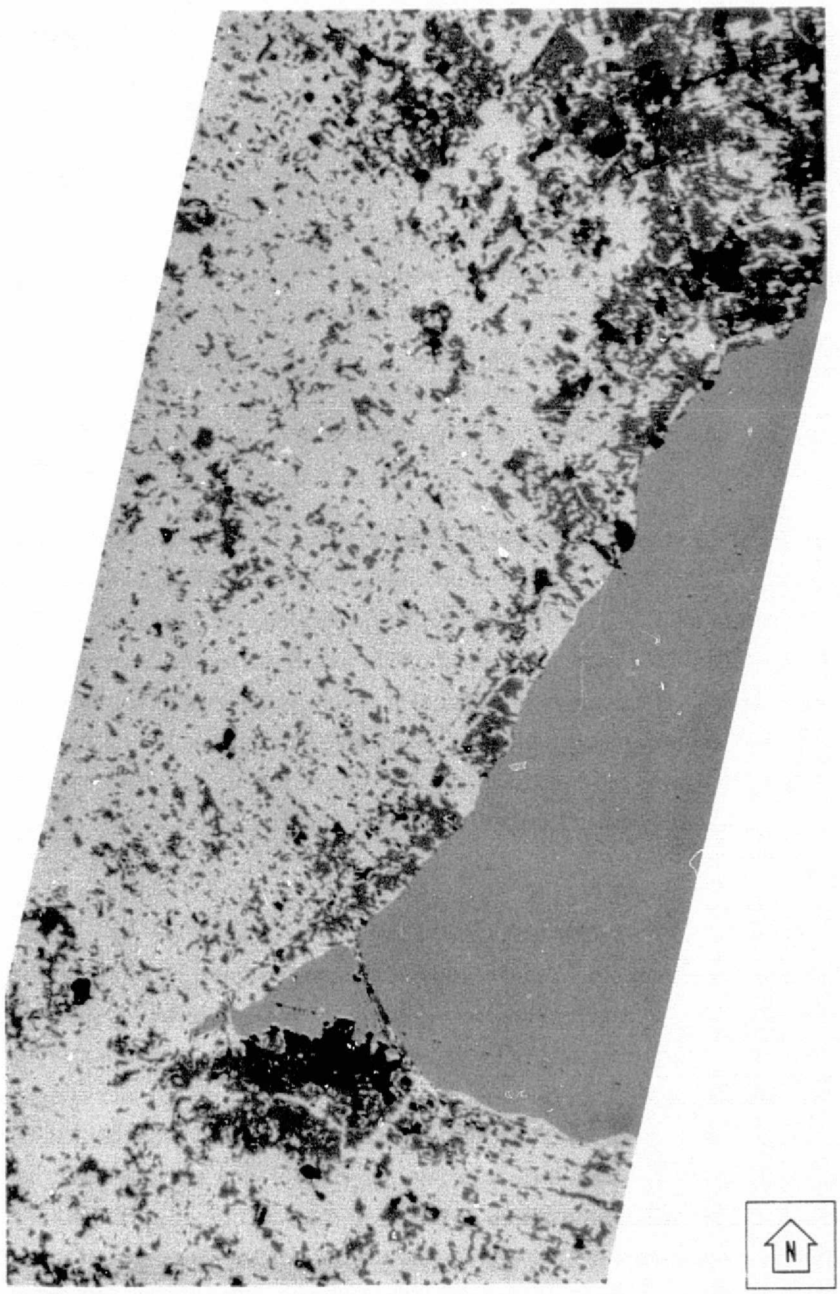
(f) MSS-7/MSS-5

FIGURE 17. COMPARISON OF ERTS RATIO IMAGES OF BELLEVILLE-PICTON AREA OF ONTARIO. Portion of ERTS Frame No. 1028-15290, 20 August 1972. (Concluded)



(a) Terrain Classes

FIGURE 18. TWO RECOGNITION IMAGES FOR THE HAMILTON-TORONTO AREA, 21 AUGUST 1972 (Continued)



(b) Impervious Surfaces

FIGURE 18. TWO RECOGNITION IMAGES FOR THE HAMILTON-TORONTO AREA, 21 AUGUST 1972 (Concluded)

cities of Hamilton and Toronto at a scale of approximately 1:300,000. This area includes the cities of Burlington, Oakville, Port Credit, and Brampton and the 21,000-hectare East and Middle Oakville Creek drainage basin.

3.2.3 COLOR ADDITIVE IMAGES

Color additive processing of ERTS data is principally a photographic procedure whereby black and white transparencies (negative and/or positive) of individual ERTS bands are reproduced in color using a continuous tone transparency material. Two, or commonly three, single-band images are reproduced in different colors, overlaid, registered, and photographed. This allows the use of color to add an additional dimension to the interpretability of the resulting image. While essentially a non-quantitative procedure and one dependent on working with a film base, striking color combinations may be produced which allow rapid identification of certain features.

A standard NASA-produced ERTS product is the "false color" composite image (not shown). In this image spectral data from MSS-4 is coded yellow, from MSS-5 magenta, and from MSS-7 blue. The resulting composite image shows vegetated terrain as red, urban and bare areas as blue-grey, and water areas as dark blue. Clouds, light toned in all bands, appear white and their shadows appear nearly black. This image is optimal for showing areas of water, vegetated terrain, and cities. Within each of these terrain features color and film density variations are limited, obscuring some of the details which are apparent in other image and color combinations. By carefully selecting the transparencies and colors, different combinations of features can be enhanced.

3.2.4 STATISTICAL PATTERN RECOGNITION

Multiband pattern recognition is one of the most sophisticated types of multispectral data processing. The technique utilizes computer-implemented statistical decision criteria to determine whether any given pixel is similar to any one of a number of a predetermined spectral signatures. "Similarity" is defined by a decision rule which computes the maximum likelihood that a pixel is a member of a recognition class and then prints out that pixel if it meets a threshold criterion. The concept is based on a probability model that assumes that an unknown pixel will have spectral characteristics similar to a known object class, represented by one or more training sets, if it is a member of that class. Two major difficulties with this technique lie in establishing representative signatures and in the costliness of this type of processing using conventional computer facilities.

This section describes the digital computer processing of a small portion of the Lake Ontario basin—the East and Middle Oakville Creek representative basin. The objective was to develop and test digital procedures for mapping hydrologically significant land-use or surface-cover categories of watersheds using ERTS-1 data.

3.2.4.1 Computer Training

The accurate designation of representative training sets from which to extract signatures is one of the greatest problems in the use of these statistical techniques. Ground observations are a necessary precondition for the selection of homogeneous training-set areas. The following training-set selections were made using aerial photography and were confirmed by personnel of the Ontario Ministry of the Environment and the University of Guelph. The signatures are listed in Table 2.

The training set used to establish the water-1 signature was free from surface vegetation. The area used to establish the water-2 signature had large amounts of surface algae during August. This vegetation accounts for the difference in the two signatures.

Two signatures for hardwoods were established. The major difference in the training set areas was stand density. The trees in hardwood-1 were an average of 15-20 feet apart and canopy cover was estimated at 60-70%. In hardwood-2 the tree spacing was approximately 10-12 feet, and canopy cover was close to 95%. Both training sets were mature sugar maple (Acer saccharum) stands with an average tree height of 30-65 feet and undergrowth of approximately 50% cover. The understory of hardwood-1 was red maple and grasses; for hardwood-2, it was a combination of hemlock and red maple. A few white ash and elm were associated with the sugar maple in hardwood-1, and beech was the principal associate in the hardwood-2 case.

The conifer group was also represented by two signatures. One was derived from an area of reforested red pine (Pinus resinosa) spaced 5.5 feet apart with no understory. The pines provided nearly 100% canopy cover. The second conifer signature, called mixed conifer-hardwood, represented an area dominated by white cedars (Thuja occidentalis) about 30 feet in height. Associated with the cedar were white birch, hemlock, and spruce. Tree canopy cover was approximately 90%. Red pine is an upland species preferring dry soils. White cedar is found in moist locations and frequently on limestone-derived soils.

A shrub swamp signature was obtained from a wet area containing white cedar, white birch, and hemlock with some elm, yellow birch, red maple, and black ash. Maximum diameter of these trees was about 6 inches. Many swamp shrubs and a few red maple were also present. Although both this and the mixed conifer-hardwood signature represented areas composed of white cedar, the cedar areas identified by the mixed conifer-hardwood signature were generally in drier habitats.

A marsh signature was established from an area of standing water covered by sedges (Carex spp.) and a few cattails (Typha spp.)

Two signatures representing surface mining activities were obtained. One was derived from a limestone quarry and the other from a sand and gravel quarry.

A general urban land-use signature was obtained from a training set in the city of Oakville. However, since no communities consisting of more than a cluster of a few buildings occurred within the East and Middle Oakville Creek basin, this signature was not used.

A highway signature was established using a section of a four-lane divided highway (401) going through the Oakville basin. Since the ERTS-1 resolution was greater than the average width of the highway lane, a data pixel represented a combination of both highway and adjacent areas. The inclusion of these boundary materials resulted in a signature which was not representative of a highway surface per se. Attempts to refine a pure highway surface signature were unsuccessful.

Finally, training sets were established and signatures derived for bare soil, pasture, and several agricultural areas.

3.2.4.2 Recognition Processing

Based upon the characteristics of the data set and the final classification categories desired, a sequential processing scheme was adopted. All non-herbaceous and lowland herbaceous vegetation classes were separately identified; subsequently, percent cover determinations were made for the remaining herbaceous vegetation areas. In an effort to determine how well this separation could be done and to see which signature pairs might be similar enough to prevent errors in the separation, an analysis was performed. Table 9 shows the pairwise separation of signatures in ERTS four-channel hyperspace. All signatures used to generate a classification map plus signatures representative of the four classes of herbaceous cover are listed, though the pairwise separation of all the signatures was not determined. The separability of the signatures is given in terms of standard deviations. A small standard deviation implies poor separability of the paired signatures and that significant error is likely. An average covariance matrix was assumed for each of the signatures in a paired set, such that the standard deviation is the same in each direction and the table is diagonally symmetrical.

From Table 9 it is evident that marsh and pasture were not easily separable and classification errors are expected for this pair. (This is not surprising in view of the fact that the differences between various types of green herbaceous vegetation are not great in mid-August.) Also, the hardwood-1 signature (representing the less dense stand) is less separable from the agricultural and herbaceous cover signatures than is the hardwood-2 signature. The hardwood-2 signature, on the other hand, is spectrally closer to signatures representing dense tree cover conditions (pine, shrub-swamp, mixed conifer-hardwood) than is the hardwood-1 signature.

Considerable variability existed with certain terrain classes. This variability was of two types: one consisting of a closely spaced continuum of mean signature values and the second of widely spaced signature means. In the first case, if the center of the continuum was reasonably

TABLE 9. LISTING OF THE PAIRWISE DISPLACEMENT OF SIGNATURES IN FOUR CHANNEL HYPERSPACE. Signatures are from ERTS Observation 1029-15345 of 21 August 1972 over southern Ontario. Displacements are in terms of standard deviations. A dash indicates the calculation was not performed.

	WATER-1	WATER-2	MARSH	SHRUB SWAMP	HARDWOOD-1	HARDWOOD-2	MIXED CONIFER-HARDWOOD	PINE	QUARRY (SAND & GRAVEL)	QUARRY (LIMESTONE)	PLOUGHED FIELD	AGRICULTURE/IDLE (0-10% green cover)	AGRICULTURE/IDLE (10-60% green cover) field 1	AGRICULTURE/IDLE (10-60% green cover) field 2	AGRICULTURE/IDLE (60-80% green cover) field 1	AGRICULTURE/IDLE (60-80% green cover) field 2	AGRICULTURE/IDLE (80-100% green cover)	PASTURE (% cover unknown)	CORN (80-100% green cover)	AGRICULTURE (% cover unknown)
Water-1																				
Water-2	4.0																			
Marsh	-	-																		
Shrub Swamp	22.5	17.0	4.1																	
Hardwood-1	-	-	7.1	7.2																
Hardwood-2	-	-	12.2	6.6	9.7															
Mixed Conifer-Hardwood	-	-	6.1	3.3	8.8	7.0														
Pine	27.2	23.5	8.4	6.3	13.2	8.0	2.4													
Quarry (Sand & Gravel)	-	-	-	-	32.6	-	-	-												
Quarry (Limestone)	-	-	-	-	15.9	-	-	-	-											
Ploughed Field	-	-	-	-	16.5	-	-	-	6.3	5.1										
Agriculture/Idle (0-10% green cover)	-	-	-	-	12.6	-	-	-	-	8.1	7.7									
Agriculture/Idle (10-60% green cover) field 1	-	-	2.9	-	5.5	-	7.0	8.2	-	-	8.4	-								
Agriculture/Idle (10-60% green cover) field 2	-	-	4.4	-	5.4	10.1	7.1	10.2	-	-	12.1	-	-							
Agriculture/Idle (60-80% green cover) field 1	-	-	15.2	-	5.1	14.8	14.7	22.0	-	-	-	-	-	-						
Agriculture/Idle (60-80% green cover) field 2	-	-	9.6	-	5.7	8.6	9.1	17.2	-	-	-	-	-	-	-					
Agriculture/Idle (80-100% green cover)	-	-	13.4	14.1	7.4	12.0	-	-	-	-	16.3	-	-	-	-	-				
Pasture (% cover unknown)	-	-	1.9	2.9	6.1	9.4	4.5	-	-	-	11.7	4.8	3.6	4.7	9.1	4.6	-			
Corn (80-100% green cover)	-	-	14.0	11.0	8.0	9.1	13.3	18.5	-	-	-	-	-	-	9.2	9.8	4.7	9.4		
Agriculture (% cover unknown)	-	-	9.8	11.8	4.2	12.4	12.5	-	-	-	12.2	-	-	-	-	-	-	8.2		

distinct from similar classes, the signature representing the center was used for the recognition of that class. (Incorporating all signatures in the continuum into one super-signature would probably have increased the recognition errors between classes because the continuums of most vegetation classes overlapped.) The second case, illustrated by the two hardwood signatures, resulted when apparently only the end points of the continuum were present in the scene. When these end points were reasonably distinct, and the range between them was a range in which the center of other classes occurred, both signatures were used in the recognition processing.

A sequential processing method involving a series of steps was devised. Three basic steps were required in this scheme: (1) classification according to signatures; (2) level slicing on the basis of the chi-square value; and (3) classification by level slicing a ratio. A new algorithm module, SPEC., was written to incorporate these processing steps into the basic classification algorithm such that the sequential processing required only a single program.

SPEC. (see Appendix) acts as an internal function to the ERIM general pattern recognition program [CLASFY.(LIN)] which performs maximum likelihood processing using a linear decision rule. SPEC. performs linear decision rules, consisting of level slicing single channels and ratios, singly or in combination after CLASFY. has operated on the data. SPEC. reclassifies all pixels designated as unclassified by CLASFY.(LIN). In addition, all pixels classified under any other signature may be reclassified under SPEC. Signatures may be used, therefor, merely to refine the criteria for decisions under the maximum likelihood rule used in CLASFY. The capability also exists in SPEC. to slice on the exponent channel, differentially for each category. [The exponent channel is the second channel of output under the CLASFY.(LIN) program. This exponent, consisting of the chi-square value times a constant (5.12), is a measure of the nearness of the classified data pixel to the signature of that class. The value in the exponent channel is generally defaulted to 511, which implies a chi square of 19.5.] SPEC. will take each pixel above the exponent level slice for that category and reclassify it.

For the Oakville basin thirteen signatures were used as inputs to the classification program. The first ten (listed in Figure 19) were classes desired on the final output; the last three (pasture, ploughed field, and corn) were included because of the improvement these provided in operation of the maximum likelihood rule. In order to reduce the possibility, discussed previously, of misclassification evident in Table 9, low chi-square (i.e., exponent) levels were established for marsh and hardwood-1. Any pixel classified as marsh which had an exponent value of 48 or greater (chi square of 9.38) and any pixel classified as hardwood-1 with an exponent value of 75 or more (chi square of 14.65) was put in the "pool" of data points to be reclassified under SPEC. Any pixels classified as pasture, ploughed field, or corn were also put into the reclassification pool. This was also done with pixels which were not classified by signatures.

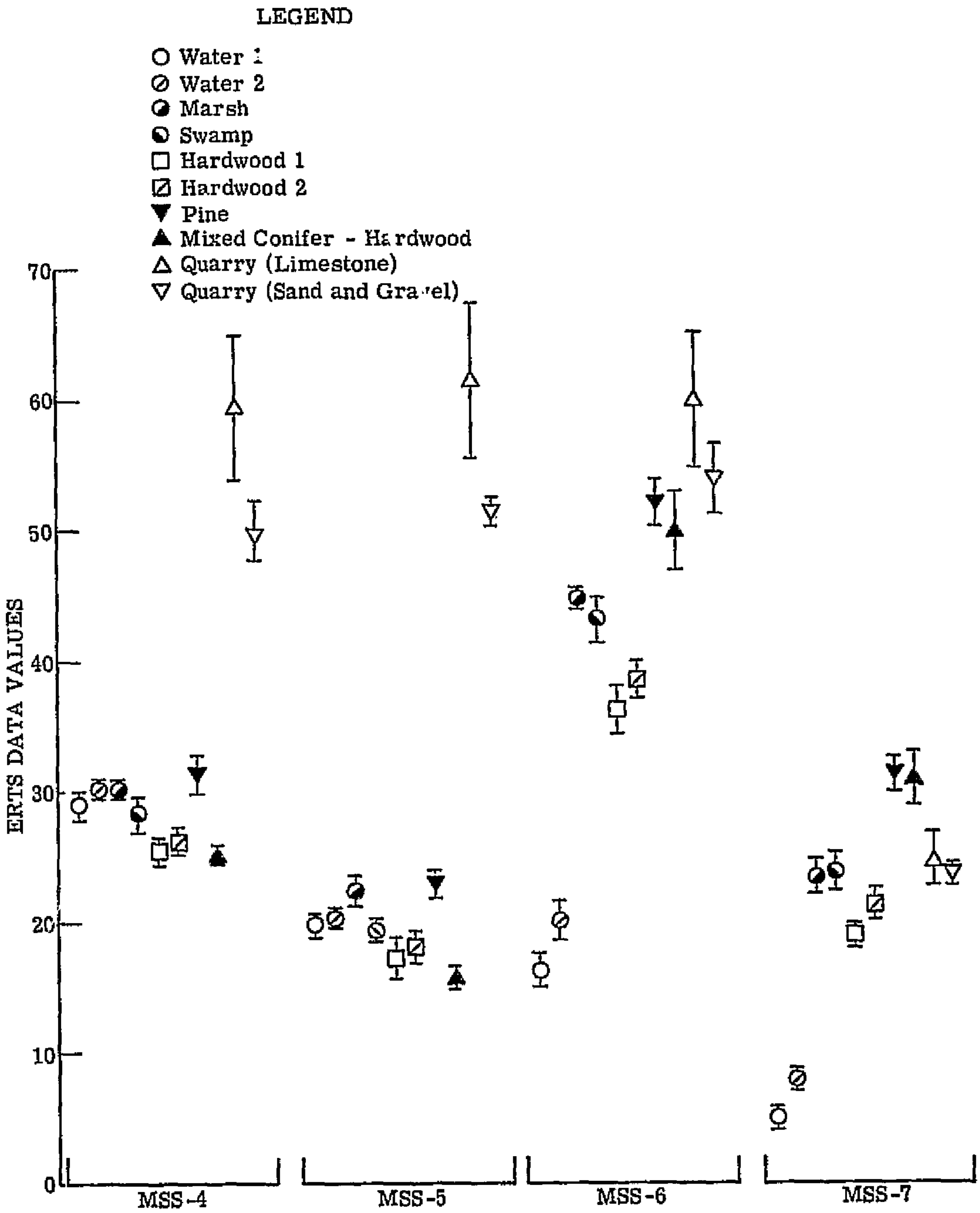


FIGURE 19. SPECTRAL SIGNATURES USED IN THE MULTISPECTRAL PROCESSING OF ERTS-1 DATA OF 21 AUGUST 1972, SCENE OBSERVATION 1029-15345. The signature mean and one standard deviation are shown.

SPEC. then classified pixels on the basis of level slices of a single channel and/or ratios of channels. A pixel was put into the impervious category if it had a value of 31 or greater in MSS-5 and a ratio value of MSS-6/MSS-5 greater than 1.3. These values were determined by noting signature values of the various classes.

Investigators at ERIM and elsewhere have found that an IR/red reflectance ratio can be indicative of the amount of vegetation present in the scene, particularly the percent of green vegetative cover. This is especially true if the green vegetation is not significantly obscured by dead vegetation in the canopy. In addition, a given relationship is most valid when applied to vegetation canopies that are physiognomically similar. The majority of the research has been directed toward grasses and small grains. For this reason we attempted to edit out all non-herbaceous vegetation before using the IR/red ratio for percent cover determinations. (Marsh, while also herbaceous vegetation, was edited out as a spearate class because of its significance hydrologically.)

An IR/red ratio also tends to normalize soil reflectances. This is a highly desirable trait, since at low values of percent cover, variations in soil reflectance may produce large variations in reflectances in any one wavelength region. Work done at ERIM has shown that an IR/red reflectance ratio substantially reduces the effects of variations in soil reflectance and amount of litter. This permits the extension of the IR/red ratio method for determination of percent cover over a broad area potentially incorporating a variety of soil reflectances.

An ERIM investigator [39] examined the relationship between an IR/red reflectance ratio for oats and timothy and green percent cover. This relationship is reasonably valid for a variety of types of soils (i.e., different soil reflectances) and for different types of herbaceous vegetation. While the curve based on the relationship will vary slightly depending on the conditions relating to the specific data set (look angle, zenith angle, vegetation type, etc.) the general shape of the curve will remain fairly constant.

ERTS data is in terms of voltages which are proportional to the radiances of the terrain recorded in each spectral band. Since this is a small area, only a portion of one ERTS frame, in which irradiance is fairly constant, IR/red radiance ratios should be approximately proportional to reflectance ratios, and the curve of such a ratio should have approximately the same shape as the reflectance ratio curve mentioned above.

We calculated IR/red ratios (MSS-7/MSS-5) for several training sets from the Oakville data representing various types of non-wetland herbaceous vegetation. Using these, and ground data plus photointerpretation for estimates of percent cover, we constructed a curve similar to the IR/red reflectance curve just mentioned (Figure 20).

Calculated MSS-7/MSS-5 values are arbitrarily indicated in Fig. 20 in the center of the

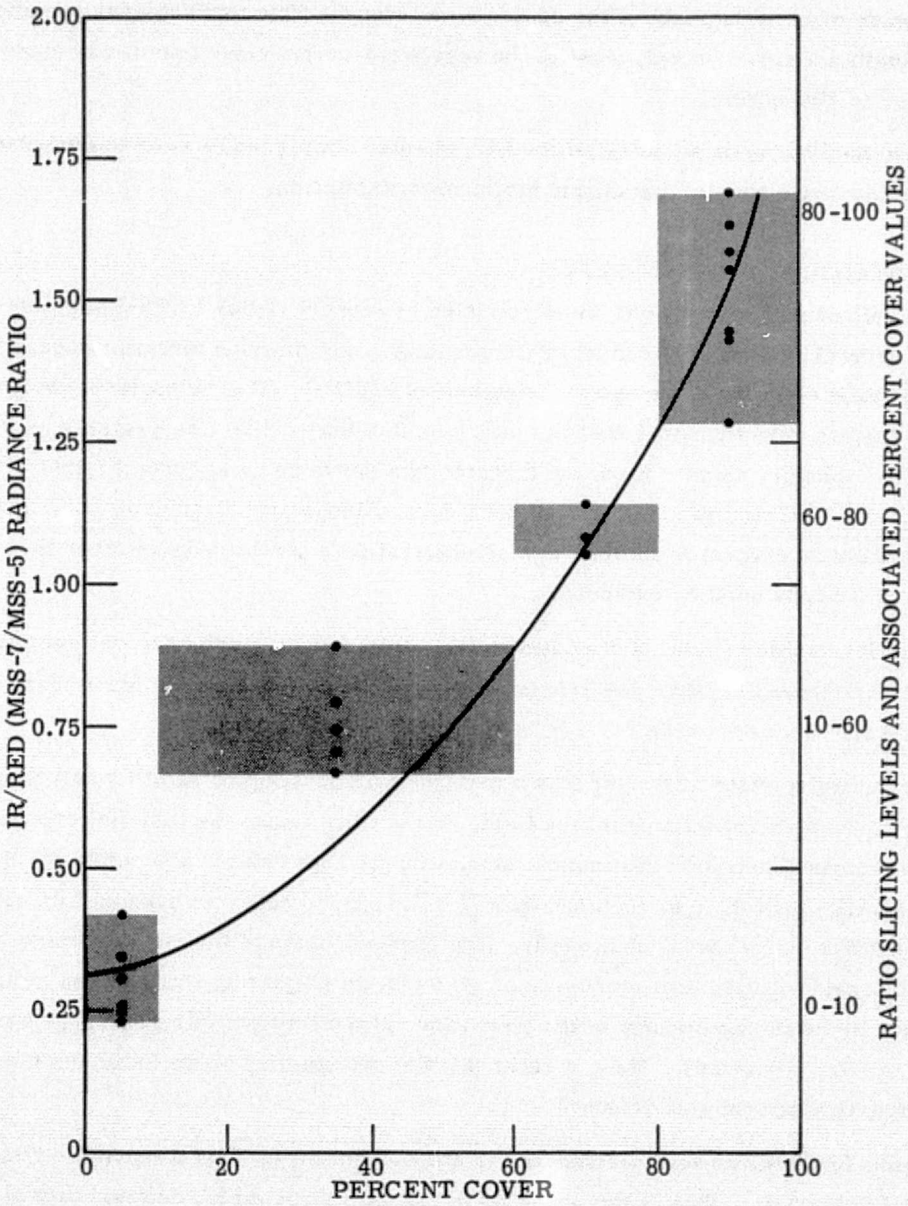


FIGURE 20. IR/RED (MSS-7/MSS-5) RADIANCE RATIO FOR NON-WETLAND HERBACEOUS VEGETATION IN THE OAKVILLE BASIN VERSUS ESTIMATES OF PERCENT COVER

related range of percent cover values. The curve goes through the center of the range of three of the four percent cover classes. With regard to the 10-60% cover class, however, the curve goes considerably to the right of the center of the range. This would appear to indicate that, if our assumptions were correct, most of the vegetation in this class is actually closer to 60% cover than to 10% cover.

Based on this curve we selected the IR/red ratio slicing levels used to designate the categories of percent cover for the upland herbaceous vegetation.

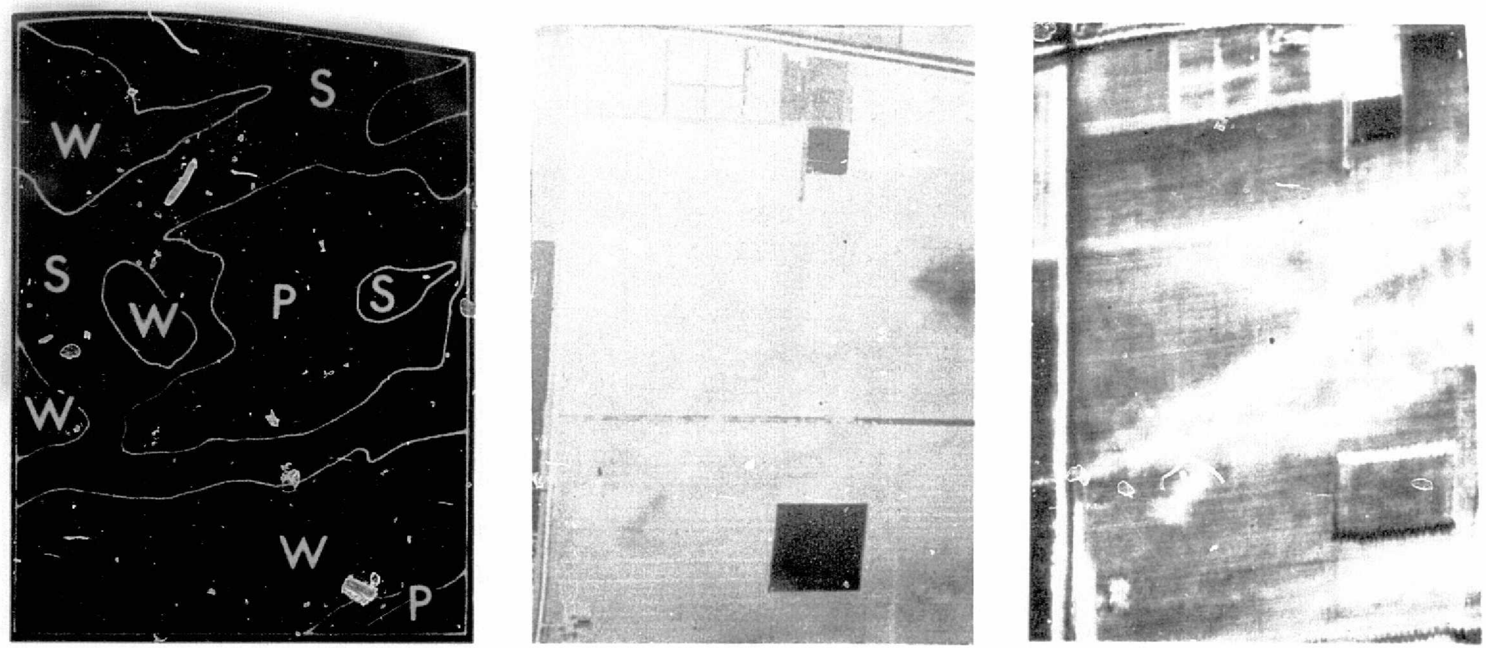
3.3 SUPPORTING AIRCRAFT DATA

Aircraft remote sensor data were collected in support of this ERTS-Lake Ontario investigation for several reasons. The most obvious was that they provide terrain imagery with finer spatial resolution in the same spectral regions as ERTS-1. This fact allows the identification of specific terrain conditions and spatial features which may not be interpretable or discernible in the ERTS-1 imagery alone. Thus, the aircraft data serve as an important type of "ground truth" for processing and evaluation of the satellite data. Also, while principally concerned with ERTS-1 data, the value of collecting and processing spectral data at wavelengths other than the current four ERTS-1 bands must be explored.

Experience with twelve-band multispectral aircraft data leads us to believe that the earth ought to be observed in other spectral bands from orbital altitudes. In particular, thermal infrared data would be most useful for hydrologic applications.

For example, Figure 21 compares a portion of a conventional detailed soil drainage map and a photograph with a ratio image of the field. In the ratio image the light patterns correspond to the areas marked as poorly drained on the soil map. This ratio image combines thermal infrared data (9.3-11.7 μm) with near infrared data (1.5-1.8 μm) to enhance these soil differences which are not evident on the aerial photogrphy. The physical basis of this soil drainage enhancement is due to organic matter differences which give rise to slight temperature and reflectance variations in the infrared range of the spectrum. In the thermal infrared range the poorly drained areas are slightly warmer. Thus, a ratio of these two spectral bands enhances the differences associated with natural soil drainage.

Figure 22 shows an aircraft scanner image mosaic of the East and Middle Oakville Creeks representative basin. This is the same basin that was selected for detailed digital processing. Using these data we can perform the same type of processing that was accomplished for the ERTS-1 data and compare the effect of the resolution differences. From the ERTS data only two water bodies were identified, a combined surface area of 24 hectares. The processed aircraft data, with a spatial resolution of about 59 m^2 (Figure 22b), shows many small water



Soil Map

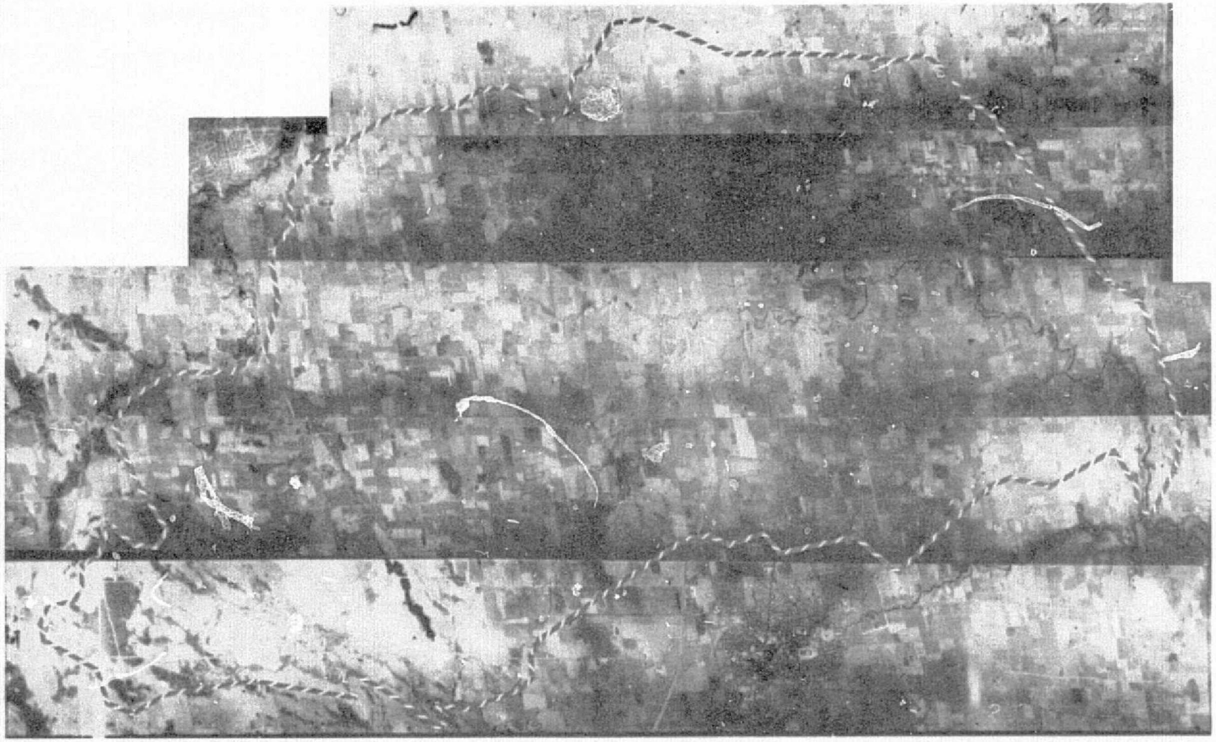
W - Well Drained
S - Somewhat Poorly Drained
P - Poorly Drained

Photo

Ratio Image

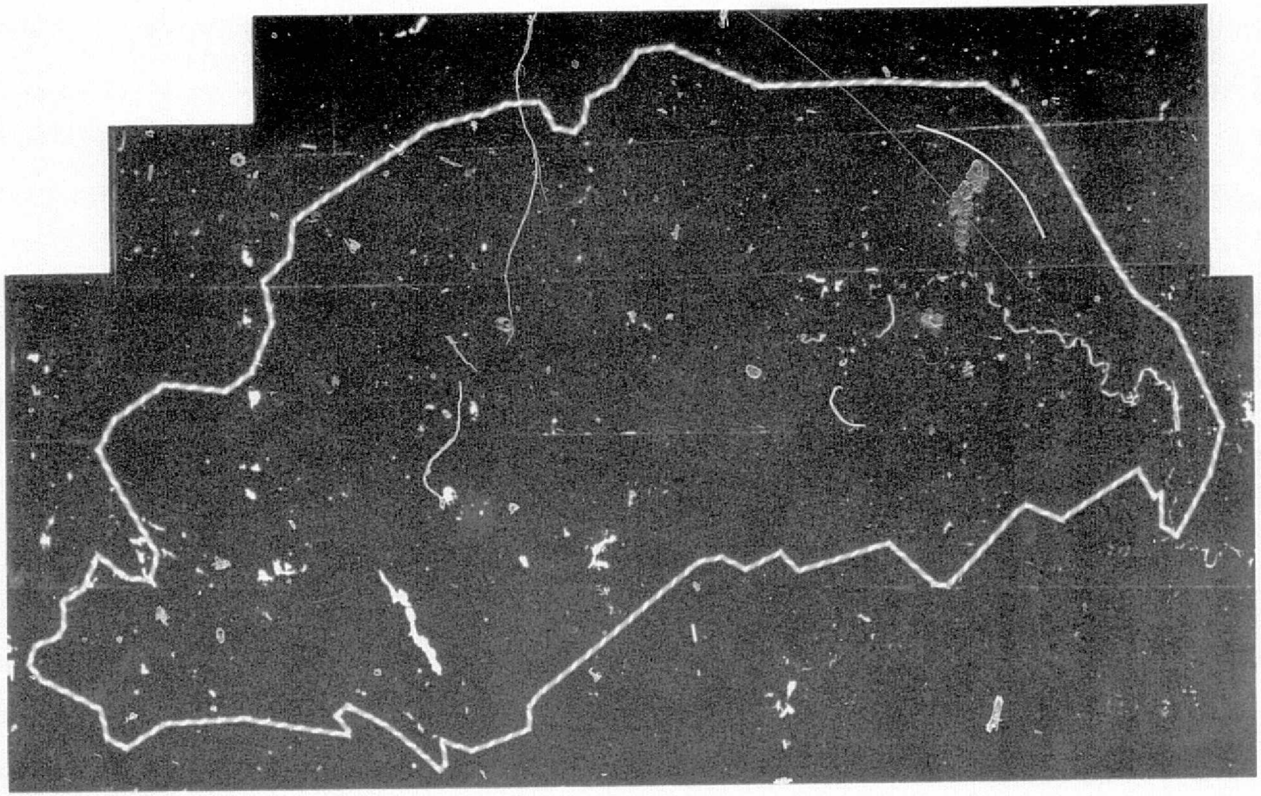
$$\frac{9.3 - 11.7\mu m}{1.5 - 1.8\mu m}$$

FIGURE 21. COMPARISON OF AIRCRAFT ENHANCED (RATIO) IMAGE WITH SOIL MAP FOR INDICATIONS OF NATURAL SOIL DRAINAGE. Data obtained near Guelph, Ontario, 17 June 1972.



(a) Aircraft Image Mosaic, 1.5 - 1.8 μm Video

FIGURE 22. EAST AND MIDDLE OAKVILLE CREEKS REPRESENTATIVE BASIN, ONTARIO. Images prepared from data obtained 11 May 1971. (Continued)



(b) Standing Water Areas

FIGURE 22. EAST AND MIDDLE OAKVILLE CREEKS REPRESENTATIVE BASIN, ONTARIO. Images prepared from data obtained 11 May 1971. (Concluded)

bodies which were missed by ERTS-1. The aircraft imagery provided a total of 143 hectares of surface water. Thus, for basins similar to this representative basin, the ERTS surface water recognition must be multiplied by a factor of 6 to obtain a better estimate of the total area of surface water. The different dates may have accounted for some of these differences. This factor will vary for different physiographic and underlying geologic conditions.

One final example of the use of aircraft data in support of ERTS-1 is shown in Figure 23. This figure compares coverage of the entire Niagara Plume obtained by ERTS with a portion of the Plume recorded simultaneously from aircraft. Clearly the aircraft image provides some of the detailed structure of the plume not observable from ERTS-1 data while the ERTS image shows the relation of the plume to other outfalls and perhaps the sources of sediments from the basin.

ERTS-1 (0.6-$0.7\mu m$)

ERIM C-47 (0.58-$0.64\mu m$)

FIGURE 23. COMPARISON OF ERTS AND AIRCRAFT COVERAGE OF THE NIAGARA PLUME ON 24 MARCH 1973

APPENDIX

SPEC. PROGRAM LISTING

```
$ COMPILE MAD
$PRINT OBJECT
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```
MAD (09 AUG 1965 VERSION) PROGRAM LISTING ... ... ...
```

```
                 EXTERNAL FUNCTION SPEC.(NEXT)
                *THIS MODULE SETS S(I) = I
                 REFERENCES ON
                 ERASABLE SKP2(225), CUNIT, CREEL, CFILE, CLINE, TWRITE, QCHAN,
               1   QNWDS, PROG, MODE1, MODE2, UNIT, CALINE, CDLINE, NSA, NSB,
               2   KS, NA, NB, KP, ID(1), TFLAG, IPACK, RESERV(4), QFACTR(49),
               3   QTITL2(19), QTITLE(19), QLIST(19), QSPARE(46), QFLAG,
               4   QDANG, QBANG, QKP, QNA, QNSS, QNCHAN, QMODE, QRECA, QRECC,
               5   QFILE, QREEL, QNWRDS
                 ERASABLE SKIP3(423), ITEST, EXTRA(4), DATUM(24), ICODE(24),
               1   NP(31), S(31), MSTART(30), ASTART(30), PSTART(30), CHSG,
               2   NT, EXPLIM, DSTART, NV, CC, L, CARDS, NN, G1, G2,
               3   TAG1(31), TAG2(31), CHAN(24), ICHAN(24), IA(30*2), C(30),
               4   AC(31), CODE(24), IC(24), ADIM(2), BDIM(4), A(1,ADIM)
                 NORMAL MODE IS INTEGER
                 FLOATING POINT DATUM, DAT32, DAT42

                 WHENEVER NEXT .E.1
 STEP(1)         LINK.(SPEC3.)
                 L1 = ICHAN(1)
                 L2 = ICHAN(2)
                 NT1 = NT + 1
                 NT2 = NT + 2
                 NT3 = NT + 3
                 NT4 = NT + 4
                 NT5 = NT + 5
                 NT6 = NT + 6
                 NT7 = NT + 7

                 OR WHENEVER NEXT.E.2
                 (I=1,1,I.G.NT7, S(I) = I)
                 END OF CONDITIONAL
                 FUNCTION RETURN

                 INTERNAL FUNCTION SPEC3.
                 WHENEVER CHAN(L1) .LE. NT-3
                     WHENEVER CHAN(L1) .E.3 .AND. CHAN(L2) .L. 35
                         FUNCTION RETURN
                     OR WHENEVER CHAN(L1) .E.8 .AND. CHAN(L2) .L. 48
                         FUNCTION RETURN
                     OR WHENEVER CHAN(L1) .NE. 3 .AND. CHAN(L1) .NE. 8
                     FUNCTION RETURN
                 END OF CONDITIONAL
                     END OF CONDITIONAL
                   CHAN(L1) = NT7
```

(Continued)

90

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WHENEVER DATUM(1).G.510.5
  (I=2,1,I.G.NV .OR. DATUM(I).L.510.5)
  WHENEVER I.G.NV, FUNCTION RETURN
  END OF CONDITIONAL
CHAN(L2) = 1
WHENEVER DATUM(2).L..01, DATUM(2) = .01
DAT32 = DATUM(3)/DATUM(2)


DAT42 = DATUM(4)/DATUM(2)

WHENEVER DATUM(2).GE.31. .AND. DAT32.G.1.3
  CHAN(L1) = NT1
OR WHENEVER DAT42 .L. .75
  CHAN(L1) = NT2
OR WHENEVER DAT42 .L. 1.25
  CHAN(L1) = NT3
OR WHENEVER DAT42 .L. 1.5
  CHAN(L1) = NT4
OTHERWISE   (WHEN DAT42.GE.1.5)
  CHAN(L1) = NT5
  END OF CONDITIONAL
FUNCTION RETURN
END OF FUNCTION
END OF FUNCTION
```

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