Assessment of Water Quality in Lakes by the Use of Bio-indices from Satellite Imagery

A Case History in 208 Water Quality Management Planning

EPA-440/3-77-019

January 1978

ASSESSMENT OF WATER QUALITY IN LAKES BY THE USE OF BIO-INDICES FROM SATELLITE IMAGERY

U.S. ENVIRONMENTAL PROTECTION AGENCY

★ Environmental Research Information Center ● Technology Transfer

★ Office of Water Planning and Standards ● Water Planning Division (WH 554)

401 "M" St. S.W., Washington, D.C. 20460

ACKNOWLEDGEMENTS

This publication contains information prepared for the U.S. Environmental Protection Agency, Environmental Research Information Center, Office of Research and Development, and Water Planning Division, Office of Water Planning and Standards.

The information in this publication was prepared by Alan E. Rimer, P.E., Wiggins-Rimer and Associates, Durham, North Carolina with the assistance of James A. Nissen, P.E., and Roger Schecter, AIP. Mr. Richard Simms and Dr. Jack Wood of the Southcentral Michigan Planning Council also assisted in preparing information.

NOTICE

This publication has been reviewed by the Environmental Research Information Center and the Water Planning Division, Office of Water Planning and Standards, U.S. Environmental Protection Agency, and is approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does any mention of trade names or commercial products constitute endorsement or recommendation for use.

CONTENTS

INTRODUCTION

With the advent of grants to areawide water quality planning agencies under Section 208 of Public Law 92-500, many agencies have been designated to undertake water quality planning. While some programs are in the early phases of planning, significant portions of others have been completed and are being implemented. The case history discussed in this publication is an example of the work of one Section 208 water quality management agency which may be applicable to the water quality planning activities of other agencies.

ASSESSMENT OF WATER QUALITY IN LAKES BY THE USE OF BIO-INDICES FROM SATELLITE IMAGERY

The Southcentral Michigan Planning Council (SMPC) has identified water quality in lakes as one of the major problems to be addressed in its areawide planning program. In addressing this problem, SMPC saw the need for a water quality assessment methodology which could be used in working with local lake associations and governmental units on a continuing basis. Toward this goal, a system utilizing LANDSAT satellite imagery has now been established to generate bio-indices which reflect overall water quality conditions throughout a given lake.

Rather than providing quantitative water quality data, the remote sensing approach identifies indicators of various water quality conditions which are then used in conjunction with soil, topographic, and land use information to delineate specific problem areas and probable causes. As part of the total lake assessment program, remote sensing is a tool which has helped to determine the need for water quality strategies on a local level.

The system allows SMPC to work with local lake associations and governmental units in monitoring the progress of programs to improve water quality. Water quality conditions identified over an extended period of time and assessed in conjunction with changing land use patterns and improved agricultural practices provide the basis for evaluations of the relative success or failure of alternative regional water quality management strategies.

BACKGROUND

SMPC was formed in 1973 as the regional planning agency for the counties of Barry, Branch, Calhoun, Kalamazoo, and St. Joseph. In June 1975, the organization was funded to develop an areawide water quality management plan under Section 208 of the Federal Water Pollution Control Act Amendments of 1972. The region includes two major urbanized areas: the cities of Kalamazoo and Portage with combined populations of about 130,000, and the city of Battle Creek with a population of about 40,000. At present the total population in the region is estimated to be approximately 500,000. Although land use in the region ranges from urban and industrial to rural, agricultural, and recreational, the region is dominated by nonurban land use categories.

The SMPC region forms a part of the lower Lake Michigan drainage basin and contains portions of three major contributing river systems – the Thornapple, Kalamazoo, and St. Joseph. In addition to the major river systems, there are numerous lakes within the region, ranging in size from several acres to several square miles. While most of these lakes are natural or man-made parts of river systems, many are self-contained with no significant tributary flow. Figure 1 illustrates the major river systems and the predominance of lakes throughout the five-county planning area.

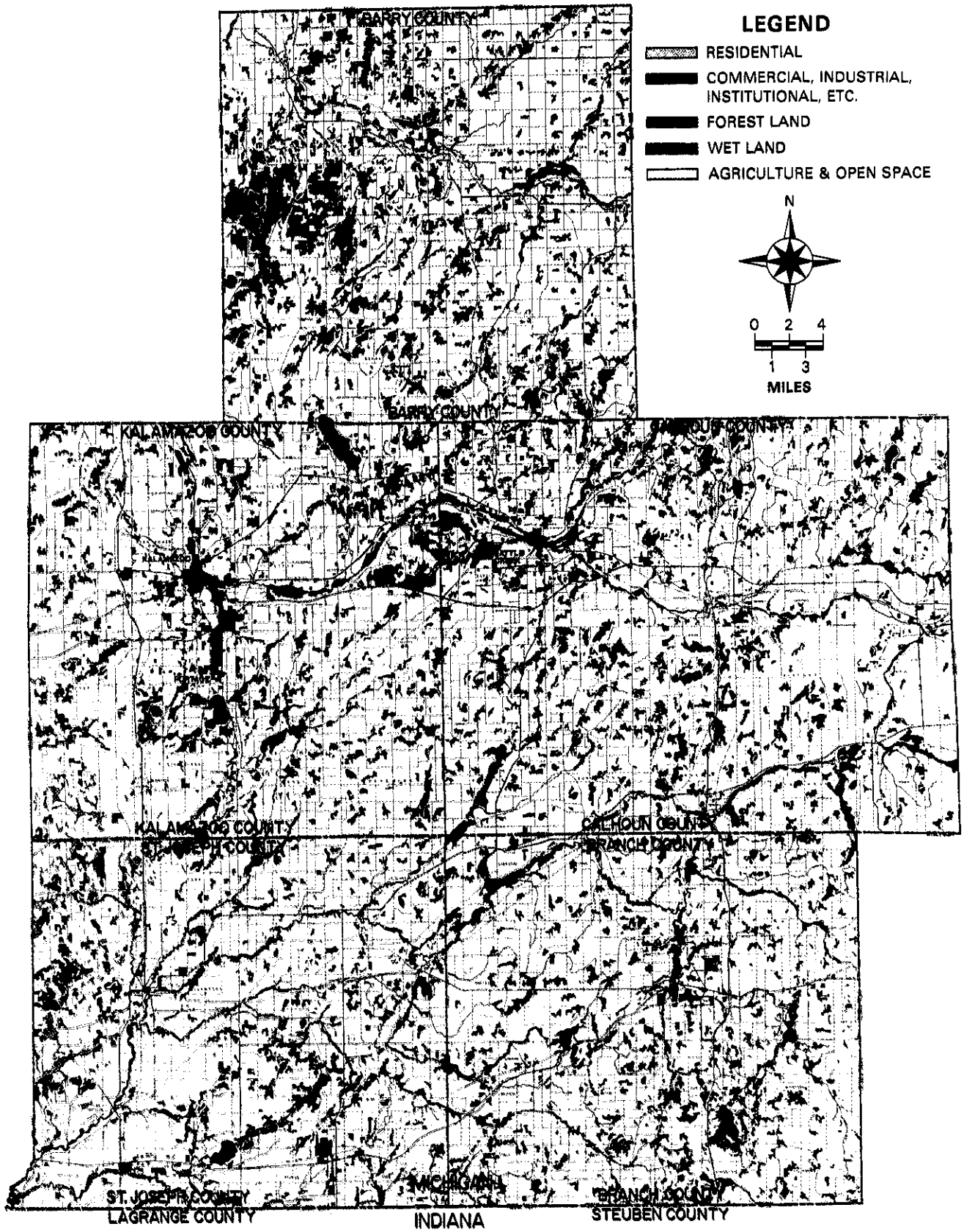


Figure 1. Southcentral Michigan Planning Council 208 Area.

Over the years, a considerable amount of water quality information has been collected on the various river systems as a result of monitoring municipal and industrial wastewater effluents. Monitoring efforts have been intensified in recent years because the data is necessary for ongoing 201 facilities planning studies. In addition, various institutions and private organizations have collected specific, localized, water quality data (primarily biological) from many individual lakes in the region. However, this information has not been comprehensive enough for regional purposes and, with few exceptions, has not identified pollutants from nonpoint sources.

In developing an areawide planning program for the region, SMPC saw the need to focus on those water quality problems believed to be most important by the people of the region. Two basic objectives were identified and addressed. One was the integration of the various ongoing 201 planning studies into a comprehensive plan for point source wastewater management, and the other was a clear-cut assessment of water quality in the region's lakes and a formulation of plans for improving water quality where problems exist. Lakes have posed the biggest unresolved water quality problem in the region. In this area SMPC has developed a unique method for assessing water quality and a tool with which the impact of best management practices (BMPs) applied at the local level can be determined through the monitoring of individual lakes over a period of time.

THE SMPC APPROACH TO ASSESSMENT OF WATER QUALITY IN LAKES

The largest collection of existing water quality information in the region is maintained by the Michigan Department of Natural Resources (DNR). The state has set up a series of permanent monitoring stations which have generated a wide-ranging data base which can be used in overall water quality planning. The monitoring stations are located predominantly on the major river systems. While numerous studies have been undertaken by DNR and other institutional and private agencies on specific lakes in the region, these have not generated data comprehensive enough for areawide application. Consequently, the development of a procedure for assessing general water quality in lakes was necessary in order to identify potential problem areas.

The basic causes of lake water quality problems in the region are residential dedelopment and surface runoff. Recently, homes have been built on the periphery of many of the lakes with recreational potential. The majority of these lake developments are not included in municipal sewerage systems and must therefore rely on subsurface systems for wastewater treatment and disposal. As a result of high groundwater levels, these disposal systems have not always been adequate and many have significantly increased nutrient loadings to some lakes. In addition, runoff from nearby agricultural lands and fertilized residential lawns has increased nutrient levels in many lakes, and stormwater runoff from newly developed and agricultural areas around the lakes has led to increasing sediment loads.

Given the large number of lakes in the region and the time and financial constraints of the SMPC water quality management program, it would have been impossible to sample and generate laboratory data for each lake. It was also felt that water quality sampling data *per se* would not be of substantial benefit in identifying problems and developing potential solutions. While sampling and laboratory analysis would generate specific constituent levels at the sampling point, it would not necessarily depict the overall condition of water quality in various sections of the lakes unless each section was sampled. In addition, the sampling approach would be cost prohibitive on a continuing basis and, therefore, could not be used as an an ongoing method for developing and evaluating the success or failure of local BMPs utilized to upgrade water quality. It became apparent that a system was needed to assess general water quality in a lake, not necessarily through the use of parametric data, but through the use of bio-indices which could lead to the identification of particular problem zones throughout a lake and, ultimately, to potential causes of the problems.

Toward this objective, the SMPC staff and their consultants worked with the Bendix

Company, Aerospace Systems Division, in developing a methodology for identifying different aquatic-biological community types by means of LANDSAT satellite imagery. Multispectral scanners in the satellite detect reflected light from the earth's surface at an altitude of 570 miles. Land and water features exhibit differing light reflectance characteristics and a particular feature will exhibit a particular reflective index. Shallow water, for example, has a reflective index different from deep water or water with emergent vegetation. Some features may have similar reflective indexes and consequently, computer analysis of the satellite imagery is required to separate or categorize the particular features into the desired classifications.

Using multi-spectral analysis techniques, it was possible to interpret the satellite imagery to delineate bodies of water and then separate various aquatic classifications within them. These classifications were categorized (or calibrated) according to known biological communities and available water quality information on specific lakes. Six biotic communities were established as indicators of general water quality in lakes throughout the region. The six bio-indices chosen were interpreted to be indicative of the water quality conditions listed in table 1.

Table 1.—Bio-indices identified using LANDSAT imagery

Water quality category	Explanation
Shallow clear water	Water generally considered to have a low algal, silt and sediment content. The water may be shallow or appear so because of submerged vegetation or some other factor limiting light penetration.
Blue-green algae	Water considered to have blue-green algae concentrations in excess of levels normally found in cold water plankton populations. It generally is an indicator of high nitrate and phosphorus levels and warm water temperature, resulting in eutrophication.
Green algae	Water considered to have green algae concentrations in excess of those normally found in cold water plankton populations. It is an indicator of nutrient rich water containing high phosphorus levels as well as high levels of nitrates. These waters may be somewhat cooler but are, nonetheless, subject to eutrophication.
Emergent vegetation	Water generally dominated by plant life covering much of the surface. It may also indicate organic bottoms or very shallow waters exhibiting such characteristics as algal blooms.
Silt and sediment	Water dominated by high levels of soil particles or organic matter in suspension. Included in this category are suspended benthic materials, heavy detritus, zooplankton having a large percentage of debris and possibly heavy concentrations of bacteria and other non-algal organics. It may be indicative of heavy organic or nutrient loads where conditions are not favorable to algal or plant growth.
Deep clear water	Water not nutrient enriched beyond normal levels for a cold water lake. The waters may be naturally eutrophic, but do not contain heavy concentrations of phytoplankton or zooplankton. This category is an indicator of generally good water quality as based on records and opinions of the Michigan Department of Natural Resources (DNR).

The categories noted in table 1 are the predominant bio-indices in the lakes as determined by computer interpretation of LANDSAT data. Each 1.1-acre area is indicated on the computer output. A water quality profile of the lake is obtained by analyzing the pattern of these features.

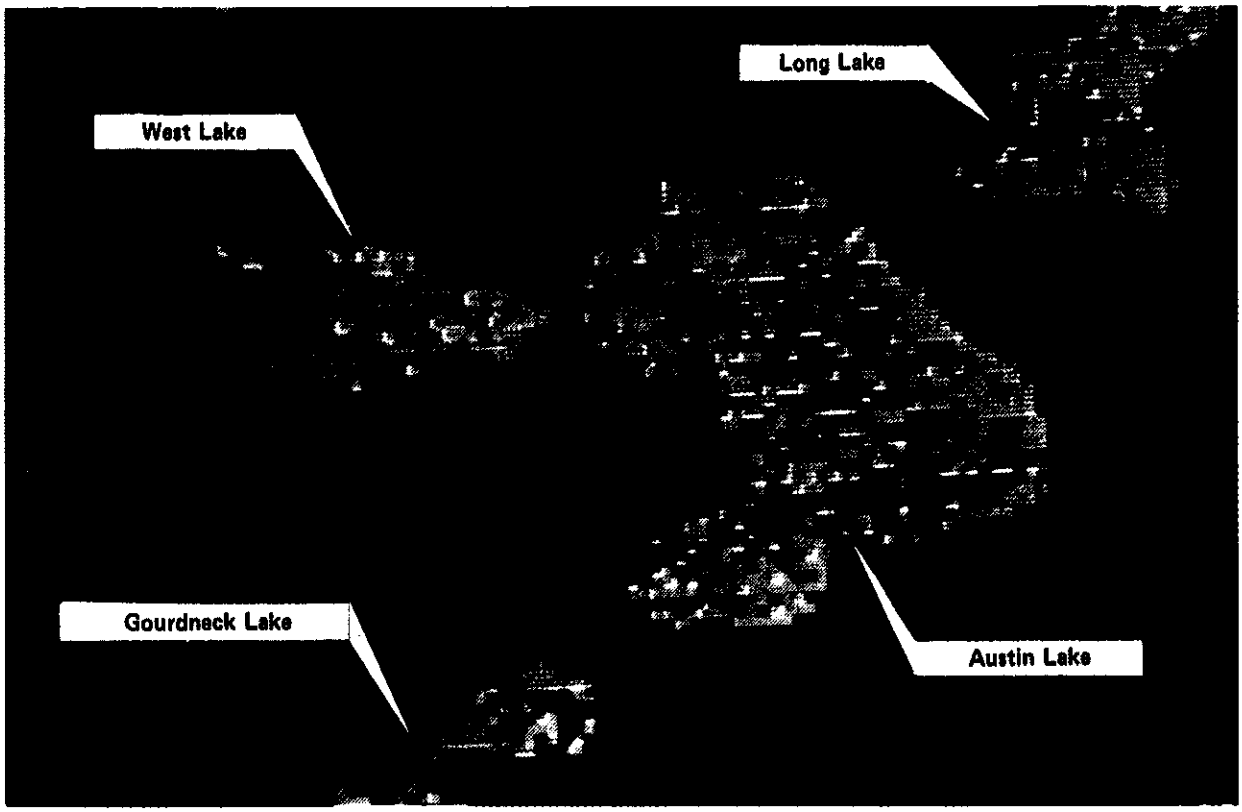
In order that the public become involved in the lake assessment program and become aware of the program's value as a continuing planning tool, the assistance of the SMPC Water Quality Commission's Citizens Advisory Committee was solicited. Twenty lakes of specific interest to members of the committee or of known water quality were used for testing the validity and benefit of the procedure. Color photographs of the computer video display unit, indicating the nature of water quality in these lakes, were prepared and distributed to the local lake associations involved. These lake associations are made up of local residents who have a specific interest in maintaining the integrity of lakes in their area and detailed knowledge of water quality conditions in the lakes. The lake associations were informed of what the photographs depicted and for what use they were intended. They were asked to verify the information shown, based on their knowledge and visual inspection of the lake systems. Replies were received from the lake associations and, for the most part, the water quality information depicted on the color photographs was verified as accurate. Furthermore, acceptance of the program was widespread and its usefulness in identifying potential problem areas was established.

Figure 2 is an example of a LANDSAT-generated color photograph taken from the computer video display unit. Shown in this particular figure are Austin and West Lakes, both of which are located in the SMPC region and serve as contrasting illustrations of the information which can be derived from the water quality assessment program. The colors in the figure indicate bodies of water, with the black background constituting land. Each colored block, as indicated previously, represents an area of approximately 1.1 acres.

Austin Lake appears to be a shallow lake with areas of green and blue-green algae problems, particularly in the northwest, east, and southeast portions. These areas may be associated with inadequate subsurface disposal systems adjacent to the lake. Scattered areas of silt and sediment indicate some potential problem with stormwater drainage discharging into the lake. West Lake contrasts with Austin Lake in that its major water quality problem appears to be silt and sediment. Nutrient loadings to West Lake do not appear to be nearly as high as to Austin Lake, but stormwater runoff from adjacent residential development and nearby agricultural lands is causing significant amounts of sediment to be washed into the lake.

As illustrated in figure 2, the information developed from the program has been directed toward a qualitative comparison of lake water quality throughout the region. The program has not attempted to provide a quantitative analysis of the biological or chemical constituents of a specific lake water. However, the bio-indices identified can be compared on the basis of percent of area classified in each category. The conceptual approach of the program has the limitation of being unable to consider the intensity of localized problems (e.g., relative density of algal populations or relative concentration of silt and sediment). It is able to examine broad problems, however, and is suitable for correlation with existing land use data to aid in the identification of potential causes of those problems. The information can then be used in working with local lake associations and governmental units, such as municipalities and townships, to develop alternative strategies for solving specific water quality problems.

The key to the development of this assessment program was public participation, both for political and financial reasons. Obviously, it took a great deal of work on the part of the SMPC staff and consultants to synthesize existing water quality data for use in calibrating and categorizing computer interpretations of the LANDSAT imagery. However, the role of the public sector (i.e., in verifying results and accepting the program as a beneficial tool) was critical in making the approach effective.



Legend

Color	Water quality category
Light blue	Blue-green algae
Medium blue	Shallow, clear water
Dark blue	Deep, clear water
Green	Green algae
Rust	Emergent vegetation
Yellow	Silt and sediment

Figure 2. Example of LANDSAT-generated color photograph for Austin and West Lakes.

REFINEMENT OF WATER QUALITY INFORMATION

The initial remote sensing work was performed to evaluate the use of satellite imagery for assessing general water quality conditions in lake systems. The categorized imagery also provided a means of obtaining field verification of the information and promoting public participation in the program. However, in order to make use of the information for technical purposes in identifying and solving problems, it became apparent that refinement of the satellite imagery interpretations would be needed. This refinement, which could not be achieved by further use of color photographs, thus introduced a research element into the work effort.

Discussions with the Laboratory for Applications of Remote Sensing (LARS) at Purdue University indicated that potential refinement of the water quality information was a possibility. The LARS system, known as LARSYS, utilizes the same satellite technology and a similar computer interpretation system to that of the system at Bendix. The main difference in the two systems is that LARSYS generates the water quality information in standard computer output form instead of the color photographs produced by the formerly-used Bendix interpretation system. A LARSYS printout provides a line-column designation for each grid in a body of water, thereby allowing surface cross-sectional analyses to be performed and the accuracy of information to be better determined.

An example of a LARSYS printout, featuring ten water quality categories, is shown in figure 3. The lakes are again Austin and West Lakes and are based on the same satellite imagery used in the Bendix interpretation (see figure 2). However, the LARSYS interpretation provides ten water quality categories (within acceptable confidence limits) whereas LANDSAT color analyses had provided only six.

Based on the LARSYS interpretation, Austin Lake shows large areas of submerged vegetation throughout the west, central, and south portions and appears to be severely eutrophic. However, the pockets of blue-green algae are isolated from the submerged vegetation. It appears that the submerged plants may be serving to tie up nutrients, thus limiting algal growth. Isolated areas of organic sediments predominantly due to local drainage can also be seen in Austin Lake. West Lake appears to have heavy organic sediment loads as well as a large number of submerged plants. The problems with this lake appear to be associated with drainage from surrounding bog-type lands which are easily disturbed by development and other human activities.

While the analyses derived from the LARSYS interpretations of the June 1973 satellite imagery are no more significantly detailed than those derived from the Bendix interpretations, LARSYS has the additional capability of being used in conjunction with a mobile, truck-mounted spectrophotometer to increase resolution to an area as small as an 8-inch diameter circle. If the truck-mounted unit is used when the satellite is passing, more detailed information can be obtained within the standard 1.1-acre grid. This information, combined with selective sampling and laboratory analysis, can result in more detailed knowledge of what each category represents and a greater number of water quality categories in future efforts.

Of major concern to the SMPC staff was the cost of providing water quality information on the many lakes throughout the region. A comprehensive sampling and laboratory analysis program would have been cost prohibitive. On the other hand, the initial work at Bendix to evaluate the use of satellite imagery cost approximately $2,000 for an analysis of about 40 lakes. The work at LARS to refine computer interpretations and provide more detailed information regarding relative compositions and concentrations will amount to about $22,000 for the analysis of approximately 300 lakes. It should be emphasized that much of this cost is related to development of a system to provide the specific information desired by SMPC. Once the system is set up, the major costs will be for new tapes of LANDSAT data and for computer time,

Figure 3. Example of LARSYS printout for Austin and West Lakes.

which amounts to about $250 per hour. Representative runs indicate that a LARSYS printout of five lakes can be accomplished in less than ten seconds of computer time. This corresponds to a computer cost of less than one dollar per lake. While the cost of operating the truck-mounted unit must also be included in some cases, it can be seen that the overall approach of using satellite imagery to analyze lake water quality in the SMPC planning area is cost-effective on a continuing basis and was a positive factor in its development.

USE OF WATER QUALITY INFORMATION IN DEVELOPING POINT AND NONPOINT SOURCE CONTROL STRATEGIES

As an areawide planning tool, the remote sensing of lake water quality has been used, in conjunction with storm runoff and stream modeling, to determine the need for BMPs on a sub-basin level. In a sense, areawide BMPs are being defined on a broad conceptual basis, with actual point and nonpoint source control measures being developed and implemented on a local basis. This type of analysis was made possible by the nature of the water quality information generated by LARSYS. Since the drainage areas of many of the lakes constitute major portions of sub-basins, the information generated on water quality can be used in assessing the overall impact of stormwater runoff from those sub-basins.

The most important use of the remote-sensing water quality information as a planning tool is in assessing the impact of changing land use around the lakes. These changes in land use are most prevalent where residential development around the periphery of lakes has accelerated in recent years. In making this assessment, SMPC had planned to compare the original satellite imagery from June 1973 with more recent information to be generated by LARSYS. This more recent information was to be based on satellite imagery taken in June 1976. However, because of weather conditions, it was not possible to obtain suitable LANDSAT data from June 1976 and therefore imagery from July 1976 was utilized. Although SMPC expected that changes in land use during that 3-year period would produce changes in lake quality (based on satellite imagery as well as other ongoing studies in water quality), it is difficult to draw conclusions about actual changes in lake ecosystems on the basis of data taken in two different calendar months.

The LARS water quality information generated to date has been used by sewage treatment facility planning agencies and shows that water quality in the region's lakes has changed in some areas served by septic systems. Although replacement of subsurface disposal systems by sewerage systems may be effective in some cases, SMPC has shown, using the same water quality information, that sewers may not be the answer in all cases and that there are other nonpoint sources of pollution which could result in alternative solutions. The satellite imagery program has been useful in locating areas of the lakes showing the greatest impact.

Several specific, nonpoint source pollution problems have been identified in lakes as a result of the total water quality assessment program. For example, Goquac Lake has been severely impacted by stormwater runoff from surrounding residential development. Gull Lake has been impacted by septic tank discharges and fertilizers from residential lawns. Barton Lake has been impacted by the discharge of treated municipal wastewater. Several other lake systems have been shown to be degraded due to agricultural contributions of silt and nutrients.

By using the lake assessment program to identify current and past water quality conditions and by correlating this information with existing and past land use data, SMPC is able to verify problems caused by inadequate control of land use activities. With this information, it will be possible to suggest controls which might, for example, guide development or impose subdivision regulations in the vicinity of lakes.

The initial areawide plan lists sediment control procedures and other forms of control strategies which can be adopted and implemented locally. Work on model ordinances is now proceeding. SMPC will monitor

land use activities and it hopes to reassess the lakes periodically to provide information either confirming the need for controls or proving that the controls are not effective and other methods need to be considered. The importance of such a continuing program is emphasized by the fact that the majority of townships surrounding lake areas do not now control land use and/or development activities as they relate to water quality. In some areas, SMPC will monitor specific lake systems to determine the impact of proposed sewer facilities which are currently being planned. If it is found that lake water quality is continuing to be degraded after these systems have been constructed, the annual updates will serve as evidence that other control measures, in addition to wastewater collection, are needed.

From the time of initial public participation in verifying water quality information, support of the program has grown significantly. Two lake boards were formed by the Michigan legislature and have the authority to regulate development and assess charges for programs. They are actively involved in planning studies and are investigating the possibility of obtaining federal lake restoration grants using SMPC information to document problems. At least seven other local lake associations, which do not have the authority to regulate or levy assessment, are investigating the possibilities of similar grants through their elected officials. In addition, many other lake associations are actively investigating measures, one of which might be the creation of a lake board, in order to better control related water quality activities.

To date, no specific control strategies have been implemented as a direct result of the water quality assessment program. However, the program has identified general water quality problems, and local water quality priorities have been established. Each sub-basin has been evaluated in detail regarding land use, surface runoff and water quality, and the resulting priorities will be used in establishing specific local control programs. The public has been kept informed about the water quality assessment study, verified its accuracy and have become aware of its benefit to them on the local level. SMPC is now laying the political groundwork for establishing some of the controls that they and local goverments will ultimately need in order to implement the areawide wastewater management plan.

U.S. ENVIRONMENTAL PROTECTION AGENCY
★ ENVIRONMENTAL RESEARCH INFORMATION CENTER • TECHNOLOGY TRANSFER
★ OFFICE OF WATER PLANNING AND STANDARDS • WATER PLANNING DIVISION