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APPLICATION OF LANDSAT TO THE SURVEILLANCE OF LAKE EUTROPHICATION IN THE GREAT LAKES BASIN

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16. Abstract

The cost benefits of using LANDSAT on an operational basis in the surveillance of lake eutrophication was established. To accomplish this, LANDSAT data were used to derive maps and data graphics to support the EPA's study of lake eutrophication in Saginaw Bay, the State of Michigan, and the State of Wisconsin's lake and watershed studies. These users provided ground truth and supported evaluation of cost benefits of LANDSAT products. The significant results of the program included the demonstration of cost-effective systems for monitoring: trophic state of areas/scenes containing 200 or more lakes of 50 acres or larger; trophic state of the Great Lakes; and watershed land use required to predict pollutants in runoff.

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PREFACE

OBJECTIVE OF THE PROGRAM

The overall objective of this investigation was to establish the cost benefits of using LANDSAT on an operational basis in the surveillance of lake eutrophication. This objective was accomplished by supporting, with LANDSAT data products, bona fide users who evaluated the data's usefulness to on-going programs concerned with the classification and control of lake eutrophication. The products supplied to the users were made as applicable as possible to their data needs. The following, therefore, were specific objectives addressed:

1. To identify the data requirements of the users and to relate these to LANDSAT data with respect to land-water categories, detail, scale, and frequency.

2. To identify water quality parameters which relate directly to eutrophication and to determine quantitative levels of these parameters by which lakes may be categorized as to trophic state.

3. To identify land use patterns which relate to trophic state.

4. To develop and apply LANDSAT data imaging and interpretation techniques to categorize water and land use features identified in order to produce information products of value to users.

SCOPE OF WORK

The scope of this work is to provide LANDSAT-derived information products to three federal and state agencies involved in the planning and management of water quality of lakes in the Great Lakes basin. Support is provided to the Environmental Protection Agency water quality survey and modeling study of lake eutrophication in Saginaw Bay; the State of Michigan Department of Natural Resources survey of inland lakes and watersheds for the purpose of assessing the degree of eutrophication in these lakes and the potential for further enrichment and pollution due to land use practices; and the State of Wisconsin Department of Natural Resources lake survey to determine eutrophication status, causes, effects, and control treatments.

CONCLUSIONS

The significant results of this investigation include:

A. System for Monitoring Trophic State of Inland Lakes - A step-by-step procedure for establishing and monitoring the trophic status of inland lakes with the use of LANDSAT data, surface sampling, laboratory analysis, and aerial observations was demonstrated. LANDSAT and surface data collected during a 3-week summer period between August and September can be applied to computer processing to generate color maps showing lake weeds and six to ten concentrations of algal biomass. The biomass is related to chlorophyll a concentrations, water clarity, and trophic state. The procedure provides a 90% or better correct classification for lakes of 50 acres or larger and is cost-effective when the area contains 200 or more lakes per scene. The cost for monitoring lakes by conventional surface sampling ranges from $60 to $1,000 per lake depending upon agency and technique used. Application of LANDSAT in conjunction with surface sampling costs $10 to $40 per lake based on typical scenes in Wisconsin, Minnesota, and Michigan. This is the total cost, including field work, processing, field verification, and final map.

B. Technique for Mapping Water Quality in Large Lakes - A procedure was developed for using surface sampling, LANDSAT data, and linear regression equations to produce a color-coded image of large lakes showing the distribution and concentration of water quality parameters (e.g., nitrogen and phosphorus) causing eutrophication as well as parameters which indicate its effects (e.g., chlorophyll a). Although the procedure is scene and surface truth dependent, it can be applied to almost any situation to monitor water quality parameters with a predictable accuracy. The trophic state of Saginaw Bay was estimated from chlorophyll a and phosphorus concentrations and by water clarity as indicated by Secchi depth. The application of this procedure to generate a map of Saginaw Bay showing nine water quality parameters used measurements from 16 surface stations collected the same day as LANDSAT data and cost $1 to $2 per square mile. Similar maps estimated from surface sampling alone required measurements from 33 to 60 stations collected by boat(s) over a 3-day period. In this situation, LANDSAT would save 2 days of surface sampling, related laboratory analysis, and data reduction estimated at 6,000 to 10,000 dollars. Furthermore, LANDSAT produced a synoptic map of water quality parameters that no reasonable amount of point sampling could duplicate.

C. Cost and Benefits for Land Cover Data Required for Water Quality Programs - The investigation demonstrated that LANDSAT provides an economical source of land cover information in proper format and with desired categories and accuracy needed in developing and applying procedures for forecasting effects of existing and new land uses on water quality. Cover categories readily derived from LANDSAT are those for which loading rates are available and are known to have major effects on the quality and quantity of runoff and lake eutrophication. Included are urban, barren land, cropland, grassland, forest, wetlands, and water. For some applications, it is important that LANDSAT can also separate cropland into row and field crops and forestland into broadleaf and evergreen trees. In the urban area, LANDSAT can interpret two to ten categories of percent impervious although separate analyses are required for the urban and nonurban areas. The most useful product formats are area tables listing land covered by category, as pollution loads are estimated directly by multiplying tabulated cover by loading rates. For a more detailed analysis, land cover is more readily combined with soil, slope, etc., when the cover is recorded on map overlays and digital tape files. The cost for the required land cover information derived from aerial photography is about $8.00 per square mile if photography is available and $11.00 to $13.00 per square mile if new photography is needed. For areas of 1000 sq. miles or more LANDSAT provides the required cover types in the desired formats for $1 to $4 per square mile, depending upon the product.

D. Cost and Benefits for Land Cover for Other Planning Activities - LANDSAT is the faster and least-cost method for generating land cover categories required to assess runoff within watersheds on a regional or state-wide basis. Some other planning needs (e.g., transportation planning, etc.) require detail or categories (e.g., mobile home parks, single family housing, roads, forested wetlands, small orchards, etc.) best obtained from aerial photography or field data and only available at the higher cost. These detailed categories typically cover only 2 to 10% of a region and can be selectively interpreted from photography or maps, digitized, and merged with LANDSAT data to produce the desired data graphics. This multi-source product contains detail not available from LANDSAT data alone, and the cost is much less than using only aerial photography.

RECOMMENDATIONS

This investigation established the basis for the following LANDSAT applications and research:

A. Monitoring Trophic State of Inland Lakes - Michigan, Wisconsin, Minnesota, and any region containing more than 200 lakes of 50 acres or more should include LANDSAT data with surface sampling to establish the trophic state of inland lakes. All lakes would be assessed on a 5-year cycle with screening and detail analysis applied to problem lakes during intermediate years. The 5th year's data would be compared with the 1st year's processing for changes in water quality. All lakes showing major changes would be investigated. Lake property owners should be included in the gathering of surface data when possible.

B. Establishing Trophic State of the Great Lakes - The procedure using surface sampling, LANDSAT data, and linear regression equations should be applied to assess the trophic state of all the Great Lakes during the late summer of the same year and repeated on a 5-year cycle. Problem areas (e.g., Saginaw Bay, Lake Erie, Lower Green Bay, etc.) would be monitored on an annual or more frequent basis. Ship sampling schedules on the Great Lakes should be coordinated with satellite coverage to make this assessment possible.

C. Inventorying Lake Watersheds - LANDSAT data should be used in the inventory of watersheds of the Great Lakes basin, larger river basins, and smaller lakes and river basins nation-wide. The work demonstrates that for areas of 1000 sq. miles or more LANDSAT provides an economical source of land cover information with format, categories, and accuracy needed to develop and apply procedures for forecasting effects of existing and new land uses on water quality.

D. Integrating LANDSAT Data with Information from Other Sources - A program is recommended which would demonstrate the best techniques for collecting, formatting (digitizing), merging, and manipulating LANDSAT data with other data sources in assessing the effects of existing and new land use on lake eutrophication. For large areas LANDSAT is the most economical source for watershed land cover. Aerial photography used selectively over 2 to 15% of the watershed would provide land use. Topography and soil maps would provide the required soil texture and slope.

E. Establishing Cost and Benefits for Multiseason and Signature Extension - Continued research on inland lakes would establish the cost and benefits for: (1) processing eight-channel tapes composed of spring and summer LANDSAT data to differentiate rice beds from humic water and possibly defining different types of algae in lakes, and (2) obtaining and using atmospheric parameters derived from analysis of lake and laboratory measurements.

F. Determining Additional Application and Benefits for Monitoring Great Lakes - Additional work on the Great Lakes is warranted to establish feasibility for: (1) using remote sensing to monitor plumes from waste treatment sources for compliance with limit on phosphorus, (2) applying satellite data in establishing the source, distribution, and fate of toxic substances (e.g., PCBs, mercury, etc.), and (3) developing, calibrating, and verifying models that apply both land cover and water quality parameters derived from remote sensing to estimate source and fate of pollutants.

G. Continuing Research in Saginaw Bay to Establish Additional Techniques and Benefits - LANDSAT monitoring of Saginaw Bay in concert with the EPA sampling program should continue in order to determine the additional cost benefits obtained from using nonlinear regression analysis and signature extension techniques. Application of these procedures should decrease the standard errors of estimate in predicting water quality parameters and should result in the possible further reduction or more efficient use of surface sampling.

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1. INTRODUCTION

This investigation established the cost benefits of using LANDSAT on an operational basis in the surveillance and control of lake eutrophication. To achieve this objective, the program identified the information needs of users conducting on-going water quality programs, transformed these needs into remote sensing requirements, produced LANDSAT maps and data graphics as responsive as possible to the requirements, and compared the information and cost achieved by LANDSAT with those obtained from other data sources.

The remote sensing requirements developed by this program and summarized in Section 2 are based on: literature reviews; interviews with persons conducting on-going water quality programs in Michigan, Wisconsin, and Minnesota; laboratory analysis at the University of Wisconsin; and experiences achieved in processing LANDSAT data. The finding of particular importance is the requirement to monitor trophic state of lakes by categorizing three or more concentrations of biomass during the 3-week summer period between August and September when the maximum amount of lake nutrients are converted into algae and weeds. The desired output format for this information is a color map showing biomass concentration correlated to chlorophyll a, water clarity, and trophic state. LANDSAT can readily provide this information for lakes of 50 acres or larger, depending upon the shape of the lake. Land cover categories of major interest are those for which loading rates are generally available and are known to have significant effects on quantity and quality of runoff. These include: urban, barren land, cropland, grassland, forest, wetlands, and water. The desired data format is a function of the model used to predict runoff. Most users requested area tabulation. Some needed map overlays and digital land cover tape files. For most applications, the present LANDSAT resolution is sufficient. Lakes of 30-acre size or smaller require better resolution for monitoring trophic state. A resolution of 10 to 50 meters will be needed to monitor lakes of 10 acres or larger and to monitor waste treatment sources in the near-shore areas of the Great Lakes. In all cases, users required maps and data within 4 months or less from the time of satellite coverage. Meeting this need will require improvements in tape data handling and distribution.

Section 3 reviews the work accomplished in establishing the cost benefits of using LANDSAT on an operational basis for: (1) monitoring trophic state of inland lakes, (2) mapping water quality in large lakes, and (3) inventorying land cover information required to predict quality and quantity of runoff.

To obtain the desired assessment of LANDSAT's capability, maps and data graphics were produced to support the Environmental Protection Agency (EPA) study of lake eutrophication in Saginaw Bay, the State of Michigan Department of Natural Resources (DNR) Survey of Inland Lakes and Watersheds, and the State of Wisconsin Department of Natural Resources (DNR) Lake Survey. These user agencies, in turn, provided detailed ground truth on water quality and watershed land use, and supported the studies and evaluations of the usefulness and cost benefits of the LANDSAT products.

Products required by the users were generated from LANDSAT computer-compatible tapes (CCTs) recorded on the test areas shown in Figure 1-1, which included: Saginaw Bay and Watershed; 19 lakes in southern Michigan and watersheds (most of Michigan's lower peninsula); lakes of southern Wisconsin (Madison area) and northwest Wisconsin (Spooner area); and lakes of northeast Minnesota (Duluth to Ely area).

The products were produced in the Bendix Earth Resources Data Center (see Section 3.1) in Ann Arbor, Michigan and included: color-coded water quality maps where the color was used to identify the concentration and range in various water quality parameters (e.g., chlorophyll a); land cover tabulations which list by watershed the percent coverage, acres, and square kilometers occupied by each land cover type; color-coded land cover maps and map overlays; and digital tape land cover files.

The work for EPA summarized in Section 3.3 included the demonstration of a cost-effective procedure for using surface sampling and LANDSAT data in assessing the trophic state of the Great Lakes and other large water bodies. The same technique may be applied to assess the source and fate of toxic substances and to establish the phosphorus concentration from waste treatment sources.

Support for the Michigan DNR (summarized in Section 3.4) and the Wisconsin DNR (covered in Section 3.5) resulted in the development of a system for using LANDSAT data in conjunction with field sampling, laboratory analysis, and aerial observations for establishing trophic state of inland lakes. The procedure was proven to be cost-effective in the inventory of areas containing 200 or more lakes approximately 50 acres or larger in size. This has immediate applications in states such as Michigan, Wisconsin, and Minnesota which contain 10,000 or more lakes. The 30-meter resolution available when LANDSAT-D becomes operational will permit smaller lakes to be monitored; this should result in additional cost benefits.

The work in Michigan and Wisconsin shows that the LANDSAT-derived land cover tabulations, map overlays, and digital land cover files contain categories and accuracies needed by models and procedures used to predict pollutants in runoff. LANDSAT provides a cost-effective source for land cover data for planning regions covering 1,000 square miles or more. A procedure is demonstrated in Section 3.3.3.1 for merging LANDSAT data with data from conventional sources (e.g., land use maps, field data, aerial photography) to produce maps and data which are sometimes less expensive than if produced from the conventional sources alone.

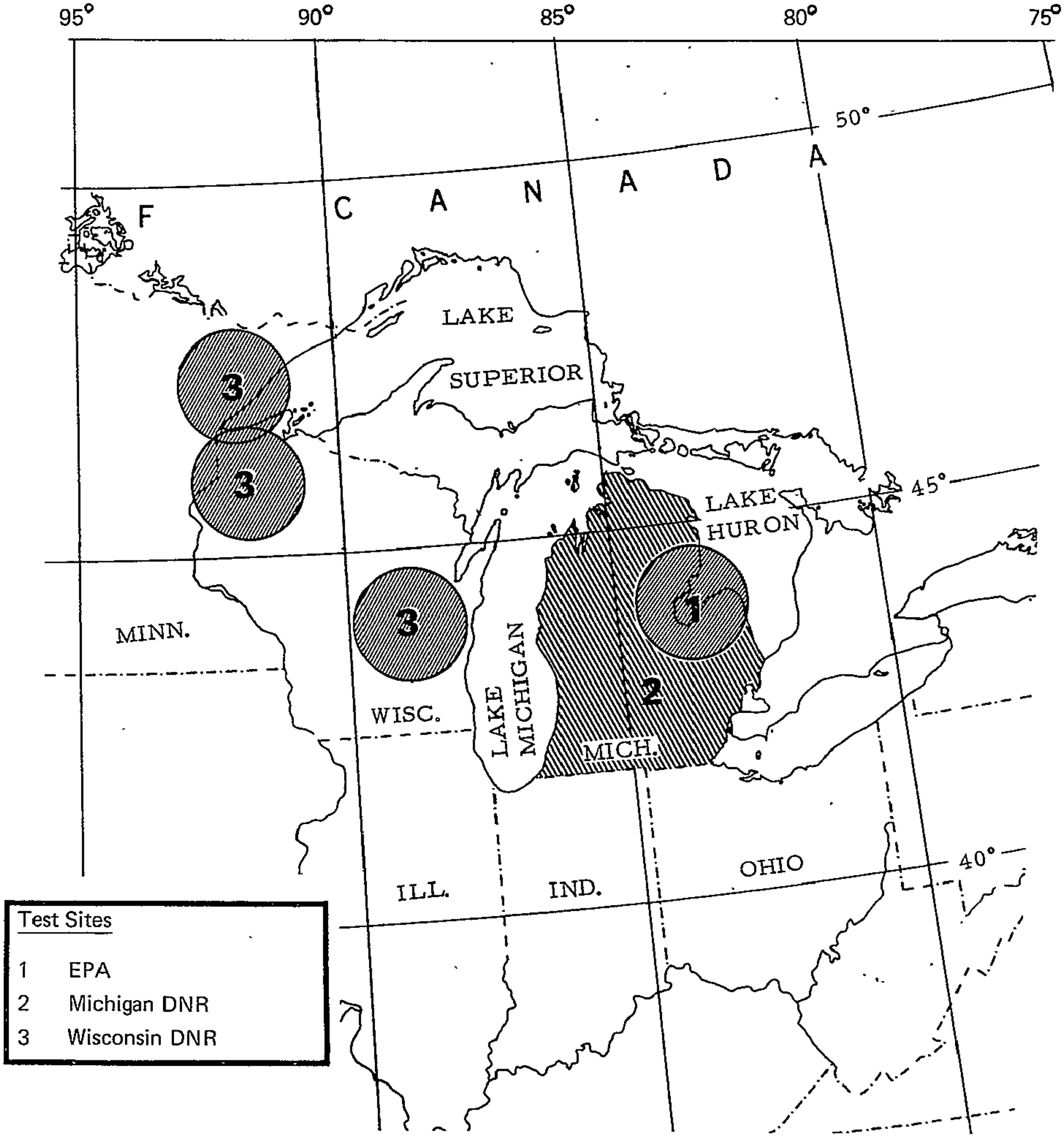

Figure 1-1 LANDSAT Test Sites

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The significant findings resulting from this investigation are listed in Section 4. Techniques proven to be cost-effective and recommended for immediate application together with recommendations for additional investigations are summarized in Section 5.

2. USER DATA REQUIREMENTS

National, state, and local government agencies, as well as conservationists, environmentalists, and private citizens, have become increasingly alarmed over the degradation in water quality in the Great Lakes and many of our public lakes. Much of this degradation is a direct result of pollution generated by man and the increased nutrient runoffs into the lakes resulting from urbanization in the watersheds. It is now realized that our water resources are not inexhaustible and that land development in the watersheds must also be planned if the conflict between utilization of our water resources and maintenance of the quality of our lives is to be resolved. It is now realized that the control of water pollution by single-step, short-range programs is not an approach that will produce noticeable results. Regulations that focus primarily on the end of a sewage discharge pipe do not address the many faceted and complex interactions which, in effect, result in polluted water. Billions of dollars have been expended solely for expensive treatment facilities without making an effort to understand the overall causes and effects of water pollution or to look toward less expensive methods for controlling its impacts. Agriculture, silviculture, mining, construction, urbanization, recreation, and natural processes all contribute in different ways to pollution loads in lakes and streams. The use of the land, the environmental processes that are occurring, and the capacities of streams and rivers to withstand pollution are interactive forces. Planning for the utilization of valuable resources must focus on a range of causes, effects, and solutions to have a meaningful impact on water quality.

In recognition of the worsening water quality in the Great Lakes and inland lakes, legislation such as the Federal Water Pollutions Control Act Admendments (FWPCAA) of 1972 Public Law 92-500 and various Sections 201, 208, 209(a), 303(e), 305(b), 314, and the US/Canadian Great Lakes Water Quality Agreement (GLWQA) have provided requirements and funding to improve water quality. The remote sensing requirements reported in this section are based on the information needs of the organizations conducting water quality programs in response to these acts and legislation.

The users were subdivided into those requiring remote sensing data on the Great Lakes and those requiring information on inland lakes. The data requirements established for the Great Lakes are based on recommendations and needs of the International Joint Commission (IJC) Canada and the United States, US Environmental Protection Agency, the Great Lakes Basin Commission, and the National Oceanic and Atmospheric Administration (Great Lakes Environmental Research Laboratory). Remote sensing required on the inland lakes is based on the needs of the Michigan and Wisconsin Departments of Natural Resources and the needs of many Sub-State Regional Planning Councils and consultants responding to the requirement to develop water quality management plans responsive to Section 208 of Public Law 92-500.

Remote sensing data requirements are a function of the intended use. Organizations having the responsibility for developing plans and recommendations for facilities (e.g., new waste treatment plants, etc.) and controls (land use permits, etc.) required to achieve water quality objectives need remote sensing data to establish the present status of water quality in relationship to published objectives and to determine effects of various sources (e.g., sewage facilities, atmosphere, land use) and controls on achieving the objectives. This effort requires both water quality and land use information for development and application of models used to forecast pollutant loads from existing and new uses of land. Organizations concerned with surveillance and enforcement of water quality need frequent data on lakes to detect potential water quality problems, to monitor progress of known problem waste treatment sources, and to evaluate lake renewal efforts. Research organizations need water quality and land use data in the continued development and improvement of models and techniques for estimating pollutant loads from various land uses, predicting the circulation and distribution of pollutants, and determining the fate of pollutants, e.g., algae growth and weeds, etc.

Techniques used to characterize the status of lake water quality (trophic state) are discussed in Section 2.2 as is the recommended approach of monitoring "biomass" concentration by remote sensing. Satellite data should be used in conjunction with surface sampling to assess trophic state during the 3-week late summer period in late August to early September when maximum amounts of lake nutrients are converted into algae and weeds (biomass). Section 2.3 reviews the sources of nutrients (e.g., phosphorus, nitrogen) which affect water quality (trophic state, eutrophication rate, etc.) and models and techniques used to assess the effects of different land uses on water quality. The role of remote sensing and data requirements are discussed in Section 2.4 for inland lakes and their watersheds and in Section 2.5 for the Great Lakes and their watersheds. These requirements are summarized in the table of Section 2.6.

In all cases, the remote sensing role was one of providing an economical and timely source of water quality and land cover information for lakes and their watersheds. The form and format of the information must be such that it can be directly applied by the user with little or no additional investment.

2.1 EUTROPHICATION: CAUSE AND EFFECTS

One role of remote sensing is that of characterizing and monitoring the effects of nutrients (e.g., phosphorus and nitrogen) on water quality; another is to assess the uses of land in the watershed which are influencing this quality.

Lakes are one of man's most valuable and fragile resources. With the development of improved highway networks, lakes that were formerly protected by distance from metropolitan areas are now within ready access. As a result, many lakes have undergone marked deterioration in response to intensive use of their water and surrounding land. Although boats (water use) and the atmosphere may degrade water quality somewhat, it is the development in the surrounding land that will usually affect lake water quality most seriously.

The reasons for this are fundamentally simple. The lake receives surface runoff and ground water from an area of land around it called the watershed; should the use of this land be radically altered, chances are that the quality of water it yields will be correspondingly altered. As the watershed is developed, forests and other naturally vegetated areas are cleared and replaced with surfaces such as pavement, bare earth, and cultivated land which become new sources of nutrients, salts, and organic debris. Ultimately, these surfaces are flushed by runoff, and the residues of fertilizers, oil, animal excrement, and other foreign substances are carried to the lake by streams, storm sewers, and drains.

The addition of nutrients (e.g., phosphorus and nitrogen) to the lake water causes eutrophication, or lake aging. Eutrophy refers to the increase in the quantity of chemical nutrients and living matter in the lake water over time. Simply put, as the mass of chemical and biological matter increases, the lake is said to grow older. By most standards, this usually represents a deterioration of water quality, especially if aging is artificially accelerated.

Lakes, although giving the impression of permanence when measured on the scale of the human life span, are transitory features of the earth's surface. All lakes, regardless of their orgin, pass through the process of ecological succession which ultimately results in a terrestrial environment.

Figure 2-1 represents the probable successional productivity relationships for a lake. Productivity is initially low, a consequence of low nutrient levels, but increases rapidly as nutrients become more available. The length of time required for completion of the successional process is a function of several factors, including lake basin morphology, climate, and the rate of influx of nutrients from the watershed. The nutrients can drastically increase the rate of lake productivity and thereby shorten the lake's life span.

Eutrophication occurs both naturally and as a result of man's activities. However, the critical factor is the rate of eutrophication under natural conditions compared to the rate under human use conditions. Development of the lakeshore and watershed almost inevitably fosters a faster rate of eutrophication than would be expected under natural conditions. While it is perhaps impossible to avoid some increase in eutrophication due to development, the central issue in water quality planning is how to avoid the enormous increase in eutrophication rate which has already damaged scores of lakes.

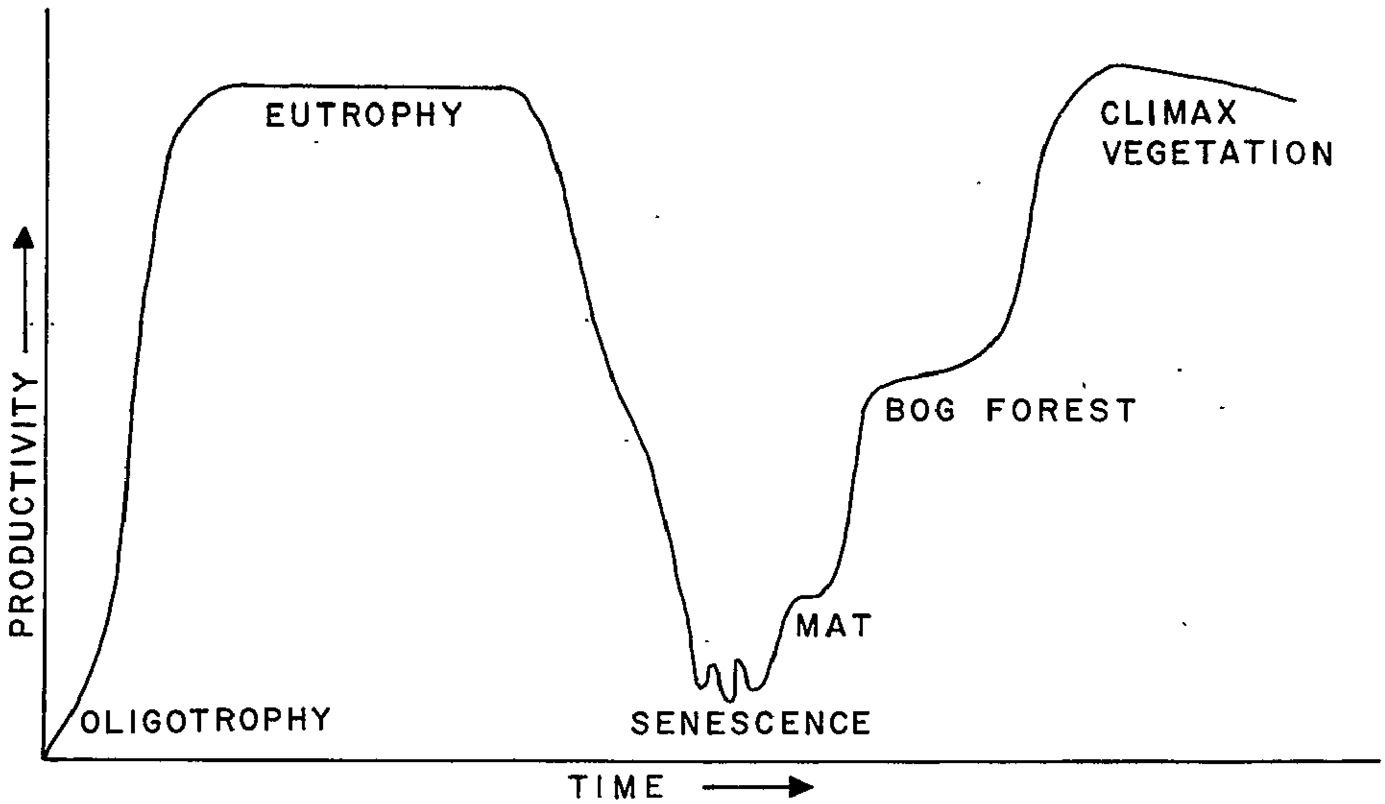

Figure 2-1 Lake Succession - Adapted from Lindemann (Ref 1) and Boland (Ref 2)

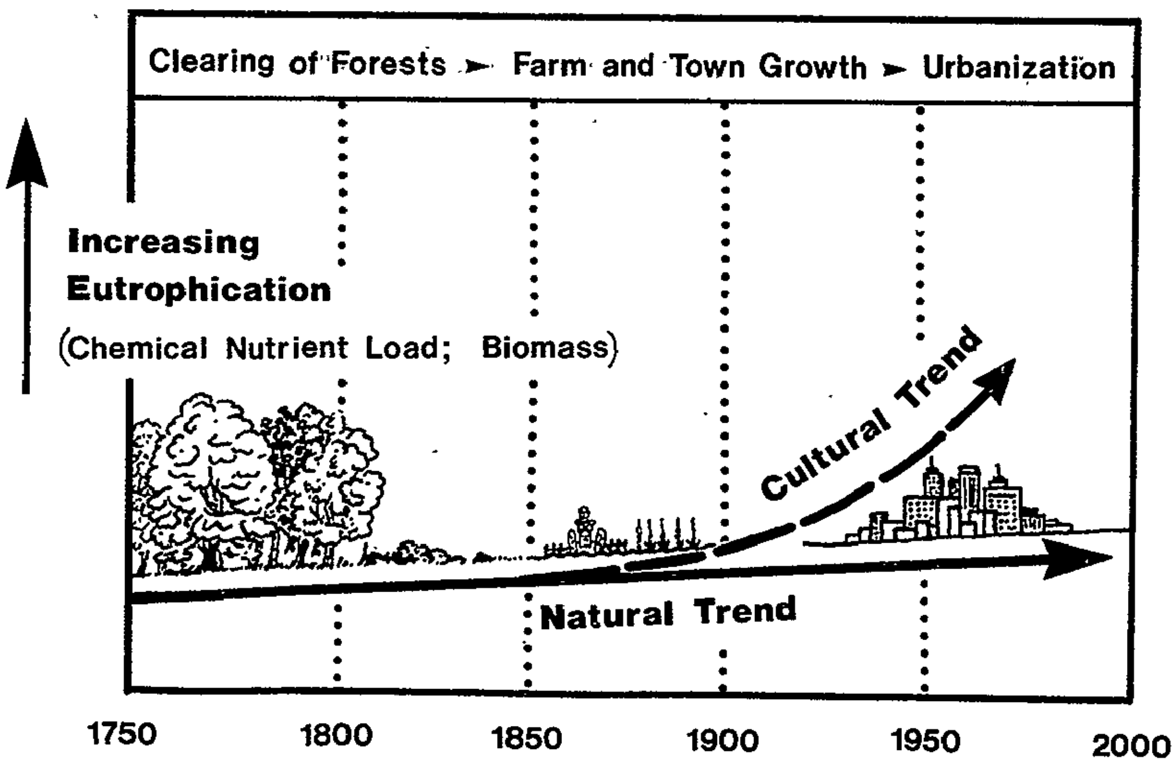

Figure 2-2 Eutrophication Rate, from Marsh (Ref 3)

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The relationship between land development and eutrophication rate is illustrated in Figure 2-2, which shows the difference between man-induced eutrophication (or cultural eutrophication) and natural eutrophication. Notice that the natural trend represents a much slower rate than the cultural trend, which increases rapidly in response to the intensity and type of development.

Many of man's practices relating to the disposition of municipal sewage and industrial wastes and to land use impose relatively large nutrient loadings on lakes and rivers and, hence, increase the rate of eutrophication. In many cases, nutrient enrichment of the lake water results in algal blooms and other symptoms of eutrophication, which often make the water body less attractive to potential users. More importantly, this enrichment accelerates lake succession and shortens the time period before a lake loses its identify and its value as a natural resource.

2.2 TROPHIC STATE

The eutrophication rate should be determined from remote sensing by systematically monitoring "trophic state." Limnologists and others concerned with lakes have used the term "trophic state" to describe two different lake characteristics, nutrient status and productivity. Thus, trophic state is a hybrid concept.

2.2.1 TROPHIC INDICATORS

Several different physical, biological, and chemical parameters are required to describe a lake's trophic state, making the concept multidimensional (Ref 4) and precluding its determination through any single direct measurement. However, it is possible to quantify trophic state through the use of trophic state indicators (indices) in conjunction with appropriate data analysis.

There are numerous indicators of trophic state, each with its merits and shortcomings. A recent summary was prepared by Boland (Ref 2). Some common indicators are listed in Table 2-1. A diversity of opinion exists regarding the number and kinds of indicators which should be considered in the classification of lakes.

Table 2-1

Trophic Indicators and Their Response to Increased Eutrophication. Adapted from Brezonik (Ref 5) and Boland (Ref 2)

Physical	Chemical	Biological
Transparency (d) (Secchi disc reading)	Nutrient concentrations (i) (e.g., at spring maximum)	Algal Bloom frequency (i)
Morphometry (d)	Chlorophyll a (i)	Algal species diversity (d)
	Conductivity (i)	Littoral vegetation (i)
	Dissolved solids (i)	Zooplankton (i)
	Hypolimnetic oxygen deficit (i)	Fish (i)
	Epilimnetic oxygen supersaturation (i)	Bottom fauna (i)
	Sediment type	Bottom fauna diversity (d)
		Primary production (i)

[a]An (i) after an indicator signifies the value increases with eutrophication; a (d) signifies the value decreases with eutrophication. The biological indicators all have associated qualitative changes (i.e., species changes occur as well as quantitative (biomass) changes as eutrophication proceeds). Adapted from Brezonik (1969).

Traditionally, lakes have been put into the three broad categories (i.e., oligotrophic, mesotrophic, eutrophic) to denote three trophic states. These terms are subjective and difficult to define in absolute values; nevertheless, they are widely used by the scientific community as descriptors of lake quality.

1. Oligotrophic lakes have few plant nutrients and support little plant growth. Biological productivity is generally low, the waters are clear, and the deepest zones are well supplied with oxygen throughout the year. Oligotrophic lakes tend to be deep.

2. Mesotrophic lakes are intermediate in character between oligotrophic and eutrophic lakes. They are moderately well supplied with plant nutrients and support moderate plant growth. Mesotrophic lakes are generally considered to be free of nuisance algal blooms, specifically blue-green algae nuisances.

3. Eutrophic lakes cover a myriad of water quality conditions, ranging from the very desirable lakes that support excellent warm water fisheries to lakes of limited recreational value. Eutrophic lakes often experience nuisance algal blooms during the summer. However, some of the most highly prized recreational lakes in the state fit in the "desirable" eutrophic classification.

2.2.2 BIOMASS RECOMMENDED AS INDICATOR OF TROPHIC STATE

Determination of trophic state has been made fron an examination of several diverse criteria, such as the shape of the oxygen curve, the species composition of the bottom fauna or of the phytoplankton, concentrations of nutrients, and various measures of biomass or production. Although each of the criteria exhibits changes from oligotrophy to eutrophy, the changes do not occur at sharply defined places, nor do they all occur at the same rate. Some lakes may be classified as oligotrophic by one criterion and eutrophic by another. This problem is sometimes avoided by classifying lakes that show characteristics of both oligotrophy and eutrophy as mesotrophic.

During this investigation, lake scientists conducting ongoing water quality work were interviewed to determine preferred methods for establishing trophic state:

1. Vern Sather with the Wisconsin DNR at the Spooner Wisconsin office said that, in his opinion, the best indicator of trophic state is the concentration of dissolved orthophosphates directly after spring turnover (these phosphates can later be used to form plant biomass which make lakes eutrophic).

2. Pat Schraufnagle and George Anderson, at the Wisconsin DNR in Madison, were contacted along with other state officials. Mr. Schraufnagle feels that the total biomass tied up in the lake in the late summer is the best indicator of trophic state. (This total biomass expressed as mass of either algae or lake weeds can be accurately sensed by aerial photos and satellite imagery.)

3. Howard D. Wandell with the Michigan DNR and Dale Trippler of the Minnesota Pollution Control Agency agreed that total biomass in the lake in late summer is one of the best indicators of trophic state.

4. Robert E. Carlson also proposed (Ref 6) a trophic state index which is based on the assessment of algal biomass as indicated by Secchi disk transparency or surface chlorophyll a.

Not only does the term trophic state connote biological activity to most limnologists, but it is the biological manifestation of trophic state (weeds and algae) far more than its causes that concerns the public. An indicator that measures and is sensitive to the manifestations would be most meaningful to lay persons and would allow easier communication between them and limnologists.

Therefore, it is the "conclusion" of this study that the best indicator of trophic state is the relative amount of biomass or organic mass produced in the lakes at the peak of the growing season when the waters are all at maximum temperatures and are thermally stratified. Certain nutrients may or may not be turned into plant biomass, depending on the balance of other limiting nutrients, so chemical analysis of any single nutrient is not the best index. However, biomass is the end product of biological production. Thus, the biomass indicator is an integration of other subtle chemical factors. Most important, biomass and organic mass can definitely be seen and monitored by aerial remote sensing.

A problem with a trophic state classification based on biomass is that unlike primary productivity, which can be based on a rate of carbon fixation, biomass is an instantaneous measurement and can only be expressed as an amount present at some point in time. The timing of biomass estimates as indicators of trophic state is a matter of judgment. This report recommends that classification be limited to the period when biological production (i.e., biomass) comes the closest to levels predicted from depleted nutrient concentrations. In essence, this implies that trophic state should be defined by the biomass present during the period of maximal biological growth. In north-temperature lakes, this is usually late August and early September. In lower latitudes, the sampling season could be extended to include most of the summer. This approach should have a favorable appeal to the public, which is more concerned with values obtained during the peak recreational months than with a yearly average.

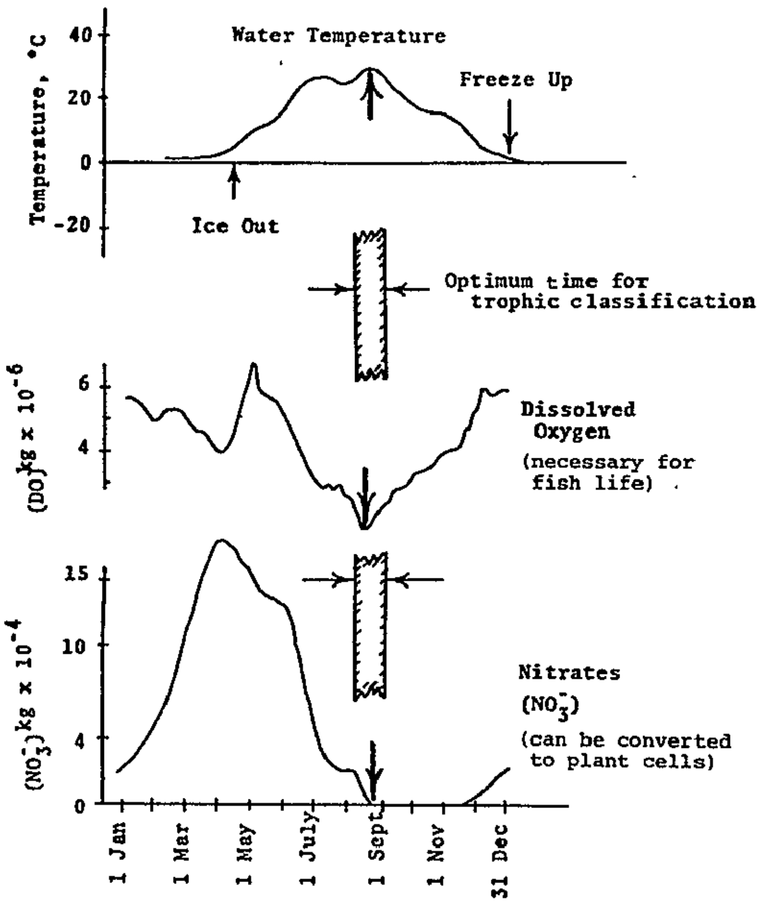
From a careful analysis of measurements derived from inland lakes in Wisconsin (Figure 2-3), it was found that maximum biomass production in this area was in a 3-week period in late August and early September. This biomass can be either algae or aquatic weeds. It is therefore a "conclusion" of this study that trophic state is best determined on inland lakes in the Great Lakes area during this brief 3-week late summer period between August and September when the maximum amount of lake nutrients is converted into algae and lake weeds (biomass). Both algae and lake weeds can be monitored from LANDSAT satellite data and other remote sensing systems.

Biomass or organic mass can be approximated through surface sampling of any one of several parameters - dry weight, volume, total organic carbon, chlorophyll, turbidity, suspended solids, ATP, or Secchi disk transparency. No parameter is ideal in every situation, nor are all the interrelationships of the various parameters well known, but biomass can be approximated by a large selection of measurable parameters, one or more of which may be appropriate in a given situation.

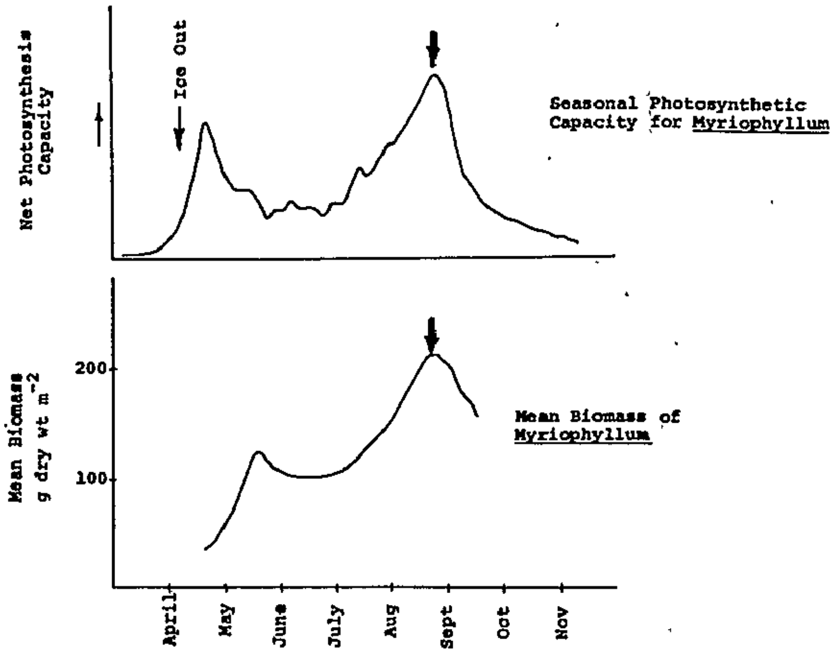
2.3 NUTRIENT SOURCES

Remote sensing can provide watershed land use in a form and format suitable for predicting nutrient loads from existing and new uses of land. Obvious signs of lake eutrophication such as abundant growth of algae and aquatic plants result from addition of nutrients (e.g., phosphorus, nitrogen) to the water from natural (rainfall, dust, bird waste) and man-made sources (e.g., municipal waste treatment plants, agricultural runoff, etc.) The planner faced with the task of controlling or improving the water quality must identify the relevant sources of nutrients, quantify their contributions, and recommend the facilities and procedures needed to control or reduce the nutrient loads.

In analysis of water quality, planners divide nutrient sources into two groups, "point" and "nonpoint" sources. A point source is a direct discharge to a lake or stream that is easily observed and measured, e.g., end of the municipal sewage discharge pipe. A straightforward control action could shut off the nutrient input or reduce it to a specified level. A nonpoint source is the entry of nutrients into waterways in a diffuse manner. This source is often difficult to measure and does not lend itself to a straightforward control action. This category includes natural sources such as atmospheric inputs (wet and dry fall) and storm water runoff. Nonpoint sources frequently are initiated by and associated with precipitation and/or snowmelt events. The EPA has identified (Ref 8) the 21 categories of nonpoint source contributions listed in Table 2-2.



Water temperature, dissolved oxygen, and nitrates plotted against time. Lake Mendota, 1971. Data from Stauffer, Robert Elihu, Ph.D. thesis, University of Wisconsin, 1974.



Seasonal photosynthetic capacity and mean biomass of Myriophyllum spicatum (rooted lake weed) in Lake Wingra (Madison area lake) in 1971. (Modified from Adams and McCracken, 1974).

Figure 2-3 Curves Showing that the Ideal Time for Trophic Classification of Lakes by Remote Sensing is a Several-Week Period in the Last Part of August to the First Part of September (Scherz, Ref 7)

Table 2-2

Nonpoint Sources	
Agriculture	Salinity
Dry land	Irrigation
Irrigation	Oil field brines
Animal Wastes	Natural
Range lands	Deicing
Silviculture	Municipal and Industrial Effluents
Forestry management	Urban Runoff
Harvesting	Storm
Mining	Surface runoff
Active	Rural sanitation
Inactive	Construction
Tailings and overburden	Land development
Ground water	Heavy construction
Hydrographic modification	

Combined sewer overflows and separate sanitary sewer overflows are sometimes grouped with nonpoint sources because of their intermittent nature connected with storm events.

As discharges from industries and municipalities are abated, the relative significance of nonpoint sources will rise. The EPA has estimated that approximately one-third of the pollution in streams not currently meeting water quality standards comes from nonpoint sources. New findings in Lake Ontario (Ref 9) suggest expected improvements in water quality may be limited by effects of phosphorus inputs from land drainage and the atmosphere. Chapra reports (Ref 10) that from an analysis of domestic sewage, land runoff, and atmospheric inputs, the runoff from agricultural sources is a major contributor of phosphorus to Saginaw Bay and lower Green Bay. He also notes that, to obtain the desired trophic conditions in lower Green Bay, Saginaw Bay, and western Lake Erie, that careful management of sewage and land practices will be needed.

Control of point sources (sewage facilities) is a billon dollar proposition. Funding by the end of 1977 is expected to be about $5 billion for Great Lakes waste control (Ref 9). Hence, it is becoming increasingly important to identify/quantify both point and nonpoint sources of pollution and to establish their relative contribution. One task for remote sensing in this effort is to provide an economical and accurate source of information on the characteristics and coverage of nonpoint land cover sources.

2.3.1 LAND COVER AND RELATIONSHIPS TO NUTRIENTS

Watershed land uses should be derived from remote sensing in a format suitable for models used to predict nutrient loads from land use.

Parameters having major effects on quantity and quality of runoff from the nonpoint (land use) source include: intensity and duration of rainfall, characteristics of drainage area (i.e., size, slope, etc.), land use characteristics, and soil texture and slope. Marsh (Ref 3) notes that the efficiency of the flow system or channels that link the drainage area to the lakes is also an important parameter. Although many factors affect lake water quality, the dominant one is the use of land adjacent to and surrounding the water.

The lake gains its water from an area of land around it called the "watershed," and should the use of this land be radically altered, chances are that the quality of water it yields will be correspondingly altered.

During periods of rain or thaw, sediment and nutrients within the watershed are washed directly into nearby water bodies. Each land use/land cover category has a different effect on the quantity and quality of stormwater runoff. For example, urban lawns and streets discharge more nutrients, especially phosphorus, than do rangeland and forested land. Cropland is often tilled in the spring when rainfall is heaviest and absorbs much of the water, but erosion in the form of sediments containing pesticides and fertilizer are washed into nearby streams. This differs from what happens in a center city area where virtually all of the ground is covered by pavement and buildings and little or none of the water is absorbed into the earth. Instead, the water flows rapidly into storm sewers, carrying with it dirt, oil, animal waste, etc. from streets and buildings.

The assessment of effects of nonpoint (land use) sources on water quality is accomplished in two or more phases. One phase is the development and application of models for predicting the quantity and quality of runoff and the resulting concentration of nutrients (loads) in the waterways. Another phase is one aimed at forecasting the behavior of the nutrients (e.g., nitrogen and phosphorus) on aquatic ecosystems (e.g., algae and zooplankton). Reckhaw has reported (Ref 11) a technique for relating phosphorus loads to the development of biomass and lake eutrophication. Major parameters included in this model were water volume and detention time (flushing rate). State water quality standards are stated in terms of permissible (maximum) concentrations of water quality parameters. (e.g., total solids, coliform bacteria, compounds of nitrogen and phosphorus, etc.) which can be derived from direct measurement or sampling. The planner assumes that the relationships between permissible concentrations of nutrients and lake eutrophication rate growth of algae and weeds, etc. have been previously established and that land use, and facilities that produce less nutrients, will have little or no impact on lake eutrophication rates. Hence, the planner's goal is generally a quantitative one of designing facilities and controls to maintain nutrient concentrations in the waterways to a measurable and permissible value. The planning tasks include relating existing and future land uses to expected nutrient concentrations and providing the facilities and controls to maintain the concentrations at the permissible levels.

Many models and procedures have been derived to predict quantity and quality of nutrient and other pollutant loads resulting from storm runoff. Some of the available techniques have been listed by EPA (Ref 12) and are summarized below. An important requirement for remote sensing is to provide land cover information in a directly usable format for these techniques.

2.3.1.1 Black-Box Predictor

One of the most widely used techniques involves an in-depth literature review to find the applicable "areal mass loading factor" (also termed mean total nutrient export factor, loading rate, etc.) for each land use category of interest. These factors are typically expressed in terms of weight per area per time (e.g., kilograms per square kilometer per year or pounds per acre per year). The procedure is to multiply this export factor by the area covered by the corresponding land cover type within each drainage area to determine load (e.g., kilograms per year) in the receiving waterbody. This method yields good accuracy if detailed land cover data are available and particularly if local mean loading factors are available. EPA recommends this procedure for "preliminary analysis."

Several extensive literature reviews have recently been published which provide loading factors for various land use categories as related to nitrogen and phosphorus concentrations and loads in streams. See Omernik (Ref 13) for references to their reviews and recent factors summarized by Omernik. In developing systems for estimating nutrient runoff from land use based on coefficients developed entirely, or in part, from the literature, most reviewers summarize their findings by presenting a range of values and, in some cases, midpoints or averages. Omernik (Ref 13) has reports on the analysis of data from 473 nonpoint type drainage areas in the eastern United States for relationships between drainage area characteristics (particularly land use) and nutrient levels in streams. This is a spinoff of the National Eutrophication Survey (NES), which is using 1,000 nonpoint drainage areas to look at land use-nutrient-load relationships and eutrophication on a national scale, and to develop a system using coefficients or a range of coefficients, to reflect geographical or regional differences.

The NES effort (Ref 14) and work reported by Omernik (Ref 13) considers the following land use categories: (1) forest, (2) cleared-unproductive, (3) agriculture, (4) urban, (5) wetland, and (6) other (includes barren, extractive, and open water). In analysis of watersheds, NES and Omernik have characterized watersheds by the criteria shown in Table 2-3.

Table 2-3

National Eutrophication Survey Land Cover Categories

1. Forest; other types negligible
   a. > 75% forest (including forested wetland)
   b. < 7% agriculture
   c. < 2% urban.

2. Mostly forest; other types present
   a. > 50% forest
   b. Not included in forest category.

3. Mostly agriculture; other types present
   a. > 50% agriculture
   b. Not included in agriculture category.

4. Agriculture; other types negligible
   a. > 75% agriculture
   b. < 7% urban.

5. Mostely urban
   > 39% urban

6. Mixed; not included in any other category.

Phosphorus and nitrogen export factors for the six NES categories averaged over a 23-state area by Omernik are shown in Figure 2-4. Omernik notes that these data and other results show significant relationships including: (1) mean total phosphorus export from agricultural lands is 3.7 times greater than that from forested lands; mean total nitrogen export was 2.2 times greater, and (2) mean total phosphorus concentrations in streams were nearly 10 times greater in streams draining agricultural lands than in streams draining forested areas. The difference in mean total nitrogen concentrations was about fivefold.

Great care must be taken in the use of export and loading factors obtained from the literature. Soils, slope, rainfall characteristics, and agricultural practices are also important parameters to consider in using loading factors.

Regional Application - An example of the application of the Black-Box Predictor method with land cover derived from LANDSAT is reported (Ref 15, 16) by the East Central Michigan Planning and Development Region (a 13-county region covering 8,700 square miles and contained within the Saginaw Bay watershed).

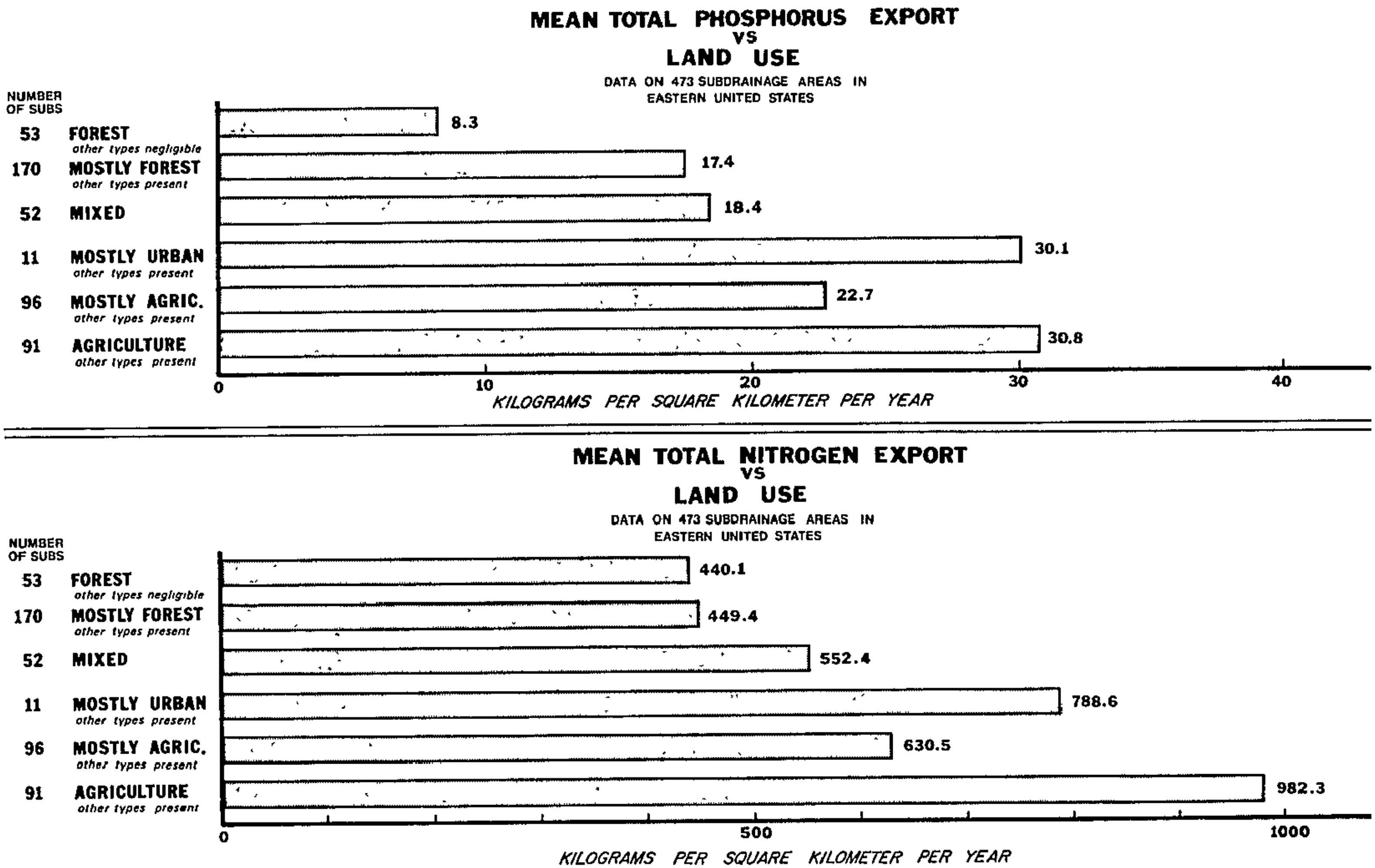


Figure 2-4 Relationships between General Land Use and Stream Exports of Total Phosphorus and Total Nitrogen (from Ref 13)

LANDSAT data were processed by Bendix into approximately 39 land cover categories. These were aggregated by the region into the six categories shown in Table 2-4 and assigned loading rates (export factor).

Table 2-4

Loading Rates (Ref 15)
(lb/acre/yr)

PARAMETERS \ LAND COVER	URBAN/ IMPERVIOUS	AGRICULTURE/ INTENSIVE	FOREST	AGRICULTURE/ RESIDENTIAL	GRASSLAND	BARREN/ EXTRACTIVE	ATMOSPHERIC
BOD_5	56	10	0.1	1	1	0	0
Suspended Solids	560	1,500	30	300	300	3,000	0
Ammonia	1	0.75	0.2	0.5	0.5	0	2
Oil and Grease	40	0	0	0	0	0	0
Total Nitrogen	16	10	0.1	1	1	0	20
Total Phosphorus	7	5	0.05	0.5	0.5	0	0.5

No loads were assumed for water, wetlands, and uncategorized categories that were also mapped. These loading rates were multiplied by the area covered by each land cover type within the watershed to compute loads available to the streams and rivers in each of the region's 22 watersheds.

Remote sensing information required to estimate loads by this procedure is the area covered by each land use category in acres or square kilometers by drainage area. The number and type of categories required depend upon availability of the areal mass loading factors (loading rates) for cover types in the region.

2.3.1.2 Sediment/Nutrient Predictors

Pollution from sediment and associated nutrients, pesticides, and other contaminants occurs to some degree during any land disturbing activity and thus is associated with mining, construction, agricultural activities, etc. The EPA (Ref 17) lists representative rates of erosion from various types of land cover. From this (Table 2-5), it can be seen that active surface mining and construction activities create the largest amount of sediment—forest the least. Vegetation density has an important relationship to soil erosion.

Table 2-5

Representative Rates of Erosion from Various Land Uses (Ref 17)

Land use	Tons per mi^2 per year	Relative to forest = 1
Forest	24	1
Grassland	240	10
Abandoned surface mines	2,400	100
Cropland	4,800	200
Harvested forest	12,000	500
Active surface mines	48,000	2,000
Construction	48,000	2,000

A class of methods based upon soil erosion and sediment transport to streams has also been developed in an attempt to satisfactorily quantify pollutant loadings from nonpoint sources. Erosion rates are computed using the Universal Soil Loss Equation "USLE" or the Musgrave equation (Ref 12, 18, 19). Sediment transport is accounted for by determining or estimating the ratio of sediment generated in the drainage area to that actually reaching the receiving water. Fixed multiples of the sediment mass loads are used to estimate the loadings of BOD, nutrients, pesticides, and other contaminants.

The USLE and Musgrave equations require data inputs for factors such as rainfall, soil, erodibility, slope length, and slope gradient. Additionally, Musgrave uses factors for cover type (R), and the USLE contains a parameter for crop management (c) and erosion control practice (P).

These equations are used primarily for agricultural lands, and regional values for each of the variables are generally available. Local Soil Conservation Service (SCS) offices have data specific to the particular soils and crops in their districts. The SCS uses the USLE to estimate sediment yields from croplands.

Regional Application - An example of the application of a modified USLE with land cover information derived from LANDSAT is reported (Ref 18, 19) by the Ohio-Kentucky-Indiana Council of Governments (OKI). The model was applied to each of 226 rural watersheds which ranged in size from 20 to 100 square miles. LANDSAT data categorized into cropland, woodland, and grassland provide the land cover source. The cover information was recorded on black/clear map overlays, where each cover type is on a separate overlay. The overlays were placed over soil maps to determine the area covered (acreage) by each cover type, by soil type, for each drainage area. Cropping management factors and erosion control factors were derived from the soil/land use combinations and input to the USLE together with information on drainage characteristics (slope and length) and rainfall to estimate annual loads within each of OKI's 226 rural watersheds.

The number and type of land use categories required from remote sensing depend upon the dominant cover type of the region and the availability of published factors to account for the cover type, cropping management factors, and erosion control practices. The cropping management and erosion control factors are derived as in the OKI example from a knowledge of the combination of land cover and soil type. Hence, the user of this model requires land cover information (overlays, tables, etc.) in such a form that it can be easily combined with soil and other sources of information.

2.3.1.3 Hydrographic Predictor

Unit hydrographs are sometimes used as a method for estimating pollutant loadings from nonpoint sources. This method is normally used for urban watersheds and yields loads for an individual storm event. The data requirements include detailed (hourly) rainfall information, the nature and extent of land cover types, deposition rates of pollutants on impervious surfaces, antecedent rainfall data, and a prediction method for determining washoff as a function of rainfall intensity. This method can be expanded to give "pollutographs" and "loadographs," i.e., plots of water quality parameter levels versus time at a given location.

Literature reviews have reported (Ref 14) a number of articles on pollutant loadings from nonpoint sources in urban areas. Sartor and Boyd (Ref 20) analyzed urban runoff with respect to land use for a number of cities. They concluded that streets in industrial areas tend to be more heavily loaded with pollutants than residential and commercial streets. Commercial areas, which are swept regularly for esthetic purposes, have the lowest pollutant loading intensities, although they may receive more pollutants than residential areas. The results of their findings are reported; a summary of the various contaminant loadings with respect to land use is presented in Table 2-6.

Table 2-6

Distribution of Contaminant Load by Land-Use Category (lb/curb mile)

	RESIDENTIAL	INDUSTRIAL	COMMERCIAL
Total Solids	1,200	2,800	360
Volatile Solids	86	150	28
BOD_5	11	21	3
COD	25	100	7
Kjeldahl Nitrogen	2.0	3.9	0.4
Nitrates	0.06	0.18	0.18
Phosphates	1.1	3.4	0.3
Total Heavy Metals	0.58	0.76	0.18
Total Pesticides	--	--	--

Phosphorus and nitrogen export factors are generally concluded to increase as the intensity of land use increases - as percent impervious area increases, and as vegetation density decreases. This is related to two facts: (1) intensive human activities generate large amounts of surface residue, and (2) impervious surfaces associated with intensive land uses generate a large and fast flowing volume of runoff that flushes the residue from the land. A tenfold increase in phosphorus content of surface runoff was found when forested land was converted to agriculture use (cropland) and a twentyfold increase when cropland was converted to urban usage (Ref 21).

Models providing "pollutographs" have been computerized to facilitate analysis. Table 2-7 is a partial list of computerized models that can be used to estimate various water quantity and quality parameters for storm runoff. Further details on these watershed models can be obtained by consulting the sources of information cited in Table 2-7 and the reports (Ref 14, 22, 23).

A detailed breakdown of the urban categories is required from remote sensing for some models: i.e., residential, industrial, and commercial. Other models use factors such as percent impervious, housing density, population density, etc.

Table 2-7

Summary of Information on Four Computerized Watershed Simulation Models*

Model Name	Source of Information	Availability	Principle Uses
MIT Catchment Model (MITCAT)	Resources Analyses, Inc. 1050 Massachusetts Ave. Cambridge, Mass. 02139	"Use fee" charged per simulation run No fixed lease fees or monthly charges	- Simulates runoff hydrographs from urban and rural basins - Flood event simulator - No groundwater flow component
Hydrocomp Simulation Program (HSP)	Hydrocomp, Inc. 1502 Page Mill Road Palo Alto, CA 94304	Available on lease from Hydrocomp	- Simulates runoff hydrographs from urban and rural basins - Continues simulations over long time periods - Has groundwater flow component
Storm Water Management Model (SWMM)	U.S. Environmental Protection Agency Attn. Harry Torno, Staff Engineer Office of Research and Development Washington, D.C. 20460	Available from U.S. Environmental Protection Agency	- Simulates performance of urban storm drainage systems - Used in storm system design - Flood event simulator - No groundwater flow component
Urban Stormwater Runoff Model (STORM)	The Hydrologic Engineering Center U.S. Army Corps of Engineers 609 Second Street Davis, CA 95616	Available from Hydrologic Engineering Center	- Used in reconnaissance level studies for planning urban storm water controls - Employs unsophisticated rainfall-runoff and routing procedures

*Source: Brown, J.W. et al., 1974, Ref 22.

2.3.1.4 Direct Measurement

Where the previous techniques start with land and forecast its effects on water, the direct measurement approach starts by first examining the nutrient concentration in the water, assigning a loading factor, and attempting to identify the source(s) of these loads. One method of implementation requires a system of simultaneous equations, which describes pollutant input to streams as a function of land cover. Data requirements include detailed land cover data and mass loadings of pollutants for a specified storm event or time period. The mass load at a point within the stream would be equal to the sum of the loadings from each land cover type in the upstream drainage area. It is assumed that there is a constant areal loading factor associated with each land cover classification; therefore, the total load of a particular pollutant from a particular land cover type is simply the loading factor times the total land area of that land cover type.

2.3.2 ATMOSPHERIC SOURCES AND RELATIONSHIP TO NUTRIENTS

Another important nonpoint nutrient source is rain and snow falling directly on lakes. Lake scientists have recognized that phosphorus and nitrogen are present in precipitation. Often the concentration is higher in the rainfall than in the lake. One study has shown that rainfall in the Cincinnati, Ohio area averaged 0.69 mg/L inorganic nitrogen and 0.88 mg/L total phosphorus. To appreciate the significance of these levels, note that only 0.30 mg/L of inorganic nitrogen (or one-half of the concentration found in the rainfall) is required to produce algal blooms in lakes. Similarly, the total phosphorus level in rainfall is 80 times higher than the 0.01 mg/L inorganic phosphorus threshold concentration. Since inorganic phosphorus is always a fraction of total phosphorus, the inorganic fraction in rainfall would often be equal to or greater than 0.01 mg/L.

Nitrogen and phosphorus contributed by rainfall is a significant part of a lake's total annual nutrients. A study at Houghton Lake (Roscommon County, Michigan) found the nutrients in direct precipitation accounted for 41% of the total phosphorus and 49% of the total nitrogen contributed annually from all sources.

In addition to rainfall and snow, another atmospheric source of nutrients is dust fallout. A Cincinnati, Ohio study found that dust from atmospheric fallout averaged 300,000 pounds per square mile per year and in some areas could reach 80,000 pounds per square mile per month. Since atmospheric dust (soil particles) often contains absorbed phosphorus, reduction in the annual dust contribution to the lakes aids in slowing the rate of eutrophication.

Future remote sensing programs should also address the need for additional information on atmospheric sources and quantifying their contribution of nutrients, etc.

2.4 INFORMATION REQUIRED ON INLAND LAKES AND THEIR WATERSHEDS

Information on Inland lakes and associated drainage areas is needed by state and sub-state (3 to 13 county planning regions) planning agencies responding to the need to control and improve water quality of inland lakes.

2.4.1 STATE AND REGIONAL NEEDS/LEGISLATION

2.4.1.1 State

Land cover and water quality data are needed by Michigan, Wisconsin, and most states for the purpose of: (1) assessing and monitoring the trophic state of lakes (to determine eutrophication rate), (2) evaluating aquatic nuisance control treatments, lake renewal efforts, and other management measures expected to change a lake's trophic status, (3) detecting nutrient pollution inflows where controls may be needed, and (4) developing, calibrating, and applying models to forecasting effects of existing and new land uses on rate of eutrophication. Achieving these goal will aid the states in reaching their ultimate objective of determining how the states' land use practices should be modified so as to ensure the protection of lake recreational values. The data collected on water quality are also needed by the states to respond to Section 305 (b) of the Federal Water Pollution Control Act Amendments (FWPCAA) 1972, Public Law 92-500. This section requires each state to prepare an annual report describing the water quality conditions for all navigable waters.

2.4.1.2 Regional

Land cover and water quality information is needed by the EPA-designated planning regions (Figure 2-5) that are developing Water Quality Management Plans (WQMP) in response to Section 208 of the FWPCAA.

Section 208 initiated a coordinative approach for addressing the problems of water pollution. Provisions of this act provide designated federal, state, and sub-state regional planning agencies with financial support to develop a comprehensive Water Quality Management Plan (WQMP) (Ref 12, 24) for their respective planning regions. This funding (typical 2-year grants) requires the designated agencies to develop a WQMP for improving water quality while concurrently addressing key environmental aspects which are directly related to implementing the plan. Environmental factors include the physical environment (e.g., air, water, wildlife habitat), the social environment (e.g., housing, culture), and the economic environment (e.g., per-capita income, employment). Figure 2-5 shows that approximately 150 regions (state and sub-state) have been designated to develop WQMPs.

The objective of the 208 WQMP is achievement of water quality consistent with the 1983 water quality goals for swimmable and fishable water. These requirements are translated by each state into more specific physical, chemical, or biological requirements given in terms of the state's water quality standards (e.g., turbidity, fecal coliform, phosphorus, etc). Thus the assessment of the effects of WQMP elements on water quality reflect the water quality parameters used in specific state standards. Such a planning process deals with both the "point sources"

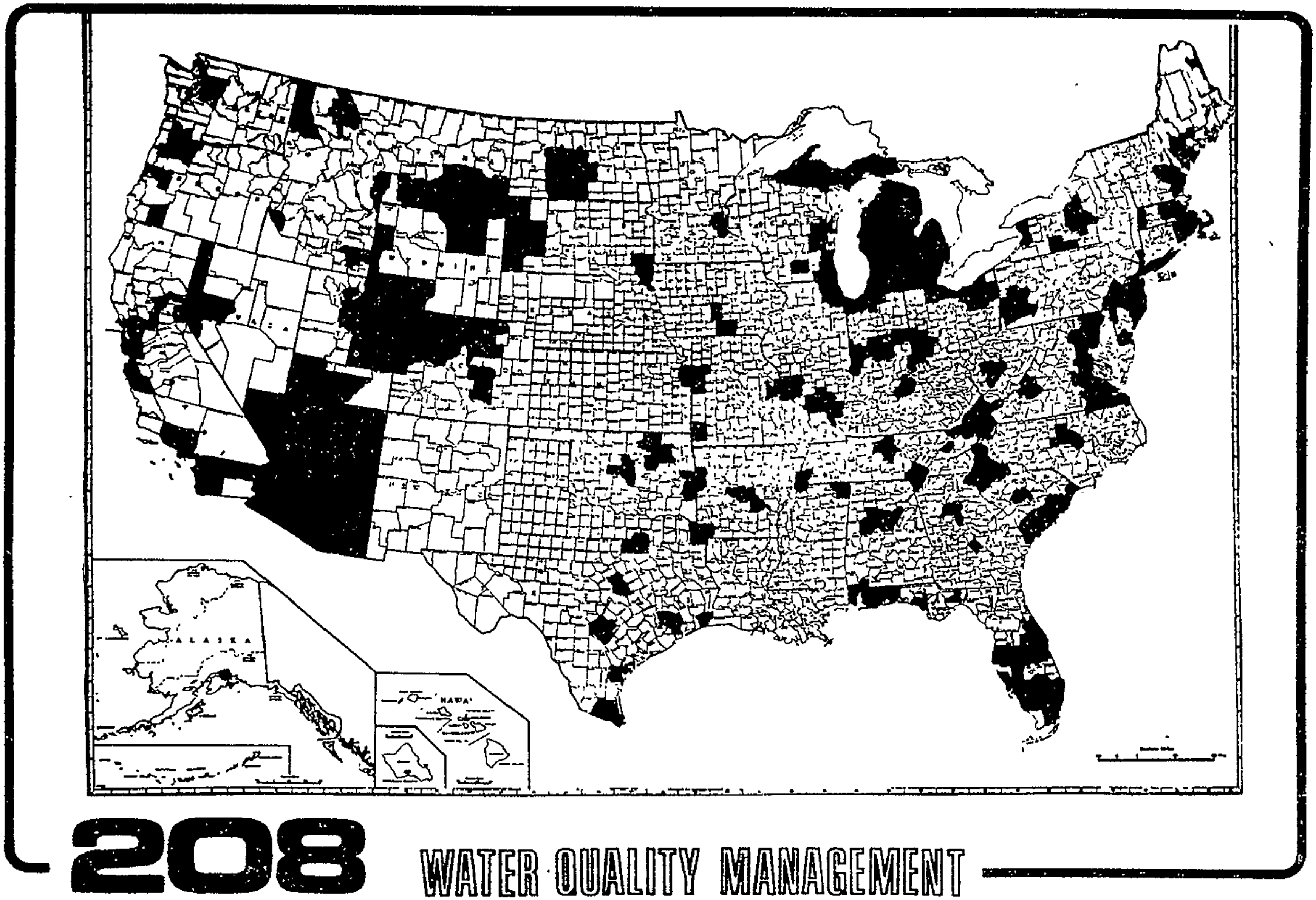


Figure 2-5 Section 2-8 Local Agencies

(such as waste treatment facilities) and "nonpoint sources." These nonpoint sources include storm-water runoff from agricultural areas, urban runoff, erosion from construction sites, and leachates from septic tanks.

2.4.2 WATER QUALITY NEEDS: TROPHIC STATE

The states need information on the trophic status of lakes to prepare reports on conditions of navigable waters (Section 305-b), to evaluate aquatic control and lake renewal programs, to detect problem lakes where controls may be needed, and in the development and use of models for evaluating land use practices in watersheds of public lakes. The Sub-State Regional Planning Groups responding to Section 208 guidelines need water quality information to establish present quality of water in regard to 208 objectives and in development and use of models for estimating effects of sources (land use, sewage) and controls on water quality. Water quality information is generally collected by the states and placed into computer storage and retrieval systems, i.e., the US Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) (Ref 25). Data are available from WATSTORE to anyone who needs it. The planning regions responding to 208 grants generally do not have time nor the funding to undertake an extensive sampling program and thus obtain whatever data they can from WATSTORE and other sources.

2.4.2.1 Michigan's Self-Help Program

Michigan, Wisconsin, Minnesota, and most states have programs whose objectives are to monitor trophic status of inland lakes. As one of several initial steps taken by Michigan toward a statewide inland lake, a cooperative eutrophication "warning" system was established in the spring of 1974 by the Inland Lake Management Unit - Michigan Department of Natural Resources; its purpose was to assess the trophic status (degree of eutrophication) of Michigan's recreational lakes. It utilizes citizens as active participants in conjunction with the state's lake scientists. Because of the citizen involvement, it goes by the name "Inland Lake Self-Help Program" (Ref 26). Eighty-nine lakes were enrolled in the 1976 program, and approximately 150 for the 1977 season.

The Michigan program revolves around a central theme - i.e., the annual amount of nutrients (phosphorus and nitrogen) reaching a lake is responsible for the eutrophication rate. These nutrients act as fertilizers and are responsible for an increase in the quantity of algae and aquatic plants in the water. In general, as the annual quantity of nutrients entering the lake increases, there usually follows a corresponding increase in the amount of algae and a decrease in the transparency of the water. The Self-Help Program monitors the "size" of the algae population by determining the chlorophyll _a_ concentration and water transparency.

Chlorophyll _a_ is used to measure algal biomass present for photosynthesis and growth. It is one of a number of green pigments in all plants, and is found in the leaves of higher aquatic plants and in the cells of algae. Chlorophyll is necessary for conversion of sun energy into chemical energy in the forms of carbohydrates, fats, and proteins. This process is termed photosynthesis. There are five recognized chlorophylls; a, b, c, d, and e. Only chlorophyll a is common to all aquatic algal groups; hence, it is useful in estimating algal abundance. Although there are some limitations on the use of chlorophyll a as a measure of algal standing crop, it is still a reasonable estimate for this type of program.

Water transparency measurements are used to determine the depth of light penetration. This is a relatively simple measurement requiring only the use of a round black and white 8-inch disc (Secchi) connected to a graduated line (Ref 26).

The Secchi disc is used to measure transparency (clarity). Twice the depth of the Secchi disc measurement designates the euphotic zone; this is the zone that contains sufficient light for plant growth (Figure 2-6). Composite water samples are collected from the euphotic zone, preserved with 3 to 4 drops of a supersaturated solution of magnesium carbonate, and mailed to the Department of Natural Resources Laboratory in Lansing, Michigan for analysis.

Data on water clarity and chlorophyll a are obtained weekly/biweekly between 10:00 a.m. and 2:00 p.m. from May through September by an individual appointed by the lake association. Transparency measurements and water samples are collected from the open water zone over the deepest part(s) of the lake.

The Michigan Self Help Program derives an estimate of biomass (algae) from chlorophyll a and Secchi disk transparency and relates these measurements to trophic state as shown by Tables 2-8 and 2-9.

Table 2-8

Michigan Self-Help Chlorophyll a Criteria Compared with Other Studies

Trophic Conditions	Chlorophyll a (µg/L) - ppb Michigan Self-Help Survey	National Academy of Science[27]	Sakamota[28]	Dodson[29]	National Eutro Survey[30]	Ministry of the Envir.[31]
Oligotrophic	0-4	0-4	0.3-2.5	0-4.3	<7	0-3
Mesotrophic	4-10	4-10	2.5-15	4.3-8.3	7-12	3-5
Eutrophic	>10	>10	15-40	>8.8	>12	>5

Table 2-9

Self-Help Secchi Disc Criteria Compared with Other Studies

Trophic Condition	Transparency (feet) Michigan Self-Help Study	Dobson[29]	National Eutrophication Survey[30]	Ministry of the Environment[31]
Oligotrophic	>15	>20	>12	>16.5
Mesotrophic	6.5-15	10-20	6.5-12	10-16.5
Eutrophic	<6.5	<10	<6.5	<10

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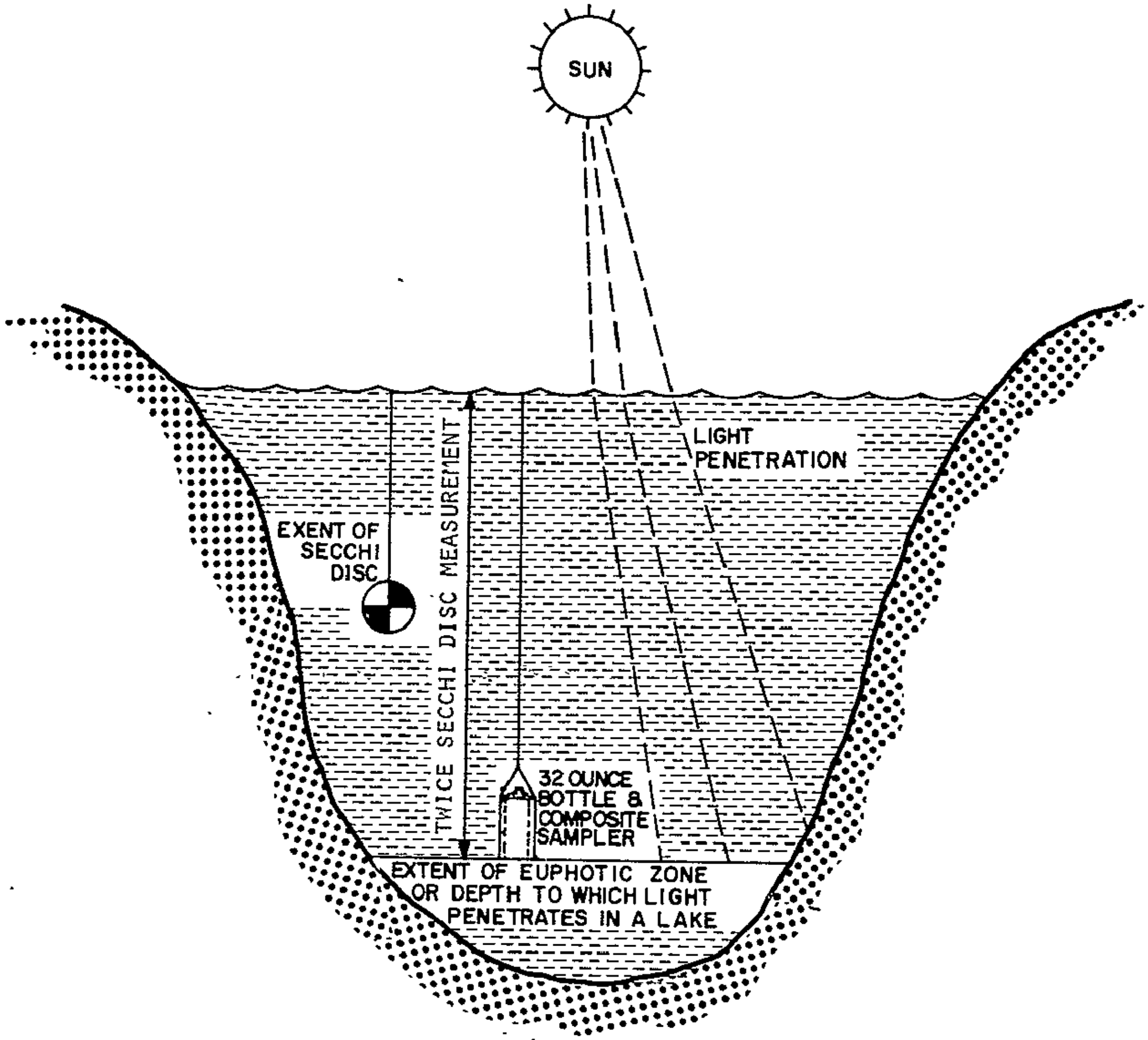

Figure 2-6 Sample Collection Method

An arithmetic mean of the measurements over the entire sampling period is calculated and located in Tables 2-8 and 2-9. The trophic classification used is the one which places a lake in the most productive category. Thus, a lake, which had a mean chlorophyll a concentration considered to be mesotrophic and a mean Secchi transparency considered to be eutrophic, would be classified as a eutrophic lake. The present technique does not take into account the biomass of higher aquatic plants (i.e., weeds, wild rice, etc.).

2.4.2.2 Need for Additional Monitoring

Most of the states have access to laboratories and field crews for analyzing lake water quality and establishing trophic state. Due to funding and staff limitations, these crews are limited to sampling about 3 to 5 lakes per day. The states in the Great Lakes test area with present funding/facilities can sample at most 50 to 200 lakes during the 3-week window in August and early September when the maximum amount of lake nutrients are converted to biomass and lakes are at maximum stratification. Ideally, all lakes should be assessed at this time to obtain a good relative comparison between them. The 50 to 200 lakes which states can presently handle is a small fraction when compared to Michigan's lakes: (1) 1,000 lakes exceeding 100 acres, (2) 2,000 lakes exceeding 50 acres, and (3) 10,000 lakes exceeding 10 acres. Wisconsin has some 10,000 lakes, more than half of which exceed 20 acres. The problem of inventorying thousands of lakes in a brief late summer period is a challenge to any state.

2.4.3 REMOTE SENSING REQUIREMENTS: TROPHIC STATE

The requirements for remote sensing to establish trophic state is the same for the state and sub-state planning regions. The only difference is the size of the region of interest and the number of lakes within it. The role of remote sensing to both users is providing a cost-effective source of information on trophic state of the lakes of interest. At the state level, the task of remote sensing is to extrapolate measurements from about 200 lakes of known trophic state sampled by citizens and the state to the remaining 10,000 or more state lakes. Remote sensing should map the effects of both algal biomass and weeds of all lakes in the late summer every 5 years with problem areas updated annually. Close coordination with state and regional efforts would be required to optimize use of sampling throughout the state

The following summarizes these findings in terms of remote sensing data requirements:

1. Water Quality Parameter - The best indicator of trophic state is biomass (algae and weeds). Surface measurements easily obtained which relate directly to algal biomass are chlorophyll a and water clarity as estimated by light transmittance or Secchi depth.

2. Format - Color-coded image/map is needed showing various concentrations (levels) and distributions of biomass and location and extent of weeds. The user-preferred map scales are 1:250,000 to 1:24,000.

3. Detail - The present LANDSAT resolution of 80 meters is sufficient for 50-acre or larger lakes, but not adequate for lakes of 10 acres or smaller. A resolution of 10 to 40 meters is needed to monitor 10-acre lakes.

4. Time and Frequency of Measurement - It is recommended that remote sensing be coordinated with state sampling and be accomplished in the 3-week late summer period (August - early September). First-year data would be collected and processed to establish trophic level of all lakes. Second through fourth year data are collected and screened but not analyzed in depth unless problems are suspected. Fifth-year trophic levels of all lakes are determined. Schedule repeats.....

5. Data Age - Data age as defined here is the time period between detection (coverage) of parameter with remote sensor and presentation of map (information) to user. A 3 to 4 month or shorter response is needed.

2.4.4 WATER QUALITY NEEDS: LAND COVER

2.4.4.1 State

The state needs land use information together with water quality data for use in developing and applying procedures (models, etc.) for forecasting effects of existing and new land uses on water quality. Achieving this objective aids state and local officials in determining how the state's land use practices should be developed and executed to ensure the protection of lake recreational values.

Land use information presently available to the state planners assigned the job of water quality management is not adequate for planning purposes, and their present budgets preclude the gathering and formatting of the needed information. USGS maps are available as are special-purpose maps derived by other state organizations. In almost every case, grassland and cropland have been lumped into one category labeled open space, or undeveloped. Barren/extractive land is not mapped. Urban growth has made maps showing urban areas outdated and category names are not identified in terms usable for water quality planning (e.g., percent impervious, etc.). Aerial photography is usually available, although the high cost of interpretation and transforming information into desired format (e.g., area tabulations by watershed, black/clear map overlay, digital cover files) precludes its use - except on a very selective basis.

2.4.4.2 Sub-State Regions

Planning regions developing Water Quality Management Plans (WQMPs) in response to Section 208 of FWPCAA need remote sensing data for establishing present status on water in relationship to published objectives (state standards) and in determining effects of various sources (e.g., land use, sewage facilities, etc.) and controls in achieving objectives. The 208 programs have the additional problems of limited time to develop plans, i.e., a maximum of 2 years which restricts land and water inventories into a 4 to 6 month period. Another problem that regions share with states is limited budget for obtaining land cover and water quality information. The regions have the same difficulty as the states have in obtaining adequate land cover information. Available maps do not contain the land cover types needed for quantifying nutrient loads, and it is generally too expensive or time-consuming to convert available data on photography, maps, notes, etc. into the desired tabular or overlays formats needed for the analysis.

2.4.5 REMOTE SENSING REQUIREMENTS: LAND COVER

The land cover information required from remote sensing for water quality planning is the same at the state and sub-state level. The only difference is the size of the specific area of interest. The role of remote sensing to both users is the provision of an economical and accurate source of land cover information for lake watersheds in a form and format suitable for estimating nutrient loads from existing and new land uses.

The following summarizes these requirements as established for inland lake watersheds in the Great Lakes Region.

Categories - The categories should be those for which loading factors or other coefficients can be derived from the literature or established through a sampling program. This study concludes that as a minimum those categories listed below in order of their potential to discharge nutrients, especially phosphorus, are required from satellite remote sensing:

1. Urban.
2. Barren Land.
3. Agriculture Land (Cropland).
4. Grassland (Cleared-Unproductive).
5. Forest.
6. Wetlands.
7. Water.

These categories are the same as those used by the National Eutrophication Survey (NES) with the addition of water and barren land, which NES merges into an "other" category (Ref 13). It should be noted that this would be a minimum set of categories for which loading factors are generally available and which satisfies EPA guidelines for "preliminary analysis." When other cover types are known to have significant impact on loads and loading factors are known, then additional cover categories should be included. Urban has been successfully subdivided into residential, industrial, and commercial and used by computerized hydrographic predictors (Section 2.3.1.3) in production of "pollutographs," etc. Agricultural land has been subdivided into row (e.g., corn) and close grown (e.g., wheat) crops and forest into broadleaf and evergreen trees for use in sediment and black box predictors (Section 2.3.1)

Format - The desired map and data graphics depend upon the analysis technique used by the planner. The cover information must be in a format (e.g., table, overlays, etc.) that is readily applied to the model or technique the planner uses to estimate loads and impact of loads on water quality. The black box predictor (Section 2.3.1.1) requires: area covered by each land use category by drainage area, the sediment/nutrient predictor (Section 2.3.1.2) requires data in the form of map overlays or digital land cover files which are used to determine manually or by computer the amount of each soil type covered by each type of land cover in the drainage area.

Detail - The present 80-meter LANDSAT-2 resolution provides adequate land cover detail for estimating quantity and quality of runoff.

Frequency of Measurements - It should be the same as surveillance cycle used to establish and monitor trophic state. First-year data should be collected on all watersheds of interest (state, region, etc.). Second through fourth year data are collected and screened, but not processed for detail land cover unless a problem is suspected. Fifth-year repeat inventory of watersheds - compare with first year for major changes in land use. Schedule repeats.

Data Age - A three to four month or faster response is needed.

2.5 INFORMATION REQUIRED ON GREAT LAKES AND WATERSHEDS

Information on the Great Lakes and their watersheds (Figure 2-7) is needed by State and Federal Agencies responding to the need to improve water quality in the Great Lakes. One basis for this action is the Great Lakes Water Quality Agreement (GLWQA) between the US and Canada signed by Prime Minister Trudeau and President Nixon in April 1972. This agreement established water quality objectives (standards) and recommended procedures and plans for their achievement. The agreement also established an International Joint Commission (IJC) to oversee progress in meeting the water quality objectives and recommending needed action. The IJC has become an important coordinating element in the drive to clean up the Great Lakes. Its annual reports provide a lake-by-lake assessment of the problems and recommend additional water quality objectives and needed actions. A similar role is accomplished by the Great Lakes Basin Commission for the US waters and lands. One task for this commission is to coordinate US programs in the Great Lakes Basin which affect water quality of the Great Lakes. Its annual reports (Ref 32) record almost all water-related research and development activities in the Basin. Other reports (Ref 33) establish priorities for proposed or new programs.

The Great Lakes Basin encompasses about 118,000 square miles of land area and some 61,000 square miles of lake surface within the United States boundaries. In addition, another 116,000 square miles of land and water area are under Canadian jurisdiction. The Great Lakes system, approximately 2,000 miles long and with a total lake surface area of some 95,000 square miles, is the largest freshwater system in the world.

The Great Lakes Basin on the US side (Region) covers about 4% of the land area of the US and includes portions of eight states: Minnesota, Michigan, Wisconsin, Illinois, Indiana, Ohio, Pennsylvania, and New York. This Region, shown in Figure 2-7, is characterized by short streams, small drainage basins, and thousands of inland lakes. Forest and woodland, mainly concentrated in northern Minnesota, Michigan, Wisconsin, and New York, make up 48% of the total land base. Cropland and pasture, covering 33% and 6%, respectively, of the total land area, are located primarily in eastern Wisconsin, southern Michigan, northern Indiana, Ohio, and eastern New York. The remaining 13% of the land area is nonagricultural and includes urban, commercial, transportation, and industrial developments, as well as farmsteads, idle lands, and wildlife and small water areas. Some of the richest and most abundant natural resources of the North American Continent lie within the Basin.

The natural features of the Great Lakes Region account, in large part, for its population and economic growth. In 1970, more than 29.3 million people lived in the US portion of the Great Lakes system, about 14.4% of the national total in that year. Some 23.6 million persons in the Region were classified as urban residents. Major urban-industrial centers in the Region include Milwaukee, Chicago, Detroit, Toledo, Cleveland, and Buffalo. In general, the southern portion of the Region specializes in manufacturing and is heavily urbanized. Durable goods industries, especially those involving the production and utilization of steel, are especially important. Approximately 50% of the nation's steel is produced in the Region, mostly in the southern portion. In contrast, much of the northern, western, and eastern portions of the Region are devoted to dairy farming, lumbering, mining, and recreation.

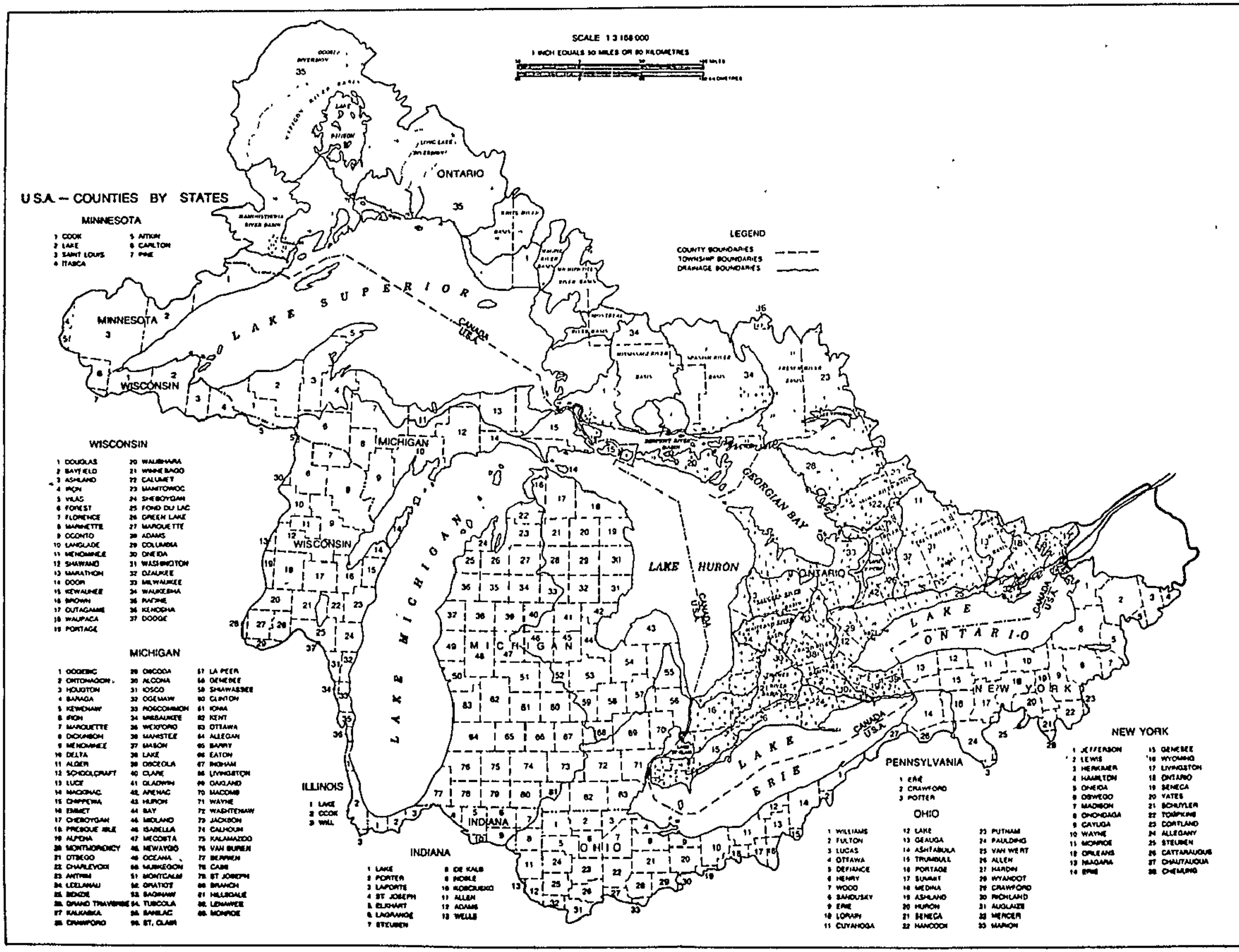

Figure 2-7 Great Lakes Basin Drainage and Political Divisions

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The Great Lakes Region is subject to a variety of demands from within and outside the Basin. Its abundant resources provide a generally high quality, easily obtainable water supply for all uses, raw materials for manufacturing, waste disposal, and medium and diversified recreational opportunities. The Great Lakes themselves provide an access route to national and international markets and transport 100 billion ton-miles of freight each year. In addition, they provide a valuable resource for commercial and sport fishing and recreational boating. However, increasing population, urban concentration, and per-capita demand for natural resources continue to create great pressures in the Region.

The Great Lakes system faces a multitude of social, economic, political, legal, and institutional problems. Physical problems are created, or at least enlarged, by these factors and the demands they engender. One of the most pressing problems facing the Great Lakes system is water quality degradation. A large part of the population and industry of the US is dependent on this water resource for present use and future growth. It is imperative that the downward trend in quality be reversed and active programs for this purpose be continued and expanded.

In recognition of this worsening water quality in the Great Lakes, legislation such as Public Law 92-500 and the US/Canadian Great Lakes Water Quality Agreement (GLWQA) have provided the requirements and funding to improve water quality. The role and data requirement of remote sensing reported in the remainder of this section are based upon the water quality (Section 2.5.1) and land cover (Section 2.5.2) information needs of the organizations responding to these agreements and legislation. Specific organizational data needs addressed here include: IJC, US EPA, Great Lakes Basin Commission, and NOAA.

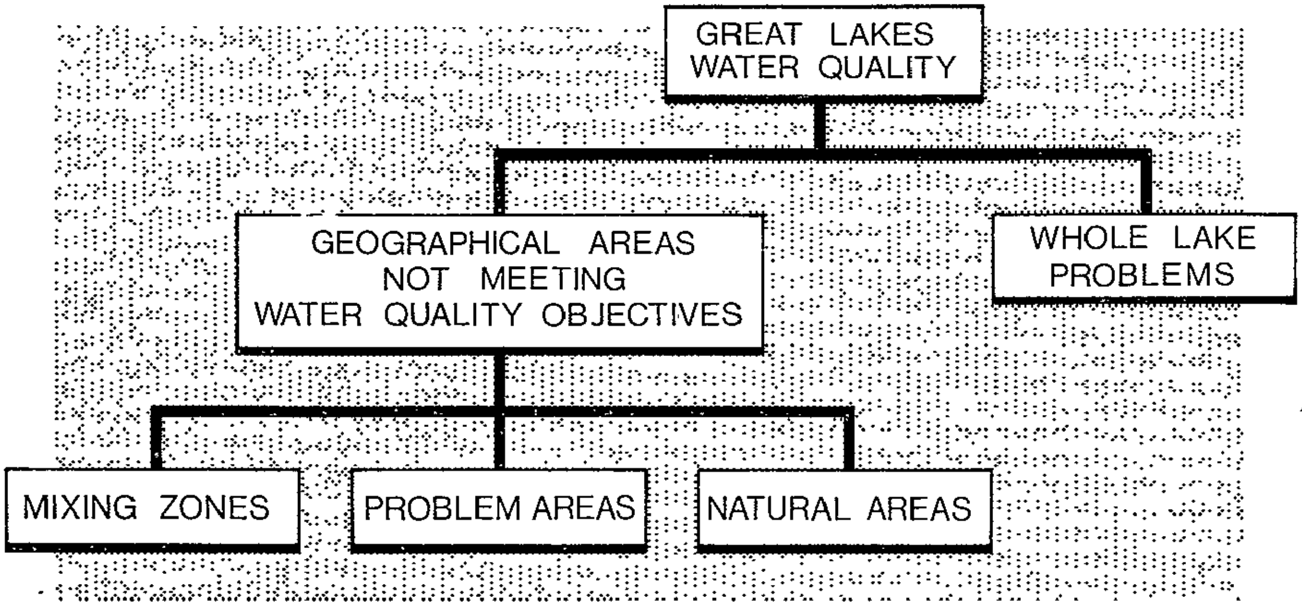
2.5.1 WATER QUALITY NEEDS: WATER QUALITY DATA

Information on water quality of the Great Lakes is needed to: (1) establish and monitor the trophic state of whole lakes, (2) monitor progress of known "problem" waste treatment sources for achieving water quality objectives, (3) detect new problem areas, and (4) develop, calibrate, and verify models used to forecast the circulation and concentration of pollutants and resulting fate.

The framework under which water quality is assessed by the IJC is shown in Figure 2-8. The principal criterion used in gauging water quality in specific areas is its relationship to the published water quality objectives of the Great Lakes Water Quality Agreement (Ref 9).

2.5.1.1 Water Quality Needs: Trophic State

Information is needed to establish and monitor the trophic state of the Great Lakes, representing a water surface area of about 94,250 square miles (Table 2-10). In its 1975 annual report (Ref 9) the IJC noted that problems having the greatest adverse effect on the recreational use of the lakes are offensive growth of the algae *Cladophora* and unacceptable bacterial levels at a number of public beaches.



EXPLANATION OF TERMS

MIXING ZONES - Restricted zones in the vicinity of point source wastewater discharges within which the specific water quality objectives shall not apply.

NATURAL AREAS - Areas that do not meet water quality objectives due to natural conditions.

PROBLEM AREAS - General geographical locations where water quality objectives and/or standards are not being met. The water quality in these locations can be improved through remedial measures.

Problem areas are further classified as:

a) Short Term Problems. Where the water quality parameters identified with the problem can be improved through short term abatement programs.

or

b) Long Term Problems. Where the parameters identified with the problem are expected to be improved through long term abatement programs. These are problems for which technological and/or legal remedial measures may not be currently available.

Figure 2-8 Guidelines for Great Lakes Water Quality Assessment (Ref 9)

The trophic status of the main body of Lake Ontario has not changed significantly since 1967 and may not improve over the next decade or so. A recent analysis of Lake Ontario suggests expected improvements in its trophic state may be limited by the effects of phosphorus inputs from land drainage and the atmosphere.

Lake Erie continues to have excessive algal growths and depressed oxygen levels. Phosphorus loadings to Lake Erie from major urban centers are three times greater than 1975 targets - Cladophora and other aquatic plants are still a problem in all of the lower lakes and may worsen unless programs for controlling the point sources are accelerated and solutions found for remaining sources.

In its fight to slow eutrophication rates in the Great Lakes, the IJC has recommended: a 1 mg P/L limit on phosphorus in all waste water treatment discharges, a complete ban on phosphates in all detergents, identification of specific phosphorus loadings from the atmosphere and land drainage, and measures to control new uses of land which could result in increased phosphorus loadings.

Implementation of this 1 mg P/L ban on waste discharges is a multibillion dollar investment. Funding by September 1977 is expected to exceed $5 billion for waste control facilities. Thus, it is of great importance to establish and monitor changes in trophic levels resulting from the ban and compliance (or noncompliance) of waste treatment facilities in phosphorus removal efforts. It is also important to identify/quantify specific nonpoint sources of phosphorus loadings from the atmosphere and land drainage and determine their relative significance.

The assessment of the trophic status of the Great Lakes is presently based on surface sampling collected by surveys, investigations, and routine monitoring conducted by a large number of state and federal organizations. Present ship and laboratory resources limit sampling of each lake to approximately once every 9 years with some select problem areas sampled "intensively." There is presently no system for economically obtaining overall assessment of trophic status of all lakes during any 1 year or season.

Table 2-10

Great Lakes Surface Area, United States and Canada

Lake	Area (square miles)	World Ranking (Freshwater)
Superior	31,700	1
Huron	23,000	4
Michigan	22,300	5
Erie	9,910	11
Ontario	7,340	14
Total	94,250	

2.5.1.2 Remote Sensing Requirements: Trophic State

Remote sensing data are required with data derived from coordinate surface sampling to provide a cost-effective and more frequent assessment of trophic conditions of the Great Lakes. For the near term (summer 1977/1978), remote sensing could be coordinated and provided on presently designed sampling schedules. In the longer term, schedules should reflect the use of remote sensing. Remote sensing would map the distribution of algal biomass of all lakes in the late summer of the same year every 9 years (or as needed) with problem areas updated annually (i.e., Saginaw Bay, lower Green Bay, western Lake Erie, etc).

The following summarizes findings of this study as to requirements remote sensing data must fill to serve a useful role in this effort.

Water Quality Parameter - The best indicator of trophic state is the relative amount of biomass (phytoplankton or algae) produced in the lakes at the peak of the growing season (late summer). Surface measurement easily obtained which relates directly to algal biomass is chlorophyll a.

Format - Color-coded image or map showing various concentrations of biomass (algae). Algal biomass would be keyed to chlorophyll a concentration, cell counts, etc. The user generally prefers a map scale of 1:500,000 for whole lakes and 1:250,000 to 1:100,000 for problem areas under intensive study.

Detail - The present LANDSAT-2, 80-meter resolution is needed for monitoring of smaller problem areas, such as Saginaw Bay. Less resolution (up to 800 meters) would be satisfactory for analysis of open waters.

Frequency of Measurement - The IJC has proposed (Ref 9) that the open waters of the lakes be sampled on a 9-year cycle, that lakes Michigan, Erie, and Ontario be sampled intensively for 2 years, consecutively during the cycle. Lakes Huron and Superior will be sampled for 1 year during the cycles.

Data Age - A 3 to 4 month response is required.

2.5.1.3 Water Quality Information Needed for Monitoring Toxic Substances

In addition to monitoring trophic status of whole lakes, information is also required on the source, distribution, and fate of toxic substances (organic and metallic). The IJC reported (Ref 9) that five of the Great Lakes were contaminated by toxic substances, which have damaged the important commercial and sport fisheries. The chief concern for Lake Ontario is the bioaccumulation of toxic contaminants such as polychlorinated biphenyls (PCBs) and Mirex (a pest control and flame retardant product) in fish and wildlife. Mercury contamination of fish is a problem in the weatern basin of Lake Erie. In lakes Huron and Michigan, PCBs in fish are a major concern. Items of concern in Lake Superior include aacumulation of PCBs and mercury in fish and high concentrations of asbestiform fibers in the water.

2.5.1.4 Remote Sensing Requirements: Toxic Substances

In response to the toxic substance problem, legislation has been proposed/enacted in the US and Canada to regulate the quantity and use of contaminants. Little is known about the pathways and fate of specific toxic substances once they enter the waterways. Although this investigation did not address the remote sensing data needs of the toxin issue, the results of the work in Saginaw Bay (Section 3.3) show the potential for using LANDSAT to map distribution and concentration of toxins through their association with particles in the water column. This investigation has shown that the distribution of chlorinated hydrocarbons and heavy metals is highly correlated with that of particulate matter. Those parameters that affect water color and volume reflectance, which are mapped directly by LANDSAT, may be useful as tracers to establish the sources and concentrations of "invisible" toxins. LANDSAT's role in providing useful information on toxins should be evaluated and the data needs and cost benefits for this role determined.

2.5.1.5 Water Quality Needs: Source of Contamination

In addition to monitoring the distribution and effects of contaminants on whole lakes, there is an associated requirement for information on their sources. These are generally municipal and industrial waste treatment outfalls where one or more of the water quality objectives are not being met. This near-shore zone must be frequently monitored to establish progress of known facilities "problem areas" in achieving water quality objectives and to locate possible new sources.

In its 1975 annual report (Ref 9), the IJC identified the 63 problem areas shown in Figure 2-9. These sources result in some of the following contaminants.

Municipal Waste - Forty-one percent of the people living in the US communities along the lakes do not have adequate sewage treatment facilities (Ref 34). This means the lakes are continuing to get a heavy load of organic matter and phosphorus from detergents. Nutrients from these sources are a major cause of increased eutrophication rates in the lakes. The nutrients cause frequent blooms of aglae and other aquatic plants which deplete the near-shore water of oxygen, causing the fish to either suffocate or leave the areas. Sewage that is inadequately treated also carries pathogenic bacteria, which are a hazard to swimmers.

Combined and Storm Sewer Overflow - Combined and storm sewer problems are a significant cause of water quality impairment in the "problem areas." Most cities have just one system of sewers. Rainwater drains off through the same network that handles raw sewage. When a heavy storm hits a city, the sewers fill beyond the capacity that can be handled by the treatment plant. The result is a momentary bypass of the facility which means that, for a period of minutes or hours, the sewers are emptying directly into the lake with little or no treatment. Although much of this is just rainwater, some is not and this creates a health problem when it happens.

Many US communities that are now violating water-quality standards are building new facilities. When construction now under way is completed, only 8% of

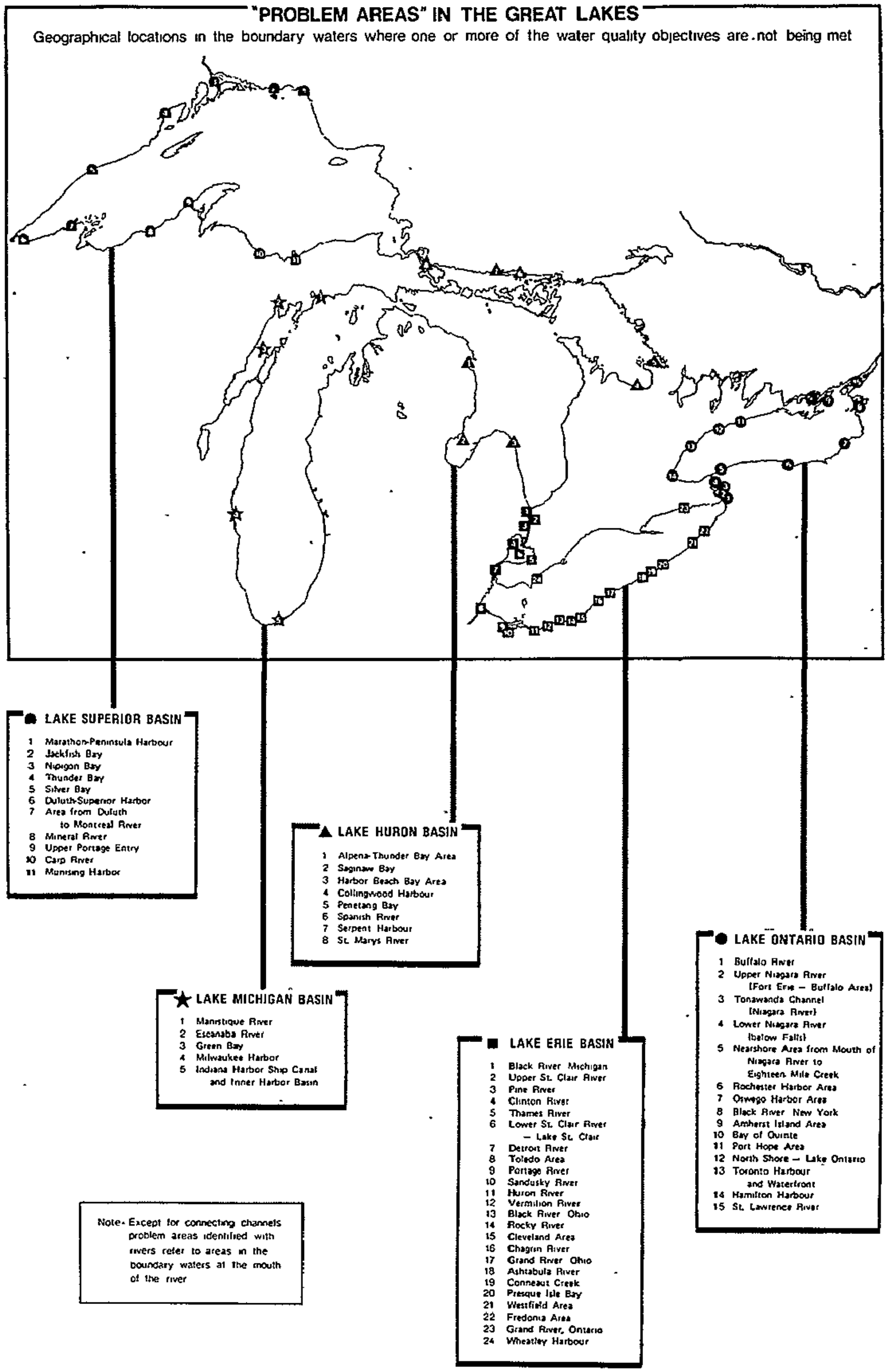


Figure 2-9 Problem Areas in the Great Lakes (Ref 9)

the population will be in violation (Ref 34). Ninety-four percent of Canada's population living on the lakes has proper treatment already. Completion of current construction will bring that close to 100% in the next few years (Ref 34).

Industrial Waste - More than 400 major industrial complexes discharge waste water into the Great Lakes Basin. On the US side, 22% of the industrial dischargers are failing to meet cleanup deadlines set by the Government (Ref 34). Waste controls at certain paper mills on the Canadian side of Lake Superior are inadequate, and the discharge from the Reserve Mining Company on the US side continues (Ref 9). On the Canadian side, 85% are not meeting Government deadlines (Ref 34). With very few exceptions, requirements for industrial waste treatment or control have been established for all plants in the Great Lakes System, and program emphasis will soon shift to monitoring, surveillance, and enforcement.

Toxic and Hazardous Substances - Toxic and hazardous materials represent a major threat to water quality and fisheries of the Great Lakes. PCBs occur throughout the system in the Upper Lakes as well as in the Lower Lakes and notably in Lake Ontario where a large part of the population of salmonid species and American eels contain PCBs at levels above both the US FDA guideline of 5 µg/g and Health and Welfare Canada's guideline of 2 µg/g for human consumption. New findings of toxic substances, particularly serious in Lake Ontario, point to the need for further surveillance and possibly federal legislation (Ref 9).

Radioactivity - Problem areas have been identified in lakes Ontario and Huron with radioactive substances resulting from uranium mining and refining and nuclear fuel reprocessing and power generation. The need for continuing surveillance in these areas is obvious. Both the US and Canadian officials are also concerned with the potential impact on water quality of the growing nuclear power industry.

Other Contaminants - Some of these same contaminants, although not plotted as a point source in Figure 2-9, result from the shipping and dredging operations throughout the Great Lakes.

2.5.1.6 Remote Sensing Requirements: Monitor Sources

Ideally, surveillance of water quality in the near-shore zone would be continuous. The location of a new problem source should be known immediately. Frequency measurements are also needed to determine rate of progress of known facilities in achieving water quality objectives. Surveillance of the near-shore areas is generally performed by the individual states. The frequency and detail of sampling depend upon budget and staff limitations. In Michigan, the near-shore areas are sampled once every 5 years. If a problem source is noted, the source may be sampled each year. The mouths of major tributaries are sampled monthly in Michigan.

The IJC notes (Ref 9) that it is in this near-shore area where the quantity and quality of data are poorest. The lack of an adequate near-shore surveillance program on the US side has made identification of problem areas very difficult. In some cases, tributaries or point source discharges are suspected of causing water quality problems and noncompliance with water quality objectives, but direct evidence may be lacking.

The remote sensing role in providing an improved surveillance program would be to work in concert with surface sampling to provide a more cost-effective and more frequent assessment of the near-shore areas. Requirements that remote sensing data must satisfy to accomplish this goal include:

- Water Quality Parameters - Monitoring of waste treatment sources for compliance with water quality standards would be best accomplished through detection and mapping of source plumes and establishing their phosphorus content, as a function of turbidity, in respect to the permissible value.

- Format - Color-coded images and maps showing concentration and distribution of phosphorus from point sources at scales of 1:24,000 to 1:48,000.

- Detail - Resolution of 30 to 80 meters is needed for detection (location) of sources; 10 to 50 meters is required for analysis.

- Frequency of Measurement - Ideally "continuous" monitoring. IJC suggests (Ref 9) that these sources be sampled "intensively." This study interprets this as year-around measurements at the same frequency which IJC recommends for major tributaries, i.e., 26 times per year.

- Data Age - Ideally "real time," i.e., less than a day, more reasonably 1 to 2 weeks.

2.5.1.7 Water Quality Need: Water Quality Model (Trophic State)

Water quality parameters are needed in the development, calibration, and verification of deterministic models used to forecast the circulation and concentration of pollutants and the resulting fate, i.e., growth of algae and weeds, etc. Information needed in the development of model is a function of the characteristics of the test site (water volume, flushing rate, etc.) and specific water quality parameters the model attempts to predict. EPA's program in Saginaw Bay (Lake Huron) is developing a deterministic model that will describe water quality changes within the bay and their relationships to enrichment and pollution caused by man. The resulting model will be used to evaluate various strategies to control nutrient flow into the bay. Important goals of the EPA project are to describe, on a seasonal basis, the circulation and water quality in Saginaw Bay, to monitor inputs of nutrients from its watershed, and, ultimately, to develop and evaluate models for predicting water quality in the bay as a function of various control strategies.

2.5.1.8 Remote Sensing Requirements: Water Quality Parameters

In the initial phase of developing the Saginaw Bay model, 30 different water quality parameters were sampled (at several depths) from 59 stations at 18-day intervals. Due to limitations in the number of boats, 3 days were needed to complete sampling. This investigation established that the primary role of LANDSAT in the early phases of model development is its use in extrapolating measures from sampled areas to unsampled areas and its capability to provide a synoptic view (color map) of water mass boundaries correlated to water quality parameters that are difficult to obtain from other sources.

To successfully carry out a role in model development related to trophic state, it was determined that remote sensing must provide synoptic maps keyed to concentration of major nutrients (phosphorus and nitrogen) and effect of nutrients biomass. Biomass can be represented by chlorophyll a and organic matter in suspension. Remote sensing information is needed at least once a month or more frequently on a year-around basis, if possible, to study effects of various parameters (rain, wind, flushing rate, etc.) affecting the model.

These remote sensing requirements are summarized by the following.

Water Quality Parameters - The major nutrients (phosphorus, nitrogen), and effects of nutrients on algal biomass and organic matter. Algal biomass is best keyed to chlorophyll a concentration or actual cell counts.

Format - Color-coded images/overlays, maps keyed to show concentration and distribution of water quality parameters, i.e., total phosphorus, total Kjeldahl nitrogen, chlorophyll a, turbidity, etc. Images (maps) at scales of

1:48,000 to 1:500,000 are desired. In addition to the map products, the user also needs the associated statistical information describing accuracy of estimates of water quality parameters (e.g., standard error of estimate, regression correlation coefficients, etc).

Detail - The present LANDSAT-2 resolution of 80 meters is sufficient for this task.

Frequency of Measurement - Sampling schedule is a function of characteristics of circulation patterns for test area. For the Saginaw Bay test site, a year-around, once-a-month data set is required. For support of modeling efforts, the more frequent the coverage the better. Some users need once-a-week coverage.

Data Age - One month preferred by all users, 3 months is the maximum.

2.5.2 WATER QUALITY NEEDS: LAND COVER

In addition to data needs required to assess quality of water there is a corresponding requirement to identify/quantify specific sources of contaminants (phosphorus, nitrogen, etc.) from the atmosphere and land drainage and determine their relative significance. Land use information is needed for this effort to develop, calibrate, and verify models and technique for forecasting pollutant loading from existing and new uses of land.

Results of analysis reported by Chapra (Ref 10) and shown in Figure 2-10 indicate that agricultural sources are major contributors of phosphorus to Saginaw Bay and lower Green Bay. His results indicate that, to obtain the desired trophic conditions in lower Green Bay, Saginaw Bay, and western Lake Erie, careful management of both sewage and land use will be needed.

Chapra relates total phosphorus concentration in Figure 2-10 to trophic state by assuming that mesotrophy is bounded by phosphorus concentrations of 10 and 20 μg/L. While total phosphorus is a cause rather than an effect of eutrophication, it has been used by Chapra and a number of other investigators as an approximation to aid interpretation of trophic state.

Only marginal further reductions in phosphorus loading from municipal and industrial sources are possible after achieving 1 mg P/L, while significant amounts are entering the lake from the atmosphere, lake sediments, and land drainage.

Control of the sewage facilities is a billion dollar proposition in the states ringing the lakes. Hence, it is becoming increasingly important to identify/quantify both point and nonpoint sources and to establish their relative contributions. One role of remote sensing in this task is providing an economical and accurate source of land cover information.

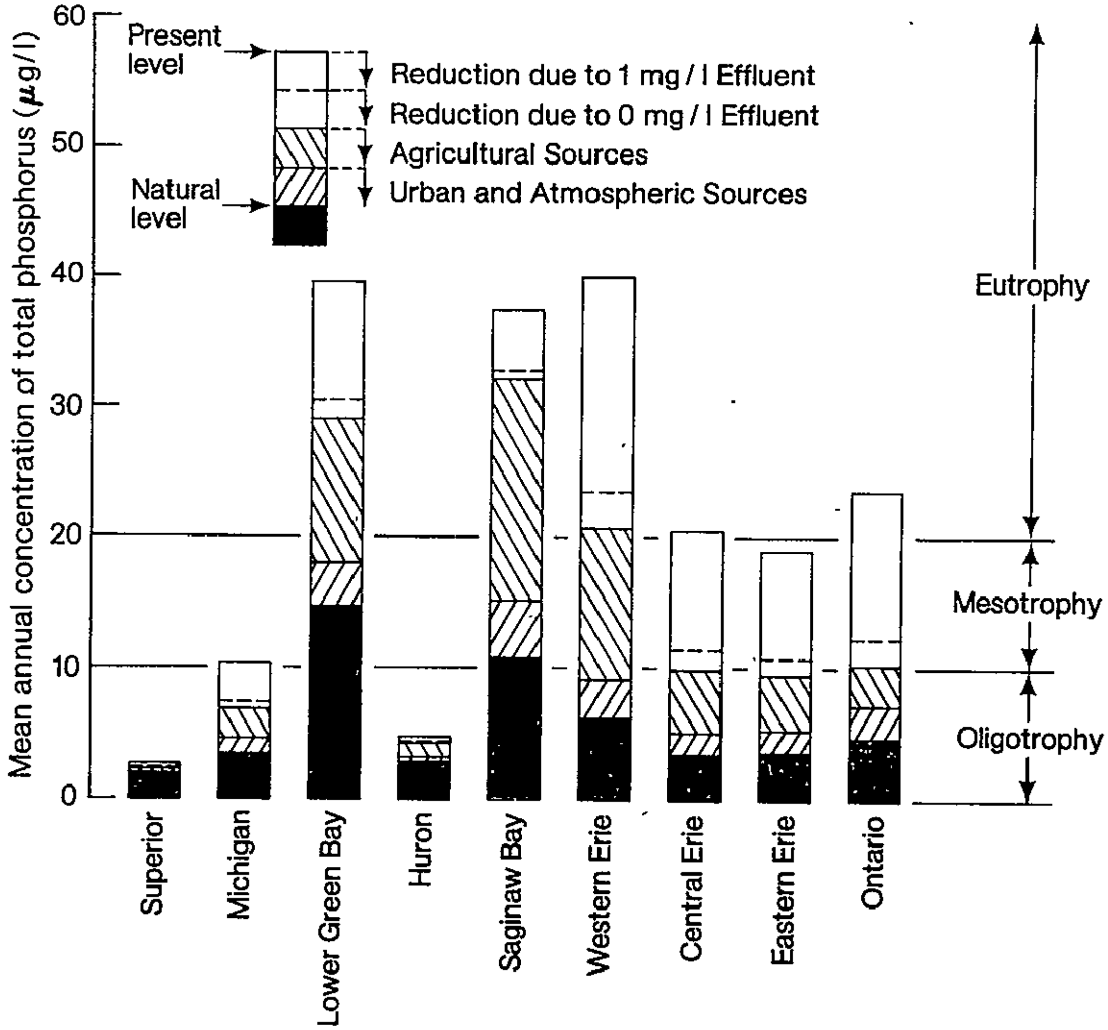


Figure 2-10 Total Phosphorus Concentrations (µg/L) Resulting from Various Treatment Schemes for the Great Lakes (Ref 10)

Organizations/users concerned with land use and effects of this use on water quality in the Great Lakes include the IJC, the US and Canadian Governments, monitoring and enforcement organizations such as the US EPA and its Canadian counterparts, Great Lakes Basin Commission, State Agencies responsible for water quality management in the near-shore area, the US Fish and Wildlife Service which has an interest in wetland areas bordering lakes, NOAA, and various research organizations concerned with development and analysis of models relating to land and its effects on water. These and other organizations need an accurate and economical source of land cover information in a form and format suitable for water quality planning.

The problems in obtaining suitable land cover information for the Great Lakes Basin are the same as those (Section 2.4.4) encountered by the State and Regional planning councils. This would be expected as the land use map and data sources are the same. The problem of assessing land use in Great Lakes watersheds is compounded by the large areas to be covered and inconsistencies between US and Canadian maps and categories (cover types). As noted previously, maps available to the US and Canadian organizations do not include the minimum categories needed for water quality assessment purposes and it is too expensive and time-consuming to convert available data sources (photography, maps, etc.) into the tabular, map overlays or digital land cover tape files needed for input to models (Section 2.3.1) and analysis

2.5.3 REMOTE SENSING REQUIREMENTS: LAND COVER

A detailed user-needs analysis would subdivide data requirements by user and by user application. The requirement addressed here is land use for assessing trophic state. The uses are many and include international (e.g., IJC), federal, state and institutions concerned with various aspects of water quality. The primary difference in user needs is the size of the area of interest. The IJC, NOAA, etc. need land use in each of the five major lake basins - a total land area of over 234,000 square miles. The US EPA is interested in US water (61,000 square miles) and lands (118,000 square miles) as noted in Figure 2-7. The states are interested in their territories. Each user subdivides his region of interest into smaller sub-basins and drainage areas for analysis.

The land use categories required by the users are the same as those needed by state and sub-state regions as reviewed in Section 2.4.5, and they are limited in category and number by the state-of-the-art for published (applicable) loading factors needed to relate land use to predicted nutrient loads.

The following summarizes these land cover requirements as established for the Great Lakes.

Categories - The cover types are the same as those specified for planning and management of inland lakes. This is a minimum set that would be needed for preliminary analysis:

- Urban.
- Barren land.
- Agriculture land (cropland).
- Grassland (cleared-unproductive).
- Forest.
- Wetlands.
- Water.

If additional (applicable) loading factors are known, corresponding cover types should be developed. It would be particularly useful to have factors for close grown and row crops and broadleaf and evergreen trees that are applicable on both US and Canadian lands.

Format - Area tabulations listing the area covered by each land cover category by drainage area are needed for input to models such as the "Black-Box" predictor (Section 2.3.1.1). An example of this model is the one used by Chapra to produce Figure 2-10. If sediment-based models (Section 2.3.1.2) are used where soils are an important factor, then the desired format is black/clear or color map overlays or land cover digital files. The overlays and tape files facilitate combining the cover information with soils data.

Detail - The present LANDSAT-2 resolution is required for this task.

Frequency of Measurement - Same as that used to establish tropic state for whole lakes (9-year cycle). This schedule is limited by available boats and laboratories for establishing trophic state. With use of remote sensing on the Great Lakes, more efficient use of available resources should make it possible to monitor lakes and watersheds on a more reasonable schedule, e.g., every 5 years. May need multiseasonal frequency to refine categories (loading factors) as a function of time (month), i.e., amount of bare earth per month, vegetation density per month, etc. May also want to analyze problem areas more frequently.

Data Age - Three to 4 months.

2.6 SUMMARY OF REMOTE SENSING DATA REQUIREMENTS

Table 2-11 shows requirements for applications of remote sensing data on inland lakes, the Great Lakes, and associated watersheds. This table addresses those users and applications identified during this investigation where satellite (remote sensing) has an immediate and useful role. In all cases, remote sensing is coordinated with and used in conjunction with surface sampling. The satellite data provide an effective means of extrapolating point sampling to large areas and provide a synoptic view not readily available from other sources.

Findings of particular importance as to users' needs are the requirements for a color-coded map showing the geographic distribution and predicted concentrations of algae, organic matter and circulation and distribution of other water quality parameters. This is an important contribution by remote sensing; desired image scales range from 1:24,000 to 1:500,000 depending upon user application. Color maps showing land cover/land use have little value in water quality planning except for reports and public meetings—the primary need is for quantitative information on land cover by drainage area. In all cases, the land cover data must be combined with other data (e.g., loading factor, soils, topography, etc.) to estimate the nutrient loads, which is the desired information. To facilitate the use of land cover data with predictive models and other applications, the desired formats include: tabulations of land cover by drainage area, map overlays, and digital land cover files. The overlays are useful over soil maps for manually determining land coverage for each soil type. The digital files are useful for accomplishing this task with the computer.

For most applications, the present LANDSAT resolution of about 80 meters is sufficient. Lakes 30 acres in size or smaller require some better resolution for analysis. A resolution of 10 to 50 meters will be needed to monitor lakes of 10 acres or larger and to monitor waste treatment sources in the near-shore areas of the Great Lakes. Almost continuous satellite coverage will be required for the near-shore areas and frequent cloud-free coverage is also needed in the development of water quality models of areas such as Saginaw Bay.

In all cases, the users requested data ages of less than 4 months, i.e., the time from detection to delivery of needed information. This will require improvements in taped data handling and distribution.

Table 2-11

Remote Sensing Requirements: Water Quality Applications

Application	Area	Information Needed	Parameters	Format	Detail	Time/Frequency	Data Age	Reference
Evaluate Weed Control Efforts. Assess Lake Renewal Efforts. Locate Problem Lakes. Respond to Section 305(b) PL92-500 (Conditions of Navigable Waters) Respond To Section 208, PL92-500 (Status of Water and Development of Cause - Effects Models).	Inland Lakes State-Wide Sub-State	Trophic State	Biomass Algae & Weeds	Color Images and Maps 1 24,000 to 1·250,000 Scale	80M - 100 Acre Lakes - 50 Acre Lakes - 10 Acre Lakes	3-Week Period Late Aug-Early Sept All Lakes 1st Year Collect - Screen 2nd - 4th Yr. All Lakes 5th Year Report	3 to 4 Months	2.4.3
Identify/Quantify Sources of Lake Nutrients. Develop an Application of Models for Forecasting Effect of Present and New Land Use Respond to Potential State Land-Use Acts. Respond to Section 208 PL92-500 Determine Effects of Sources (Point and Non-Point) and Controls on Achieving 208 Objectives.	Inland Lakes Watersheds State-Wide Sub-State	Land Cover	Urban Barren Cropland Grassland Forest Wetlands Water	Tabulations Black/Clear Map Overlays 1·24,000 to 1:250,000 Scale Digital Land Cover Files	80 Meters	Same as Trophic State	3 to 4 Months	2.4 5
Determine Effectiveness of Controls/Policies Established by Great Lakes Water Quality Agreement 1972, i.e. 1 mg P/L Limit on Phosphorus. Establish Need for Additional Controls	Great Lakes Whole Lakes	Trophic State	Biomass Algae & Weeds	Color Images & Maps Whole Lakes. 1:500,000 Scale Problem Areas 1·100,000 to 1 250,000 Scale	80 Meters - Weeds and Problem Areas 800 Meters - Whole Lakes	9 - Year Cycle Limited by Ships and Laboratories	3 to 4 Months	2.5.1.2
Establish Source, Distribution, Concentration and Fate of Toxic Substances, i.e. PCBs, Mirex, Mercury, Asbestiform Fibers Etc.	Great Lakes Whole Lakes	Toxic Substances	Unknown	Color Images & Maps Keyed to Substance of Interest.	800 Meters Whole Lakes	Unknown	Unknown	2.5 1.4
Monitor Known Problem Waste Treatment Sources for Progress (Compliance) in Achieving Water Quality Objectives and to Locate New Problem Sources.	Great Lakes Near Shore Zone	Location and Quality of Sources of Pollution	Total Phosphorus	Color Images and Maps 1.24,000 to 1 48,000	30 - 80 Meters Detection 10-50 Meters Analysis	Ideal - Continuous IJC - 26 Times Per Year	2 Weeks	2.5.1.6
Develop, Calibrate, and Verify Models Used to Forecast Distribution and Fate of Pollutants.	Great Lakes Estuaries & Bays Areas Near Major Tributaries	Distribution, Concentration, and Fate of Various Water Quality Parameters	Broad Range Temperature, Conductivity, Nitrogen, Total Phosphorus, Major Metals, etc.	Color Maps Keyed to Parameter of Interest and Statistical Information	80 Meters	18 - Day Cycle Saginaw Bay Other - Depends Upon Circulation Patterns	3 Months	1.5.1.8
Identify/Quantify Sources of Lake Nutrients. Assess Relative Effects of Point Sources, Atmospheric and Land Use. Apply Models to Forecast Effects of Existing and New Land Use	Great Lakes Basin and Sub-Basins	Land Cover	Urban Barren Cropland Grassland Forest Wetlands Water	Tabulations Black/Clear Map Overlays 1 500,000 to 1·250,000 Digital Land Cover Files	80 Meters	9 Year Cycle Limited by Ships and Laboratories	3 - 4 Months	2.5.3

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3. USER SUPPORT

To establish LANDSAT's capability of providing the information required by water quality programs and of determining the cost and benefits for this information, LANDSAT data products were produced to support on-going programs concerned with the classification and control of lake eutrophication. This support was provided to: the Environmental Protection Agency's Water Quality and Modeling Study of lake eutrophication in Saginaw Bay; the State of Michigan Department of Natural Resources survey of inland lakes and watersheds for the purpose of assessing the degree of eutrophication in these lakes and the potential for further enrichment and pollution due to land use practices; and the State of Wisconsin Department of Natural Resources lake survey to determine eutrophication status, cause, effects, and control treatments.

The maps and datagraphics required by the users were generated from LANDSAT Computer-Compatible Tapes (CCTs) in the Bendix Earth Resources Data Center located in Ann Arbor, Michigan. This facility (Section 3.1) was used to produce color-coded water quality maps showing Saginaw Bay and inland lakes in Michigan, Wisconsin, and Minnesota. Land cover information was produced and recorded: in tabular form by watershed, on color maps and overlays, and on digital land cover files. One of the most useful information formats was the color maps of water bodies keyed to water quality parameters. This synoptic view of lakes, which shows the concentration of specified water quality parameters, is not readily available from conventional sources (e.g., point sampling, etc.). The area tables, map overlays, and digital tape files were the most responsive formats for the land cover data and facilitated analysis of land cover with other information, e.g., loading rates, soil texture, slope, etc. needed to estimate pollution loads.

Conclusions and significant findings based on this effort are also summarized in Section 4. Recommendations for immediate applications and additional investigations are discussed in Section 5.

Ground truth information was supplied by the user organizations and by the color photography collected over the Michigan DNR test lakes and Saginaw Bay during the late summer of 1976. The NASA mission and flight lines are shown in Section 3.2.

The remainder of this section is organized to describe the work accomplished and results achieved in support of the user organizations. The work for EPA, summarized in Section 3.3, included the development and demonstration of a cost-effective technique using LANDSAT data, surface sampling, and linear regression equations for generating a quantitative water quality map of large lakes. This technique should be applied now in the routine assessment of the trophic state of all the Great Lakes.

The work accomplished in Michigan (Section 3.4) and Wisconsin (Section 3.5) demonstrates a system composed of LANDSAT data, surface sampling, laboratory analysis, and aerial observations which can be applied to assess the trophic state of inland lakes for $10 to $40 per lake. This is a significant saving when compared with surface sampling alone, which costs from $60 to $1,000 per lake and is limited to a few hundred lakes per year. The work in Michigan, Wisconsin, and other areas also shows that LANDSAT provides the least expensive source of land cover information in the proper format and with the desired categories and accuracy needed to assess pollutants in storm water runoff on a regional or statewide basis. Data from conventional sources can be interpreted, digitized, and merged with LANDSAT data when needed to make the best use of available information and data sources.

Products produced for EPA and the Michigan and Wisconsin DNRs were evaluated by the users and compared with similar products, where possible, produced from conventional sources (e.g., aerial photography, windshield surveys, point sampling, etc.). Results of these comparisons together with recommendations for future work are presented.

3.1 DIGITAL PROCESSING FACILITY

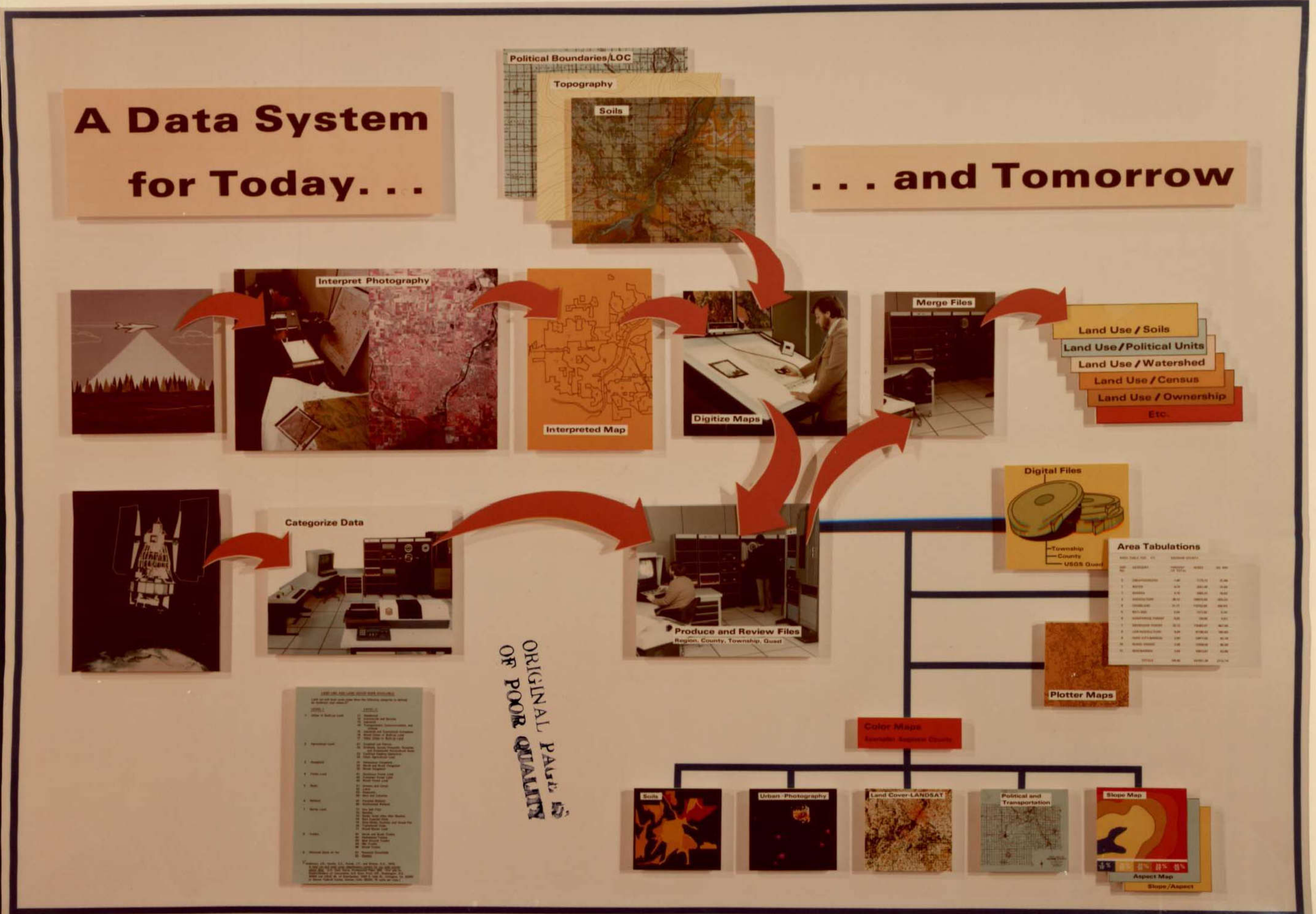
The Bendix Earth Resources Data Center (ERDC) located in Ann Arbor, Michigan was used to produce interpreted land cover and water quality maps responsive to the users' requirements (Figure 3-1). Major elements of this system, shown in Figure 3-1, include: a Bendix Datagrid® Digitizer System 100 for digitizing graphical data and a Bendix Multispectral Data Analysis System (MDAS) for the analysis of LANDSAT (CCTs). MDAS, the result of an evolutionary program initiated by Bendix in 1967, is dedicated to the processing of remote sensing data (Ref 35).

The nucleus of MDAS is a Digital Equipment Corporation PDP-11/35 computer with 128K words of core memory, three 1.5M-word disk packs, two nine-track 800 bit-per-inch (bpi) tape transports, and a Decwriter unit. Other units are an Ampex FR-2000 14-track tape recorder, a bit synchronizer and tape deskew drawers which can reproduce up to 13 tape channels of multispectral data from high-density tape recordings, a high-speed hard-wired special-purpose computer for processing multispectral data, a 9 1/2-inch Optronics drum recorder for recording imagery on film, and a color moving-window computer-refreshed display. Additional information on MDAS is published in the reference (Ref 35).

LANDSAT MSS data acquired on the study areas were transformed into interpreted land cover and water quality maps and data graphics data by categorical processing. These categorization techniques (Ref 36, 37, 38) have been under continuous development at Bendix for the past 9 to 11 years, primarily using aircraft multispectral scanner data. More recently, LANDSAT MSS and Skylab/EREP-S192 data have been used. Steps used to transform LANDSAT CCTs, photo-interpreted data, soil maps, and other data sources into maps and data graphics are illustrated in Figure 3-1 and summarized in the following.

3.1.1 PROCESSING OF LANDSAT DATA

LANDSAT CCTs acquired over portions of Michigan, Wisconsin, and Minnesota were processed into land cover and water quality maps and data. The first processing phase is to acquire data and transform the CCT into interpreted "categorized" data tapes. On this new CCT each LANDSAT picture element "pixel" (57 x 79 meter cell covering about 1.1 acres) is represented by code designating the interpreted land-water


A Data System
for Today. . .
. . . and Tomorrow
Political Boundaries/LOC
Topography
Soils
Interpret Photography
Interpreted Map
Digitize Maps
Merge Files
Land Use / Soils
Land Use / Political Units
Land Use / Watershed
Land Use / Census
Land Use / Ownership
Etc.
Categorize Data
Produce and Review Files
Region, County, Township, Quad
Digital Files
Township
County
USGS Quad
Area Tabulations
Plotter Maps
Color Maps
Soils
Urban - Photography
Land Cover-LANDSAT
Political and Transportation
Slope Map
Aspect Map
Slope/Aspect
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category. The second processing phase is to develop an earth (latitude and longitude) to LANDSAT coordinate transformation. This transformation is needed to produce maps and graphics that are geometrically corrected and correspond to a specified geographical area and scale. The work accomplished in the categorical and geometric processing of LANDSAT CCTs is summarized in the following.

3.1.1.1 Categorical Processing

Training Set Selection - The first step in categorizing the satellite data is to locate and designate to the computer a number of LANDSAT picture elements or "pixels" that best typified each land-water category which was to be mapped, the "training sets." These areas of known characteristics are established by referring to aerial photography and ground survey data. These training areas are located on the LANDSAT CCTs by viewing the CCT data on the MDAS TV monitor. The coordinates of the training areas are designated to the computer by placing a cursor over the desired area and assigning a training area designation, category code, color code, and name. Several training areas are picked for each category, with each pixel corresponding to a ground coverage of 57 x 79 m. The color code is used in later playback of the tapes when the computer-categorized data are displayed in the designated colors and compared with the reference data.

Development of Processing Coefficients - The LANDSAT spectral measurements within the training area boundaries are edited by the computer from the CCT and processed to obtain a numerical descriptor (computer-processing coefficients) to represent the spectral characteristics of each land cover category. The descriptors included the mean signal and standard deviation for each of the four LANDSAT bands and the covariance matrix taken about the mean. The descriptors were then used to generate a set of processing coefficients for each category. In multivariate categorical processing, the coefficients are used by the computer to form a linear combination of the LANDSAT measurements for each pixel. The variable produced has an amplitude which is associated with the probability that the unknown pixel measurements belong to each of the particular land cover categories sought. In categorical processing, the probability of a LANDSAT pixel arising from each one of the different land cover categories of interest is computed for each pixel and a decision, based on these computations, is reached. If all the probabilities are below a threshold level specified by the operator, the computer will decide that the category viewed is unknown, or "uncategorized."

Evaluation of Training Set Selection and Processing Coefficients - Before producing categorized data for the entire area, a number of tests are applied to evaluate the computer's ability to perform the desired interpretation. These tests include reviewing training statistics for consistency, categorization tables for training set accuracy, and viewing the processed data on the color display and comparing them with the reference data.

Generation of Categorized LANDSAT Tapes - When the categorization accuracy achieved on the land and water categories is satisfactory, the processing coefficients are placed into the computer disk file and used to process the CCTs. This step in the categorical processing resulted in new or "categorized" CCTs, where each LANDSAT pixel is represented by a code designating the different land-water categories.

3.1.1.2 Geometric Processing

Geometric processing establishes an earth (latitude and longitude) to LANDSAT (scan line and element number) coordinate transformation and removes the skew in the LANDSAT data due to the earth's rotation. The procedure for developing the transformation is to digitize carefully selected ground control points (GCPs) from USGS 7.5- and 15-minute quad maps using the Bendix Datagrid® Digitizer, and to convert the latitude and longitude of these GCPs to LANDSAT pixel coordinates using a theoretical transformation derived from known and assumed spacecraft parameters including: heading, scan rate, altitude, and a knowledge of earth rotation parameters. The LANDSAT GCP coordinates and transformation matrices thus obtained are approximate, based on the use of the nominal spacecraft parameters. This transformation matrix is accurate enough to locate and display on the TV monitor the area containing the GCP. The exact GCP location is designated to MDAS by using a cursor. The procedure is repeated with additional GCPs until the desired geometric accuracy is achieved. This rapid interactive procedure is essential for producing a transformation matrix which provides an accurate correction of the spacecraft data. Once the operator has designated each of the GCPs on the MDAS monitor, an improved set of coefficients for the transformation matrix is computed. After the transformation matrix is obtained for the scene, it is applied in the production of geometrically correct maps and digital data products.

3.1.2 PROCESSING PHOTO-INTERPRETED MAPS AND OTHER DATA SOURCES

Sketch maps derived from photo interpretation, soil maps, topographic maps, and other nondigital sources are obtained and transformed into digital data files. The Bendix digitizer cursor is used in this effort to trace and code each polygon (area) to be digitized. The Polygon Digitizer program is on line, fully interrupt driven, and highly interactive. The program requires that the operator first digitize the four reference corners of a map or tick marks on photography having known earth coordinates. When the operator has completed this sequence, each of the boundaries is traced and identified by a code, one boundary at a time. This can be accomplished in either the digitizer "stream" mode (points recorded automatically at preset intervals) or the "point" mode (points recorded on operator command). The output of this step is a disk file containing the latitude and longitude of each point of each boundary. These data, which are in a digital vector (polygon) format, can now be used to drive plotters or used as an input to the "Scan Convert" program. Scan Convert generates cellular files for: merging with LANDSAT data; MDAS display; filming; area tabulations; and tape files. The digitizing is checked by the operation on MDAS display where files are shown in color.

3.1.3 MERGING DIGITAL FILES

An optional processing step available in the Bendix system is the merging of digital files. This is an important function when the user needs information best obtained from a combination of sources, i.e., LANDSAT and aerial photography. Digital files coded by land cover interpreted from LANDAT are overlaid in the computer with files of the same area interpreted manually. A new file of the area is produced where manual interpretations override and replace LANDSAT interpretations, producing a new file containing both LANDSAT and manually derived data. Bendix has found this technique to be particularly useful for regional studies requiring a high degree of interpretation within the urban areas (e.g., mobile home parks, single family housing, transportation, etc.) which are best derived from photography, and within nonurban areas (e.g., forest, wetlands, water, etc.) which are best obtained by LANDSAT. The merged data files are used by the MDAS programs to produce image and data products containing information from the multiple data sources.

3.1.4 MAP AND DATA GRAPHICS

The digital files resulting from LANDSAT or multisource processing are used to produce color-coded maps, map overlays, area tabulations, and digital land cover files. A brief summary of the graphics follows.

Color Map, Photo Process - A map where color is used as a code to designate the different categories of information: cover types, soil types, etc. To produce this map, the digital files are first used to film a set of three separations on a film recorder. These three black and white separations are photographically combined and processed into a color transparency and color negative. The color negative is enlarged and printed to the desired scale. Almost any scale is possible; typical ones range from 1:24,000 to 1:1,000,000. The color negative and positive transparency resulting from this process are on 8 x 10 inch film and generally show the area at a scale one-fourth that of the deliverable prints. These same basic filming steps are also used to produce the false color images referred to as "color-composite prints." For this product, three LANDSAT bands are filmed onto corresponding color separations before photographically combining them into the color positive, negative, and print.

Map Overlays - A set of transparent map overlays where each overlay shows only one category of information (e.g., land cover category or water quality parameter, etc). Black or a color is used to show the category. To produce these overlays, the digital files are filmed on the film recorder, one category (one film) at a time. The 8 x 10 inch black/clear transparency resulting from this task is enlarged to the final desired scale. The overlays can be transformed into color-coded overlays or a color-composite map by use of a Cromalin® System.

Area Tabulations - A table printout from computer listing percent coverage, acres, and square kilometers occupied by each category of information, i.e., land-water cover types, etc. To produce these tabulations, the boundaries of areas of interest are digitized on the Bendix Datagrid® Digitizer and input to MDAS together with digital file tape. The area is located on the file, cells aggregated, and the results printed.

Resampled File Tape - Digital tape files produced from processing of LANDSAT or multi-source data in a format specified by user. The digital files can be aggregated into almost any cell size (1, 10, 40, or 80 acres, etc.) to be compatible with other coded information on the region. Bendix provides these tapes on nine-track, 800 or 1,600 bpi CCTs.

3.2 NASA AIRCRAFT SUPPORT

As a part of this LANDSAT investigation to establish the relationship between water quality and land use, a NASA aircraft acquired color photography, at approximately 1:40,000 scale, and 11-band scanner data for inland lakes and watershed during August and September of 1976. Lakes in the southern half of the lower peninsula of Michigan were overflown in the first mission, while those in the northern half were overflown in a second mission 3 weeks later. The coverage, as shown in Figure 3-2, included the water bodies and associated watersheds (Table 3-1).

Table 3-1

Lakes and Watersheds Covered by NASA Flight Lines

Mission #343 8-30-76 Lake Area	Flight Line(s)	Mission #344 9-17-76 Lake Area	Flight Line(s)
Saginaw Bay	1-6	Carp	26
Higgins	16, 17, 27	Wycamp	26
Houghton	16, 17, 27	Larks	25
Reeds	11	Douglas	24, 25
Fremont	12	Munro	24, 25
Long	13	Black	23, 24
Jordon	10	Mullet	23, 24
Lansing	9	Burt	22
Pleasant	8	Pickerel	21
Silver	7	Walloon	20,21
Town Line	14	Clear	19
Budd	15	Big Twin	18
		Porter Marsh	28
		Higgins	16, 17, 27
		Houghton	16, 17, 27

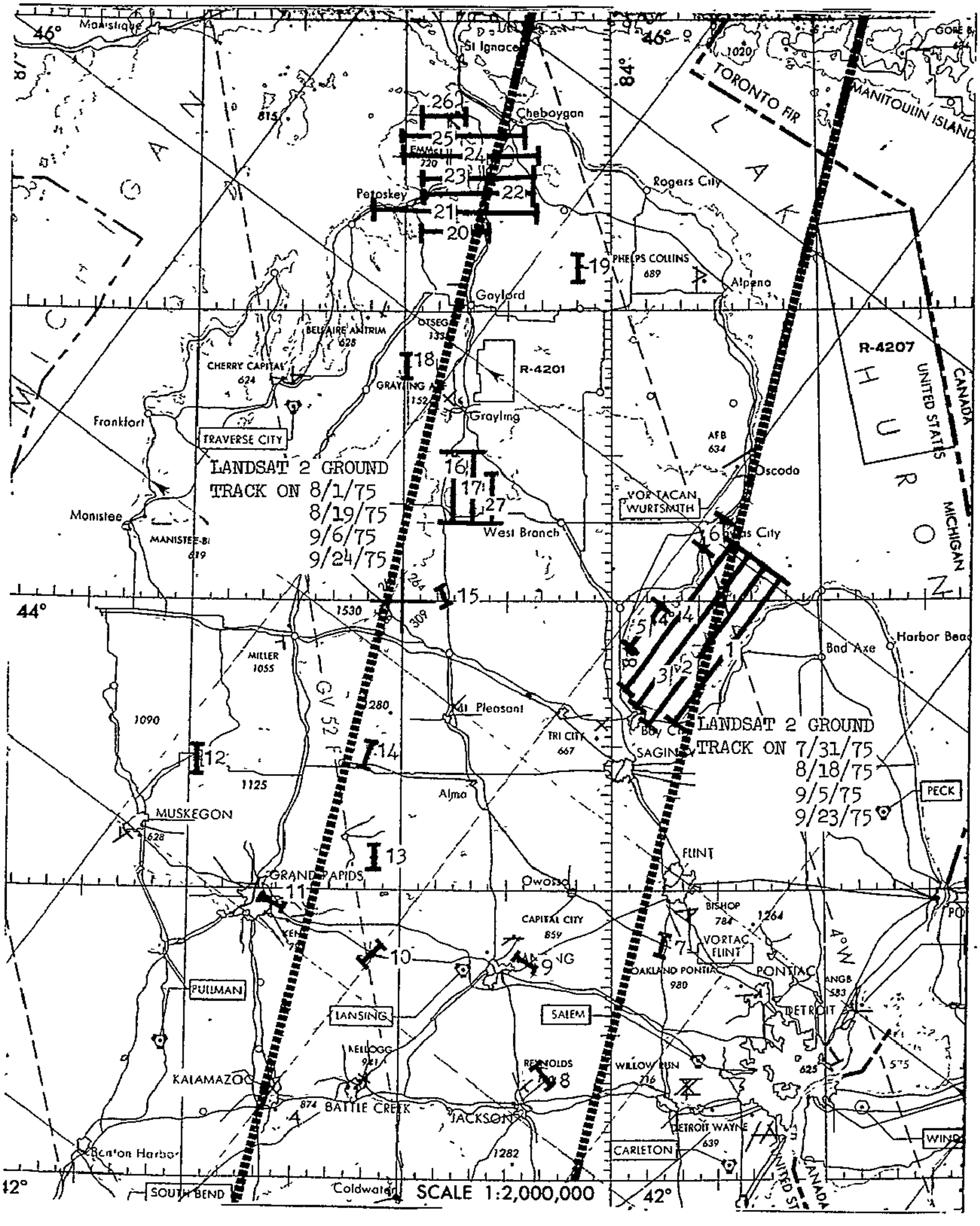


Figure 3-2 NASA Flight Lines

3.3 SUPPORT FOR THE EPA STUDY OF WATER QUALITY IN SAGINAW BAY

In response to the needs (Section 2.5) for improved water quality management in the Great Lakes, a number of US and Canadian agencies are conducting ongoing programs. One of these is the Environmental Protection Agency (EPA) water quality survey and modeling study of lake eutrophication in Saginaw Bay. The goals of the EPA program are to establish a base of water quality information by which effects of future reduced loading to the bay can be judged and to develop a deterministic model that will simulate bay water quality changes within the bay and their relationships to enrichment and pollution caused by man. The resulting model will be used to evaluate various strategies to control nutrient inputs to the bay. Important goals in this project are to describe, on a seasonal basis, the circulation and water quality in Saginaw Bay, to monitor inputs of nutrients from its watershed, and ultimately, to develop and evaluate models for predicting water quality in the bay as a function of various control strategies.

The work accomplished and objectives achieved towards EPA's goals are discussed in the following section and include:

1. Established Remote Sensing Requirements - EPA's goals and needs of other organizations concerned with water quality in the Great Lakes were transformed into remote sensing data requirements (Section 2.5). These requirements, as related to EPA's study of lake eutrophication in Saginaw Bay, resulted in the production of color-coded maps keyed to water quality parameters and an area tabulation on Saginaw Bay watershed. The color image of the bay was coded to identify concentrations and distributions of water quality parameters. Of major interest were the nutrients (e.g., forms of phosphorus, nitrogen) and parameters indicating biomass concentration (e.g., chlorophyll a). Accomplishing this task in addition to showing usefulness to modeling effort also showed the feasibility of monitoring phosphorus concentrations which is a requirement (Section 2.5.1.6) for surveillance of waste treatment effluents. The area tabulation(s) produced for the Saginaw Bay watershed established percent coverage, acres, and square kilometers occupied by each land use/cover category in the watershed, an area of over 5.8 million acres. These data were needed as an input to the Black-Box Predictor (Section 2.3.1.1) used to estimate nutrients in runoff from existing and new uses of land. Categories of interest include: urban, barren land, cropland, grassland, forest, wetlands, and water.

2. Generated Quantitative Water Quality Maps - Maps were produced which were responsive to EPA data requirements showing the concentration and distribution of water quality parameters (e.g., nitrogen and phosphorus) causing eutrophication, as well as parameters which indicated its

effect (e.g., chlorophyll a), (Section 3.3.2). These water quality parameters were related to trophic state by criteria used by Michigan (Section 2.4.2.1), Chapra (Section 2.5.2), and others.

3. Produced Land Cover Data - Land cover data were generated on the Saginaw Bay watershed and over 100 sub-basins (Section 3.3.3). The cover types were responsive to EPA requirements as well as to needs of sub-state planning regions responding to 208 guidelines. Cover types were those most requested by users conducting water quality programs and included; urban, barren land, cropland, grassland, forest, wetland, and water. Area tabulations of these and other cover types were used by models to predict nutrients (e.g., phosphorus, nitrogen) and other pollutants in runoff which affect trophic state and rate of eutrophication.

4. Determined Usefulness and Cost Benefits - The synoptic map showing the distribution and concentration of water quality parameters and extent of weeds was an important remote sensing contribution that no reasonable amount of point sampling could have duplicated. The map generated from LANDSAT and 16-point surface measurements on some data was previously derived by EPA from 30 to 60 samples collected over a 3-day period; this represents a potential saving of 2 days in boats, crews, and lab analysis. Land cover categories required to predict nutrients in runoff are not available on maps available to most users. The cost of transforming data from photography, field data, etc. into desired formats (area tables, map overlays, tape files) is either too expensive or time-consuming. LANDSAT products cost $1.00 to $4.00 per square mile, depending upon map scale and products. Similar information from photo interpretation is $8 per square mile if photography is available and $11.00 to $13.00 per square mile if new photography is needed.

The work accomplished and evaluations of resulting maps and data are discussed in the following sections which are subdivided into Water Quality Maps (Section 3.3.2) and Land Cover Data (Section 3.3.3); the ground truth effort is reviewed in Section 3.3.1.

3.3.1 GROUND TRUTH

In addition to the NASA aircraft support (Section 3.2), ground truth information needed to generate the map and data graphics were provided by EPA, the Cranbrook Institute of Science, the Michigan Department of Natural Resources, the University of Michigan (Great Lakes Research Division and Sea Grant Program), the East-Central Michigan Planning and Development Region (Region VII), the Michigan GLS Region 5, and the Michigan State University Remote Sensing Project. EPA grantee personnel, under the direction of Dr. V.E. Smith, LANDSAT Co-Investigator, were funded ($269,000) by the EPA to provide a detailed water chemistry program of the bay over the period from April 1974 to November 1975.

3.3.1.1 Test Area

Saginaw Bay, a shallow extension of Lake Huron, is bounded by five counties of southeastern Michigan (Figure 3-3). The bay has an area of some 2,960 km^2 and a maximum length and width of 82 km and 42 km, respectively. The mean depths are 4.6 m for the inner bay and 14.6 m for the outer bay. The Saginaw River enters the bay at its extreme southwestern end and contributes approximately 90% of the pollutants found in the bay (Ref 39). This river and its tributaries drain a watershed of more than 16,060 km^2 and contain four major cities and much agricultural land. Consequently, inputs of salts, nutrients, and pollutants to the bay have been increasing for many years. Levels of turbidity and algal production are consistently high, especially within the inner bay. Major declines in commercial fish yields, wildfowl populations, and esthetic values have resulted from this eutrophication. The natural estuarine-like movement of pollutants from the bay into southern Lake Huron may also reduce water quality throughout the lower Great Lakes. While circulation within the bay is highly wind-dependent, the pattern is generally counter-clockwise. Clear Lake Huron water enters mainly along the western shore; turbid bay water exits along the eastern shore. Significant but unknown quantities of sediment are resuspended regularly by wave action. The lower two-thirds of Saginaw Bay usually freezes over during January and February. These and other characteristics of Saginaw Bay have been documented by Freedman (Ref 39).

3.3.1.2 Sampling

The EPA sampling program initiated April 1974 and coordinated by Dr. Smith gathered samples at the stations distributed over Saginaw Bay as shown in Figure 3-1.

Sampling and in situ monitoring were conducted at 18-day intervals during April-October (coinciding with LANDSAT satellite passes) and approximately at monthly intervals during November-March. On 1 April 1975, this sampling effort was shifted from LANDSAT-1 to the LANDSAT-2 schedule. Parameters, which were monitored at several depths at 59 stations in 1974 and a subset of 37 stations in 1975, included: temperatures, dissolved oxygen, conductivity, chloride, pH, alkalinity, Secchi depth, chlorophylls, nitrogen, phosphates, total phosphorus, organic carbon, total solids, and major metals. Results of 32 cruises in 1974 and 1975 were published (Ref 40). Normally, two boats with crews and three consecutive days are required to sample all stations. Additional diurnal or daily sampling was conducted at selected stations. Samples were analyzed aboard ship or at the EPA Large Lakes Research Station at Grosse Ile and filed in STORET. Enumerations of phytoplankton and zooplankton were also made. Coordinated studies of current patterns, nutrient inputs, and bottom fauna were also accomplished by EPA. The sampling program is continuing at present on a reduced level and is scheduled through 1978.

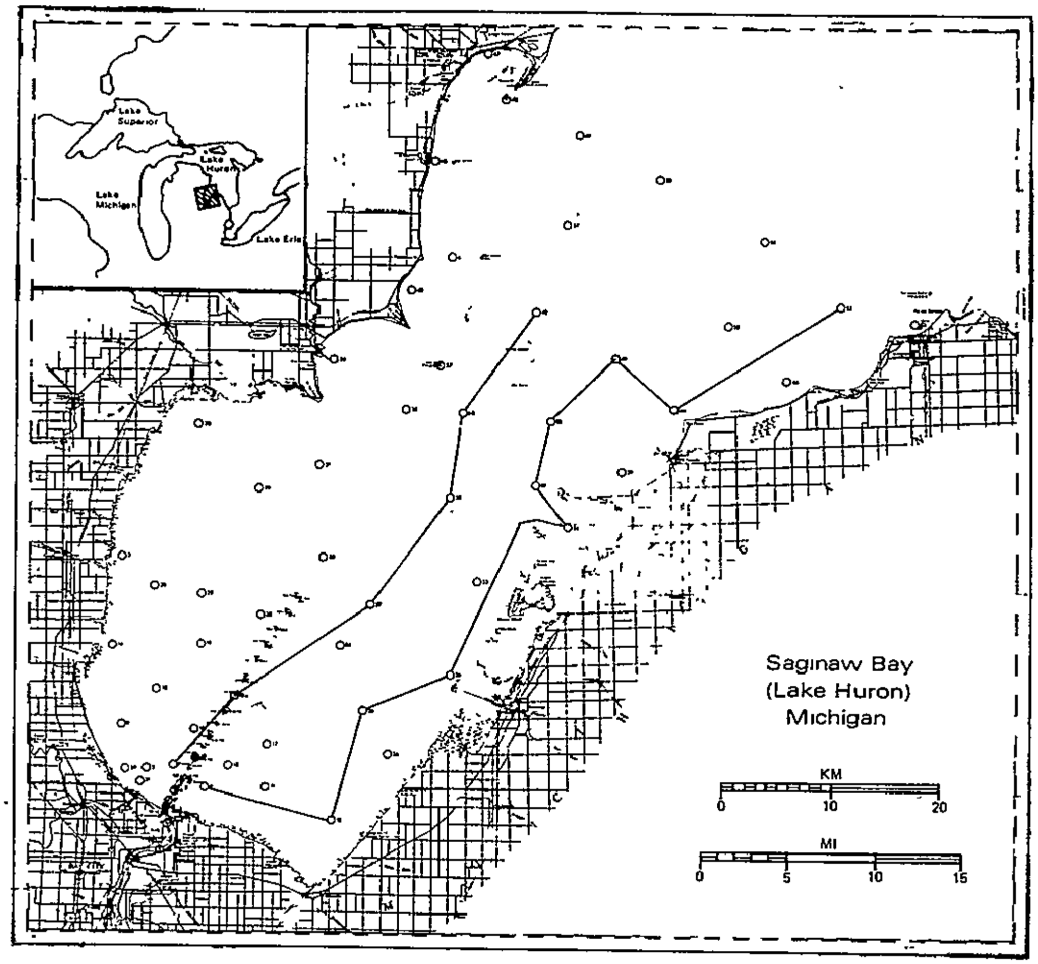
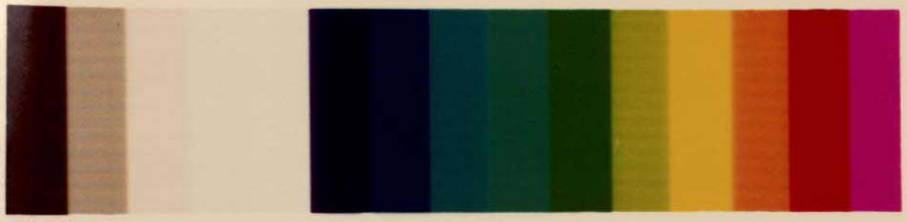
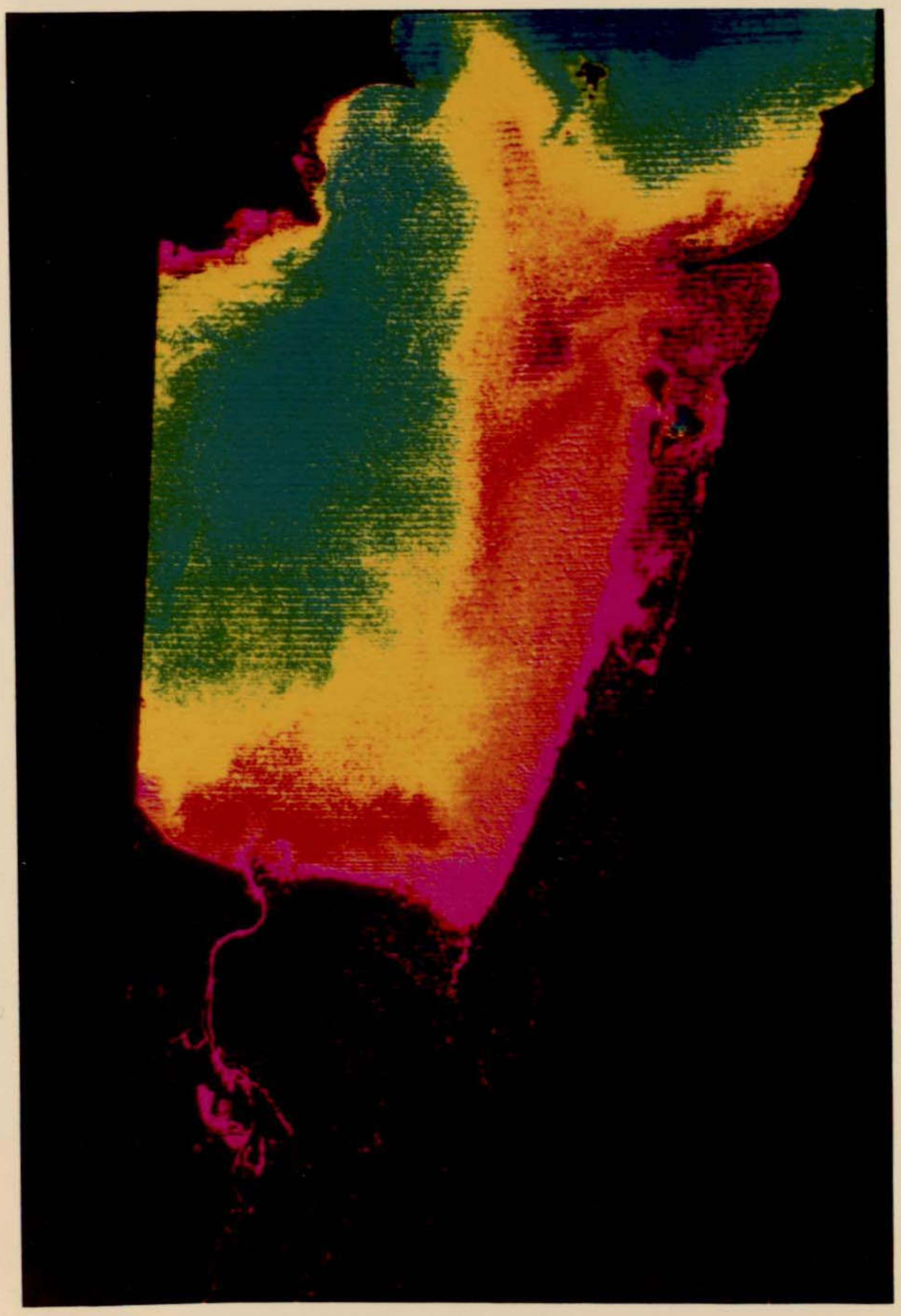


Figure 3-3 Map of Saginaw Bay Showing 61 Water Quality Stations by Symbol ⊙ ; Cruise Tracks of Two Vessels and 16 Stations Sampled on Day of LANDSAT Overpass (31 July 1975) Also Shown

TURBIDITY MAP OF SAGINAW BAY

ERTS Scene 1680-15455
June 3. 1974





Color	Secchi Depth (meters)
Magenta	0.3
Red	0.6
Orange	0.8
Yellow	1.0
Dark Green	1.3
Light Green	1.5
Blue Green	1.7 to 1.8
Cyan	2.2
Dark Blue	3 to 3.3
Black	Uncategorized

Map covers area approximately 25 by 40 nautical miles.

Produced by Computer processing of ERTS tapes by Bendix Aerospace Systems Division.

3.3.2 WATER QUALITY MAPS

A procedure was developed by this investigation to transform LANDSAT computer-compatible tape (CCT) data and surface sampling into the required color-coded water quality maps. Color is used on this image as a code to identify the mean concentration or range of a specified water quality parameter. More importantly, the procedure shows the distribution and concentration of the desired parameters (e.g., phosphorus, nitrogen, chlorophyll a) with a known (predictable) error. Color-coded maps were produced to support the EPA study from data collected on 3 June 1974 and 31 July 1975 by LANDSAT and surface crews. Map scales ranged from 1:1,000,000 to 1:100,000.

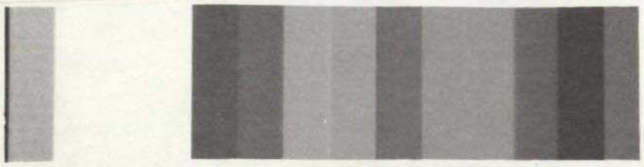
3.3.2.1 Preliminary Mapping Approach

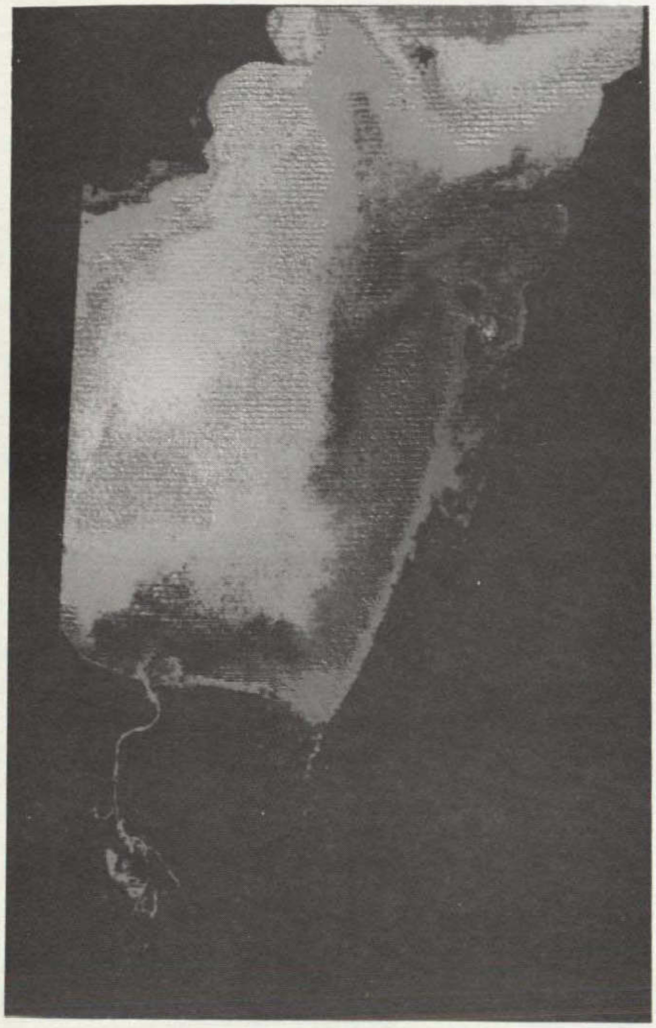
During evolution of the "preferred" method for producing the water quality map, a number of procedures were evaluated (Ref 41 through 44). The earliest effort reported (Ref 41) on the "supervised" processing of the 3 June 1974 LANDSAT scene (No. 1680-15455). This work produced a nine-color image (Figure 3-4) where each color was keyed to Secchi depths from 0.3 to 3.3 meters. At the time of this processing, Secchi depth was the only parameter fully reduced for all bay stations and was an indicator of turbidity. Of particular importance in this first effort was development of a technique used on the MDAS for editing LANDSAT measurements from areas around bay stations based on station latitude and longitude coordinates. LANDSAT measurements edited from stations of known Secchi depth were extracted and used as training areas and a basis for categorizing each picture element (pixel) within the bay into the nine Secchi depth ranges (nine colors).

Secchi depth ranges shown on the color map were correlated to the other water quality parameters (Table 3-2) by plotting the desired parameters (such as total phosphorus) against Secchi depth. Plots such as Figure 3-5 were prepared for total phosphorus, total Kjeldahl nitrogen, and chlorophyll a and used to convert the Secchi color ranges shown on the image into corresponding ranges in concentration of the nutrients and chlorophyll. This method worked well due to the relatively high degree of correlation (Table 3-3) between these parameters, but it did not provide a quantitative estimate of the error.

TURBIDITY MAP OF SAGINAW BAY

ERTS Scene 1680-15455
June 3, 1974



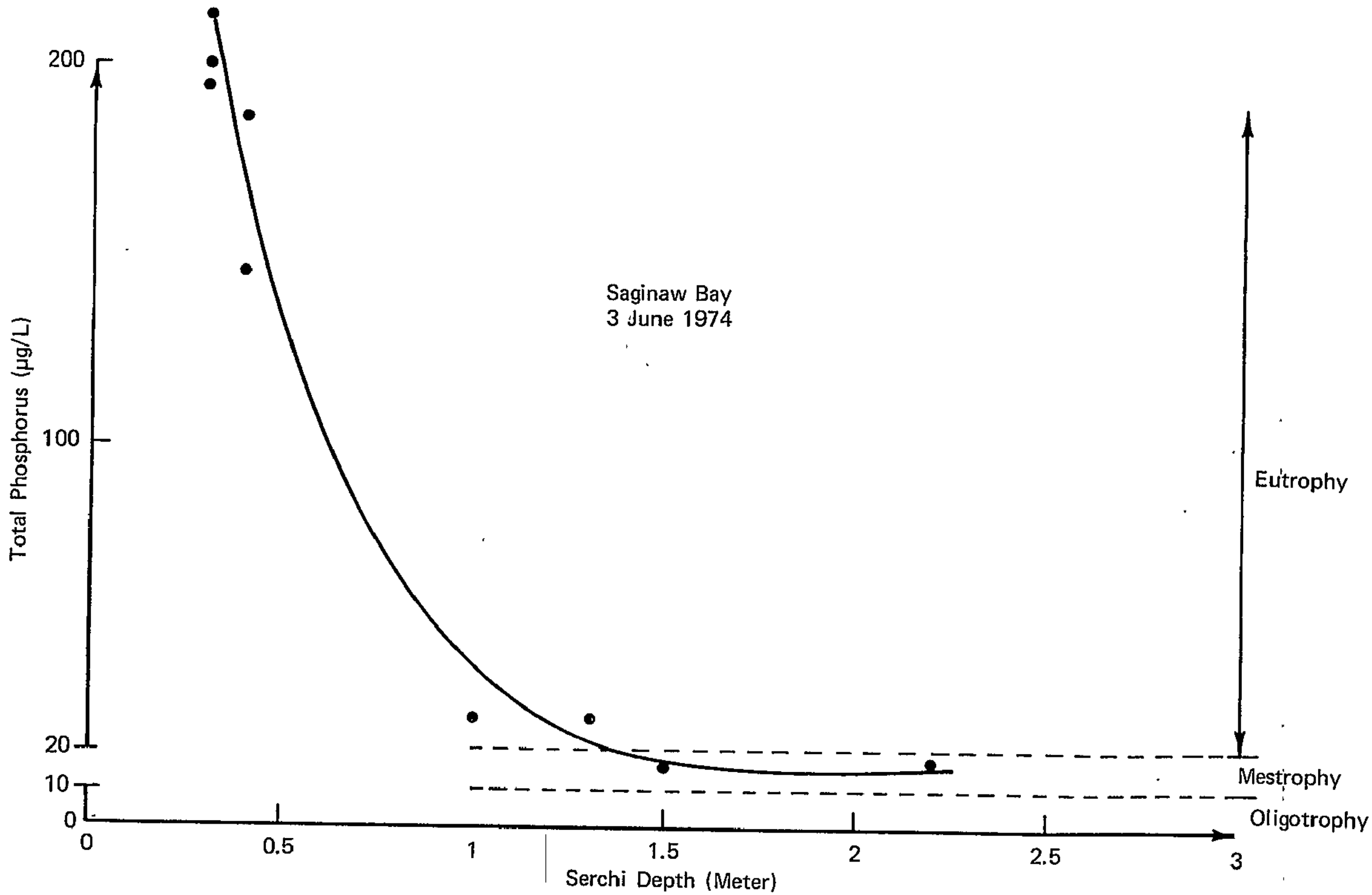


Color	Secchi Depth (meters)
Magenta	0.3
Red	0.6
Orange	0.8
Yellow	1.0
Dark Green	1.3
Light Green	1.5
Blue Green	1.7 to 1.8
Cyan	2.2
Dark Blue	3 to 3.3
Black	Uncategorized

Map covers area approximately 25 by 40 nautical miles.

Produced by Computer processing of ERTS tapes by Bendix Aerospace Systems Division.

Figure 3-4 Turbidity Map of Saginaw Bay



Note: Definition of Trophic State after Chapra, Others (Ref 10)

Figure 3-5 Relationship Between Secchi Depth and Total Phosphorus, Saginaw Bay, 3 June 1974

Table 3-3

Correlation Coefficient Matrix of Water Quality Parameters for Saginaw Bay, April 1 - June 30, 1974

	T	SD	CON	Cl	CH-ā	Na	K	Mg	Ca	TDP	TKN	TP
Temperature (T)	1.000											
Secchi Depth (SD)	-.179	1.000										
Conductivity (CON)	.304	-.470	1 000									
Chloride (Cl)	.251	-.465	.958	1.000								
Chlorophyll ā (CH-ā)	.223	-.446	.733	.784	1.000							
Sodium (Na)	.324	-.468	.962	.973	.689	1.000						
Potassium (K)	.301	- 500	.960	.940	.752	.933	1.000					
Magnesium (Mg)	.372	-.586	.921	.920	.760	.879	.917	1.000				
Calcium (Ca)	.328	-.534	.942	.927	.751	.900	.940	.918	1.000			
Total Dissolved Phosphorus (TDP)	.214	-.158	.558	.077	.206	.663	.593	.509	.611	1.000		
Total Kjeldahl Nitrogen (TKN)	.285	-.484	.604	.617	.680	.683	.745	.738	.725	.275	1.000	
Total Phosphorus (TP)	.289	-.506	.609	.523	.531	.617	.649	.677	.689	.515	.485	1.000

Applying the trophic state definition used by Chapra (Ref 10), mesotrophy defined by a range of 10 and 20 μg/L total phosphorus, to Figure 3-4 (image) and Figure 3-5 (plot), it is noted that all waters having Secchi depths greater than 1.5 m would be considered mesotrophic; the other depths and colors would represent eutrophic waters. Applying State of Michigan criteria (Section 2.4.2.1) of Secchi depth and chlorophyll a, the waters having Secchi depths greater than 2.2 m would be considered mesotrophic. By any definition, the major mass of water in Saginaw Bay would be considered eutrophic. This work shows that a trophic state classification can be achieved from remote sensing data in conjunction with surface sampling and remote sensing provides the additional spatial (synoptic map) perspective of trophic state.

3.3.2.2 Recommended Mapping Approach

The preferred approach for producing the water quality map provides a quantitative measure of error in the prediction of the water quality parameters. A general step-by-step description of this technique follows together with its application to data collected 31 July 1975 by LANDSAT (2190-15401 and 2190-15404) and and surface crews.

Step 1. Collect Ship and Satellite Data - Three consecutive days and two boats were generally required to sample the 37 bay stations in 1975. For the maps produced in this example, only those surface samples taken the same day as the overpass, from 16 of the 37 stations, were used (Table 3-4).

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Table 3-4

EPA Water Quality Data for Saginaw Bay, 31 July 1975
(Measurements Made at Water Depth of One Meter)

Station	Temperature (°C)	Secchi Depth (m)	Chloride (mg/l)	Conductivity (micromhos)	Total Kjeldahl Nitrogen (mg/l)	Total Phosphorus (mg/l)	Chlorophyll a (µg/l)
7	26.1	1.9	10.9	243.	0.37	0 012	20.70
8	26.7	1.6	11.1	258.	0.41	0.017	9.38
12	26.8	1.3	18.8	277.	0.65	0.027	10.70
18	23.6	2.0	9.8	237.	0.38	0.012	5.61
26	26.0	1.6	13.8	251.	0.35	0.018	11.60
27	23.7	2.0	10.1	239.	0.29	0.012	7.38
32	24.8	1.8	10.1	235	0.33	0.010	7.38
34	26.9	10.6	24.1	294	1.00	0.039	68.50
38	25.1	1.4	11.7	244.	0.29	0.014	13.60
42	20.4	5.5	6.6	211.	0.14	0.002	1.84
43	23.5	1.5	12.1	246.	0.42	0.013	15.60
44	24.4	1.0	20.1	281.	0.72	0.027	37.10
52	21.5	2.1	10.4	238.	0.33	0.009	10.00
56	23.7	2.2	10.6	244.	0.26	0.014	6.58
60	22.5	5.0	6.9	215.	0.17	0.004	1.84
61	25.7	1.2	12 7	252.	0.42	0.020	18.00
Mean	24.46	2.0	12.5	247.8	0.41	0.016	15.36
Std. Dev.	1.92	1.3	4.7	21.8	0.22	0.009	16.53

Step 2. Provide Geometric Processing of Satellite Data - LANDSAT-2 CCTs for two consecutive scenes acquired on 31 July 1975 (2190-15401 and 2190-15404) were processed on a Bendix MDAS. The satellite data were first geometrically controlled by digitizing ground control points (GCPs), such as prominent coastal features, from a navigation chart. This investigation used 20 GCPs. The latitude and longitude of each GCP was converted to LANDSAT coordinates, using the interactive display routine on MDAS, and a geometric transformation matrix was established for the bay area. The bay station coordinates were transformed to LANDSAT coordinates with an error of less than one picture element (pixel). A LANDSAT pixel corresponds in this case to an area of 57 by 79 m (0.44 hectares).

Step 3. Edit LANDSAT Measurements from Bay Station Areas - The geometric correction matrix and the MDAS TV monitor were used to display the single pixel best corresponding to the digitized location of each bay station. The MDAS cursor was then positioned, expanded, and shaped by the operator about each station site to designate a station area of 60 to 100 pixels in size. Once the station areas were designated, the MDAS computer extracted the measurements from all four bands of all pixels defined by the cursor and calculated the mean digital count in each band (Table 3-5).

Table 3-5

LANDSAT Data for Saginaw Bay, 31 July 1975

Station	Number of Pixels to Station Area	Mean Reflectance of Station Area Band 4 254*	5 254*	6 254*	7 252*
7	56	40 6	27 5	14 8	1 4
8	63	44 0	29 5	16 3	1.5
12	72	42 8	29 5	16 2	1 7
18	72	38.1	24.7	13 8	0 5
26	64	42.7	28 3	14 7	0 4
27	90	38 1	24 5	12 2	0 3
32	100	37.2	23 2	11 7	0 1
34	100	38 6	29.1	16 4	0 9
38	121	40.4	26 1	12.3	0.1
42	72	32 3	20.3	9 8	0 3
43	72	36.0	23.1	10.9	0 2
44	72	35.6	25 5	14.5	0.8
52	72	32 3	21.1	11.0	0.4
56	72	39.5	25 2	12.8	0.6
60	110	34.0	21.0	10.1	0.1
61	99	43.7	28.7	14.1	0.6
Mean	81.7	38.5	25.4	13.2	0 6
Std Dev		3.8	3.1	2,2	0,5

*Maximum pixel count

Step 4. Correlate LANDSAT and Ship Data by Regression Equation - The LANDSAT measurements stored on the MDAS disk file were used in a stepwise linear regression program (Ref 45) to establish relationships between the LANDSAT measurements and each of the nine water quality parameters shown in Table 3-6.

Table 3-6

Regression Equations for
Saginaw Bay, 7/31/75 (16 Samples)

Temperature (°C)	= 9.61 + 0 007 (Band 4) + 0.572 (Band 5)
Secchi Depth (m)	= 8.24 + 0 142 (Band 4) - 0 458 (Band 5)
Chloride (mg/l)	= 9.489 - 2.040 (Band 4) + 3.202 (Band 5)
Conductivity (micromhos)	= 194 2 - 7.72 (Band 4) + 13.79 (Band 5)
Total Kjeldahl Nitrogen (mg/l)	= 0 419 - 0.102 (Band 4) + 0.153 (Band 5)
Total Phosphorus (mg/l)	= -0.0069 - 0.0033 (Band 4) + 0.0059 (Band 5)
Chlorophyll a (ug/l)	= 41.04 - 8.32 (Band 4) + 11.57 (Band 5)
Total Solids (mg/l)	= 154.1 - 7.73 (Band 4) + 12.93 (Band 5)
Suspended Solids (mg/l)	= 0.908 - 1.02 (Band 4) + 1.67 (Band 5)

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The regression procedure first determines which single independent variable (one of four LANDSAT bands, a ratio of bands, etc.) provides the best statistical correlation with the dependent variable (one of the water quality parameters). In successive steps, a second independent variable (band) was added, if necessary, to improve the multiple correlation. The results of various applications of the regression equation to the 3 June 1973 and 31 July 1975 scene have been reported (Ref 42, 43, 44). Findings of this early work show that, if given a choice between a single LANDSAT band and a ratio of bands, the ratio will be chosen first in most cases. The work also shows that from a statistical point of view (prediction error) there is no difference between the use of a pair of bands (as in Table 3-6) or the ratio of the two bands. It was also established that measurements in bands 4 and 5 provide best correlation to water quality parameters and, of the two bands, 5 is the most significant. Accordingly, this final analysis effort used only data from bands 4 and 5 (Table 3-6).

The stepwise linear regression program also resulted in regression correlation coefficients and standard errors of estimate (Table 3-7) which indicates how well the remote sensing measurements correlated with the water quality parameters.

Table 3-7

Regression Results for Saginaw Bay, 7/31/75 (16 Samples)

Water Quality Parameter and Range	Regression Correlation Coefficient	Standard Error of Estimate
Temperature (20 - 27°C)	.94	0.68
Secchi Depth (0.6 - 5.5 m)	.73	0.97
Chloride (6 - 24 mg/l)	.92	1.9
Conductivity (211 - 294 micromhos)	.93	8 6
Total Kjeldahl Nitrogen (0.1 - 1.0 mg/l)	.94	.08
Total Phosphorus (0 002 - 0.039 mg/l)	94	.0035
Chlorophyll a (1.8 - 68.5 ug/l)	.90	7.6
Total Solids (150 - 244 mg/l)	.79	15.
Suspended Solids (1 - 13 mg/l)	.74	2.3

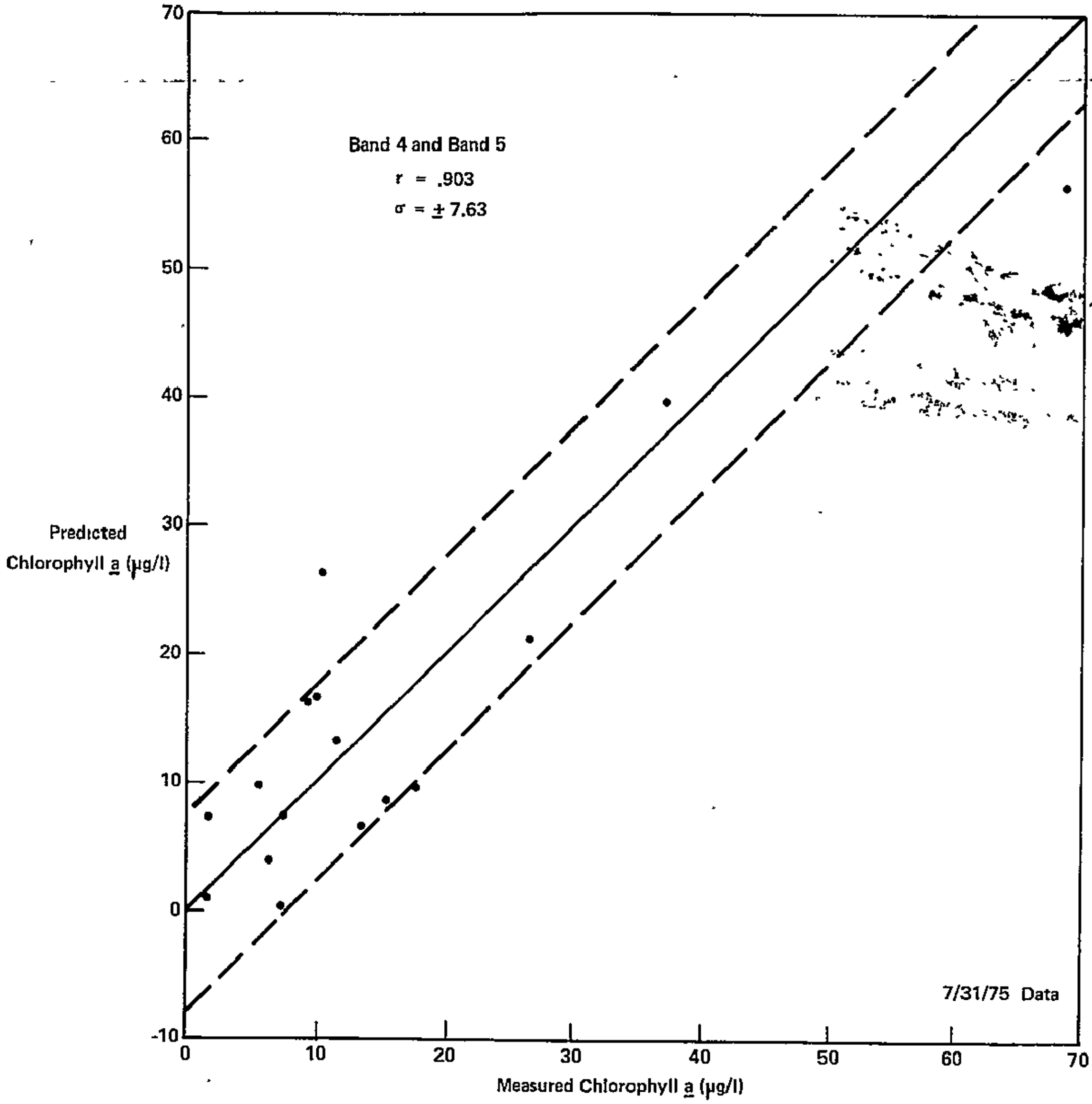
The regression correlation coefficients noted in the table provide a measure of the fit of the regression equation to the data and have a maximum possible value of unity. The standard error of estimate is in the same units as the dependent variable (e.g., μg/L).

Another way of assessing overall prediction capability of the regression equations is visually as in Figure 3-6. In this example LANDSAT band 4 and 5 measurements were used to predict chlorophyll a with the equation in Table 3-6. The predicted value was in turn plotted against the measured value of chlorophyll. If the predictions had been perfect all points would have fallen on the straight line with unity slope in Figure 3-6.

Step 5. Produce Water Quality Map - The final task was that of producing an image from LANDSAT CCTs and keying the gray scales or image colors to the desired water quality parameters. The image can be produced from a single band (level sliced), the ratio of bands, supervised categorical processing (using all bands), etc. The objective is to produce a good geometrically corrected image, establish the LANDSAT digital counts for each color or gray scale, and apply these counts in the regression equation to predict the desired water quality parameter for each image color. The image can be optimized to show one water quality parameter or a number of parameters. The imaging technique should employ the same bands used in the regression equation. An important point to note is that the LANDSAT digital counts (water quality parameters) are assumed approximately constant within a given gray scale or color generated from LANDSAT CCTs.

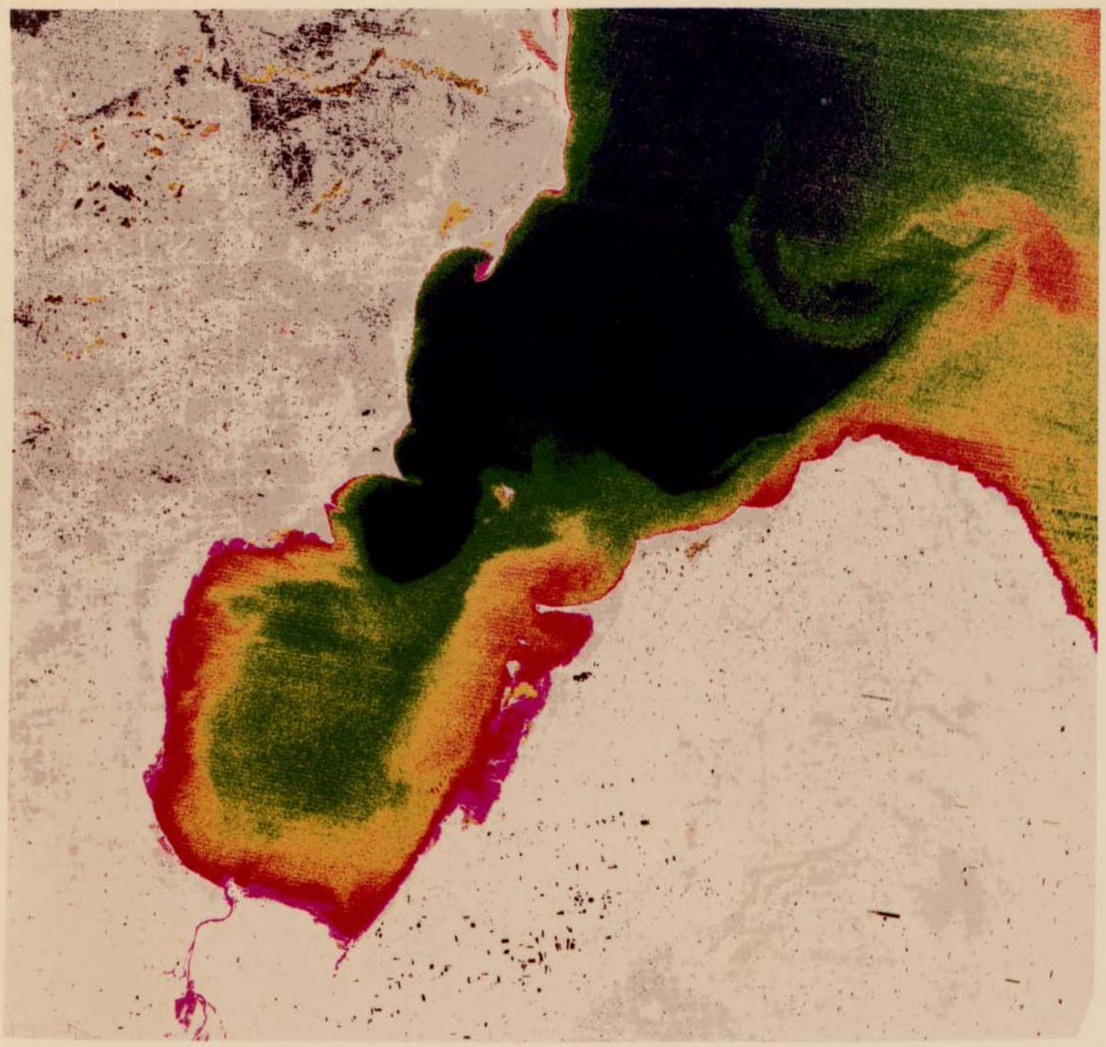
This investigation used the MDAS supervised processing technique to generate the color image from LANDSAT CCTs. It was determined that this technique provides the investigator with the best control of the colors and categories in the final map. The bay was first screened in both false color and single channel levels slice mode on MDAS to determine how many distinct water masses or zones were present. Five such levels of water quality were identified. The mean radiance of training sets for each of these five areas (categories) was computed and assigned a color code (Table 3-8). These training data were then used by MDAS to categorize each LANDSAT pixel for the bay into one of the five categories (colors). This categorization was then geometrically corrected and filmed (Figure 3-7).

The relationship between the LANDSAT measurements and color (Table 3-8) were transformed into estimates of desired water quality parameters using the regression equations in Table 3-6. The standard error of estimate was also included (Table 3-9) to provide the user with a measure of the accuracy of the predictions.



The standard error of estimate is shown in this figure as a dashed line.

Figure 3-6 Predicted versus Measured Chlorophyll a



10 Mi

16 KM

WATER QUALITY MAP
SAGINAW BAY, LAKE HURON

	Blue	Green	Orange	Red	Magenta	Standard Error of Estimate
Temperature (°C)	20.6	23.3	25.2	27.3	31.6*	1.6
Secchi Depth (m)	3.9	2.7	1.9	0.4	< 0.4*	1.1
Chloride (mg/l)	8.2	9.9	10.4	19.7	37.5*	1.9
Conductivity (micromhos)	221	235	243	284	363*	8.9
Total Keldahl Nitrogen (mg/l)	.22	.27	.28	.71	1.55*	.08
Total Phosphorus (mg/l)	.005	.012	.014	.032	.066*	.004
Chlorophyll $\overline{a}$ (ug/l)	7.6	7.6	5.0	37.5	99.1*	8.5
Total Solids (mg/l)	164	174	179	217	290*	15
Suspended Solids (mg/l)	1.6	2.7	3.2	8.1	17.6*	2.2

*These values are beyond the range of the sample data.

The water quality parameter levels were determined by regression analysis of Landsat digital data (31 July 1975, 2190-15401 and 2190-15404) and surface sample data collected at 16 bay stations on the same date by the United States Environmental Protection Agency (cruise 25).

Land features are shown as white for urban and built up, light gray for agricultural and grasslands, dark gray for forests and yellow for wetlands.

Bendix Aerospace Systems Division

Computer processed for NASA by the Bendix Aerospace Systems Division

WATER QUALITY MAP
SAGINAW BAY, LAKE HURON

	Blue	Green	Orange	Red	Magenta	Standard Error of Estimate
Temperature (°C)	20.6	23.3	25.2	27.3	31.6*	1.6
Secchi Depth (m)	3.9	2.7	1.9	0.4	< 0.4*	1.1
Chloride (mg/l)	8.2	9.9	10.4	19.7	37.5*	1.9
Conductivity (micromhos)	221	235	243	284	363*	8.9
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Total Phosphorus (mg/l)	.005	.012	.014	.032	.066*	.004
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Land features are shown as white for urban and built up, light gray for agricultural and grasslands, dark gray for forests and yellow for wetlands.

Computer processed for NASA by the Bendix Aerospace Systems Division (June 1976).

Figure 3-7 Water Quality Map, Saginaw Bay, Lake Huron

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Table 3-8

LANDSAT Training Set Means

Color	4	5	6	7
Blue	30.3	18.9	9.5	0.2
Green	36.7	23.5	11.6	0.2
Orange	41.6	26.8	14.2	1.2
Red	42.7	30.4	17.2	3.1
Magenta	45.6	37.8	25.1	6.8

Table 3-9

Explanation Block for Water Quality Map (Figure 3-7)

	Blue	Green	Orange	Red	Magenta	Standard Error of Estimate
Temperature (^{o}C)	20.6	23.3	25.2	27.3	31.6*	1.6
Secchi Depth (m)	3.9	2.7	1.9	0.4	< 0.4*	1.1
Chloride (mg/l)	8.2	9.9	10.4	19.7	37.5*	1.9
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Suspended Solids (mg/l)	1.6	2.7	3.2	8.1	17.6*	2.2

*These values are beyond the range of the sample data.

3.3.2.3 Analysis and Evaluations of Water Quality Maps

Application of the trophic state criteria used previously (mestotrophy is bounded by 0.01 and 0.02 mg/L total phosphorus) to the color map (Figure 3-7) shows that the deep Lake Huron water (blue color) would be classified olgotrophic, the inter-bay (green and orange) mesotrophic, and near shore (red and magenta) eutrophic. The Michigan criteria (Section 2.4.2.1) would also define the near-shore (red, magenta) waters as eutrophic. As important as trophic classification is the fact that the map provides quantitative estimates of the desired nutrients (phosphorus, nitrogen), algal biomass as indicated by chlorophyll a, and other parameters and the synoptic view of their concentration and distribution.

Review of the final water quality map with color key (Figure 3-7) has confirmed some known features of circulation and water quality in Saginaw Bay. Previous surveys of the bay (Ref 39 and 40) have indicated that the predominant flow of Saginaw River water is northward along the eastern shore of the bay. Less turbid Lake Huron water dominates the outer bay and enters the inner bay chiefly along the western shore. Zones of mixing and local circulation are apparent on the map, as are shoal areas where sediment evidently has been resuspended.

The Saginaw River enters Saginaw Bay at its extreme southwestern end and contibutes the majority of pollutants found in the bay. The magenta color, which represents levels of water quality that are beyond the range of the sample data used in the regression program, enhances the plume of turbid water that enters the bay from the Saginaw River and extends in a southeast direction. In the shallow near-shore zone (less than about 10 feet deep) of the lower bay, the magenta denotes areas where there are significant local resuspension of sediment.

A lobe of relatively clean Lake Huron water (blue) appears to enter the mouth of the bay between a central island (Charity Island) and a coastal point (Lookout Point) and flows up the bay (south) along its deepest channel. The boundary of the lobe and the bay water (green) is very pronounced and not gradational as is the case with the remaining three water mass boundaries.

A third feature is the spiral of water masses just northeast of the "thumb" of Michigan. This is an apparent mixing zone of the turbid water that has been transported from the bay into Lake Huron. The transporting current may have been set up by the counterclockwise deflection of southward moving Lake Huron water, along the shallow area between Charity Island and the eastern shore of the bay mouth (Oak Point). Thus, one mass of Lake Huron water enters the bay along its western shore, while another mass is prevented from entering but helps transport turbid bay water into Lake Huron. The apparent increase in turbidity at the top right corner of the map is due to the presence of an atmospheric haze associated with clouds, about 25 km northeast of the right corner of the map, but within the full scene.

The coefficients in the regression equations (Table 3-6) used to relate LANDSAT measurements to water quality parameters are dependent on scene and surface truth. Thus, the five-step procedure would be repeated for each different LANDSAT scene to adjust for differences in the atmosphere and in the relationships between water quality parameters.

It should be emphasized that LANDSAT is sensitive to color or volume reflectance of the water and does not, for example, measure temperature, chloride, conductivity, etc. directly. Only a few water quality parameters, viz., turbidity, chlorophyll, algal population, and particulate matter, directly affect reflectivity of Saginaw Bay water. However, the other invisible water quality parameters do correlate secondarily with color or volume reflectance to the extent that they all characterize the same water masses (Table 3-10).

Table 3-10

Correlation Coefficient Matrix (59 Stations)

Cruise 25
July 29 - 31, 1975

	T	SD	Cl	Con	Ch a	TKN	TP
Temperature (T)	1.00						
Secchi Depth (SD)	-.76	1.00					
Chloride (Cl)	.48	-.54	1.00				
Conductivity (Con)	.47	-.54	.99	1.00			
Chlorophyll a (Ch a)	.54	-.67	.41	.37	1.00		
Total Kjeldahl Nitrogen (TKN)	.59	-.66	.94	.92	.61	1.00	
Total Phosphorus (TP)	.39	-.50	.98	.98	.39	.91	1.00

Because of the secondary correlations between water quality parameters, the approach of remote sensing and surface sampling may well be applied to map the extent and concentrations of the toxic substances (Section 2.5.1.4), which are generally associated with particulate matter in natural waters.

In summary, all nine water quality parameters were mapped as one color-coded image. If separate maps were required for each parameter, the boundaries between colors could be relocated so as to better proportion the levels. For example, the map in Figure 3-7 shows that chlorophyll a is low in the outer bay and central portion of the inner bay but extremely high in the near-shore zone of the inner bay. A separate map, made with different training areas, could be made for each parameter. In the case of chlorophyll a, this would permit perhaps one color code for the areas of low concentration and four colors for the areas of high concentration as opposed to three and two, respectively.

3.3.2.4 Comparisons with Other Methods and User Evaluations

A comparison was made between the LANDSAT-derived water quality map and a map produced by a technique used by EPA. The EPA commonly makes machine-plotted contour maps for areas such as Saginaw Bay from station data that are filed in the EPA-STORET system. Figure 3-8 is a copy of one such map for chloride and shows the 16 stations, the parameter values at each station, and the computed contour lines. Figure 3-9 is a copy of the chloride map for 3 days of ship data with shading to reflect the same levels of water quality that are shown in the LANDSAT map in Figure 3-7. The boundary values of the shaded areas correspond to midrange values as determined from Table 3-9. A comparison of Figure 3-7 with Figure 3-8 shows that plotter maps of 1 day's data to not provide an accurate synoptic portrayal of bay water quality. Figure 3-7 compares very favorably with Figure 3-9, but the LANDSAT technique provides a much more detailed portrayal that is more realistic in pattern than that provided by the machine-plotter technique. Figure 3-10 is included to provide further comparison of LANDSAT with one additional water quality parameter, Secchi depth estimated from 33 samples. One conclusion of this comparison of techniques is that a water quality map derived from the computer processing of LANDSAT data and one day's surface truth provides as much, if not more, detail than a water quality map made from the machine contouring of 3 days of surface truth. If the LANDSAT-derived maps meet the standards and needs set up by the water quality investigator, then in subsequent studies the 3-day ship survey cruise could be shortened to 1 day at a cost savings of about $5,000 to $10,000.

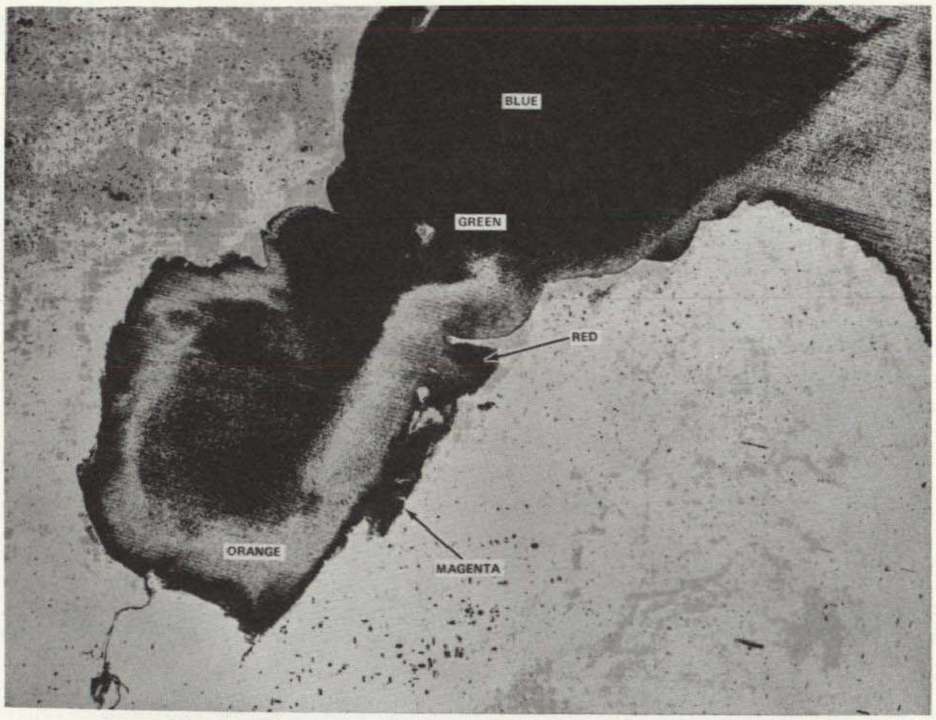
EPA Comments

1. Remote sensing was shown to be useful for extrapolating water quality to unsampled areas on a survey-by-survey basis.

2. In summary, it is apparent that regular LANDSAT mapping of water quality in the bay is feasible with the following provisions: that sampling is conducted within a few hours of LANDSAT passage; that such concurrent measurements are used to "recalibrate" the satellite data on each occasion; and that the errors of estimation for each parameter (based on comparison of actual and predicted values) are within acceptable limits.

3. The advantages of using LANDSAT monitoring as an adjunt to conventional point-sampling is that it provides an economical basis for extrapolating water quality parameters from point samples to unsampled areas, and it provides a synoptic view of water mass boundaries that no reasonable amount of point sampling could duplicate.

4. Survey vessels should carry out continuous monitoring of at least two parameters, percent transmittance and conductivity, in order to locate water mass boundaries and define chemical gradients. This information, together with sample and satellite data, could be used to map certain parameter distributions throughout the bay.



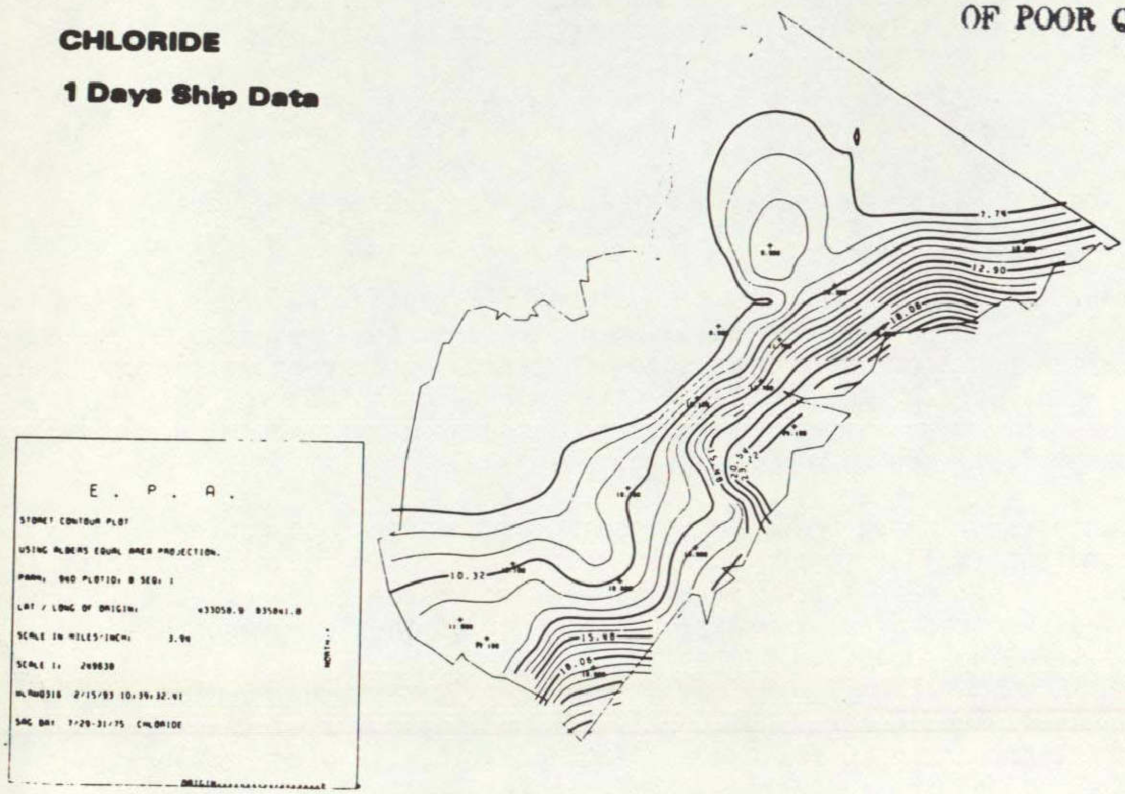


Figure 3-8 Machine Contour Plot of Chloride Data from 16 Stations, Compared With LANDSAT Map from Same Day, 31 July 1975

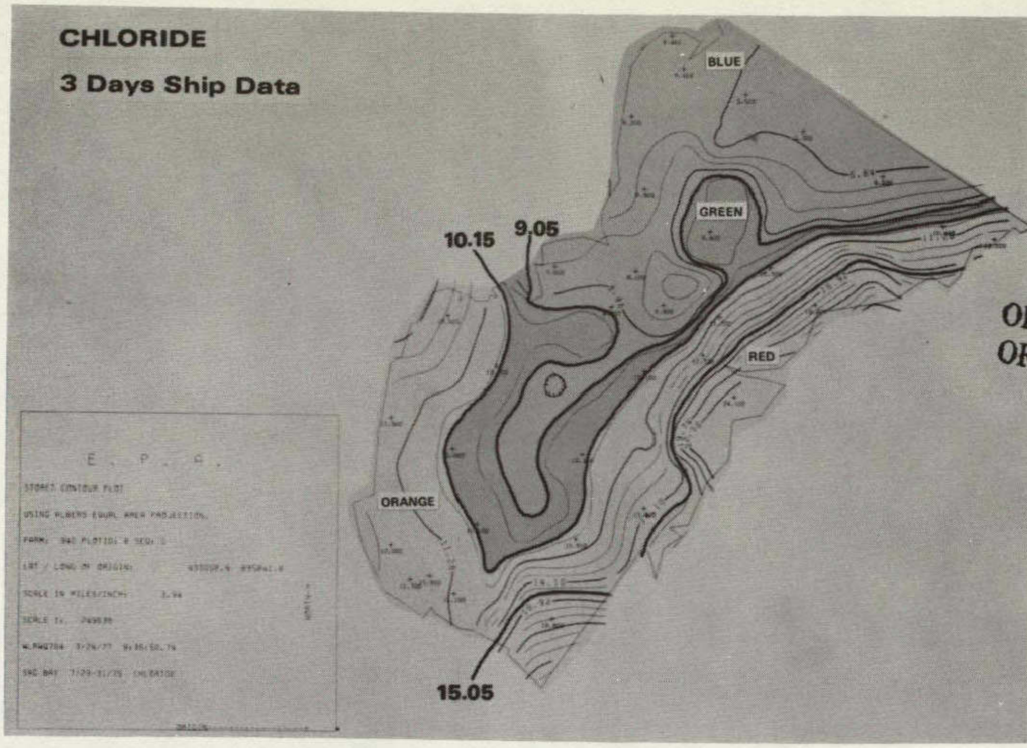


Figure 3-9 Machine-Contoured Chloride Data,
33 Stations, 29-31 July 1975

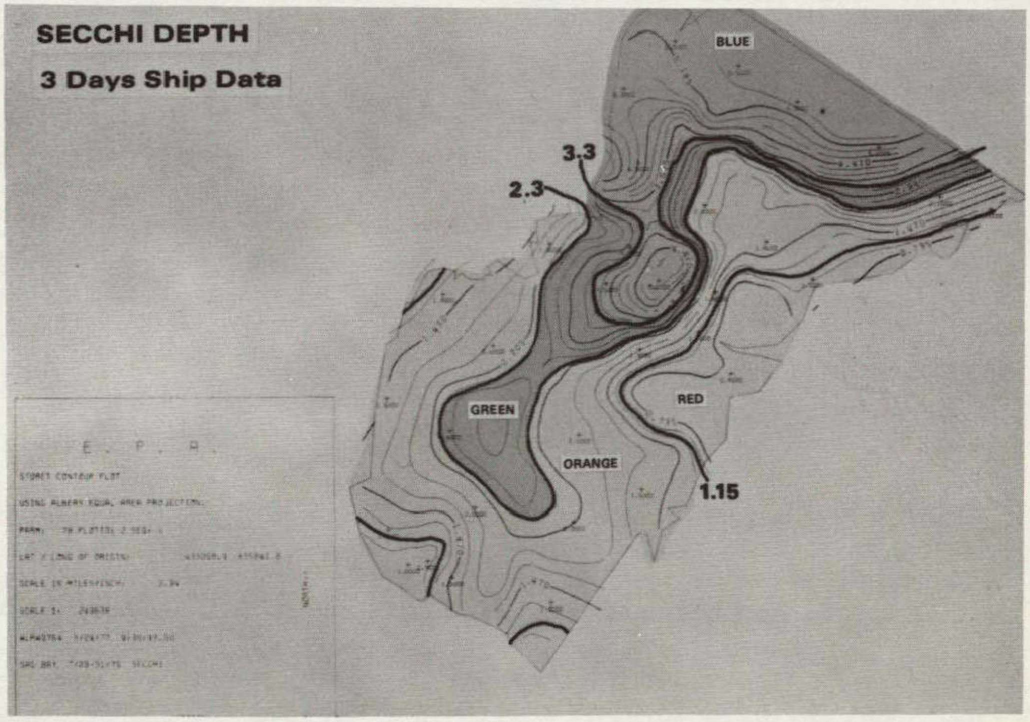


Figure 3-10 Machine-Contoured Secchi Depth Data,
33 Stations, 29-31 July 1975

5. More frequent satellite coverate is needed. We require cloud-free data on a monthly or more frequent basis. The present LANDSAT coverage only provides three or four clear scans each year.

3.3.2.5 Recommended Future Work

The work in Saginaw Bay has demonstrated a step-by-step procedure for using surface measurements and LANDSAT data to produce a color-coded map showing the distribution and concentration of various water quality parameters. Although the procedure is dependent on scene and surface truth, it can be applied in its present form to monitor various water quality parameters with a known accuracy (predictable accuracy). Specific recommendations are:

1. It is recommended that the procedure demonstrated by this program be used in the assessment of trophic state of large lakes. On-going water quality and sampling programs on the Great Lakes do not, for the most part, reflect availability and usefulness of satellite data. Assessment of the Great Lakes for trophic state is presently limited by available boats and laboratories to about once every 9 years. It is now recommended that shipping/sampling schedules be coordinated with satellite coverage whenever possible. With coordinated sampling, the satellite could then extend the measurements over large areas, thus permitting assessment of all the lakes on a more reasonable schedule, e.g., even 4 or 5 years or as desired.

2. It is recommended that remote sensing data be used to develop, calibrate, and verify models used to assess the source, distribution, and fate of pollutants. Water quality as well as nonpoint source land cover data could be derived from remote sensing. This requires monthly or more frequent coverage for water quality parameters and one-time only or once every 5 years for land cover. This is the type of program EPA is conducting in Saginaw Bay. It is recommended that similar efforts be undertaken in other problem areas in the Great Lakes Basin, e.g., Lake Erie, lower Green Bay, southern Lake Michigan, etc.

3. An aircraft/multispectral scanner program is recommended to determine the sensor requirements (i.e., resolution, bands, coverage, etc.) and benefits for monitoring plumes of waste treatment sources for phosphorus content. This would establish future requirements and benefits for satellite monitoring of near-shore zones of all lakes. The IJC pointed out (Figure 2-9) 63 known problem sources in its 1975 annual report. These sources must be monitored for progress in achieving water quality objectives, and new sources must be detected when phosphorus content exceeds water quality objectives.

C-2

3.3.3 LAND COVER DATA

Remote sensing requirements for land cover data (Sections 2.4.5 and 2.5.3) as related to water quality planning are similar at various planning levels, i.e., Great Lakes basins, Saginaw Bay watershed, inland lake watersheds, and river drainage areas. The role of remote sensing in all cases is providing a responsive inventory of land cover for watersheds in a format suitable for estimating nutrient loadings from existing and new land uses. This investigation produced tabular and other land cover data in response to the needs of EPA in studies of the Saginaw Bay watershed and to sub-state planning regions within the watershed concerned with inland lakes and waterways. The work accomplished in support of the planning regions and for the larger basin are summarized to show the range of applications for remote sensing data to ongoing water quality programs. The major product required by all users within the basin was the land cover tabulation. The tabulations in all cases included the categories (urban, cropland, grassland, forest, water, wetlands, barren land) required by models (Section 2.3.1) used to predict nutrient runoff.

3.3.3.1 Support for East Central Michigan Planning and Development Region (Region 7)

LANDSAT data graphics were produced to support the development of a Water Quality Management Plan (WQMP) by the East Central Michigan Planning and Development Region (Region 7) in response to Section 208 guidelines (Section 2.4.1). This region contained within the center of the Saginaw Bay watershed includes the 14 counties shown in Figure 3-11, an area of 8,700 square miles.

A LANDSAT inventory of the region was the only reasonable land cover source for this large 208 region. Primary considerations in the choice of LANDSAT data were: (1) no other available data, (2) need for tabular land cover data on 66 hydrologic subdivisions (average size 125 square miles each), (3) requirement for consistent categories from same data source and season, (4) time constant (less than 6 months), and (5) money constraint (under $25,000).

LANDSAT products derived for the 14-county region included: color-coded maps at 1:250,000 scale; color-coded map overlays at 1:250,000 scale; 20 color-coded maps of selected 15-minute quads; resampled digital land cover files; and 98 area tabulations for 66 hydrologic subdivisions, 14 counties, and 18 special areas. The five LANDSAT scenes (2191-15462, 2189-15350, 2191-15460, 2190-15401, and 2190-15404) collected on July 30-August 1, 1975 were submitted to categorical and geometric processing in Bendix Data Center (Section 3.1) to produce the required land cover data. Ground truth information was obtained from the NASA photography and field observations by the Region 7 personnel. Thirty-nine distinct cover types were categorized over the five scenes and were later aggregated into the 13 listed in Table 3-11 for production of color maps and overlays. Figure 3-12 shows one categorized area composed of two LANDSAT scenes (end-to-end merge of scenes) collected on 31 July 1975. Note that these are the same data processed for the water quality parameters and shown previously in Figure 3-7.

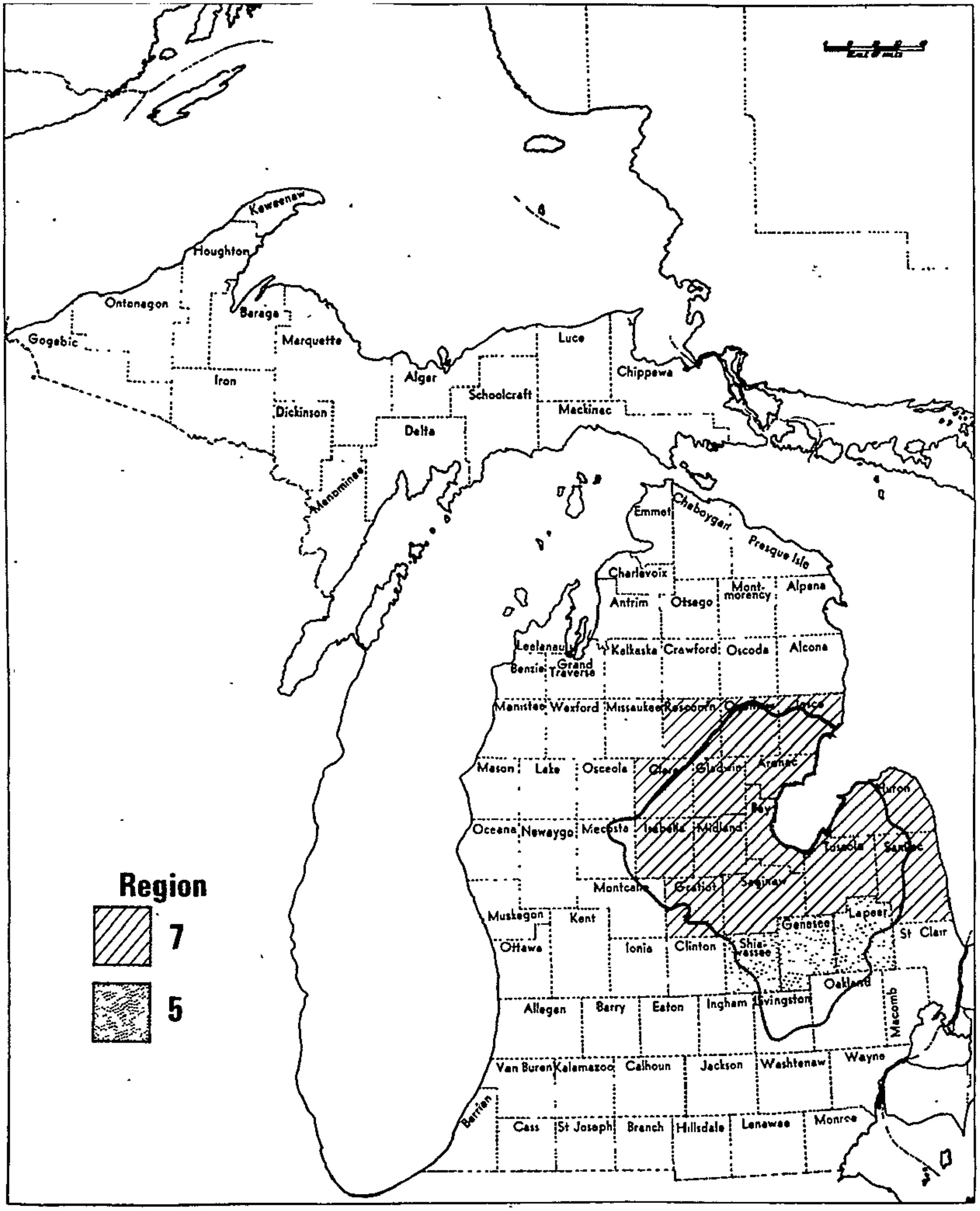


Figure 3-11 Planning Regions and Saginaw Bay Watershed

C-2.

Table 3-11

Categories and Color Codes for Image Showing Michigan Planning Region 7

Computer Processed from LANDSAT Data of 31 July 1975 Scenes 2190 - 15401 and 2190 - 15404

Categories developed for the East Central Michigan Planning and Development Regional Commission

Urban and Built-Up Land	
Industrial and High Density Residential	Bright Red
Medium Density Residential	Orange
Agricultural Land	
Cropland	Gray
Pasture	Brown
Rangeland	
Grassland	Bright Yellow
Forest Land	
Deciduous	Bright Green
Coniferous	Dark Green
Mixed	Green
Water	Blue
Wetlands	
Brush	Cyan
Nonforested Wetland	Cyan
Barren	
Sand and Bare Ground	Purple
Uncategorized	Black

Figure 3-12 Color-Coded Image of Michigan Planning Region 7, Color Codes in Table 3-11

Tabular and cover printouts were generated for the 66 hydrologic subdivisions and 14 counties shown in Figure 3-13. A hydrologic subdivision is that portion of a watershed contained within a county. The 22 major watersheds in Region 7 are listed in Table 3-12. Tabular printouts listing 39 categories of land cover by hydrologic subdivision were aggregated into the nine categories listed in Table 3-13 for assignment of loading factors used to compute pollution loads.

A model developed (Ref 16) by Region 7 was used to transform the 1975 land cover data derived from LANDSAT into projections of land cover for 5-year intervals to the year 2000. A major driving function for this effort was the anticipated population for the same time period. The model was used by the region to predict land cover for each of the hydro subdivisions, 22 watersheds, and 14 counties to the year 2000. Table 3-14 is an example showing land cover in four of the watersheds for the five time periods.

Loading rates (previous Table 2-4) were multiplied by the predicted land cover to estimate total loads in the watersheds through the year 2000. Table 3-15 shows predicted loads in six of the 22 watersheds. Agriculture was the dominant category governing loads from each watershed due to high loading rates and predominance of agricultural land cover. Urban areas were the second most important contributors of loads.

<u>Regional Summary of Land Utilization</u> - The LANDSAT figures on a regional basis provide an interesting picture of the East Central Region. A summary of the region as derived from LANDSAT is shown in Table 3-16.

As noted in the table, the most prominant land cover category is the Forested category, followed closely by the Intensive Agriculture category. An analysis of the land cover data in conjunction with the Region's use of land shows that over 50% of the Region's land is agriculturally related.

In terms of the projected changes to be made, most of the projected cover change is expected to occur in the category of Forested or Intensive Agriculture, with most of these lands being converted to a Grassland or Agricultural-Residential classification. The counties, listed in Table 3-17, illustrate land cover changes predicted by the region for the year 2000.

In terms of absolute land cover acreage change, the counties of Clare, Bay, and Saginaw are expected to see the greatest land cover acreage changes. It is important to note that while a county may have a large percentage of land changing activity (land use changes), the counties may have a much smaller relative percentage changing land cover. This is a result of very low density development and the utilization of land much less intensively than in more urbanized areas.

Since the estimated land cover change was closely associated with projected population, the projected acreage changes are somewhat representative of the net population change by the year 2000. However, because of density considerations and the different impacts that added population has on an urban area as opposed to a rural area, this list would not necessarily duplicate a list of counties ranked by expected population change.

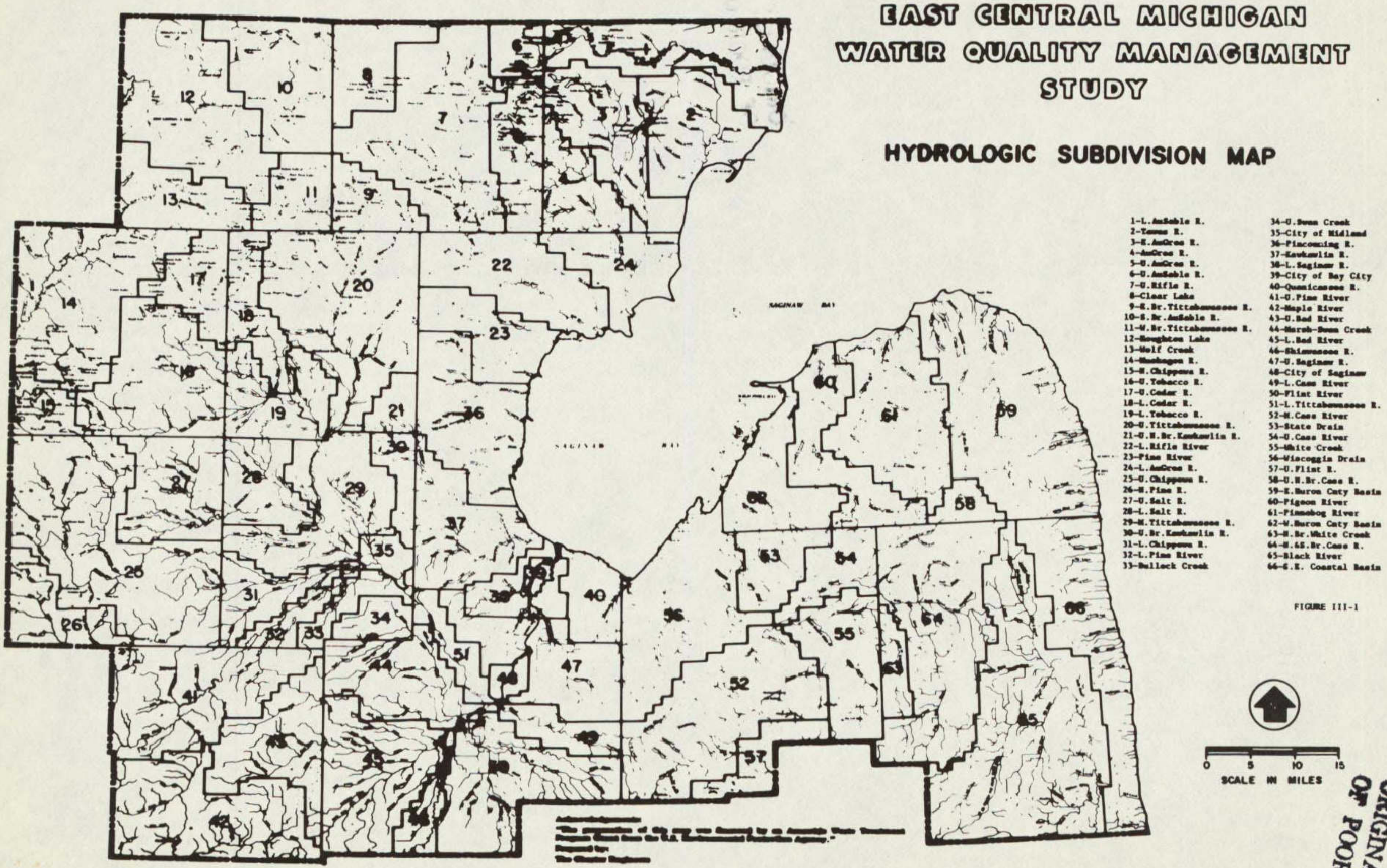


Figure 3-13 East Central Michigan Hydrologic Subdivisions

Table 3-12

Hydrologic Subdivisions Grouped by Watershed

WATERSHED	HYDROLOGIC SUBDIVISIONS
Au Sable	1
	6
	8
	10
Tawas	2
Au Gres	3
	4
	5
	24
Rifle	7
	22
Muskegon	12
	13
	14
Upper Tittabawassee	9
	11
	16
	17
	18
	19
	20
Western Saginaw Bay Shoreline	23
	36
Chippewa	15
	25
	31
Pine	26
	41
	32
Lower Tittabawassee	27
	28
	29
	33
	35
	51
Kawkawlin	21
	30
	37
Maple	42
Shiawassee	34
	43
	44
	45
	46
Flint	50
	57
Saginaw	38
	39
	47
	48
Southern Saginaw Bay Shoreline	40
	56
Cass	49
	52
	54
	55
	58
	63
	64
Sebewaing	53
	62
Pigeon	60
Pinnebog	61
Black	65
Lake Huron Shoreline	59
	55

Table 3-13

Category Descriptions

Water: This category includes deep Lake Huron water, rivers, lakes, streams, and marshes. In the shoreline counties, some Lake Huron water acreage may have been included because of shoreline deviations from mapped areas.

Wetlands: Land which is water covered, heavily saturated, or seasonally water covered.

Forest: All land, tree, or brush covered, including forested wetland areas.

Intensive Agriculture: Those lands which were under production as a cropland.

Grassland: Those lands covered predominantly by grasses, including pastures, lawns, recently cut hay crops, etc.

Residential-Agriculture: This category includes some prime agricultural or cropland areas and land which is being converted to residential uses at very low densities.

Urban-Impervious: Areas where a high percentage of the soil has been covered by concrete or asphalt.

Barren: Soil areas where bedrock has been exposed or where soil without cover was predominant; includes above-ground mining operations.

Uncategorized: Lands which, because of cloud cover, unique spectral "signatures," etc., could not be interpreted or related to any other category.

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Table 3-14

Land Cover Projections by Watershed
(Land Cover in Acres)

LAND COVER CATEGORY	SHIAWASSEE				FLINT			
	1975	1980	1990	2000	1975	1980	1990	2000
WATER	1313	1313	1313	1313	357	357	357	357
WETLANDS	353	353	353	353	173	173	173	173
FORESTED	55124	55015	54969	54894	26467	26207	26010	25795
AG-INTENSIVE	180121	179675	179407	178992	77472	77071	76768	76433
GRASSLANDS	67101	67504	67540	68070	32825	33331	33713	34133
AG/RESIDENTIAL	31102	31254	31532	31492	12209	12364	12482	12612
URBAN/ IMPERVIOUS	556	556	556	556	166	166	166	166
BARREN/ EXTRACTIVE	1252	1252	1252	1252	1056	1056	1056	1056
UNCATEGORIZED	4801	4801	4801	4801	2538	2538	2538	2538
TOTAL	341723	341723	341723	341723	153263	153263	153263	153263

LAND COVER CATEGORY	SAGINAW				SOUTHERN SAGINAW BAY SHORELINE			
	1975	1980	1990	2000	1975	1980	1990	2000
WATER	5306	5306	5306	5306	6566	6566	6566	6566
WETLANDS	770	770	770	770	754	754	754	754
FORESTED	4178	3972	3813	3627	10498	10498	10498	10498
AG-INTENSIVE	64267	60666	57589	53900	117748	116995	116454	115765
GRASSLANDS	32790	33886	35028	36236	32914	33426	33786	34240
AG/RESIDENTIAL	37566	39745	41436	43580	17950	18191	18372	18607
URBAN/ IMPERVIOUS	4499	5031	5434	5957	557	557	557	557
BARREN/ EXTRACTIVE	2328	2328	2328	2328	1165	1165	1165	1165
UNCATEGORIZED	3075	3075	3075	3075	3687	3687	3687	3687
TOTAL	154779	154779	154779	154779	191839	191839	191839	191839

Table 3-15

Total NPS Loads by Watershed

WATERSHED	YEAR	TOTAL LOADING NITROGEN (1,000 LB/YR)	PHOSPHORUS (1,000 LB/YR)	AMMONIA (1,000 LB/YR)	BOD_5 (1,000 LB/YR)	SUSPENDED SOLIDS (1,000 TON/LB)	OIL & GREASE (1,000 LB/YR)
Shiawassee River	1975	1,900	950	200	1,900	150	22.0
	1980	1,900	950	200	1,900	150	22.0
	1990	1,900	950	200	1,900	150	22.0
	2000	1,900	950	200	1,900	150	22.0
Flint River	1975	840	410	87	830	67	6.6
	1980	840	410	87	830	67	6.6
	1990	840	410	87	830	67	6.6
	2000	840	410	87	830	66	6.6
Saginaw River	1975	890	390	99	970	64	180.0
	1980	870	380	99	960	62	200.0
	1990	850	360	98	960	60	220.0
	2000	820	350	97	950	58	240.0
Southern Saginay Bay Shoreline	1975	1,300	620	130	1,300	98	22.0
	1980	1,300	620	130	1,300	98	22.0
	1990	1,300	610	130	1,200	97	22.0
	2000	1,300	610	130	1,200	97	22.0
Cass River	1975	2,600	1,300	280	2,600	210	26.0
	1980	2,600	1,300	280	2,600	210	27.0
	1990	2,600	1,300	280	2,600	210	28.0
	2000	2,600	1,300	380	2,600	210	30.0
Sebewaing River	1975	810	380	76	780	61	7.2
	1980	810	380	76	770	61	7.2
	1990	810	380	76	770	61	7.2
	2000	800	380	76	770	61	7.2

Table 3-16

Regional Land Cover Summary

Category	Acreage	Percent
Water	73,361	1.32
Wetlands	35,757	.65
Forested	2,243,254	40.48
Intensive Agriculture	1,896,753	34.23
Grasslands	817,704	14.75
Residential-Agriculture	327,073	5.90
Urban-Impervious	11,876	.21
Barren	19,195	.35
Uncategorized	116,233	2.10
TOTAL	5,541,206	99.99

Region Comments on Application of LANDSAT Data - LANDSAT data applied to watershed areas or counties are extremely efficient and reliable. The data regarding land cover are an asset in the development of water quality/land cover relationships. Future work in the area of projection of land cover should result in continued advances in the reliability and application of projected data.

Table 3-17

Land Cover Change Summary Table, Year 2000

County	Acres Activity Change	Acres with Cover Change	County Total Acreage	% of Acres with Cover Change
Arenac	13,102	1,966	232,471	.85
Bay	14,622	11,252	284,725	3.95
Clare	52,341	12,857	366,291	3.51
Gladwin	32,114	6,038	325,021	1.86
Gratiot	3,265	1,916	360,754	.53
Huron	25,557	4,264	546,569	.78
Iosco	37,988	9,517	356,532	2.67
Isabella	9,693	6,199	365,648	1.70
Midland	10,839	3,883	332,684	1.17
Ogemaw	31,294	4,694	361,101	1.30
Roscommon	59,716	8,958	369,635	2.42
Saginaw	13,221	10,963	512,788	2.14
Sanilac	44,936	6,740	611,817	1.10
Tuscola	22,842	7,918	515,170	1.54
TOTAL	371,530	97,165	5,541,206	1.75

3.3.3.2 Support for the Genesee, Lapeer, Shiawassee Planning and Development Region (Region 5)

LANDSAT data graphics were produced to support the development of a Water Quality Management Plan (WQMP) by Region 5 in response to Section 208 guidelines (Ref 46). Additionally, the graphics were to be used to support transportation planning and to assist the planning activities of local units of government. This region contained within the Saginaw Bay watershed (Figure 3-11) cover the three counties of Shiawassee, Genesee, and Lapeer, an area of about 1,840 square miles.

The inventory of the region was accomplished by deriving eight urban categories from aerial photography on about 10% of the region and four nonurban categories from LANDSAT on remaining 90% of the region. The merging of these two sources in the Bendix facility (Section 3.1) permitted the region to be inventoried with cost savings only available with LANDSAT data and detail in the urban areas best obtained from photo or field interpretations. Primary criteria used by the region in selecting this approach was its responsiveness to the region's needs: (1) 75-day response, (2) funding (under $21,000), and (3) desired data formats and graphics.

Products derived for the region are noted in Figure 3-14 and include: digital land cover files organized by township and coded by dominant cover within each 10-acre cell; area tabulations for each of 31 watersheds, 52 townships, and 36 municipalities; color-coded regional map at 1:96,000 scale showing full 1.1-acre detail; plotter-generated township maps at 1:24,000 scale for each township and 1:48,000 scale for each county.

The three primary sources of data input were LANDSAT scene 2190-15404 of 31 July 1975, color infrared aerial photography gathered by NASA in May 1975, black and white aerial photography gathered by NASA in May 1975, and black and white aerial photography of June 1975. This LANDSAT scene was one of the five used in the Region 7 effort and also applied in the analysis of water quality in Saginaw Bay. Region 5 also made available black and white aerial photography for the region of June 1975.

The LANDSAT CCTs and aerial photography were transformed into the desired data format by Bendix (Section 3.1) and Michigan State University (MSU). Personnel from the MSU Remote Sensing project provided the photo interpretation and production of plotter maps. The steps used to produce the land cover data are shown in Figure 3-14 and described in Section 3.1. It summarizes the work involved in categorical and geometric processing of LANDSAT data to produce a digital land cover file coded to the 1.1-acre pixel detail. The manually interpreted urban areas derived from photo interpretation were traced and transformed into a similar pixel file structure. The LANDSAT and photo derived files were combined in the computer, permitting the photo file to overwrite the LANDSAT file. The resulting file constructed from this multisource data was used as the basis for all maps and data graphics.

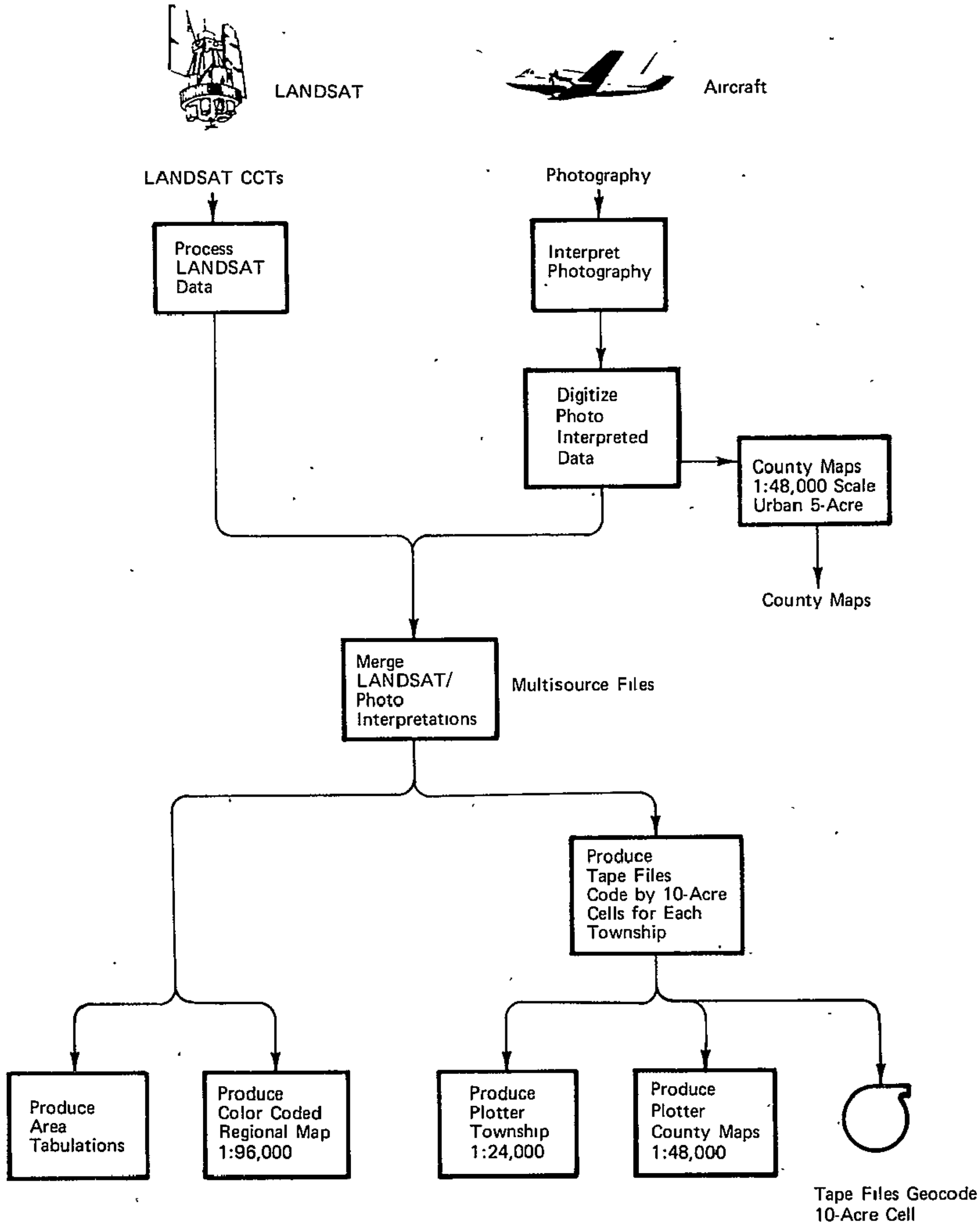

Figure 3-14 Summary of Processing Steps

Table 3-18 lists land cover categories and their sources, whether LANDSAT, photo interpretation, or both. Table 3-19 shows area tabulations prepared for the three counties. Similar tabulations were prepared for watersheds, townships and municipalities.

For analysis related to the water quality investigations the most useful products were the area tables and digital land cover files. The tables can be used as in the Region 7 example to estimate land cover/use by watershed for various time periods, and combined with loading rates to predict watershed loads as a function of time. When more detailed analysis is required and greater consideration is given to soil type and topography, the digital cover files will facilitate combining cover with these other sources by computer techniques.

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

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

Four-hundred 10-acre cells in the region were randomly selected by MSU to determine the overall categorization accuracy of the land use/cover data. The land use/cover of those selected cells that were categorized from LANDSAT data was verified through photo interpretation whereas cells having photo-derived categories were verified on the ground. The sample survey showed that the land use/cover data are 93.4% accurate at the 0.1 confidence level. Table 3-20 is a summary of the sample survey.

The multisource technique was particularly cost-effective for GLS Region 5, which required both a high degree of interpretation within the urban areas (i.e., mobile home parks, single family housing, transportation, etc.) best derived from photography, and within nonurban areas (forest, wetlands, water, etc.) best obtained by LANDSAT. Table 3-19 shows that even though 8 out of 12 (67%) of the categories were derived from aerial photography, more than 90% of the total area was categorized by LANDSAT. The nonurban categories, which generally account for a major portion of the planning region, were mapped from LANDSAT data with an accuracy of 93% or better, depending on the category, scene quality, and ground truth availability. This equals or betters the accuracy obtained by manual photo interpretation, but it is achieved at much lower cost.

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Table 3-18

Land Use Definitions and Sources

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

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Table 3-19

Area Tables Produced from Multisource Data

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

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

*Parks, cemeteries, outdoor recreation.

Table 3-20

LANDSAT Categorization Accuracy
(Summary of Sample Survey)

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

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

3.3.3.3 Saginaw Bay Watershed Land Cover

Area tabulation of land cover was derived to support EPA's modeling effort in Saginaw Bay and to support modeling efforts of NOAA and the Great Lakes Basin Commission. The area tables were produced from tabulations of LANDSAT and multisource data generated in support of Michigan's Region 7 and Region 5 work in the Saginaw Bay watershed and reported in previous sections. The two LANDSAT scenes (2190-15401 and 2190-15405 of 31 July 1975) were used in this effort.

The tabulations resulting from this task are shown in Table 3-21 and Table 3-22. Table 3-21 shows that land contributing runoff/nutrients directly into Saginaw Bay water. The total land is subdivided into that draining from the west and east sides of the basin divided by the Saginaw River. Table 3-21 shows that the dominant cover is forest on the west side and agricultural on the east side. This is confirmed in the processed LANDSAT image in Figure 3-12. Table 3-22 shows land cover in the Saginaw Bay watershed. This table also shows that parts of Region 7 and Region 5 are contained within the watershed. From comparison of the two tables, it is readily observed that land influencing Saginaw Bay water is predominantly agricultural-related and that the sources of nutrients from the watershed are contributed mostly by the rivers draining the basin as opposed to direct runoff into the bay.

Table 3-21

Land Draining Directly into Saginaw Bay

COVER TYPE*	PERCENT OF AREA (%) W. Bank	E. Bank	TOTAL AREAS Sq. KM	Acres
Urban (Impervious)	0.05	0.1	10.	2,471.
Residential/Agriculture (Grassland)	1.8	4.5	433.	106,994.
Barren	0.15	0.25	26.	6,425.
Agricultural	9.9	26.8	2478.	612,314.
Grassland	6.0	9.6	1061.	262,173.
Forest	29.5	6.7	2621.	647,649.
Wetland	0.4	0.1	37.	9,143.
Water	0.4	0.55	68.	16,803.
Uncategorized	1.8	1.4	232.	57,327.
	50.00% 3699 sq km	50.00% 3267 sq km	6966 sq km	1,721,299. acres

*Categories Defined in Table 3-13 Produced from 31 July 1975 LANDSAT Data.

Table 3-22

Land Cover Tabulation Produced by Bendix from
LANDSAT Satellite Data Collected on Saginaw Bay, 31 July 1975

CATEGORY	%	SAGINAW BAY WATERSHEDS A ACRES		REGION 7 (12/14 CO.)B ACRES		REGION 5 (TOTAL) C ACRES
URBAN	2.2	126,004		10,498[1]		115,506[3]
AGRICULTURAL	37.1	2,130,528		1,548,837		581,691[4]
GRASSLAND	21.1	1,220,999		971,703[2]		249,296[4]
FOREST	35.6	2,048,417		1,848,093		200,324
WATER	0.9	53,245		44,070		9,175
WETLAND	1.0	60,110		28,960		31,150
BARREN	0.3	16,246		16,246		[5]
UNCATEGORIZED	1.7	95,344		95,239		105
TOTAL		5,750,893	(79.4%)	4,563,646	(20.6%)	1,187,247

A. Includes the Saginaw River Basin and "ON-BAY" watersheds

B. Includes: Arenac, Bay, Clare, Gladwin, Gratiot, Huron, Iosco, Isabella, Midland, Ogemaw, Saginaw and Tuscola Counties.

C. Includes: Genesee, Lapeer and Shiawassee Counties.

1. Includes only the "Urban Impervious"
2. Includes both "Grassland" (694,805 acres) and "Residential/Agricultural" (276,898 acres)
3. Includes 8 urban and residential categories interpreted from aerial photography.
4. These values were calculated by a .7X and a .3X factor as applied to the original "Agricultural/Open Space" category (830,988 acres). The factors were obtained by comparing the percentages for adjacent areas in Tuscola and Lapeer counties.
5. Not identified.

Quantitative estimates of nutrient loadings from existing and potential land uses are obtained by multiplying the loading rates in Table 2-4 of Section 2.3.1.1 by the areas listed in Table 3-21 or Table 3-22. To obtain future loads, a technique such as the one reported (Ref 16) by Region 7, which modifies cover type based on population projections, can be used.

3.3.3.4 Comparison with Other Methods

There was no other available source to EPA or the planning regions for the needed land cover information. Available maps (USGS, etc.) do not break out the minimum categories: urban, barren, cropland, grassland, forest, wetlands, and water required to estimate nutrients and other pollutants in runoff. For areas of 1000 sq. miles or larger LANDSAT provides the necessary land cover at a cost of $1.00 to $4.00 per square mile in the desired formats, e.g., tabulations, maps, etc. This cost is based on standard Bendix price list dated 3/24/77. The cost for mapping from aerial photography is a function of the number of land use categories, smallest detail of interest, scale of aerial photography, and output products. It is also a function of the pay scale of persons doing the work, e.g. students, in-house staff, outside contractor, etc. The Michigan State University Remote Sensing project reports* cost to be about $8 per square mile for interpreting and mapping to 10-acre detail 18 USGS Level II categories using available 1:60,000 scale aerial photography. If new photography is needed the cost would be $11 to $13 per square mile.

3.3.3.5 Recommendations for Future Work

This work demonstrates that satellite remote sensing provides an economical source of land cover information in proper format and with the desired categories and accuracy needed to assess nutrient potentials of watersheds through the Great Lakes Basin. It is recommended that this procedure be used in the inventory of that basin and smaller watersheds in the Great Lakes drainage system. Other areas and regions where techniques demonstrated here should be applied include: (1) river basin plans produced by the states under the requirements of Section 303 (e) of the FWPCA Amendments of 1972, (2) ongoing waste treatment facility planning prepared locally under the construction grant requirements of Section 201 of the FWPCA, (3) urban study programs conducted by the US Army Corps of Engineers, and (4) flood plain planning accomplished by the USGS, the US Geological Survey, the US Army Corps of Engineers, and HUD's Federal Insurance Administration, etc.

*Presented at the First Conference on the Economics of Remote Sensing Information Systems, San Jose State University, San Jose, Calif., Jan 1977.

3.4 SUPPORT FOR THE STATE OF MICHIGAN DEPARTMENT OF NATURAL RESOURCES SURVEY OF INLAND LAKES AND WATERSHEDS

Remote sensing data requirements (Section 2.4) are the same at the state and sub-state planning level in regards to the planning and management of water quality (e.g., trophic state) of inland lakes. Data applications vary with organization, but requirements are the same except for size and location of area of interest. The Michigan Department of Natural Resources (DNR) needs data on trophic status of lakes in order to prepare reports on conditions of navigable waters in response to Section 305b of the FWPCA Amendments of 1972, to evaluate lake renewal programs, and to detect problem lakes where state actions may be needed. The regions need the same data but for use in studies concerned with effects of point and nonpoint sources and controls on trophic state (eutrophication rate). The land cover data are needed by the state and sub-state regions for obtaining estimates of nutrient loads from existing and new land use in watersheds. The state also uses these predicted loads to analyze how its land use practices should be applied to protect lake recreational value. The regions use the results in the development of water quality management plans that show the effects of various sources (i.e., land use, sewage facilities, etc.) and controls on water quality.

The work accomplished in responding to the state's needs are discussed in this section. Objectives achieved in this effort included:

1. Established Remote Sensing Requirements - The Michigan DNR needs and requirements of sub-state planning regions conducting EPA 208 programs concerned with lake eutrophication were transformed into remote sensing data requirements (Section 2.4). At the state level, the water quality requirements involve extrapolating measurements from 100 to 200 lakes of known trophic state to the remaining 10,000 or more lakes. Remote sensing must produce a color map of lakes showing algal biomass and weeds and relate these measurements to trophic state. The requirements for sub-state planning regions are the same except that there are less lakes and the areas are smaller. At the state and sub-state level, the remote sensing requirements are to produce land cover data in a format suitable for direct input to models used to estimate nutrients from land runoff. This can be area tables, map overlays, or tape files. The land cover inventory must contain a minimum of seven categories (including urban, barren land, cropland, grassland, forest, wetlands, and water) to have maximum utility to water quality programs.

2. Produced Quantitative Water Quality Map - Color-coded maps and data graphics were produced from LANDSAT data showing eight concentrations of biomass (algae and weeds) in about 1,000 lakes of northern Michigan. Algal biomass was related to chlorophyll a and trophic status by use of Michigan's classification criteria. Five categories mapped were in the "oligotrophic" range, showing the extreme sensitivity of remote sensing to biomass in the late summer.

3. Generated Land Cover Data - Eleven LANDSAT scenes covering more than 97% of Michigan's lower peninsula were categorized for land cover types required for estimating nutrient loads. Resulting maps and data were used to support the DNR and seven other organizations conducting on-going water quality programs. Land cover tabulated by watershed was required by the DNR and organizations using a "black box" predictor to estimate nutrients. The map overlays and digital files were required by users who combine cover data with soils and topography before estimating nutrients. Although the number and type of categories varied from scene to scene due to availability of ground truth and user requirements, in all cases the basic (minimum) seven categories required for predicting nutrient loads were determined.

4. Determine Usefulness and Cost Benefits - The DNR can sample approximately 3 to 5 lakes per day for parameters (e.g., chlorophyll a, secchi depth, etc.) needed to establish trophic state. The Michigan Self-Help Program establishes trophic state over the summer period for about 150 lakes. These programs do not assess weed effects. LANDSAT (remote sensing) data from these 150 lakes of known trophic state can be extrapolated to the remaining 2,000 or more lakes of 50 acres or larger. Remote sensing can map the effects of both algal biomass and weeds of lakes "statewide" in the required 3-week period in late summer. The total cost for a Michigan Statewide Inventory of trophic status by LANDSAT coordinated with state and regional efforts would be about $20 to $40 per lake for lakes 50 acres or larger (approximately 2,000 lakes). This includes all costs, i.e., data processing, sampling, lab analyses, field verification, etc. This price may be lower by a factor of 2 or more with a sensor resolution of 20 to 30 meters needed to categorize lakes, etc., of the 10-acre size. Michigan DNR's cost for sampling is about $60 per lake. An additional benefit of remote sensing is the color image/map of a lake showing distribution of algal biomass and weed. This is difficult to obtain by any reasonable amount of point sampling. Cost benefits of land cover inventory by remote sensing have been noted previously (Section 3.3). Maps available to the water quality planner do not contain categories needed to estimate nutrient loads. Transforming data from conventional sources into the desired formats (area tabulations, map overlays, or digital tape files) costs $8.00 or more per square mile. The required data and maps can be generated from LANDSAT CCTs for $1 to $4 per square mile, depending upon the product and scale.

A description of the Michigan test site and work toward coordinating ground truth for this site is summarized in Section 3.4.1. Section 3.4.3 describes the generation and evaluation of a water quality map showing trophic status of Michigan lakes. In Section 3.4.4, the work accomplished and the results achieved in developing the required land cover information for the DNR and other on-going water quality programs in Michigan are reviewed.

3.4.1 GROUND TRUTH

The area of interest to the Michigan DNR is the entire state. For this investigation, this area was reduced to 19 lakes in southern Michigan, which represented a broad spectrum of water quality and trophic conditions. Figure 3-15 identifies the counties where these lakes are located. Table 3-23 lists some physiographic and quality data for these lakes. The Michigan DNR completed an intensive sampling program on the lakes during LANDSAT passes during 1975. These surveys include measurements of suspended solids, turbidity, transparency, chlorophyll a, and water chemistry variables. Land use and cover factors that may impact water quality were also being studied within these watersheds.

In addition to the DNR intensive sampling obtained on test lakes, this investigation also used measurements from Michigan's Self-Help Program. This program, described in Section 2.4.2.1, uses chlorophyll a and Secchi depth derived from measurements obtained weekly/biweekly from May through September by lake citizens. These measurements are related to lake biomass and trophic state by the use of Tables 2-7 and 2-8. An arithmetic mean of measurements taken over the period May through September is used in this assessment. Application of this procedure to 89 lakes (Figure 3-16) involved in the Self-Help Program in 1976 indicated that 11% of the lakes were oligotrophic, 70% were mesotrophic, and 19% were eutrophic. Figure 3-17 shows this distribution as reflected in chlorophyll a parameters – the best indicator of algal biomass. Approximately 150 lakes are enrolled in the Self-Help Program for the 1977 season. It is proposed that LANDSAT extrapolate the measurements taken on these lakes during the 3-week period in late August to early September to the other 2,000 or more lakes of 50 acres or larger.

Sampling and watershed land cover analysis in the two most northern counties of the lower peninsula, Emmet and Cheboygan, were obtained by Dr. John E. Gannon (Resident Limnologist) at the University of Michigan Biological Station at Douglas Lake. Dr. Gannon coordinated sampling and field observation concurrent with LANDSAT and NASA aircraft flights in the summer of 1975.

The major sources of land cover information for lake watersheds were NASA aircraft photography (Section 3.2) and photography and field observations provided by users conducting on-going water quality investigations throughout the state. For the most part, these were the sub-state planning regions developing water quality management plans for the EPA 208 program. Included were the East Central Michigan Planning and Development Region (Section 3.3.3.1), the Genessee, Lapeer, Shiawassee Region (Section 3.3.3.2), the South Central Planning Council, and the Michigan Planning Region 2. A large amount of the photography used by these councils was NASA photography borrowed from the film library maintained by the Michigan State University Remote Sensing Project.

3.4.2 WATER QUALITY MAPS

To assess LANDSAT's capability of producing the required map showing concentration of biomass (algae and weeds) in inland lakes, LANDSAT scenes (2191-15453 and 2191-15460) of 1 August 1975 were submitted to categorical (Section 3.1.1.1) and

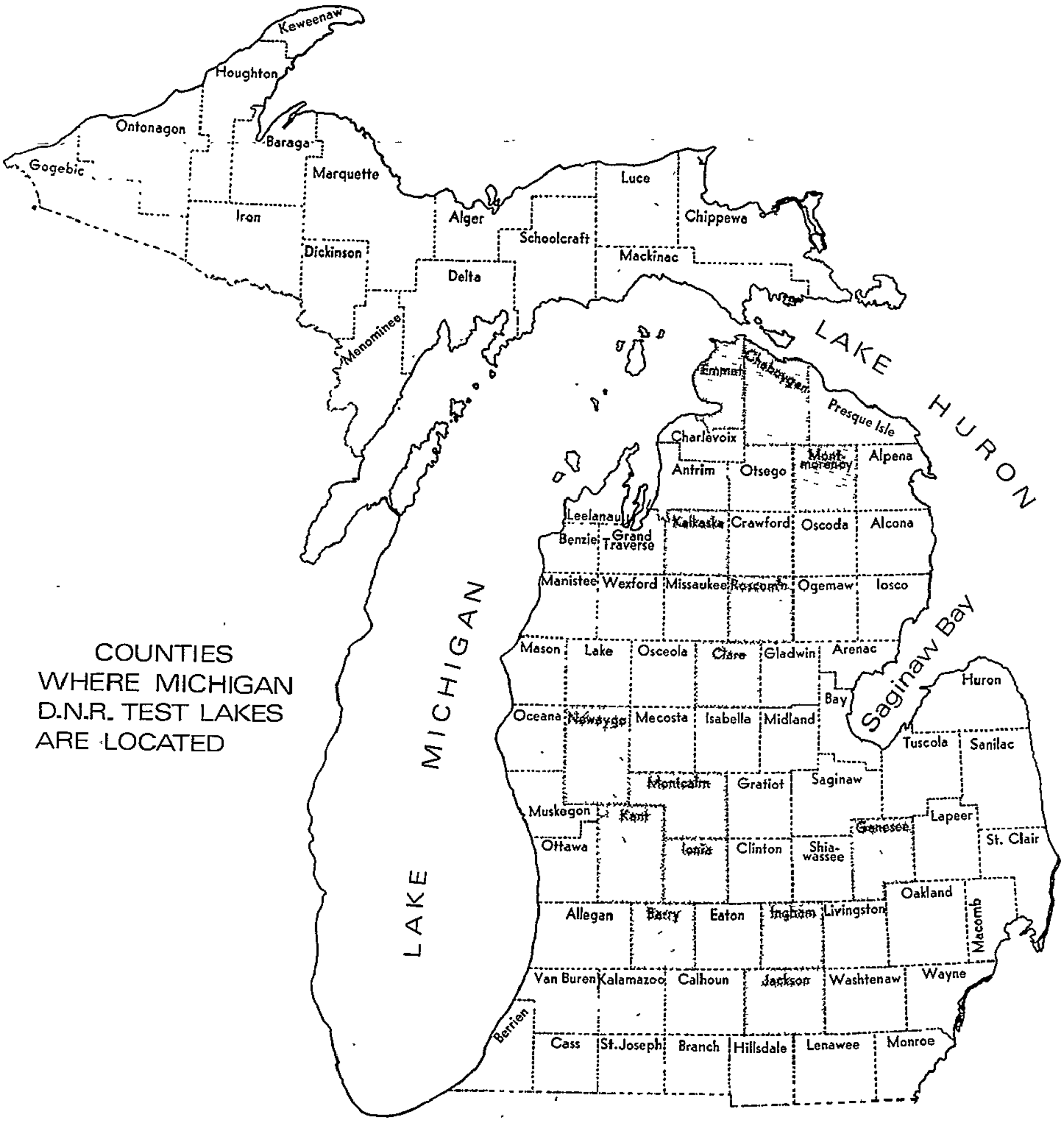

Figure 3-15 Location of Michigan Test Areas (Saginaw Bay and Inland Lakes)

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Table 3-23

Physiographic Data on Michigan DNR Test Lakes

Lake	County	Lake Area Acres	Lake Area KM^2	Watershed Area Acres	Watershed Area KM^2	Shore Length Miles	Shore Length KM	Lake: Watershed Area Ratio	Approx. Trophic Level
Pleasant*	Jackson	247	1.00	519	2.10	279	4.49	1:2.10	Mesotrophic
Lansing*	Ingham	454	1.84	2081	8.42	365	588	1:4.58	Eutrophic
Silver*	Genesee	252	1.02	2050	8.30	5.01	8.07	1:8.13	--
Jordan	Ionia & Barry	372	1.51	3626	14.68	4.48	7.20	1:9.73	Hypereutroph
Long	Ionia	358	1.45	373	1.51	3.60	5.80	1:1.04	Mesotrophic
Reeds*	Kent	267	1.08	1811	7.33	3.27	5.26	1:6.76	Mesotrophic
Townline*	Mortcalm	292	1.18	1770	7.16	5.02	8.08	1:6.07	Mesotrophic
Fremont	Newaygo	802	3.25	3830	15.50	5.44	8.75	1:4.77	Hypereutroph
Budd*	Clare	155	.63	864	3.49	4.15	6.68	1:5.56	Mesotrophic
Houghton	Roscommon	19,646	79.51	31361	126.92	30.09	48.43	1:1.60	Eutrophic
Higgins	Roscommon	10,300	41.68	21953	88.84	20.78	33.44	1:2.13	Oligotrophic
Bit Twin	Kalkaska	220	.89	1649	6.67	2.51	4.03	1:7.51	Oligotrophic
Clear	Montmorency	145	.59	779	3.15	2.11	3.40	1:5.37	--
Munro*	Cheboygan	686	2.78	2285	9.25	4.46	7.20	1:3.33	Eutrophic
Long*	Cheboygan	395	1.60	1028	4.16	5.37	8.66	1:2.60	Mesotrophic
Devercaux*	Cheboygan	35	.14	2492	10.09	.91	1.47	1:72.07	Mesotrophic
Wildwood*	Cheboygan	221	.90	2167	8.77	5.78	9.32	1:9.79	Hypereutroph
Silver*	Cheboygan	76	.31	1292	5.23	.62	1.00	1:16.98	Oligotrophic
Larks*	Emmett	598	2.42	1020	4.13	3.88	6.26	1:1.71	Mesotrophic

(*Indicates intensive ground surveys underway)

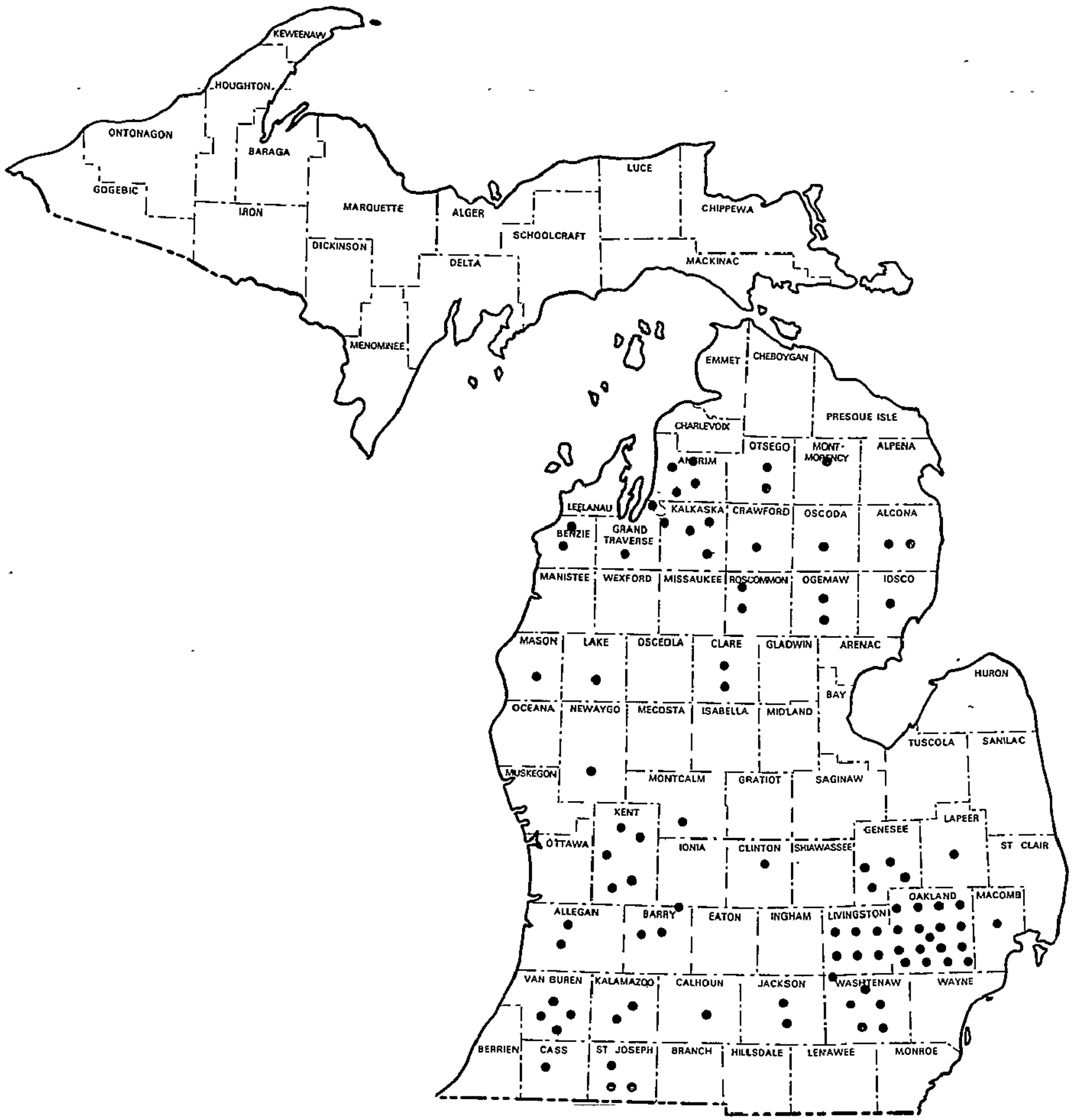


Figure 3-16 Inland Lakes in Self-Help Water Quality Monitoring Program (1976)

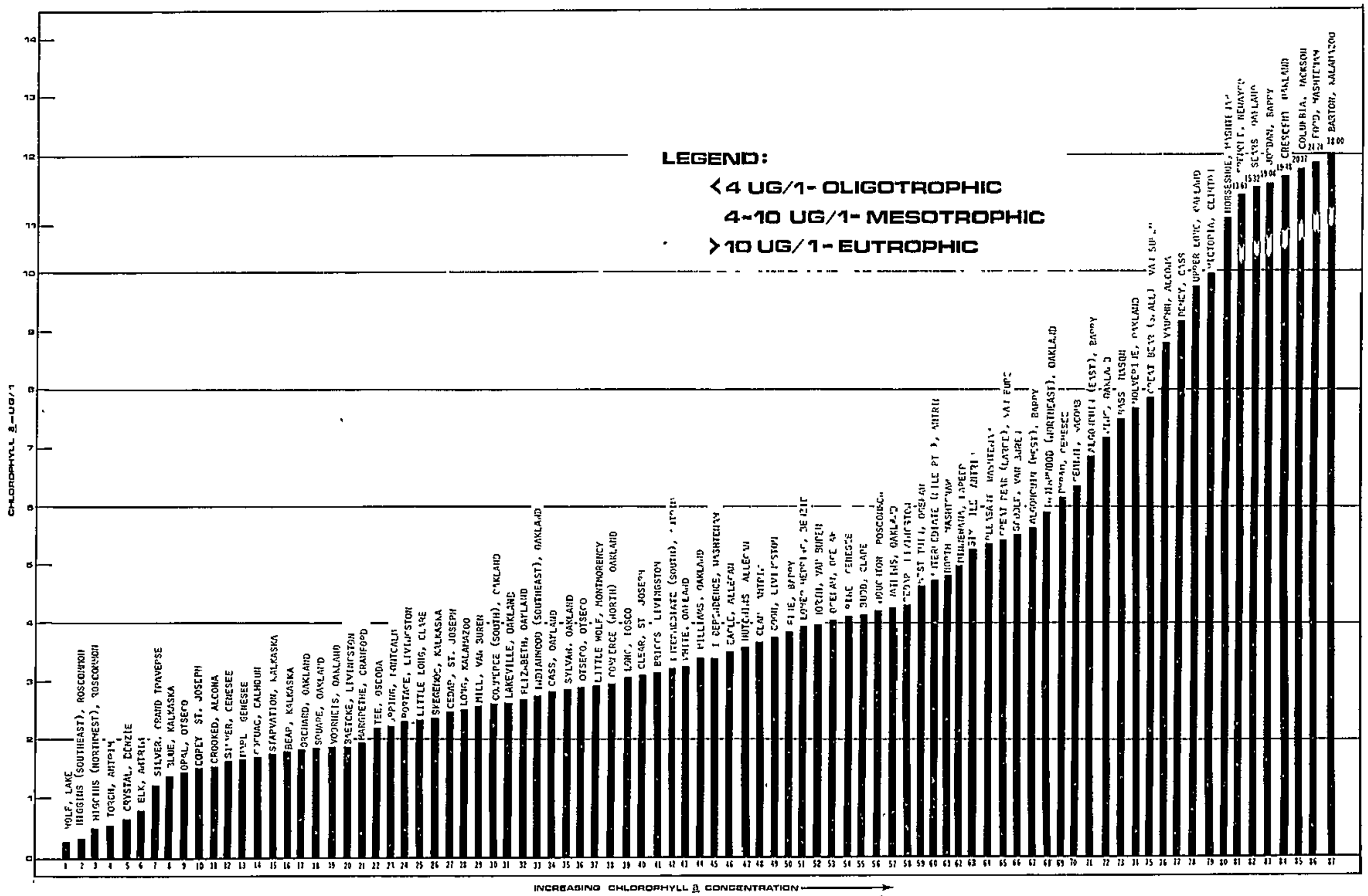


Figure 3-17 Michigan Lakes (81 Lakes, 87 Basins) in 1976 Self-Help Monitoring Program
Ranked on Basis of Increasing Summer Chlorophyll a Concentration

geometric (Section 3.1.1.2) processing. Weeds and six algal biomass categories were mapped in over 1,000 lakes. Five of these categories were in the oligotrophic range, one in the mesotrophic, and one in the eutrophic state. This map established the sensitivity of LANDSAT to monitor biomass in late summer and demonstrates LANDSAT's capability of establishing trophic state during the very early stages of eutrophication.

Field data brought to the Bendix facility by Dr. Gannon and LANDSAT CCTs collected 1 August 1975 were used on MDAS to identify 16 distinct water spectral categories. These categories were aggregated and mapped into the seven categories ranked by trophic state in Table 3-24. The spectral training areas for this processing were taken from the northern-most counties of Cheboygan, Emmet and Charlevoix and represented a good range of categories showing biomass and trophic state in this three-county area. Application of these training data to the other 14 counties in the scene and later analysis with sampling provided by the DNR established that the training in these lakes (categories) were not optimum for the complete scene. The northern counties from which training were derived contain many of the clearest, most-prized lakes in the state. The image produced from this effort (Figure 3-18), however, demonstrated the sensitivity of LANDSAT measurements to low concentrations of biomass.

Five of the categories (blue, brown, yellow, white, and green) separated by LANDSAT are within the 0.5 to 2 μg/L chlorophyll a range; based on Michigan trophic state criteria (Section 2.4.2.1), they are classified as oligotrophic. This shows that LANDSAT can monitor differences in trophic state within the lowest trophic category. Lakes with the largest biomass and shown as red in Figure 3-18 contain a broad range of lakes in both the mestrophic and eutrophic ranges. It is recommended that this scene be reprocessed to separate the red into three or four categories with more even subdivisions between the mesotrophic and eutrophic lakes. The purple color is used to show the distribution of weeds; lakes covered by weed (purple) would be defined eutrophic by any of the previously discussed criteria.

3.4.2.1 Comparison with Other Methods

A closeup view of some of the lakes in Figure 3-19 shows that LANDSAT maps the geographical distribution of algal biomass and weeds. This is a unique contribution of remote sensing that is difficult to achieve with any reasonable amount of point sampling.

Lakes categorized into the yellow category as shallow water or light algal biomass could be checked by aerial observations to improve or refine interpretation. Aerial observations are best used to check maps already made. The eye can easily see bottom effects and weeds, but it is virtually impossible to estimate concentrations of biomass in lakes when they are flown over and observed at different times and under different lighting conditions. LANDSAT can image hundreds of lakes under the same lighting condition in a scene acquired in about 26 seconds.

Table 3-24

Color Codes and Description of Lake Categories for LANDSAT Water Quality Map, Figure 3-18, Showing Northern Michigan, 1 August 1975

Color	Description
Purple	Rooted vegetation and eutrophic lakes. Lakes are richly supplied with plant nutrients and support heavy plant growths. Biological productivity is generally high; waters may be turbid due to dense growths of phytoplankton or may contain an abundance of rooted aquatic plants; deepest waters exhibit reduced concentrations of dissolved oxygen during periods of restricted circulation. Eutrophic lakes tend to be shallow, with average depths less than 10 meters (33 ft) and maximum depths less than 15 m (50 ft). Chlorophyll *a* concentration in these shallow lakes would be greater than 10 µg/L.
Red	Highest concentration of algal biomass. For this image cover, a broad spectrum of lakes covering both eutrophic and mesotrophic. Mesotrophic lakes are intermediate in characteristics between oligotrophic and eutrophic, are moderately well supplied with plant nutrients, and support moderate plant growth. Chlorophyll *a* concentration ranges from 4 to 10 µg/L or more. Some small lakes, 1 to 30 acres, of good water quality may be processed incorrectly into this category due to mixture of water/weeds/surrounding land.
Green	Moderate concentration of algal biomass. This category, together with white, yellow, brown, and blue, would be classified oligotrophic water. These lakes are poorly supplied with plant nutrients and support little plant growth. As a result, biological productivity is generally low, the waters are clear, and the deepest layers are well supplied with oxygen throughout the year. Oligotrophic lakes tend to be deep, with average depths greater than 15 m (49 ft) and maximum depths greater than 25 m (80 ft). Average chlorophyll *a* range in green lakes is 2.2 µg/L with variations from 1.6 to 3.5 µg/L.
White	Marl lakes with moderate concentration of algal biomass. Marl is biologically precipitated calcium carbonate (lime). These lakes also fall into the oligotrophic range. They appear as emerald green to the eye. Average chlorophyll *a* concentration was about 2 µg/L with variations from 1.5 to 3.4 µg/L.

Table 3-24 (Cont.)

Color	Description
Yellow	Light concentration of algal biomass in deep lakes. Also oligotrophic water. Chlorophyll *a* concentration averages about 1.6 μg/L (somewhat less than the green category) with variations from 1.3 to 2.1 μg/L. Shallow water with sand or marl bottoms also placed in this category.
Brown	Humic water (stained water) with low algal turbidity. Due to few number and small size of these lakes in Michigan, biomass and their trophic status are not well determined. From one or two samples, it was estimated that average chlorophyll *a* concentration was about 1 μg/L, which classifies these lakes as oligotrophic.
Blue	Low concentration of algal biomass, oligotrophic waters. These were the clearest lakes containing the least amount of algal biomass and weeds; average chlorophyll *a* concentration was 0.9 μg/L with variations from 0.57 to 1.8 μg/L.


WATER QUALITY MAP
NORTHERN MICHIGAN
Bendix
COUNTY AND LAKE IDENTIFICATION
WATER QUALITY PARAMETERS
The water quality map shows Michigan lakes ordered by level of enrichment/eutrophication indicated by total biomass (algae or weeds) monitored 1 August 1975 by LANDSAT (satellite) and surface sampling.
Order | Color | Category | Average Chlorophylla (mg/m³)
I | Purple | Rooted vegetation | 4.0
II | Red | High Algal Turbidity | 3.0
III | Green | Moderate Algal Turbidity | 2.0
| White | Marl Turbidity | 2.0
IV | Yellow* | Light Algal Turbidity | 1.5
| Brown | Tannin (Stained) | 1.0
V | Blue | Low Algal Turbidity, Clear | 1
*Yellow also denotes shallow water, with sand or marl bottom.
Douglas Lake
Black Lake
Burt Lake
Walloon Lake
Lake Charlevoix
Torch Lake
Fletcher Pond
Higgins Lake
Houghton Lake
Emmet
Cheboygan
Presque Isle
Alpena
Charlevoix
Ostego
Montmorency
Antrim
Alcona
Oscoda
Crawford
Kalkaska
Leelanau
Iosco
Ogemaw
Grand Traverse
Roscommon
Benzie
Wexford
Missaukee

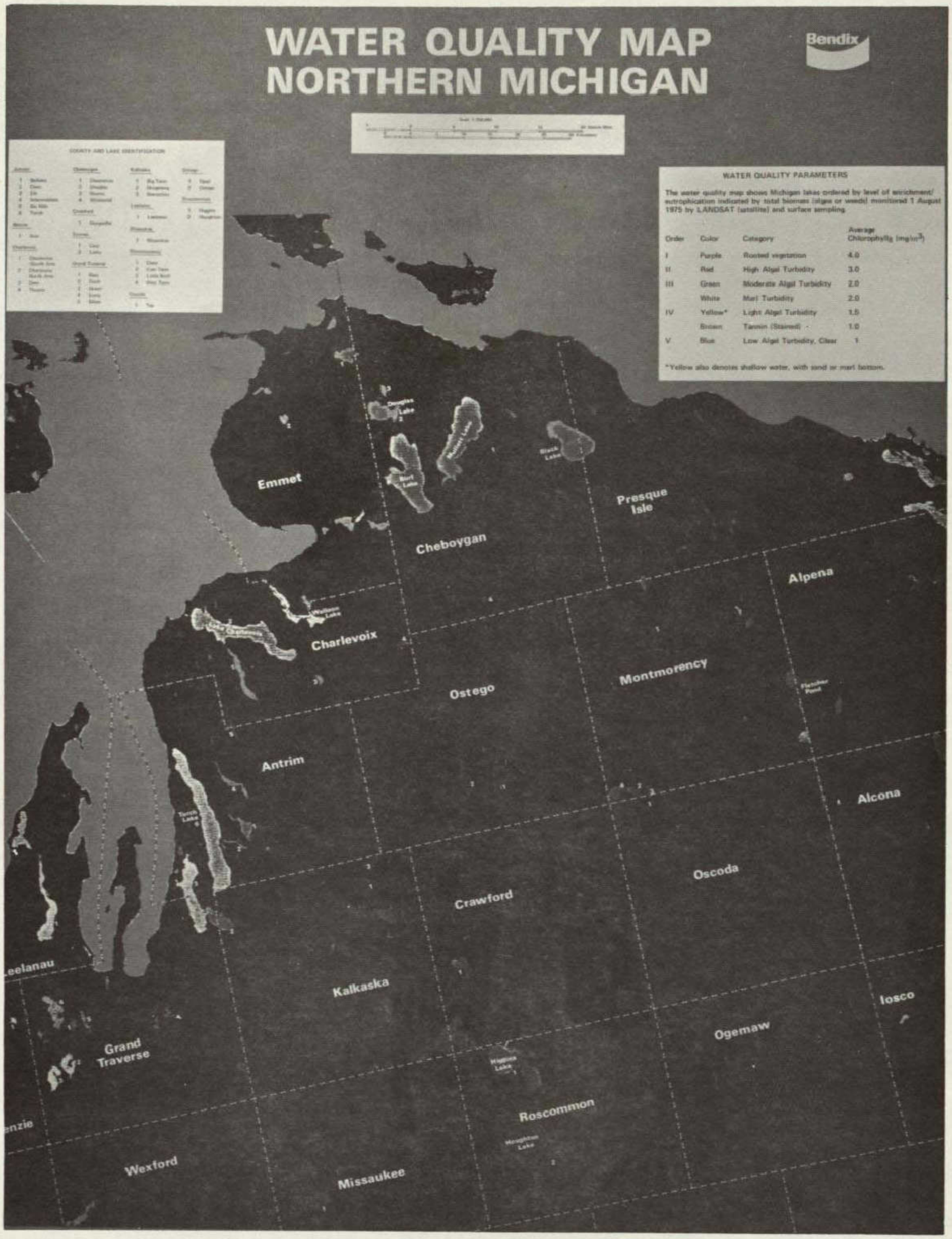


Figure 3-18 Water Quality Map of Northern Michigan

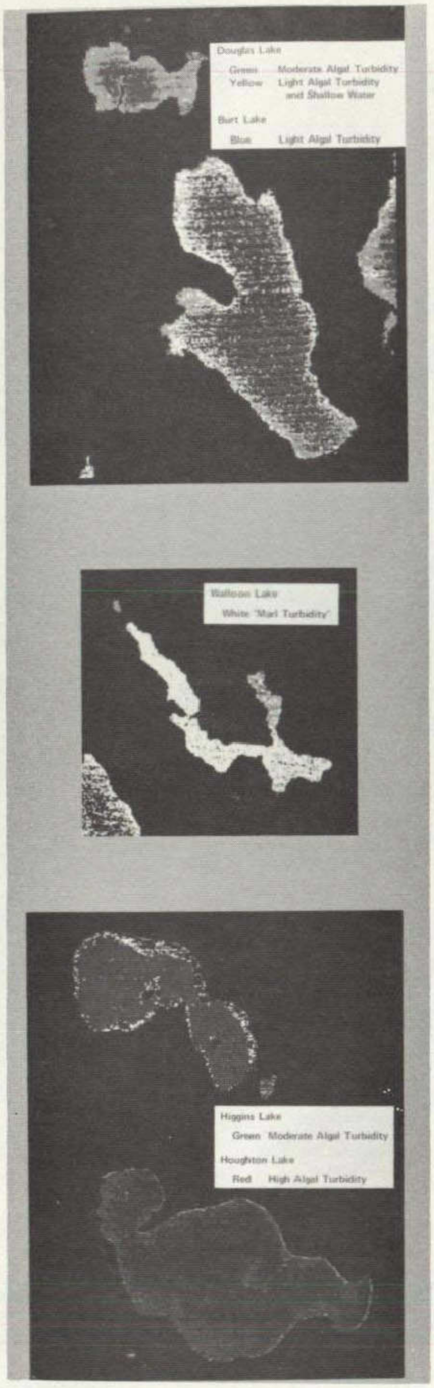
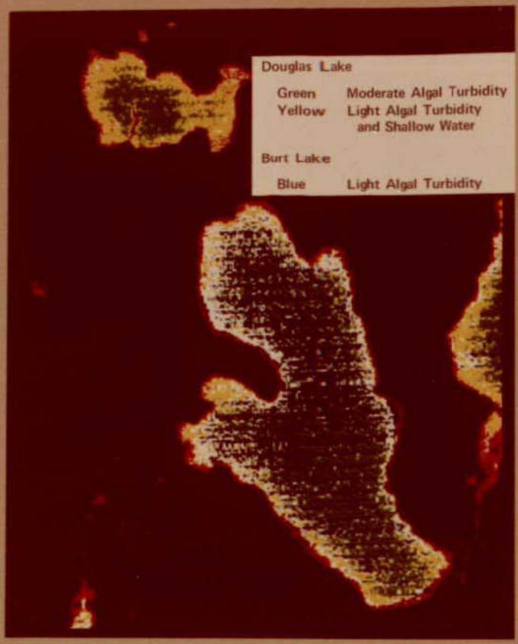
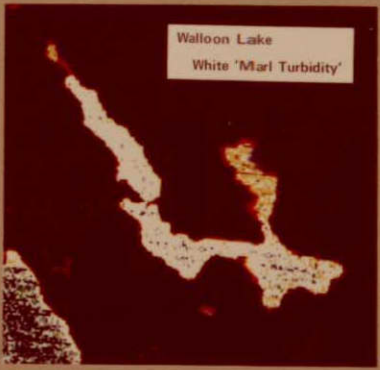
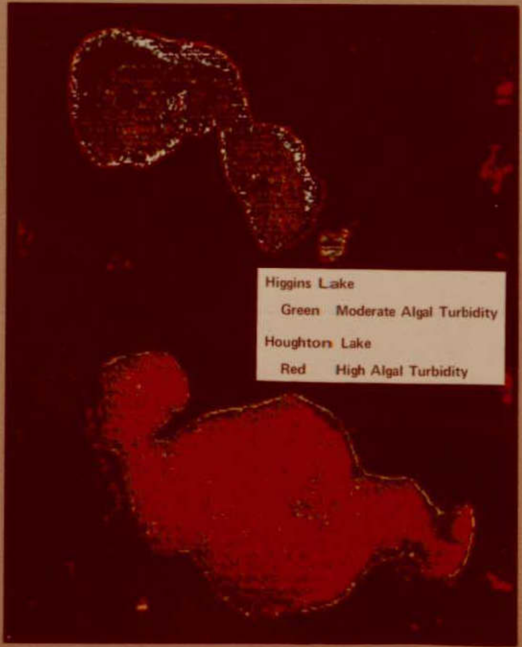


Figure 3-19 Enlargement of Lakes Shown in Water Quality Map Figure 3-18


Douglas Lake
Green Moderate Algal Turbidity
Yellow Light Algal Turbidity and Shallow Water
Burt Lake
Blue Light Algal Turbidity


Walloon Lake
White 'Marl Turbidity'


Higgins Lake
Green Moderate Algal Turbidity
Houghton Lake
Red High Algal Turbidity

As a step towards this program, the first effort would be to reprocess the 1 August 1975 scenes used for Figure 3-18 to obtain a more uniform set of categories from oligotrophic to eutrophic. Once the six to ten categories based on biomass are established, all of the state's lakes would be reviewed in the context of LANDSAT coverage to identify at least one lake representative of each category within each scene. Most of these lakes should be available in the Self-Help Program (Figure 3-16). Those not available would be sampled by the Michigan DNR field teams. The 30 to 50 lakes selectively sampled by the state during the required 3-week window in late summer, together with 150 lakes sampled by Self-Help, should be sufficient to calibrate LANDSAT and provide the desired water quality maps statewide.

3.4.3 LAND COVER DATA

To establish user requirements and cost benefits of LANDSAT data, this investigation produced maps and data graphics to support on-going water quality programs of the Michigan DNR, four sub-state planning regions responding to the EPA 208 requirements, the Michigan Biological Station's NSF-RANN program, and the EPA's study of lake eutrophication of Saginaw Bay. The application for land cover data by these organizations is somewhat different, as can be noted in Table 3-25, but the data requirements, in terms of categories, detail, frequency, and data age, are the same. The only difference in remote sensing needs of these users was the size and location of their area of interest. The Michigan DNR needs cover information in watersheds of all public lakes statewide; EPA's concern is the watershed having direct impact on the water quality in the Great Lakes; and the planning councils are concerned with watersheds within their planning regions.

Area land cover tabulations by watershed were produced for the Michigan DNR and five other users. Nutrients and other pollutants in runoff were directly obtained for each watershed by multiplying loading rates by areas listed in the tabulations. Organizations such as the Southcentral Michigan Planning Council and Michigan Region 2, who combined cover type with soil type and slope to derive coefficients for sediment-based models, required map overlays and digital land cover files to facilitate combining the cover with soils and slope information.

To produce the data required by the DNR and the other user organizations, 12 LANDSAT scenes (Table 3-26) were submitted to categorical and geometric processing. Over 97% of Michigan's lower peninsula was inventoried in this effort as shown in Figure 3-20. Only the dark shaded areas on Michigan northwest coast were not covered in this task. Those counties in the lower peninsula with no code number or shading have land cover data available from two or more scenes.

The MDAS-supervised processing was used to transform the LANDSAT CCT data into interpreted land cover data. The categorization achieved in this effort from the 12 summer scenes are listed in Table 3-27. The seven categories required for water quality planning are achieved in all cases, i.e., urban, cropland, grassland, forest, water, wetland, and bare land. The wetland category for the Jackson, Michigan area (denoted as code 4) is included in the flooded cropland category. The urban category is generally subdivided into one to three urban density related cover types. Bendix and other investigators have determined that, if more than two or three urban

Table 3-25

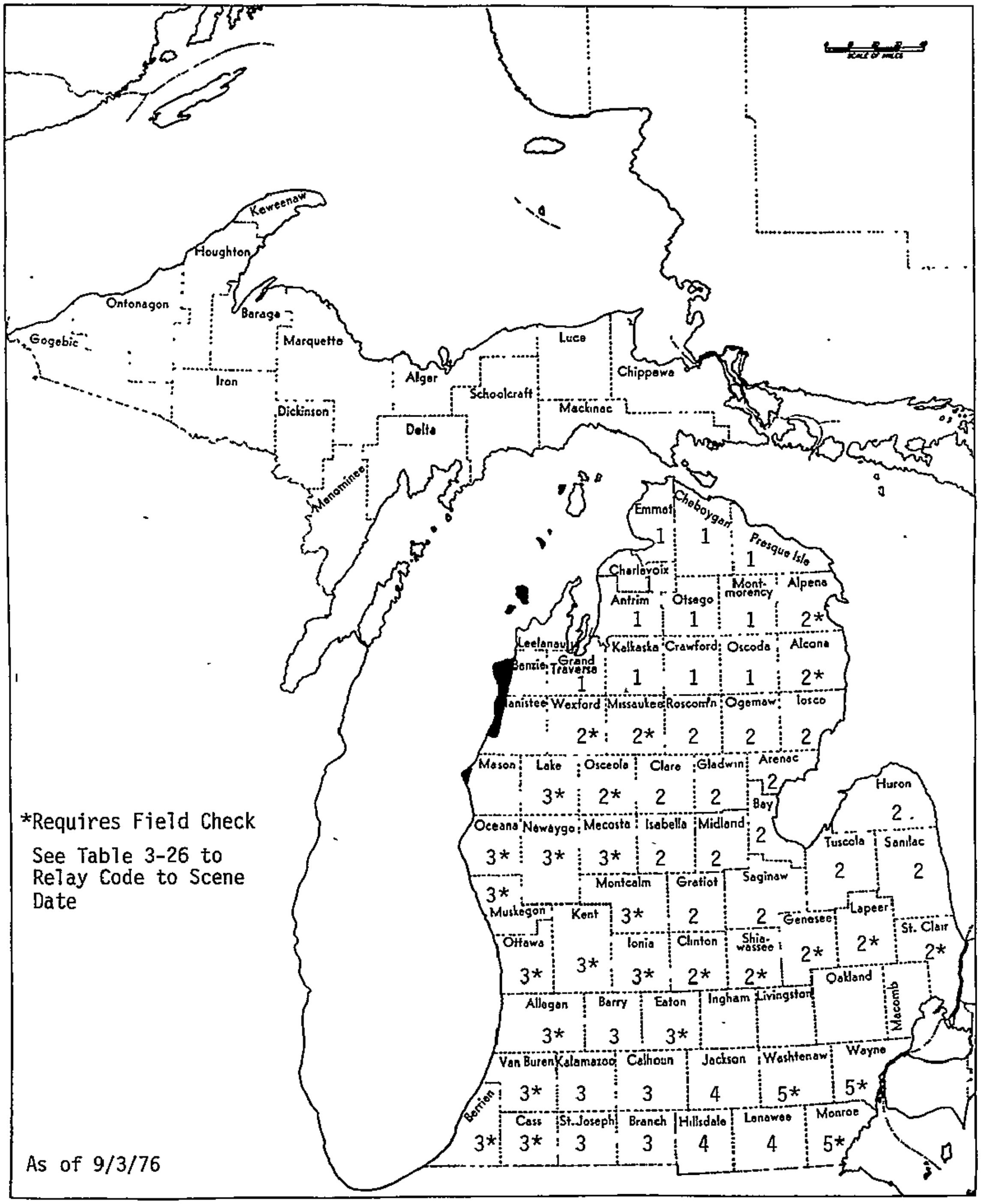
Support Provided to Users in Michigan Conducting
On-Going Water Quality Investigations

USER	PROJECT AREA	APPLICATION/PRODUCTS
Southcentral Michigan Planning Council (Region 3) Nazareth College Nazareth, Michigan 49074	Five county region Southcentral Lower Peninsula Michigan (3,000 sq. mi.)	EPA 208 Program - Water Quality Management Plan (WQMP); Land Cover Inventory: Tabulation by watershed, map overlays 1:96,000 scale, color map 1:250,000 scale, water quality image from display.
Michigan Planning Region 2 312 S. Jackson Jackson, Michigan	Three County Region (2,000 sq. mi.)	EPA 208 program - WQMP; Land Cover Inventory: Map overlays 1:48,000 scale digital tape files 50 meter cell.
East Central Michigan Planning and Development Region, (Region 7) 1003 Woodside Essexville, Michigan 48732	East-Central Lower Peninsula Michigan (8,700 sq. mi.)	EPA 208 Program - WQMP; tabulations by Hydrologic Subdivision; color map overlays and maps at 1:250,000 scale; color maps and overlays at 1:62,500 scale for 20 select 15 min quad. areas. Digital tape files 50 meter cell.
University of Michigan Biological Station Pellston, Michigan 49769	North Part Lower Peninsula The Inland Water Route Region (2,000 sq. mi.)	NSF-RANN Program Cause effect relationships Color coded water quality and land cover maps, 1:250,000 scale tabulations
Genesee, Lapeer, Shawassee Planning Region (Region 5) 100 Phoenix Bldg. 801 South Saginaw St. Flint, Michigan 48502	West-Central Michigan (1600 sq. mi)	EPA 208, HUD 701 Water Quality Management Plan Land Cover Inventory: Tables, tape files, color map region at 1:48,000 scale
Michigan Department of Natural Resources Division of Land Resources Programs Stevens T. Mason Bldg. Box 30028 Lansing, Michigan 48909	Select Test Lakes and Watershed Lower Peninsula	LANDSAT evaluation program - Technique Development Color maps: showing trophic state inland lakes; land cover tabulations by watershed, other.
U.S. Environmental Protection Agency Large Lakes Branch Grosse Isle, Laboratory Grosse Isle, Mich. 48138	Saginaw Bay and Watershed	Development of water quality models Water quality and land cover maps scales of 1:1,000,000 to 1:100,000 Land cover tabulation by watershed

Table 3-26

LANDSAT Scenes Processed to Support
Michigan Water Quality Investigations

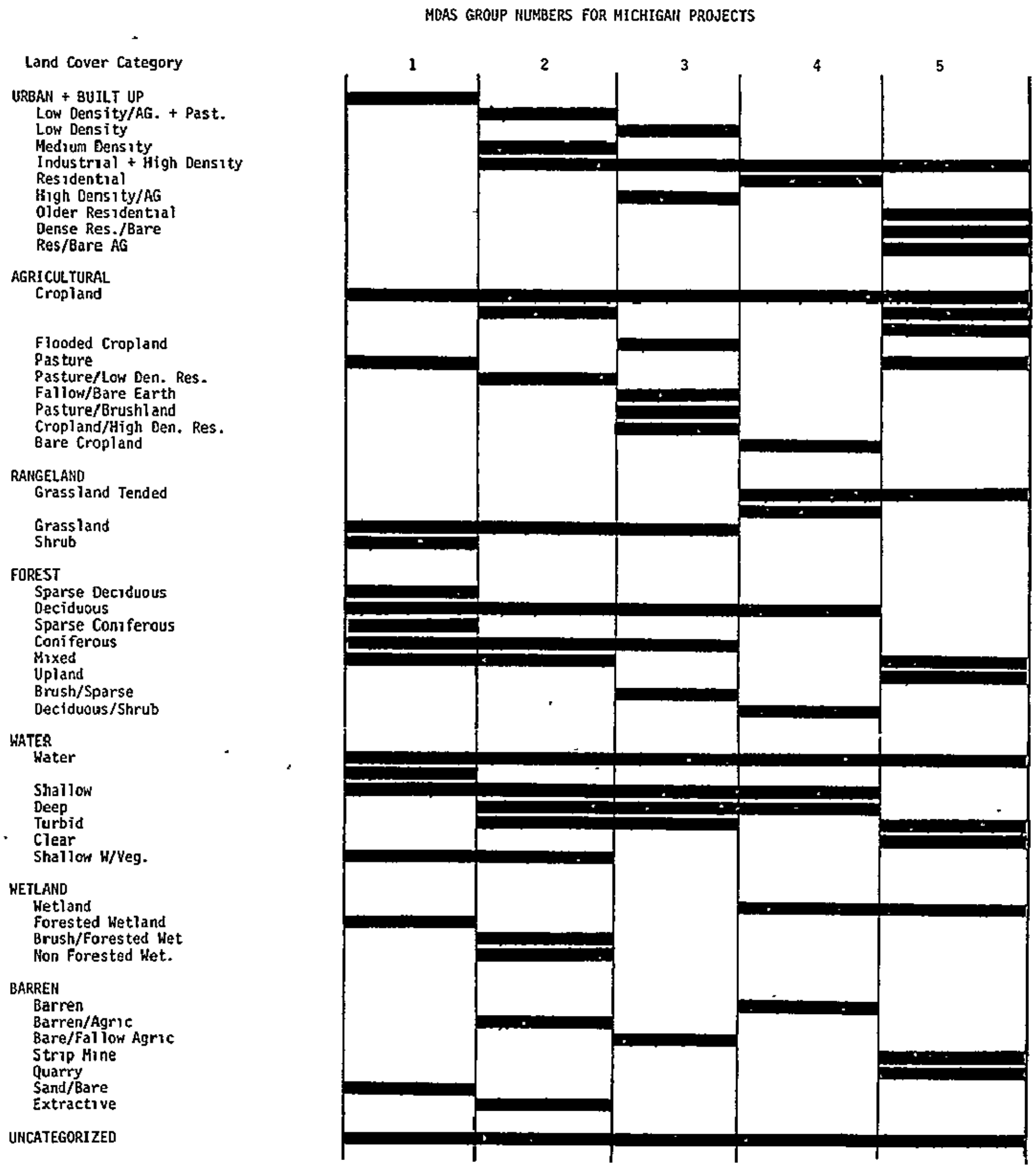
CODE	DATE	SCENE ID	AREA/GROUND TRUTH SUPPORT
1	1 August 1975	2191-15453 2191-15460	Northern portion of Lower Peninsula (U.M. Biological Station)
2	30 July 1975	2189-15350	East-Central (Area Aground Saginaw Bay)
	31 July 1975	2190-15401 2190-15404	Michigan Region 7 Michigan Region 5 (31 July Scene)
	1 August 1975	2191-15460 2191-15462	
3	8 June 1973	1320-15532	Southwest Michigan
	9 June 1973	1321-15584 1321-15590	Region 3
4	19 September 1974	1788-15428	South-Central Michigan (Jackson Area) Region 2
5	31 July 1975	2190-15410	Southeastern Michigan (State of Ohio)



Landcover data in blank counties, in the lower peninsula, available from two or more scenes.
Shading indicates areas for which no LANDSAT data have been processed.

Figure 3-20 Land Cover Data Derived from LANDSAT Processing

Land Cover Categories Denoted on Michigan Test Sites



categories are attempted without application of special techniques (i.e., partitioning data into urban/nonurban area, etc.), urban and nonurban categories having the same spectral characteristics are confused. Cropland can be subdivided into as many categories as the user requires, the primary limitation being ground truth needed to establish crop types concurrent with LANDSAT. Loading rates are sometimes available for row crops (e.g., corn) and close grown crops (e.g., wheat). Forest is always accurately categorized into deciduous and coniferous trees. Barren land is almost always accurately mapped by LANDSAT. Many water categories are possible as shown previously in Section 3.4.2. However, as in the urban case, subdividing water into more than two to three categories causes confusion between water and nonwater categories.

Categorization accuracy generally exceeded 85% on all nonurban categories. The Michigan State Remote Sensing Project reported (Ref 46) the accuracy to be 93.4% of the 10-acre (dominant cover type) level for work in the GLS Region 5 area (Section 3.3.3.2).

The categorized LANDSAT data were used to produce the maps and data requested by the users (listed in Table 3-25). Included were land cover tabulation, color maps and overlays with scales ranging from 1:48,000 to 1:1,000,000 and digital land cover tape files formatted on the basis of 7.5-minute quad areas and containing 50-meter grid cells. One of the color map products resulting from this effort is shown in Figure 3-21. This map was produced from two 1 August 1977 LANDSAT scenes (2191-15453 and 2191-15460) to determine the land cover in the northern portion of Michigan's lower peninsula. The 17 categories mapped in this test area are listed in the first column of Table 3-27 and related to map colors by Table 3-28. The image in Figure 3-21 would be about 1:1,000,000 scale. The user was supplied with one four (4) times larger, i.e., 1:250,000 scale. The land cover image of Figure 3-21 can be compared directly with the water quality image in Figure 3-18 showing the same area.

Land cover tabulations were generated for the DNR's test lakes and other watersheds in the support of the seven water quality programs listed in Table 3-25. Figure 3-22 shows tabulations produced on the DNR's watersheds containing Higgins and Houghton lakes. These lakes can be observed in Roscommon county on the land cover map (Figure 3-21) and the water quality maps (Figures 3-18 and 3-19). A close view of the two lakes in Figure 3-19 shows that LANDSAT interpreted Higgins Lake as having moderate concentrations of algal biomass, oligotrophic (green), and Houghton with high concentrations of algal biomass (red). The area tabulations on watershed land cover, when multiplied by loading rates such as those shown in Table 2-4 of Section 2.3.1.1, provide an estimate of potential nutrients and other pollutants in runoff. This estimate, when combined with nutrients and other pollutants from point sources, i.e., sewage facilities and nutrients from atmosphere (rain, water), provides the total load for each lake. Table 3-29 summarizes the land cover in the DNR's watersheds.

Table 3-28

Land Cover Map of Northern Part of Michigan's Lower Peninsula[1]

Computer Processed from LANDSAT Data of 1 August 1975 (2191-15453 and 2191-15460)

Category	Color
Urban	Light Purple
Agriculture	
Cropland	Red-orange
Pasture	Ochre
Grassland	
Short & tended grass	Bright Yellow
Sparce shrubs on old-field grass	Light Gray
Forestland	
Shrubs[2]	White
Sparce deciduous[3]	Bright Green
Mixed deciduous, mainly soft woods[3]	Dark Green
Mixed deciduous, mainly hard woods[3]	Greenish Blue
Mixed coniferous and deciduous	Brown
Coniferous, includes wetland swamps	Light Pink
Coniferous, mainly uplands	Dark Red
Wetland	
Forested wetland[4]	Cyan
Barren	
Sand, bare ground, urban	Purple
Water	
Deep water	Blue
Shallow water (with and without submergent vegetation)	Bright Blue
Uncategorized	Black

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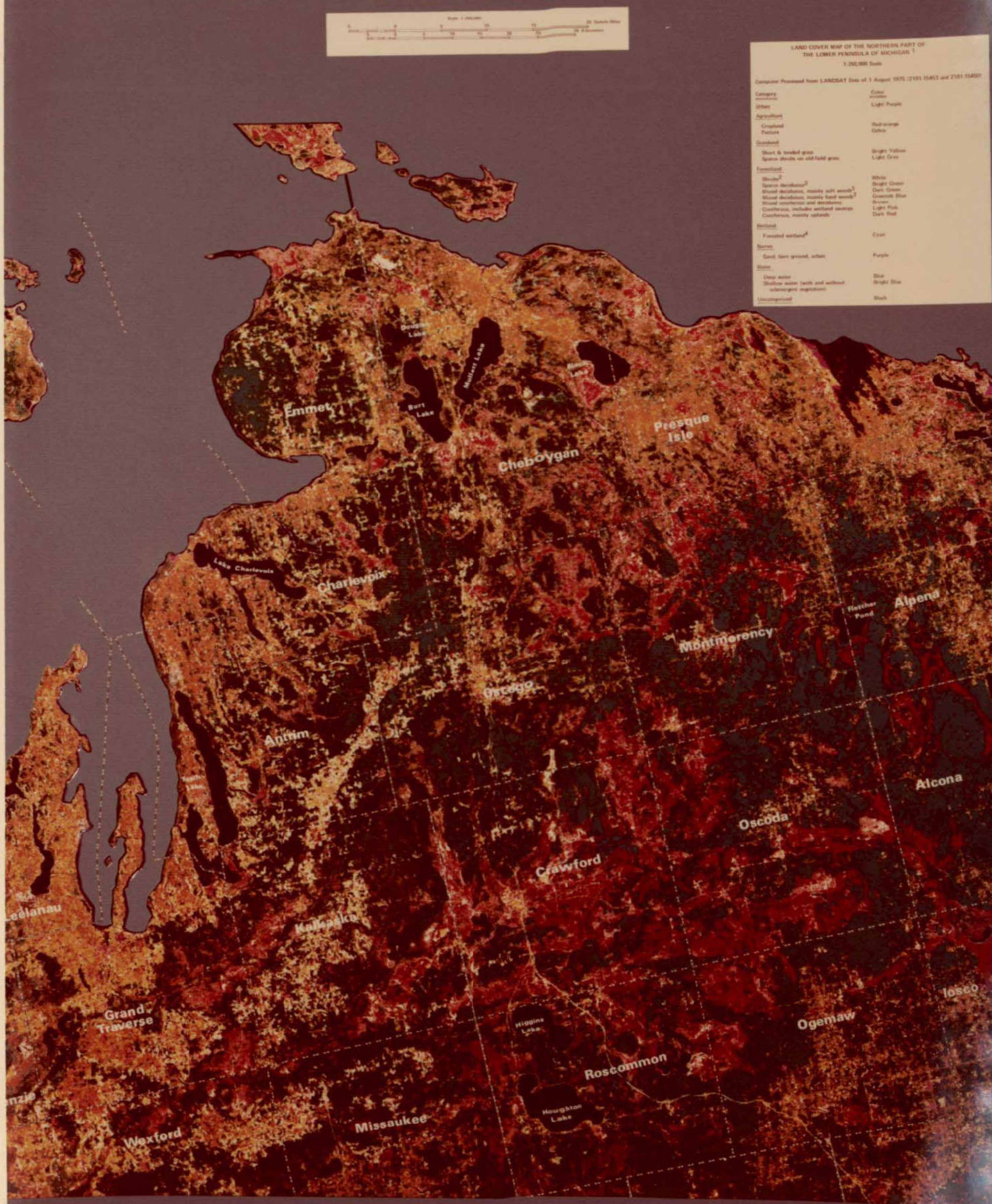
1 Categorization is most reliable within the upper half of the scene (location of training sites).

2 The shrubs category is predominately shrubby growth on old farm fields. It also includes old lake beds with shrubby growth (marshes, fens, bogs), pine plantations, shallow wildlife impoundments and flooded forests.

3 Dark green, greenish-blue, and bright green roughly correspond to major morainic systems. The three categories could be combined as upland hardwood forest.

4 This wetland category greatly underestimates the areal extent of wetlands. Areas coded white (marshes, fens, bogs) and light pink (coniferous swamps) also include wetlands.

LAND COVER MAP
NORTHERN MICHIGAN



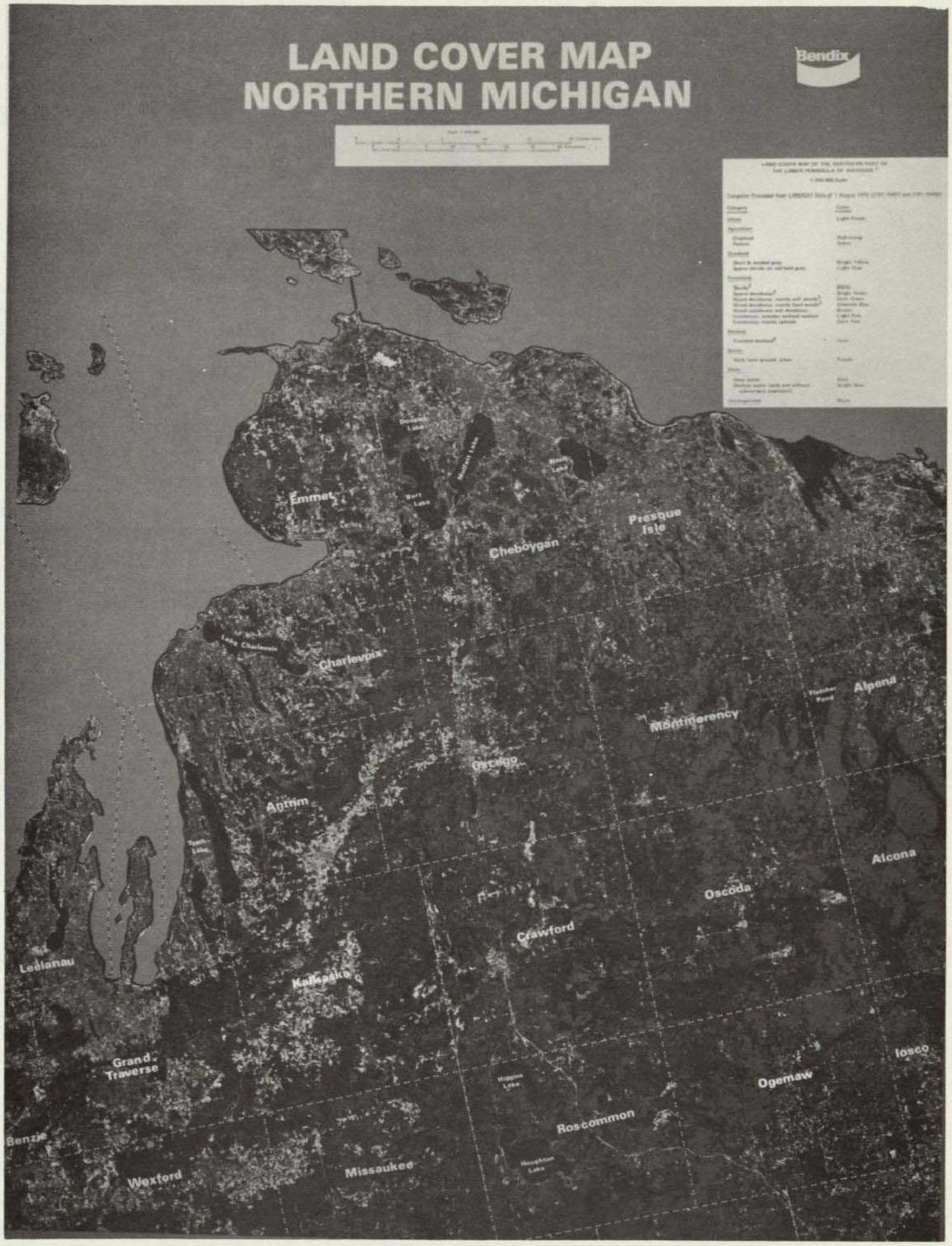


Figure 3-21 Land Cover Map of Northern Michigan

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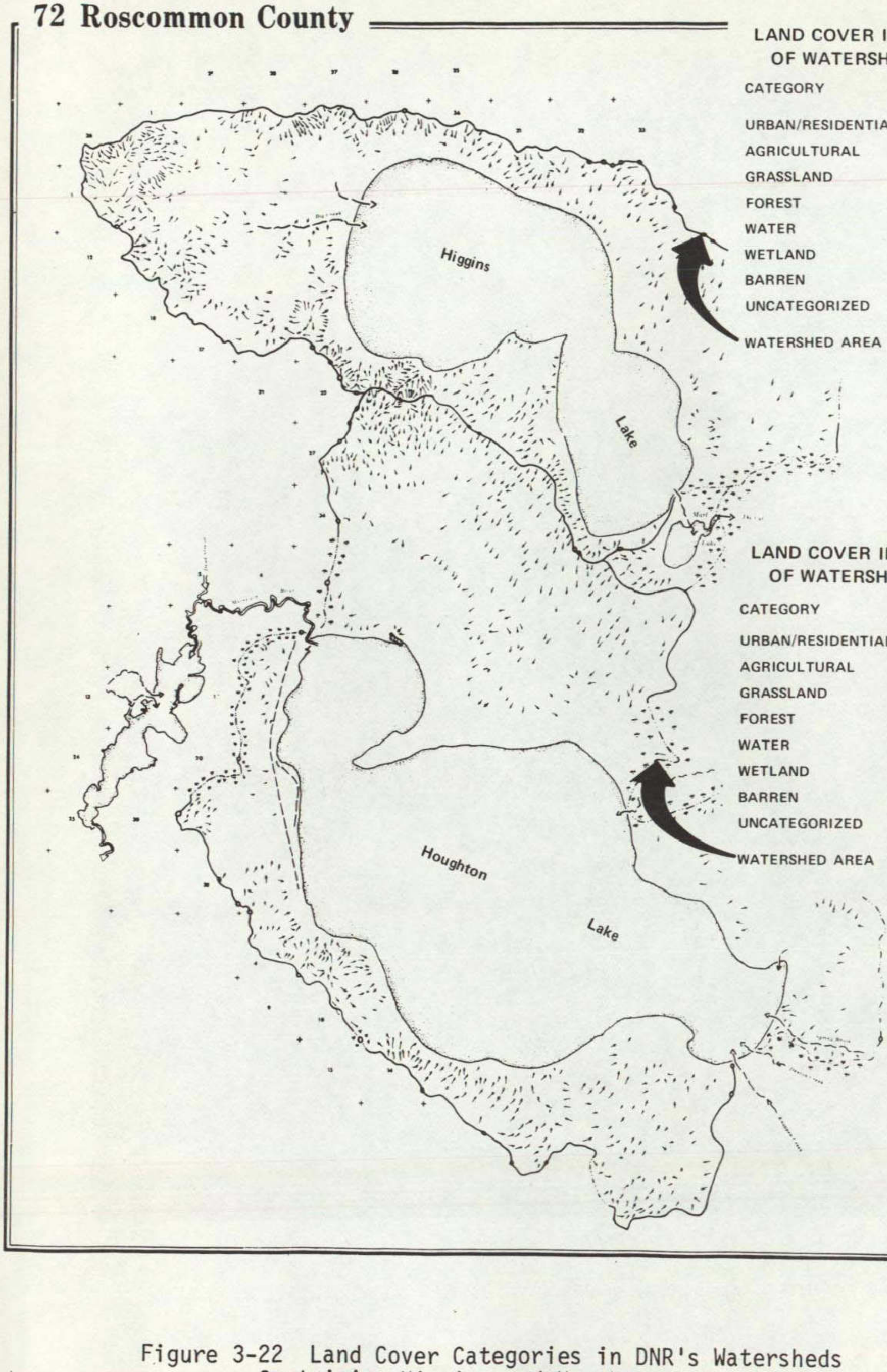


LAND COVER IN PERCENT OF WATERSHED AREA

CATEGORY	
URBAN/RESIDENTIAL	3.5
AGRICULTURAL	2.0
GRASSLAND	7.5
FOREST	29.6
WATER	29.3
WETLAND	16.6
BARREN	1.1
UNCATEGORIZED	10.3
WATERSHED AREA	32,253 ACRES 130.5 KM^2

LAND COVER IN PERCENT OF WATERSHED AREA

CATEGORY	
URBAN/RESIDENTIAL	4.4
AGRICULTURAL	4.5
GRASSLAND	8.8
FOREST	27.7
WATER	38.0
WETLAND	10.7
BARREN	1.2
UNCATEGORIZED	4.6
WATERSHED AREA	51,007 ACRES 206.4 KM^2

Figure 3-22 Land Cover Categories in DNR's Watersheds Containing Higgins and Houghton Lakes

3.4.3.1 Comparison with Other Methods

The cost for production of the LANDSAT maps and data graphics varies as a function of specific product desired by user and map scale. For users supported in Michigan (Table 3-25), the cost varied from $1 to $4 per square mile, excluding cost for ground truth provided by the users and by NASA photography. All of the products were completed within 3 to 4 months from receipt of the user's requirement. To produce a similar product from conventional sources (i.e., windshield survey, photo interpretation, other) would cost $8 or more per square mile and require 6 to 12 months if the user had the source material on hand. If new photography is needed, about $3 to $6 per square mile should be added, amounting to a total cost of $11 to $14 per square mile.

A factor often overlooked by users is the cost for formatting (e.g., tables, overlays, tapes) information required for water quality programs. Almost all LANDSAT product costs are contributed by data formatting. This is fast and relatively inexpensive when data are in a digital format (LANDSAT CCTs) and computer assistance is available. Information from most conventional sources (photos, maps, etc.) must be manually transformed into the desired formats, requiring a large effort in man-hours which results in the higher cost and longer delivery schedules.

3.4.3.2 Recommendations for Future Work

One of the most serious obstacles confronting Michigan's efforts in applying planning and management concepts to inland lake watersheds on a statewide basis has been the lack of inexpensive data sources and facilities needed to manipulate and analyze the data in regard to lake eutrophication. A planning and approach method has been published by the Michigan DNR (Ref 3). Implementation of this approach requires information on land cover and use, and data on slope, drainage features, drainage dividers, and soils. The best sources for this information would be LANDSAT for general land cover in the watershed, aerial photography used "selectively" for land use, and topography maps and soil maps for soil type and drainage features. A program is recommended which would demonstrate the techniques and methods for collecting, formatting (digitizing), merging, and manipulating the required multisource data in the analysis required to assess effects of existing and new uses of land on lake eutrophication.

3.5 SUPPORT FOR THE STATE OF WISCONSIN DEPARTMENT OF NATURAL RESOURCES LAKE SURVEY

The Department of Natural Resources of the State of Wisconsin is committed, under Section 314 of the Federal Water Pollution Control Act Amendments of 1972, to classify (by trophic status) the 10,000 lakes of that state. Other objectives include: evaluating aquatic nuisance control treatments, lake renewal efforts, locating lake nutrient inflows, locating pollution sources, and measuring effects of numerous kinds of environmental impacts. Sub-state planning commissions responding to programs, e.g., EPA 208, 201, etc. have similar objectives but their areas of concern are smaller. The work accomplished in responding to the Wisconsin DNR needs is discussed in this section. Objectives achieved in this effort included:

1. Establish Remote Sensing Requirements

   The Wisconsin DNR needs concerned with lake eutrophication were transformed into remote sensing data requirements (Section 2.4). These requirements are the same as those of the Michigan DNR with the possible exception of some difference in number and sizes of lakes. Wisconsin has over 10,000 lakes of which about half are 50 acres or larger. The remote sensing requirements (Section 2.4.3) are the extrapolation of measurements from about 100 lakes of known trophic state to the remaining 10,000 or so lakes. Remote sensing must produce a quantitative image/map of each lake showing various concentrations of algal biomass and areas covered by weeds. This assessment would be accomplished every 5 years with problem lakes updated annually. The data collection on all lakes must occur during the 3-week window in late summer (August-September) when the maximum amount of lake nutrients is converted into biomass.

2. Produce Quantitative Water Quality Maps

   Maps and data responsive to DNR requirements were produced from spring and summer LANDSAT scenes to show various concentrations of algal biomass and weeds in lakes of southern Wisconsin (Madison area), northwest Wisconsin (Spooner area), and southeast Minnesota (Duluth to Ely area). In late summer during maximum algal growth, LANDSAT signals from deep, clear water were subtracted from signals from other lakes to obtain residual spectral characteristics ("fingerprints") for lakes with silt, weeds, sand bottom, humic water with various concentrations of algae, and clear water type lakes (nonhumic) with various amounts of algae. Color-coded maps and data graphics containing these categories and providing the trophic status of several thousand lakes were produced. Field checking of lake categories by three separate individuals revealed approximately 90 to 95% correct classification.

3. Generate Land Cover Data

Urban, croplands, and forest cover were mapped together with lake weeds, shallow water (silt or sand bottom), three concentrations of suspended red clay in Lake Superior water, three concentrations of algal biomass in nonhumic waters, and humic waters. The urban and cropland categories were the dominant nonpoint sources affecting lake eutrophication. Processing of LANDSAT data on Madison area with emphasis on land cover established: two urban categories (urban/industrial, tended grass), three agricultural categories (close grown crops, row crops, improved pasture), three forest types (lowland hardwoods, upland hardwoods, and evergreens), natural grassland, bare land (sand), wetlands, and water. This exceeded the basic seven cover types required (Section 2.4.5) for most water quality analyses.

4. Determine Usefulness and Cost Benefits

The work demonstrates a practical and cost-effective procedure for assessing trophic state of lakes on a statewide or regional basis. The DNR of Wisconsin and other states are limited by staff and funding to assessing about 100 to 200 lakes by point sampling during the required 3-week period in late summer. LANDSAT in conjunction with this sampling can extrapolate measurements from these known lakes to the remaining 5,000 or more lakes, 50 acres or larger in size, and to 10,000 or more lakes, 20 acres or larger in size, when the improved resolution of LANDSAT-D is available. Assuming accurate categorization of about 1,000 lakes/scene, the cost for mapping water quality (trophic state) in Wisconsin is about $20 per lake. This is the total cost, including field work, data processing, field checking of map and final map product, etc. The estimated cost for sampling and analysis by present techniques quoted by EPA, US Forest Service, and states varied from $100 to $1,000 per lake. Remote sensing also produces the added benefit of the color map showing the concentrations of algal biomass and distribution of weeds. This map is not available from present sampling techniques and is required (Section 2.4.3) to fully achieve the DNR goals related to evaluating aquatic nuisance control treatments, locating lake nutrient inflows, and locating pollution sources.

3.5.1 GROUND TRUTH

The test area contained three test sites: (1) the Madison, Wisconsin area (Figures 3-23 and 3-24) where the lakes were essentially clear water type lakes (nonhumic) with various amounts of algae, shallow water (bottoms showing), and weeds, (2) the Spooner, Wisconsin area (Figure 3-25) which included some humic water and rice-type lakes as well as lakes of the type found near Madison, and (3) the Ely, Minnesota lakes which are primarily humic water and rice-bed lakes.

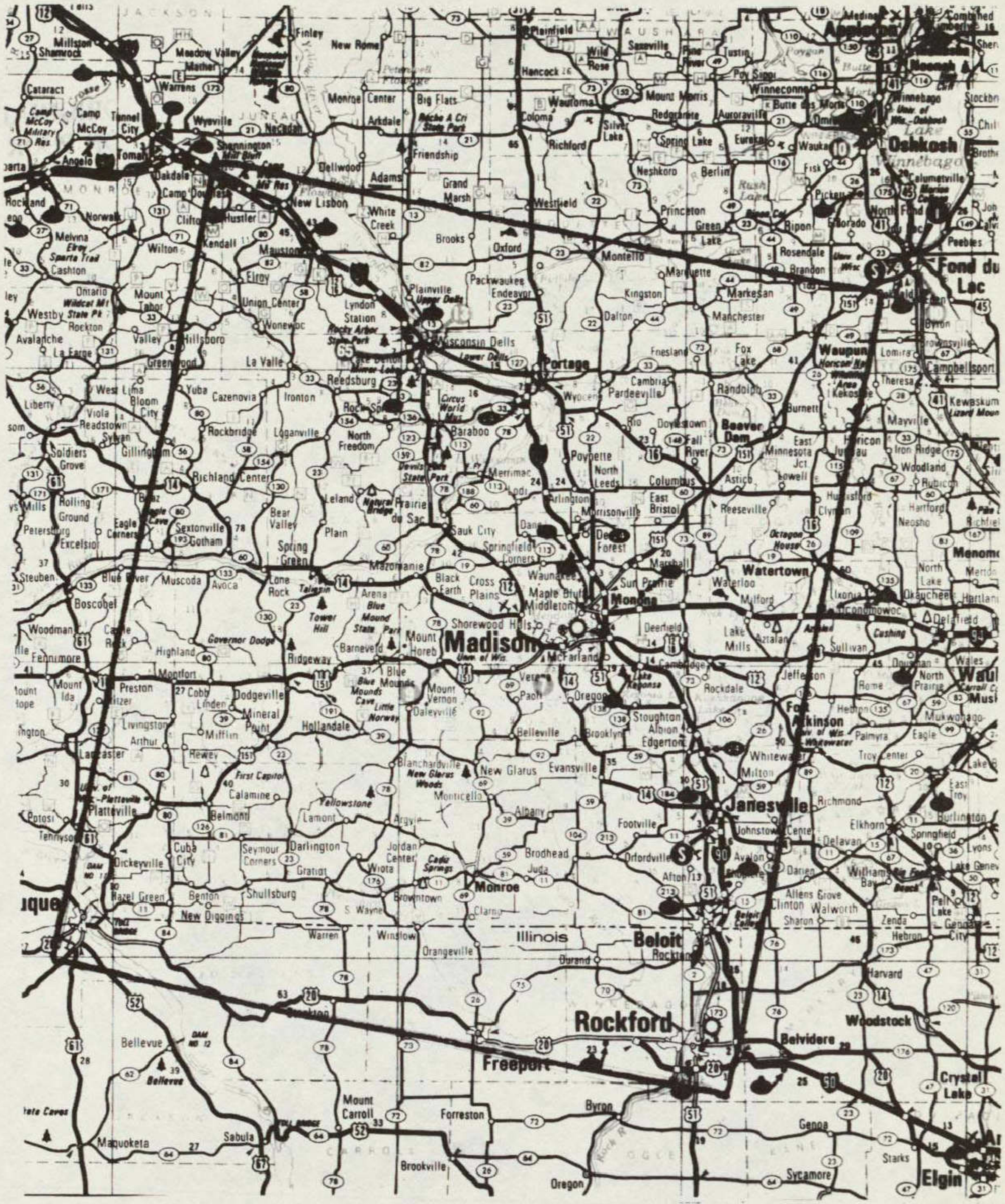


Figure 3-23 Map Showing Madison Area and Coverage by
18 August 1974 LANDSAT Scene 1756-16061

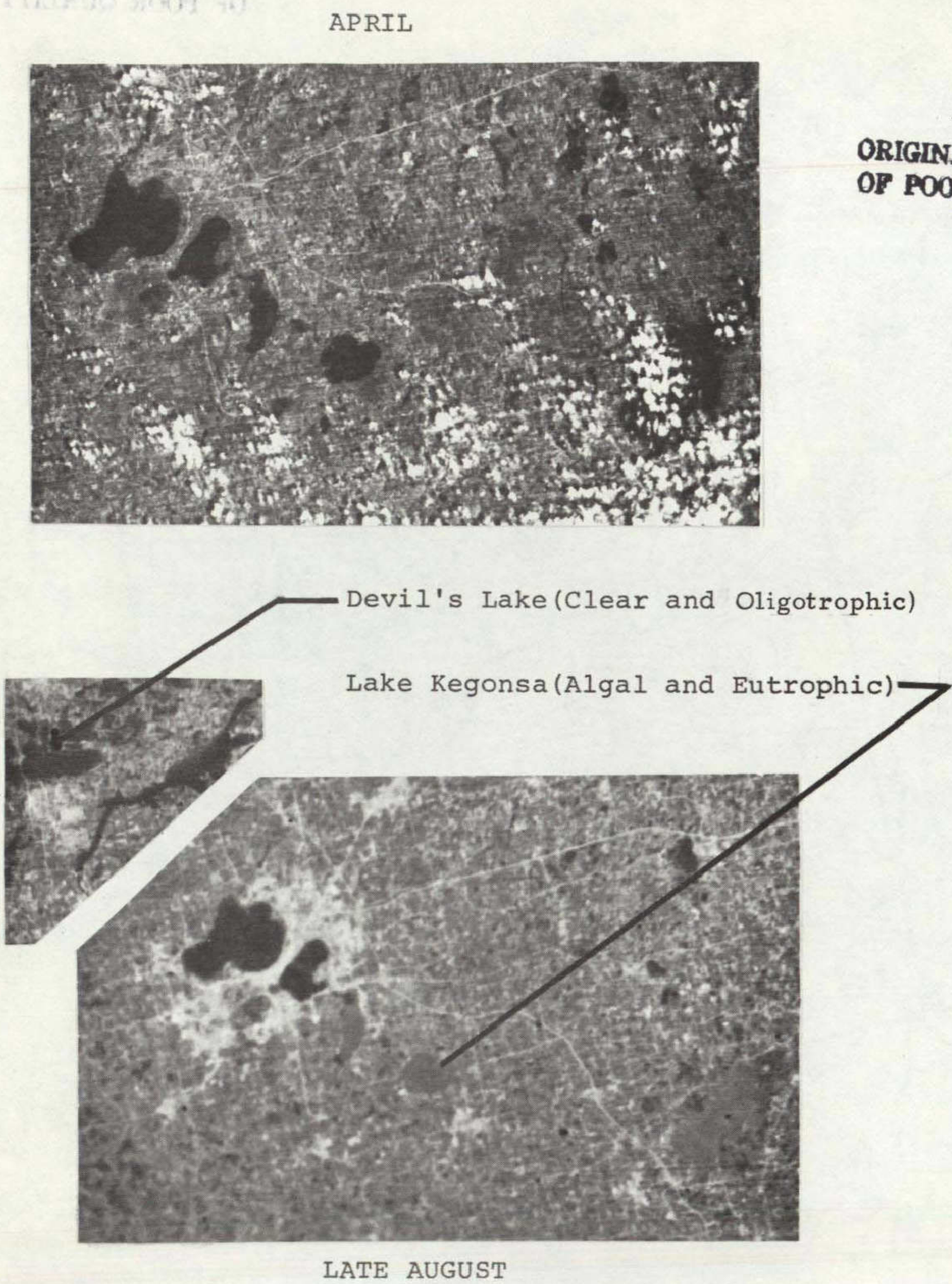


Figure 3-24 LANDSAT Images of Lakes near Madison, Wisconsin in Early Spring When Algae and Lake Week Growth is a Minimum and in Late August When It Is Maximum - Band 5 (Red)

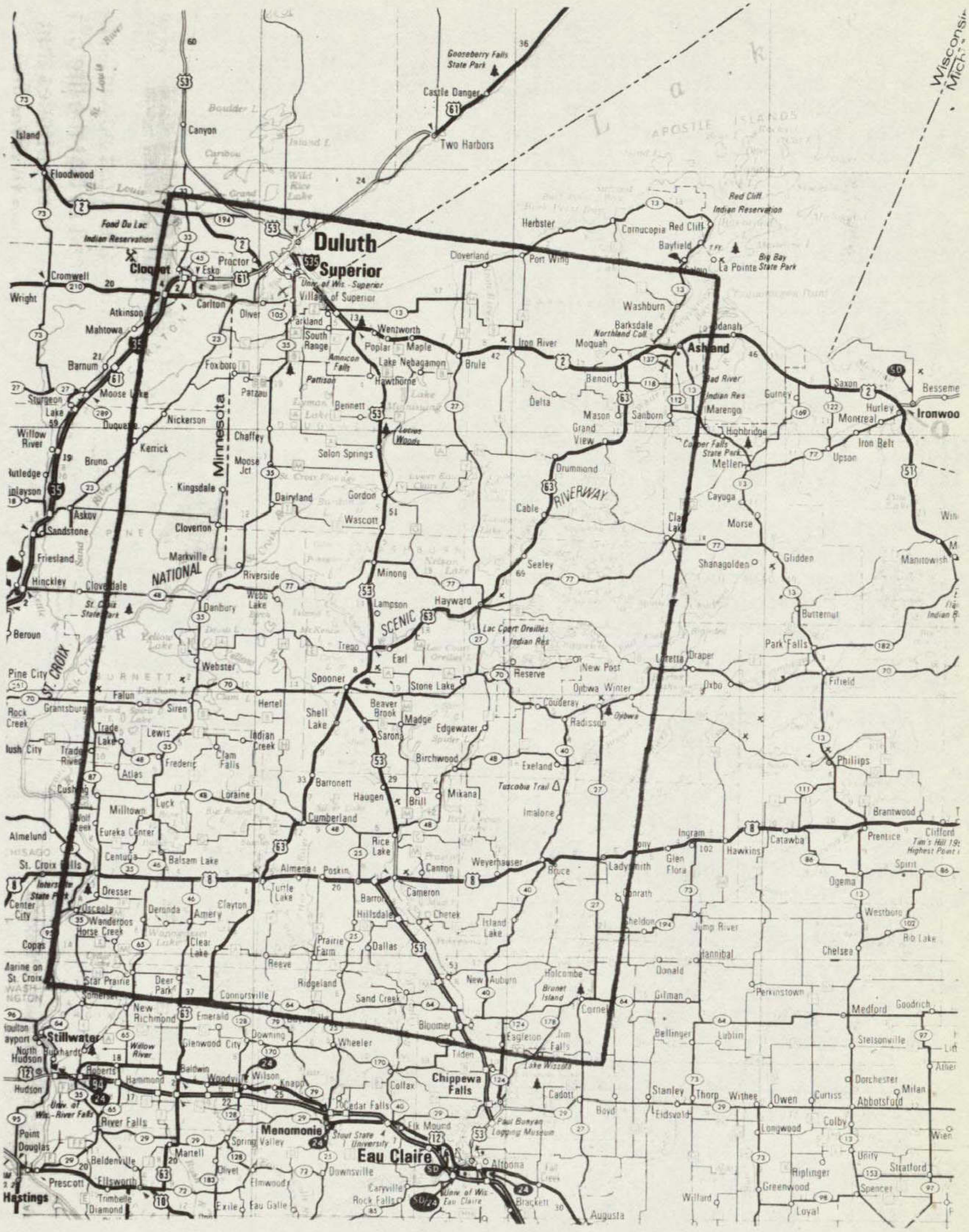


Figure 3-25 Map Showing Spooner, Wisconsin Area and Part of 12 August 1972 LANDSAT Scene 1020-16255

Ground truth activities were coordinated by Dr. James P. Scherz (Co-investigator) of the University of Wisconsin Department of Civil Engineering. Dr. William J. Woelkerling and Dr. Michael Adams of the University's Department of Botany supported Dr. Scherz in airborne and field data collection. Dr. Kenneth Holtje of the US Forest Service, Vern Sather of the Wisconsin DNR (Spooner, Wisconsin office), and Pat Schraufnagle and George Anderson of the Madison DNR office provided greater truth and professional advice.

Aerial observation of lakes and watersheds was made by Scherz, Woelkerling, and Adams during the spring of 1975 for collection of reference and calibration data. This was followed by several flights in the summer of 1975 to determine LANDSAT's classification accuracy. The DNR participated in some of these flights.

3.5.2 DATA PROCESSING

To assess LANDSAT's capability of producing the required maps and datagraphics, three LANDSAT scenes were submitted to categorical (Section 3.1.1.1) and geometric (Section 3.1.1.2) processing on the Bendix system. The specific three scenes were: (1) 18 August 1974, scene 1756-16061, showing Madison area (Figures 3-23 and 3-24), (2) 12 August 1972, scene 1020-16255, showing Spooner area (Figure 3-25), and (3) 12 August 1972, scene 1020-16252, showing the Duluth to Ely area. A spring scene of the Madison area was also analyzed (Figure 3-24). A preliminary and a final classification were performed on the summer scenes to establish and refine the categories/colors and accuracy. The work accomplished and the results achieved in carrying out this procedure on a step-by-step basis is summarized below.

3.5.2.1 Spectral Characteristics

A procedure was developed and previously reported (Ref 7 and Ref 47 through 50) in detail whereby LANDSAT signals from deep clear water were edited on MDAS and subtracted from signals from other lakes to obtain a "spectral fingerprint" of the material added to the water of other lakes. The material could be algae, humic material, silt, etc. Furthermore, laboratory apparatus were demonstrated which could synthesize most types of water volumes and obtain corresponding LANDSAT measurements. The procedure used for obtaining this spectral characteristic from LANDSAT data is summarized in this section.

The application of remote sensing to lake classification requires consideration of factors which do not exist when using remote sensing for general level cover mapping. A major factor is the specular reflection of the skylight from the water's surface. This factor can be significant (Ref 51). There are other factors such as diffuse reflectance from dirt and foam on the water surface, which add to the total satellite signal. Also, in shallow lakes, signals from the bottom of the water body are present. However, it is the material in the volume of the water, such as algae, humic material, silt, etc., which causes the backscatter that relates to water quality.

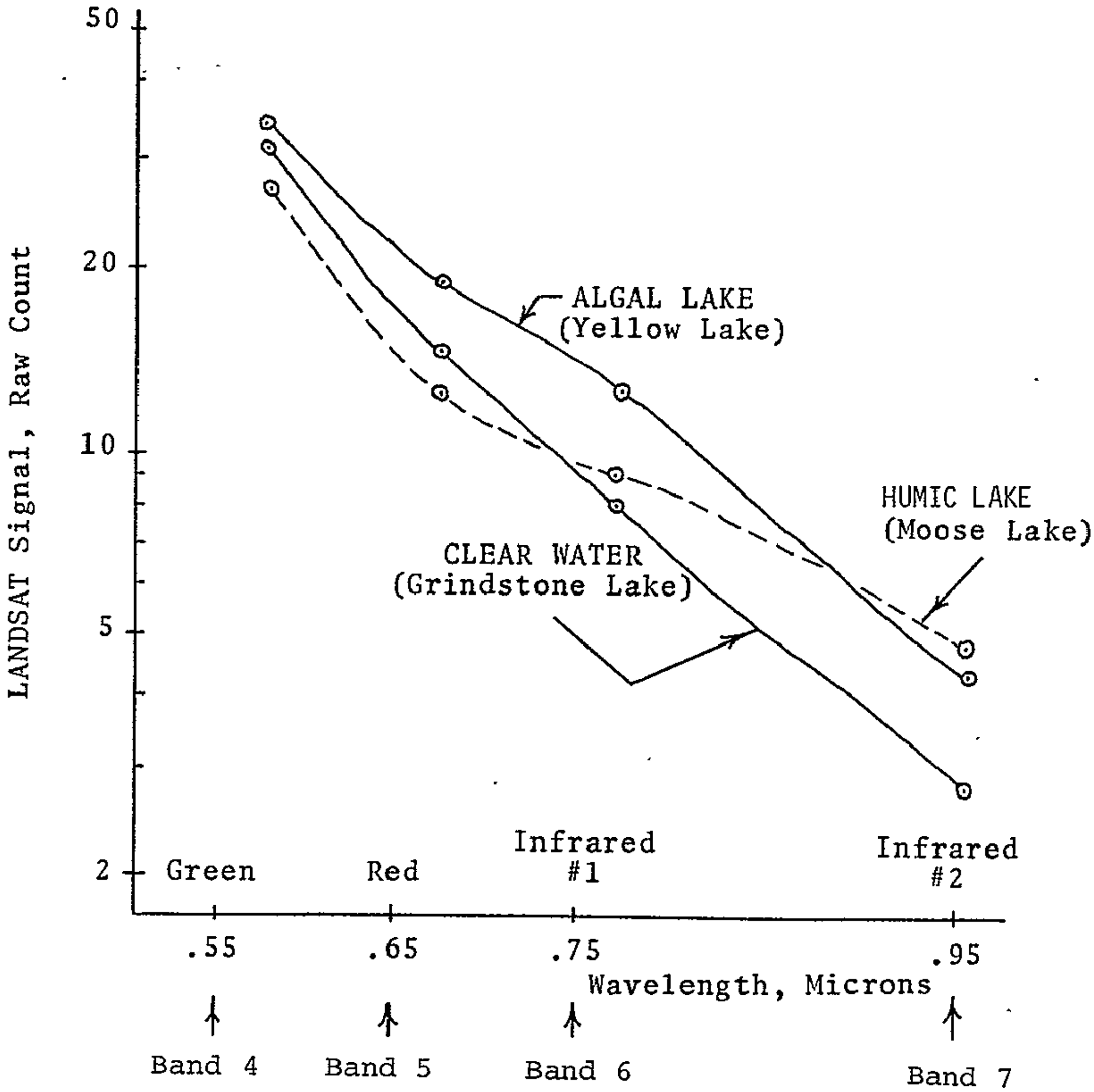


Figure 3-26 Satellite Spectral Signatures for Three Types of Lakes
(Raw Count from LANDSAT Multispectral Scanners)

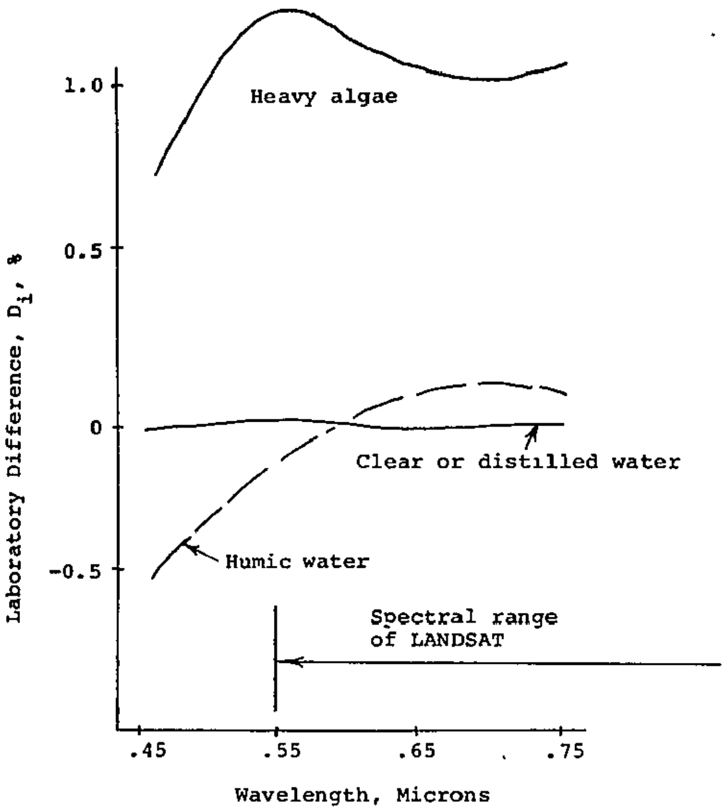


Figure 3-27 Characteristic Laboratory "Fingerprints" of Two Types of Material in Water; Laboratory Difference, $D_i = (\rho_{Vi} - \rho_{V1})/\rho_{PL}$ Where ρ_{V1} and ρ_{Vi} are the volume Reflectance for Distilled Water and the Water in Question; ρ_{PL} is the Reflectance of a Standard Panel

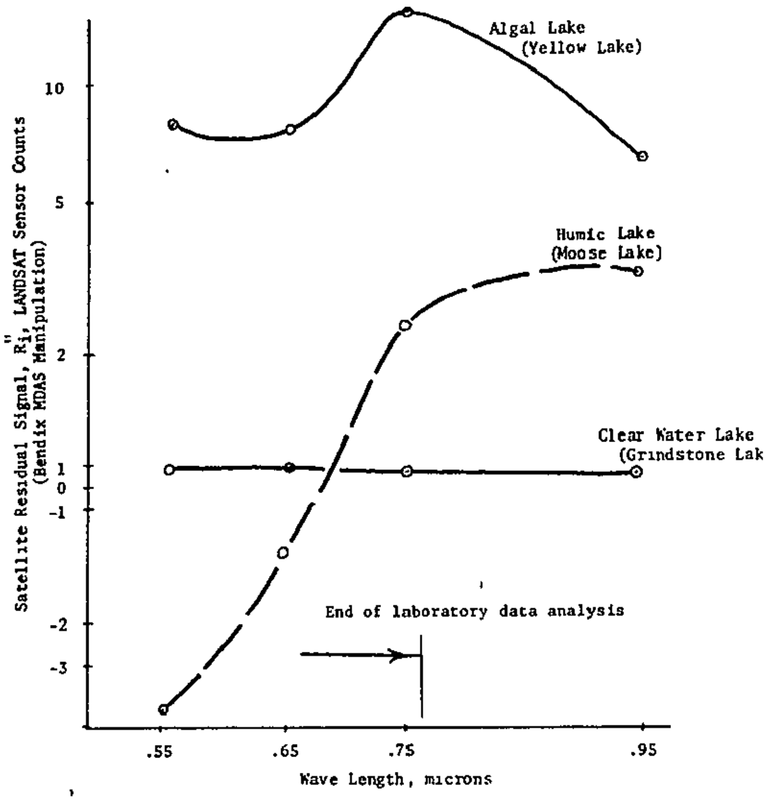


Figure 3-28 Characteristic Fingerprints from Satellite Residual Signal, R", for the Three Water Types (from Scherz, Crane, and Rogers, 1975)

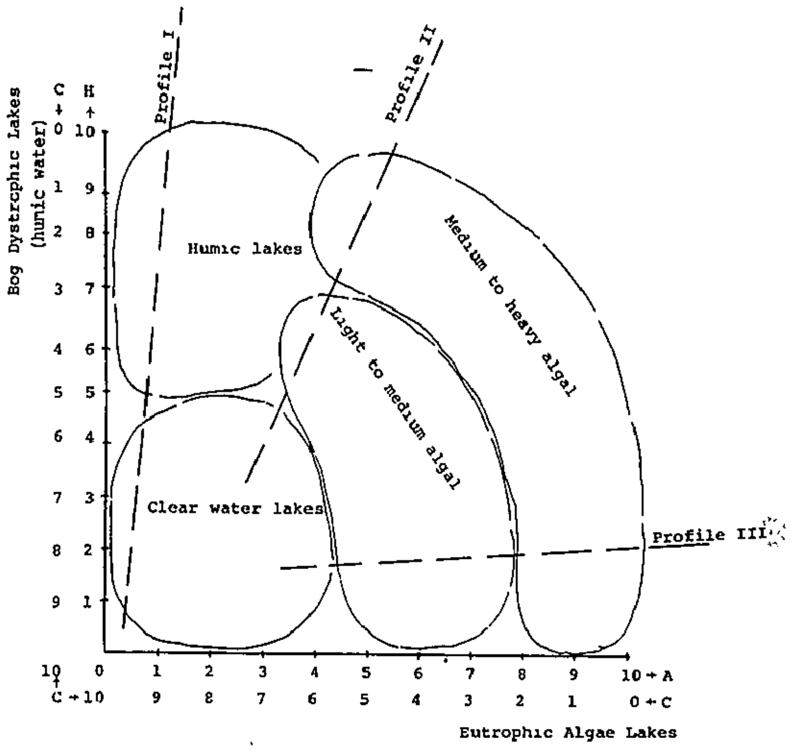


Figure 3-29 Scheme Used to Classify Lakes from LANDSAT Data; Curve Based upon (Nonremote Sensing) Lake Classification Scheme Originally Proposed by Wetzel; Satellite Residual Fingerprints along Profiles I, II, and III Are Shown in Figures 3-30, 3-31, and 3-32

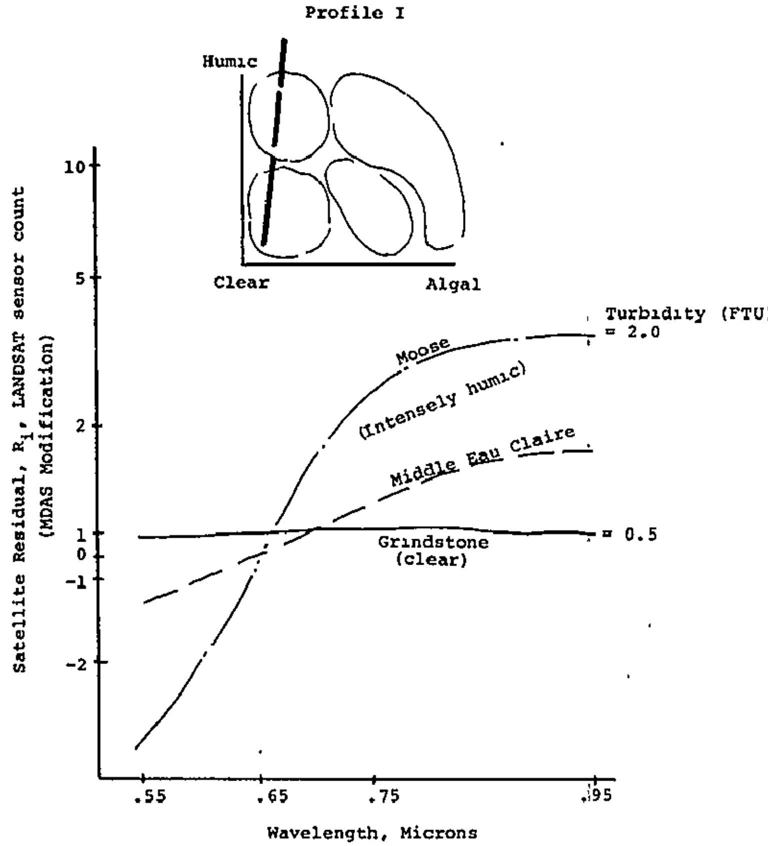


Figure 3-30 Satellite Residual Fingerprints for Clear, Moderate, and Intensely Humic Lakes (Profile I in Figure 3-29)

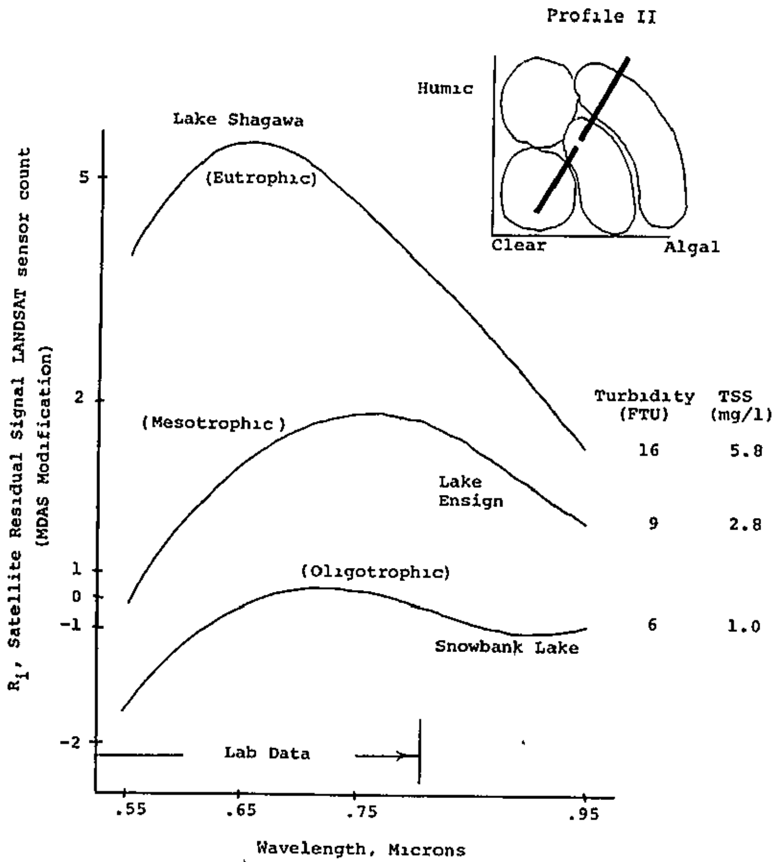


Figure 3-31 Satellite Residual Fingerprints of Moderately Humic Lakes Containing Various Amounts of Algae (Profile II in Figure 3-29); Three Lakes Near Ely, Minnesota; Shagawa = Eutrophic, Ensign = Mesotrophic, Snowbank = Oligotrophic;

TSS = Total Suspended Solids

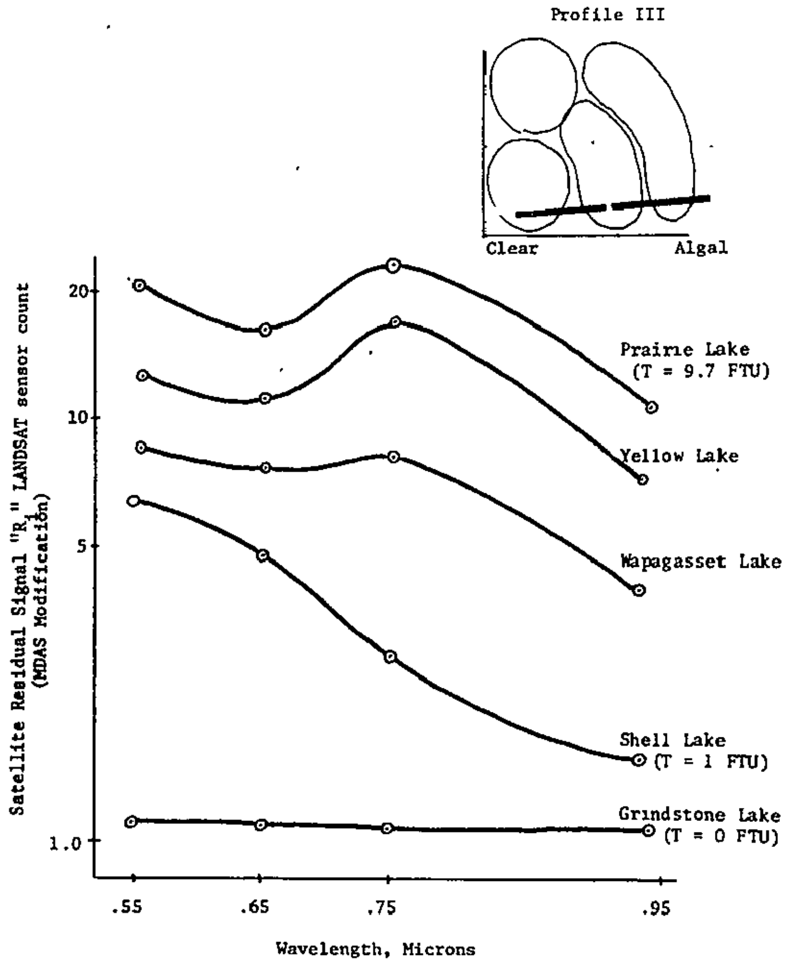
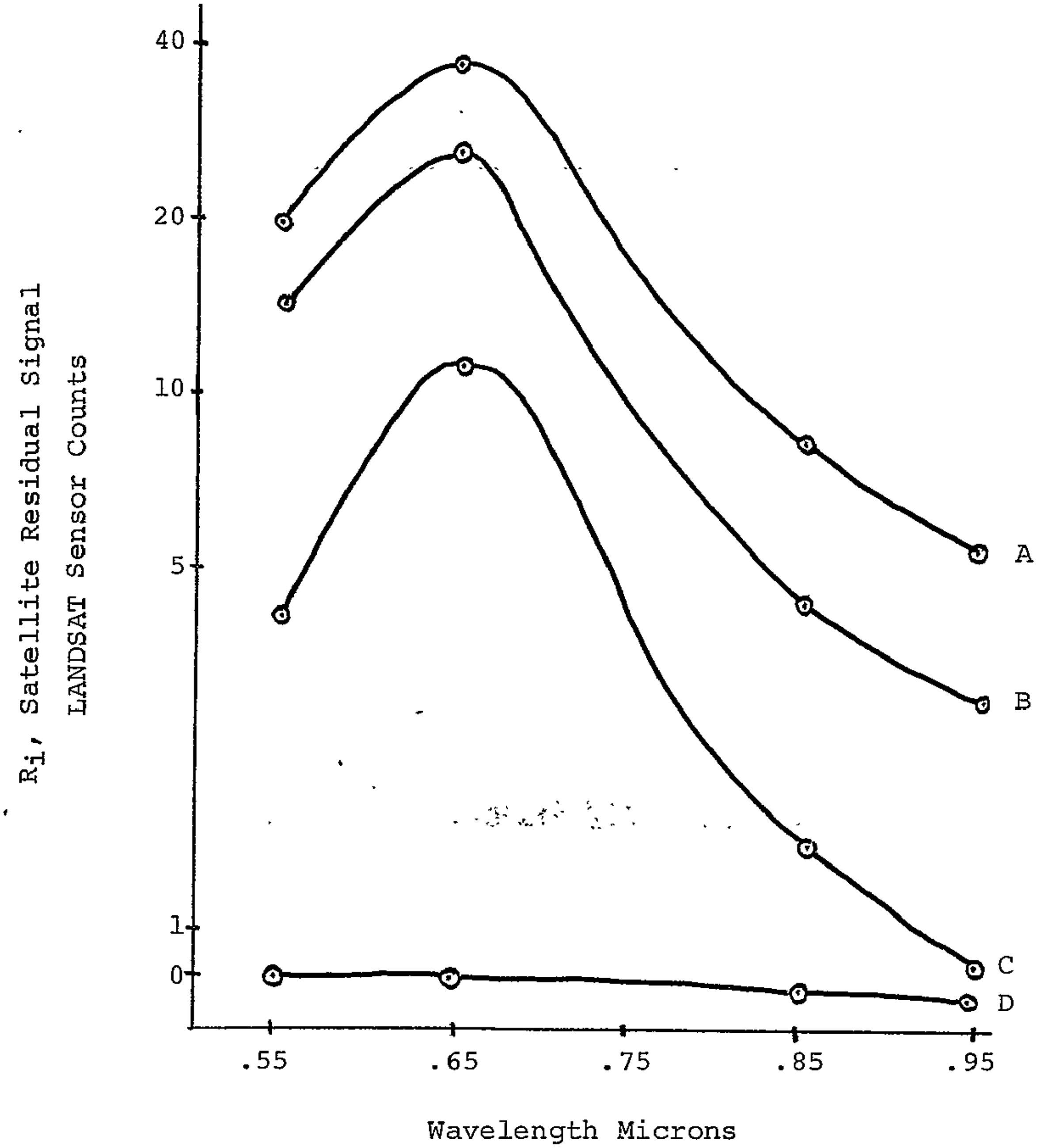


Figure 3-32 Satellite Residual Fingerprints of Nonhumic Type Lakes (Clear Water Type) Containing Various Amounts of Algae (Profile III in Figure 3-29); T = Turbidity



Site	Approx. Turb. (ftu)	Approx. Solids (mg/L)
A	100	400
B	50	200
C	5	50
D	0.2	0

Figure 3-33 Effect of Red Clay in Clear Lake Superior Water

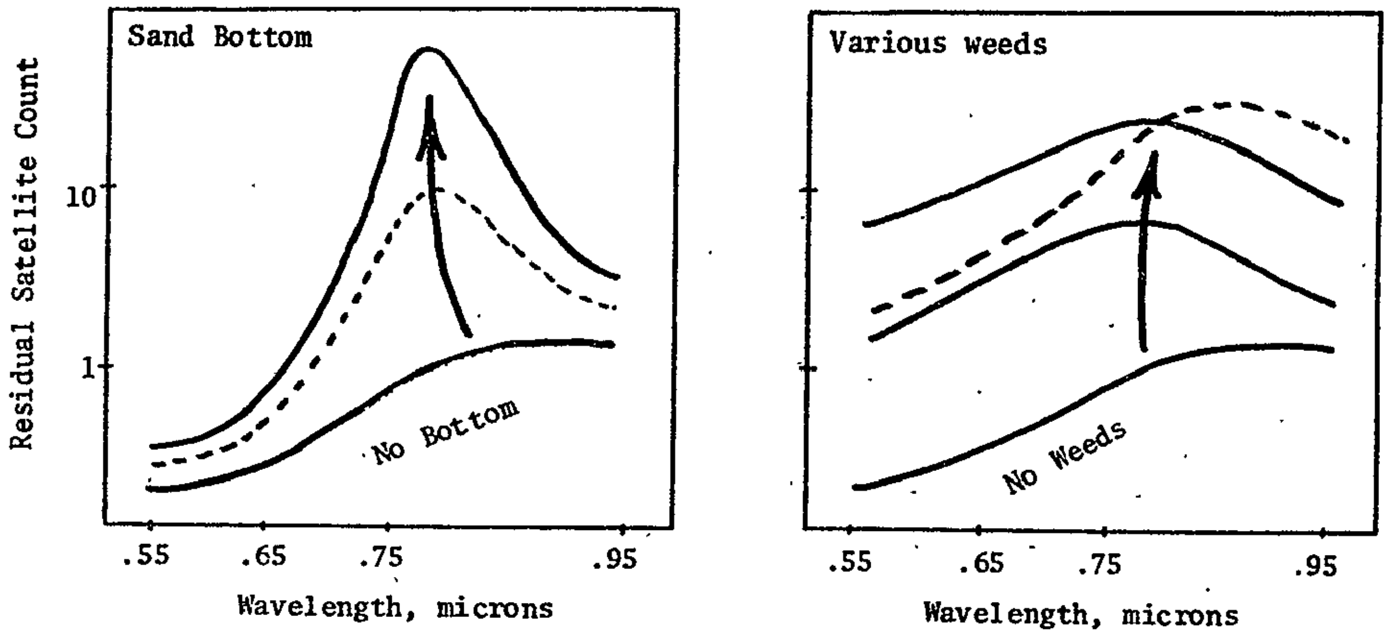


Figure 3-34 Effect of Sand Bottom and Various Kinds of Weeds on Satellite Signal of a Humic Water Lake

3.5.2.2 Color-Coded Image Maps

To assess LANDSAT's capability of producing the required color maps, showing biomass concentrations, the summer LANDSAT scenes of the Madison, Ely, and Spooner areas were submitted to categorical and geometric processing (Section 3.1.1). Training set selection was accomplished by Dr. James P. Scherz who brought to the Bendix facility the necessary ground truth information. It must be emphasized that good ground truth in the form of aerial observations of the test lakes is essential for the training of the MDAS equipment. The aerial observations are especially essential in locating the troublesome bottom effects (shallow areas), which might show up in a training set without the aerial observations.

LANDSAT data products resulting from the MDAS processing included color-coded image maps where the color was used as a code to identify the various land and water categories. Categories and colors produced by Dr. Scherz are listed in Tables 3-30, 3-31, and 3-32. A portion of the color-coded image produced from the Madison scene is reproduced in Figure 3-35. This image shows some of the same lakes pictured previously in Figure 3-24. Note the red lakes: weeds, the three colors corresponding to the three algal concentrations in clear water lakes (dark blue: clearest water, blue-green: light to medium algae, green: medium to heavy algae), the brown/orange: humic lakes, and yellow: shallow water. Some of these same colors and categories can be seen (Figure 3-36) in the lake classification of the Spooner area where many more humic lakes and Lake Superior are observed. Close inspection of the lakes in the color images show different classifications of pixels within a lake, indicating perhaps a sand bar on one end, a weed bed at the other, and perhaps even a humic water stream discharging into the lake somewhere else. This information is not readily available from point sampling or derived by averaging and analysis of signals from only the deep water area.

Whenever more than the three or four land cover categories (i.e., urban, forest, cropland) were included with the water quality categories, misclassifications occurred. To determine the land cover categories which could be accurately mapped in Wisconsin without these confusions, the Madison area scene was again submitted to supervised MDAS processing. This effort resulted in color-coded maps and data showing two urban categories (urban/industrial, tended grass), three agricultural categories (close grown crops, row crops, improved pasture), three forest types (lowland hardwoods, upland hardwood, and evergreens), natural grassland, bare land (sand), wetlands, and water. This exceeded the basic seven cover types required (Section 2.6) for preliminary estimates of nutrients and other pollutants in runoff. An example of one of the maps produced from this effort is shown in Figure 3-37, which shows a 15-minute quad area north of Madison, Wisconsin. The area contains Lake Wisconsin, which was previously shown in Figure 3-35 classified as humic water, and Devils Lake, which was used as the training area for deep, clear nonhumic water.

Table 3-30

Lake Classification, Madison, Wisconsin Area Lakes - LANDSAT Scene 1756-16061, 18 August 1972

Color Code (10 colors used, about maximum usable without reading error)

Dark Blue - Clear, deep lake (trained on Devils Lake) nonhumic water.

Blue-Green - Light to medium algae nonhumic water.

Green - Medium to heavy algae nonhumic water.

Yellow - Silt bottom of lake showing or silt suspended in water.

Brown-Orange - Humic water.

Red - Lake weeds.

Dark Gray - Forest.

Light Gray - Cropland.

White - Urban.

Black - Unclassified.

Note: Based on the above categories and a field check in August 1975, the correct classifications calculated by two separate calculations were 99% and 93% correct (estimated error in field methods was ± 5%).

Table 3-31

Lake Classification, Spooner Area Lakes in Northwest Wisconsin, LANDSAT Scene 1020-16255, 12 August 1972

Color Code (10 colors used, about maximum usable without reading errors)

Dark Blue - Deep, clear nonhumic water.

Blue-Green - Light to medium light algae nonhumic.

Green - (a) Inland lakes - medium to heavy algae nonhumic water.

(b) In Lake Superior and next to purple band - light rock flour or red clay in Lake Superior water.

Purple - Light-medium red clay in Lake Superior water.

Yellow - Sand-silt bottom of lake showing or medium to heavy silt suspended in lake water.

Brown - Humic water lakes, or humic water lakes with mud bottom, or humic water lake with mud bottom and wild rice-type plants growing.

Dark Gray - Forest.

Light Gray - Cropland, grassland, light trees.

White - Urban.

Black - Unclassified.

Note: Based on above categories and a field check in August 1975, the correct classifications calculated by two separate calculations were 99% and 93% correct (estimated error in field methods ± 5%).

Table 3-32

Lake Classification, Duluth to Ely, Minnesota Area Lakes - LANDSAT Scene 1020-16252, 12 August 1972

Color Code (10 colors used, about maximum usable without reading error)

Dark Blue - Deep, clear nonhumic water.

Blue-Green - (a) Inland lakes - light to medium algae in clear type water (nonhumic).

(b) In Lake Superior - light to medium concentration of red clay or rock flour in clear Lake Superior water.

Green - (a) Inland lakes - medium to heavy algae nonhumic water.

(b) In Lake Superior - next to purple color - medium concentration of red clay or rock flour in Lake Superior water.

Purple - (in Lake Superior only and between yellow and green colors) Light-medium concentration of red clay in Lake Superior water.

Yellow - Sand/silt bottom of lake showing or silt or red clay suspended in water.

Brown - Deep humic water, or humic water with black mud bottom showing, or humic water with black mud bottom and wild rice-type plants growing.

Dark Gray - Forest.

Light Gray - Cropland.

White - Urban.

Black - Unclassified.

Note: Based on above classification categories and a field check in August 1975, the correct classifications calculated by two separate calculations were 87% and 96% correct (estimated error in field methods ± 5%).

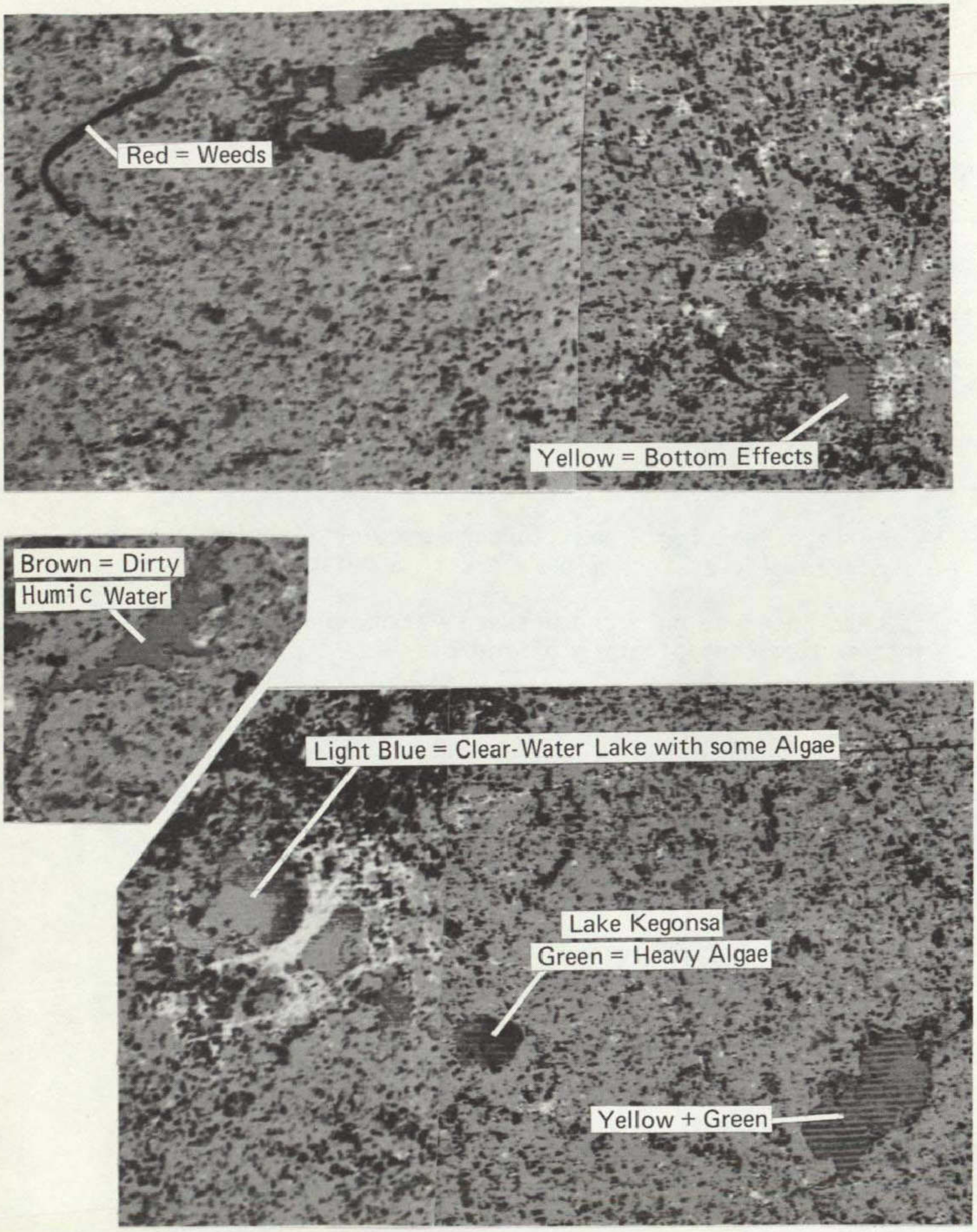
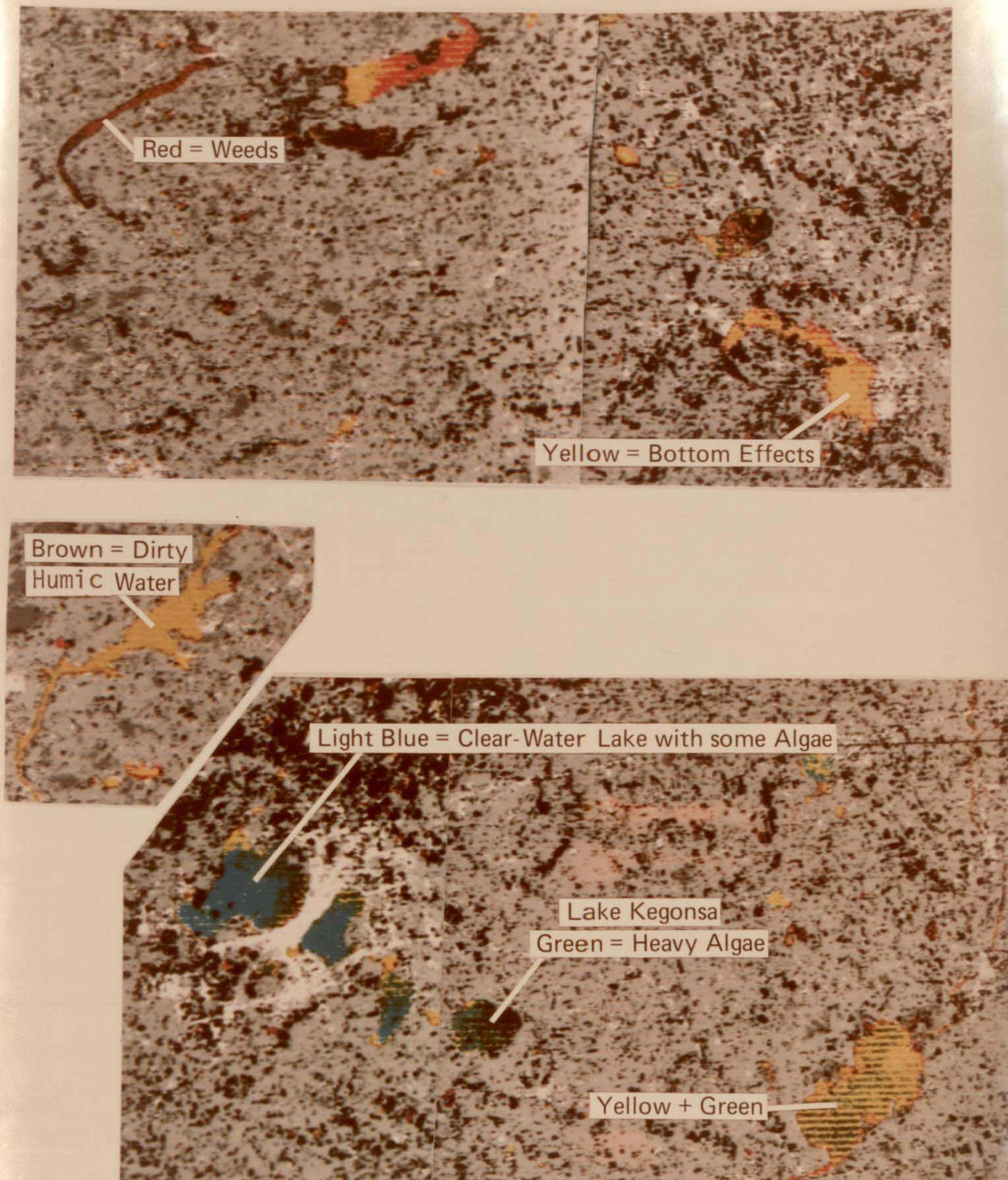


Figure 3-35 Initial Water and Land Categories of Portion of Madison Area (LANDSAT Scene 1756-16061 of 18 August 1974)



Red = Weeds
Yellow = Bottom Effects
Brown = Dirty
Humic Water
Light Blue = Clear-Water Lake with some Algae
Lake Kegonsa
Green = Heavy Algae
Yellow + Green

LAKE CLASSIFICATION

SPOONER AREA
Bendix M-DAS
Lake Classification
from ERTS Data 12 Aug. 1972

Color Code

Dark Blue = deep, clear water

Blue Green = (a) inland lakes: light algae
(b) in Lake Superior: very light red clay in water

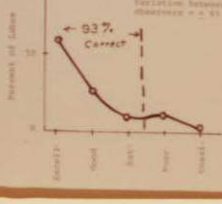
Green = (a) inland lakes: medium to heavy algae
(b) in Lake Superior: light to medium red clay

Purple = medium to heavy red clay in Lake Superior

Yellow = sand-silt bottom or heavy silt or clay suspended in water

Brown = humic (tannic) lakes and mud bottom in humic lakes or wild-rice-type plants growing in mud bottoms of humic lakes and cloud shadows.

Accuracy



145 lakes checked
3 checks by 2 people
Variation between observers = ± 6%

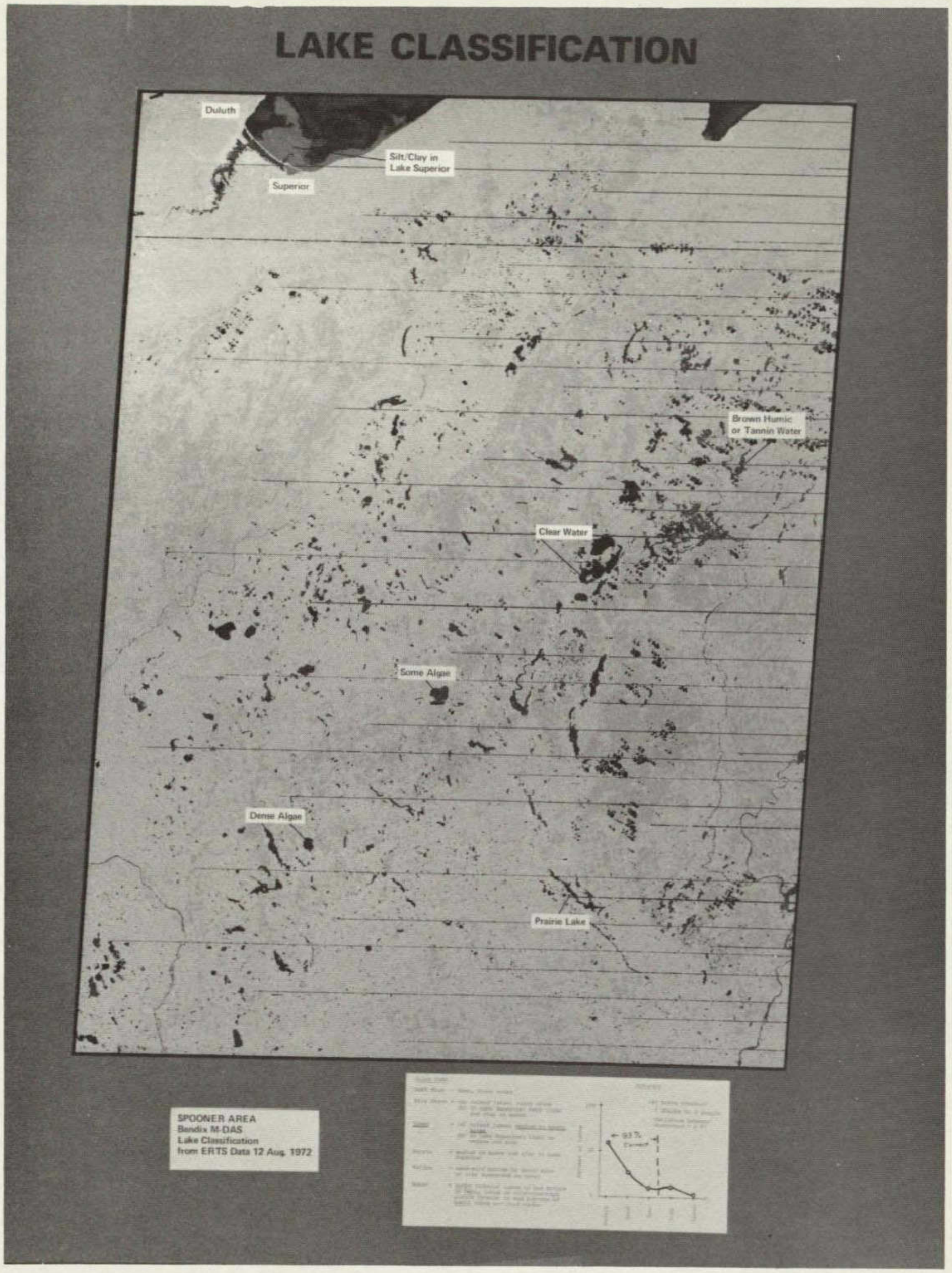


Figure 3-36 Water and Land Classification of Spooner Area
(12 August 1972, LANDSAT Scene 1020-16255)

Bendix

Baraboo Quadrangle
Wisconsin

Figure 3-37 Color-Coded Map of 15-Minute Quad Area Produced from LANDSAT Data

ORIGINAL PAGE IS
OF POOR QUALITY

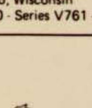
Baraboo Quadrangle
Wisconsin

Background Map Information
from 15 Minute USGS Quad
of Baraboo, Wisconsin
AMS 3070 - Series V761 - 1959

1 0 1 2 3 4
Miles

Natural Grassland
Lowland Hardwood Forest
Upland Hardwood Forest
Tended Grassland
Evergreen Forest
Wetland
Water
Urban/Industrial
Cropland
Improved Pasture
Truck Crops
Sand
Wetland
Uncategorized

Land-Cover Mapped from LANDSAT
August 1974



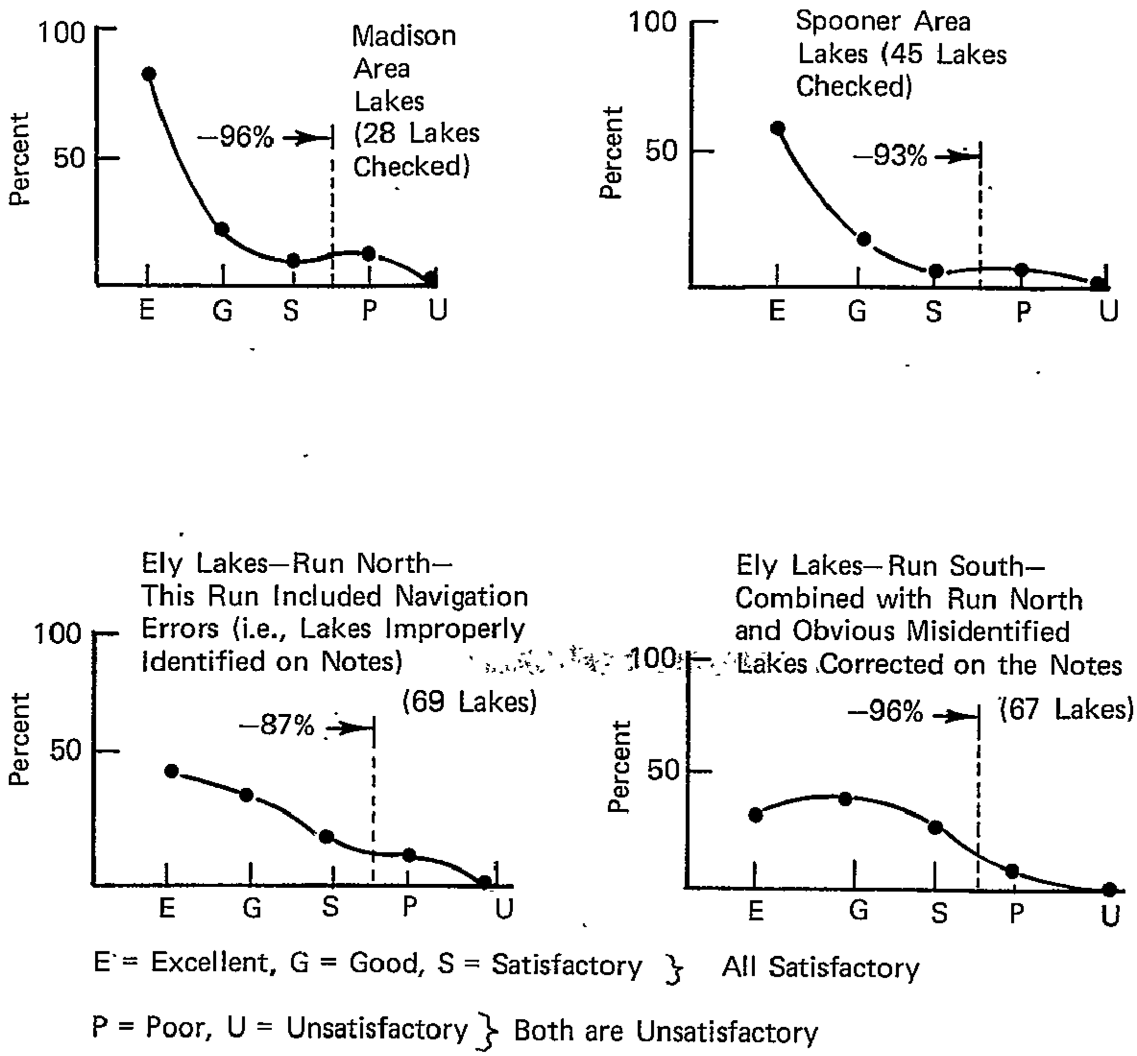


Figure 3-38 Plots of Lake Classification Accuracy

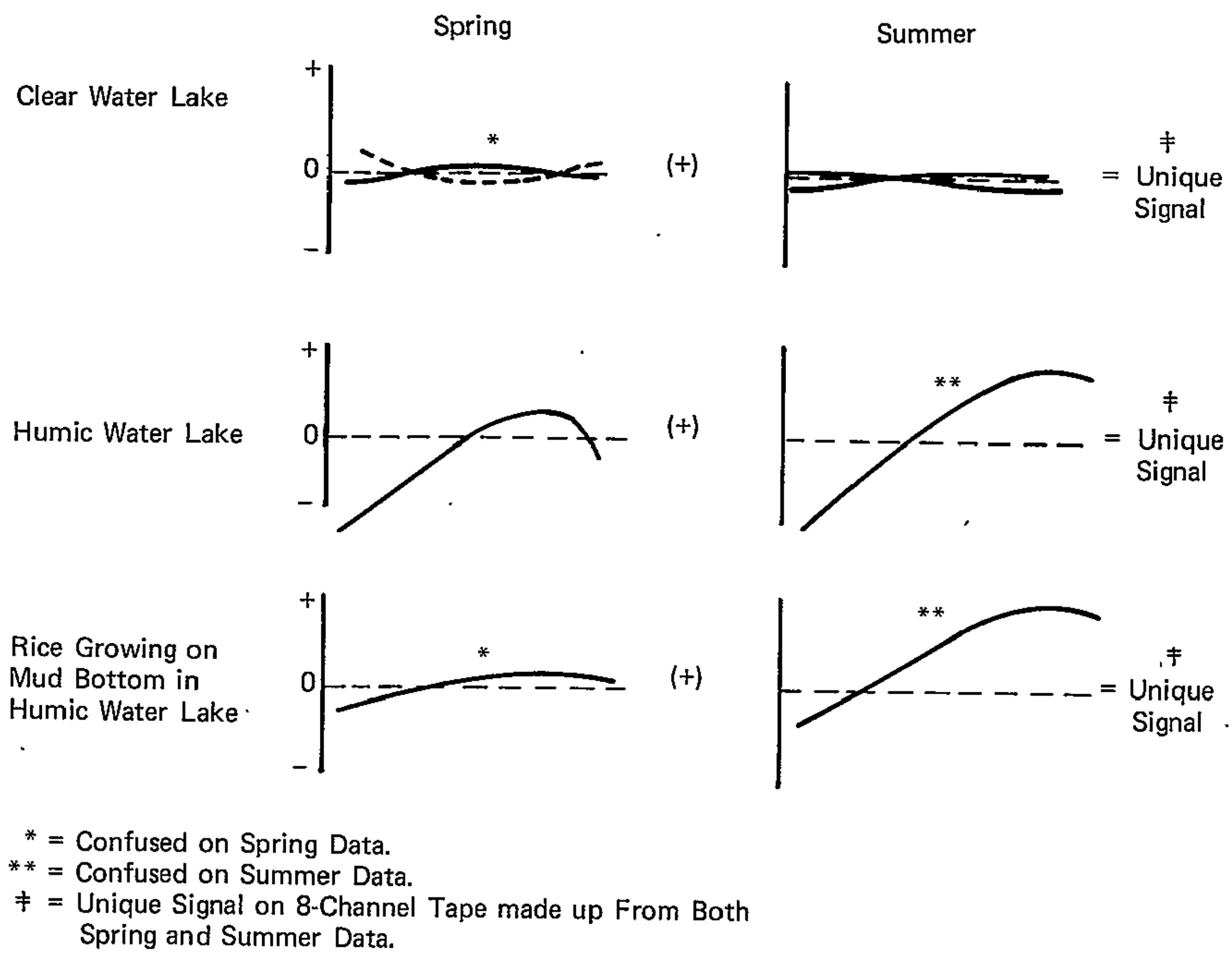


Figure 3-39 Plots of Residual LANDSAT Signals Versus Band Number

The time and available money, however, prevented a meaningful investigation into the multiseason approach. Consequently, the humic and rice bed lakes in the Spooner and Ely scenes were put into the same category and indicated by a brown color as humic water. Since the rice lakes may be well known anyway, it appears that the lumping together of these two types of lakes may not be too serious or a hindrance to the trophic classification. Also, there is the unanswered question of whether or not the additional time and money required to make an eight-channel tape would be justified to merely separate out the rice bed lakes from an otherwise excellent classification possible from just the summer data.

3.5.4 COMPARISONS WITH OTHER METHODS

Comparison with EPA Analysis - The EPA National Eutrophication Survey (Ref 53) gives some two dozen different measurable parameters for different lakes which were used to determine eutrophic classification. However, it is not easily possible to determine from this report at what time of the year the water samples were taken. Of the 33 lakes listed by the EPA report in the Wisconsin and Minnesota areas of interest, none were classified by EPA as oligotrophic; 5 were classified as mesotrophic and 28 were classified as eutrophic. It is appropriate here to point out that while conventional classification schemes produce categories that conservatively are heavily weighted on one end, remote sensing can create categories of many degrees of algae in the water. For the final map produced for this investigation, three types of algal lakes were indicated: (1) heavy algae, (2) moderate algae, and (3) either no or light algae. Eight or more categories were separated by the computer as shown in Figure 3-31 (humic water) and Figure 3-32 (nonhumic water), but they were not printed because the eye could not reliably distinguish more tones of color. That is, when eight or more colors are used to show biomass concentration and are combined with three to five additional colors needed to show weeds, shallow water, silt, and some land use categories, then the eye becomes confused between colors.

Ten of the lakes classified by the EPA fell within the three test areas. Essentially, the final LANDSAT classification was three algal levels (dark green: heavy or medium algae; blue-green: moderate algae; and blue: either no or light algae). Brown indicates humic water and yellow indicates bottom or silt. It is also necessary to identify lakes where bottom effects override the signal from the water itself. The work by Boland (Ref 2) and the EPA (Ref 53) in Wisconsin, although good initial work, overlooked this important source of signals. Lakes where bottoms show need to be field-checked. Of the 10 lakes which the EPA classified, five appeared dark green on the final LANDSAT image and were classified by the EPA as eutrophic. One lake appeared blue-green on the printout and was classified by EPA as mesotrophic. Four lakes appeared as brown on the printout and were classified by EPA as eutrophic. These lakes were Castle Rock and Lake Wisconsin on the Wisconsin River, Big Eau Peine Reservoir, and Lake Wissota. All of these lakes are reservoirs on rivers heavy in humic water. If lake classifications are to be useful, the relative amount of eutrophication must be shown, not just that they are in a eutrophic state.

As to the probable costs of the ground and lab methods used by the EPA investigation, the commercial costs of the some two dozen tests run on each lake would be $1,000 to $2,000 or higher. In addition to the laboratory and field work, there would be the cost of drawing the maps.

US Forest Service Estimate of Costs - The US Forest Service, as well as the Wisconsin DNR, participated in this study by providing ground truth and professional advice. Since the US Forest Service concentrated their work in a smaller area while the Wisconsin effort was distributed over two sites, a more in-depth comparison was performed near the Ely Area. Dr. Kenneth Holtje of the US Forest Service estimates that the field work required to duplicate the information depicted on the water quality maps would cost about $100 per lake. Of course, meaningful field efforts for a two-man team doing the optimum late summer sampling would be limited to about 10 lakes per day or, say, 100 lakes per season. These data then would have to be analyzed and plotted. In addition, the subtle differences in algal concentrations occurring over an individual lake and mapped by LANDSAT may be lost by manual plotting.

Cost to Property Owner - On the final lake classification map of the Spooner, Wisconsin area (Figure 3-36), it was determined that Prairie Lake in Barron County, Wisconsin (southeast end of scene) had the highest amount of algae present of all the lakes. Low level aerial photos and aerial observations showed that the highest algae concentration was at the mouth of Rice Creek, which empties into the north end of Prairie Lake. Further lower level aerial investigations and ground checking revealed about 100 cows in about 70 springs in a small unique wooded area that is the primary headwaters of Rice Creek. Since each cow contributes approximately as much pollution as 10 people, this cattle yard had the approximate pollution equivalent of a community of 1,000 people dumping their raw sewage into Rice Creek. This is also the lake where the resort owners for years have banded together and at a cost of many thousands of dollars have treated the lake with copper chemicals in an attempt to kill the algae. As a result of the LANDSAT data, the citizens of Barron County, Wisconsin, around the Prairie Lake, are now taking corrective action with regard to the cows in the springs of Prairie Lake. Hopefully, the quality of water in Prairie Lake soon may improve because of the perspective view shown by LANDSAT.

Aerial Observation and Photos - The aerial observations undertaken by Adams, Woelkerling, and Scherz in conjunction with Vern Sather of the Spooner DNR Office cost about $50 per lake for the air time and labor. However, if the data were sketched and turned into a map, the cost would be a completely different matter. Several times as long would be required over each lake to make rather than check a map. The aerial observation technique is best used to check maps already made. The eye can easily see bottom effects, but it is virtually impossible to compare the concentration of algae or tannin in one lake to another when they are flown over and observed at different times and under different lighting conditions. The satellite, of course, sees hundreds of lakes at one instant of time and under the same lighting conditions. Aerial observations are good for checking, but would be recommended not as an alternate classification technique but as an additional aid in the classification to check those lakes flagged as tannin or bottom by the satellite classification.

From other studies, it appears that acquisition of good quality aerial photos at the correct time of the year, and the somewhat ambiguous water quality data that can be extracted without elaborate qualitative analysis, make aerial photos useful as a check but certainly of less use than aerial observations. However, individual photos of the clear-water test lakes and the lakes with weed beds were extremely valuable in the selection of training sets for MDAS analysis.

Cost Summary - An estimate of the cost for producing a water quality map from LANDSAT data for an area like the Spooner location would be perhaps $20,000 maximum. Included would be ground truth, aerial observations, and processing and filming of the color-coded lake classification maps. A rough count of the number of lakes classified in the Spooner Area (three-fourths of a full LANDSAT scene) was between 750 to 1,000. Assuming an average number of 1,000 lakes/scene, the cost is $20 per lake including analysis ground truth, field checking of the map, and the final map product. None of the other estimates included the cost of the final map. The costs of lake classification utilizing LANDSAT and the costs of classification based on conventional sampling by the user organizations are compared in Table 3-33.

Table 3-33

Cost Summary

	Summary	Approximate Cost/Lake	Map Product Included
(1)	Water Sampling as Done by EPA Eutrophication Survey (a few hundred lakes per year).	$1,000 +	No
(2)	Specialized Water Sampling by US Forest Service and Wisconsin DNR (100 to 200 lakes per year).	$ 100	No
(3)	LANDSAT/Computer-Assisted Interpretation (thousands to tens of thousands of lakes per year possible.	$ 20	Yes

It should be noted that use of LANDSAT data does not eliminate the need for point sampling and aerial observations. Rather, its use simply extends these observations and measurements over more lakes, thus making the total inventory more cost-effective. Remote sensing also contributes the color-image/map of lakes showing variations in concentration of biomass and locations of weeds.

3.5.5 RECOMMENDATIONS FOR FUTURE WORK

The work in the Wisconsin and Minnesota area has produced what is believed to be a very effective lake classification system. The system is useful and ready to apply right now as it stands. However, other possible areas of research have been exposed by this study:

1. Use of multi-season imagery to differentiate rice beds from humic water and possibly to further define different types of algae in lakes. This would involve combining spring and summer data into an eight-channel tape which would then be analyzed on the Bendix MDAS system. Not only does the theory indicate that this would be an area of fruitful research, but personnel from the Minnesota rice-growing regions have expressed their eagerness to help by providing ground truth.

2. Atmospheric effects. Since the absolute reflectance from a deep, clear water lake can be calculated in the laboratory, the difference between the lab and the satellite reflectances is the noise caused by the atmosphere. These values on this project have been subtracted out to obtain the residual water signals, but the same data could be a desirable signal for someone interested in the atmospheric parameters. The atmospheric parameters as determined using clear water lakes appear to be an area of promising further research requiring very little additional expenditure of effort or dollars.

3. Combining of water quality and ground cover mapping in the watershed. As the land cover mapping capability has been around for some years and the water quality mapping capability is available at the conclusion of this project, it is now possible to combine the results and check for possible correlations between land cover in the watershed with the water quality in the lakes. This is another area which shows promise of some definite answers with relatively little additional expenditure of dollars or research effort. If such a correlation between land cover and water type exists, it would be a very valuable modeling tool for those responsible for managing the water quality and watersheds of the corresponding lakes.

4. CONCLUSIONS

The significant results of this investigation are summarized in Sections 4.1 and 4.2.

4.1 LAND COVER/LAND USE

1. Pollutants (e.g., nutrients, toxic substances, microorganisms) in storm water runoff from nonpoint sources (land cover) have significant impact on water quality and must be considered in concert with pollutants from the atmosphere and from point sources (e.g., sewage facilities).

2. Land cover information is required at international, federal, state, and sub-state planning levels in the development and application of models and techniques for forecasting pollutant loading from existing and new uses of land.

3. The need for land cover information to predict pollutants in storm runoff is the same at international, national, state, and sub-state planning levels. The primary difference in information needs is the size and location of watersheds of interest.

4. Land cover categories of major interest are those for which loading rates are generally available and are known to cause significant differences in quantity and quality of runoff. These include: urban land, barren land, cropland, grassland (cleared-unproductive), forest, wetlands, and water. This is a sufficient set of categories for the "preliminary analysis" of most regions and LANDSAT can map these categories with the exception of forested wetlands. Of importance to some analyses is that LANDSAT can also distinguish cropland as row (e.g., corn) and field (e.g., wheat) crops by crop type if needed and forest land as broadleaf or evergreen trees. In the urban area, LANDSAT can interpret two to six categories related to their degree of permeability, although separate analyses are generally performed for the urban and nonurban areas.

5. LANDSAT's spatial resolution and frequency of coverage are sufficient for land cover data required by most models and techniques used to predict pollutants in runoff.

6. The 3 to 4 month delivery of maps and data required by most users will depend on improved LANDSAT tape handling procedures by NASA and USGS.

7. The required data format is a function of type of model and facilities available to the user. The area tables listing land cover categories by watershed is one of the most useful data formats as loads can be estimated directly by multiplying tabulated land cover by loading rates. For more detailed analysis, the land cover is more readily combined with soil texture, slope, and other information when the land cover is recorded on map overlays and digital tapes.

8. The majority of planners do not have the land cover information required to assess impact of land cover on water quality. The standard USGS topographic maps and other maps generally available in state and regional offices do not categorize land into cover types which have predictable effects on the quality and quantity of runoff. In almost every case, grassland and cropland have been lumped into one category labeled open space or underdeveloped. Bare land is not always mapped. Population growth and expansion have outdated most maps of urban areas, and the category names are not identified in terms (e.g., percent impervious, housing density, etc.) usable for estimating pollution loads.

9. The cost for obtaining and formatting the required land cover information from conventional sources (e.g., aerial photography, field or "windshield" surveys, etc.) is either too expensive or time consuming, or both. The cost for obtaining information by "windshield" survey is relatively expensive, \$5 to \$7 per square mile, and has dubious or unknown accuracy. The cost for information derived from aerial photography is about \$8.00 per square mile if photography is available and \$11.00 to \$13.00 per square mile if new photography is needed. LANDSAT provides the required land cover information in the desired formats for \$1 to \$4 per square mile, depending upon the type of product and scale.

10. Computer-assisted interpretation of LANDSAT computer-compatible tapes (CCTs) permits products to be produced within 3 to 4 months for most planning regions, covering three to thirteen counties, and within 4 to 8 months for state size or large areas. Other techniques generally require two to three times longer if new photography or surveys are needed.

11. Processing of LANDSAT CCTs results in digital land cover files produced with minimum additional effort. This is of primary interest to planning organizations who use a computer in the compositing and analysis of land cover with other data sources which have been digitized (e.g., photo interpretations, soils, topography, etc).

12. LANDSAT is the fastest and least costly (i.e., \$1 to \$4 per square mile) method for deriving land cover categories (e.g., urban, forest, cropland, grassland, barren land, etc.) required to assess runoff within watersheds on a regional or statewide basis. Some other planning needs (e.g., transportation planning, etc.) require additional categories (e.g., mobile home parks, single family housing, roads, forested wetlands, small orchards, etc.) best obtained from aerial photography or field surveys at a higher cost (i.e., \$8 to \$13 per square mile). These categories typically cover only 2 to 10% of a region and can be interpreted from photography or field data digitized and merged with LANDSAT data to produce a multisource data file, maps, and datagraphics with significant savings in cost and time.

13. In summary, LANDSAT data in conjunction with computer-assisted interpretation provide the maps and datagraphics required by state and regional programs concerned with the planning and management of water quality. LANDSAT data can be merged with conventional data sources to satisfy other planning needs. The savings in time and money and responsiveness to data needs achieved by LANDSAT or LANDSAT in conjunction with conventional data sources warrant its application to most state and regional efforts.

4.2 WATER QUALITY

1. Information on water quality in the Great Lakes is needed at the international, federal, and state planning levels to: (1) establish and monitor the trophic state in lake waters, (2) locate sources, and map distributions and fates of toxic substances, (3) monitor known waste treatment sources upgraded to achieve water quality objectives, (4) locate new problem areas, and (5) develop, calibrate, and verify models used to forecast transport and fate of pollutants.

2. The states and sub-state planning regions require information on the trophic status of inland lakes in preparation of reports on conditions of navigable waters, to evaluate aquatic weed control and lake renewal efforts, to detect problem lakes where controls may be needed, and to develop and use models for evaluating land use practices in watersheds.

3. Remote sensing data requirements of the states (e.g., Michigan, Wisconsin, Minnesota) are those of extrapolating measurements from 150 to 200 lakes of known trophic state (as determined by chlorophyll a concentration and water clarity) to the remaining 10,000 or more lakes during the brief late August to September time period when primary production is stabilized. The requirements at sub-state planning levels are the same except for smaller areas of interest and fewer lakes. Trophic status of all lakes should be determined every 5 years with problem lakes updated annually.

4. Remote sensing on the Great Lakes must extrapolate measurements from presently scheduled ship-sampling schedules. For the most part, these schedules do not coincide with availability and use of satellite data. Assessment of the Great Lakes for trophic state is presently limited, by boats and laboratories, to about once every 9 years.

5. Probably the best single indicator of trophic state is the concentration of biomass or organic mass produced in the lakes at the peak of the growing season when the waters are all at maximum temperatures and are thermally stratified. In the Great Lakes region, this is a brief 3-week, late summer period between August and September. In the inland lakes, this biomass is in the form of plankton and weeds while in the Great Lakes it is predominantly phytoplankton. During this summer period, LANDSAT can readily categorize six to ten concentrations of algal biomass which are readily correlated to chlorophyll a concentrations, water clarity, and trophic state. Additionally, LANDSAT maps inshore areas of floating and emergent macrophytes.

6. LANDSAT signals from deep clear water, when subtracted from signals from more turbid lakes, provide a residual signal "fingerprint" of the suspended materials in the water; materials which can be identified as to algae, humic material, marl, red clay, etc. Laboratory apparatus can be used to synthesize and predict LANDSAT measurements from almost any type of water volume.

7. LANDSAT measurements from Wisconsin and Minnesota lakes show that LANDSAT can separate (categorize) three or more ranges of algal concentrations in humic water and five or more concentrations in nonhumic water: a total of eight or more concentrations or trophic states. The work in Michigan shows the sensitivity of LANDSAT measurements to low concentrations of biomass where five categories (concentrations) within the "oligotrophic" range were mapped. LANDSAT can easily provide six to ten categories related to biomass concentration and trophic state when monitoring is accomplished in the recommended late summer time period.

8. LANDSAT spatial resolution is sufficient for establishing trophic status in lakes of 50 acres or larger but is marginal for 30-acre lakes. It is more than adequate for assessing trophic states in the Great Lakes where turbidities are sufficiently high. A resolution of 10 to 40 meters will be needed to monitor lakes of 10 acres or larger and to monitor waste treatment sources in the near-shore areas of the Great Lakes.

9. The frequency of LANDSAT coverage is probably adequate for assessing trophic status of inland lakes and the Great Lakes subject to cloud cover limitation. More frequent coverage is required, i.e., weekly or twice weekly (ideally continuous), to satisfy requirements associated with development of models used to predict circulation and distribution of pollutants and to monitor waste treatment effluents in near-shore areas of the Great Lakes.

10. Delivery of maps and data within 3 to 4 months, required by most users, calls for some improvement in LANDSAT tape handling procedures by NASA and USGS.

11. The most useful data format is the color map produced from LANDSAT measurements which shows the distribution and concentration of various water quality parameters (e.g., chlorophyll a, phosphorus, nitrogen, etc.) within specified confidence limits. This is an important contribution by remote sensing that is not readily obtained from other sources.

12. The work in Saginaw Bay demonstrated a step-by-step procedure for using surface measurements and LANDSAT data to provide a color-keyed image map showing the distribution and concentration of water quality parameters (e.g., nitrogen and phosphorus) causing eutrophication, as well as parameters that indicate its effects (e.g., chlorophyll a). Although

the procedure is image and surface truth dependent, it can be applied to almost any situation to monitor various water quality parameters with a known accuracy (definable accuracy). Parameters keyed to the final Saginaw Bay water quality map included chlorophyll a, total phosphorus, total Kjeldahl nitrogen, Secchi depth, total solids, suspended solids, conductivity, chloride, and temperature.

13. Work on Wisconsin and Minnesota Lakes shows that most users can only distinguish about 10 different color codes on color image maps produced for field verification. These colors were used on maps produced on Wisconsin and Minnesota test sites to show: water with silt, weeds, sand bottom, humic water, three different amounts of algae in nonhumic water, urban, cropland, and forest. The Michigan lakes and categories were weeds and six algal biomass categories. Algal biomass was related to chlorophyll a, water clarity, and trophic state.

14. Aerial observations of over 200 lakes by three separate individuals established LANDSAT categorization accuracy to be 90 to 95% correct for Wisconsin and Minnesota lakes; variations between observers was about 5%.

15. In summer LANDSAT imagery, humic water lakes are confused with lakes with wild rice growing on mud bottoms. In spring imagery, rice beds are confused with nonhumic (clear water) lakes. Confusion can be resolved by ground or aerial observations and/or multiseasonal processing.

16. Aerial observations may be used selectively to improve or refine LANDSAT classifications by checking those lakes flagged as humic water or bottom lakes (shallow). Aerial observations are best used to check maps already made. The eye can easily see bottom effects, but it is virtually impossible to estimate concentrations of biomass in lakes when they are flown over and observed at different times and under different lighting conditions. LANDSAT sees hundreds of lakes at one instant of time under the same lighting condition.

17. LANDSAT data coordinated with surface sampling provide a cost-effective system for monitoring inland lakes of 50 acres or larger when the area contains 200 or more lakes per scene. The cost for obtaining lake inventories by conventional techniques ranges from $60 to $1,000 per lake, depending upon the agency and the techniques used. Monitoring by LANDSAT in conjunction with surface sampling costs $10 to $40 per lake based on typical areas in Wisconsin, Minnesota, and Michigan. This is the total cost and includes field work, processing, field verification, and the final map. The price may be reduced to $5 to $20 per lake with the 30-meter resolution available by LANDSAT-D and the anticipated capability of inventorying lakes of 10 acres or larger.

18. LANDSAT data coordinated with surface sampling provides an economical method (approximately $1 per square mile processing cost) of extending surface sampling on the Great Lakes. The water quality map produced by this investigation was generated from LANDSAT data and 16 surface measurements obtained on the same day. A similar map produced by techniques presently applied by the EPA requires from 33 to 60 samples collected over a 3-day period. Thus, LANDSAT data provided a potential savings of 2 days in boat crews and a lab analysis estimated at $6,000 to $10,000.

5. RECOMMENDATIONS

5.1 INLAND LAKES

1. It is recommended that the States of Michigan, Wisconsin, Minnesota, and other states and regions containing more than 100 to 200 lakes per LANDSAT scene undertake programs to integrate surface sampling and LANDSAT data in monitoring of all lakes of 50 acres or larger. Smaller lakes would be included in the program with the aid of airborne multispectral scanners or when LANDSAT-D is operational. All of the states' lakes would be assessed during the first program year for trophic state. Data would be collected and screened during the second, third, and fourth years and analyzed in depth if a problem were suspected. Detailed processing of all lakes would be repeated during the fifth year and compared with the first year's processing for improvements or losses in water quality. All lakes showing major changes would be investigated for cause-effect relationships.

2. One of the most serious obstacles confronting efforts by Michigan and other states in applying planning and management concepts to inland lake watersheds on a statewide basis has been the lack of an inexpensive data source and facilities needed to manipulate and analyze the data with regard to lake eutrophication. A planning and management approach has been published by the Michigan DNR. Implementation of this approach requires information on land cover and use, data on slope, drainage features, drainage divides, and soils. The most economical and responsive sources for this information would be LANDSAT for general land cover in the watershed, aerial photography used selectively on 2 to 15% of the watershed for land use, and topography and soil maps for soil type and drainage features. A program is recommended which would demonstrate the best techniques for collecting, formatting (digitizing), merging, manipulating, and using this multisource information in assessing the effects of existing and new land uses on lake eutrophication.

3. It is recommended that multiseason imagery be evaluated for differentiating rice beds from humic water and for possibly further defining different types of algae in lakes. This would involve combining spring and summer data into an eight-channel tape which would then be analyzed on the Bendix MDAS system. Not only does the theory indicate that this would be an area of fruitful research, but personnel from the Minnesota rice growing regions have expressed their eagerness to help by providing ground truth. This effort would also document the additional costs and benefits that would result from processing eight-channel data.

4. The absolute reflectance from a deep, clear water lake can be determined in the laboratory; the difference between the laboratory and the satellite measurements is due to atmospheric parameters, e.g., path attenuation (τ) and backscatter (H_{sky}). The effects of these parameters have been reduced during this investigation by subtracting signals from a clear water lake from other lakes to obtain residual water signals which characterize the material within the water. These same measurements could be used to obtain atmospheric parameters required in the development, calibration, and verification of models and techniques for predicting atmospheric parameters required by signature extension procedures. It is therefore recommended that future research will document the best method for obtaining the atmospheric parameters from the analysis of lakes and laboratory measurements and estimate the error, cost, and benefits achieved by the use of these parameters.

5.2 GREAT LAKES

1. This work demonstrates that satellite remote sensing provides an economical source of land cover information in the proper format and with the desired categories and accuracy needed in developing and applying procedures for forecasting effects of existing and new land uses on water quality of the Great Lakes. It is recommended that this procedure be used in the inventory of that basin and smaller watersheds in the Great Lakes drainage system. The same procedures are applicable, worldwide, to large and small river and lake basins.

2. The procedure demonstrated by this program using surface sampling, LANDSAT data, and linear regression equations proved to be a cost-effective method for extending surface sampling and producing water quality maps of known accuracy. It is recommended that this method be used to assess the trophic state of all the Great Lakes. Sampling schedules on the Great Lakes should be coordinated when possible with satellite coverage so that this assessment can be accomplished on all lakes during the late summer of the same year and repeated on a 5-year cycle. Problem areas (e.g., Saginaw Bay, western Lake Erie, lower Green Bay, southern Lake Michigan, etc.) would be monitored on an annual or more frequent basis.

3. LANDSAT data should be used to develop, calibrate, and verify models used to assess the source and fate of pollutants. Application of these models to assess the effects of point (e.g., waste treatment facilities), and nonpoint (e.g., land use, atmosphere, etc.) sources are of particular importance in the problem areas, e.g., Saginaw Bay, lower Green Bay, Lake Erie, etc. It is recommended that modeling efforts in these areas be continued or expanded to include use of LANDSAT data as a source for land cover and water quality parameters.

4. A program is recommended which would determine sensor requirements (e.g., resolution, bands, etc.) and benefits for monitoring plumes from waste treatment sources for phosphorus content for compliance with water quality standards (1 mg P/L). The near-shore zone around the Great Lakes should be monitored to locate new sources whose phosphorus concentration exceeds permissible amounts and to monitor progress of known problem sources in achieving water quality objectives. The IJC 1975 annual report identified 63 known problem sources. This program would use data collected by aircraft multispectral scanners and would establish future requirements and benefits for satellite monitoring of the "near-shore zone" of all lakes.

5. A program is recommended which would determine the needs, capability, and benefits of satellite remote sensing data in establishing the source, distribution, concentration, and fate of toxic substances (organic and metallic), i.e., PCBs, mirex, mercury, asbestiform fibers, etc. The IJC has reported that all five of the Great Lakes are contaminated by toxic substances. The work in Saginaw Bay shows the potential for using LANDSAT to map the distribution and concentration of toxins through their association with particulate matter in the water column.

6. LANDSAT monitoring of Saginaw Bay should be continued to refine the techniques developed by this investigation and to evaluate new techniques which offer additional cost benefits. The EPA sampling in Saginaw Bay will continue through the summer of 1978 and is coordinated with the satellite schedule. Two or three clear images were acquired during the summer of 1977 which this investigation did not analyze. Techniques which should be evaluated include: use of nonlinear regression analysis for improving accuracy in mapping water quality parameters and signature extension for evaluating use/accuracy of regression equations (coefficients) over multiscene areas. Application of these techniques should decrease the standard error of estimate in predicting water quality parameters and result in the possible further reduction of surface sampling. The maps and data resulting from this work will also help further the goals of the EPA's study of lake eutrophication in Saginaw Bay.

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