E7.6-10.0.58.
CR-145750

A Progress Report To

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Office of University Affairs
Washington, D.C. 20546

(E76-10058) ON MULTIDISCIPLINARY RESEARCH ON THE APPLICATION OF REMOTE SENSING TO WATER RESOURCES PROBLEMS Progress Report, 1974 - 1975 (Wisconsin Univ.) 154 p HC $6.75 CSCL 08H G3/43

N76-13545

Unclas 00058

On Multidisciplinary Research On The Application of Remote Sensing To Water Resources Problems

Research Funded Under Grant #NGL 50-002-127

1974-1975

from

James L. Clapp, Project Leader

Institute for Environmental Studies
The University of Wisconsin
Madison, Wisconsin 53706

TABLE OF CONTENTS

I. INTRODUCTION

This is a progress report on NASA's Office of University Affairs grant to the University of Wisconsin for Multidisciplinary Research on the Application of Remote Sensing to Water Resources Problems. During the 1974-75 period the project was fundamentally directed towards the application of the knowledge gained from past research efforts to operational water resource monitoring problems confronting the State of Wisconsin. More specifically this program focused upon:

(1) providing the Wisconsin Department of Natural Resources (DNR) with a first level classification of eutrophication of the lakes of Wisconsin; investigating methods by which this classification system may be further refined; and determining the most cost effective system by which DNR might obtain a complete eutrophication classification;

(2) providing data on the shape and size of effluent mixing zones of concern to the DNR; providing them with tested plans for operational monitoring of the mixing zones together with cost/benefit analyses of their effectiveness; developing phenomenological mixing zone models, relating plume size to plant load, river flow, wind and other factors using observed quantities only; and investigating the development of mechanistic models of mixing zones based upon rational numerical models;

(3) demonstrating the effectiveness of remote sensing in the determination of hydrologically active source areas and developing the significance of these areas in effective water quality management for diffuse contaminant sources.

This program is significantly related to other programs at the University of Wisconsin-Madison as well as other state and federal agencies. Included in these are the Water Resources Center of the University of Wisconsin, the Lake Wingra Program of the International Biological Program funded by the National Science Foundation, the Marine Studies Center, and the Center for Biotic Systems of the Institute for Environmental Studies, the ERTS-1 Program formerly funded by NASA and the State of Wisconsin Department of Natural Resources. We gratefully acknowledge the cooperation and support of these organizations.

II. CLASSIFICATION OF EUTROPHICATION LEVEL OF FRESH WATER LAKES

Principal Investigators

Michael S. Adams, Associate Professor, Department of Botany

Frank L. Scarpace, Assistant Professor, Department of Civil and Environmental Engineering, and Institute for Environmental Studies

James P. Scherz, Associate Professor, Department of Civil and Environmental Engineering

F. H. Schraufnagel, Chief, Bureau of Standards and Surveys, Department of Natural Resources

William J. Woelkerling, Assistant Professor, Department of Botany

Other Investigators

Lawrence T. Fisher, Assistant Professor, Department of Electrical and Computer Engineering

Research Assistants

Douglas Crane, Department of Civil and Environmental Engineering

William Johnson, Department of Civil and Environmental Engineering

Other Personnel

John VanDomelen, Visiting Associate Professor, Department of Civil and Environmental Engineering

ABSTRACT

The classification of eutrophication level of fresh water lakes has involved studies of water quality measurements, the detection of planktonic algae, the measurement of macrophyte vegetation, and the use of these data in developing large scale remote sensing based classification schemes for lakes which can be utilized by agencies such as the Wisconsin Department of Natural Resources. Based on data obtained during the funding period, results indicate that changes occur both seasonally and at shorter intervals in water appearance. Tannin containing waters, algae, and turbidity can all be measured by remote sensing techniques and each can be quantified and distinguished from the others. The role of bottom effects has yet to be fully assessed. Algal studies have suggested that a 70mm format offers distinct advantages for aerial photography over the 35mm format. Data from ground samples currently is being analyzed to determine how accurate quantitative estimates of algal biomass are when made from aerial photographs. Monitoring of macrophytes continues in Lake Wingra and attempts are being made to correlate imagery taken at 60,000 ft. to aquatic vegetation cover and lake classification. Satellite data from a considerable number of Wisconsin lakes is being examined by interactive computer analysis and shows promise of application on a large scale by agencies such as the Wisconsin DNR. Data obtained from all aspects of the eutrophication study will be incorporated into a "User Manual" which will be prepared in the coming year.

A. Introduction and Background

In this subproject investigations which were presented in our 1973-74 proposal under the titles "Application of Remote Sensing to the Determination of Water Quality" and "Application of Remote Sensing to Aquatic Ecosystems Analysis" had been focused on a single problem. Two factors have led to this focus. First, the State of Wisconsin Department of Natural Resources under a directive from the Environmental Protection Agency (EPA) is confronted with the monitoring problem of classifying some 10,000 lakes according to level of eutrophication. Second, remote sensing investigations which have been under study for some five years have matured to the point where the application of the knowledge acquired to operational problems now appeared possible. It was proposed to apply the knowledge gained from the past research to a first level eutrophication classification of the lakes in Wisconsin; to continue the research effort directed toward a more refined classification; and to determine the optimum cost-effective system for classification.

These investigations are now well advanced, and it is the intent of all personnel connected to pool their results and prepare a manual on Eutrophication Assessment and Remote Sensing in the coming months. This Progress Report addresses the following topics (Principal Investigator listed in parenthesis):

(1) Water Quality Measurements (J.P. Scherz)

(2) Algae Detection (W.J. Woelkerling)

(3) Aquatic Vegetation Detection (M.S. Adams)

(4) Involvement with Wisconsin Department of Natural Resources (F.L. Scarpace)

B. Water Quality Measurements

1. Calibration of ERTS (LANDSAT) Data

a) Analysis of Samples Taken in Summer 1974

During the summer of 1974 at every LANDSAT overflight between early June and October, the sky conditions were such that the Madison area lakes could be seen on the LANDSAT images. On these overpasses, water samples were collected either with the float plane or by using canoes or rubber rafts. Secchi disc readings were taken and, where the float plane was used, low altitude photos of the water were also taken.

The water samples were analyzed for lab reflectance properties and were sent to the Wisconsin DNR for analysis of solids and turbidity. Data compilation is still in progress but so far the following conclusions can be made:

1) There is a tremendous change in the algae content in lakes between spring thaw and fall freeze-up. An individual eutrophic lake can go from a clear water lake to a very algal lake and back to a clear water lake. Late August appears to be the time of maximum algal growth in such lakes and the best time for eutrophic classification of all lakes (see Fig. 1). An oligotrophic lake will not show the reflectance fluctuation shown for an eutrophic lake.

2) There appears to be a universal relationship between laboratory reflectance and turbidity for all the lakes sampled which follows the equation: $T = 5.21(AP)^{2.00}$, where T = Turbidity and AP = Apparent Laboratory Reflectance (using a $BaSO_4$ reflection panel with reflectance of 39%)(see Fig. 2). Most of the spread data on Fig. 2 is due to different types of water reflecting differently at various wavelengths. Tannin waters, for example, lie on the lower part of the curve due to energy absorbtion characteristics of tannin.

3) If lab reflectance of distilled water is subtracted from the lab reflectance of other waters, the difference D_i is due only to the material added to the pure water of the other samples. Plots of D_i versus wavelength (Figs. 3 and 4) indicate very closely the type of material in the water and the concentration. Tannin lakes and green versus blue-green algae are easily discerned as well as the concentration of algae.

b) Physical Relationship Model and Bridging Between Laboratory and Satellite

From efforts by Scherz, Van Domelen and Crane, and with the use of the Bendix Radiance Precise Measuring Instrument (RPMI) and advice from Bendix personnel, it has been possible to develop and test the physical model that ties laboratory, boat level, and airborne reflectance values together.

From such an understanding it is possible to determine atmospheric and surface effects and to subtract them to create the satellite residual values R_i which, like the laboratory difference D_i values, are dependent only on the material within clear water. Satellite residual values for clear water and tannin water with various amounts of material added to them are shown in Figs. 5, 6 and 7. These satellite residual curves are essentially the same shape as the laboratory difference curves for the same type water. One will note on Figs. 5, 6 and 7 that characteristic differences between curves are often less than a full satellite sensor count on the y-axis. Also it must be pointed out that these curves were obtained with the Bendix Multispectral Data Analysis System (M-DAS) equipment and each full count on the y-axis is 1/4 of a full satellite signal. Therefore, significant differences between curves are less than 1/4 of a full satellite count. Such accuracy is due to the sophisticated statistical refinement of the M-DAS analysis equipment and the techniques used.

c) Bottom Effects

Figs. 8, 9 and 10 show satellite residual R_i versus wavelength curves for various lakes where bottoms are evidently showing through. The heavy weeds in Buffalo Lake (Fig. 10) cause it to be very eutrophic yet the water is as free from algae as if it were an oligotrophic lake (Fig. 4). These weeds and bottom effects must be properly handled. Weeds on the bottom of a lake are as important an indication of eutrophic conditions as heavy algae within the water. For further study of the bottom effects, aerial photos must be taken to ascertain how much of what bottom material is where in the lake. Then satellite images can also be analyzed to determine the spectral signature for various types of bottoms and weeds. Such photos as yet are not available for analysis.

2. Supporting Projects

a) Waste Treatment Plants

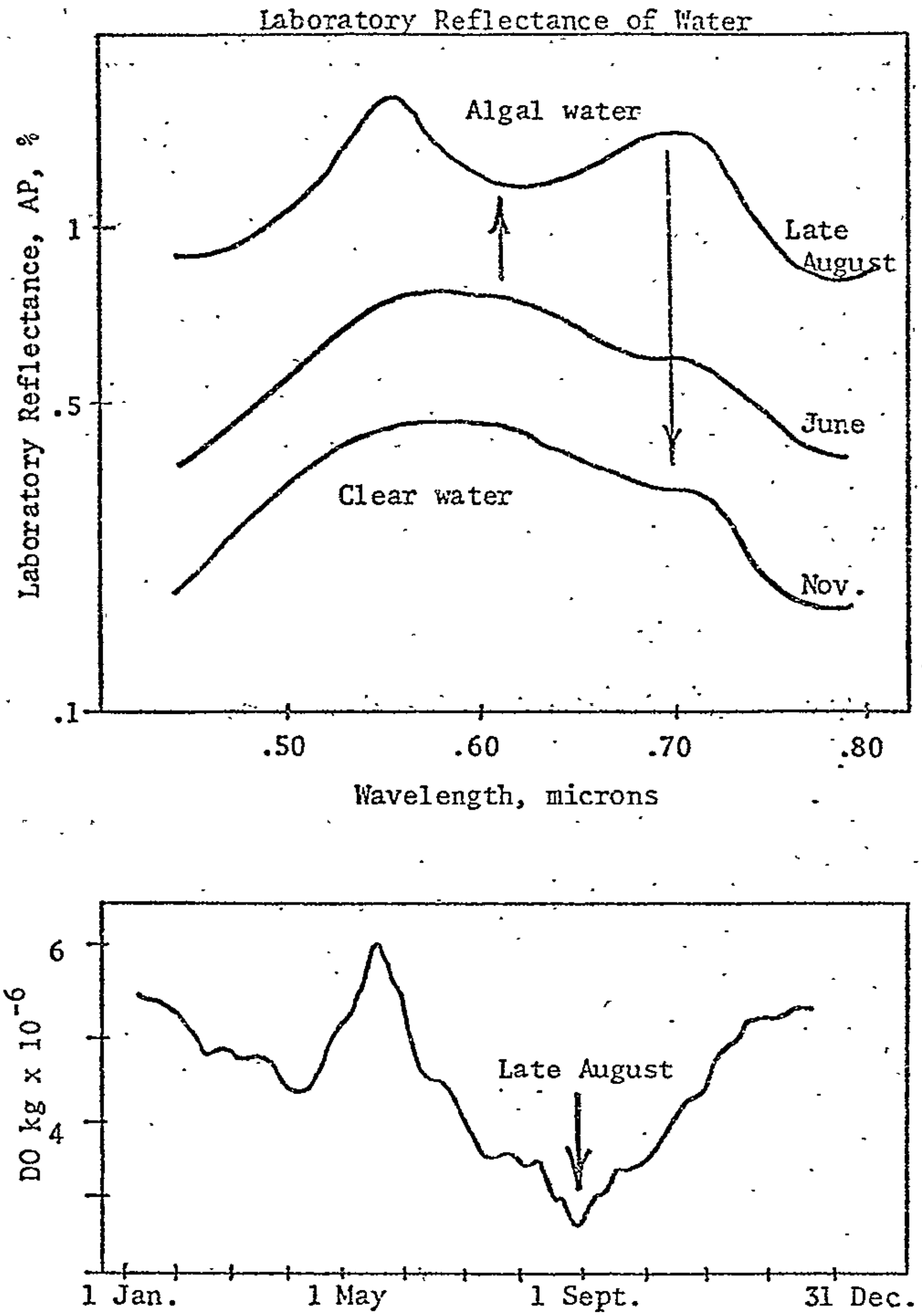
In early spring, reconnaissance flights outlined waste treatment plants on the Wisconsin River which we desired photographed. In August, photos were taken but are not yet available for study.

b) Atmospheric Variability

Fig. 11 shows satellite signals (% maximum) versus turbidity in Madison area lakes for two days in August. It is obvious from the curves that the height of the curve changes from day to day and that no universal curve of satellite data values versus turbidity can be used for all days without taking atmospheric effects into account.

3. Cost-Effectiveness of Remote Sensing Lake Classification

To date, some lakes have been analyzed using the interactive graphics data display and accessing program described in Section III-E. It appeared from such analysis that the signal differences between tannin and non-tannin lakes might not be large enough for differentiation. The knowledge gained in this method was used in testing the more refined statistical analysis schemes of the Bendix M-DAS system which produced the data in Figs. 5 through 10. Two color-categorized test images were also produced by Bendix. These images must be field checked for accuracy determination but already it is clear that where bottom effects show, aerial photos may be needed of such lakes. A remote sensing classification scheme must be balanced with both satellite and airplane data. As yet adequate aerial photos have not been available of bottom lakes to allow us to make final decisions concerning the optimum satellite-airplane system and therefore a complete cost analysis.



DO = Dissolved oxygen

Figure 1. Time of year effect on Laboratory Reflectance of Lake Mendota. Maximum Reflectance occurs at the same time as minimum dissolved oxygen, in late August.

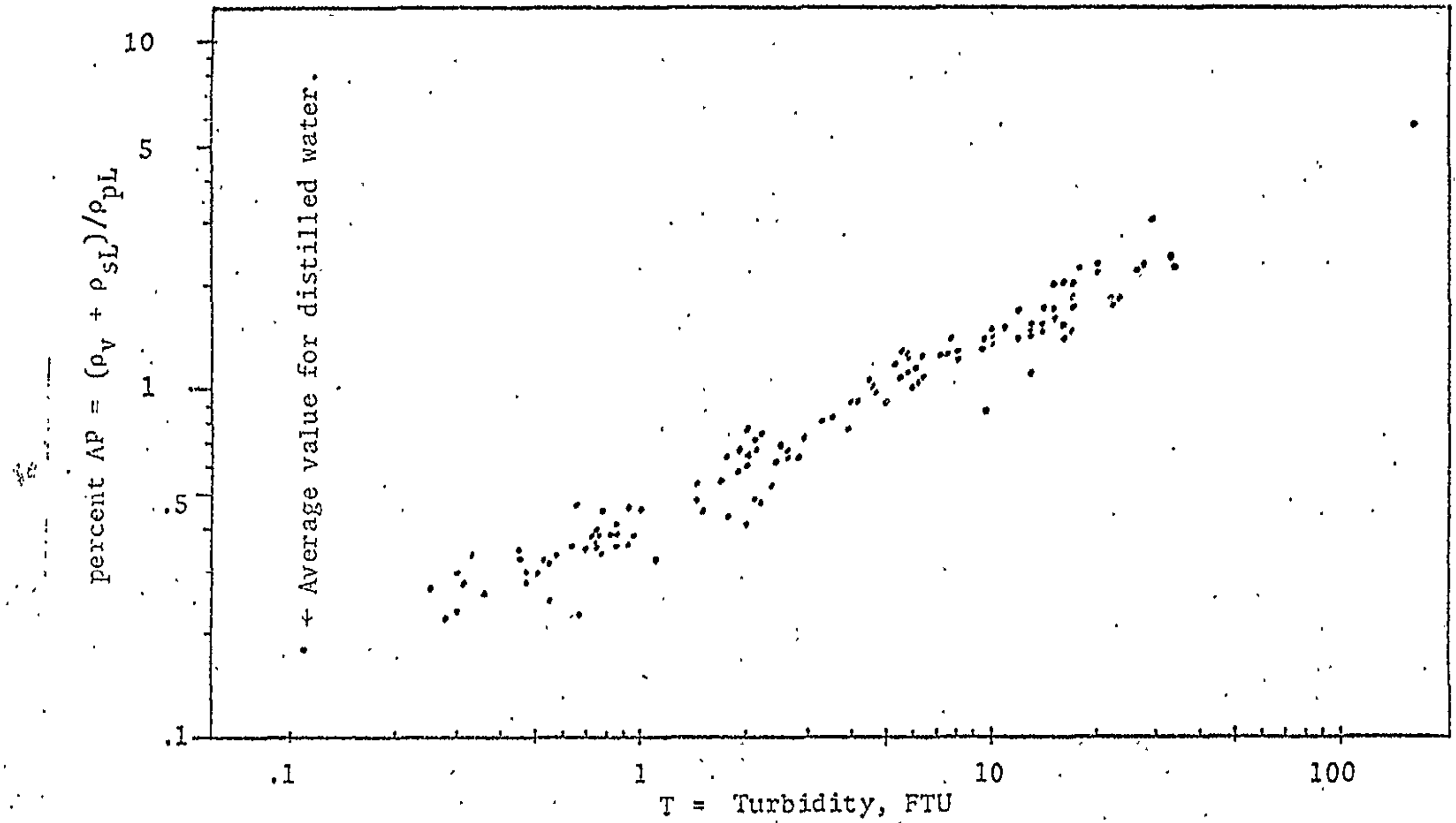


Figure 2. Laboratory backscatter expressed as apparent laboratory reflectance, AP, plotted against turbidity for 127 different lake samples collected over three years. This curve is for red light (0.65 microns). The best fit equation for this data is $T = 5.21(AP)^{2.00}$

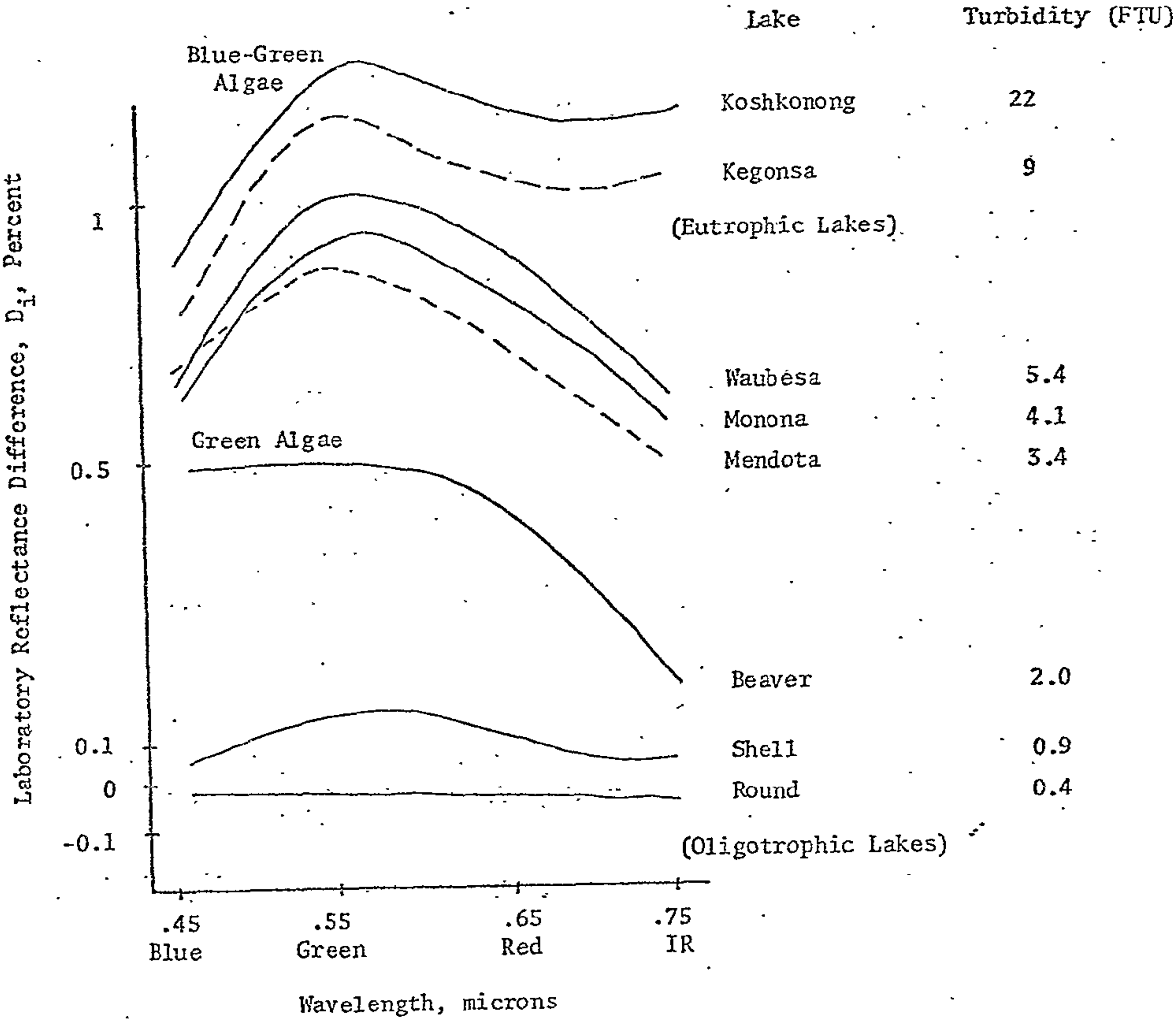


Figure 3. Laboratory Reflectance Difference Curves (D_i) for clear-water type lakes with various amounts and types of algae present.

$$D_i = (\rho_{vi} - \rho_{vl}) \div \rho_{PL}$$

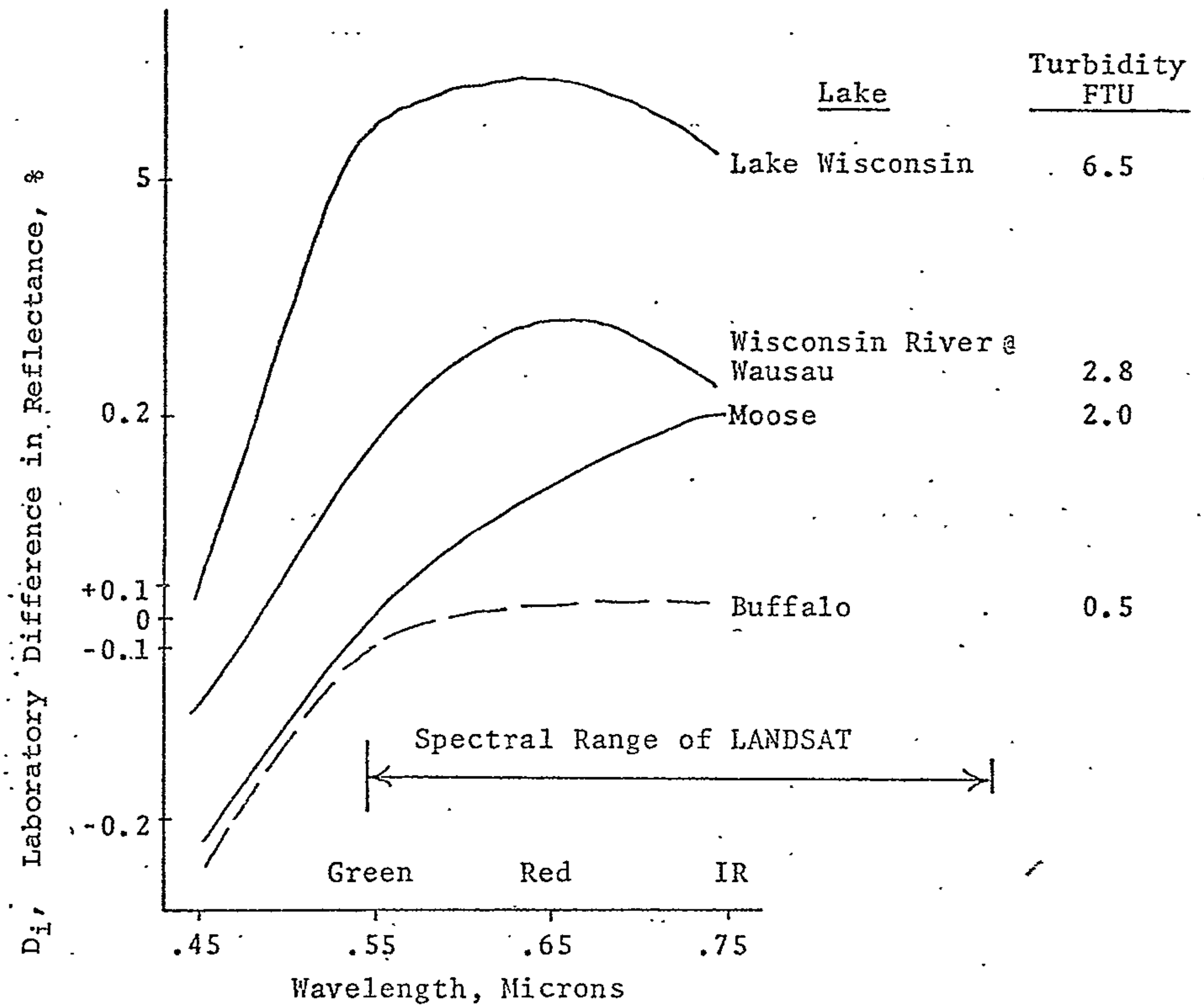


Figure 4. Laboratory Reflectance Difference Curves (D_i) for tannin water lakes.

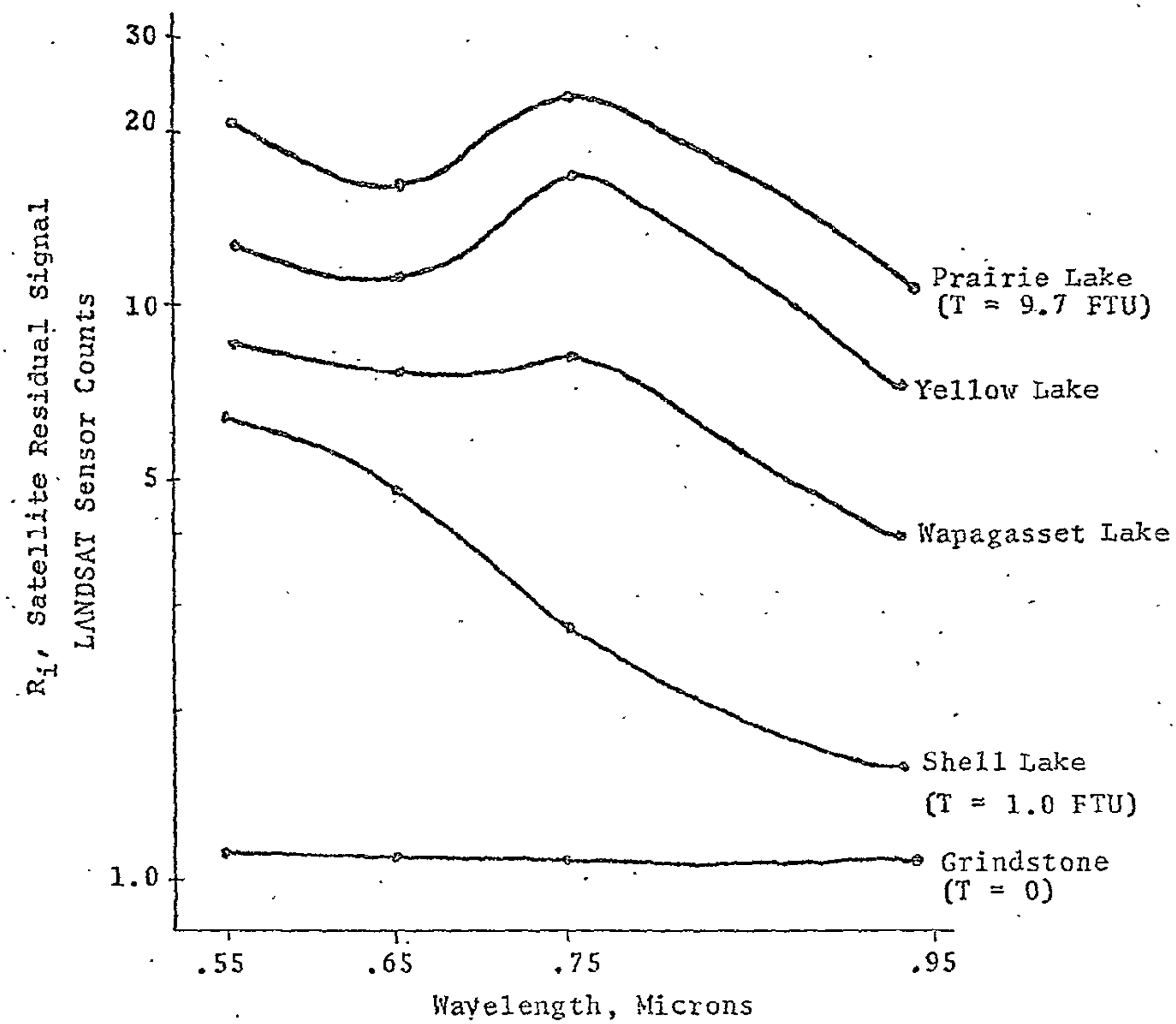


Figure 5. Satellite Residual Spectral Signatures for Non-tannin Type Lakes (Clear Water Type) Containing Various Amounts of Algal. (Residual Reflectance = Signal from Target Lake Minus Signal from Very Clear Lake). T = Turbidity.

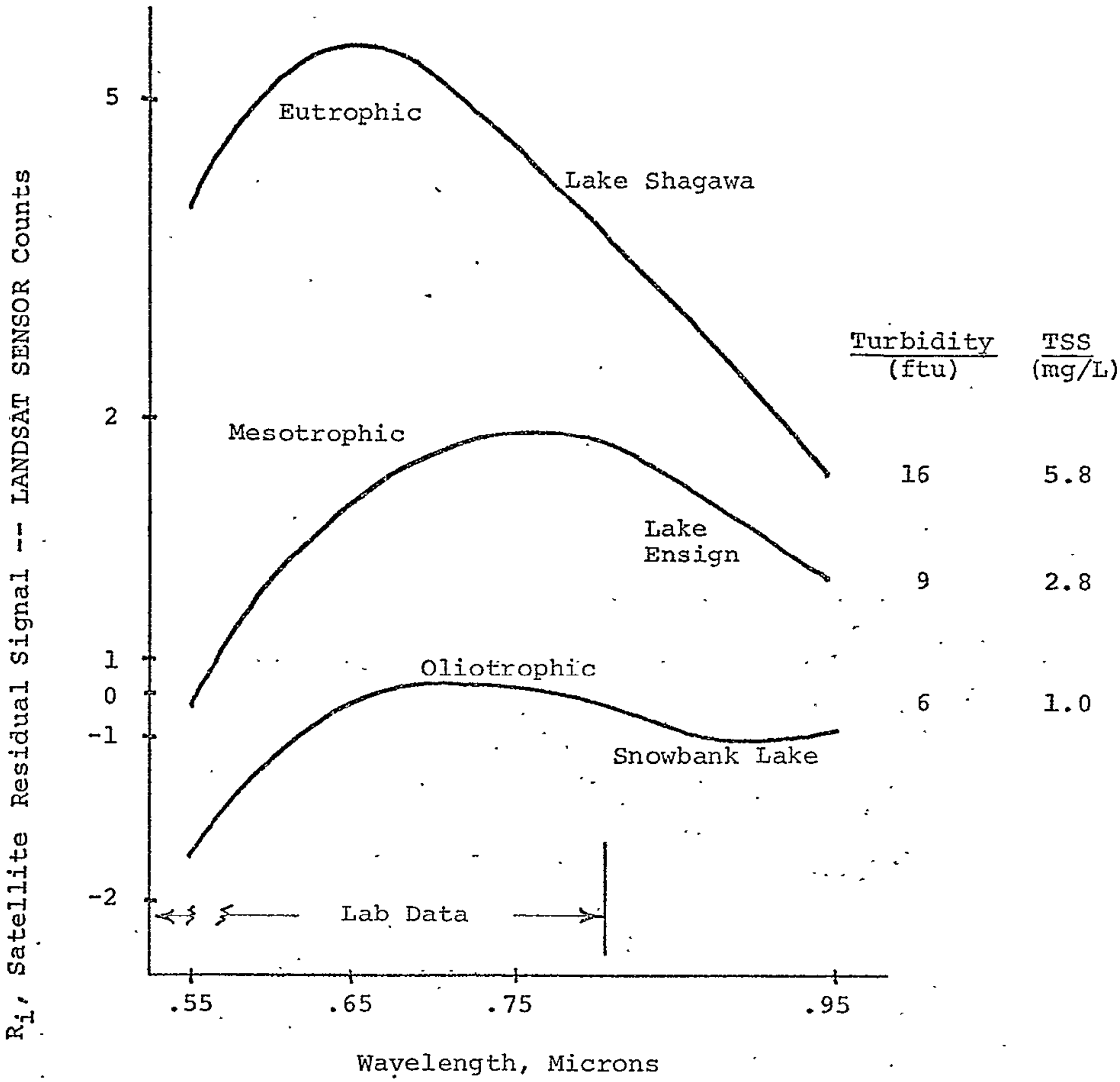


Figure 6. Satellite Signatures from Three Lakes near Ely, Minnesota.
Shagawa = Eutrophic, Ensign = Mesotrophic, Snowbank = Oliotrophic.

TSS = Total Suspended Solids

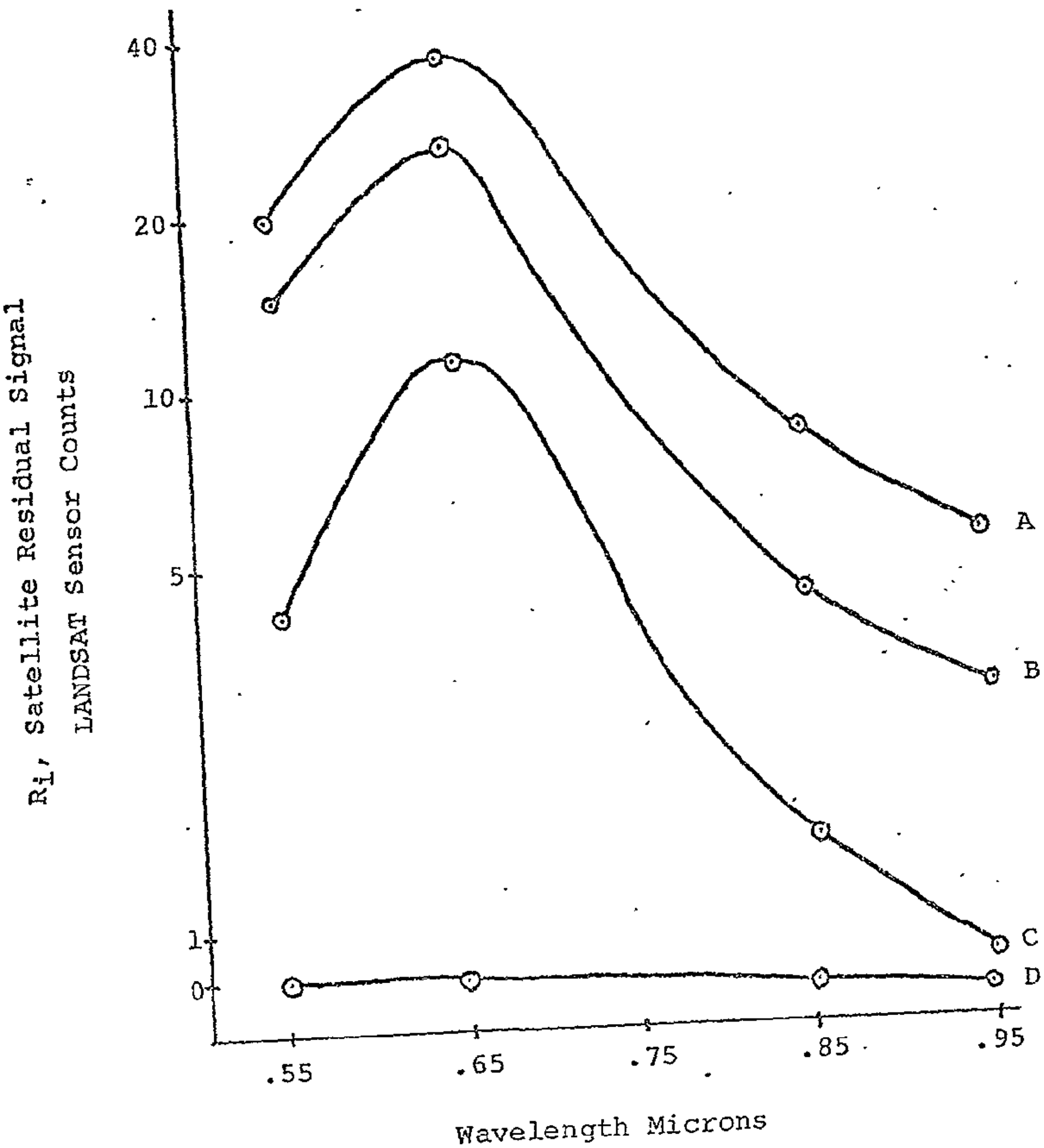


Figure 7. Effect of Red Clay in Clear Lake Superior Water.

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

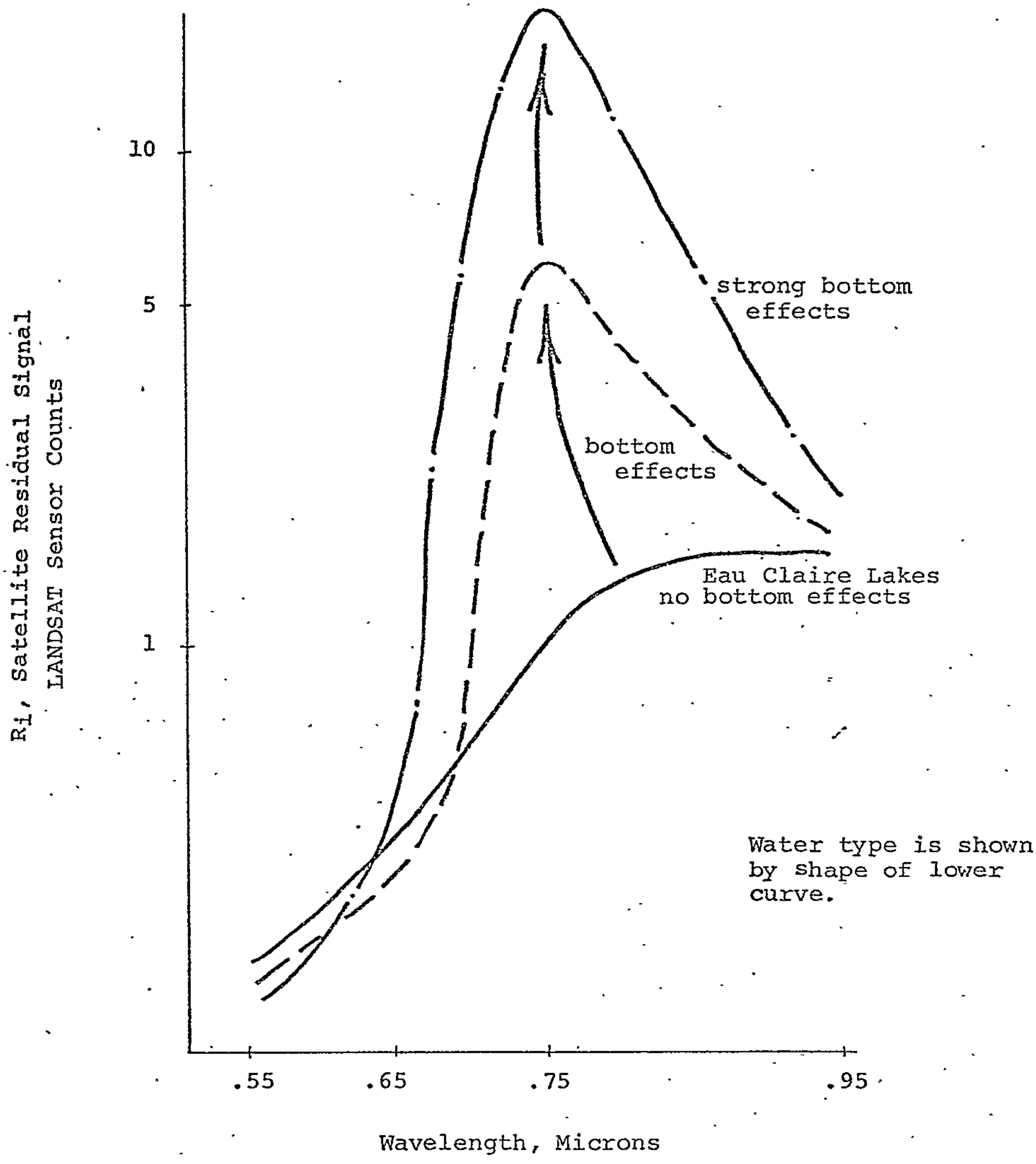


Figure 8. Effects of Sand Bottom on Signal from a Clear Type Lake with Very Slight Tannin Content.

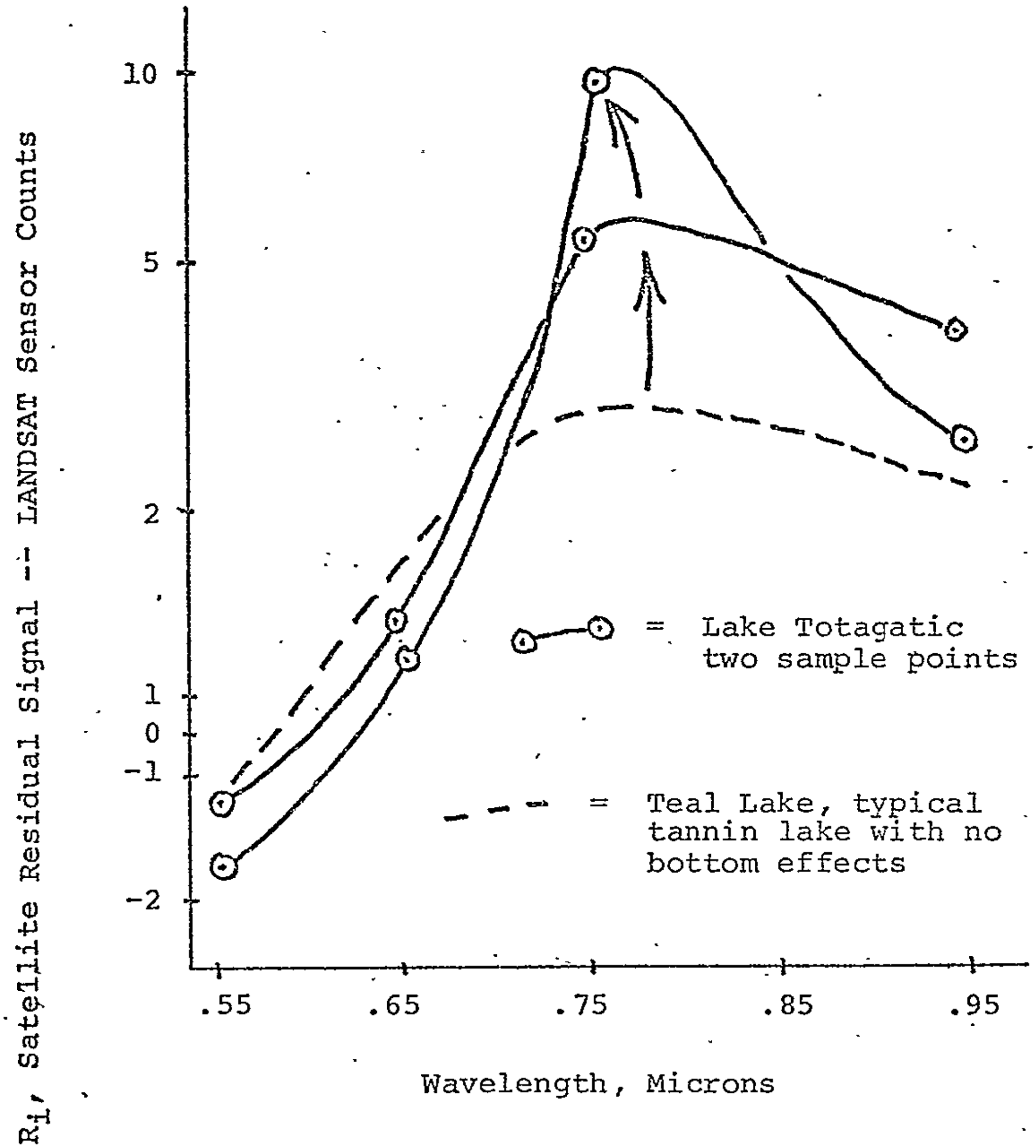


Figure 9. Effects of Mud Bottom and Wild Rice Plants on Satellite Signal from Shallow Tannin Lake Whose Bottom was Entirely Visible During a Reconnaissance Flight.

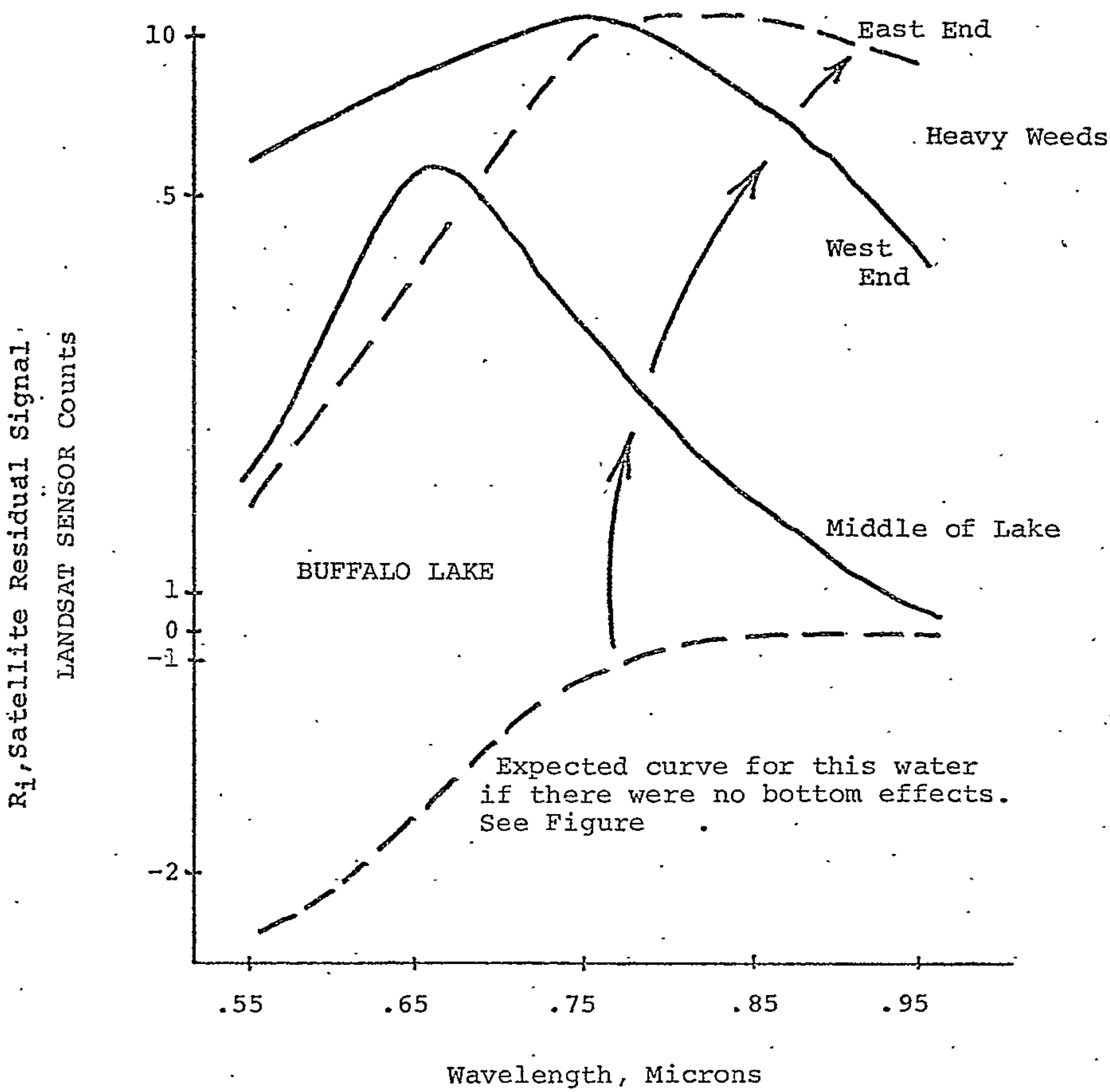
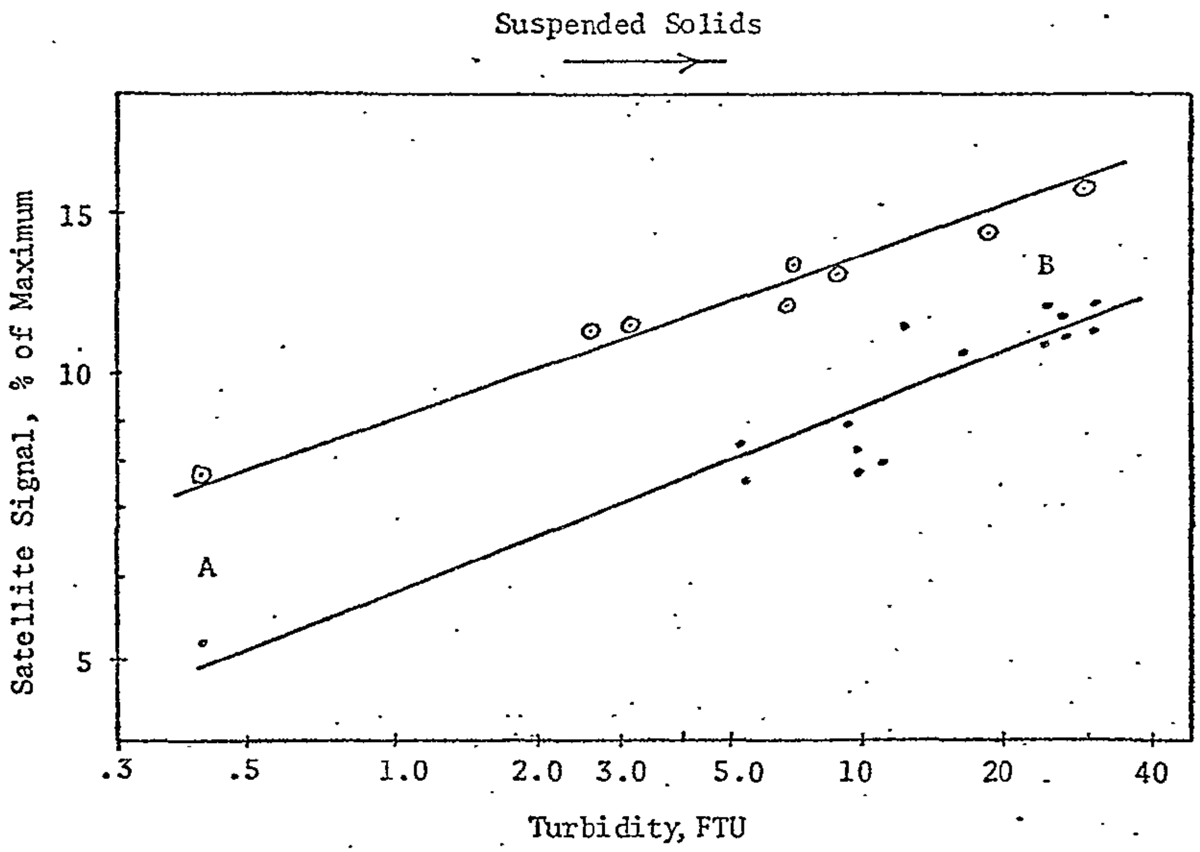


Figure 10. Effect of Shallow Mud Bottom and Heavy Weed Growth on the Expected Signal from a Non-Turbid Tannin Lake. Although the water is low in turbidity (T = 0.5, Figure 5) and free of algae, this is an eutrophic type lake because the nutrients are tied up in the lake weeds .



• = 28 August 1972 ⊙ = 5 August 1973

A = Devil's Lake (clear, oligotrophic lake)

B = Lake Kegonsa (algae filled and eutrophic)

Figure 11 -- Strength of Backscatter Signal Received by Band 5 of ERTS (LANDSAT). Madison Area Lakes. Note shift in height of curve for different days due to atmospheric change.

C. Algae Detection

1. Recording of Narrow Band Reflectance Measurements and Algal Biomass Detection

During the summer of 1974, color infrared and black-and-white narrow band imagery was obtained for three sites on Lake Mendota, Madison, Wisconsin. Five separate flights provided fifteen sets of imagery for regression onto ground truth. Integrated samples from the mixed layer of algae were collected and analyzed for dry weight, a measure of turbidity. Samples were preserved for organic carbon analysis, another measure of turbidity due to organic matter. Difficulties in processing the high speed black-and-white film (Kodak 2475) in the 35mm format slowed any possible data analysis. A rather crude hand processing technique was finally worked up and the film was developed. The sampling sites and the lighting standards on the film have been densitized. A regression between algal biomass and film density is presently in process. Preliminary work during the past year on developing regressions with color infrared film suggested that black-and-white narrow band imagery will be better suited for this application.

Statistical estimation of surface algal concentration by the use of a stratified random sampling design was also attempted twice during the summer of 1974. Both sites were located on Lake Mendota. A sampling axis was constructed perpendicular to a wind-driven gradient of blue-green algal surface concentration. Sampling in a random fashion took place parallel to the algal gradient. Color infrared and narrow band black-and-white imagery were taken simultaneously with sampling. Imagery is now being densitized to develop correlations between blue-green algal surface biomass and film density.

During the summer of 1975, a better system for the narrow band imaging of suspended algae was developed. With the acquisition of two motorized Hasselblad cameras, the shift was made to the 70mm film format. Film development with the 70mm format is quicker and under stricter quality control. The first set of imagery produced this year appears much clearer, more uniform, and more sharply detailed. The shutter system in the previously used 35mm Nikon cameras did not allow for uniform exposure of the film. The optics (Zeiss) in the Hasselblad system are also of higher quality. Band widths of the narrow band filters were doubled. Doubling the band width increases the available light exposing the film to the point of permitting imaging capabilities under cloud cover. The former system (Nikon with narrower width filters) could only function under sunny conditions. Given the ability to account for different atmospheric conditions, the newly-developed Hasselblad system has much more potential for use in a practical lake classification scheme.

Work during the summer of 1975 also has been concentrating on defining capabilities for discriminating differences between algal and non-algal turbidity. Other workers in the Lake Eutrophication sub-project have predicted good correlation between turbidity and narrow band film density using a band centered at 650 nanometers (nm). Work of the Lake Eutrophication sub-project has also indicated that the maximum potential for low altitude, narrow band film density correlation with algal biomass should be made with a band centered at 550 nm. Ground truth collection has been modified to focus on differences between algal and non-algal turbidity.

2. Data Analysis and Statistical Verification

Direct measurements of upwelling narrow band light on a variety of Wisconsin lakes is being made with a Lambda Instruments quantum sensor. The sensor has been modified to accommodate the same narrow band filters used in the Hasselblad photographic system. Light backscattered from the layer of algae in the lakes is being measured with each available narrow band filter (550 nm, 625 nm, 650 nm, and 670 nm). Readings are standardized by a similar measurement of light incident upon the lake. Samples are taken at one meter intervals down to the Secchi disc depth. The Secchi disc depth was chosen because it has been proven by Lake Eutrophication sub-group members to be the maximum depth for photographic penetration (i.e., light penetration) and return to the surface. Samples are then integrated by mixing the depth profile of samples in equal proportions to provide a single sample for analysis. Integrated samples are being analyzed for turbidity by dry weight determinations. Specific algal biomass is being measured by total cell volume analysis.

Low altitude photography (1,000 feet) is also being conducted in conjunction with ground truth measurement. Both surface and integrated samples are being analyzed for turbidity by dry weight determinations. Specific algal biomass during overflight sampling will be assessed by chlorophyll and total cell volume analysis. Surface versus integrated sample comparisons will yield information concerning the ability of the sensor to penetrate the water column. Fifteen sampling sites in ten different Wisconsin lakes are being used for this analysis to discriminate between algal and non-algal turbidity. Comparison of relationships between direct upwelling light and photographically-imaged upwelling light should provide an indication of any atmospheric interference.

In addition, a pattern analysis will be conducted on Lake Mendota. Pattern analysis involves sampling a linear transect at regular intervals. The transect is established in a manner similar to that of the stratified random sampling design transect. A total of 128 surface samples will be taken at half-meter intervals along the linear transect. Pattern of suspended material is related to film pattern by analyzing covariance between the two patterns. Ground truth will be in the form of dry weight (total turbidity measure) and total cell volume (algal biomass measure). Covariance between film density and turbidity/biomass will provide a statistical relationship between film density and turbidity/biomass. The statistical relationship will be in the form of a correlation coefficient between film density and algal biomass and/or turbidity. Hopefully, the statistical relationship gained through pattern analysis will be significant and generalizable to the regression derived from data taken at the 10 lakes sampled throughout Wisconsin.

For purposes of lake classification, a relationship between algal biomass and film density must eventually be generalized to a large group of lakes. Work during the summer of 1974 may provide a regression of algal biomass on film density for a single lake situation. However, to develop an input to a lake classification model, this single lake case must be generalized. Work during the summer of 1975 involved the sampling of different lakes in an attempt to provide a general algal biomass quantification model. Analysis of all data collected during 1974 and 1975 hopefully will be completed within the next 9 months. At that time, we expect to be able to assess the worth of narrow band imagery for use in algal quantification and consequent lake classification.

D. Aquatic Vegetation Detection

1. Remote Sensing of Vegetation

a) Continued Monitoring of Lake Wingra

Flights and corresponding fieldwork for this year's research have not progressed as far as anticipated because of several complications. First, an aircraft with open vertical photographic capability was required but could not be obtained until the first week of July. Second, weather problems (wind and cloud cover) have interfered with photography. Third, a delay in getting the first films processed and analyzed occurred due to mail problems, resulting in loss of flight time. We needed results of first test flight before scheduling further flights.

Since photography was not obtained until late July, a complex record of the growing season of the littoral zone was not obtained. Complete coverage of the lake was obtained on two dates: 31 July and 11 August. Plans were made for further photography in late August and mid-September.

Vegetation trends were recorded through sketches on a base map.

b) Correlation of Changes in Photographic Imagery With Changes in Vegetation

As mentioned before, a complete record of the growing season was not obtained for Lake Wingra. Imagery which has been obtained this summer, and from previous seasons, has been examined to check that exposure is correct and that coverage is complete. However, since the main thrust of energy has been towards preparation for flights and collection of ground data, analysis of film has not been done. When flights have been completed, the imagery will be correlated to the ground truth and interpretations made during the winter 1975-76.

2. Lake Classification Scheme - Littoral Zone Vegetation

a) Use of Color IR Film in Low Altitude Photography to Quantify Littoral Zone Vegetation in Terms of Biomass, Plant Density and Cover

Most of this season's fieldwork has been directed towards this project since it requires extensive ground preparation and data gathering. Five flights have been flown and respective ground truth collected as follows: two of University Bay (Lake Mendota), three of Lake Wingra, and one of Lake Como in southern Wisconsin.

Basic film analysis was done on the imagery from the first flight to determine correct exposure range. Several interesting facts were obtained:

1) A range of exposures is needed because of the range of vegetation types studied. Because of their high reflectance, floating-leaved plants such as water lilies and emergents such as cattails must be photographed at short exposure times to insure that the dye layers are not removed. Dense beds of _Myriophyllum spicatum_ at the water

surface also require short exposure. However, moderate to sparse beds at the surface and submerged beds require a higher exposure time. This characteristic of the littoral zone vegetation makes it imperative to have a "bracketted" series of exposure settings. This, of course, also ensures that the best exposure is obtained for any one site.

2) Panels used as standards must be fairly large--4 ft. x 4 ft.--to allow several density readings to be taken. Two colors of panels, dark gray and a lighter gray, are used to insure that the standard panels will fall on the linear portion of the D log E curve.

3) Earlier work resulting from Gustafson's thesis demonstrated that in Lake Wingra, corrected film densities (ratio of "open water" film densities to "macrophyte community" film densities) could be regressed against standing crop of plants (milfoil) in the water, or against plant stem density, with good correlation. Work to date this year has shown that some difficulties will arise if this technique is applied to a variety of lake classes in which phytoplankton community composition (species, numbers of organisms, and biomass) differ markedly from that of Lake Wingra.

4) Field observations during the summer have led to a reappraisal of the approach needed for measuring the littoral zone vegetation for a lake classification scheme. The results and conclusions of work by Ms. Billie Lofland are included as Appendix A of this section.

b) Photointerpretation of Color IR, High Altitude (60,000 ft.) Imagery and Correlation to a Lake Classification Scheme Constructed by the Water Resources Program of the University

Some good results are being obtained, but further work should be done. High altitude photography has definite advantages because of the large coverage obtained. Difficulties which we have encountered during the past year in this aspect of the project have included mechanical problems in the application of the scanning microdensitometer, and the needs of more than one investigator to work with original film and not copies.

3. Evaluation of Aquatic Plant Communities and Ecological Conditions in University Bay, Lake Mendota

Complete low altitude aerial photographic coverage was obtained on two days, using type 2443 color IR film. Panels were set out to delineate the basic species. Processed film of the flight has not yet been received. We hope this will provide a key by which the success of each species in relationship to the others can be monitored. The late start in flights prevented our obtaining a complete record of the growing season. This summer's imagery will record the unusually low density of *Myriophyllum spicatum* and greater growth of other species.

4. Results of LANDSAT Lake Skadar Project

LANDSAT Data of Lake Skadar during the growing season could not be obtained for past years. We have recently been informed that tapes of this summer are available. Efforts are now being made to secure these tapes from Telespazio (address: Telespazio s.p.a. per le comunicazion spaziali, 00198 Roma, Corsa d Italia 43, Italy). Computer compatible tapes of Lake Skadar will be valuable in helping to estimate lake surface area covered by Nymphaea alba and Nuphar lutea, two important floating-leaved species in Skadar. These data would be used in another project in which the role of a littoral zone in affecting phosphorus loading to an open water zone of a large lake is under study. We expect the role of the littoral zone in affecting phosphorus transfer from a fish canning factory on the lake edge to be quite important.

5. References

Gustafson, T.D., and M.S. Adams, 1973. The Remote Sensing of Aquatic Macrophytes. Report No. 24, University of Wisconsin Institute for Environmental Studies, Remote Sensing Program, Madison.

Von Steen, D.H., R.W. Leamer, and A.H. Gergermann, 1969. Relationship of film optical density to yield indicators. Proc., 6th Symposium on Remote Sensing of Environment, pp. 1115-1125. Univ. Michigan, Ann Arbor.

E. Involvement with the Wisconsin Department of Natural Resources

During the funding period progress has been made in the design and implementation of an operational lake monitoring program using satellite imagery for the DNR. The developmental techniques are detailed in the enclosed research papers. An outline of the procedures and a summary of the results will be given here.

1. Previous Research Results (1973-1974)

The original thrust of this sub-project was to find the most cost-effective method of classifying lakes in Wisconsin to satisfy the federal legislation "Federal Water Pollution Control Act Amendments of 1972," section 314. Experiments first centered upon densitometric analysis of photographic products derived from LANDSAT-1.

Thirty-seven lakes in northern and southern Wisconsin, ranging in trophic status from oligotrophic to highly eutrophic, were selected for which Secchi depth readings were available within 25 days of a sufficiently clear LANDSAT pass. These lakes were free of tannin coloring, were at least 20 feet deep to minimize bottom interference, and were large enough to ensure that the measurement spot of the microdensitometer was wholly within the lake.

Densitometric measurements of photographic imagery in all four multi-spectral scanner bands were obtained with a Gamma Scientific spot micro-densitometer, and these were correlated with ground truth data. It quickly became evident that radiometric quality of 9x9 inch imagery was too poor for this type of analysis, and so the effort was shifted to analysis of the much higher quality 70mm imagery. A measurement spot size diameter of 50 microns, which corresponds to 550 feet on the ground, was selected for the analysis of transmitted intensity. This is large enough to average across several LANDSAT picture elements (pixels), each about 200 feet in size on the ground. On any one frame, lake image transmittance might be expected to correlate with Secchi depth. However, the transmittances of lakes on different frames are not comparable because of photographic processing differences. These processing differences can be normalized by using the film wedges provided on each frame to calculate the relative exposure of each lake, so the wedges were also densitized using a 1mm spot size for each wedge step. A transmittance versus exposure curve was plotted for each frame and used to relate densitometric readings to exposures.

Correlation plots for each of the LANDSAT multispectral bands are shown in Figs. 12 to 15. It is apparent from these that Band 5 (600-700 nanometers) correlates best with Secchi depth. Band 4 (500-600 nm) is next best.

As Figs. 14 and 15 indicate, the infrared bands, Bands 6 and 7, provide essentially no correlation with Secchi depth and apparently cannot be used for water quality measurement. This was expected because water absorbs essentially all incident energy in these wavelengths, reflecting very little to the satellite. The infrared bands, however, were valuable because lakes can be readily located with them, a task which is much more difficult in Bands 4 or 5, especially considering the very small image size of small lakes. Procedures were developed to position the densitometer spot over a lake on the Band 7 image using a microscope; the Band 4 or 5 image would then replace the infrared image for densitometric analysis.

2. Lake Classification Using Densitometric Methods (1973-1974)

Based on the preceeding studies, LANDSAT Band 5 70mm imagery was densitized to develop a trophic status ranking of all lakes greater than 100 acres in the state of Wisconsin, a size selected to ensure that densitometry was done entirely within the lake. About 1000 lakes were studied. Theoretically, 17 LANDSAT images from one 6-day overpass period would provide complete coverage of the state of Wisconsin. However, because of cloud cover and missing imagery, this project used 26 images from four different 6-day overpass periods. The 5-day period from 3 through 7 August 1973 provided most of the imagery used.

Densitometer readings for each lake were key punched, along with lake name, an arbitrary identification number, latitude and longitude, county, Secchi disc depths when available, maximum water depth, an arbitrary 0,1,2 ranking for atmospheric haze, and an arbitrary 0,1,2 ranking for irregular lake shapes where the densitometer spot might extend beyond the lake.

Computer programs were developed to calculate lake exposure and to rank the 1000 lakes by exposure in each county, DNR district, or the state as a whole. In addition, sorting routines sorted the lakes by depth, haze, or size.

A rough estimate of costs indicated that a production effort based on this technique would involve labor and computing costs of about $3.00 per lake.

3. Interactive Computer Analysis (1974-1975)

By the spring of 1974, it had become clear that techniques using photographic products suffered from several limitations. Among these were data degradation during the production and processing of imagery, errors introduced by the densitometer, spot sizes which spanned several pixels, and extremely small image sizes, especially with very small (e.g., 20 acre) lakes. Accordingly, attention was focused on analysis techniques using LANDSAT computer-compatible tapes (CCT's). An initial experiment located and extracted CCT data for a sample of 11 lakes. Band 5 correlations with Secchi depth for these lakes are shown in Fig. 16 and appear to provide substantially less scatter than corresponding results from densitometry (Fig. 13).

During this same period, Dr. Lawrence T. Fisher became involved with the project and began development of a large computer program for display and extraction of data using interactive graphics techniques. This program has since evolved into a general purpose analysis and extraction program for display, classification, and extraction of data from a variety of sources and for a number of applications.

Figure 17 shows a Princeton Electronic Products PEP-801 interactive graphics terminal. This terminal has been selected as the standard graphics terminal for hardware and software support by the Madison Academic Computing Center (MACC), and so was selected as the basic device for our program. The terminal communicates with MACC's Univac 1110 computer via a 120-character per second telephone link. It is capable of alphanumeric input and display (with three character sizes) and can construct vectors between arbitraty points. An operator-controlled "joystick" can be steered to any location to transmit positional information to the computer. Displays are formed on a storage tube which is scanned to produce a high quality video display. Once formed, a display remains usable for periods up to several hours with no computer involvement. A substantial FORTRAN subroutine set has been developed by MACC to support this hardware. The terminals are comparatively inexpensive (about $12,000) so that user agencies can afford their acquisition. (The Wisconsin DNR has owned one for the past year.)

Efforts have been made to make the program as general and versatile as possible but yet easy to operate. Data entries are prompted by "conversational" requests. "Default" conditions are provided which are invoked by simple carriage return entries. Large amounts of internal checking are done to detect operator errors without affecting program operation.

A flow chart of the program is shown in Fig. 18. Major portions include:

Tape Reading -- Raw data from LANDSAT or other sources (e.g., digitized aerial photographs) is read at resolutions of every 1, 2 or 3 rows onto a disc file, starting at any desired row. Only data from selected bands is retained.

Display -- A 90x90 row and pixel portion of the data is displayed as an array of alphanumeric characters. One to nine such characters are selected, along with "decision bounds" for each. These bounds can set the upper and lower limits within a single band for "level slicing", or they can involve several bands for "box classification". Displays may show every 1, 2 or 3 rows and columns. Combining tape reading resolution with display resolution allows display of ground areas ranging from 90 LANDSAT rows x 90 columns (5.2 x 7.1 km) to 810 rows x 810 columns (46.3 x 64.1 km). Location of a display within the area for which data was extracted is accomplished by pointing the cursor at the desired location. Resolutions and location can be easily changed to allow searching or "zooming" onto a feature of interest. A photograph of a typical display is shown in Fig. 19.

Data Extraction -- With a display present, entry of alphabetic characters is interpreted as a "locale name". Subsequent cursor position entries cause input data at those points to be extracted. This data is filed in a catalogued file for later access by any desired analysis program. It is also printed at program termination, and can be punched on cards if desired. Either single points or blocks of points can be extracted.

Data Extraction Options -- During the data extraction phase, certain keyboard characters are specially interpreted:

(a) "!" causes a "printer map" of the display to be produced. It will include any "locale names" and corresponding extracted data points to be shown; an example is shown in Fig. 20.

(b) "?" calculates latitude and longitude of a specified cursor position to aid in identification of features from LANDSAT images.

(c) "#" allows updating of the latitude-longitude reference values from a point of known location. Otherwise, scene-center values from the LANDSAT tape are used.

(d) Two numerals, n_1 and n_2, cause the last extracted data point to be erased and replaced with a new one n_1 rows down and n_2 columns to the right.

(e) "<", ">", "*" allow a new display, new tape reading, or termination, respectively.

Histogramming.-- An option allows specification of a set of rectangular "training sets". Histograms for these can then be produced and used to set new bounds for the same or a different character set. This enhances the ability to perform multispectral scene classification.

4. Interactive Computer Lake Classification (1974-1975)

The interactive graphics computer program described above was used to extend the lake classification effort to all Wisconsin lakes larger than 20 acres and deeper than 10 feet, a total of about 3000 lakes. In this project, Band 7 data was used to produce "level sliced" displays which clearly outlined lakes. Band 5 data was then extracted, and "printer maps" were produced showing the precise locations of extracted data. Data for all lakes were tabulated and listed, by county, in order of decreasing average Band 5 values. A sample of such a listing is shown in Fig. 21. These results, along with 35mm film records of the printer maps, have been delivered to the DNR and have been distributed to the various DNR districts for comment.

A report of this work was submitted to the EPA in April 1975 by the DNR for compliance with section 314. The cost of this project for the analysis of 3000 lakes has been less than $5.00 per lake, including operator time, computer time, and LANDSAT tape acquisition costs. University investigators' time and computer program development were funded with NASA funds through this grant, and the DNR has contributed approximately $25,000 during the last year and one-half for LANDSAT tapes and computer time.

5. Anticipated 1975-1976 Work

Research during the spring and summer of 1975 has indicated that a better classification of the trophic status of lakes would result if: (1) sequential satellite imagery were used instead of only one date; (2) some type of correction for atmospheric conditions was made for each scene; and (3) all four bands were used to differentiate between lakes with different types of problems.

From inspection of LANDSAT imagery and from the knowledge of the biological processes in lakes, it has been found that eutrophic lakes behave differently than clear lakes during the summer months. Typically an eutrophic lake is clear early in the spring, becomes turbid during the summer, then clears again in the fall. Turbidity shows up most distinctly in Band 5 of the LANDSAT imagery. Figs. 22 and 23 are color-coded Band 5 imagery for Lake Ripley, near Cambridge, and Lake Wingra, in Madison, each at three different dates. The color codes indicate Band 5 values as shown in Fig. 24, where each level represents a range of 2 or 3 brightness levels (or "satellite counts"). In each of these cases, it can be observed that Band 5 brightnesses are high in the late June imagery, and in the case of Lake Wingra (Fig. 23) remained at nearly the same level at the end of July. By 18 August, brightnesses of both lakes had declined substantially. Essentially the same values remained in Lake Ripley in early September (Fig. 22). Although these results are sketchy, they reinforce conclusions by Scherz et al. (Section II-B) that knowledge of seasonal change is important in assessing lake quality. Accordingly, we are beginning to develop techniques which will allow multi-date data extraction.

Several of our students have been investigating multi-date scene overlay problems using "printer maps" such as the one shown in Fig. 20, produced by the program described earlier. Manually overlaying such "maps" for three or more lakes observed at different dates, they have recorded row and column offsets between the two LANDSAT scenes. An affine transformation is then applied to best describe locations of lakes on one scene based on locations on a "master scene". Results indicate that this process correlates easily to accuracies of 2 or 3 pixels at worst, which is generally quite adequate for our data extraction needs. Since "master scene" coordinates have been recorded for all lakes inventoried, the multi-scene data extraction does not appear especially difficult. One portion of our work this fall will be to mechanize a system, part manual and part automated, to perform this data extraction on a production basis.

Another area needing attention is correction for atmospheric effects. Scherz' work, along with our own observations and those of investigators in other institutions, indicate that this is an important variable whose effects must be carefully considered. Scherz et al. suggest corrections based on observed data for known oligotrophic lakes. Others have reported good results by taking ratios of various LANDSAT bands. We intend to incorporate these approaches or others, and plan to implement one or more such techniques in the next production system.

A lake eutrophication manual is being written by Scherz et al. (Section II-B) and we intend to work closely with that group to implement as many of their recommendations as we can into our system.

Preparation of computer programs, manual aids such as plastic overlays for lake location, and a set of detailed procedures will be assembled into a complete operational system late in the spring of 1976 and will be delivered to the DNR.

6. References

Scarpace, F.L., R. Wade and L.T. Fisher, 1974. Lake Classification Using ERTS Imagery. Proc., Fall ASP Convention.

Scherz, J.P. and D. Crane, 1975.

Fisher, L.T. and F.L. Scarpace. A Versatile Interactive Graphics Technique for Extraction of ERTS Data. Proceedings, ASP Convention, March 1975, pp. 601-612.

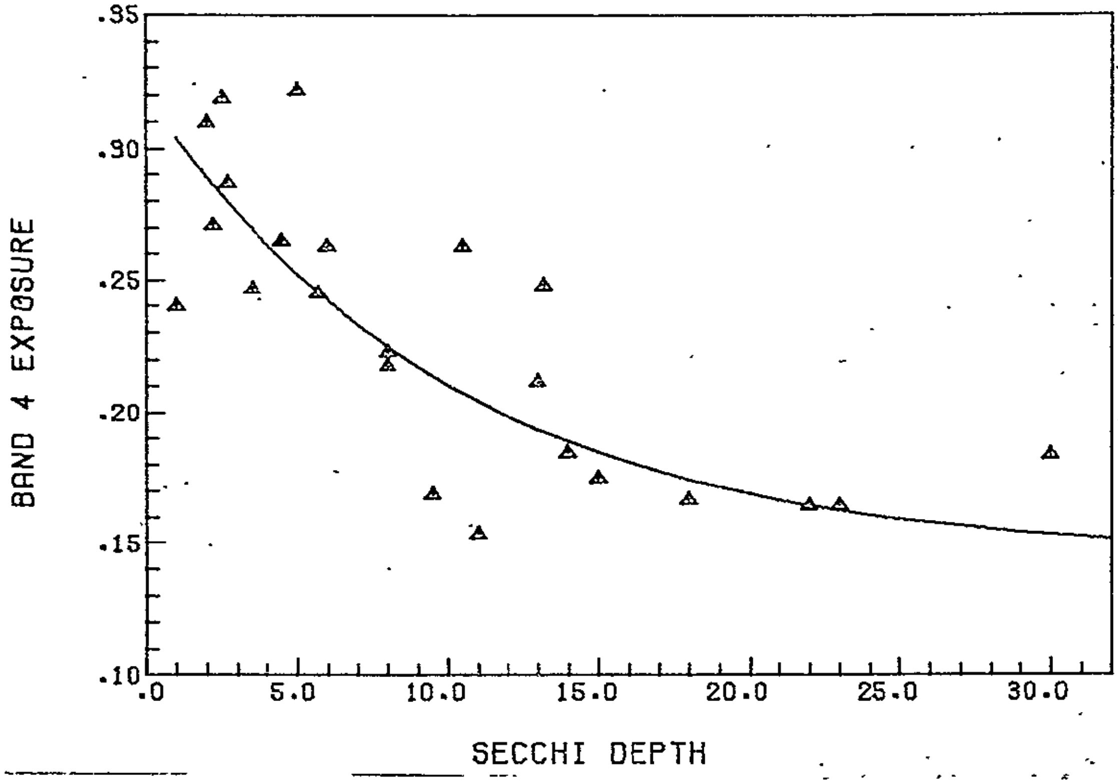


Figure 12 -- Band 4 Exposure vs. Secchi Depth -- ERTS 70mm Imagery, Exponential Regression Represented by Solid Line.

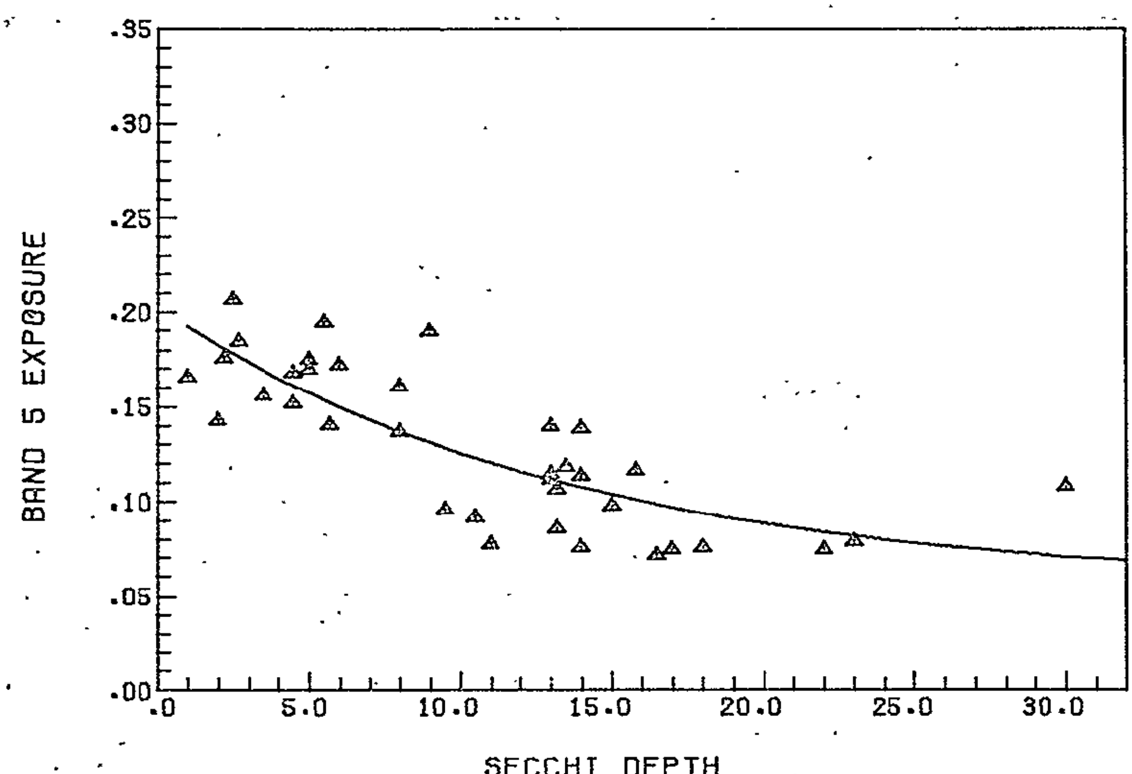


Figure 13 -- Band 5 Exposure vs. Secchi Depth -- ERTS 70mm Imagery, Exponential Regression Represented by Solid Line.

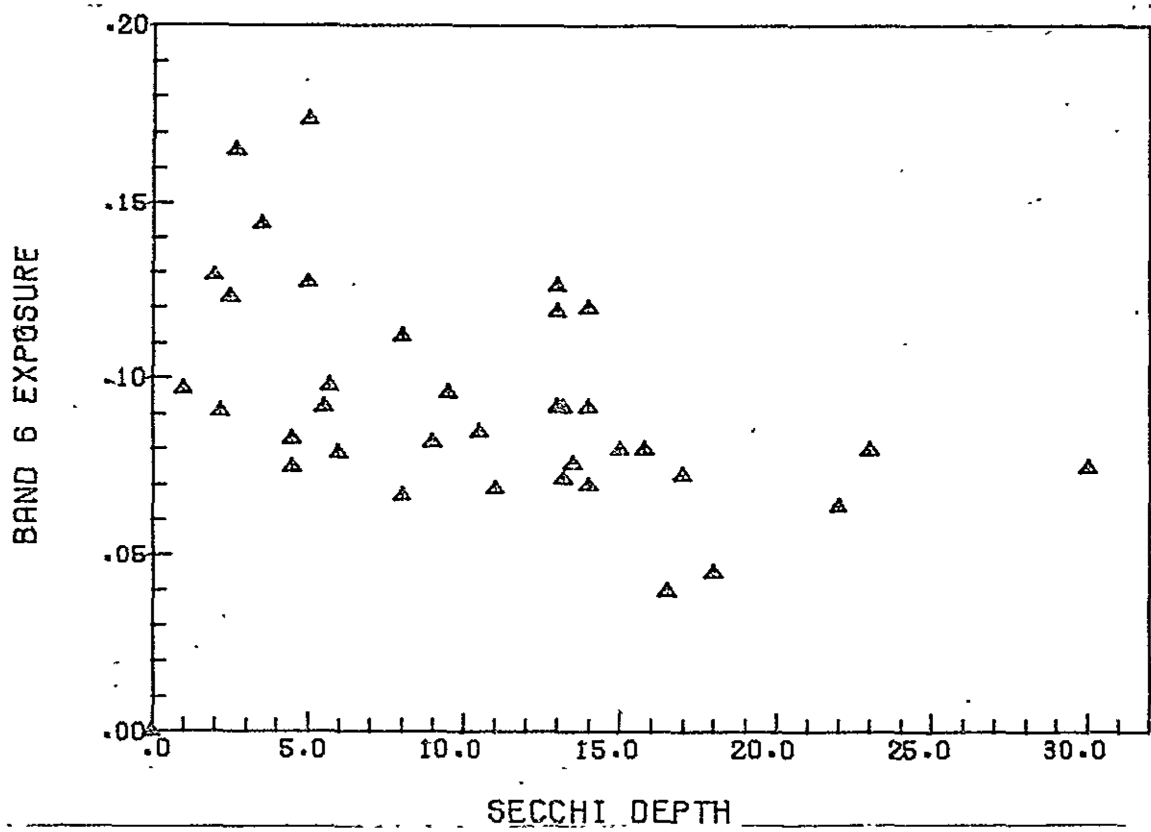


Figure 14 -- Band 6 Exposure vs. Secchi Depth -- ERTS 70mm Imagery.

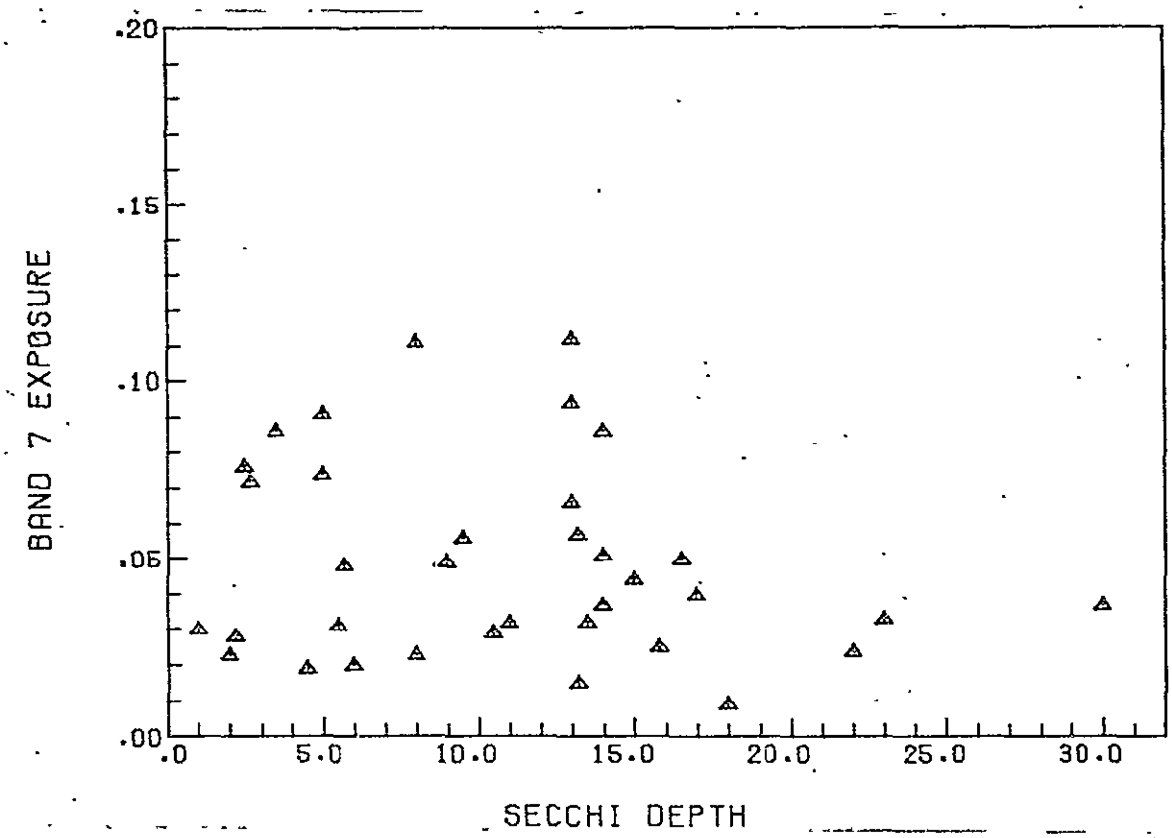


Figure 15 -- Band 7 Exposure vs. Secchi Depth -- ERTS 70mm Imagery.

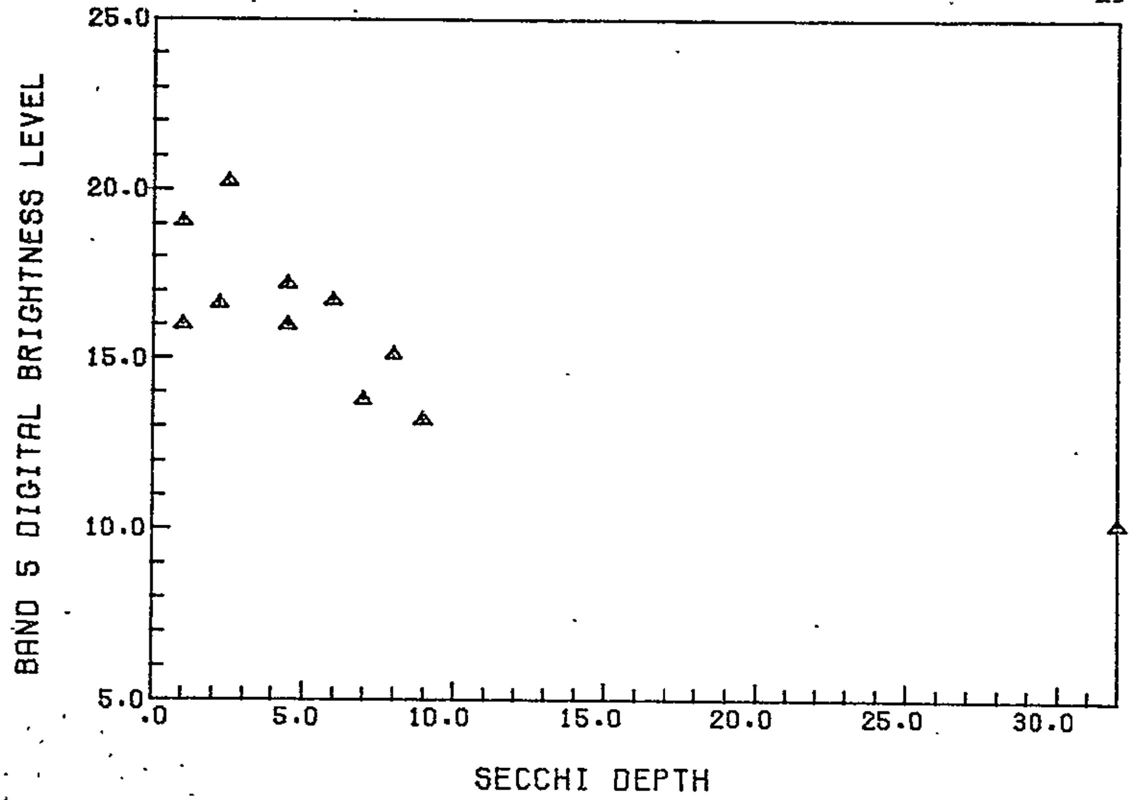


Figure 16 -- ERTS Band 5 Brightness Values vs. Secchi Depth for Eleven Non-Tannin Wisconsin Lakes.

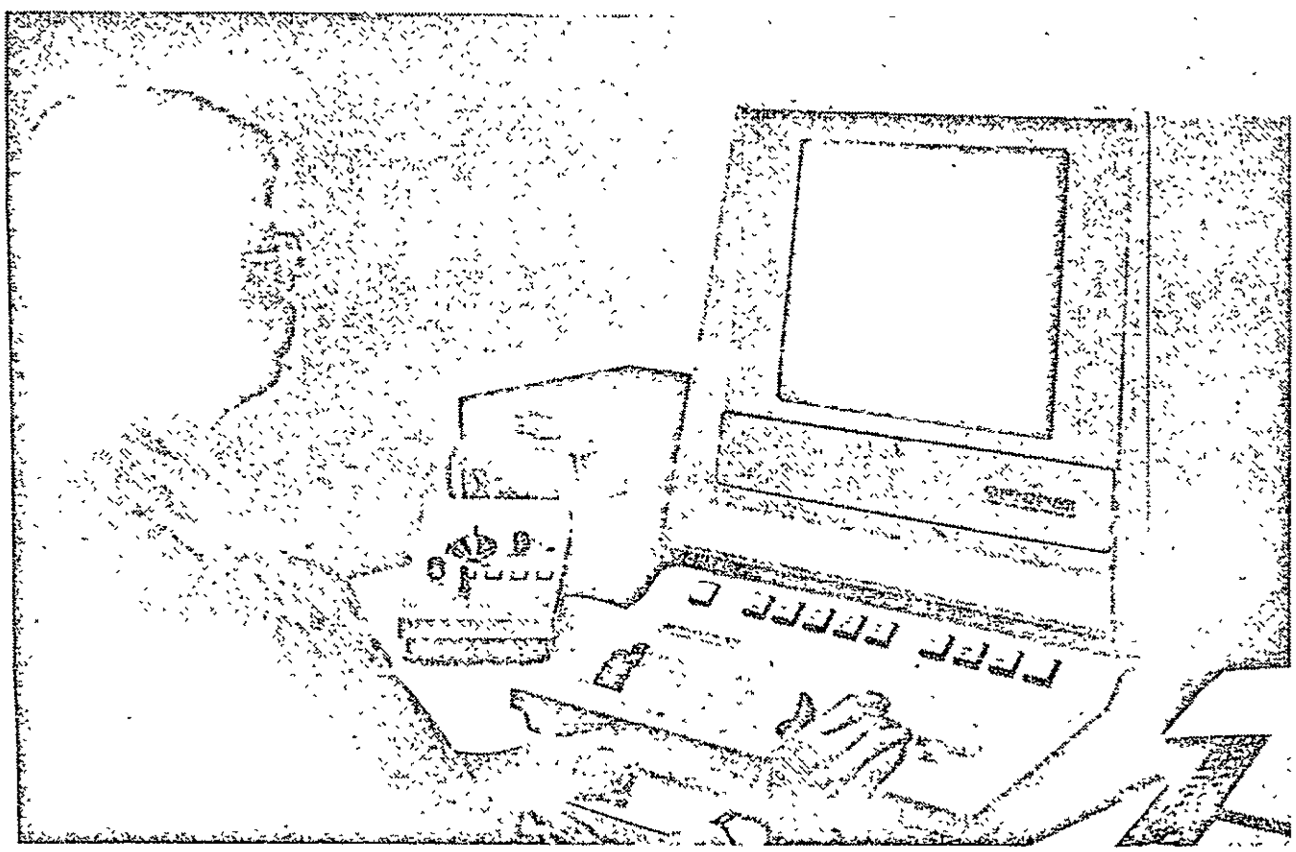


Figure 17 -- Princeton Electronics Product PEP 801 Interactive Graphics Terminal.

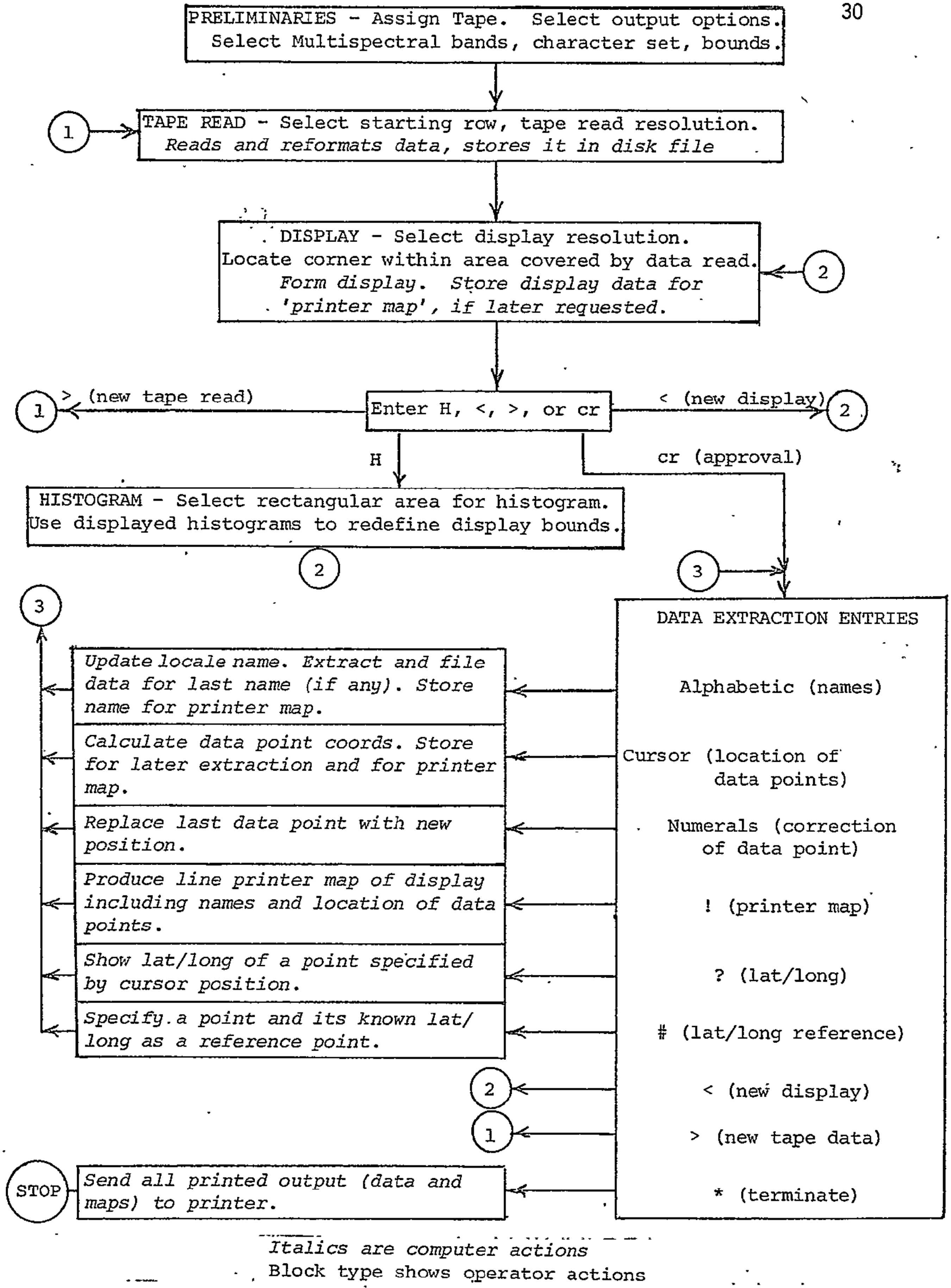


Figure 18 -- Flow Chart of Interactive Graphics Data Extraction Program.

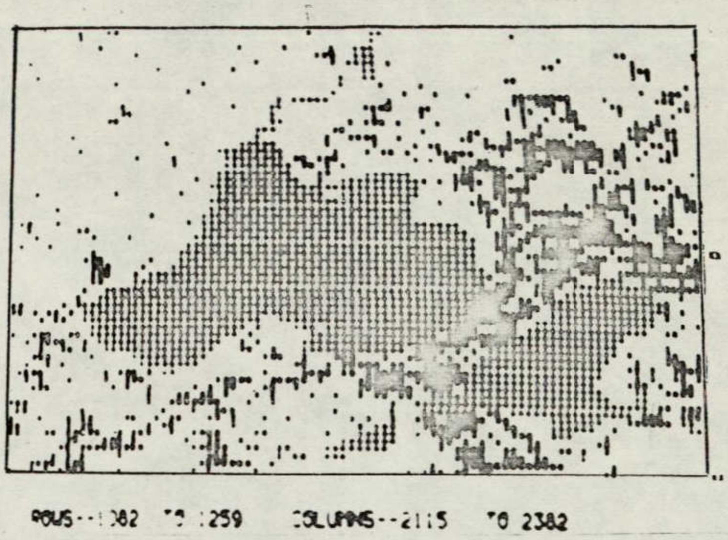


Figure 19 -- Graphics Terminal Display of Madison, Wisconsin and Lake Mendota and Monona.

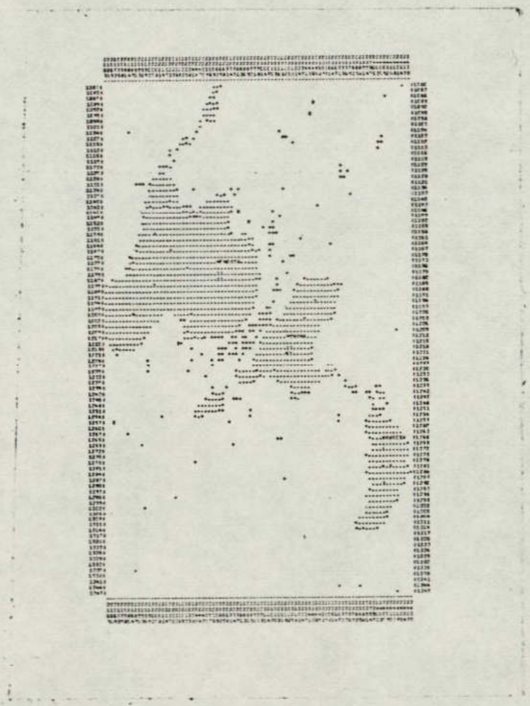


Figure 20 -- Line Printer Output (Reduced) Showing Madison Area Lakes.

DNR DISTRICT NO. 1 NAME: SOUTHERN
COUNTIES IN THIS DISTRICT ARE

NAME	NUMBER
COLUMBIA COUNTY	11
DANE COUNTY	13
DODGE COUNTY	14
GRANT COUNTY	22
GREEN COUNTY	23
IOWA COUNTY	25
JEFFERSON COUNTY	28
LAFAYETTE COUNTY	33
RICHLAND COUNTY	52
ROCK COUNTY	53
SAUK COUNTY	56

Figure 21 -- Sample Lake Classification Output Delivered to the DNR, Columbia and Dane Counties, Wisconsin.

ORIGINAL PAGE IS OF POOR QUALITY

COLUMBIA

RANK	LAKE NAME	NUMBER OF POINTS	BAND 5 AVERAGE	BAND 5 RANGE	SCENE IDENTIFICATION
1	SWAN	4	16.50	16 - 18	1378-16151 3
2	LONG	2	15.50	14 - 17	1378-16151 3
3	LAZY	3	14.67	14 - 15	1378-1615100 4
4	PARK	4	14.50	14 - 15	1378-16151 3
5	SPRING	3	14.00	14 - 14	1378-1615100 3
6	LAKE WISCONSIN	9	14.00	13 - 15	1378-1615100 3 1378-16151 3
7	BECKER	2	13.50	13 - 14	1378-1615100 3
8	SILVER	2	13.50	13 - 14	1378-16151 3
9	GEORGE	2	13.50	13 - 14	1378-16151 3
10	WYONA	2	13.50	13 - 14	1378-16151 3
11	CRYSTAL	1	13.00	13 - 13	1378-16151 3

DANE

RANK	LAKE NAME	NUMBER OF POINTS	BAND 5 AVERAGE	BAND 5 RANGE	SCENE IDENTIFICATION
1	KEGONSA	7	22.00	21 - 24	1378-16151 4
2	BASS	3	21.67	21 - 22	1378-1615100 4
3	BELLEVILLE MILLPOND	2	19.00	18 - 20	1378-1615100 3
4	MONONA	6	17.00	15 - 19	1378-1615100 3
5	WINGRA	3	17.00	17 - 17	1378-1615100 3
6	WAUBESA	4	16.50	16 - 17	1378-1615100 3
7	CRYSTAL	3	16.33	16 - 17	1378-1615100 3
8	HARRIET	2	16.00	15 - 17	1378-1615100 3
9	MUD T7R12	2	16.00	15 - 17	1378-1615100 4

Figure 22 -- LANDSAT Band 5 Values in Lake Ripley near Cambridge, Wisconsin for Three Dates, Summer, 1974.

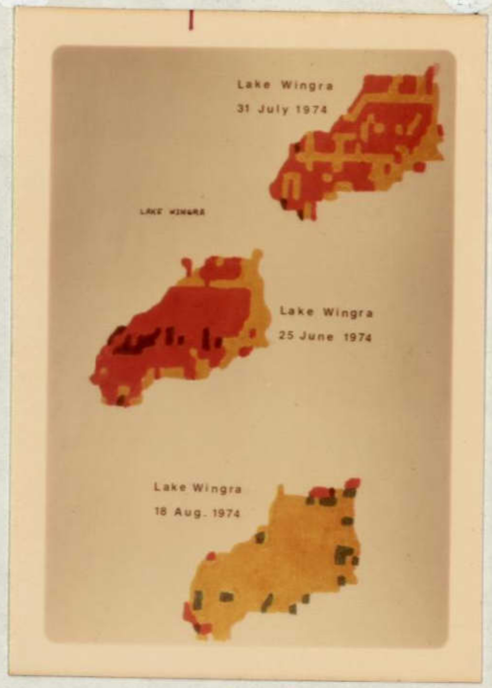


Figure 23 -- LANDSAT Band 5 Values in Lake Wingra, Madison, Wisconsin for Three Dates, Summer 1974.

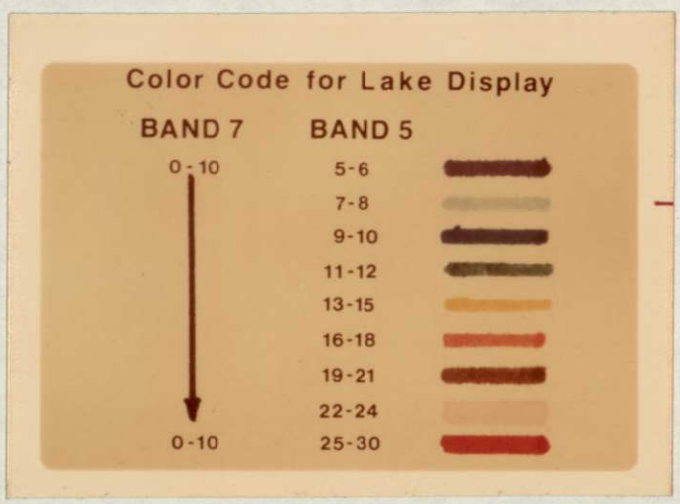


Figure 24 -- Color Coding for Figures 22 and 23.

SECTION II

APPENDIX A

FEASIBILITY OF USING COLOR IR IMAGERY FOR QUANTIFYING AQUATIC MACROPHYTE COMMUNITIES

Ms. Billie Lofland

FEASIBILITY OF USING COLOR IR IMAGERY FOR QUANTIFYING AQUATIC MACROPHYTE COMMUNITIES

By

Ms. Billie Lofland

The use of color IR film as a tool to describe the aquatic communities has been investigated over the past several years. We observed that the different communities, and even different species, could be more clearly differentiated with color IR imagery than with color. Gustafson (1973) demonstrated that film density measurements taken from color IR imagery of Myriophyllum spicatum beds in Lake Wingra could be correlated to the actual plant density. This summer's research has been an extension of Gustafson's work. Of primary importance is to determine whether the linear regression of plant density to film density developed by Gustafson on Wingra could be extended to other lakes, and secondly, whether other aquatic communities (such as floating-leaved communities) can be similarly quantified.

Since the original work with Myriophyllum spicatum was done on Lake Wingra, that lake is being used as the major study site. Gustafson's techniques of standardization are being modified. Finding an accurate standardization technique is important to record fluctuations in sunlight conditions during the flight and in processing film. Gustafson used open water readings for the standards in his densitometric analysis because of complications encountered while using panels. The number of panels needed for the entire lake would have been large. Also, the panel color changed in time. During film analysis we found that readings taken from the panels could be misleading. Subsequent study has shown that the panels were too light and too highly reflective. However, panels were not readily needed in this particular case because Lake Wingra has an unusually constant green color throughout the season, due to the characteristics of the phytoplankton. This green color proved ideal for use as a standard because the resulting blue color on the color IR imagery is on the linear portion of the D log E curve of the film. Other Madison area lakes have variable blooms which change the reflectance of the lake during the season and from day to day. Because of the variable water reflectance from lake to lake and even within the same lake, open water readings are not expected to be reliable standards. Panels were used this summer. Preliminary work determining the correct size and color for the panels was first completed. Two gray 4 ft. x 4 ft. panels were selected for each site, with one being considerably darker than the other. The basic approach this summer was to establish a number of sites (quadrats), marked with panels, which represent a gradient of plant cover and of plant density. Gustafson used general areas of differing density rather than establishing specific sites. With his method, problems would occur when sampling several lakes in the time allocated for the research. On the same day the panels are placed on the lake, color IR photography was planned from 1,000 feet above ground level. A regression between film density and plant cover was to be conducted. Two other lakes, Lake Como and Lake Mendota, were also selected for additional photography. Quadrats in each of these lakes were to be installed and photographed, with cover and plant density data to be collected. Previous studies with terrestrial vegetation have shown that film density is most closely related to optimal cover (Von Steen et al.). Gustafson (1973) has shown that film density is more closely related to stem density than to biomass. Therefore, we planned to test whether the cover and density estimates determined from the film density data of these "spot check" sites would correspond to the actual field data.

Observations made during the first flight of the season led me to conclude that a regression of plant cover and film density to be used on many lakes could not be developed using our procedures. Biological and physical parameters prevent a specific film density range from representing a specific plant cover range found in various lakes. The structure of the Myriophyllum community itself can present complexities as it can change within one lake from year to year and from lake to lake. It may be very homogeneous, composed of just Myriophyllum, or other species may co-occur. Another variable of the plant community structure is the distance of the plant below surface. Therefore, the effects of the varying water column on the reflectance signal must also be considered. The differences in water conditions from lake to lake can affect the reflectance signal from the plants. The average depth of the water to the plants from the surface must be determined which requires substantial field work. Other physical parameters, such as wind and light, will alter the morphology of the community. Winds strong enough to cause choppiness of the water can move the Myriophyllum clumps that were at the surface to be as far as 6 inches below. Increased turbidity caused by wave action decreases visibility to such a degree that attempts made to take ground data from plants below the water surface become inaccurate. Turbidity also interferes with the reflectance signal from the plant community. Sunlight conditions, too, will affect the community morphology. The plants have been observed closer to the surface when irradiance is high. Imagery for each lake should be taken when standard, optimum physical conditions exist -- low wind and high sunlight. Such conditions are surprisingly hard to obtain. In addition to the problems associated with the plant community structure and morphology, and with the physical parameters, there is the situation where substances on the plant will differ. For example, in Lake Wingra this year, two conditions have been seen. There are tips covered by precipitates and those covered also with filamentous algae (Oedogonium). The immediate solution for this specific lake is to fly early in the season before the algal mat has developed. The Myriophyllum in University Bay, Lake Mendota, is covered with another species of filamentous algae, which exists on the plants before they reach the surface. And, in general, non-filamentous diatoms also occur on milfoil as a dense community of epiphyton.

The uniqueness of each lake in terms of Myriophyllum community and of the water characteristics may prevent a standard regression of film density and plant cover or plant density from being applicable to different lakes.

Originally it seemed that the floating-leaved community would be easier to monitor than that of Myriophyllum spicatum. While there is not the problem with the intervening water column, there is another dimension added because the stems may extend above the water surface. This can place the leaves up to six inches above the water. Wind will cause the leaves to bend. Frequently the spaces between the water lily leaves are filled with other species such as Myriophyllum, Ceratophyllum, Lemna (duckweed), or filamentous algae, depending on the lake and the time of year. However, the water lily community is probably more homogenous from lake to lake. The sampling technique used is simplified because of the more shallow water depth. The water lily community may provide a more positive correlation of film density and plant cover from lake to lake.

I do believe aerial photography is a valuable tool in monitoring aquatic vegetation; however, a more simplistic approach than that attempted this summer may prove more efficient. High altitude (60,000 ft.) and low altitude (4,000 ft. - 1,000 ft.) color IR imagery has shown that the basic aquatic plant communities - the submergents, emerged-submergents, emergents and floating-leaved - are easily distinguishable. The general area of each community can be outlined and measured. Visual interpretation by a practiced individual can allow differentiation of the communities into general categories such as sparse, moderate and dense. It has been suggested that the error introduced by the previously mentioned variables will not be so large as to render densitometric analysis useless. It is possible that it may be effective when the broad categories mentioned are used. Research using a variety of filters in photography with black-and-white film could provide a new area of study.

III. APPLICATION OF REMOTE SENSING TO THE DETECTION AND MONITORING OF THE MIXING ZONE

Principal Investigators

Kenneth L. Beghin, Chief, Aeronautics Section, Department of Natural Resources

Theodore Green III, Professor, Department of Civil and Environmental Engineering, and Meteorology Department

John A. Hoopes, Professor, Department of Civil and Environmental Engineering

Robert P. Madding, Project Associate, Marine Studies Center, and Environmental Monitoring and Data Acquisition Group

Jerome R. McKersie, Chief, Water Quality Evaluation Section, Department of Natural Resources

Frank L. Scarpace, Assistant Professor, Department of Civil and Environmental Engineering and Institute for Environmental Studies

James R. Villemonte, Professor and Chairman, Department of Civil and Environmental Engineering

Research Assistants

Vahid Alavian, Department of Civil and Environmental Engineering

J. Wayland Eheart, Department of Civil and Environmental Engineering

Dennis Houk, Oceanography and Limnology Program, Marine Studies Center

Wilhelm Reindl, Oceanography and Limnology Program, Marine Studies Center

G. Nicholas Textor, Department of Civil and Environmental Engineering

Dong-Shan Wu, Department of Civil and Environmental Engineering

ABSTRACT

The work of this group concerns mixing zones from effluent discharges into surface water bodies. In particular studies of power plant effluents (thermal plumes) in Lakes Michigan and Monona and of municipal and industrial effluents in Wisconsin rivers have been conducted. Ground and aerial measurement techniques have been used to determine effluent concentrations, movements and mixing rates and to define parameters and test models of effluent discharges. The results of this work are being used by the state in the establishment of water quality guidelines and in the implementation of a statewide monitoring program; in addition, these results contribute important information needed in the design of outfalls by industries and municipalities.

A. Introduction

The "mixing zones" in which waste effluent discharges are dispersed and diluted to legally allowed concentrations will be of importance in national, state and local efforts to reduce water pollution for a long time. Although many standards are currently phrased in terms of mixing zones, the Environmental Protection Agency (EPA) is formulating standards based on the effluents themselves. In the establishment of any such standards, the manner and speed with which the effluents are diluted and degraded in the receiving water are important considerations.

The study of such mixing zones in natural water bodies is very difficult due to the size of the region and to the complex and varied physical and biological phenomena occurring therein. Monitoring of small and large scale processes and dilute concentrations, both on and below the water surface, requires testing, development and perfection of special sampling techniques. Furthermore, inferences regarding effluent behavior, based upon limited samplings, require development of appropriate confidence intervals. Finally, as our knowledge of mixing phenomena and sampling methods increases and more data are acquired, this information must be incorporated into the program. Consequently, a number of approaches and methods of attack are needed in such a study.

Mixing zones can be usefully divided into river and lake types. In rivers, the water is quite shallow, there is an opposite shore, and the current is essentially unidirectional and fairly strong. Large, wind-generated waves are not present. In lakes, the opposites of most of these statements hold true. In addition, for purposes of characterization and modeling, mixing zones are subdivided into near field and far field regions. The near field, which begins at the outfall, is the region in which the effects of the outfall and effluent discharge (coupled with ambient water body characteristics) govern the rate of effluent mixing and spreading. The far field, which follows the near field and begins at a location where the effluent momentum and buoyancy have been essentially converted to those of the ambient water, is the region in which the ambient water body currents, turbulence and other characteristics govern the rate of effluent dilution and spreading. This project includes work on the near and far fields of effluent discharges into rivers and lakes and hence on both types of mixing zones.

The results of this ongoing work during 1974-75 are described below. The overall objectives of this project are to:

(1) Continue to provide data to the State of Wisconsin, Department of Natural Resources (DNR) on the shapes and sizes of mixing zones of direct interest to them.

(2) Provide DNR with tested plans for operations and routine monitoring, together with crude cost/benefit analyses of their effectiveness (i.e., ratio of information accuracy and statistical reliability to the cost of acquiring it).

(3) Provide DNR with phenomenological ("correlation") mixing zone models,

relating plume size to plant load, river flow, wind, and other factors, using observed quantities only.

(4) Provide DNR with mechanistic models of mixing zones based on rational numerical models. Such models will be capable of being generalized and improved, based upon continuing study and observations of mixing zones.

B. Lake Michigan Plumes

Routine thermal scanning of the Wisconsin shore of Lake Michigan has continued during 1974-75 using the DNR DC-3. We have now scanned each of the major power plants along the shore about 100 times. Funds for these flights were provided by the Wisconsin Electric Power Company. Ground truth was provided by the various power companies.

These data are now being analyzed using an interactive digital analysis scheme, adapted by Dr. L.T. Fisher from programs developed for lake classification (see Section III-E of this report). Film calibration problems prevented us from using the scanning densitometer (mentioned in the last proposal) to find the areas within certain key isotherms, which will be used later in section 316A hearings. Thus, we have reanalyzed the data by digitizing the original tapes into 4096 levels (12 bits). The digital data, read off tape into a Univac 1110 computer, are sliced to nine levels and a character image is displayed on a PEP interactive graphics terminal. The operator chooses the ground truth locations on the image and enters the appropriate temperatures. A temperature calibration is performed after which the operator may choose test points to observe the apparent temperature anywhere on the image. When satisfied that the calibration is correct the operator outlines the portion of the image he wishes to be analyzed. Extraneous heat sources (e.g., land features) are thus excluded. Once a satisfactory border is obtained the data enclosed are processed. Printout and microfiche of the plume surface areas enclosed within isotherms are produced. This task is two-thirds done, and will be complete by December 1975. The data will be given to DNR and the power companies in the format shown in Figure 25 and prefaced by a report describing the remote sensing program, including equipment and data analysis.

The entire coastal zone of Lake Michigan has been flown once. The main stumbling block to productive use of these flights has been the lack of adequate ground truth outside Wisconsin. This has turned out to be an extremely difficult organizational problem, and we do not seem to have the manpower to solve it. We are still trying to interest other states (notably Michigan) in joining and actively supporting such a program. However, other industrial remote sensing groups seem to have blocked these efforts.

The data with which to build a phenomenological model of the surface features of thermal plumes are now being obtained (see above). By December 1975, we will be able to begin correlating plume surface areas and shapes with wind, waves, plant load and other parameters.

Three scanning missions with intensive ground truth provided by well stirred, "kiddy swimming pools" were conducted in 1974. The best of these was the basis of an independent study report for the Master of Science Degree in Ocean Engineering by Mr. Larry Jaeger. This report, which is being prepared as a Remote Sensing Technical Report, should be available by December 1975.

Several experiments were conducted at the Point Beach Nuclear Plant in conjunction with Argonne National Laboratory. In this work, Argonne people towed a chain of thermistors through the plume immediately before and after scanning flights by the UW group. Plume contours were compared, and were usually surprisingly close. The results were presented at a symposium on the physical and biological effects on the environment of cooling systems and thermal discharges at nuclear power stations held in Oslo, Norway. One implication of the agreement is that the surface-film effect is relatively unimportant.

Our planned experiments involving the relation of water skin temperature to bulk temperature have not been carried out. To a large extent, this is a manpower problem. However, the literature research and preliminary work we have done on this problem has indicated strongly that this is a very difficult problem, and one not likely to be resolved by any effort we can mount in the near future. Thus, our work along these lines will most likely be discontinued.

Our additional measurements of the vertical instantaneous temperature and velocity structure, utilizing the pole in the plume at Point Beach, have been discontinued. (The pole fell into the lake. It acquired a large ice pack above the water during the winter of 1974 and collapsed due to its own weight.) However, the data analysis of high-frequency temperature fluctuations in the plume, obtained prior to the fall of the pole, continues. The results will be interpreted in terms of vortex pairing due to an interfacial instability and will be presented at the 1976 Offshore Technology Conference along with scanning data taken at Point Beach.

C. River Plumes

A report on the field studies of the mixing and spreading characteristics, including some modeling and assessment of mixing zone extent, for the effluent discharge from the Waukesha Sewage Treatment Plant (STP) into the Illinois-Fox River has been completed and is being typed. A similar report for the field studies of the effluent discharge from the Weston Power Plant into the Wisconsin River is nearly done and should be completed this fall. Initial drafts of reports have been completed on the field studies of the effluent discharges from the Kimberly Clark Paper Mill into the Fox River (independent study report for the Master of Science degree in Civil and Environmental Engineering (CEE) by G. Nicholas Textor covering the ground measurements and Ph.D. thesis in CEE by Thomas M. Lillesand covering the aerial photographic concentration mapping), from the Neenah-Menasha STP into the Fox River, and from the American Can Company Paper Mill into the Wisconsin River. Similar reports on the effluent discharges from the Ladish Malting Company into the Rock River and from the Consolidated Paper Company into the Wisconsin River were completed previously.

Development of an integrative report, which delineates mixing zone characteristics in terms of river, outfall, effluent and meteorological conditions, and is based upon the above field studies and the mathematical and laboratory modeling work, will not be undertaken until the field study reports have been completed. Work on this report should be initiated this year. A report on a generalized mathematical model for predicting mixing and spreading characteristics of shoreline surface and submerged discharges into surface water bodies is presently being typed. This report, which is based upon the Ph.D. thesis in CEE by Dong S. Wu, will provide DNR or other regulatory agencies and municipalities and industries with a documented computer program including a discussion of the model basis, a description of how to use the program and examples of the program use; this model and program should be helpful in determining the spreading and mixing patterns for existing and proposed discharges. Independent study reports and a thesis for the Master of Science degree in CEE by Gerald Bastian, James Jacques and John Niemeyer, respectively, describing laboratory modeling work are available for use in the integrative report.

A mathematical model for the two-dimensional behavior of aquatic pollutants in streams in which the mixing is affected by channel geometry and velocity patterns has been developed. The model has been tested for accuracy by comparing its results for channels with simple geometry and flow field with analytical models for the same channels and has been found to achieve acceptable accuracy.

The model has been tested with field data from the effluent discharge of the Janesville Sewage Treatment Plant. Two types of field observations were made -- BOD samples and thermal scanning measurements. While the model generally predicts the data trend for the BOD data, these data are themselves too scattered to support a confident, statistical assessment of the model's performance. The temperature data, on the other hand, are statistically significant, despite the scatter occasioned by the fact that the instantaneous data from each of several consecutive, scanning passes were averaged to give a time-averaged pattern. The temperature data show that, while the statistical fit between observed and predicted data is not as close as desired (due probably to errors in measuring the flow field), the performance of the model, including channel geometry and velocity variations, is far superior to that of the Gaussian model (which assumes a rectangular channel and uniform velocity) frequently used in problems of this sort.

That the temperature data yielded more statistically significant results than the BOD data is an indication that thermal scanning may be used as an indirect measure of BOD, insofar as BOD itself may be determined. Inasmuch as the rule-of-thumb accuracy usually ascribed to the BOD test is around 10%, the conclusion that temperature may be used as a tracer for BOD is probably justified.

More detailed results and discussion are presented in the Ph.D. dissertation of J. Wayland Eheart (to be completed in September 1975).

D. Lake Monona Site

The major efforts on the condenser cooling water discharge from the Madison Gas and Electric Company (MGE) have been directed towards: (1) planning and testing of measurement methods for sampling the plume in order to determine particular quantities and to delineate various processes; and (2) developing this site into a national facility for studies of condenser cooling water discharges.

Field work was undertaken to establish control stations for location purposes in ground and aerial surveys, to map the lake hydrographically in the outfall region, and to test different schemes for sampling plume temperatures and velocities. Shore stations have been established in the outfall area from which boats, drogues and other equipment in the lake can be located. A scale map (1in = 50ft) has been prepared of the outfall area for use in data plotting. A map of the same scale, showing the lake hydrography (obtained from soundings), also has been prepared.

Skin temperatures, vertical temperature profiles, and velocity measurements over the plume area were taken periodically throughout the summer under different meteorological conditions. A PRT5 was used for measuring the skin temperature, and a Whitney thermometer was used to measure the subsurface vertical temperature structure. Velocities inside and near the plume were measured using surface and subsurface drogues. A two-component, electromagnetic current meter also was used for velocity measurements; the meter was fastened to a cable track on a pole which was anchored to the lake bottom (by pushing the pole into the bottom) at various locations in the plume.

In order to obtain continuous and accurate ground measurements at many locations of the plume velocity and temperature structure (free from the influence of a boat), various designs of a rigid yet light and portable instrumentation platform or pole presently are being considered. Use of a phototheodolite for simultaneous tracking of a series of drogues also is being studied.

The concept of a national facility to study thermal plumes evolved this past fall and winter from meetings with various persons in the Engineering Division of the National Science Foundation (NSF). Based upon the experience and expertise of the UW group developed over the past 8-10 years with thermal plumes (at the Lake Monona site and elsewhere) and upon the critical national need to find aquatic sites and methods environmentally suitable for disposal of the heat rejected to the condenser cooling water of steam-electric power plants, NSF has given strong encouragement for the development of such a facility on Lake Monona in conjunction with the MGE power plant. DNR and MGE both support such a project. This facility would include complete ground instrumentation for thermal scanner calibration and various remote sensing experiments. There would be provisions for studies of outfall design, mixing zones, and the physics of plume behavior. Through a series of meetings this spring and summer a preliminary proposal, requesting funds to prepare a national facility proposal, has been prepared and submitted to NSF. With the expected support of NSF, work on the facility proposal will begin this fall.

E. Involvement with DNR

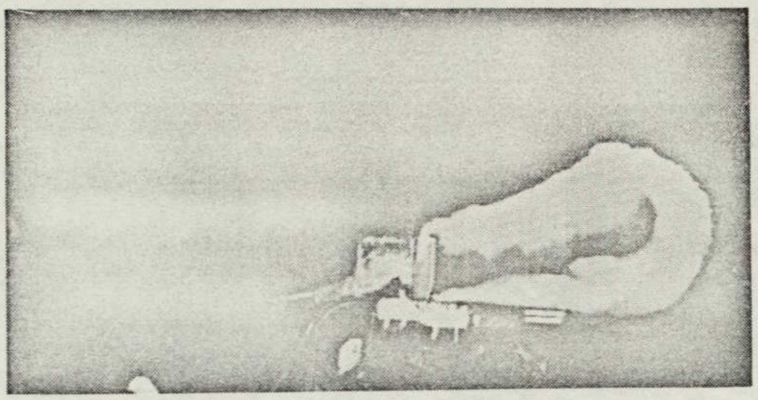
Our cooperative scanning program involving the power plants along the Lake Michigan shoreline is coming to an end. The data analysis is expected to be completed and a final report submitted to DNR and the power companies by December 1975. We are now using this program as a model on which to base a more well rounded cooperative effort guided by a UW-DNR interagency committee. Meetings related to this effort are planned for September, 1975.

The NEPA Section 316A hearings at which the power-plant thermal scanning data should see heavy use have yet to get underway; they are expected to begin in a few months.

Regular formal meetings of the UW and DNR groups were not held; however, the two groups met once in the fall, and many informal meetings and discussions were held throughout the year. Through such discussions the need in monitoring, in enforcement, in permit granting and in standards work for a climatological grouping and classification of effluent discharges in rivers, similar to that being developed for thermal discharges in lakes (see above), was identified. As this effort would require a significant redirection of the project work, it is being given further consideration by the two groups. The field study and other reports, including modeling work, have and continue to provide useful input to DNR in the issuance of discharge permits and in the establishment of mixing zone guidelines and criteria.

Continued meetings between the two groups will enable more rapid and effective implementation of project results regarding mixing zone monitoring and specification and redirection of project work to meet new DNR needs.

OAK CREEK March 27, 1974 13:51



surface wind

1000 ft

ENVIRONMENTAL DATA

Surface Wind: 9 kts SE
(5 kts SE: HM)
Waves: 1/2 ft
(2 ft: HM)
Air Temperature: 33°F
Humidity: 72%
Cloud Cover: 9/10

Water Temperature:
Point A: 51°F
Point C: 42°F

COMMENTS:

AREAS WITHIN ISOTHERMS

Isotherm	Areas (ft^2)
3°F	7.0×10^6
5°F	4.9×10^6
10°F	1.6×10^5

PLANT DATA

Load: 905 MW
Pumping rate: 1738 cfs

Figure 25--Typical Thermal Plume Data Delivered to the DNR and to Power Companies

IV. HYDROLOGICALLY ACTIVE SOURCE AREAS

Principal Investigators

Ralph W. Kiefer, Professor, Civil and Environmental Engineering

Frank L. Scarpace, Assistant Professor, Civil and Environmental Engineering and Institute for Environmental Studies

Research Assistants

Lester Forde, Department of Civil and Environmental Engineering

Achi Ishaq, Department of Civil and Environmental Engineering

Richard Pearsall, Department of Civil and Environmental Engineering

Bruce K. Quirk, Department of Civil and Environmental Engineering

ABSTRACT

The past year has been a transition period. Greater emphasis has been placed on the development of automated techniques for land cover mapping in support of hydrological analyses, and the primary test site has been shifted from the Lowery Creek Watershed in Iowa County to the Menomonee Creek Watershed in Milwaukee County. The research in progress emphasizes the following tasks: (1) to further develop the list of land cover and hydrologic features that should be identified and mapped in order to delineate hydrologically active source areas and other areas which are non-point sources of pollution; (2) to further develop and refine computer programs for the identification and mapping of areas which are non-point sources of pollution using high-altitude and LANDSAT imagery; (3) to investigate the cost-effectiveness of computer-based analyses compared with conventional photo-interpretation and field sampling methods; and (4) to coordinate this research with the needs of state and regional planning agencies.

A. Introduction

The past year has been a transition period. After an extended leave-of-absence, Professor Dale D. Huff resigned his position in the Department of Civil and Environmental Engineering. He was replaced on the project by Professors Ralph W. Kiefer (Civil and Environmental Engineering) and Frank L. Scarpace (Insitute for Environmental Studies) in January 1975. Since that time, greater emphasis has been placed on the development of automated techniques for land cover mapping in support of hydrological analyses. Also, the primary test site has been shifted from the Lowery Creek Watershed in Iowa County to the Menomonee Creek Watershed in Milwaukee County, a watershed with which the Wisconsin Department of Natural Resources is more actively involved.

B. Activities from September 1974 to December 1974

During this period, the collection of hydrologic data was the dominant activity. Planning for future work also constituted a significant effort during this period.

Data collection consisted of precipitation data from the three precipitation stations, streamflow data from the flow records on Lowery Creek and the measurement of runoff on the subwatershed using the IMW weir. Some additional data collected during this period (such as snowfall) is not presently used in the source area concept or model.

The data collection activity was a continuation of the work carried out by Achi Ishaq for his doctoral thesis. The planning activities were based on the main recommendations for further work outlined in Ishaq's thesis. These recommendations may be summarized as:

(1) further development and testing of the model developed for the watershed;

(2) determination of the expansion and shrinkage of the source areas; and

(3) complete definition of the total runoff from one of the subwatersheds.

In working toward these objectives, considerable effort was placed on continuing hydrologic data collection and analysis. Additional time was spent on planning additional ground instrumentation to characterize the size and shape of source areas (and temporal changes therein) and the runoff from one of the watersheds.

In the data collection, a problem developed with the IMW weir. Data indicated that although the instrument was working in the field the data obtained was unreasonable. No runoff was indicated from this subwatershed although there was sufficient rainfall to produce runoff. Visual examination of the weir plate showed water marks indicative of considerable flow (this was confirmed by conversations with neighboring farmers). As a result the complete unit was removed for repair.

Discussion of the recommendations for continued work proposed by Ishaq and summarized above resulted in the decision that since model testing was very involved the main research thrust should be directed towards the other three recommendations (2-4, above).

The determination of the temporal and spatial changes in the source areas should be attempted by obtaining aerial photographs (using color IR film) of the watershed immediately before, immediately after and, if possible, during rainfall events. This should be continued for 1-2 days after. In this way, changes in the source areas could be seen photographically. High altitude photography should be attempted in order to encompass the whole watershed on several frames. The film obtained should be analyzed using the interactive graphics computer program described in Section 2E of this report with the film density response scheme suggested in Ishaq's thesis. During these photographic flights ground truth should be collected, including runoff, soil moisture, and precipitation measurements. The soil moisture measurements should provide a direct indication of source area changes; one possible method for defining these changes would involve soil resistivity as an indicator of soil moisture. In this method electrodes would be placed in the soil at a number of locations. Since resistivity should decrease with increasing moisture content, measurement of the resistivity between various pairs of electrodes at different times should enable the source area boundaries to be located. This technique would first have to be tested in the laboratory in order to test its feasibility and sensitivity; field calibration will be needed. It is also considered important to install several IMW weirs in the subwatershed in order to obtain outflows (if possible) from individual source areas. These data would be very useful, in combination with source area changes in size, in understanding and defining the flow from a source area.

The recommendations by Ishaq are valid and the methods suggested in this report for their implementation are feasible; further work should be directed toward realizing these goals. The maintenance of hydrologic records is important for future work; the collection of this data would involve about five hours of work per week.

C. Activities Since January 1975

(1) Introduction

As previously mentioned, in January 1975 the primary test site was shifted from the Lowery Creek watershed to the Menomonee Creek Watershed in Milwaukee County and greater emphasis was placed on the development of automated techniques for land cover mapping in support of hydrological analyses.

As recommended by Ishaq and Huff (1974) emphasis is being placed on the identification and mapping of the following features in the Menomonee Creek Watershed:

(a) the perennial river system and other open water bodies;

(b) the stream drainage pattern;

(c) areas of high moisture content along and outside the stream banks and the drainage network;

(d) marshy lands, swamps, seeps and springs;

(e) areas of subsurface drainage;

(f) impervious areas such as roads, pavements, rock outcrops, and rooftops, etc.;

(g) relief and topography;

In addition to knowing the specific landscape features cited by Ishaq and Huff, land cover information is being obtained for the entire watershed in order to facilitate watershed modeling.

(2) Objectives

The research in progress and planned for the period January 1975 through the summer of 1976 has the following principal objectives:

(a) to further develop the list of land cover and hydrologic features that should be identified and mapped in order to delineate hydrologically active source areas and other areas which are non-point sources of pollution;

(b) to further develop and refine computer programs for the identification and mapping of areas which are non-point sources of pollution using high-altitude and LANDSAT imagery;

(c) to investigate the cost-effectiveness of computer-based analyses compared to conventional photo-interpretation and field sampling methods; and

(d) to coordinate this research with the needs of state and regional planning agencies.

(3) Progress to Date

The following have been accomplished to date toward meeting the four objectives previously stated.

(a) The principal investigators have participated in seminars organized by the Wisconsin Department of Natural Resources and the University of Wisconsin Water Resources Center to discuss data needs, data collection, and data manipulation for hydrologic analyses of the Menomonee River Watershed.

(b) Existing aerial photographic coverage of the Menomonee River Watershed has been inventoried and a mosaic has been assembled from color IR prints (NASA RB-57 photography, 4 June 1972).

(c) New aerial photographic images of the Menomonee River Watershed have been acquired, as follows:

(i) 22 May 1975 (color and color-IR, 70mm)
(ii) 16 July 1975 (color and color-IR, 70mm)

(d) Progress has been made in the development of computer programs for the identification and mapping of areas which are non-point sources of pollution using high-altitude imagery. Methods have been developed by Scarpace (1974) to process aerial photographic data such that multispectral data analysis techniques can be applied to digitized high-altitude color and color-IR photographic data. The method is based on the concept that a close approximation of the wavelength distribution of the energy incident on the film can be made by converting film density measurements in three wavelength bands (narrow bands of blue, green and red energy) to "equivalent energy" values. The derivation of equivalent energy values includes a consideration of film density, film dye density curves, filters in the optical path, film processing, and non-uniformity of scene illumination at the focal plane of the lens.

Once the equivalent energy spectrum has been determined everywhere on the film format (pixel sizes of 25, 50 and 100 microns are commonly employed), a modified supervised classification scheme is used. Selected training sets of data are displayed on the screen of an interactive computer terminal (PEP Terminal) and the brightness values for each resource are established for each of three bands (blue, green and red). The values for each of these bands are interactively changed until the interpreter is satisfied that the display represents correctly the resource on the ground. After the bounds for all resources are determined, the entire scene can be classified.

(e) Problems have been encountered in attempting to digitize selected portions of RB-57 color-IR photographs of the Menomonee River Watershed. Narrow-band interference filters were acquired which will allow better color separation of the images than previously used blue, green and red filters. However, it was found that because of insufficient blue energy in the light source of the optronics scanning microdensitometer, no satisfactory color separation on the imagery is possible with the existing instrumentation. A proposal to NSF has been submitted ($85,000) for a new flat-bed microdensitometer system. Until a new instrument arrives on campus, the availability of commercial vendors for this service is being investigated.

(4) Coordination with Appropriate Agencies

Coordination to date has been principally through participation in the previously mentioned Menomonee River Watershed seminars. At those seminars, contacts have been established with the Wisconsin Department of Natural Resources, the U.S.-Canada International Joint Commission Monomonee River study group, the Southeast Wisconsin Regional Planning Commission, and the University of Wisconsin Water Resources Center. During the coming year, it is planned that the Principal Investigator from the Wisconsin Department of Natural Resources will review with other investigators the techniques for acquiring and analyzing remote sensing data and provide suggestions for refinement in view of the field demands characteristic of the work of the DNR staff. Mapping results and costs will be reviewed with representatives of the Southeast Wisconsin Regional Planning Commission in whose area the Menomonee River basin is located. Efforts will be directed toward development of resource analysis techniques that can become operational tools for state and regional planning agencies.

D. References

Ishaq, A., and Huff, D. 1974. "Application of Remote Sensing to the Location of Hydrologically Active (Source) Areas," Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Ann Arbor, Mich., 15-19 April, 1974.

Scarpace, F.L. and Voss, A.W. 1974. "Analysis of Multi-Layer Films", Proceedings of the Spring ASP Meeting, March 1974.

V. PUBLICATIONS IN 1974-1975 RESULTING FROM NASA-SUPPORTED RESEARCH

A. Lake Eutrophication

1. "Classifying and Monitoring Water Quality by Use of Satellite Imagery," James P. Scherz, Douglas R. Crane and Robert H. Rogers, Proc., Michigan Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, October 1974.

2. "Water Quality Indicators Obtainable from Aircraft and LANDSAT Images and Their Use in Classifying Lakes," James P. Scherz and John F. Van Domelen, Proc., Fall ASP/ACSM Convention, Phoenix, Arizona, October 1975.

3. "A Versatile Interactive Graphics Analysis Program for Multispectral Data," Lawrence T. Fisher and Frank L. Scarpace, Proc., Spring ASP/ACSM Convention, Washington, D.C., March 1975.

4. "Trophic Status of Inland Lakes from LANDSAT," Lawrence T. Fisher and Frank L. Scarpace, NASA Earth Resources Symposium, Houston, Texas, June 1975.

B. Mixing Zone

1. "Application of Thermal Scanning to the Study of Transverse Mixing in Rivers," J. Wayland Eheart, Presented at Earth Resources Survey Symposium, Houston, Texas, June 1975, and to be published in a NASA document of conference proceedings.

2. "Mixing Zone Studies of the Sewage Discharge from the Waukesha Sewage Treatment Plant into the Illinois-Fox River at Waukesha, Wisconsin," John A. Hoopes, Dong S. Wu and James R. Villemonte, Report to Wisconsin Department of Natural Resources and to the National Aeronautics and Space Administration, August 1975.

3. "A Model for Calculation of Mixing and Spreading Characteristics of Surface and Submerged Shoreline Effluent Discharges into Water Bodies," Dong S. Wu, John A. Hoopes and James R. Villemonte, Technical Report, Institute for Environmental Studies, July 1975.

4. "Airborne Infrared Scanning," Larry Jaeger, Technical Report, Institute for Environmental Studies, 1975.

5. "A Comparison of Aerial Infrared and In Situ Thermal Plume Measurement Techniques," R.P. Madding, University of Wisconsin, and J.V. Tokar and G.J. Marmer, Argonne National Laboratory, Symposium on the Environmental Effects of Cooling Systems at Nuclear Power Plants, Oslo, Norway, August 1974.

6. "Thermal Plume Climatology from Infrared Scanning," R.P. Madding, L. Jaeger, F.L. Scarpace and T. Green, 41st ASP/ACSM Conference, March 1975, Washington, D.C.

C. Hydrologically Active Source Areas

1. "Application of Remote Sensing to the Location of Hydrologically Active (Source) Areas," Achi Ishaq, Ph.D. Thesis, Department of Civil and Environmental Engineering, University of Wisconsin, 1974.

D. General

1. "Cases in the Relation of Research on Remote Sensing to Decision-makers in a State Agency," James W. Jondrow, Program Coordinator, Environmental Monitoring And Data Acquisition Group and Center for Biotic Systems, Institute for Environmental Studies, University of Wisconsin-Madison, Proc. NASA Earth Resources Symposium, Houston, TX, June 1975.

6 copies

CLASSIFYING AND MONITORING WATER QUALITY BY USE OF SATELLITE IMAGERY

James P. Scherz and Douglas R. Crane
University of Wisconsin
Madison, Wisconsin 53706

Robert H. Rogers
Bendix Aerospace Systems Division
Ann Arbor, Michigan 48107

BIOGRAPHICAL SKETCHES

James P. Scherz is an Associate Professor in the Department of Civil and Environmental Engineering at the University of Wisconsin where he teaches surveying, photogrammetry, remote sensing and related subjects. His primary research work is with remote sensing of water quality.

Douglas R. Crane is completing a M.S. degree in Civil and Environmental Engineering at the University of Wisconsin. His graduate research work has been on remote sensing of water quality.

Robert H. Rogers is a senior staff engineer at Bendix Aerospace Systems Division where he is a principal investigator for NASA/ERTS and co-investigator for NASA/Skylab programs.

ABSTRACT

By use of distilled water samples in the laboratory, and very clear lakes in the field, a technique has been developed where the atmosphere and surface noise effects on LANDSAT signals of water bodies can be removed. The residual signal is dependent only on the material in the water. The general type and concentration of the material can be determined from LANDSAT tapes. When this material in the water is living algae or weeds, its concentration is related to the enrichment or eutrophication of the lake. The algae and weed biomass is at a maximum in late August which is therefore the optimum time to categorize lakes.

For this project, the Wisconsin Department of Natural Resources helped provide water samples, and the University of Wisconsin under NASA support helped provide laboratory and computer analysis and aerial observation of the lakes. The Bendix Multispectral Data Analysis System (M-DAS) provided a Color Categorized Image of several hundred lakes. These lakes were categorized for tannin or non-tannin waters and for the degrees of algae, silt, weeds, and bottom effects present. The initial categorization is being field checked in late August 1975.

INTRODUCTION

When LANDSAT images are used for mapping land targets essentially two factors are involved: (1) How the sun and skylight interact with the target to form a reflected signal, and (2) how the atmosphere effects this signal before it reaches the sensor. Land targets are considered as diffuse reflectors and Lambert's Law for diffused reflection can be used in the analysis.

When LANDSAT images are used for mapping or monitoring water quality the process becomes more complex. Sunlight and skylight interact with water surface, the particles in the water volume, and in some cases with the bottom. The signal from the water surface must be treated as primarily specular reflection but there is a small surface diffused reflection component caused by dust, foam and other contaminants on the water surface. The surface specular component varies greatly depending on the skylight condition and is essentially independent of the material in the water volume (1). The signal from the water volume can be treated as diffused reflection from the suspended particles in the water. The signal from the bottom is troublesome noise which follows the laws of diffused reflection. All of these signals combine to form the total signal from the lake or other water body. This total signal is modified by the atmosphere prior to its reaching the satellite sensor.

The most important component of the signal from the water is that caused by the material in the water volume. This is called volume reflectance or backscatter and is herein denoted by ρ_V. There is a different ρ_V for each color (wavelength). The volume reflectance for a water is primarily caused by light being diffusely reflected from suspended particles in the water between the water surface and the depth where the energy is extinguished. Pure or distilled water is assumed to contain no suspended material; therefore the volume reflectance of the suspended particles in distilled water is essentially zero. However, even in the laboratory there will be some diffuse backscatter from distilled water caused by the water molecules, dust, foam, or other impurities on the water surface. Let the laboratory diffused reflectance from impurities on the water surface be indicated by ρ_{SL}. There is a different ρ_{SL} for each color or wavelength of energy.

As material is added to a pure water sample the only factor that will be significantly altered will be the volume reflectance, ρ_V. The dust, foam and other impurities are likely to remain unchanged so the ρ_{SL} should not change. In some cases oil slicks can alter this ρ_{SL} but in all other cases it is considered unchanging. It is ρ_V, volume reflectance, which changes as material is added to the water. The type and amount of material added to pure water is what alters the water quality. Each type of material such as red clay, green taconite mine tailings, blue-green algae, etc. reflect differently at different wavelengths. These different materials have unique spectral reflectance signatures which are indicated by the ρ_V at different wavelengths. The LANDSAT Satellite has four different sensor bands so the type of material in water should be detectable from the four bands of LANDSAT.

For a particular size and shape of particle, as more material is added to the water there will be more particles to backscatter the light. The volume reflectance, ρ_V, will increase as will the total signal sensed by the

Satellite. Therefore, for a particular type of material, its concentration should be related to the LANDSAT signal strength.

It should be possible to determine both the type of material and its general concentration from LANDSAT images. To do so one must manipulate the total signal from LANDSAT so that only the volume reflectance, ρ_V, is left as a residual. Only ρ_V relates to the types and concentrations of materials in water. Surface effects, bottom effects, and atmospheric effects are all noise sources which must be removed. In order to remove these effects the volume reflectance, ρ_V, of distilled water or a very clear lake approaching distilled water must be determined in the laboratory or by use of the Bendix Radiant Power Measuring Instrument (RPMI) (2). Laboratory values are more precise than field values because in the field one must contend with indirect skylight and wave action which can be eliminated in the laboratory. On the LANDSAT image a clear lake which approaches distilled water must be used for calibration. With the LANDSAT signal from this lake and the known volume reflectance for its clear water it is possible to eliminate the surface and atmospheric effects and have residual signals which are indicative only of the type and concentration of the material in other lakes.

MADISON AREA LAKES

Figure 1 shows two LANDSAT images of lakes near Madison, Wisconsin. The upper image is taken in early spring shortly after the ice had thawed; there was essentially no algae growth in any of the lakes. All lakes appear essentially the same brightness on the LANDSAT image.

The lower image shows the same area in late August when algae and weed growth are at a maximum. Those lakes which have an abundance of nutrients (eutrophic lakes) have heavy algae growths. Skylight and sunlight interact with this suspended algae and is backscattered to the satellite. The denser the algae growth, the more the backscatter and the brighter it appears on the LANDSAT image. A clear (oligotrophic lake) such as Devil's Lake does not have enough nutrients present to sustain significant algae growth and it has approximately the same strength of backscattered signal in August as in early spring. The highly eutrophic lakes such as Lake Kegonsa have backscattered signals so high in August that they are virtually indistinguishable from the green fields in Figure 1.

The backscatter from a lake can be sensed in the four bands of the LANDSAT satellite. The long-established water quality parameter used to indicate backscatter is turbidity. Turbidity is an average value determined across the visible spectrum and its units are expressed as FTU's. Figure 2 shows the strength of the backscatter signal from Madison area lakes as sensed from the LANDSAT satellite on two different days in late summer. These signals are plotted against turbidity. It is obvious from Figure 2 that for a particular day there is a good correlation between the LANDSAT signal and turbidity and eutrophic classification. However, for a different day the height of this correlation curve shifts. This shift is caused by different atmospheric parameters from day to day. If one can determine the exact location of the curve for a particular day it can be used to map turbidity if there are no tannin lakes present nor lakes where bottom effects are significant.

For tannin lakes, the tannic acid in the water creates a dark brown color

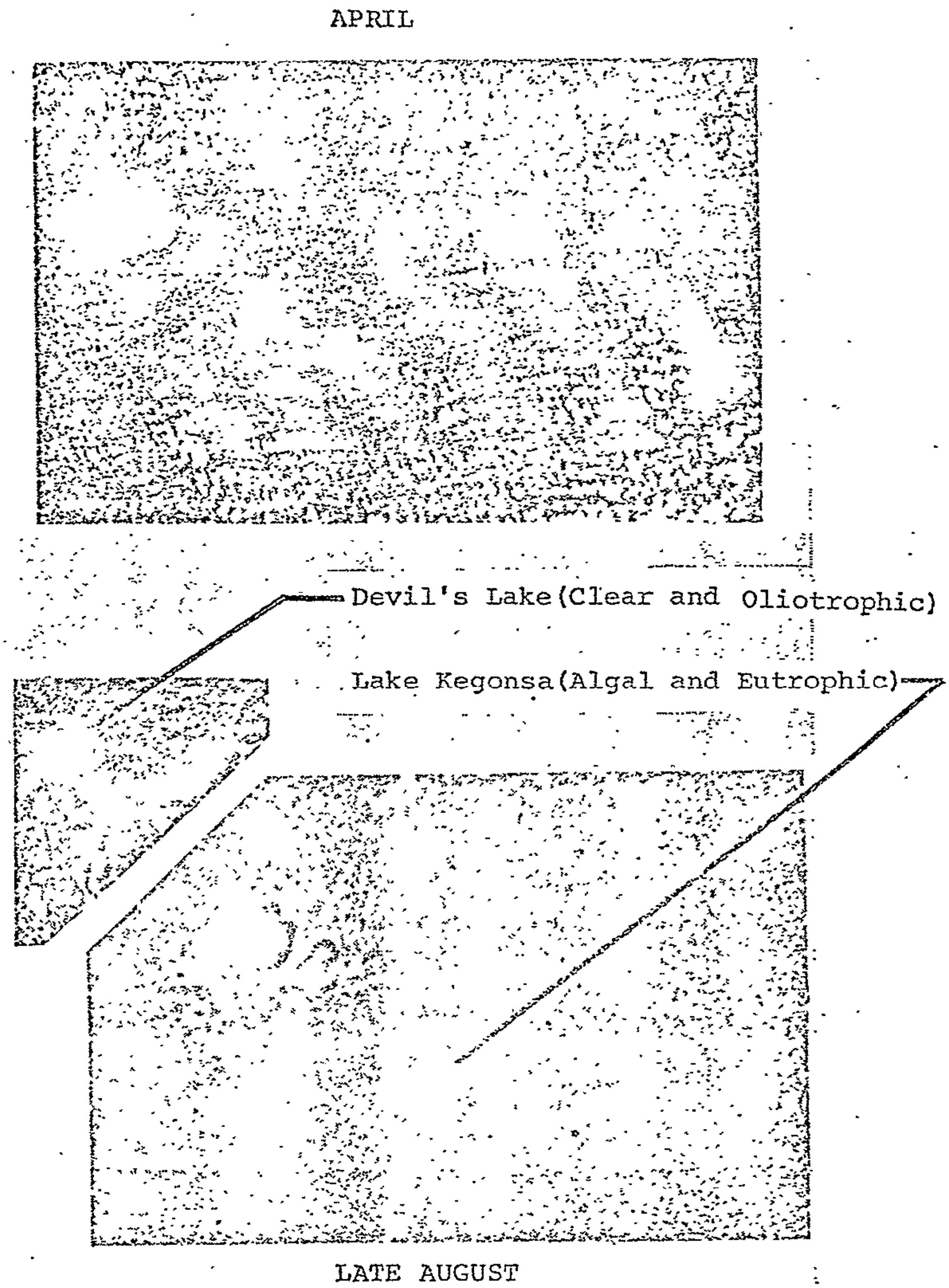
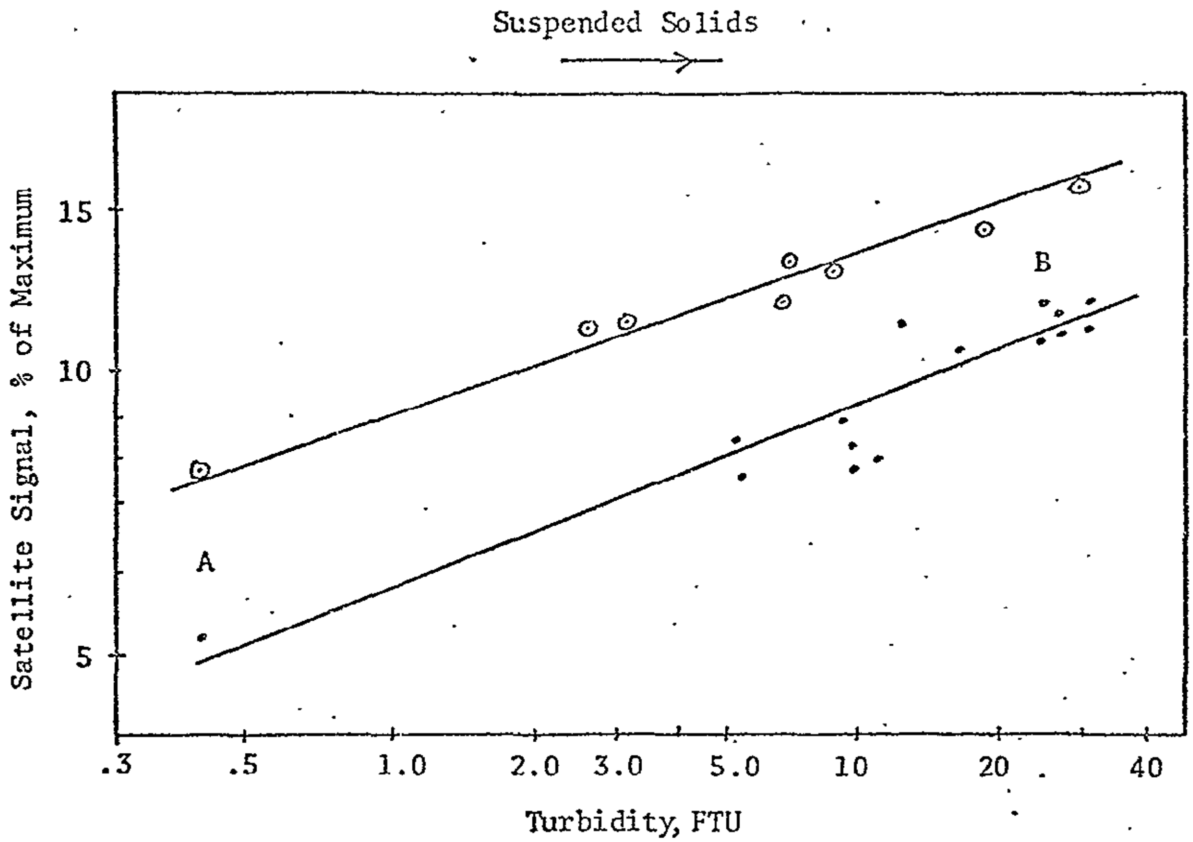


FIGURE 1 ERTS(LANDSAT) Images of Lakes near Madison, Wisc. in early Spring when Algae and Lake Weed Growth is a Minimum and in Late August when it is Maximum. Band 5 (Red)



• = 28 August 1972 ⊙ = 5 August 1973

A = Devil's Lake (clear, oligotrophic lake)

B = Lake Kegonsa (algae filled and eutrophic)

Figure 2. Strength of backscatter signal received by Band 5 of ERTS (LANDSAT), Madison Area Lakes. Note shift in height of curve for different days due to atmospheric change.

which absorbs energy. On the curve of Figure 2 such a lake would lie below the curve for the other lakes. For a lake with strong bottom effects the signal from say a sand bottom would create a point which lies far above the curve for the other lakes. In order to handle tannin and sand bottom lakes the spectral signatures must be analyzed first so the lakes can be put into classes of essentially tannin lakes, non-tannin lakes and bottom lakes. Within a class the curves, such as those in Figure 2, can be used to categorize the lakes as to turbidity and possible eutrophic classification. The lakes in Figure 2 are essentially non-tannin lakes with various amounts of algae present and no bottom effects.

In Figure 2 the shift of the signal-turbidity curve is considerable. There is no universal curve for all days. On the other hand, the laboratory curve of backscatter versus turbidity is essentially universal for all days. Figure 3 shows such a curve which combines laboratory red-light backscatter values for 127 samples analyzed over three years at the University of Wisconsin. Values for tannin lakes tend to fall slightly below the average curve and form a curve of their own, but generally speaking the laboratory backscatter versus turbidity curve is a universal curve. The laboratory backscatter in Figure 3 is indicated on the y axis by the apparent laboratory reflectance, AP, where

$$AP = \frac{\rho_V + \rho_{SL}}{\rho_{PL}}$$

and ρ_{PL} is the diffuse reflectance of the standard laboratory reflection panel. The calculated value of ρ_{PL} for .65 microns was 39%. The average approximate value of ρ_{SL} can be considered about 0.020%. With these values one can, with any ρ_V, obtain the corresponding expected value of turbidity. Once turbidity is known it is then possible to map other water quality parameters which might correlate to turbidity for that particular type of water.

The correlation of other water quality parameters such as suspended solids to turbidity is not universal but varies for different waters. It is possible to have a few large particles of dark material which have a certain weight which scatter back considerably less energy than say a large number of exceedingly fine white particles of the same total weight. For the same sized and shaped particles of a certain material there is a correlation between weight of suspended material and turbidity, but one must point out that this correlation will not necessarily hold for another material in a different type water.

When the material causing the turbidity or backscatter is say algae then there may also be a correlation between backscatter (satellite signal strength) and chlorophyll. But try the same correlation on an inorganic red clay and the backscatter-chlorophyll correlation breaks down. If the suspended material causing turbidity is municipal or industrial sewage which upon decay uses oxygen then for this situation there may be a correlation between backscatter (remote sensing signal strength) and Biological Oxygen Demand (BOD), or the dissolved oxygen which is not yet used up (3). However, try the same correlation on inorganic red clay in water and the correlation breaks down. For all waters however, the correlation of backscatter (volume reflectance, ρ_V) and turbidity holds as shown in Figure 3. For Red Energy (.65 microns) this correlation is: $T = 5.21(AP)^{2.00}$

ORIGINAL PAGE IS
OF POOR QUALITY

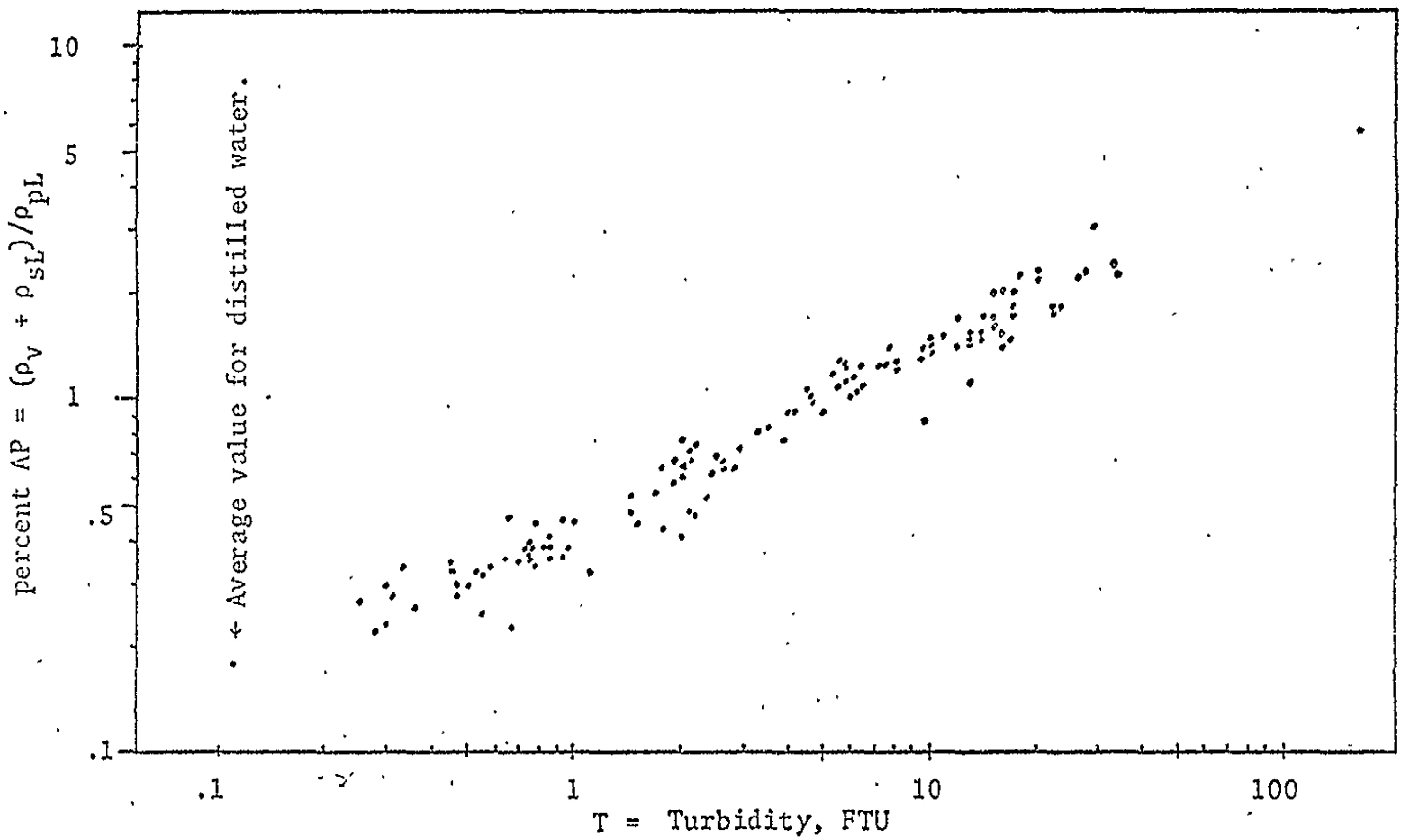


Figure 3. Laboratory backscatter expressed as apparent laboratory reflectance, AP, plotted against turbidity for 127 different lake samples collected over three years. This curve is for red light (0.65 microns). The best fit equation for this data is $T = 5.21(AP)^{2.00}$

For this investigation, the volume reflectance values, ρ_v, for a water are obtained for different wavelengths, some of which correspond to the LANDSAT bands. The resulting spectral signature allows one to put lakes into general categories such as tannin or non-tannin waters. Then within a category a curve such as in Figure 3 can be used to categorize the lakes as to relative turbidity and the amount of suspended material such as algae which causes this turbidity.

LABORATORY ANALYSIS

The volume reflectance, ρ_v, can be obtained by the scheme shown in Figure 4. In a darkened laboratory, a laboratory lamp provides light onto a standard $BaSO_4$ diffuse reflection panel and onto the water sample. The water sample is in a tube .62 meters long which has a black bottom. Shorter tubes will cause overriding bottom signals which make the results confusing or meaningless as will a bottom which is too reflective (4)(5). The sides of the tube are lined with diffusely reflecting white chronoflex which returns side-scattered energy simulating adjacent water volumes in the field.

The radiance of the lamp is L_L in watts/cm^2 s. As viewed from the level of the panel or water sample the solid angle of the lamp is ψ_L steradians. The total irradiance that reaches the level of the panel at right angles to the rays is $L_L\psi_L$. The total irradiance available on the panel per unit area is

$$H_L = L_L\psi_L\cos\theta \text{ (Watts/cm}^2\text{)}$$

where θ is the angle between the lamp and the vertical as shown in Figure 4. The indirect illumination from the ceiling L_c (watts/cm^2 s) is zero in the perfect laboratory setup.

Lambert's Law states that P, the diffuse radiance returning into space from the panel, is

$$P = \frac{H_L}{\pi}\rho_{PL} \qquad \text{equation 1}$$

where ρ_{PL} is the diffuse reflectance of the panel.

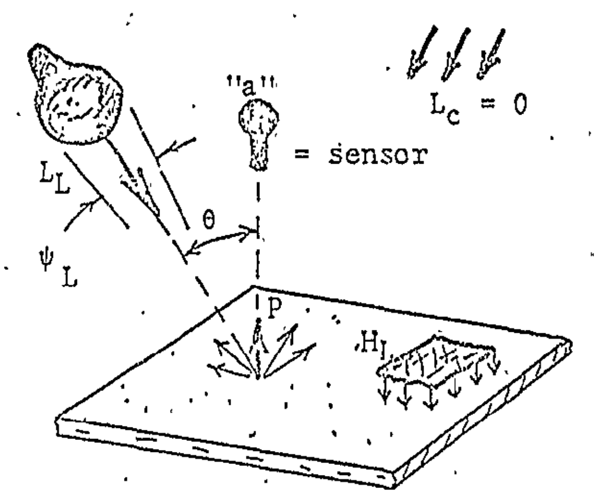
Since the dust, foam and other impurities on the water surface also behave as diffuse reflectors their signal, S_L, also follows Lambert's Law

$$S_L = \frac{H_L\rho_{SL}}{\pi}$$

where ρ_{SL} is the diffuse reflectance of the impurities on the water surface in the laboratory. The suspended particles in the water volume are also diffuse reflectors and cause the radiance from the water volume V.

$$V = \frac{\rho_v H_L}{\pi}$$

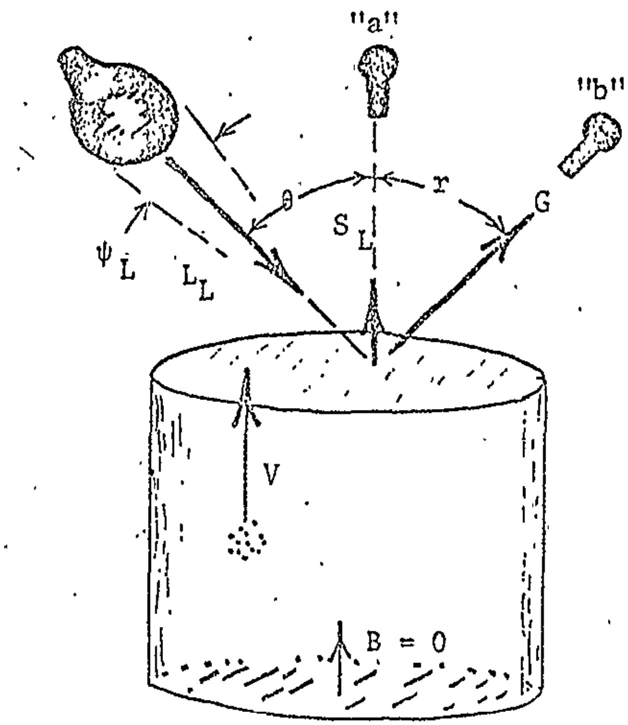
where, ρ_v = the diffuse reflectance of the particles in the water volume. This ρ_v is the all-important factor which is indicative of water quality.



Standard Diffuse Reflection Panel

L_L = Radiance of Laboratory Lamp, Watt/cm^2 s

H_L = Irradiance on Horizontal Panel caused by Lamp, Watt/cm^2



Water Sample

P, S, V, and B are Radiance values (Watt/cm^2 s) caused by Diffuse Reflection

G is glitter Radiance (Watt/cm^2 s) caused by specular reflection

Figure 4. Direct Energy Relationships in the Laboratory

The signal G does not follow the laws of diffuse reflection. When $\theta = r$, as in Figure 4, the signal G is specular reflection of the lamp's radiance from the air-water interface.

$$G = \phi L_L \text{ (Watts/cm}^2\text{s)}$$

where ϕ = the surface specular reflection of a water-air interface.

$$\phi = \frac{(n_w - n_a)^2}{(n_w + n_a)^2} \quad \text{where}$$

n_w = index of refraction of water = 1.333, and
n_a = index of refraction of air = 1.000.

$$\phi = \frac{(1.333 - 1.000)^2}{(1.333 + 1.000)2} = 0.020$$

This value holds fairly well out to angles of θ and r of about 40 degrees of the vertical. Most remote sensing operations fall within this range.

The total signal from the water as seen by the sensor is w

$$W = V + S_L$$

$$W = \frac{\rho_V H_L}{\pi} + \frac{\rho_{SL} H_L}{\pi}$$

$$W = (\rho_V + \rho_{SL}) \frac{H_L}{\pi} \qquad \text{equation 2}$$

The ratio of this signal W to the signal from the panel is called apparent laboratory reflectance AP.

$$AP = \frac{W}{P} = \frac{\frac{H_L}{\pi} (\rho_V + \rho_{SL})}{\frac{H_L}{\pi} (\rho_{PL})} = \frac{\rho_V + \rho_{SL}}{\rho_{PL}} \qquad \text{equation 3}$$

The ρ_{PL} reflectance for $BaSO_4$, for 0.65 microns by use of equation 1, was calculated to be 39% $\pm$ 1.5%. Therefore AP = $(\rho_V + \rho_{SL})/.39$. Figure 3 is a plot of this AP for waters of different turbidities.

Let subscript "1" indicate values for distilled water and subscript "2" indicate values from water sample #2 (a more turbid water). We can define $AP_2 - AP_1$ as the "Laboratory Difference, D_2" between the laboratory apparent reflectances of samples #2 and #1 (distilled water).

$$D_2 = AP_2 - AP_1$$

$$D_2 = \frac{\rho_{V2} + \rho_{SL}}{\rho_{PL}} - \left(\frac{\rho_{V1} + \rho_{SL}}{\rho_{PL}}\right)$$

$$D_2 = \frac{\rho_{V2} - \rho_{V1}}{\rho_{PL}} \qquad \text{equation 4}$$

From Figure 3 we see that for distilled water the average value of AP_1

$$AP_1 = \frac{\rho_{v1} + \rho_{SL}}{\rho_{FL}} = 0.18\%$$

A usable value for ρ_{SL} is .020%. This leaves a value for ρ_{v1} = .18%(.39) - .020%
ρ_{v1} = .050%.

From equation 4 if we have D_2; we can calculate ρ_{v2} by

$$\rho_{v2} = D_2\rho_{FL} + \rho_{v1}$$

$$\rho_{v2} = D_2 .39 + .05\%$$

The value

$$D_2 = \frac{\rho_{v2} - \rho_{v1}}{\rho_{FL}}$$

is the important factor which will be further used to correlate between laboratory values and satellite values.

BOAT ANALYSIS

When the water being analyzed is out of doors as in Figure 5 we still have the direct radiance of the sun L_s', which behaves analagously to the laboratory lamp in Figure 4. We also have L_c', the average indirect radiance from the skylight. According to Lambert's Law the total irradiance effecting a horizontal surface due to this skylight is-

$$H_c' = L_c'\pi.$$

The sun's direct contribution is $H_s' = L_s'\psi\cos\theta$. Let the total irradiance be H_o'

$$H_o' = H_s' + H_c'$$

$$H_o' = L_s'\psi\cos\theta + L_c'\pi$$

The diffuse signal from a field reflection panel, P, would be

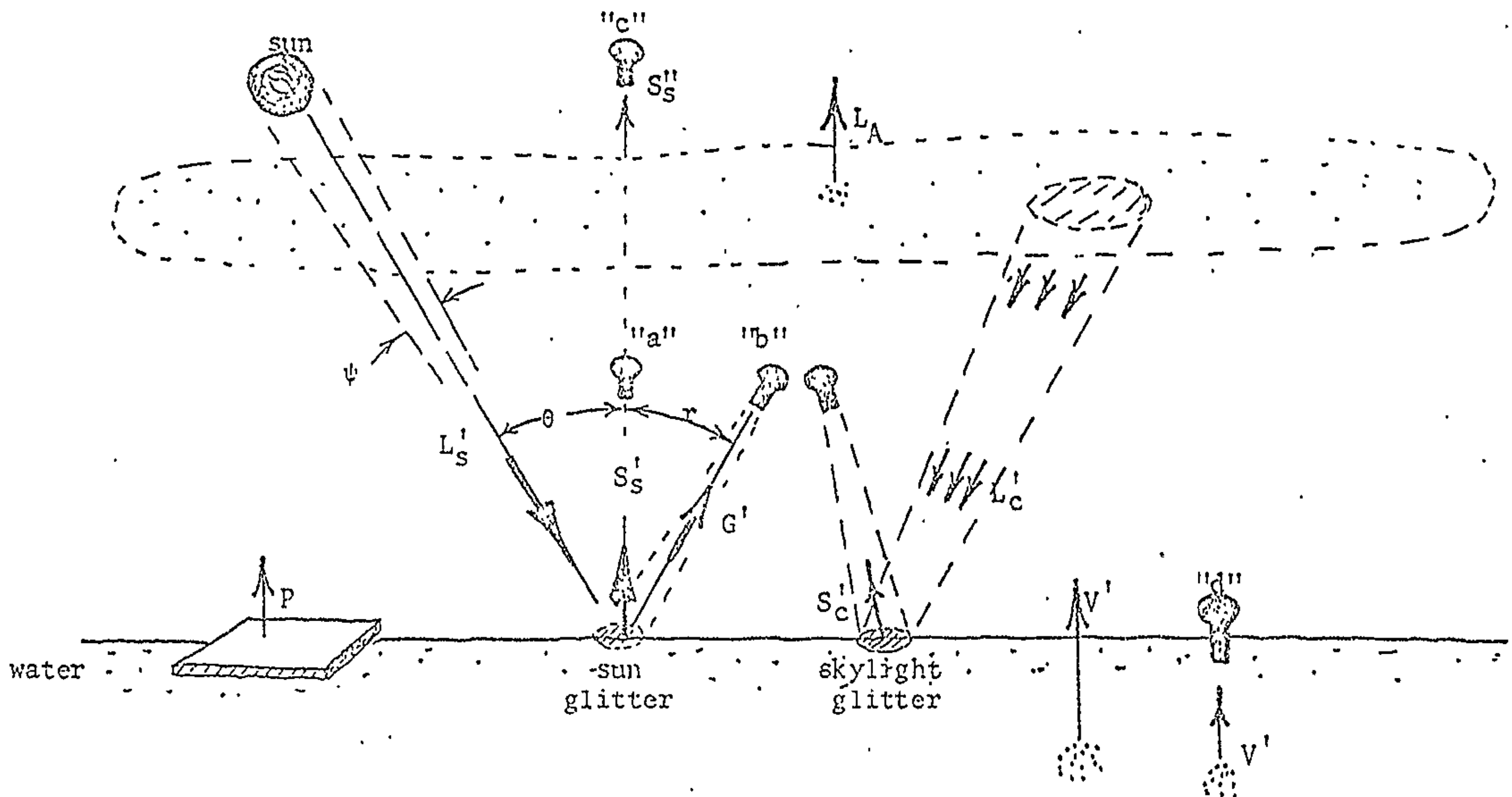
$$P = \frac{H_o' \rho_P}{\pi}$$

where ρ_P = the reflectance of this field panel.

Also following Lambert's Law for diffuse reflection, S_s', the diffuse reflection caused by impurities on the water surface is:

$$S_s' = \frac{H_o' \rho_S}{\pi}$$

where ρ_S = the field diffuse reflection for foam, leaves, and other dirt



L_s' = suns radiance reaching water

L_c' = skylight radiance reaching water; skylight irradiance on panel is H_c'; $H_c' = \pi L_c'$

S_s', V', are diffuse reflection from impurities on water surface and from material in water

G', S_c', are specular reflection of sunlight and skylight from water surface

Figure 5. Direct and Indirect Energy Relationships in the Field.

on the water surface. Also V', the radiance from the water volume is

$$V' = \frac{H_o' \rho_V}{\pi}$$

The specular reflection of the sun from the water surface (sun glitter) is

$$G' = L_S' \varphi = .020\ L_S'$$

In a similar manner the specular reflection of the skylight from the water surface is S_c'.

$$S_c' = L_c' \varphi = .020\ L_c'$$

The total signal from the water is W'.

$$W' = V' + S_S' + S_C'$$

$$W' = \frac{\rho_V H_o'}{\pi} + \frac{\rho_S H_o'}{\pi} + .020\ L_c'$$

$$W' = (\rho_V + \rho_S) \frac{H_o'}{\pi} + .020\ L_c'$$

The signal from the field panel is

$$P' = \rho_p \frac{H_o'}{\pi}$$

If one were determining the volume reflectance of a particular lake in the field with the Bendix RPMI ground truth instrument this can most easily be done by pointing the RPMI sensor telescope down through the surface of the water as in position "d" in Figure 5. Assuming no significant bottom signal the sensor at "d" only reads the radiance from the water volume V'.

$$V' = \frac{\rho_V H_o'}{\pi}$$

H_o' can be obtained directly by use of the RPMI or a reading can be taken on the panel,

$$P' = \rho_p \frac{H_o'}{\pi}$$

$$\frac{H_o'}{\pi} = \frac{P'}{\rho_p} \quad \text{and}$$

$$\rho_V = V' \frac{\rho_p}{P'}$$

Thus the ρ_V can also be obtained in the field for any water sample with the RPMI. However, due to variations in skylight and wave action in the field the laboratory determination of ρ_V is a magnitude more precise than field determinations.

ORIGINAL PAGE IS
OF POOR QUALITY

When the signal from the water level such as S_s' in Figure 5 passes upward through the atmosphere it is attenuated by the atmospheric transmittance τ; $S_s'' = S_s'\tau$. Also the atmospheric backscatter, LA, is added to the signal. Therefore, the total signal from the water as sensed at "c" in Figure 5, is

$$W'' = (V' + S_s' + S_c')\tau + LA$$

$$W'' = \left[\frac{\rho_v H_o'}{\pi} + \frac{\rho_s H_o'}{\pi} + .020\ L_c'\right]\tau + LA$$

$$W'' = (\rho_v + \rho_s)\frac{H_o}{\pi}\tau + .020\ L_c'\tau + LA$$

If we let subscripts 1 and 2 represent distilled or very clear water and a turbid lake (#2) respectively, then

$$W_1'' = (\rho_{v1} + \rho_s)\frac{H_o'\tau}{\pi} + .020\ L_c'\tau + LA$$

$$W_2'' = (\rho_{v2} + \rho_s)\frac{H_o'\tau}{\pi} + .020\ L_c'\tau + LA$$

Also if we define the satellite residual R_2'' to be the difference in signals which is caused only by the material in water #2, then

$$R_2'' = W_2'' - W_1'' = (\rho_{v2} - \rho_{v1})H_o'\frac{\tau}{\pi}$$

Again assuming the volume reflectance of distilled water, ρ_{v1}, to be known;

$$\rho_{v2} = R_2''\frac{\pi}{H_o'\tau} + \rho_{v1} \qquad \text{equation 5}$$

With this ρ_{v2} one can enter the curve on Figure 3 and obtain turbidity. What is needed in the above situation is W_1'', a reading on a very clear lake. Then this reading can be subtracted from the reading from any other lake W_i''.

$$R_i'' = W_i'' - W_1'' \quad \text{and}$$

$$\rho_{vi} = \left[R_i''\frac{\pi}{H_o'\tau}\right] + \rho_{v1}$$

If $\frac{\pi}{H_o'\tau}$ is not known the answers are in relative terms only. If the ρ_{v2} of a turbid lake (sample #2) is known then from equation 5,

$$\frac{\pi}{H_o'\tau} = \frac{\rho_{v2}}{R_2''}$$

This $\frac{\pi}{H_o'\tau}$ term can then be used to solve for the absolute volume reflectance of any lake.

The results in this paper are for relative values of ρ_{vi} only. The exact mathematical relationships were not fully understood at the time of the overflights in order to obtain the necessary simultaneous ground truth for sample #2.

SATELLITE ANALYSIS

On the LANDSAT image assume we can locate a very clear lake, "#1", which approaches distilled water in purity. This lake must be deep enough so that no bottom is showing. Aerial observation should be made to assure that there are no bottom effects showing in this test lake.

Let W_1'' equal the satellite raw reading on the clear lake. Let W_2'' equal the raw reading on Lake #2, the lake in question. The raw readings for Band 4 and Band 5 are very high due to atmospheric effects and the differential water signals are perhaps 1% of these raw readings. The raw readings are not very meaningful. However, if we subtract W_1'' from W_2'' the residual is due only to the material in Lake #2.

$$R_2'' = W_2'' - W_1'' = (\rho_{v2} - \rho_{v1})H_o' \frac{\tau}{\pi}$$

The four bands of LANDSAT cover as follows:

Band 4: 0.50 to 0.60 microns

Band 5: 0.60 to 0.70 microns

Band 6: 0.70 to 0.80 microns

Band 7: 0.80 to 1.10 microns

Let us plot the total signal from Bands 4, 5, 6, and 7, as centering on wavelengths 0.55, 0.65, 0.75, and 0.95 respectively. Figure 6 shows such a plot of the satellite residual, R_2'', for these four LANDSAT bands. Three types of waters; clear, tannin, and algal, are readily differentiated. Therefore, it is possible to separate lakes into these classes by LANDSAT signals alone. Also, within a particular class such as algal, one can categorize the lake as to how much algae is present. Figure 7 shows satellite residual signals of lakes which grade from clear to heavy algal.

The shape of the satellite residual curves of Figure 7 duplicate well the shape of the laboratory reflectance difference curves in Figure 8 for the same types of water. In Figure 7, the satellite residual

$$R_i'' = (\rho_{vi} - \rho_{v1})H_o' \frac{\tau}{\pi}$$

In Figure 8, the laboratory reflectance differences are:

$$D_i = (\rho_{vi} - \rho_{v1})\frac{1}{\rho_{p_L}} = (\rho_{vi} - \rho_{v1})\frac{1}{.39}$$

Therefore, the values on the two figures vary only by the factor:

$$\frac{R_i''}{D_i} = H_o' \frac{\tau}{\pi} \div \frac{1}{.39} = .39\ H_o' \frac{\tau}{\pi}$$

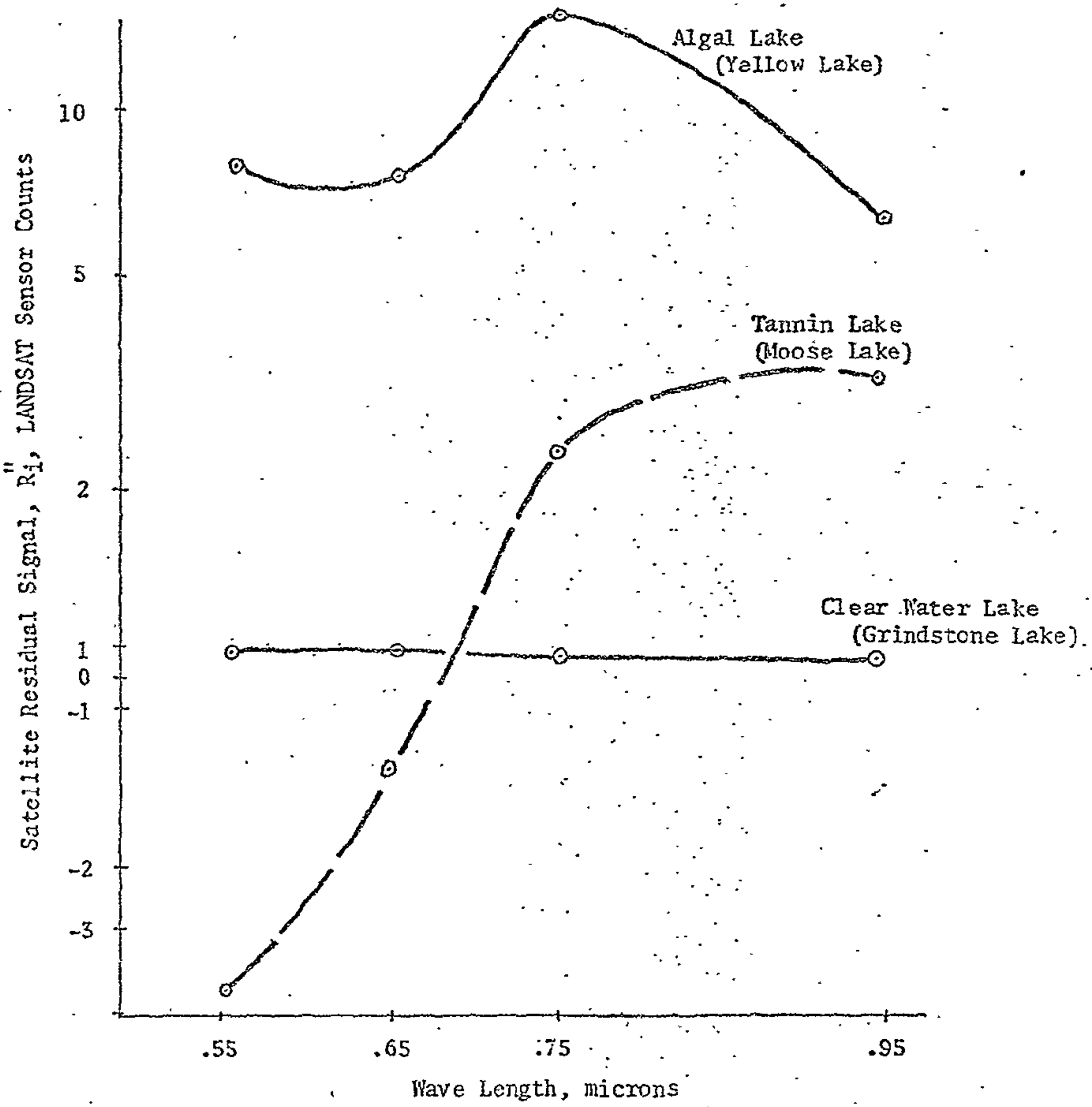
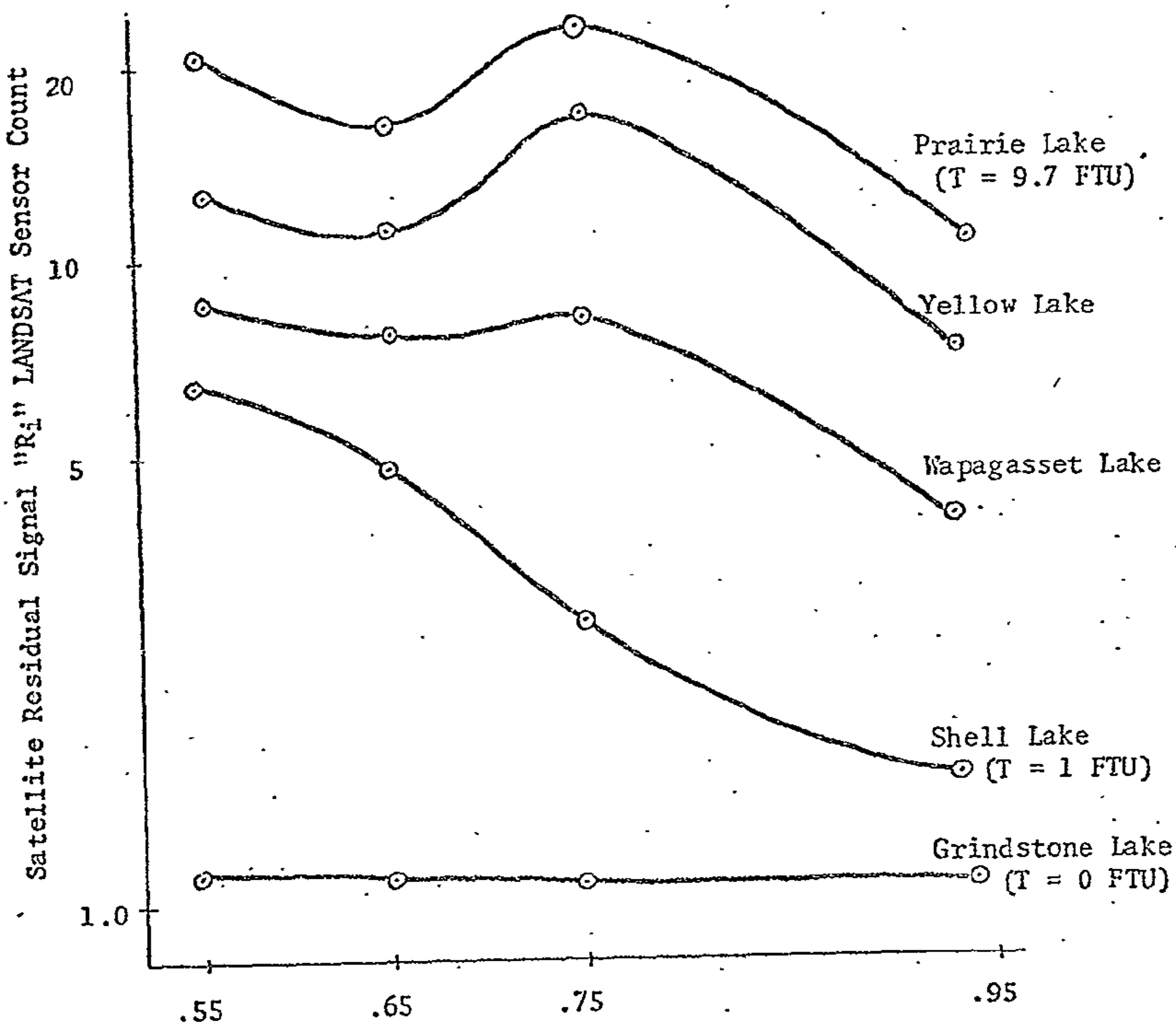


Figure 6. Satellite Residual Signal, R_i, for three water types.

$$R_i'' = W_i'' - W_1'' = (\rho_{Vi} - \rho_{V1})H_o' \frac{\tau}{\pi}$$



T = turbidity

Figure 7. Satellite Residual Signal "R_i" for clear-type water lakes with various amounts of algae present.

$$R_i = (\rho_{vi} - \rho_{v1})H_o' \frac{\tau}{\pi}$$

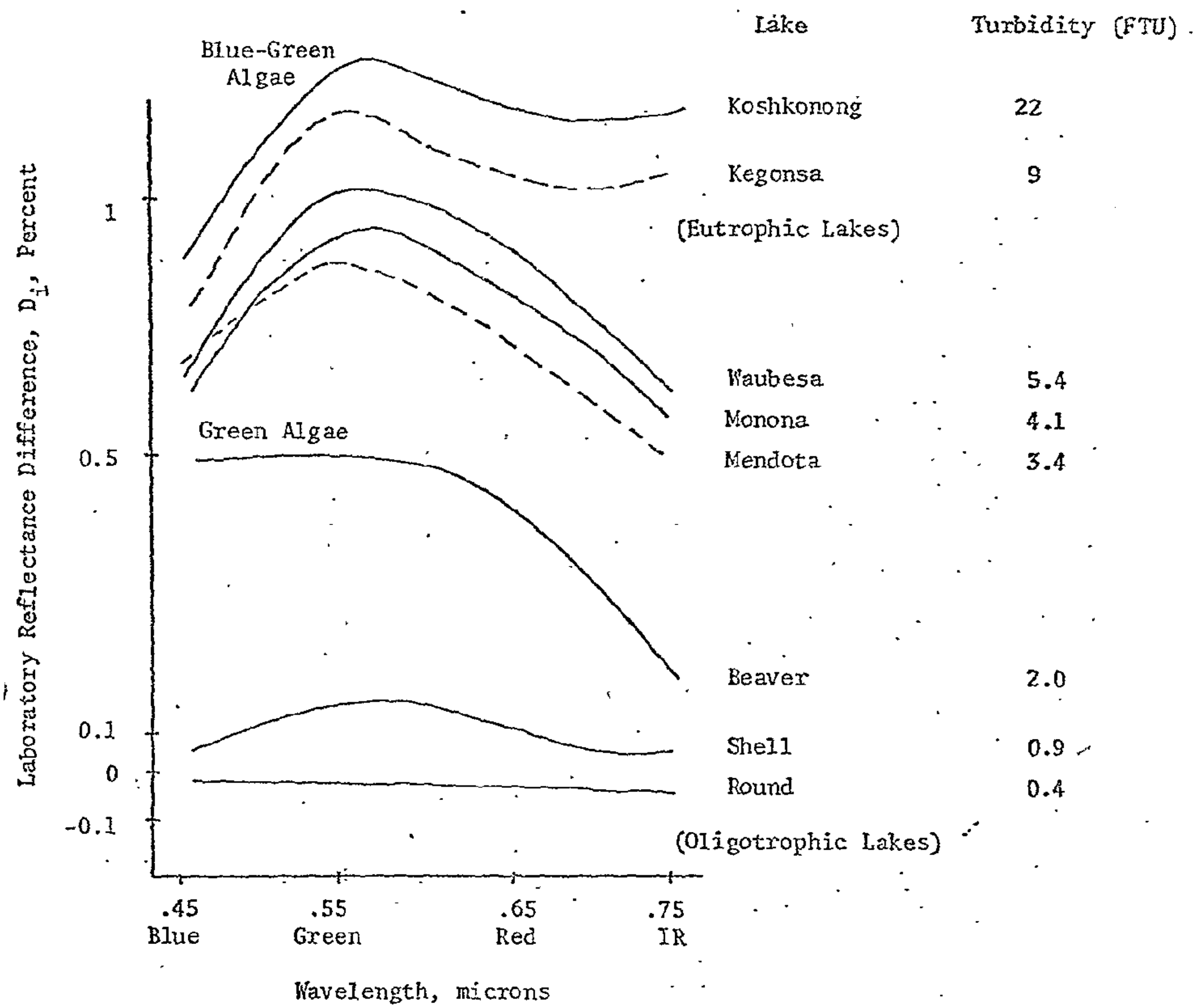


Figure 8. Laboratory Reflectance Difference Curves (D_i) for clear-water type lakes with various amounts and types of algae present.

$$D_i = (\rho_{vi} - \rho_{vl}) \div \rho_{PL}$$

The gradation between heavy algal and clear water lakes are equally apparent in both Figures 7 and 8. Exact corresponding turbidities are also shown in Figure 8. Three approximate turbidities are shown in Figure 7. On Figure 8 one can also see that it is possible to tell the differences between types of algae. Blue-green and green algae types are indicated. Green algae are usually not the nuisance types but blue-green algaes are, and are often associated with eutrophic lakes which can become low in dissolved oxygen.

Figure 9 shows that although the tannin type lakes have a different shaped characteristic curve, the more turbid tannin lakes have a higher signal and follow the same general pattern as with the algal lakes. Figure 9 also shows the relative ranges of the satellite and laboratory data.

OPTIMUM TIME OF YEAR FOR EUTROPHIC CLASSIFICATION

Figure 10 shows that in an individual lake the volume reflectance can change markedly from a characteristic clear water lake in early spring to a very algal lake in late summer and back to a clear water type lake in late fall. This is also indicated by Figure 1. The maximum algal and weed growth is in late August. This is also the time of minimum dissolved oxygen (see Figure 10) and also the time of maximum water temperature and when the nitrates become completely tied up in some lakes. From many indicators, late August is the optimum time for eutrophic classification of lakes.

BOTTOM PROBLEMS

The bottom effect problem is a difficult noise factor in satellite classification of lakes. Bottom signals can show in any of the lake types. The type of bottom (dark mud, light sand, or green weeds), also will give a different characteristic modification to signals from each of these water types. Also the depth to bottom effects the strength of the signal and also its spectral distribution.

It is anticipated that the bottom effect problem can be completely isolated by analyzing LANDSAT data from spring imagery when the lakes are clear and free of algae and the bottoms are very apparent. Where bottom signals are strong they are a characteristic signal and can be classified as another lake type. Figure 11 shows sand bottom and weed bottom effects on the satellite signals from a tannin type lake.

COLOR CATEGORIZED IMAGES PRODUCED BY THE BENDIX CORPORATION M-DAS EQUIPMENT

By training the Bendix M-DAS computer for each type of lake of interest the machine recognized all such types in the scene and displayed desired types as a color categorized image. It must be emphasized that good ground truth in the form of some water samples and aerial observations of the test lakes are essential for the training of the M-DAS equipment. The aerial observations are especially essential in locating the troublesome bottom effects which might show up on a training lake chosen without aerial observation.

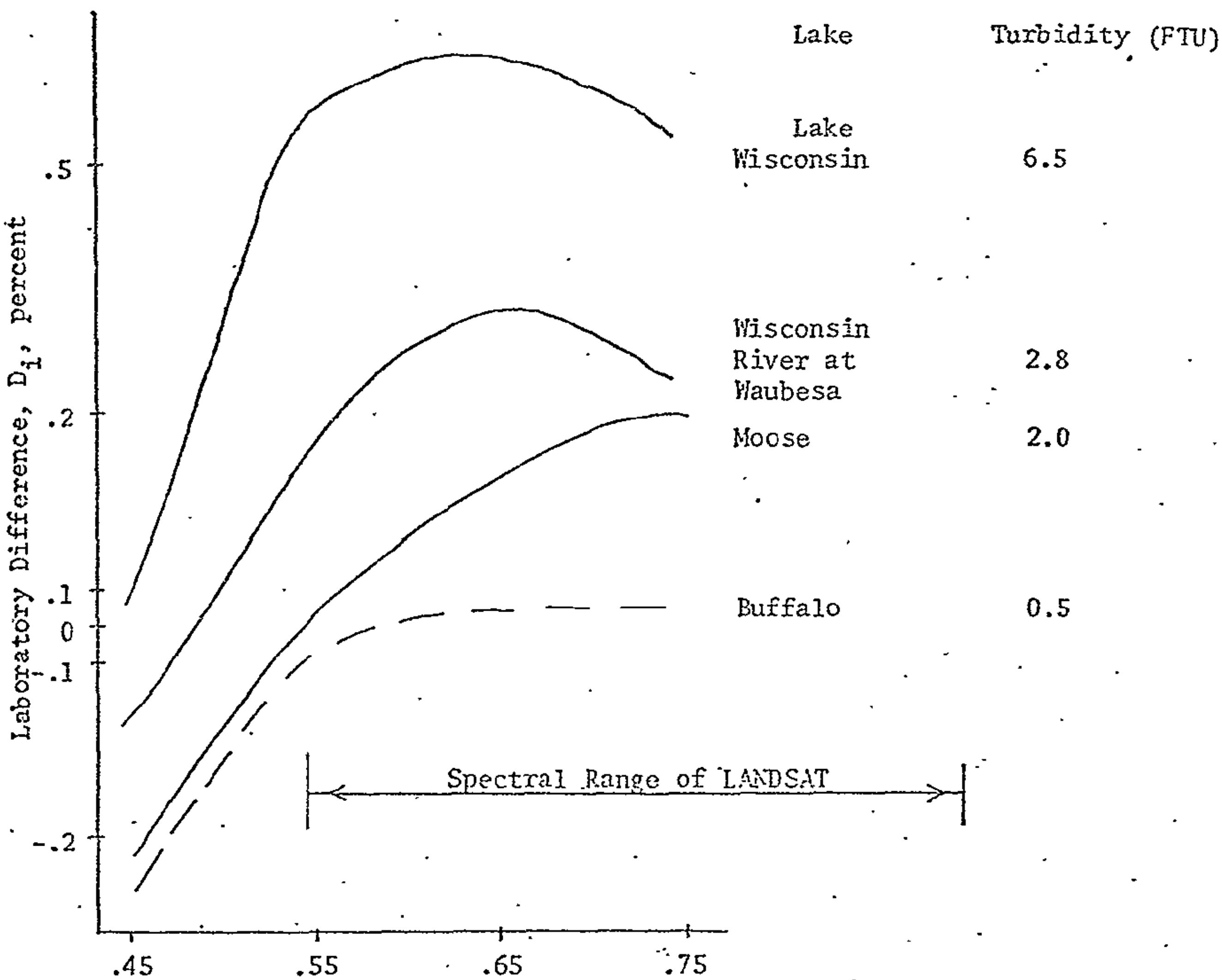
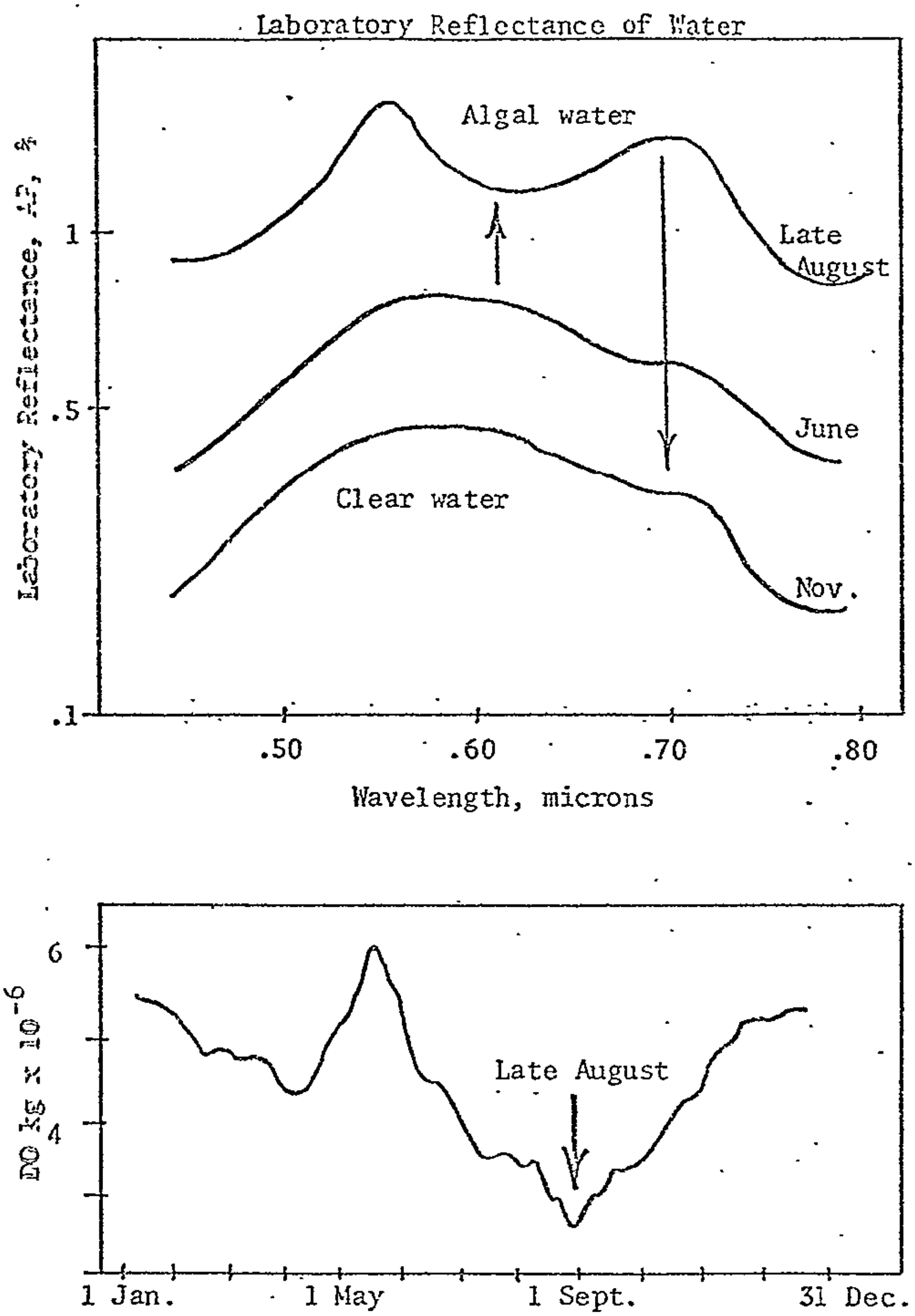


Figure 9. Laboratory Reflectance Difference Curves (D_i) for tannin water lakes.

ORIGINAL PAGE IS OF POOR QUALITY



DO = Dissolved oxygen

Figure 10. Time of year effect on Laboratory Reflectance of Madison Area Lake. Maximum Reflectance occurs at the same time as minimum dissolved oxygen, which is late August.

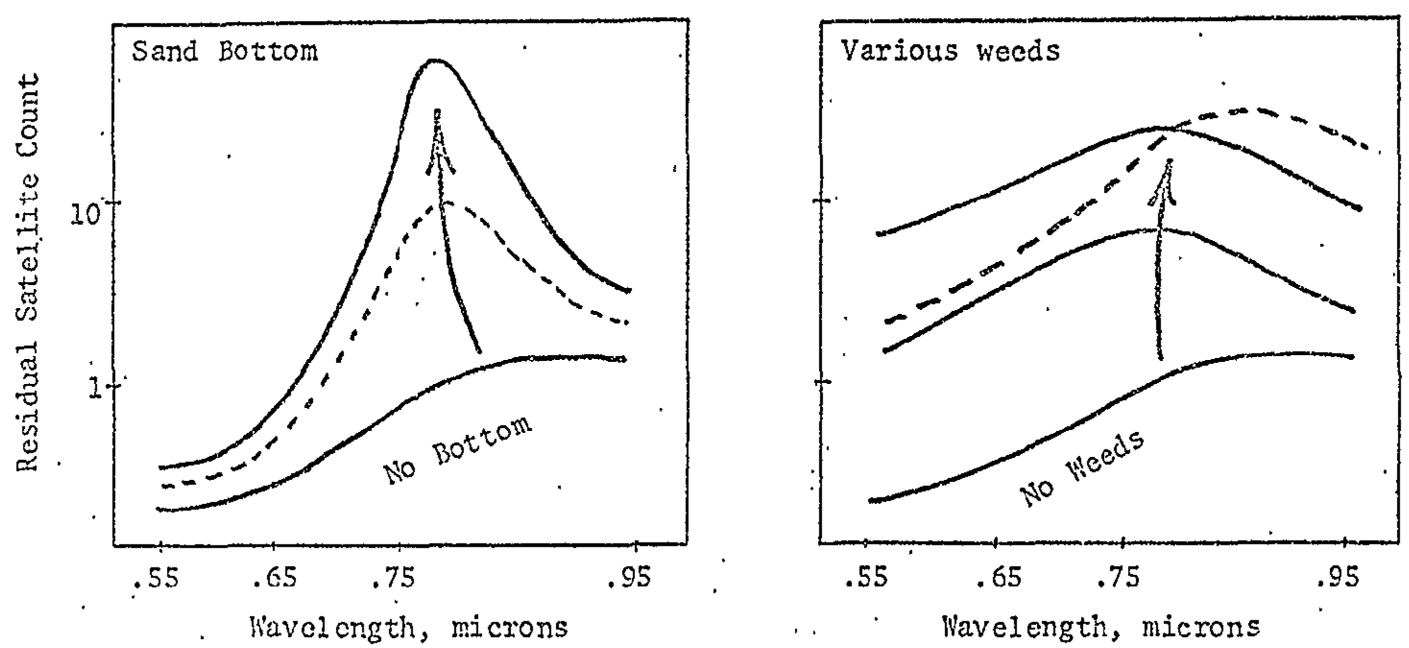


Figure 11. Effect of sand bottom and various kinds of weeds on satellite signal of a tannin-type lake.

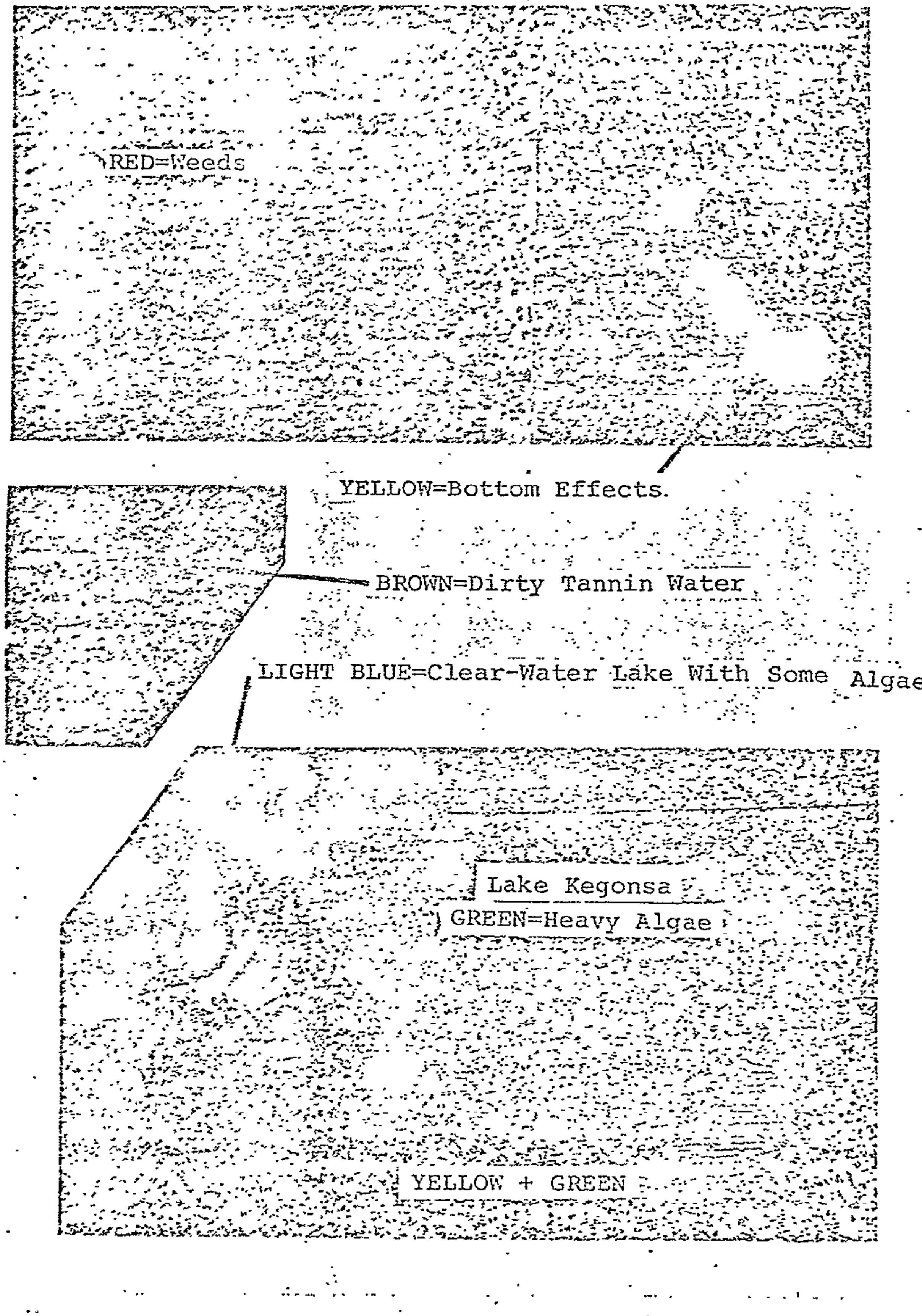


FIGURE 12 Initial Color Catagorized Image Produced by Bendix Corp. Showing Lake Catagorization.

Figure 12 shows the test color categorized image for lake categorization produced by the M-DAS equipment. The results look good and are being field checked in August, 1975. Further anticipated work includes combining spring imagery with summer imagery to completely solve the bottom effect problem.

ACKNOWLEDGEMENTS

The authors acknowledge the National Aeronautics and Space Administration for their support under Grant No. NGL 50-002-127, and NAS 5-20942 and those who helped administer these grants. The authors are also grateful to Francis Schraufnagle and other personnel from the Wisconsin Department of Natural Resources who helped especially in the field efforts. The authors also are grateful to those other persons from the University of Wisconsin and Bendix Aerospace Division who helped make this investigation possible.

REFERENCES

(1) Piech, Kenneth R. and Walker, John E. "Aerial Color Analyses of Water Quality." Journal of the Surveying and Mapping Division - Proceedings of the American Society of Civil Engineers. November, 1971.

(2) Rogers, Robert H.; Peacock, Keith; and Shah, Navinchandras J. "A Technique for Correcting ERTS Data for Solar and Atmospheric Effects." Paper 1-7 presented at the 3rd ERTS Symposium sponsored by NASA/GSFC, Washington D.C. December 10-14, 1973.

(3) Psuty, Norbert P.; Allen, James R. "Trend-Surface Analysis of Ocean Outfall Plumes." Photogrammetric Engineering. June, 1975.

(4) Gramms, Lorne C. "Reflectance and Transmittance Characteristics of Selected Green and Blue-Green Unialgae for Remote Sensing Application." PhD. Thesis, University of Wisconsin. 1971.

(5) Scherz, James P., and Van Domelen, John F. "Lake Superior Water Quality near Duluth from Analysis of Aerial Photos and ERTS Imagery." Remote Sensing and Water Resources Management American Water Resources Association. June, 1973.

WATER QUALITY INDICATORS OBTAINABLE FROM AIRCRAFT AND LANDSAT IMAGES AND THEIR USE IN CLASSIFYING LAKES

Dr. James P. Scherz
University of Wisconsin
Madison, Wisconsin

Dr. John F. Van Domelen
Norwich University
Northfield, Vermont

ABSTRACT

For remote sensing of water quality when distilled water and a very clear, deep lake approaching distilled water are used as laboratory and field reflectance standards it is possible to eliminate surface reflection and atmospheric effects. For other target lakes, the resulting residual radiance is due only to the material added to the pure water of these lakes. This material is what impairs water quality. The relative strength of the residual radiance at different wavelengths can be used to determine the type of material. The absolute strength of the radiance can be used to determine its concentration. If physical interactions are understood, these techniques can be used with laboratory, boat or satellite data.

INTRODUCTION

To adequately use remote sensing for water quality mapping, three important interactions must be understood: how sunlight and skylight interacts with (1) the surface of the water, (2) the particles within the water volume to the depth where light is extinguished and (3) where the bottom occurs before the light is extinguished, how bottom effects contribute to the total signal. The volume and bottom materials are diffuse reflectors. The water surface behaves as partially a diffuse reflector and partially a specular reflector. The relative specular component changes markedly with atmospheric conditions. Except for oil spills which alter the surface reflection it is the material added to the volume of pure water which determines water quality. Therefore the signal from the water volume is the only component that correlates to water quality. Where the bottom is significant, its signal is complex depending on the type of bottom material, its depth, and the type of water (1). When the sensor is airborne, the atmosphere attenuates all signals and also records a signal of atmospheric backscatter.

Rain water is essentially distilled water, and some lakes capture and hold this rain water in a very pure form. Light falling onto the surface of such a lake is returned by the air-water interface and to a very minute extent by backscatter caused by the water molecules. The water molecules scatter back mostly blue light. When exceedingly fine particles of suspended material such as glacial rock flour is added, the backscatter signal changes to blue-green or turquoise such as one finds in glacier-fed Lake Louise in Canada or in some spring-fed lakes in glacial till soil. As the size of the particles increase, the color of the signal approaches that of the material which forms the particles. As more of these larger particles are added more light is backscattered and the total signal increases.

Some dissolved materials absorb certain wavelengths of light. Tannic acid added to distilled water absorbs blue energy and results in a reddish-brown color. In minute concentrations it creates a "yellow" color in the water. This brown or yellow color is associated with decay of humus material often in spruce or tamarack swamps, and creates the "tannin lakes" common in northern latitudes. Blue energy absorption increases with the concentration of tannic acid, but if a suspended material such as algae is added, the backscatter it causes increases with the concentration of the algae. However, the backscatter from normal concentrations of algae in tannin waters will be less in the blue than from algae in non-tannin waters.

Most industrial and municipal pollution contains suspended particles which can be monitored by remote sensing. The type of material is associated with the relative backscatter at different wavelengths, and the concentration is related to the total signal. Where pollution is phosphate and nitrate nutrients, there is no direct backscattered signal caused by these clear dissolved materials. However, they do cause algae and weed growth both of which are detectable by airborne sensors. The maximum growth of these algae and lake weeds occurs in late August. The amount of this total biomass is associated with the lake enrichment (or state of eutrophication). Therefore airborne remote sensing can be used in late summer to detect presence and concentration of algae and weed growth which is indicative of eutrophic categorization (1).

Figure 1 shows an ERTS (LANDSAT) image of the South West end of Lake Superior near Duluth, Minnesota. The water in Lake Superior is very clear and deep and approaches distilled water in quality. The signal from site "a" is essentially a signal from distilled water of infinite depth; there are no bottom effects. At site "b", there is a heavy runoff of inorganic red clay material which causes an increased backscattered signal. The more the red clay, the higher the turbidity, and the greater the signal to the LANDSAT sensor. Turbidity which correlates to the satellite signal is an important water quality parameter. It is an average of the total light backscattered in the visible spectrum; its units are FTU's or JTU's (9). For drinking water, turbidity must not exceed 5 FTU's, but in 1969 an $8,000,000 water intake was constructed at "c" in Figure 1. It produced water too turbid for human use over 50% of the time with turbidity often as high as 100 FTU's. Had remote sensing been used in locating the water intake it should have been located not at "c" but a few miles to the north where the water remains clear as indicated by LANDSAT images such as in Figure 1.

PHYSICAL RELATIONSHIPS

Figure 3 shows the relationship between the illuminating energy and the energy returned from the water and from a standard field reflectance panel. These signals can be detected by an airborne sensor or one mounted on a boat. The bottom radiance, B, is assumed to be zero. The sun's radiance reaching the water surface is L_S' watts $cm^{-2}sr^{-1}$. (sr = steradian). The sun's solid angle is ψ and its zenith angle is θ. The solar altitude is $90° - \theta$. The sun's irradiance on a flat surface is H_S' watts cm^{-2}. $H_S' = L_S' \psi \cos\theta$. The average skylight radiance is L_C' watts $cm^{-2}sr^{-1}$. By Lambert's Law the skylight irradiance, H_C', on a flat surface is $H_C' = L_C' \pi$ watts cm^{-2}. Let H_O' equal the total radiance on a flat surface, $H_O' = H_S' + H_C'$.

All values of radiance, etc. can be determined for different wavelengths. Unless other wise noted, examples given are for red energy, 0.65 microns. The panel is a duffuse reflector and according to Lambert's Law the radiance returned upward from the panel is $P' = \rho_P H_O'/\pi$ watts $cm^{-2}sr^{-1}$, where ρ_P is the diffuse reflectance of the panel. For a styrafoam panel ρ_P was computed from the above equation to be 39.5%. Foam, dirt, leaves and other impurities on the water surface act as diffuse reflectors and create a surface signal S_S'. $S_S' = \rho_S H_O'/\pi$ where ρ_S = diffuse reflectance of impurities on the water surface.

The air-water interface also acts as a specular reflector. G' and S_C' are specular reflection signals caused by the sun and skylight radiance respectively. $G' = \phi L_S'$ where ϕ is the specular reflectance of the air-water interface. For angles of θ and r (in Figure 3) out to about 40°, $\phi = 0.020$. However ϕ becomes significantly larger approaching 0.75 when the sun is near the horizon (2,3). The skylight specular reflection component S_C' can be approximated by $S_C' = L_C'\phi$ but here both L_C' and ϕ become variable factors, dependent on that part of the sky being reflected and the angle these rays make with the water surface. Water roughness and wave height both effect L_C' and ϕ; these two factors are in effect variable depending on skylight and wind conditions. Therefore let the subscript * denote that these are complex values that change with different physical conditions, $S_C' = L_{C*}'\phi_*$.

The energy that passes downward through the air-water interface is I_o.

$$I_o = H_o'(1 - \phi - \rho_s) = H_o'(.98 - \rho_s) \tag{1}$$

The energy I_o is diffusely backscattered by the particles in the water to create signal V. $V = \rho_V I_o/\pi$ where ρ_V is the volume reflectance of the particles in the water. V' is that portion of V which passes upward through the water-air interface.

$$V' = (1 - \phi)V = 0.98V = 0.98\ \rho_v I_o/\pi;\ V' = \frac{\rho_v H_o'}{\pi}(0.96 - 0.98\rho_s) \tag{2}$$

Except for oil slick analysis, Equation 2 will be simplified to: $V' = \rho_V H_O'/\pi$. The sun glitter G' can be avoided by proper pointing of the sensor. The total vertical signal from the water is W'.

$$W' = V' + S_s' + S_c'$$

These signals pass upward through the atmosphere where they are modified by the atmospheric transmittance, τ. For example: $S_s'' = \tau S_s'$ (Figure 3). The <u>airborne sensor</u> also sees the atmospheric backscatter, LA. As seen by an airborne sensor the total signal from the water is W". $W'' = (V' + S_s' + S_c')\tau + LA$.

$$W'' = \frac{\rho_v H_o' \tau}{\pi} + \frac{\rho_s H_o' \tau}{\pi} + \phi_* L_{c*}' \tau + LA$$

The airborne signal from the panel is P"; $P'' = \rho_p H_o' \tau/\pi + LA$.

The <u>apparent airborne reflectance</u> of the water is defined as $AP'' = W''/P''$ which can be reduced to:

$$AP'' = \frac{\rho_v + \rho_s}{\rho_p}\left(\frac{1}{k}\right) + \frac{\phi_* L_{c*}' \pi}{\rho_p H_o'}\left(\frac{1}{k}\right) + (k - 1)\left(\frac{1}{k}\right) \tag{3}$$

$$\text{where } k = 1 + \frac{LA\pi}{\rho_p H_o' \tau}$$

The airborne <u>residual</u> R_2'' is defined as $R_2'' = W_2'' - W_1''$ where W_1'' is the signal from a very clear lake approaching distilled water and W_2'' is the signal from a more turbid lake, #2. R_2'' is largely due to the material in the water of lake #2.

$$R_2'' = (\rho_{v_2} - \rho_{v_1}) H_o' \ \tau/\pi \tag{4}$$

where ρ_{v_2} and ρ_{v_1} are the volume reflectance of Sample #2 and distilled water respectively. Let D_2'' denote the <u>difference</u> between apparent airborne reflectance of Lakes #2 and #1.

$$D_2'' = AP_2'' - AP_1'' = \frac{\rho_{v_2} - \rho_{v_1}}{\rho_p}\left(\frac{1}{k}\right) \tag{5}$$

Let superscript (') denote values of apparent reflectance residuals, etc. obtained from a boat. <u>At boat level</u>, $\tau = 1.0$, $k = 1.0$, and $LA = 0$. Some appropriate values for the boat level can be determined from Equations 3, 4 and 5 as follows:

$$AP_2' = \frac{\rho_{v_2} + \rho_s}{\rho_p} + \frac{\phi_* L_{c*}' \pi}{\rho_p H_o'} \; ; \; R_2' = (\rho_{v_2} - \rho_{v_1}) \frac{H_o'}{\pi} \; ; \; D_2' = \frac{(\rho_{v_2} - \rho_{v_1})}{\rho_p} \tag{6}$$

For radiance measurements in a laboratory, the perfect situation is where the only irradiance, H_L, is from a lamp. There is no ceiling light. The sample tube must be deep enough with a dark bottom least confusing bottom signals be created (4, 5).

The diffuse reflectance of impurities on the water surface in the lab is ρ_{SL}. ρ_{PL} is the diffuse reflectance of the laboratory reflectance panel. For a $BaSO_4$ standard laboratory reflectance panel, ρ_{PL} = 39%. Lack of superscripts are used to denote lab values.

$$AP_2 = \frac{\rho_{v_2} + \rho_{SL}}{\rho_{PL}} \; ; \; R_2 = (\rho_{v_2} - \rho_{v_1}) \frac{H_L}{\pi} \text{ , and } D_2 = \frac{\rho_{v_2} - \rho_{v_1}}{\rho_{PL}} \tag{7}$$

If we use laboratory and field panels of the same reflectance ($\rho_{PL} = \rho_P$) and assume equal diffuse surface reflectance ($\rho_{SL} = \rho_S$) then one can establish the theory for translating between airborne, boat and laboratory conditions. For example:

$$AP_i'' = \frac{\rho_{v_i} + \rho_s}{\rho_p} (\frac{1}{k}) + \frac{\phi_* L_{c*}' \pi}{\rho_p H_o'} (\frac{1}{k}) + (k - 1)(\frac{1}{k}) \tag{8}$$

but $(\rho_{v_i} + \rho_s)/\rho_p = AP_i$ and at the boat level k = 1. So

$$AP_i' = AP_i + \frac{\phi_* L_{c*}' \pi}{\rho_p H_o'} \text{ , etc.} \tag{9}$$

On very windy days when there is much white cap foam, one cannot however assume that $\rho_S = \rho_{SL}$. For the airborne situation, k could be determined from measurable airborne and laboratory values. By Equations 5 and 6 or 7, $k = D_2/D_2'' = D_2'/D_2''$. Figure 2 shows lab and satellite values of AP_i'' and AP_i for waters of different turbidity. The laboratory AP_i curve is essentially universal for all waters and is described as

$$T = 5.21(AP_i)^{2.00} \text{ or } AP_i = \sqrt{T/5.21} \tag{10}$$

where T is turbidity in FTU. AP_i is the apparent laboratory reflectance in percent for a water sample i. From Figure 2 the average value for AP_1 (distilled water) = $(\rho_{v_1} + \rho_{SL})/\rho_{PL}$ = 0.0018 with ρ_{PL} = 0.39, this gives $\rho_{v_1} + \rho_{SL}$ = 0.0046. If we assume an average value of ρ_{SL} = .0020, ρ_{v_1} = .0026. While the laboratory curve is universal for all samples, airborne AP_i'' curves vary from day to day due to changes in the atmospheric effects included in k. This is shown by the different AP_i'' curves for each day in Figure 2.

The factor $\phi_* L_c' * \pi/\rho_p H_o'$ is the skylight specular surface reflection component. It would be possible to create emperical curves for this factor for various solar altitudes, cloud or haze conditions, and wave heights. If such curves were available, for any day one could obtain a suitable value of $\phi_* L_c' * \pi/\rho_p H_o'$ and with it and Equations 8 and 9 translate from laboratory to boat or airborne values. A rough approximation to such curves are values of water albedo obtained from a clear lake in the Soviet Union by Ter-Markaryants and reported by Kondrat'yev in 1965 (6). Albedo is defined as total energy returning upward divided by total energy downward. For a clear lake approaching distilled water, as used by Ter-Markaryants, this albedo is essentially caused by energy returning from the air-water interface. Figure 4 shows Ter-Markaryant's curves of albedo from pure water for various cloud conditions and solar altitudes. These curves, like values of turbidity, are average values across the energy spectrum. However, approximate values for wavelengths of .45, .55, .65 and .75 microns can be determined by multiplying curve values by 0.7, 1.0, 0.75 and 0.58 respectively (2). Let the curve value multiplied by the appropriate spectral factor be called $A_i^!$ (surface albedo for distilled water). For water sample, i, if we obtain the apparent boat reflectance $AP_i^!$, and subtract $A_i^!$ we have a factor defined as $\Delta_i^!$ which is primarily caused by material in the water volume of lake i; the approximate surface reflection component has then been removed from $AP_i^!$. $\Delta_i^! = AP_i^! - A_i^!$. Relationships between $\Delta_i^!$ and turbidity (T) have been determined by Van Domelen (2) which for red energy, 0.65 microns, and a white styrafoam panel are:

$$\Delta_i^!(\%) = 4.34 - 4.61e^{-.18T} \tag{11}$$

For various values of T, Equations 11 and 10 can be used to calculate $\Delta_i^!$ and $AP_i^!$. For some values of T they compare well, but deviate at other values. This shows that the curves in Figure 4 can be used for approximations of the value $\phi_* L_c^! * \pi/\rho_p H_o^!$ in Equation 9. For more precision, curves refined specifically for this term could be drawn up, or as more data becomes available, modifications may be made to Equation 11 which might bring the values closer together.

Theoretical equations have been herein presented to help describe physical relationships. For the ultimate accuracy in actual monitoring of water quality it is often desirable to obtain a water sample of a turbid lake as a ground truth point (in addition to the very clear lake). These two lakes can be used for interpolating and ascertaining quality of various lakes within the image similar to how ground control points are used to orient a stereoplotter model for aerial topographic mapping. Also instead of working with apparent reflectance $AP_i^{''}$, if one works with satellite residuals, $R_i^{''}$ and the laboratory differences, D_i, then surface reflectance components are completely eliminated and greater accuracy achieved. This is the technique used in examples given later which show very high sensitivity.

BOTTOM EFFECTS

To this point bottom effects, B in Figure 3 were assumed zero. In many lakes B' is not zero but very large. One must know when bottom effects are significant. In Figure 3 the energy that penetrates below the water surface is I_o. The energy that reaches the bottom through depth "Y" is I_B. By definition $I_B = I_o/e^{(\alpha Y)}$ where e = 2.718 and α is the extinction coefficient of the water. If a white Secchi disc is lowered into the water to depth SD until it is no longer visible, then according to Holmes (7) the energy I_{SD} that penetrates to this Secchi disc depth is approximately 1/10 I_o. Therefore, as a working approximation $e^{(\alpha SD)} = I_o/I_{SD} = 1/0.1 = 10$, and $\alpha SD = \text{Ln } 10 = 2.3$; therefore $SD = 2.3/\alpha$.

SD is the hypothetical Secchi disc reading for a particular wavelength. In actual practice the Secchi disc reading, like turbidity, gives an average value across the visible spectrum while remote sensing investigations are concerned with exact wavelengths. The extinction coefficient, α, can be obtained for different wavelengths as well as the hypothetical Secchi disc reading, $SD = 2.3/\alpha$. Figure 5 shows such values for various waters as well as actual Secchi disc readings. From these curves one can obtain an understanding of the penetration of different wavelengths of energy into various waters compared to the readily obtained Secchi disc reading. The Secchi disc reflectance is almost always greater than the reflectance of bottom material so if the bottom is deeper than the Secchi disc reading it will not be visible to the eye yet it might be significant to more sensitive sensors.

MAGNITUDE OF ENERGY THAT RETURNS FROM BELOW THE SECCHI DISC READING AND FROM VARIOUS LAYERS OF WATER

The diffuse reflectance of a white styrafoam panel was computed as 39%. Assuming the reflectance of the Secchi disc to be the same, then B_{sd}, the energy returning upward from the Secchi disc is:

$$B_{sd} = I_{sd}(.39)/\pi = 0.1\ I_o(.39)/\pi = 0.0124\ I_o$$

The portion of this energy that returns upward to the water surface, B'_{sd}, is approximately:

$$B'_{sd} = 1/10\ B_{sd} = .00124\ I_o = 0.12\%\ I_o$$

To calculate the amount of energy that returns from various layers in the water volume, 5 equal layers of thickness "d" are created above and below the Secchi disc reading. $d = SD/5$ · (Figure 6). Let I_{in} be the energy striking any layer and I_{out} be the energy transmitted through it. (Figure 5) I_{back} is the energy backscattered by the particles in that layer. Let "b" be the unit backscatter, $b = I_{back}/I_{in}$, and let t be the unit transmittance through layers of thickness d. $t = I_{out}/I_{in}$ (Figure 6). From the extinction formula:

$$\alpha d = \text{Ln}\ (I_{in}/I_{out}) = \text{Ln}\ (1/t)$$

but α 2.3/SD and $d = SD/5$ so $2.3/SD*SD/5 = \text{Ln}(1/t)$; and from this $t = 0.63$. The unit backscatter b will change depending on the type of material but will lie between 0.37 and 0. If in Figure 6 one follows the light transmitted and backscattered from one unit volume to the next until the energy is extinguished or reaches the surface, we can calculate $\Delta V'$, the total energy coming from particles in each layer. From layer 1, $\Delta V'_1 = bI_o$. From layer 2, $\Delta V'_2 = bI_o t^2\ F$, where $F = (1 + b^2 + b^4 + b^6 + \ldots)$. For any layer:

$$\Delta V'_i = bI_o t^{(2i-2)} F^{(2i-3)}$$

The sum of all the $\Delta V'_i$ for all layers is V'.

The percent of V' that comes from the first layer is $\Delta V'_i/V'$ which for different waters is 59%; from the second and third layer it is 24% and 9.5%, etc. Figure 6 shows a graph of % energy that comes from each of the layers. This graph is very useful when used in conjunction with a Secchi disc reading. It shows how to integrate a water sample to get a representative collection of water particles which cause the energy returned to sensors from the total water volume. More than one remote sensing investigation of water quality has resulted in meaningless confusion because water samples were collected from clear water overriding polluted water into which the light penetrated and returned (8). Also the curve in Figure 6 can be used to ascertain what portion of the total signal V' still returns from below the Secchi disc reading which is often useful for bottom studies.

EFFECT OF OIL SLICKS ON THE RADIANCE FROM A WATER BODY

An oil slick modifies the radiance from water in three ways: first it has a higher specular reflection than water so the specular reflection component will increase. Second, an oil volume backscatter signal is added, and third the oil attenuates and decreases the signal fromthe water volume below. In some cases these combinations of factors will cause decreasing total signal with increasing oil thickness. In other cases an increasing total signal results (2).

Figure 7 shows a sketch of energy as it strikes a water surface with and without oil. For simplicity, consider no dust, leaves or other diffuse reflectors on the surface, i.e., $\rho_s = 0$ and $S'_s = 0$. For the no-oil case, from Equation 2: $V' = \rho_v H'_o/\pi(.96 - .98\rho_s)$. For the oil situation, the skylight reflectance from the surface of the oil is $S'_o = \phi_o L'_c$. The specular reflectance from an air-oil interface, ϕ_o, is 0.040 which is twice that for water. There is V'_o, volume backscatter from the oil of depth X. V'_o will increase as X increases up to the depth where all light is extinguished which will not occur on most thin oil spills. The signal that penetrates below the air-oil interface is $H'_o(1 - \phi_o) = 0.96\ H'_o$. This is attenuated by t_o the transmittance of the oil of depth X. As X increases t_o will decrease. The signal I_{wo} that finally reaches the water from the oil is approximately $I_{wo} = .96\ H'_o\ t_o$. This energy interacts with particles in the water volume to produce the backscatter signal U_w. $U_w = \rho_v I_{wo}/\pi = .96\rho_v H'_o t_o/\pi$. This signal is again attenuated as it passes back up through the oil to produce V'_w, the water volume signal detected by the sensor.

$$V'_w = (1 - \phi_o)\ t_o U_w = (.96) t_o (.96)\ \rho_v H'_o t_o/\pi = .92\ \rho_v t_o^2 H'_o/\pi$$

The total signal from the no-oil case, assuming non-complex surface reflections, is: $W' = S'_c + V' = .020\ L'_c + (.96\ \rho_v\ H'_o)/\pi$. From the oil case it is $W'_o = S'_o + V'_o + V'_w$.

$$W'_o = \underset{(\#1)}{.040\ L'_c} + \underset{(\#2)}{V'_o} + \underset{(\#3)}{.92\ \frac{\rho_v}{\pi}\ t_o^2 H'_o}.$$

An exceedingly thin oil film will cause a quantum jump in the total signal due to the greater reflection of skylight from the surface (#1). Component (#2), V'_o, increases slowly with more oil and "t_o" in (#3) decreases. Sometimes the signal from the water volume (#3) decreases due to "t_o" at a greater rate than the signal V'_o (#2) increases. On a very clear day with turbid waters, components L'_c and V'_o are small compared to H'_o; the major component is #3 and the total signal W'_o may decrease with increasing oil thickness. However, on a completely overcast day or with very clear water, component #3 becomes less significant and can approach zero. In this case components #1 and #2 predominate and the total signal W'_o may increase with greater oil depths. Figure 8 shows apparent reflectance $AP' = W'_o/P'$ for various thickness of oil slicks on a clear and an overcase day. On the clear day the apparent reflectance decreases with increased oil thickness while on an overcast day it increases.

VOLUME REFLECTANCE VERSUS TURBIDITY

As shown in Figure 2, the relationship between apparent laboratory reflectance AP_i and turbidity is: $T = 5.21\ (AP_i)^{2.00}$ but $AP_i = (\rho_{v_i} + \rho_{SL})/\rho_{PL}$ and with a $BaSO_4$ reflectance standard $\rho_{PL} = 0.39$; assuming an average value of $\rho_{SL} = 0.002$ this can be modified to: $T = 34.2\ \rho_{v_i}^{\ 2} + .14\ \rho_{v_i}$ where ρ_{v_i} is in percent.

TURBIDITY VERSUS SUSPENDED SOLIDS AND OTHER WATER QUALITY PARAMETERS

The correlation of other water quality parameters such as suspended solids to turbidity is not universal but varies for different waters. It is possible to have a few large particles of dark material which scatter back considerably less energy than a large number of exceedingly fine white particles of the same total weight. For a particular material in a particular water there is a correlation between weight of suspended material and turbidity, but this correlation will not necessarily hold for another material in a different type water.

When the material causing the turbidity and/or backscatter is algae then there may also be a correlation between backscatter and chlorophyll. But try the same correlation on an inorganic red clay and the backscatter-chlorophyll correlation breaks down. If the suspended material causing turbidity is municipal or industrial sewage which upon decay uses oxygen then there may be a correlation between backscatter and Biological Oxygen Demand (BOD), or with dissolved oxygen which is not yet used up. However, try the same correlation on inorganic red clay in water and the correlation breaks down. For all waters, however, the correlation of backscatter (volume reflectance, ρ_v) and turbidity holds as shown in Figure 2.

Figure 9 shows that the backscatter at different wavelengths (indicated by D_i, or ρ_{v_i}, etc.) changes with the type of material in water. Different types of material have unique spectral backscatter "fingerprints", which allows them to be identified. In the visible spectrum the total area under a curve correlates to turbidity (as in Figure 2). Figure 10 shows that the water quality parameter of suspended solids for a particular material in a particular lake correlates to turbidity. Figure 10 also shows that this correlation changes for different materials and water types.

EXAMPLE RESULTS OF LAKE CLASSIFICATION FROM LANDSAT IMAGES

Figure 9 shows that the laboratory reflectance difference, D_i, is unique for different types of material in water. For lake #2:

$$D_2 = \frac{\rho_{v_2} - \rho_{v_1}}{\rho_{PL}}$$ where ρ_{v_1} (distilled water) is .0026. Also $\rho_{PL} = 0.39$.

Changes in D_2 are really only dependent on ρ_{v_2} or the material in lake #2. Once ρ_{v_2} is known, turbidity can be determined from Figure 2. Also curves as in Figure 10 might be used to relate other parameters to turbidity.

From a satellite if a deep, clear-water lake is used to obtain a reading W_1'' (as site "a", Figure 1) and a reading W_2'' is also taken on lake #2, then:

$$R_2'' = W_2'' - W_1'' = (\rho_{v_2} - \rho_{v_1}) \frac{H_o'}{\pi} \tau = R_2'' = (\rho_{v_2} - .0026)\ H_o' \frac{\tau}{\pi} \qquad (12)$$

ρ_{v_2} can be determined in the laboratory and if desired, the term $H_o \tau/\pi$ can be calculated. Assuming that H_o' and τ do not change over the frame, the values of volume reflectance ρ_{v_i} of other lakes can be obtained by satellite data as effectively as in the laboratory (from Equation 12).

If one assumes that the center of the 4 LANDSAT bands are at 0.55, 0.65, 0.75, 0.95 then the values of R_i'' can be plotted against wavelengths. The results are spectral reflectance curves as distinct in shape and height as those obtained from the laboratory. Figure 11 shows a family of satellite curves for different concentrations of red clay in clear Lake Superior water. Figure 12 shows different distinct curves for algae in non-tannin lakes. The height of the curves correlate to the amount of turbidity and algae present. For algal lakes in late summer, this height also correlates to lake eutrophication. (1)

Silt, weeds and strong bottom effects also have distinctive satellite signatures (1). All of these lake types can be identified by computer by proper analysis of LANDSAT tapes. However, the ground truth and computer training takes a bit of skill. With the proper knowledge of how to translate from laboratory to satellite images the Bendix M-DAS computer system was trained to recognize various types of material in different waters as well as where strong bottom effects occur. The results were printed out as color categorized images with different types of lakes coded different colors. Although still being field checked and refined, the results appear excellent and the system promises to be a very effective and economical method of categorizing lakes.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the National Aeronautics and Space Administration for their support under Grant No. NGL 50-002-127 and Dr. James L. Clapp and his staff at the University of Wisconsin for administrative help; also Douglas Crane for his contributions; and Dr. Robert Rogers of Bendix Corp. for his help under NASA Grant NAS 5-20942.

REFERENCES

1. Scherz, James P., Douglas R. Crane, Robert H. Rogers, "Classifying and Monitoring Water Quality by Use of Satellite Imagery," Phoenix, Arizona: 1975 ASP-ACSM Fall Convention, October 26-30, 1975.

2. Van Domelen, John F., "Photographic Remote Sensing - A Water Quality Management Tool," Ph.D. Thesis, University of Wisconsin, 1974.

3. Piech, Kenneth R. and John E. Walker, "Aerial Color Analysis of Water Quality," Journal of the Surveying and Mapping Division, Proceedings of the American Society of Civil Engineers, November 1971.

4. Scherz, James P. and John F. Van Domelen, "Lake Superior Water Quality near Duluth from Analysis of Aerial Photos and ERTS Imagery," Remote Sensing and Water Resources Association, Proceedings No. 17, JUne 1973.

5. Gramms, Lorne C., "Reflectance and Transmittance Characteristics of Selected Green and Blue-Green Unialgae for Remote Sensing Applications," Ph.D. Thesis, University of Wisconsin, 1971.

6. Kondrat'yev, K. Ya, USSR, Actinometry. Translated by National Aeronautics and Space Administration, Washington, D.C., November, 1965.

7. Holmes, Robert W., "The Secchi Disc," an article appearing in the Martek Mariner, Vol. 2, No. 1-2.3, Martek Instruments, Inc., Newport Beach, California, 1970.

8. Scherz, James P., "Final Report on Infrared Photography Applied Research Program," inconjunction with Metropolitan Sanitary District of Greater Chicago, Report #12, The University of Wisconsin Institute for Environmental Studies Remote Sensing Program, June, 1972.

9. Standard Methods for Examination of Water and Wastewater, 13th Edition, Turbidity, American Public Health Association, 1015 Eighteenth Street, N.W., Washington, D.C., pp. 349-355.

IMPORTANT NOMENCLATURE

L_s', L_c' = Sun and skylight radiance at ground level respectively.

H_o', H_L = Total horizontal irradiance in field and lab respectively.

P, P', P" = Radiance from panel to lab, boat and airborne sensors respectively.

W, W', W" = Radiance from water to lab, boat and airborne sensors respectively.

AP, AP', AP" = W/P, W'/P', W"/P" respectively (apparent reflectance of water).

V, V' = Radiance from material in water to lab and boat sensors respectively.

S_s' = Radiance from foam and dirt on water surface to boat sensor.

G', S_c' = Specular reflection of sun and skylight radiance respectively, boat level.

ϕ = Specular reflectance for air-water interface. For near vertical rays on calm water, $\phi = 0.02$.

ϕ_* = Complex value of ϕ for rough water denoting rays from various angles.

L_{c*}' = Complex value of L_c'. For rough water different portions of the sky will be reflected and L_{c*}' denotes this summation.

AP_1, AP_1', AP_1'' = Apparent reflectance for distilled or very pure water as determined by lab, boat, or airborne sensors, AP_i and AP_2 denote waters i and #2 respectively.

$D_2 = AP_2 - AP_1$; $D_2' = AP_2' - AP_1'$; $D_2'' = AP_2'' - AP_2''$.

A_1' = Boat level albedo for distilled water (from Figure 4); $\Delta_i' = AP_i' - A_1'$.

$R_2 = W_2 - W_1$, $R_2' = W_2' - W_1'$; $R_2'' = W_2'' - W_1''$.

ρ_{v_i}, ρ_{v_2}, ρ_{v_1} = Volume reflectance of material in water i, sample 2, and distilled water respectively.

ρ_{SL}, ρ_s = Reflectance of foam, etc. on water surface in lab and field respectively.

ρ_{PL}, ρ_p = Reflectance of laboratory and field panels respectively.

Subscripts i, 2 and 1 denote waters i, #2, and #1 (distilled) respectively.

Superscripts ' and " denote data from boat and airborne sensors respectively.

Lack of superscript denotes laboratory data.

ORIGINAL PAGE IS OF POOR QUALITY

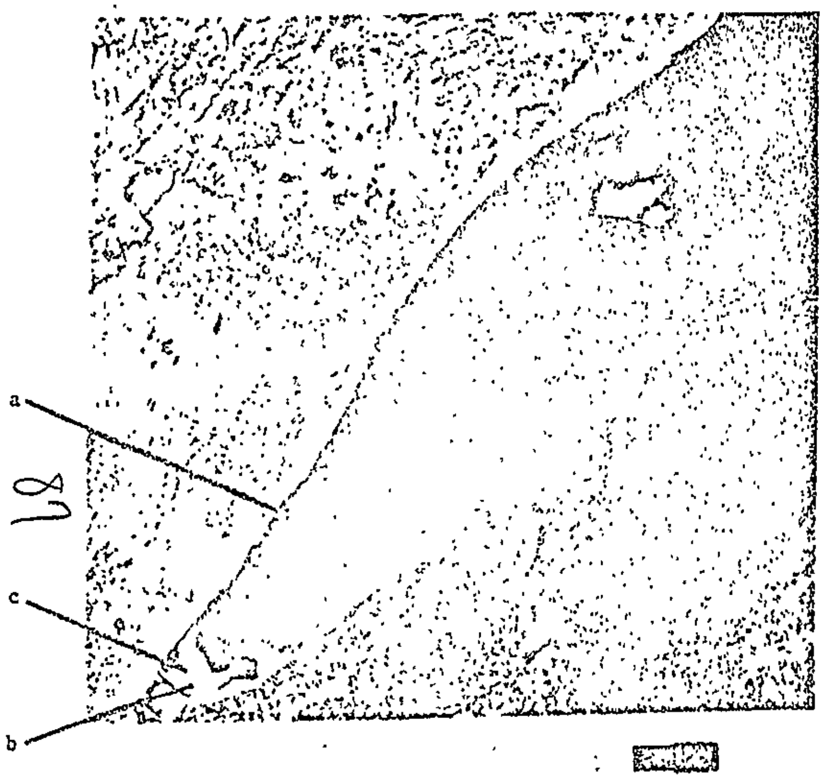


Figure 1.

ERTS (LANDSAT) image of southwestern Lake Superior. 12 August 1972. Band 5. Red Energy. Pure water of essentially infinite depth at "a". Water with turbidity as high as 100 at "b". An $8,000,000 water intake constructed at "c" produced water too turbid for human use.

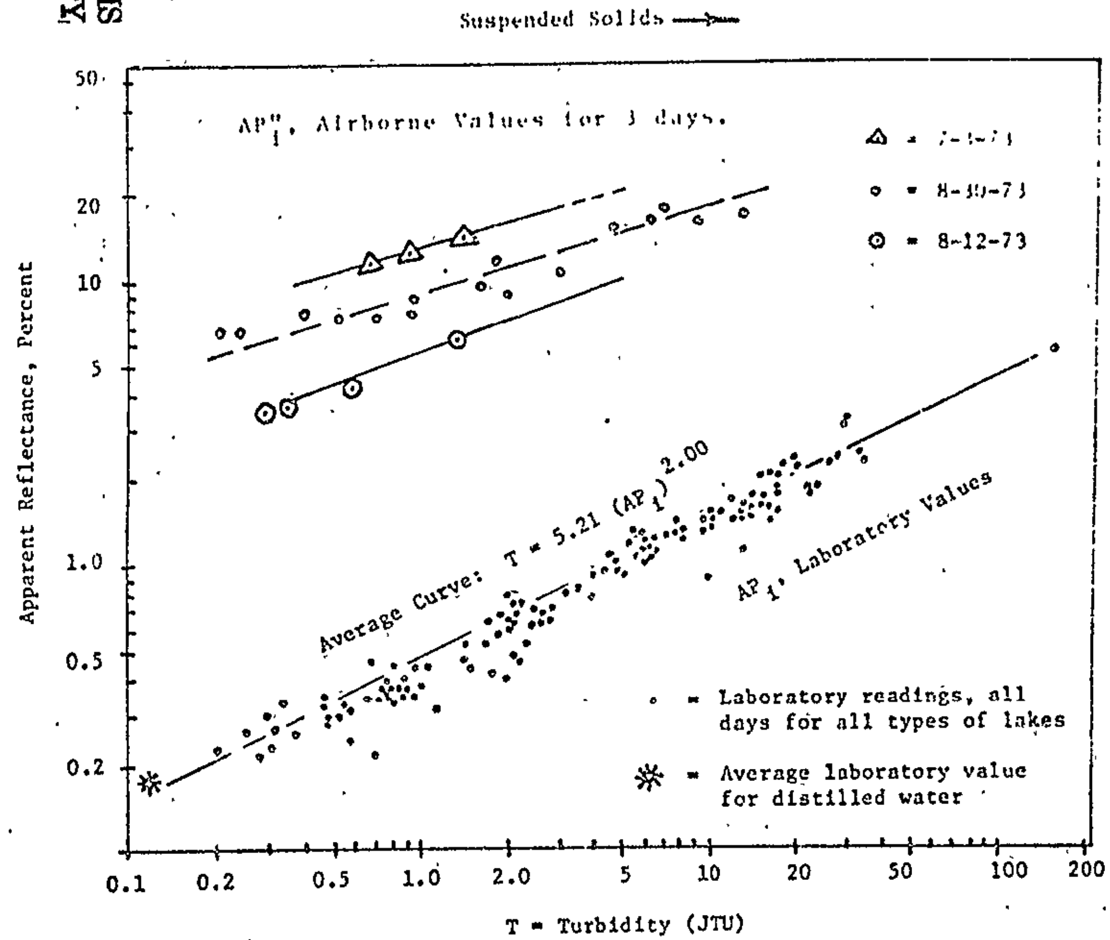
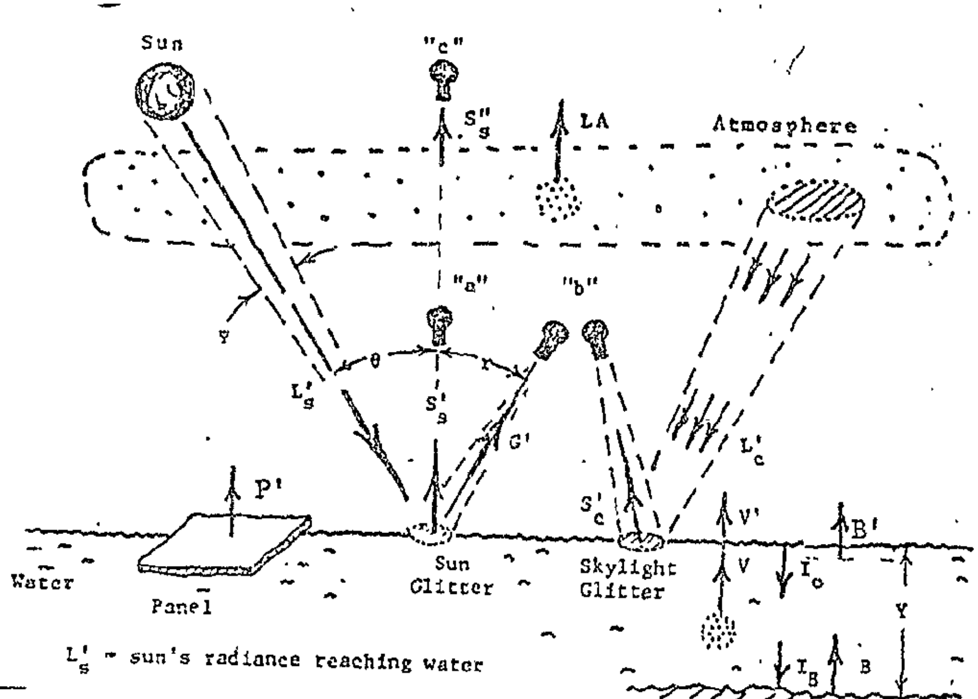


Figure 2. Apparent reflectance from laboratory, AP_i, and airborne sensors, AP_i'', versus turbidity. For red light, 0.65 microns. Airborne values are for samples from the area of Lake Superior shown in Figure 1. Laboratory samples from all types of lakes.



L_s' = sun's radiance reaching water

L_c' = average skylight radiance reaching water

H_s' = irradiance caused by sun = $L_s' \phi \cos \theta$

H_c' = irradiance caused by skylight = $L_c' \pi$

H_o' = total irradiance = $H_s' + H_c'$

Figure 3. Energy relationships in the field.

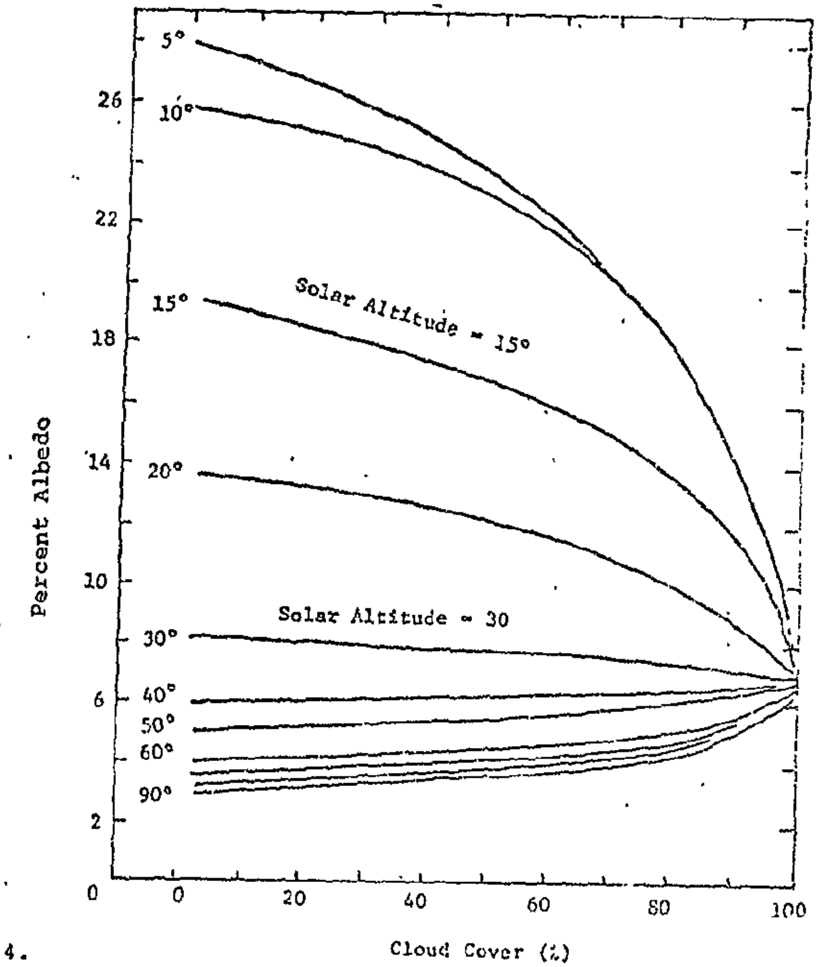
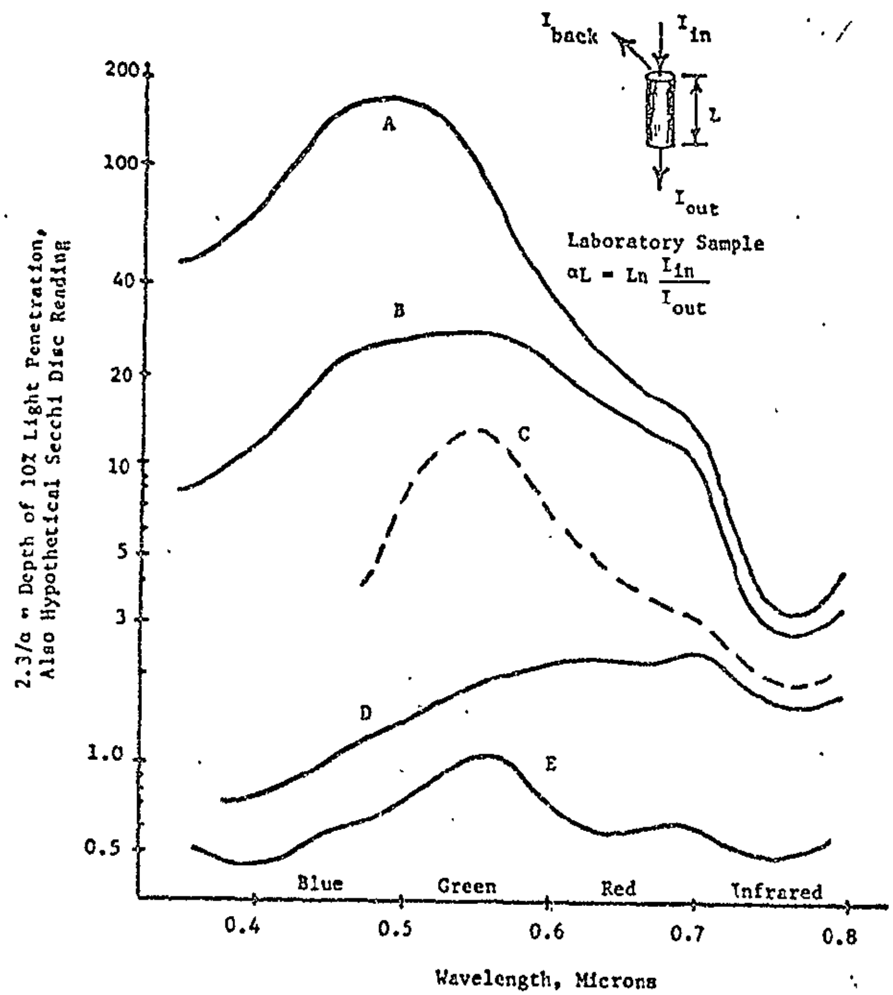


Figure 4.

Percent albedo of a pure water approaching distilled water as a function of cloud cover and sloar altitude. Data by Ter-Markaryants, USSR, reported by Kondrat'yev in 1965 (6). To obtain spectral values for 0.45, 0.55, 0.65, and 0.75 microns, multiply curve values by 0.7, 1.0, 0.75, and 0.58 respectively (2). For clear water, such as at site "a" in Figure 1, water albedo is essentially caused by surface signals S_c' and S_s'.



Sample	Water	Actual Secchi Disc Reading
A	Distilled Water	NA
B	Lake Superior, Clear	32 ft.
C	Taconite Rock Flour	9.5 ft.
D	Moderate Red Clay	6 ft.
E	Heavy Algae	1.3 ft.

Figure 5. Hypothetical Secchi Disc readings, 2.3/α, for different waters at different wavelengths.

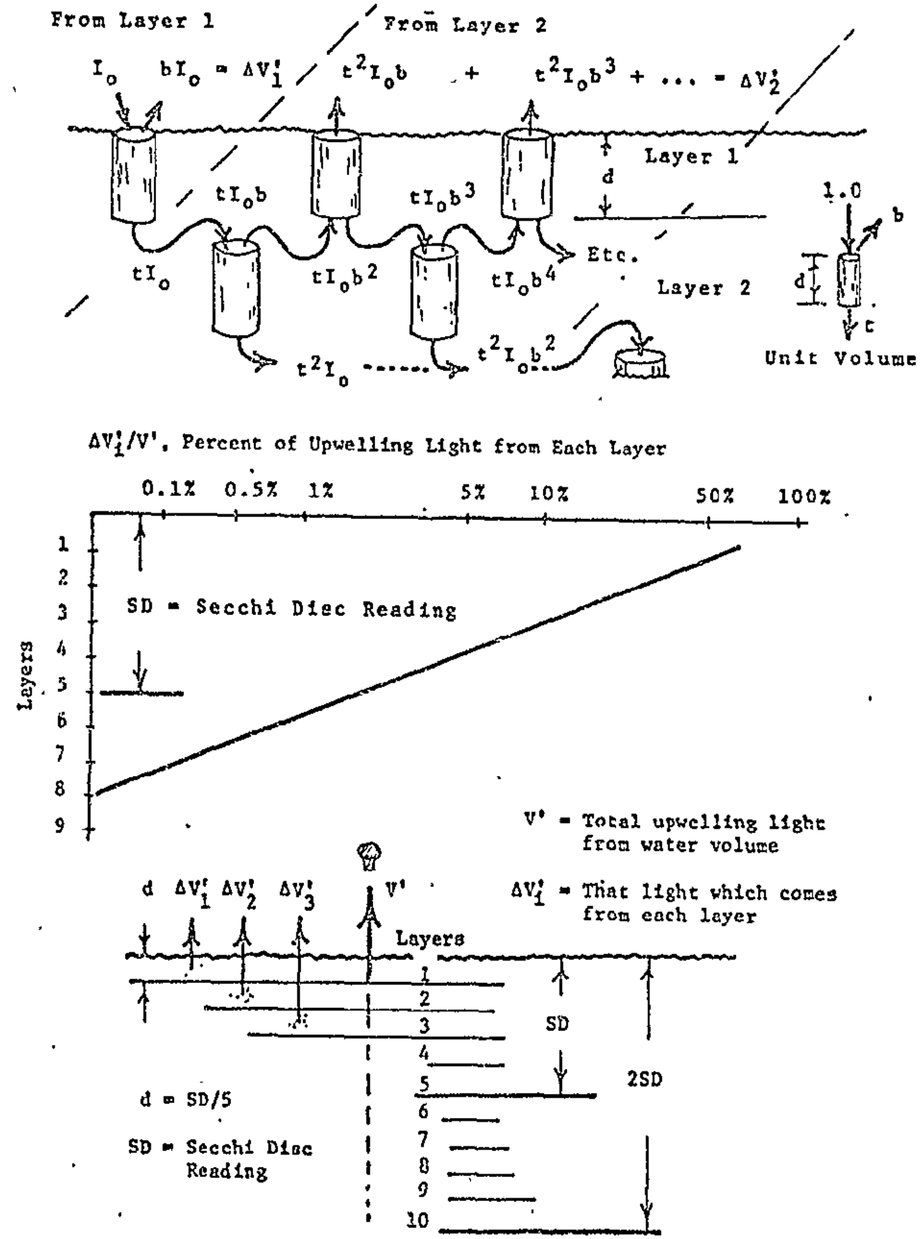


Figure 6. Determining percent of upwelling energy from suspended particles at different depths. Also percent of composite water samples to be collected at different depths.

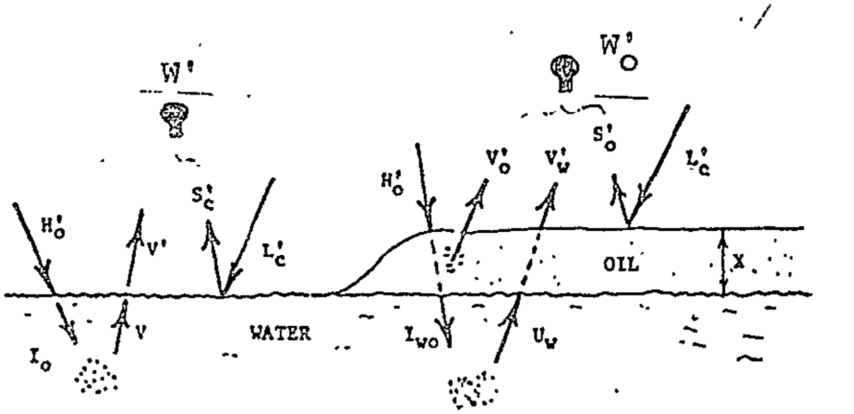


Figure 7. Energy components reaching sensor from water with and without oil. Diffuse reflectance signal, S'_s from contaminants on the air-water and air-oil interface is considered zero in this analysis.

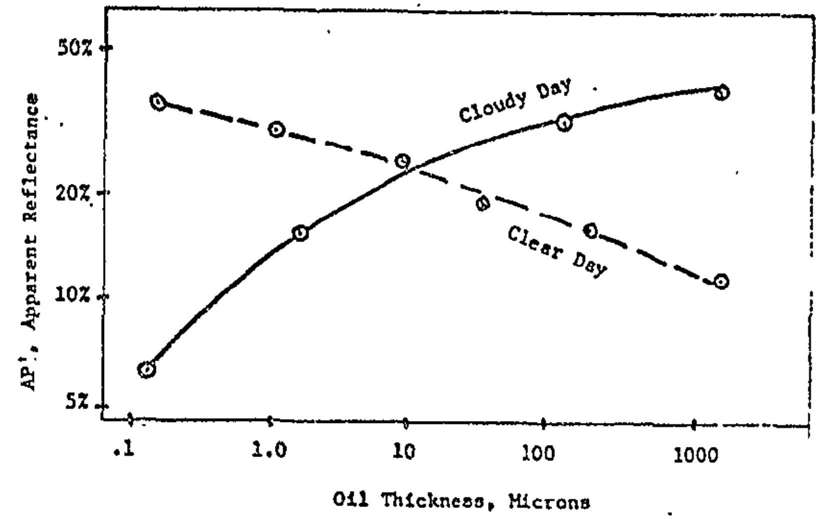


Figure 8. Apparent reflectance from a boat, AP', for oil slicks of different thickness on algal water. The reflectance standard was a white plastic hulla hoop. Color of energy was blue, or .45 microns.

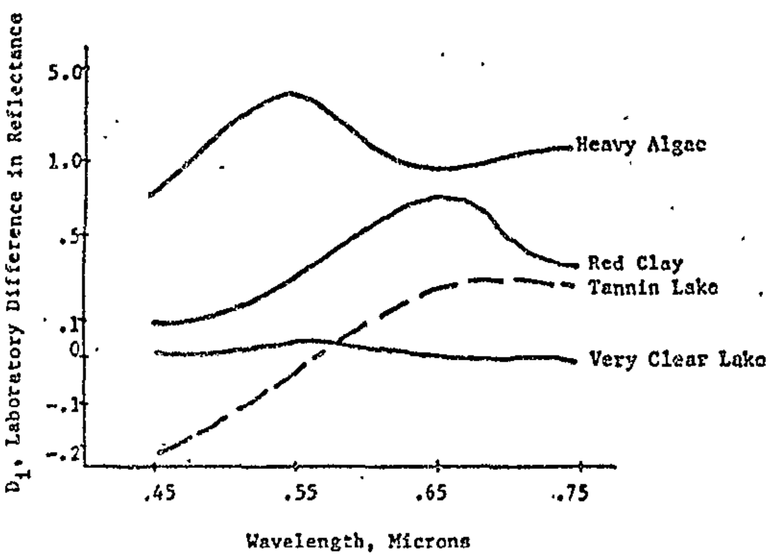


Figure 9. Laboratory differences in apparent reflectance, D_i, for various waters. $D_i = AP_i - AP_1 = (\rho_{v_i} - \rho_{v_1})/\rho_{PL}$

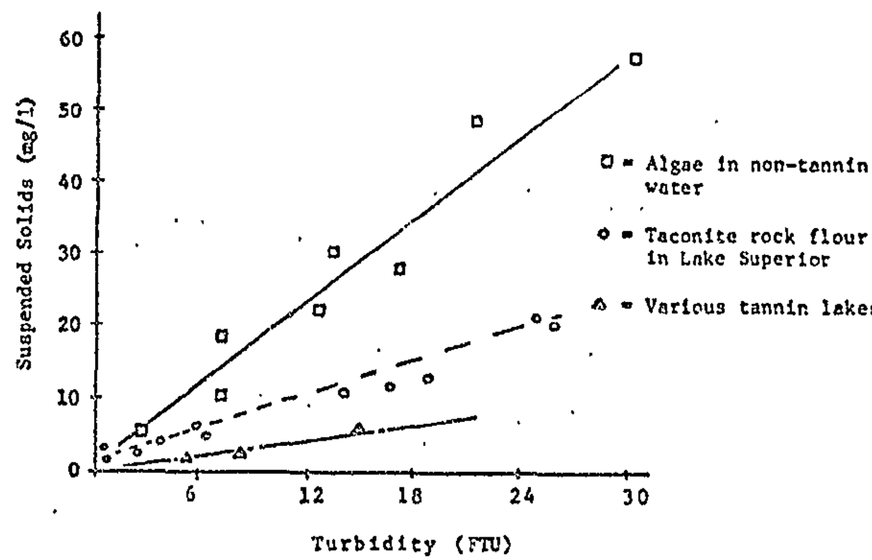


Figure 10. Correlation of suspended solids to turbidity for three types of lakes.

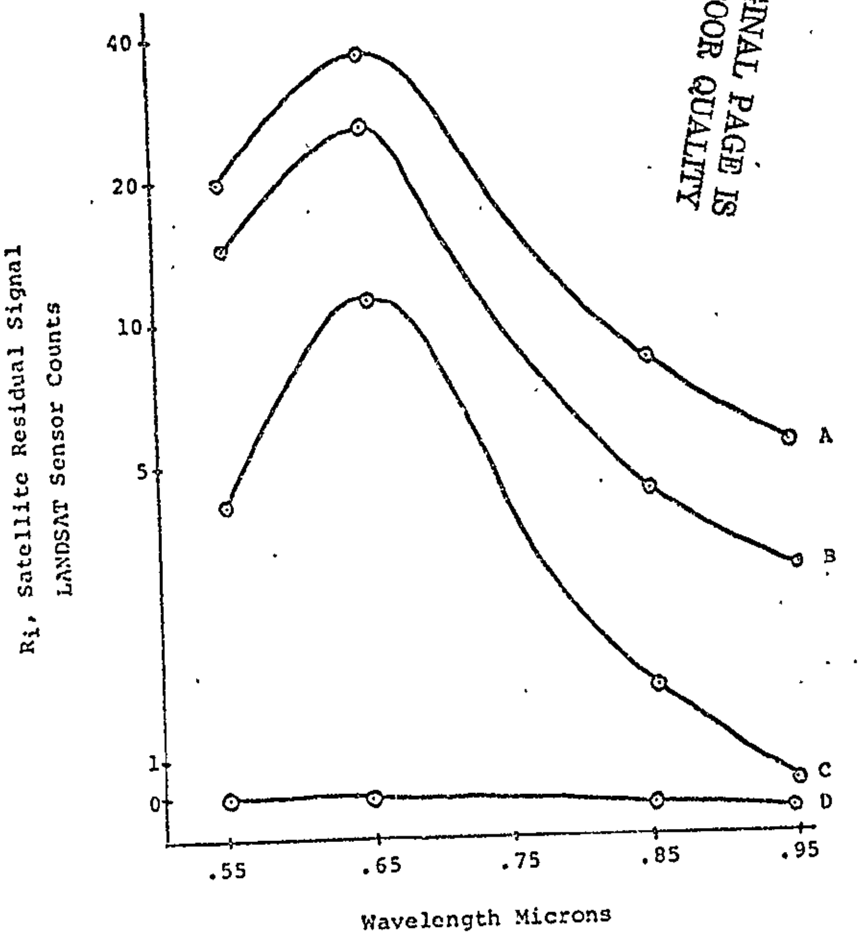


Figure 11. Effect of red clay on clear Lake Superior water.
R_i = Satellite Residual Signal.
$R_i = (\rho_{v_i} - \rho_{v_1})\, H_o'\, \tau/\pi$.

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

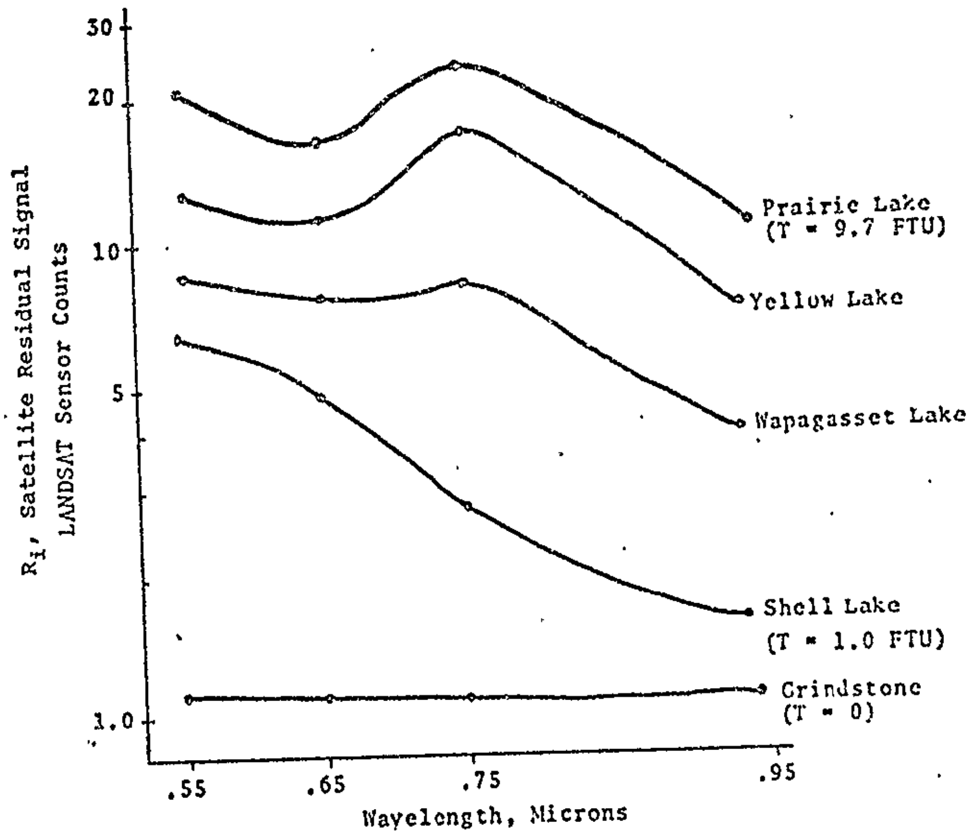


Figure 12. Effect of algae on clear (non-tannin) lakes.
R_i = Satellite Residual Signal = signal from target lake minus signal from a very deep clear lake which approaches distilled water.
T = Turbidity (FTU).

A VERSATILE INTERACTIVE GRAPHICS ANALYSIS PROGRAM FOR MULTISPECTRAL DATA

6 copies

Dr. Lawrence T. Fisher
Department of Electrical and Computer Engineering
The University of Wisconsin
Madison, Wisconsin 53706

Dr. Frank L. Scarpace
Institute for Environmental Studies and
Department of Civil and Environmental Engineering
The University of Wisconsin
Madison, Wisconsin 53706

BIOGRAPHICAL SKETCH

Lawrence T. Fisher is an Assistant Professor of Electrical and Computer Engineering at the University of Wisconsin in Madison. He received his BSEE, MSEE and Doctor of Science degrees in Electrical Engineering at New Mexico State University. His research interests include mathematical switching and automata theory and, more recently, machine analysis of remotely sensed data.

Frank L. Scarpace is an Assistant Scientist in the Institute for Environmental Studies at the University of Wisconsin in Madison. He received his BA degree at San Jose State College, MS and Ph.D. degrees from the University of Wisconsin. All of his degrees are in the field of Physics. He has research interests and publications in the fields of: Photogrommetry, Analysis of Aerial Films for Earth Resources Identification, Satellite Remote Sensing, and Application of Thermal Line Scanners to Environmental Monitoring.

ABSTRACT

A large interactive computer program has been developed and is now in production use to provide highly versatile interactive data extraction and analysis capabilities for ERTS or other multispectral data. It utilizes an interactive graphics terminal which can produce graphical or line-drawing output and which allows operator specification of coordinate positions. A large array of data is read from tape; then a display of 90 rows x 90 columns is produced for a portion of this data in the form of an array of characters, displayed when specified multispectral tests are passed. Tape read resolutions, display resolutions, display characters, and bounds are all set interactively and can be changed as desired. Histograms can be produced to assist in supervised training for feature classification. Individual data points or blocks of points can be selected after specifying locale names; data for these points are extracted, printed, punched if desired, and placed in computer files for access by other programs. Line printer maps can be produced as desired. Latitude/longitude calculations of specified points are provided for navigation. New displays of different portions of the data or different resolutions can be formed on command, or new data read from tape.

Efforts to maximize versatility, minimize effects of operator errors, and simplify operation have succeeded and produced a method of access to remotely sensed data which should be attractive, operationally and economically, to a wide body of potential users.

INTRODUCTION

A recent project of the University of Wisconsin's Institute for Environmental Studies, in cooperation with the Wisconsin Department of Natural Resources, involved densitometric analysis of ERTS photographic data of Wisconsin lakes [1]. Difficulties with radiometric quality of 9 x 9 inch photography and operational problems due to extremely small image sizes of small lakes on 70mm images prompted us to begin development of computer-assisted analysis. Since then, we have expanded the program to provide a highly versatile, general purpose multispectral analysis and data acquisition tool for several users and applications.

The objectives that were envisioned in the design of the program were:

a. Access to small, highly specific subsets of large data sets was needed. We wanted to be able to select, for example, an accurately located single data point in a bay of a lake.

b. Multispectral analysis capabilities were needed for feature selection tasks.

c. Operation needed to be highly interactive, so that options could be selected or changed easily, or feature selection training criteria easily altered under operator supervision, etc.

d. Operator-recognizable displays were needed, for example, to recognize and distinguish lakes, or to estimate acceptability of an experimental classification.

e. Navigational aides were needed to help locate areas of interest.

f. Data histogramming capability was designed to assist in supervised training for feature selection.

g. Use with a variety of data types was desirable. At the moment, the program is being used both with ERTS data and digitized aerial photography.

h. The program had to be attractive to a wide range of users. This implied that operation should be easily learned and that the program be extremely tolerant of operator errors.

i. No capital was available for hardware. We were constrained to use existing equipment.

Approach

We elected to design the program around an interactive graphics terminal and the Madison Academic Computing Center's Univac 1110 computer. One reason was that several terminals are available on campus and are given excellent software and hardware support. Second, the ability to produce a television-type image during program execution and the operator's ability to respond to the display, provided us with the man-machine interaction deemed essential. Third, graphics features allowed operator specification of data coordinates, graphical display of data histograms, and similar non-alpha-numeric input and output.

We read and decode multispectral data for a fairly large area, retaining data for whatever bands are desired and reading data tapes at any of several possible resolutions. Then a portion of this data is displayed on the terminal by means of an array of characters. Each character is displayed only if a set of tests upon the multispectral data is passed. Complete flexibility is provided in the selection of characters, bands to be tested, and test bounds; all of these can be altered at appropriate points during operation.

Displays can be located anywhere within the region for which data was extracted, and can be shown at any of several resolutions. New displays can be called at any time, perhaps at different resolutions or with different character sets or bounds.

Given a display, data can be extracted simply by pointing at desired points or blocks of points. Data for all such points is printed, punched if desired, and written into a cataloged file which is available to any other program for additional analysis.

Line printer "maps" duplicating displays and showing all extracted data points can be produced as desired.

INTERACTIVE GRAPHICS

Interactive computer terminals are becoming familiar in many applications including remote sensing data analysis. A typical terminal consists of a typewriter keyboard and some form of output device - usually a typewriter, teletype, or cathode-ray tube display. Programs can be written so that interruptions occur at points where operator intervention is needed. Keyboard responses can allow selection of options, decisions, or input of needed data, usually in response to something computed and displayed by the terminal. Such facilities, with proper programming, can provide substantial versatility and convenience.

Graphics terminals, now becoming common, add some powerful features to basic interactive terminals. In addition to display or input of alphanumeric characters, they allow computer-produced drawings of points or line segments, and operator input of coordinate positions which can be formed into graphs, outline drawings, or complex figures. They also allow for transmission of graphical or two-dimensional data to the computer.

Figure 1 shows a Princeton Electronic Products PEP-801 terminal displaying ERTS data for the Madison, Wisconsin area. Other manufacturers offer similar terminals but this model has been selected by the University of Wisconsin's Madison Academic Computing Center for hardware and software support. Displayed information--graphics as well as alphanumeric characters--are stored as an electron pattern on a storage tube which is scanned to produce a high-quality television signal. Information can be retained with no computer action for several hours. Other standard television receivers can be slaved if multiple displays are desired.

Alphanumeric data input is accomplished via the keyboard. A "cursor control unit", shown to the left of the operator, includes a joystick to maneuver a small electronically generated cursor around the screen. Pressing one of two buttons on the control unit transmits X and Y cursor coordinates to the computer. One of these buttons sends a special "terminating" character and signals that a coordinate is a "final" coordinate; the other transmits a position identified as a position identified as a portion of sequence of coordinates. The distinction between the two control buttons is important because it allows us to send either a single position, or else a string of positions. Frequently we transmit two coordinates marking opposite corners of a rectangle.

This terminal can accept data from a computer at very high rates--approximately 100,000 10-bit characters per second--but this is only possible if the computer is in close proximity. Our terminal communicates to the host computer via a 120 character/second telephone line. This slow speed precludes such things as grey scale image transmission, and is the major reason we selected character array displays in our program.

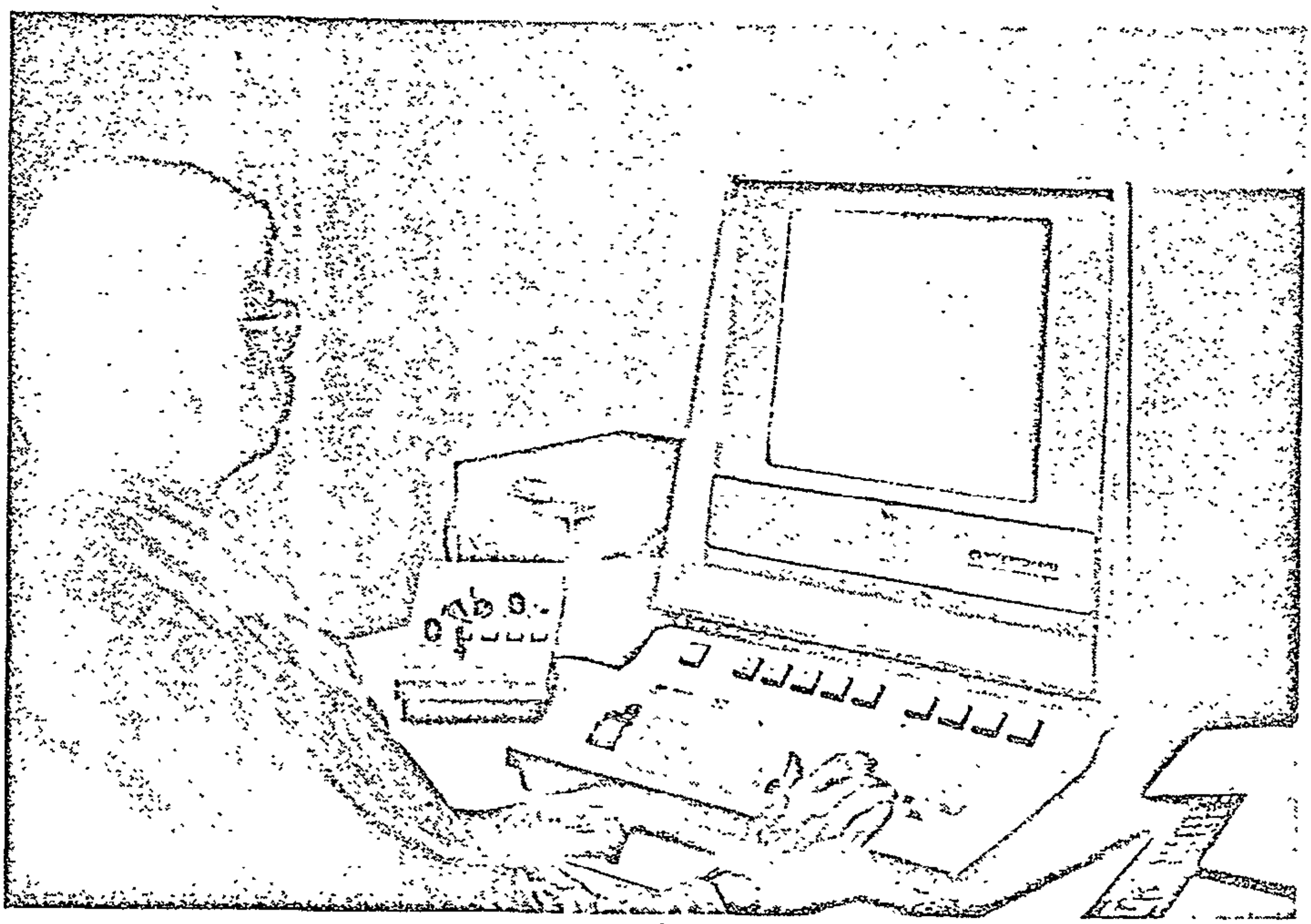


Figure 1 PEP 801 Interactive Graphics Terminal

DESCRIPTION OF THE PROGRAM

Preliminaries

Figure 2 shows a flow diagram of the program. It first inquires about a variety of options--whether punched output is desired, which printer (if any) is to be used for printed output, what data type is being used (ERTS or digitized photography), etc. Multispectral bands of interest are selected--any set of ERTS bands 4-7 can be specified; film analysis applications may use any 1, 2, or 3 or 3 spectral ranges which our data provides.

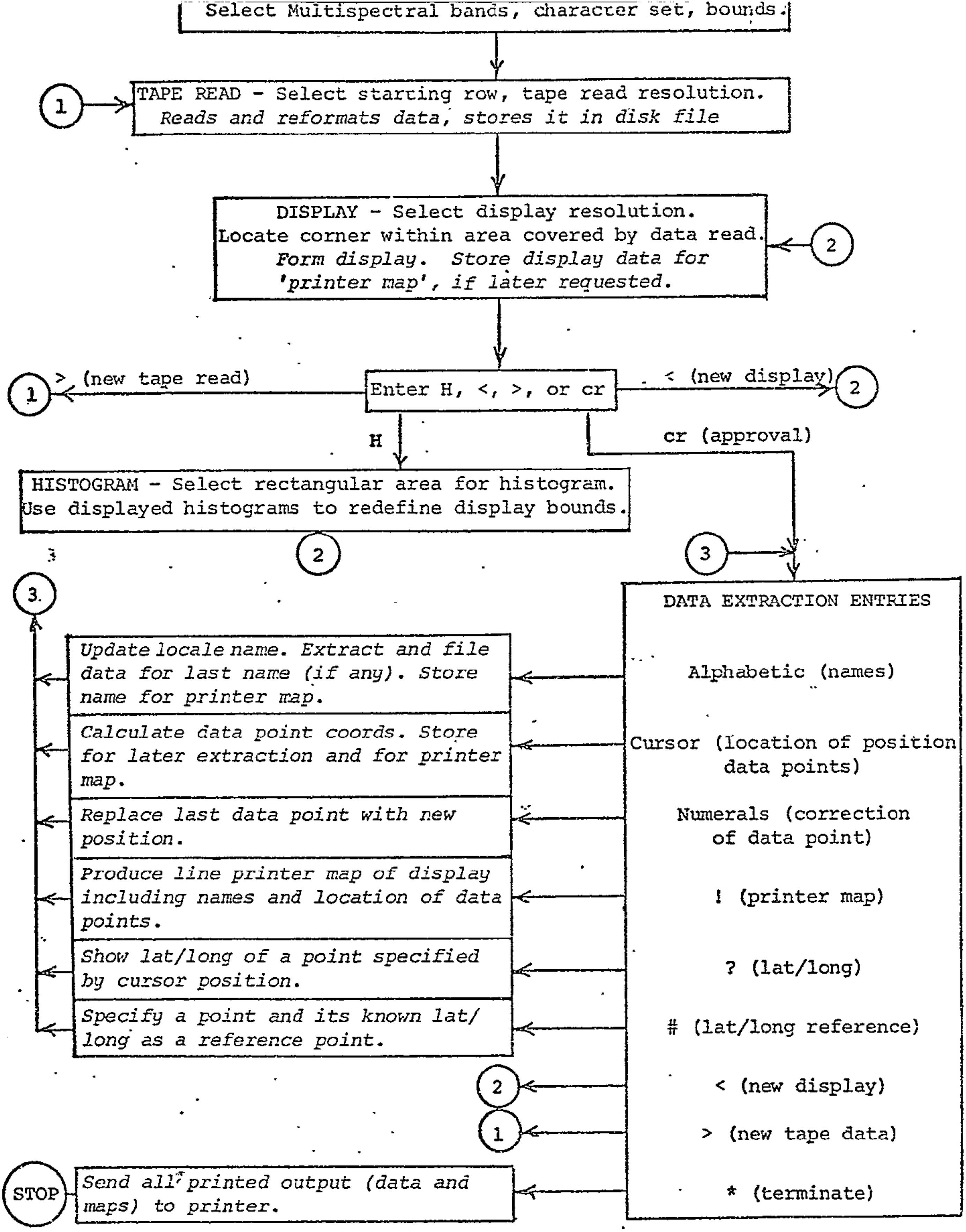


Figure 2 FLOW CHART OF INTERACTIVE GRAPHICS DATA EXTRACTION PROGRAM

Italics are computer actions
Block type shows operator actions

Tape Reading

Data can be read from tape at resolutions of every 1, 2, or 3 rows or scan lines, starting at any desired row. A total of 540 records, each consisting of one band for one row, are read, reformatted, and stored on a temporary disk file, retaining only those bands of interest to the user. Data is decoded and stored for the entire width of any row read. Ground areas covered by data retained in the file depend on the number of bands desired and on resolution, and range from 135 rows or scan lines at full resolution with four bands to 1620 rows for tape-read resolution of 3 with one band.

For ERTS, a single quarter-scene tape with 2340 rows and 810 picture elements per row covers an area of 46.3KM x 185.2KM (25 x 100 NM). Thus our program will extract data for areas from 10.7KM to 128.2KM long by 46.3KM wide, depending on resolution and number of bands. Figure 3 illustrates this, and Table 1 shows ERTS coverage for all cases.

Display

Displays usually consist of 90 rows of 90 characters. Shorter displays--30 or 60 rows-- may be required if available data dictates, or if a user has some reason to stop with a shorter one. Display resolutions of 1, 2, or 3 are allowed, showing every 1, 2, or 3 rows and appropriate columns of data from the file. The product of tape-read resolution and display resolution allows composite resolutions of 1, 2, 3, 4, 6, or 9 rows and columns, so that displays can cover an area ranging from 90 rows and columns to 810 rows and columns. For ERTS data, this corresponds to ground areas from 5.2 x 7.1 KM to 46.3 x 64.1 KM.

Location of a display within the region covered by extracted data is accomplished by pointing the cursor to the desired location in a small displayed sketch scaled to appropriate dimensions of the filed-data area. Alternatively, if a display is already present, pointing the cursor to an appropriate point on the display establishes a new corner for the next display. This allows, for example, easy "zooming" from a display at resolution 3 to a resolution 1 display of a small portion. Still another option allows location of a display by specification of row and column coordinates (as numbers).

Before a display appears, the area to be covered is outlined as a dotted line on the filed data sketch. Modification of resolution or position is allowed at this point.

Figure 4 shows a representative display for ERTS data. Examples for displays from digitized film can be found in [3] elsewhere in these proceedings. (These are negative images--blanks actually appear black on the terminal.)

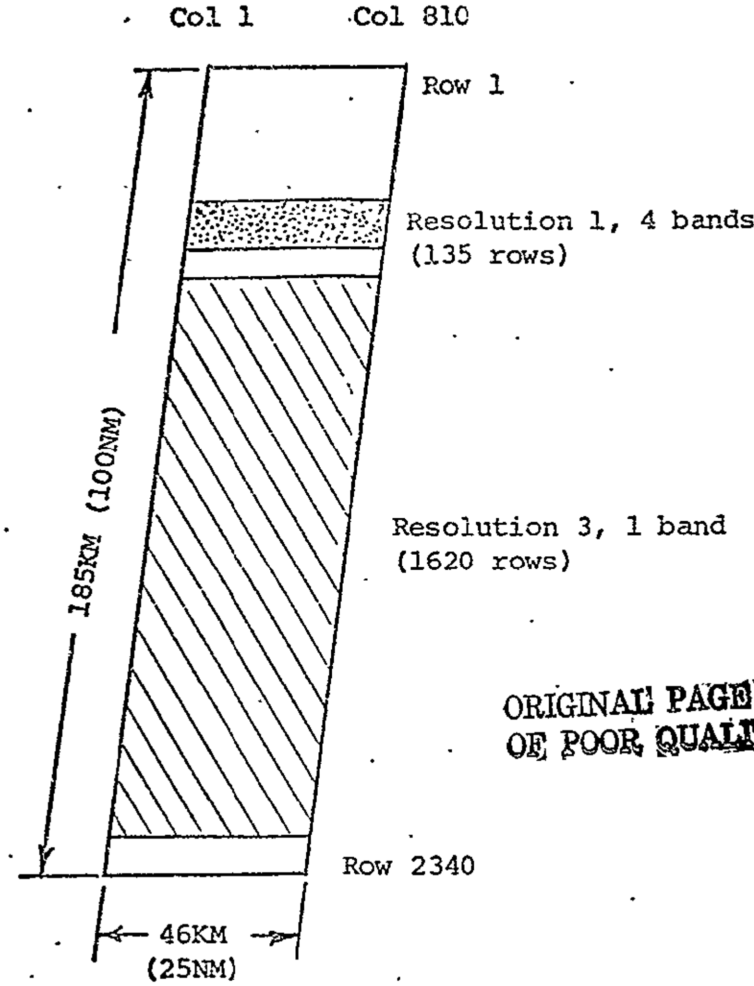


Figure 3 Relative areas covered by ERTS data extracted and saved in a single data reading cycle.

	Number of Bands			
Resolution	1	2	3	4
1	540 rows (42.7KM)	270 rows (21.4KM)	180 rows (14.2KM)	135 rows (10.7KM)
2	1080 (85.5KM)	540 (42.7KM)	360 (28.5KM)	270 (21.4KM)
3	1620 (128.2KM)	810 (64.1KM)	540 (42.7KM)	405 (32.1KM)

Table 1 Number of ERTS rows and north to south distance covered by filed data for various combinations of resolution and number of channels. Full 810 column (46.2NM) width of tape is available.

Next, the display character set is selected. Any non-blank characters may be used; the program presently allows a maximum of four but this will soon be increased to 10. For each character, at least one multispectral band number and a lower bound and upper bound are entered for display of that character. Testing data within a single band allows level slicing or up to three bands, with bounds for each, may be specified for each character, allowing multispectral "box" classification.

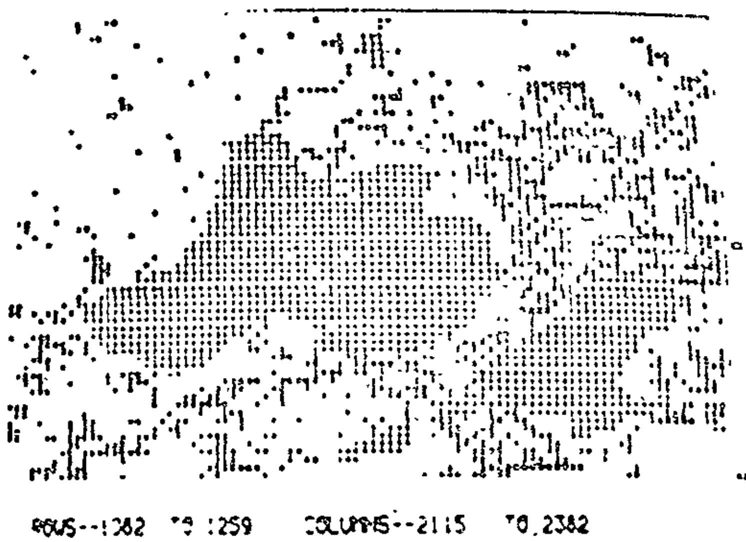


Figure 4 Madison, Wisconsin area from ERTS. Scene 1378-16151, August 5, 1973. Every third row and column is displayed, "+" symbols are water; "*" symbols correlate well with commercial urbanized area.

Histograms

Once a display is completed, histograms such as that of Figure 5 can be produced for any specified rectangular portion of the display selected by pointing at the desired corners. These can be used to revise display bounds interactively, and provide supervised training for feature classification.

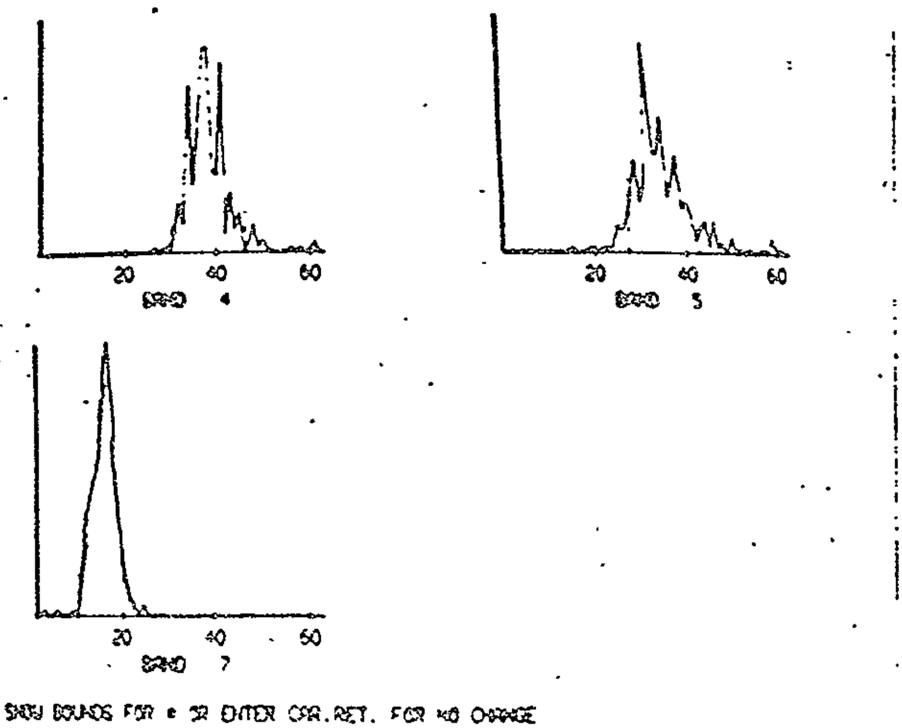


Figure 5 Representative histogram display of downtown Madison, Wisconsin area--ERTS scene 1378-16151, August 5, 1973.

Data Extraction

Data is extracted by entering a locale name beginning with any alphabetic character and then pointing the cursor at each desired point, or at alternate corners of blocks of points. A one-digit "area number" is written at each selected point in the appropriate column. Mislocated points can be moved to exactly a desired location by entering two integers, m and n, which cause the point to be erased and a new point selected m rows down and n columns to the right. For blocks, an outline sketch is drawn and either approved or disapproved, if disapproved, the sketch is erased and new corners may be entered.

Data taking continues as long as desired. It ends for a given locale with the entry of another locale name or one of the special characters described below. At this time, data for all selected bands is retrieved from the data file for all positions. It is printed, punched if desired, and placed in a cataloged file under the locale name. Other programs such as statistical analysis packages, archiving programs, or plotter routines then have direct access to it.

Special Functions

A number of keyboard entries are reserved for special purposes: "<" calls for a new display, ">" directs that new tape data is to be read into the data file. "*" terminates the program and produces all printed output.

When using ERTS data, latitude and longitude of a specified point can be determined by entering the character "?" and then locating the point of interest with the cursor. Originally, the NASA-specified scene center latitude and longitude are used as a reference, but another subroutine, called by entering the character "#", allows specification of a reference point and its latitude and longitude nearer the region of interest. Transformations from [2] are used in these subroutines.

Entry of "!" produces a line printer map such as that of Figure 6. It duplicates the display and includes all locale names and exact locations of extracted data; actual data listings precede it.

```
ERTS SCENE ID:  1378-1615100
TAPE 3 OF 4
MSS DATA MODE --047
ADJUSTED MSS LINE LENGTH --  3240  PIXELS

ANNOTATION RECORD: 03AUG73 C N43-10/W089-53 N N43-08/W089-45                    SUN EL54 AZ129 191
                   -5270- -1- 0-   NASA ERTS E-1378-16151-                                      D N-

STARTING ROW     ENDING ROW     STARTING COL     ENDING COL
   1080             1258            2184            2262
TAPE RESOLUTION IS 1,   PRINT RESOLUTION IS 2
MSS BANDS USED ARE CHANNELS 4  5  7
CHARACTER      BAND    LOWER BOUND    UPPER BOUND
   +            7           0            10
   *            4          30            46          5          27          42          7          10          24
```

Figure 6 Line printer "map" output. Locale names and data points are included as selected.

Substantial effort has been expended to make operation as simple, reliable, and conversational as possible. A special string-manipulating subroutine allows input of variable numbers of integers, keeping count of how many were entered. It also recognizes and counts alphabetic characters, senses the various special characters, detects "blank" inputs, and detects a number of types of operator errors. Every operator response is tested for such things as type of entry, ranges of values, number of integers entered, etc. Improper or meaningless entries produce an error message but do not cause termination of the program - the operator can usually recover merely by re-entering that line. Carriage returns ("blank response") are recognized throughout as the "normal" or default operator response.

APPLICATIONS AND COSTS

Production use of the program is presently in progress by several groups. One is continuing the lake analysis program mentioned in the introduction, extracting and compiling ERTS data for approximately 5,000 Wisconsin lakes.

Another active project is concerned with multispectral analysis of wetlands vegetation communities using digitized RB-57 aerial photography; their results are described elsewhere in these proceedings [3].

The program has been applied by our lake eutrophication group to study ERTS multispectral signatures of selected portions of Lake Superior and several smaller Wisconsin lakes [4].

Figure 7 shows accumulated costs during a typical production run by the lake analysis group. Ten different displays (four of 30 or 60 lines, the remainder of 90 lines) were formed for different portions of a 180 row portion of an ERTS scan. Nine printer maps were generated and both punched and line printer data were extracted for approximately 30 lakes. Total analysis time was about 75 minutes, and total costs (using late night computer rates) were just under $6.00.

Experience with untrained operators has convinced us that techniques such as this are quite promising. Operation has been easy to learn, and the immediately available results eliminate much of frustration which new corners frequently encounter when introduced to computers. This, together with low capitol costs, reasonable operating economies, and the versatile possible with our techniques, leads us to feel that the procedures would be attractive to many potential users or remotely sensed data.

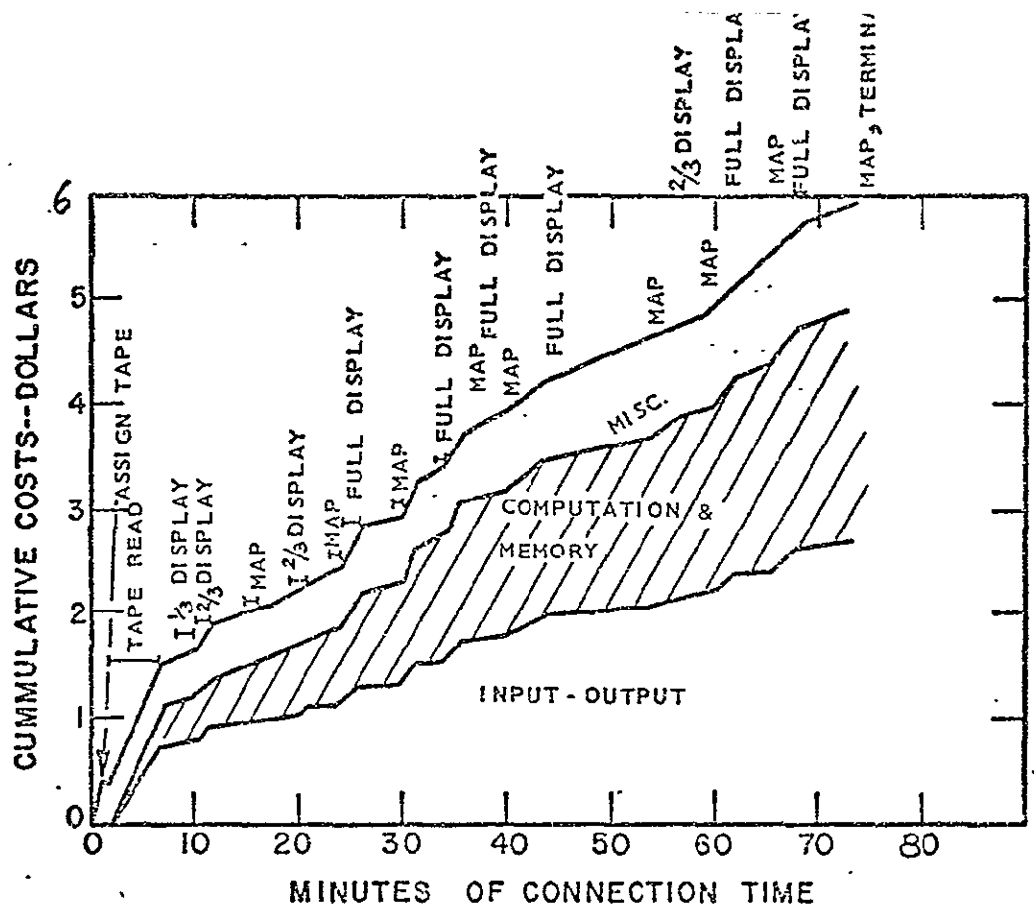


Figure 7 Costs of a typical production run (night rates).

REFERENCES

1. F. Scarpace, L. T. Fisher, R. Wade, "Lake Classification using ERTS Imagery," Proc. Symp. on Remote Sensing and Photo Interp., Comm. G, ISP, Banff, Alberta Canada, Oct. 1974.

2. W. Malila, R. Hieber and A. McCleer, "Correlation of ERTS MSS Data and Earth Coordinate Systems," Proc. Conf. on Machine Processing of Remotely sensed Data, Purdue Univ., Oct. 16-18, 1973.

3. F. Scarpace, R. Kiefer, B. Quirk, J. Friedrichs, "Quantitative Photointerpretation," Proc. of the Spring ASP-ACSM Conv., March 1975.

4. J. Scherz, Private correspondence.

LAKE CLASSIFICATION USING ERTS IMAGERY

By

F. L. Scarpace*, R. E. Wade** and L. T. Fisher***
Environmental Monitoring and Data Acquisition Group
Institute for Environmental Studies
University of Wisconsin
Madison, Wisconsin 53706

* Assistant Scientist, Institute for Environmental Studies, University of Wisconsin-Madison.
** Wisconsin Department of Natural Resources, Madison, Wisconsin
*** Assistant Professor, Department of Electrical and Computer Engineering, University of Wisconsin-Madison.

ABSTRACT

The feasibility of using photographic representations of the ERTS imagery to classify lakes in the State of Wisconsin as to their trophic level was studied. Densitometric readings in band 5 of ERTS 70mm imagery were taken for all the lakes in Wisconsin greater than 100 acres (approximately 1000 lakes). An algorithm has been developed from ground truth measurements to predict from satellite imagery an indicator of trophic status.

INTRODUCTION

The Wisconsin Department of Natural Resources (DNR) is required to classify the lakes in the state as to their trophic level in response to the federal legislation "Federal Water Pollution Control Act Amendments of 1972," section 314. This project represents an attempt to evaluate the feasibility of using photographic imagery from the ERTS (Earth Resources Technology Satellite) to accomplish this classification. The ERTS satellite passes over the same location on the ground every 18 days. Each ERTS image covers a rectangle on the ground 115 miles by 115 miles. The satellite's sensor systems (multispectral scanner) gather data in four different wavelength bands simultaneously: Band 4 (.5-.6μ); Band 5 (.6-.7μ); Band 6 (.7-.8μ); and Band 7 (.8-1.1μ).

Densitometric readings in band 5 of ERTS 70mm imagery were taken for all lakes in Wisconsin greater than 100 acres (approximately 1000 lakes). For 37 of these lakes, DNR water quality ground truth data was correlated with density readings in all four ERTS bands. The lakes in the remainder of the state were classified as to the level of eutrophication by an algorithm developed by a statistical analysis of this correlation.

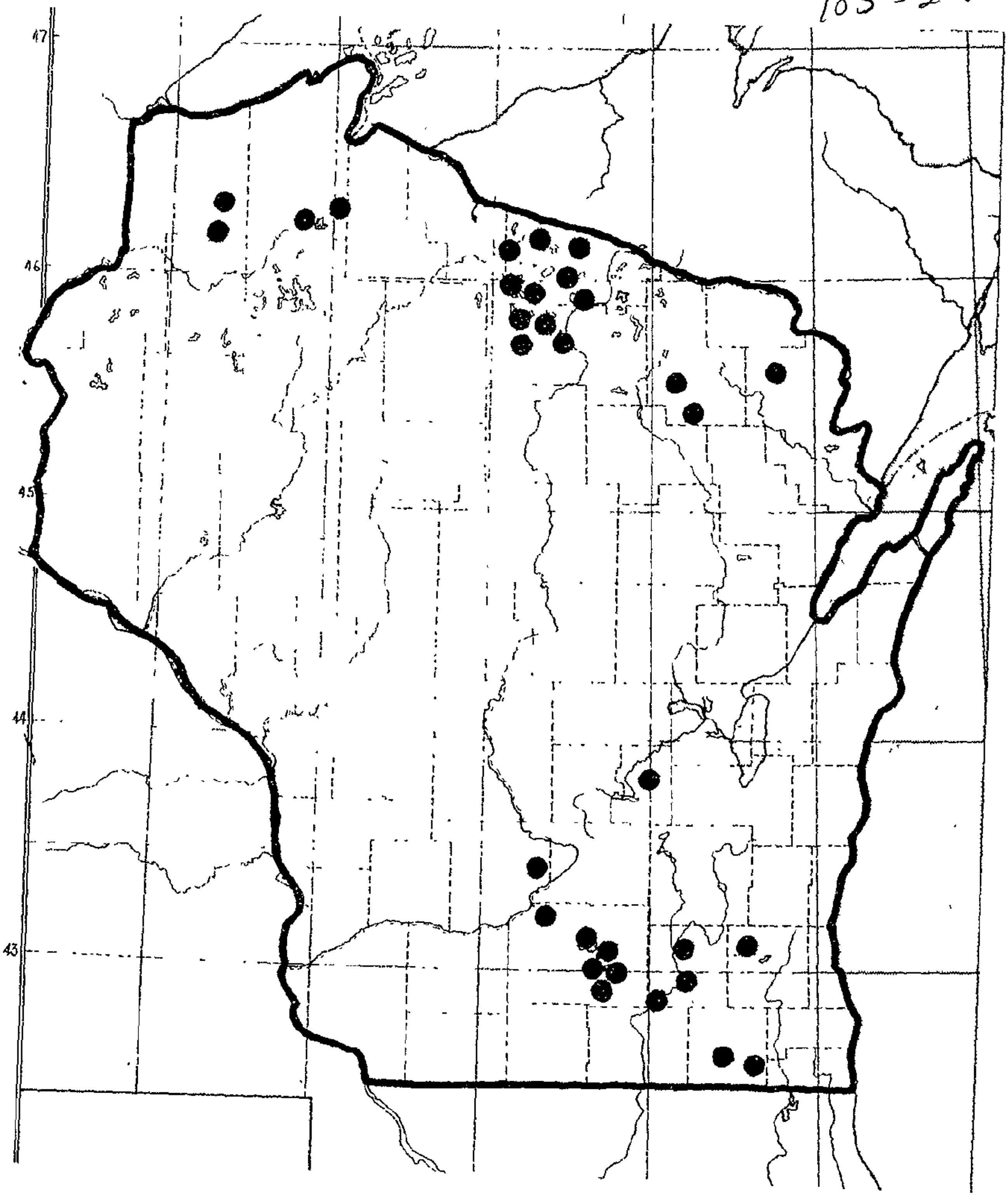
METHODOLOGY

This project involved four separate experiments: 1) Densitometric analysis of 37 lakes in each of the 4 ERTS bands using 70mm positive transparencies; this data was then correlated with secchi depth readings taken by the Wisconsin Department of Natural Resources; 2) Using specially developed computer programs and an interactive CRT terminal, ERTS digital tapes were accessed and the actual 64 scene brightness values sent back by the satellite were obtained for 14 of the above lakes; 3) A time series densitometric analysis of 20 lakes in southeastern Wisconsin on four different ERTS overflight dates; and 4) Densitometric analysis of approximately 1000 lakes in Wisconsin greater than 100 acres on band 5 of ERTS 70mm imagery.

Densitometric Analysis of 37 Lakes Using 70mm ERTS Imagery

The primary goal of this study is to evaluate the usefulness of densitometric analysis of ERTS photographic imagery as a tool for a periodic monitoring program of Wisconsin lakes for changes in water turbidity caused by the growth of phytoplanktonic algae. Thirty-seven lakes were selected for densitometric analysis in each of the four ERTS bands. The location of these lakes, which range in fertility from extremely eutrophic lakes in southeastern Wisconsin to very clear oligotrophic lakes in the northern part of the state, is shown on Map A. Eight different ERTS images were required to provide coverage of all 37 lakes. Secchi depth readings were selected as the ground truth measure of lake eutrophication to be correlated with lake exposure calculated from the ERTS image. Secchi depths and various other water quality parameters are sampled quarterly in these lakes as a part of the DNR Lake Water Quality Monitoring Program.

105-2-a



LOCATION OF LAKES ANALYZED

The sampling date of each of these lakes was within 25 days of the ERTS overflight date.* In addition, each lake 1) had no tannin coloring, 2) was at least 20 feet deep to minimize bottom interference, 3) was large enough to insure that the measurement spot of the microdensitometer was wholly within the lake, and 4) was not obscured at all by clouds or atmospheric haze.

A Gamma Scientific spot microdensitometer equipped with a digital readout photomultiplier-picoammeter combination was used for the measurement of the transmitted intensity of light through the film. A measurement spot size diameter of 50 microns, which corresponds to 550 feet on the ground, was selected for the analysis of lake imagery. This is large enough to average across several of the pixels or resolution cells of the ERTS multispectral scanner which are about 200 feet across on the ground. A one millimeter measurement spot size was used for densitizing the film wedges on each of the ERTS images.

The raw current readings output from the densitometer were used to calculate the transmittance of light through the transparency for the lake of interest. On any one frame, lake image transmittance might be expected to correlate with secchi depth. However, the transmittances of lakes on different frames are not comparable because of photographic processing differences. These processing differences can be normalized by using the film wedges provided on each frame to calculate the relative exposure of each lake. Relative exposure is proportional to the light energy hitting the ERTS multispectral scanners and is comparable from frame to frame. Each step on the film wedge was exposed during processing

*For 30 of the lakes the sampling date was within 10 days of the ERTS overflight. The remaining lakes (sampled within 11-25 days) were included because they were all known to be oligotrophic and were not expected to show much variability in algal turbidity over time.

by an amount of light proportional to a known exposure. The transmitted light was measured through each step of the film wedge on each frame. A transmittance versys exposure curve was plotted for each frame and this was used to find the exposure related to the densitometric reading for each of the lakes.

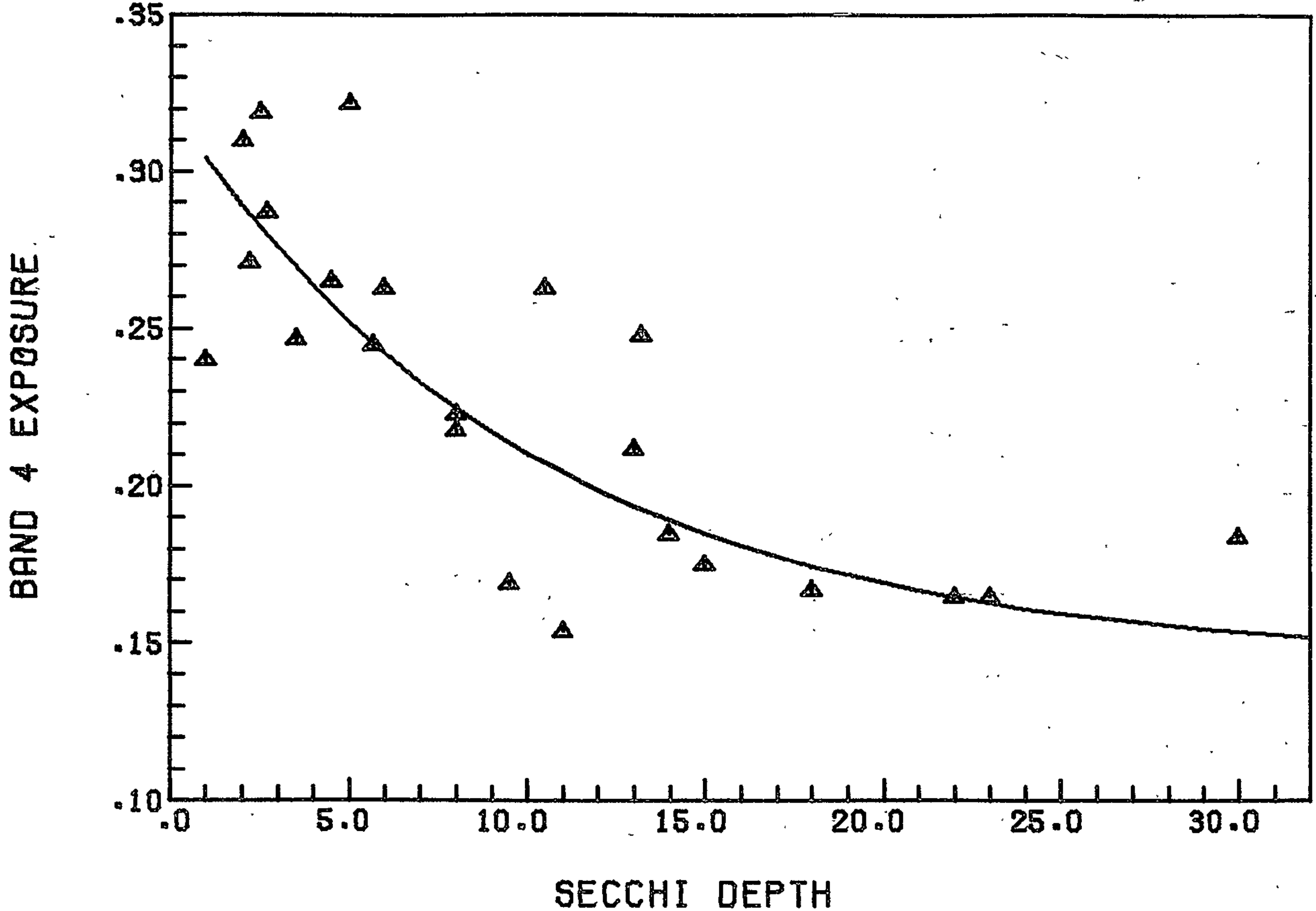
All the above calculations were done with computer programs developed for this project. The program includes a graphing subroutine for plotting exposure versus secchi depths. These plots are shown in Figures 1-6. The programs include provisions for inputting calculated lake exposures and secchi depths into a non-linear regression curve fitting subroutine for statistical analysis.

Of the four ERTS bands, band 5 and, to a slightly lesser extent, band 4 showed the best relation between lake image exposure and secchi depth. Band 5 of the multispectral scanner senses red band wavelengths from .6-.7μ. The plot of band 5 exposure versus secchi depth is shown in Figure 2. An exponential model was used to calculate the least squares regression represented by the solid line. The following equation describes this line:

$$\text{EXPOSURE} = .0543 + .148e^{.073 \text{ secchi depth}}$$

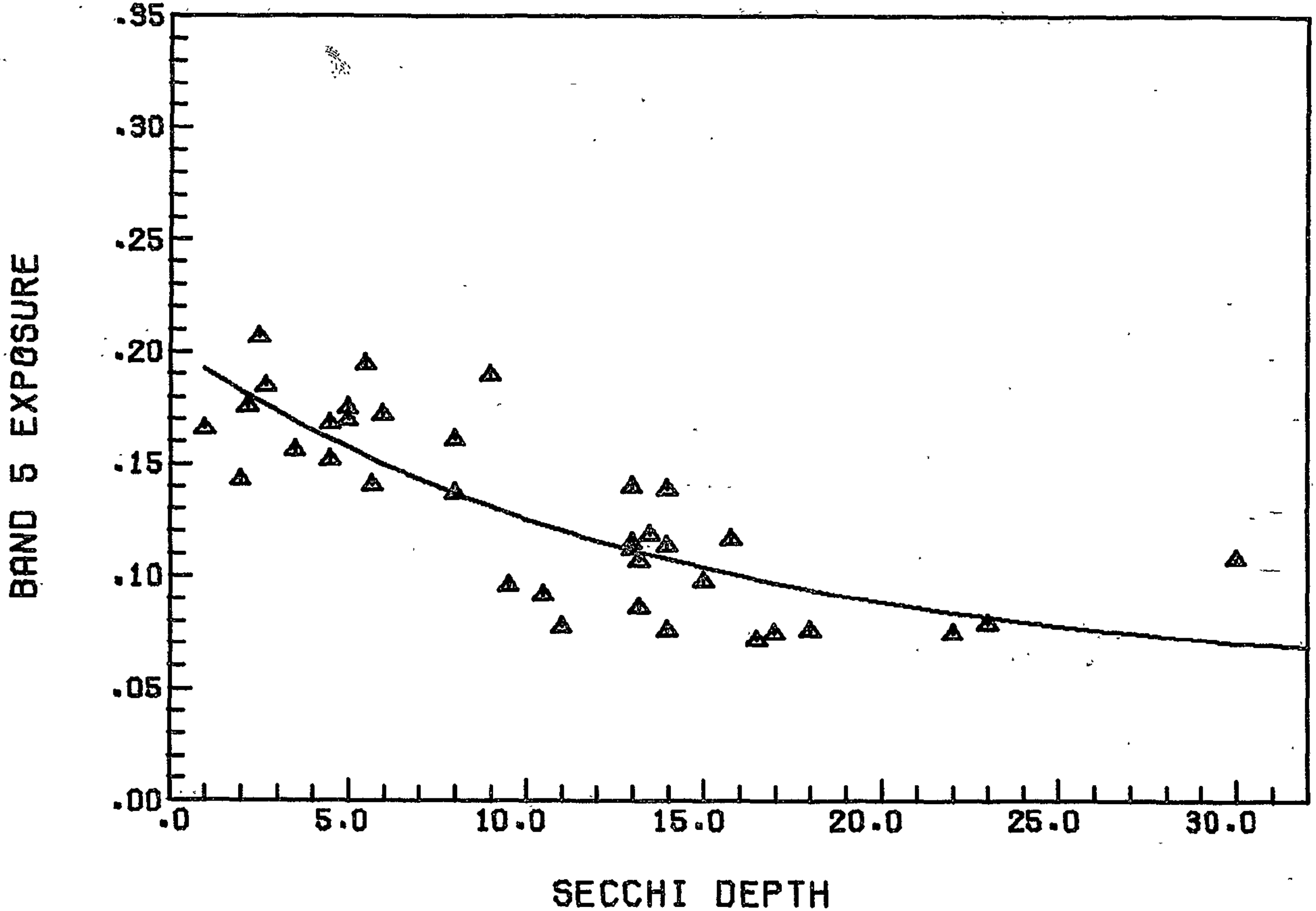
The root mean square residual (standard deviation) about the regression line is .02524. The mean measurement error in band 5 of two replicate sets of 14 lakes was 6.09%. Given this small measurement error, much of the scatter about the regression line can be assumed to be a function of the 1 to 25 day interval between the sampling date and ERTS overflight date. The root mean square residual is an indicator of how reliably the fitted curve predicts a secchi depth for a given exposure. Assuming a normal error distribution, an envelope of one standard deviation (.0254)

FIGURE 1 — BAND 4 EXPOSURE VS. SECCHI DEPTH — ERTS 70MM IMAGERY
EXPONENTIAL REGRESSION REPRESENTED BY SOLID LINE



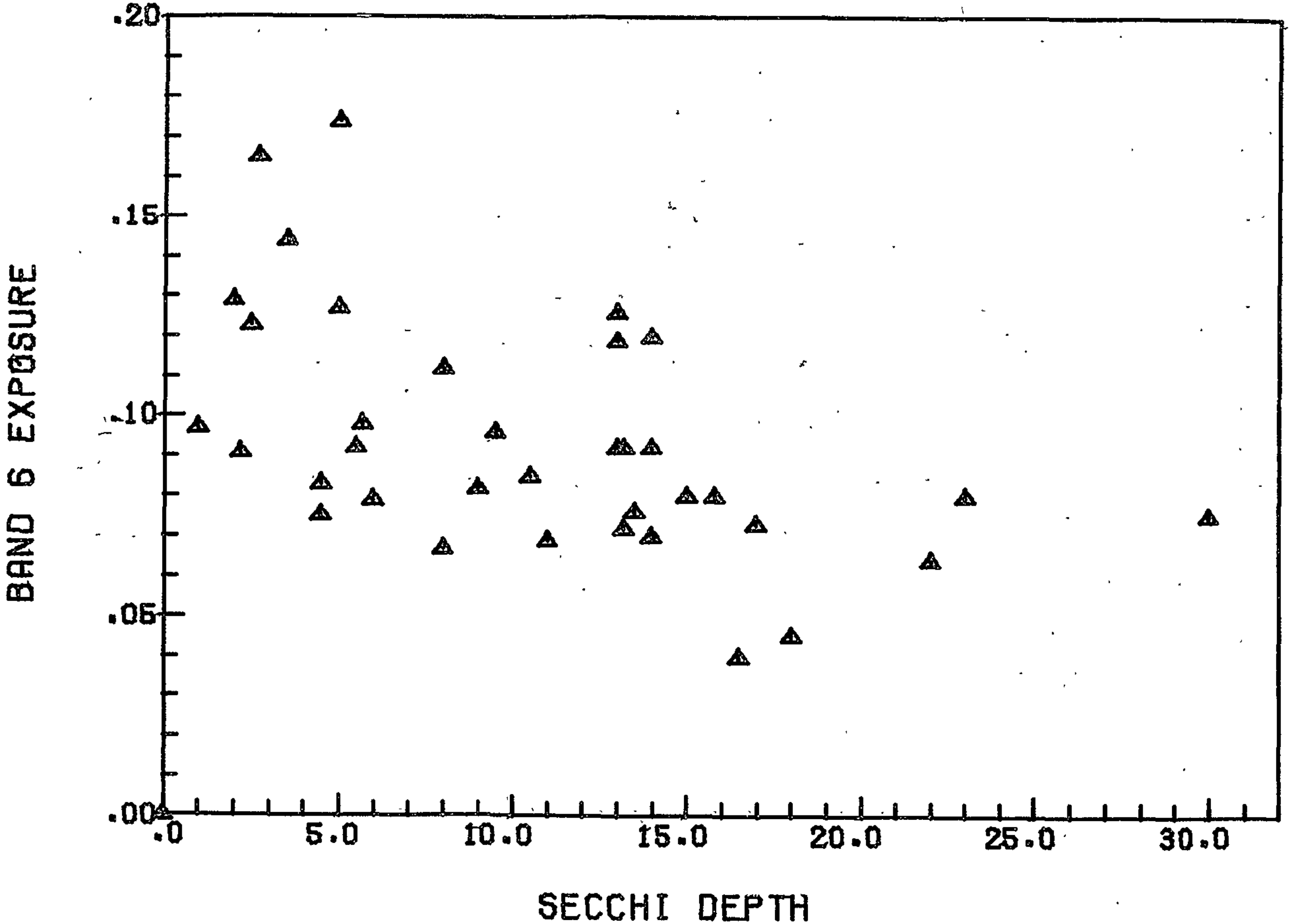
105-40

FIGURE 2 -- BAND 5 EXPOSURE VS. SECCHI DEPTH -- ERTS 70MM IMAGERY
EXPONENTIAL REGRESSION REPRESENTED BY SOLID LINE



105-48

FIGURE 3 — BAND 6 EXPOSURE VS. SECCHI DEPTH - ERTS 70MM IMAGERY



105-4C

FIGURE 4 -- BAND 7 EXPOSURE VS. SECCHI DEPTH -- ERTS 70MM IMAGERY

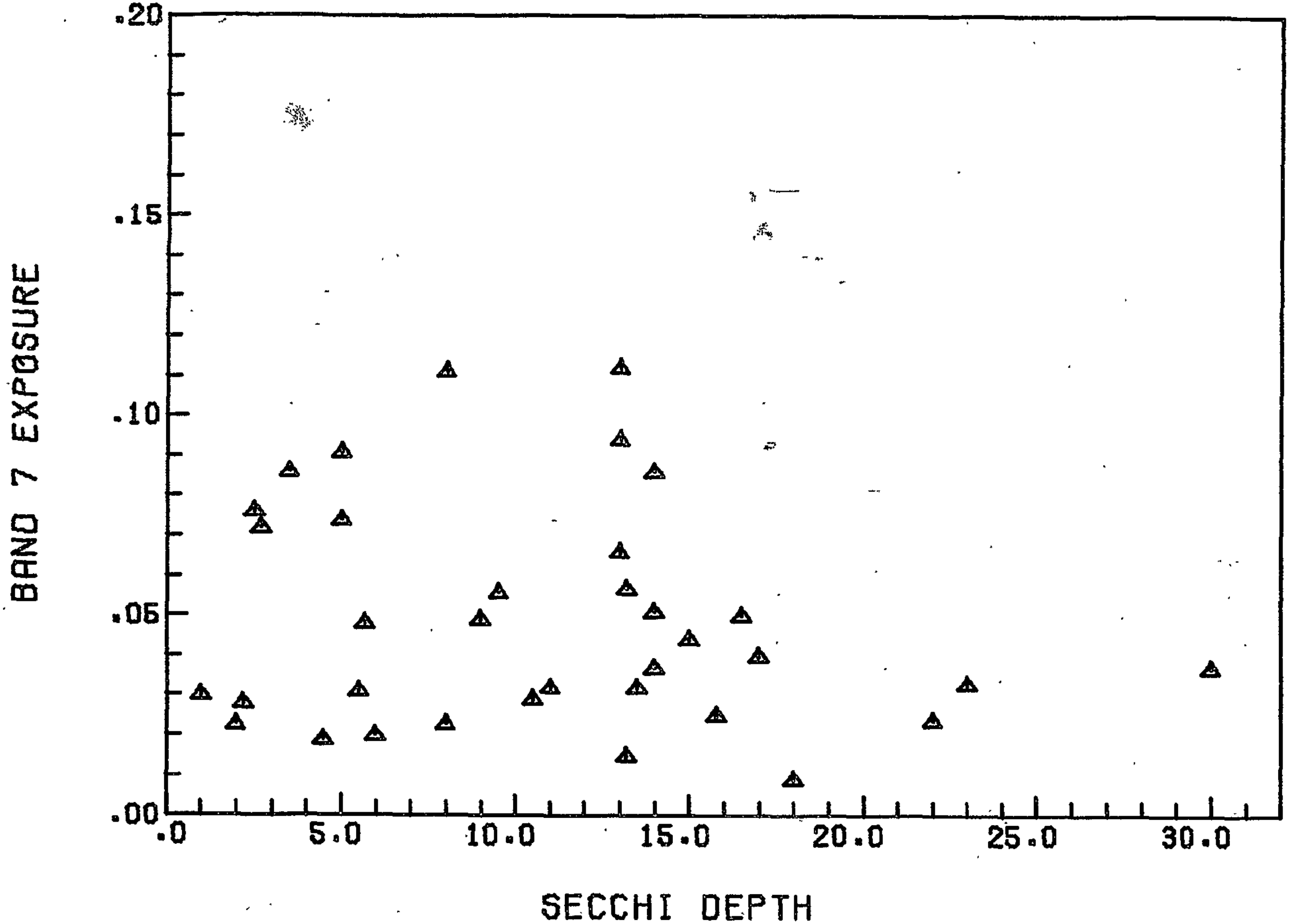
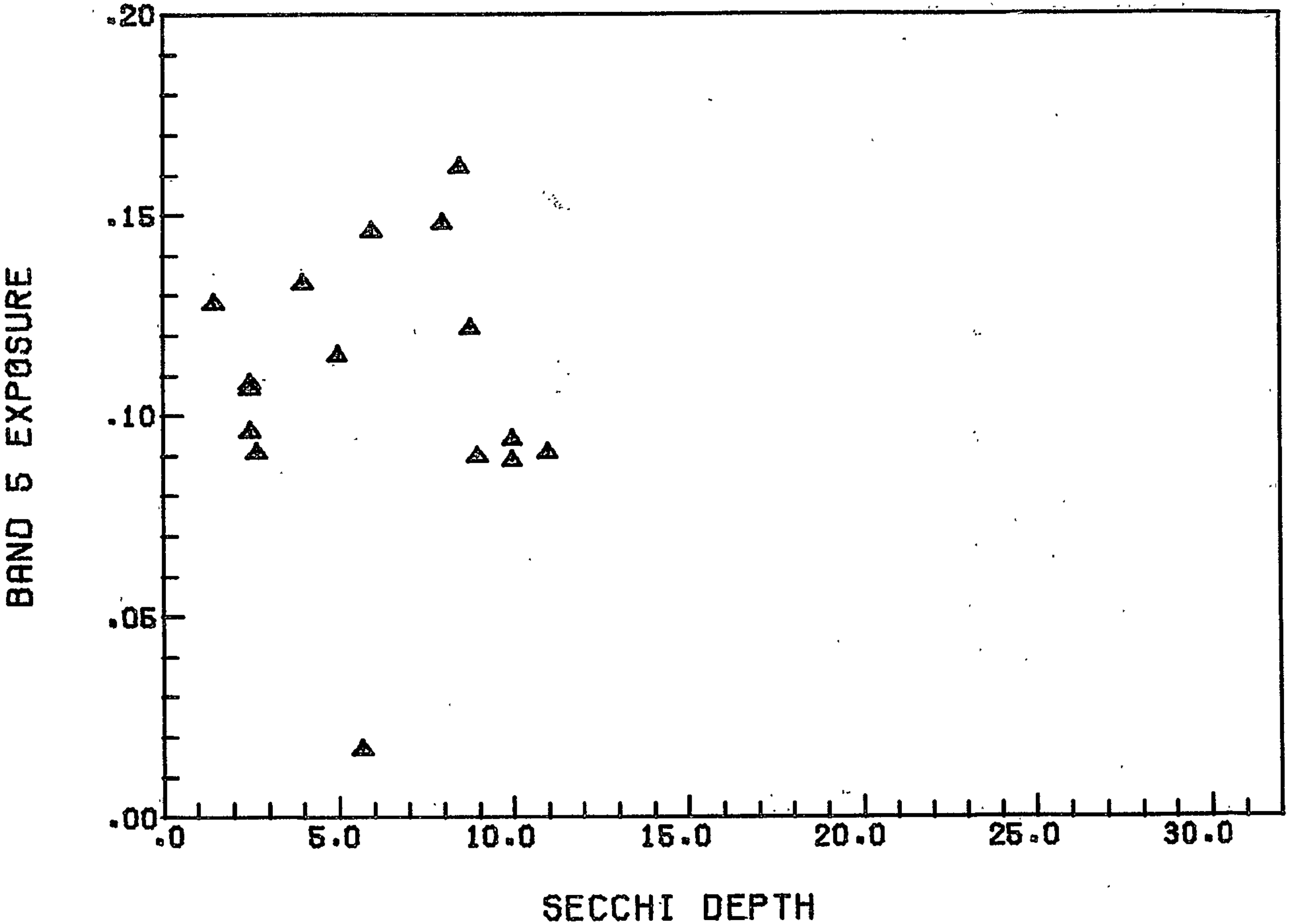
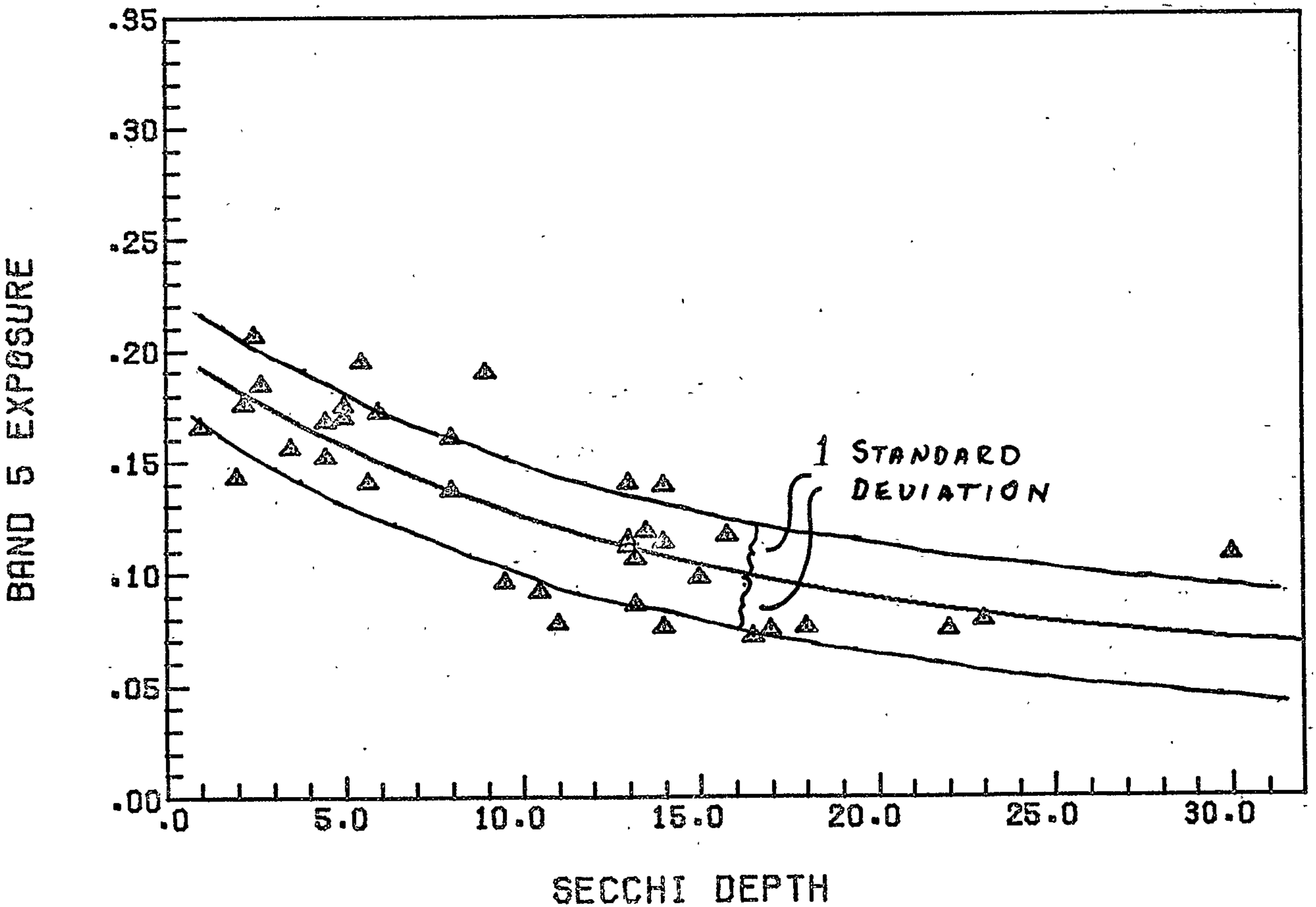


FIGURE 5 -- BAND 5 EXPOSURE -- TANNIN LAKES -- ERTS 70MM IMAGERY



105-4E

FIGURE 6 -- BAND 5 EXPOSURE VS. SECCHI DEPTH -- ERTS 70MM IMAGERY
EXPONENTIAL REGRESSION REPRESENTED BY SOLID LINE



105-4F

on each side of the fitted curve can be expected to contain a given lake exposure 68.27% of the time. (see Figure 6). An envelope of two standard deviations (.0508) on each side of the curve will contain a given lake exposure 95.45% of the time.

The plot of band 4 (green band, wavelength .5-.6μ) lake exposure is shown in Figure 1. There is very little contrast in band 4 between the lake image and the land surrounding it. To reduce the chance of measurement error caused by the inability to distinguish between the two, 12 of the smaller lakes were not analyzed, leaving 25 lakes in the band 4 sample. The exponential equation describing the least squares fit is:

$$\text{EXPOSURE} = .144 + .176e^{.0979 \text{ secchi depth}}$$

The root mean square residual (standard deviation) is .0402. The mean measurement error in band 4, calculated from two replicate sets of 14 lakes, is 4.70%.

The plots of the infrared wavelengths, band 6 (.7-.8μ) and band 7 (.8-1.1μ) exposure versus secchi depths are shown in Figures 3 and 4 respectively. There was no significant correlation between lake exposure and secchi depth in either of these two bands.

Figure 5 shows a plot of band 5 exposure versus secchi depth for tree tannin colored lakes. While exposure values for tannin lakes don't correlate with secchi depths, at a given secchi depth they consistently have lower exposure values than non-colored lakes. One possible explanation for this phenomenon is that turbidity caused by the brown colored tannin dye dissolved in the water absorbs light while the particulate turbidity caused by phytoplankton increases lake reflectivity.

Analysis of 11 Lakes Using Digital Gray Level Data From ERTS Computer Tapes

Using computer programs developed in conjunction with Dr. Lawrence

Fisher of the University of Wisconsin-Madison Department of Electrical and Computer Engineering, digital brightness values for 13 lakes in south central Wisconsin were extracted from ERTS computer tapes. The technique involves the use of a Princeton Electronic Products (PEP) interactive graphics terminal to display a representation of the area of interest in band 7. The high contrast between the lake image and the land surrounding it in this band allows for easy and positive identification of the lake to be analyzed. Using an electronic "joy stick," a cursor is positioned on the lake surface and the scene brightness value from 0 to 63 in all four bands at that location is accessed and stored on a high speed disk for further manipulation and analysis. This procedure eliminates measurement errors due to densitometer spot size and positioning, and data degradation due to photographic processing. In addition, any lake larger than several pixels (200 feet across each) can be analyzed with a high degree of accuracy. Graphs of scene brightness versus secchi depths for bands 4 and 5 are shown in Figures 7 and 8 respectively.

The relationship between scene brightness and secchi depth as found by this computer analysis are to be compared with Figures 2 and 3. The relationship found for band 5 seems to be comparable. The standard deviation is less, but significant scatter occurs. The scatter in the regression suggests that there are either measurement errors or that the conditions in the lakes changed between the time of sampling and ERTS passover. Measurement errors are almost non-existent when using the PEP terminal. This would suggest that the scatter is due to changing lake conditions.

This past summer secchi depth and other ground truth measures were taken in a number of Wisconsin lakes on the same day as the ERTS overpass. A more reliable relationship between scene brightness and secchi depth

105-6a

FIGURE 7 -- BAND 4 DIGITAL BRIGHTNESS LEVEL VS. SECCHI DEPTH

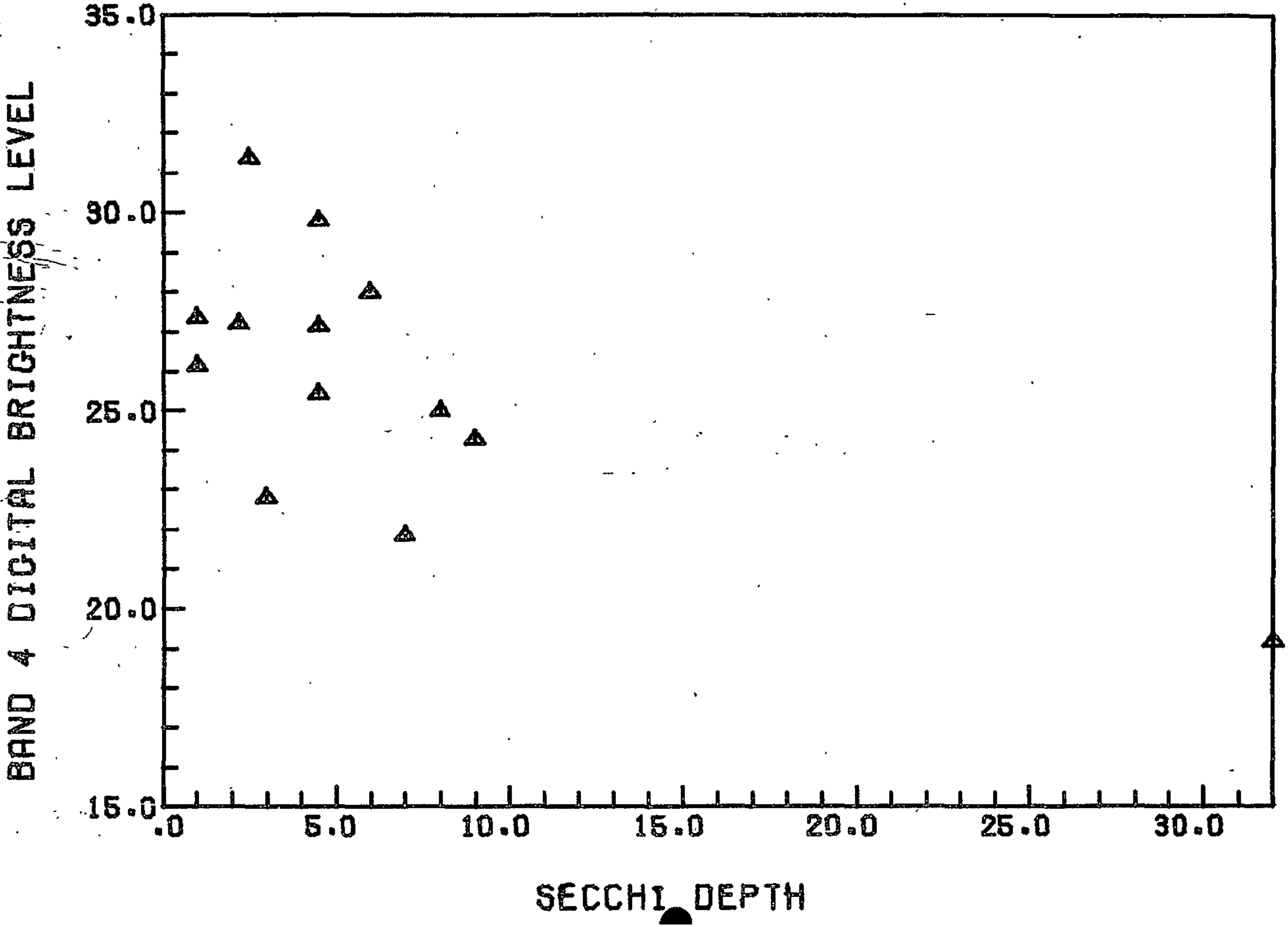
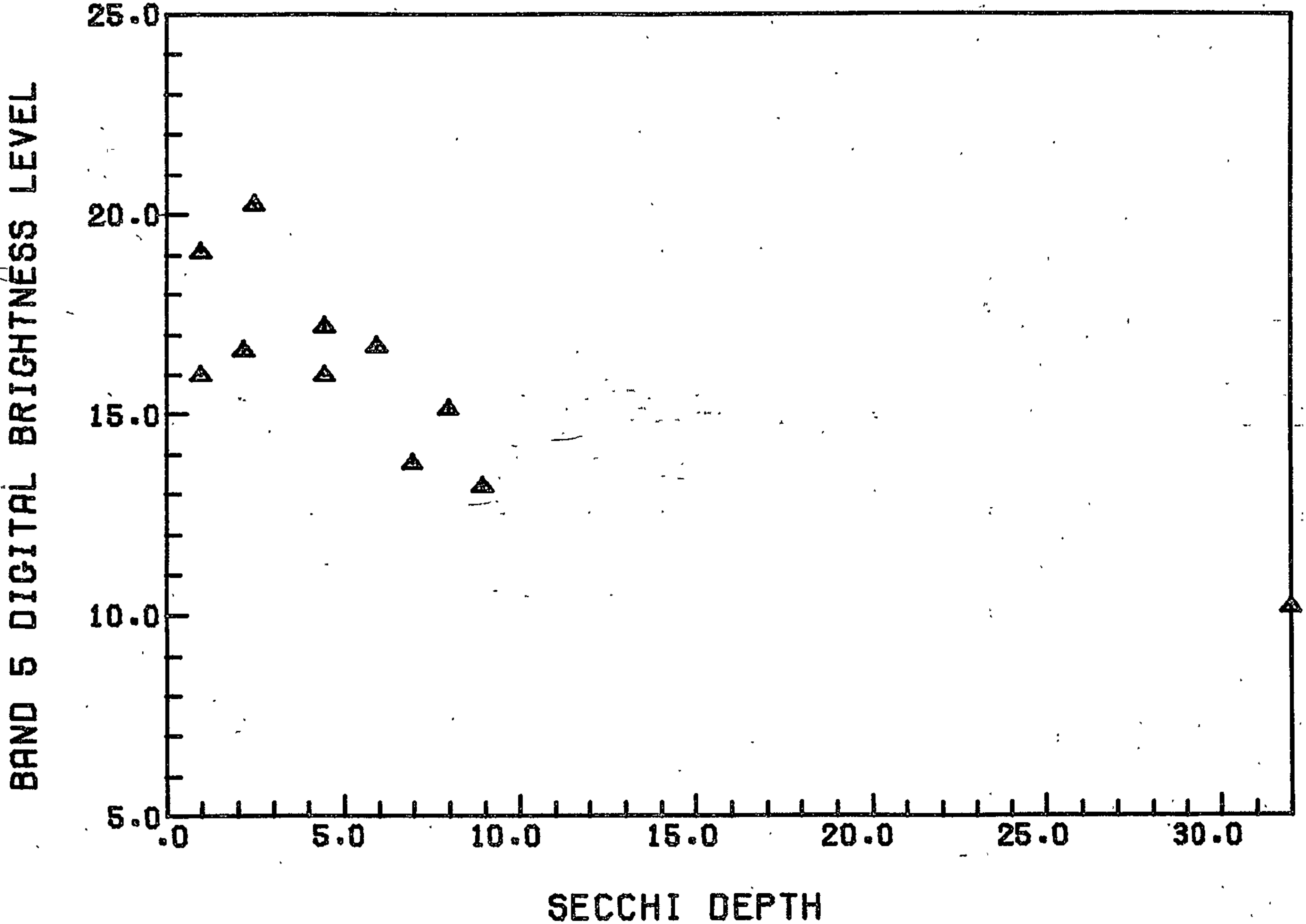


FIGURE 8 -- BAND 5 DIGITAL BRIGHTNESS LEVEL VS. SECCHI DEPTH



should be available after data from this work has been analyzed. The similarity between densitometric-derived exposures and computer-derived exposures lends confidence to the densitometric measurement of all lakes greater than 100 acres in Wisconsin. When the new exposure versus secchi relationship is derived, secchi depth will be predicted for all lakes greater than 100 acres from the exposure values derived from the measurements on the 70mm imagery.

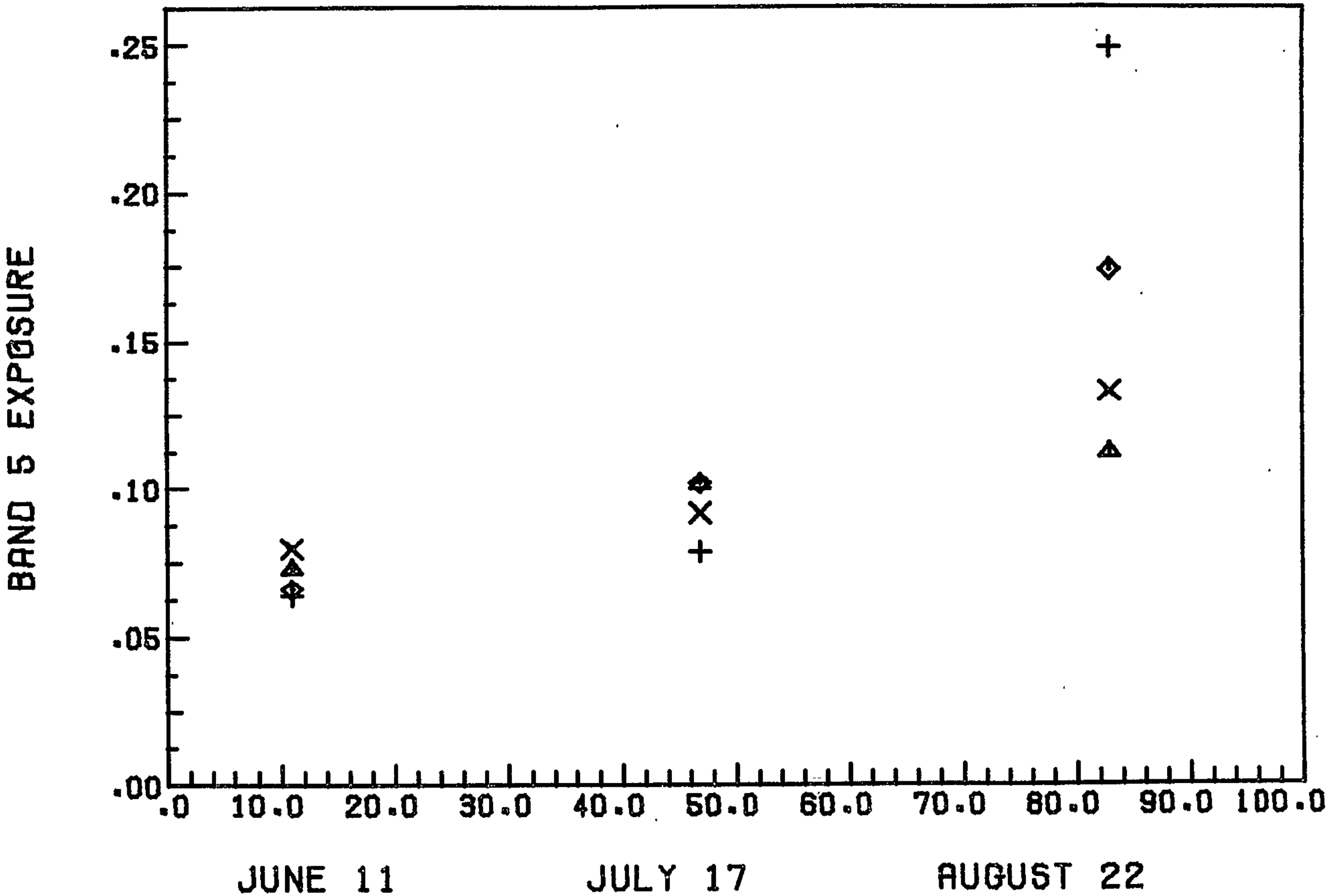
Time Series Analysis

A time series analysis was performed to evaluate the variability of lake exposure as the algae growing season progresses through the summer. Twenty southeastern Wisconsin lakes were identified on individual frames for the following dates: 9 August 1972, 11 June 1973, 17 July 1973, and 22 August 1972. All of these lakes had known fertility problems, and as would be expected the exposure in band 5 increased for almost all the lakes as the algal turbidity levels increased as the summer progressed (see Figure 9). Exposures were consistently significantly higher in August 1972 than in August 1973. This increase in exposure could be attributed to a light atmospheric haze covering the frame.

Densitometry of Wisconsin Lakes Greater Than 100 Acres Using ERTS Band 5 70mm Imagery

Based on the preceeding studies, it was decided to densitize ERTS band 5 70mm lake imagery to develop a trophic status ranking of all lakes greater than 100 acres in the State of Wisconsin. This classification is based on the relation between band 5 exposure and turbidity caused mainly by phytoplanktonic algae. Energy detected in band 5 may come from as much as 5 feet below the lake surface, and submerged rooted aquatic macrophytes are probably registered by the satellite's sensors. This study, however,

FIGURE 9 -- BAND 5 EXPOSURE TIME SERIES FOR 4 SELECTED LAKES
MENDOTA,WAUBESA,OKAUCHEE,PEWAUKEE



105-7a

has not directly addressed itself to the relation between lake exposure and the extent of these macrophyte growths.

One hundred acres was selected as the minimum lake size to be densitized based on the need for the microdensitometer measurement spot to be wholly within the lake. The 50 micron measurement spot used covers an area approximately 550 feet across on a 70mm image. A round 100 acre lake is 2300 feet across, which was felt to be the minimum lake area that could be found and measured with a reasonable degree of accuracy.

Theoretically 17 ERTS images from one 6-day overpass period would provide complete coverage of the State of Wisconsin. However, because of cloud cover and missing imagery, this project used 26 images from four different 6-day overpass periods. The 5-day period from 3 through 7 August 1973 provided the majority of the imagery used.

Densitometer readings for each lake were punched on IBM cards for computer calculation and manipulation. In addition to densitometer readings, IBM cards were also punched with each lake's name and an arbitrary identification number, the lake's latitude and longitude, county location, secchi disc depths when available, maximum water depth, an arbitrary 0,1,2 ranking for atmospheric haze, and an arbitrary 0,1,2 ranking for evaluating cases where the lake shape was such that difficulty was encountered insuring that the measurement spot of the densitometer was wholly within the lake.

Computer programs developed for this project were used to calculate lake exposure, and to rank the 1000 lakes by exposure by county, DNR district, or the state as a whole. In addition, sorting routines will sort the lakes by depth, haze, or size for analysis purposes. The computer printouts presented with this report include: 1) a sort of all lakes by district with the lakes ranked in descending order of exposure; 2) a sort of all lakes by district, with the lakes ranked in order of descending exposure by county within each district; and 3) a sort and ranking by DNR district of all lakes greater than 20 feet in depth, with no haze or clouds obscuring the imagery, and whose size and shape is such that the microdensitometer measurement spot is wholly within the lake

A rough cost estimate of labor and computing costs for future densitometry of lakes greater than 100 acres in band 5 comes to about $3.00 per lake analyzed. Based on the cost of analyzing the 13 lakes from the ERTS digital tapes, it is hoped that any lake greater than 25 acres can be analyzed in all four ERTS bands for a comparable cost per lake.

CONCLUSIONS

There seems to be a relationship between the exposure value for a lake as measured by ERTS band 5 and secchi disc depth. The exact relationship between exposure and secchi depth is still to some extent in doubt. A better relationship sould result from an analysis of the data from last summer.

If a photographic product is to be analyzed, the 70mm positive transparencies are the best approximation to the scene brightness as measured by ERTS. The most reliable data from ERTS can be derived from the ERTS digital tapes. For lakes less than 100 acres, assessment of lake conditions should be made from the digital tapes.

The costs of analysis for lakes in Wisconsin from ERTS are less than $3.00 per lake. Costs for analysis from the digital tapes should be comparable or less than the analysis of the photographic product.

TROPHIC STATUS OF INLAND LAKES FROM LANDSAT

By Lawrence T. Fisher and Frank L. Scarpace, Institute for Environmental Studies, University of Wisconsin, Madison, Wisconsin

ABSTRACT

A cooperative program between the Wisconsin Department of Natural Resources and the University of Wisconsin's Institute for Environmental Studies has resulted in a first-cut assessment of the trophic status of inland lakes in Wisconsin from LANDSAT data. To satisfy the criteria of the project, a large and versatile computer program to gain access to LANDSAT data was developed. This analysis technique has proven to be a cost-effective method of classifying inland lakes in Wisconsin.

INTRODUCTION

The Wisconsin Department of Natural Resources (DNR) is required to classify the lakes in the state as to their trophic level in response to the federal legislation "Federal Water Pollution Control Act Amendments of 1972," section 314.

This paper describes a cooperative effort between DNR and the University of Wisconsin's Institute for Environmental Studies (IES) to extract LANDSAT data providing a reasonable measure of trophic status in a cost-effective manner. An additional result has been the design of a highly versatile interactive graphics computer program available for both research and agency use.

LANDSAT's multispectral scanner (MSS) simultaneously gathers data at four different wavelengths: Band 4 (.5 to .6μ), Band 5 (.6 to .7μ), Band 6 (.7 to .8μ), and Band 7 (.8 to 1.1μ). A swath 185 km (115 mi) wide is scanned during each orbit, and this is sampled at intervals so that data is recorded for discrete picture elements or pixels whose dimensions are approximately 50 x 70 M.

In this project, Band 5 data was desired because values there can be correlated fairly accurately with lake turbidity. Band 7 data was used to form "pictures" of lakes on a computer terminal. From these, the computer program allowed the terminal operator to select individual picture elements whose data values were punched on cards.

Data was extracted in this fashion for all Wisconsin lakes with areas greater than 20 acres and depths greater than eight feet -- about 3000 lakes in all. The resulting cards were sorted, and lakes within each of Wisconsin's 72 counties were ranked in order of decreasing average Band 5 values.

LAKE TURBIDITY AND LANDSAT DATA

An earlier project (1) investigated relationships between LANDSAT Band 5 brightnesses and lake turbidity. In this project, 37 lakes included in eight different LANDSAT scenes were studied (Figure 1). The northern Wisconsin lakes were generally clear and oligotrophic; those in the southern part of the state range from moderately to highly eutrophic.

Secchi depth readings for each of these lakes were obtained by DNR personnel, but it was operationally not possible to coordinate these tests with LANDSAT overflights. In some instances, over a month's difference existed between secchi depth acquisition and a suitably cloud-free LANDSAT orbit.

Figure 2 shows correlation between LANDSAT Band 5 data and secchi depths for some of these lakes. A definite correlation is evident, and much of the scatter is felt to be due to the time differences described above.

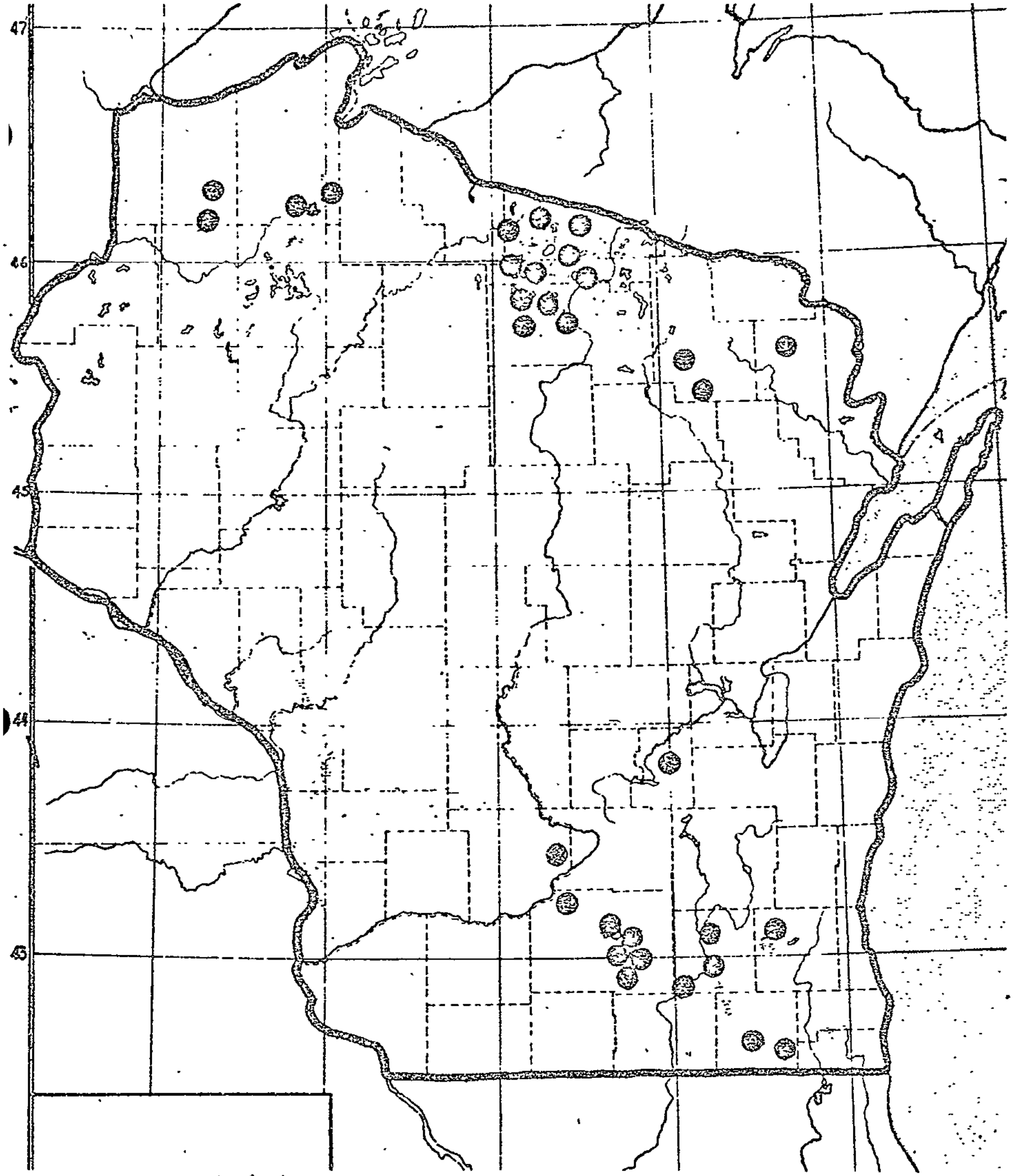


Figure 1--Map of Wisconsin Showing Locations of Lakes Sampled by the Wisconsin Department of Natural Resources

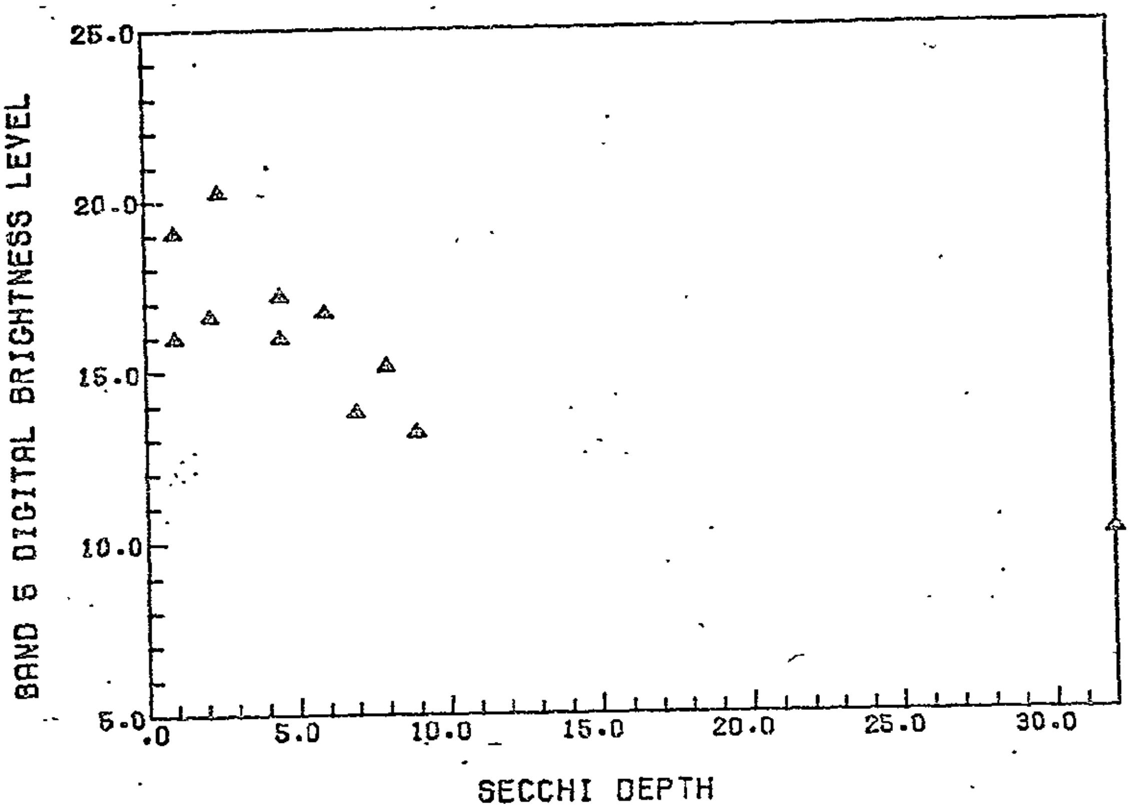


Figure 2--Correlation Between Band 5 Brightnesses and Secchi Depths for 17 Test Lakes

Originally this project involved the densitometric analysis of the photographic rendition of the LANDSAT imagery for all the large lakes in Wisconsin. Difficulties with radiometric quality of 9x9 inch photography and operational problems due to extremely small image sizes of small lakes on 70mm images prompted us to begin development of computer-assisted analysis. Since then, we have expanded the program to provide a highly versatile, general purpose multispectral analysis and data acquisition tool for several users and applications.

The objectives that were envisioned in the design of the program were:

a) Access to small, highly specific subsets of large data sets was needed. We wanted to be able to select, for example, an accurately located single data point in a bay of a lake.

b) Multispectral analysis capabilities were needed for feature selection tasks.

c) Operation needed to be highly interactive, so that options could be selected or changed easily, or feature selection training criteria easily altered under operator supervision, etc.

d) Operator-recognizable displays were needed, for example, to recognize and distinguish lakes, or to estimate acceptability of an experimental classification.

e) Navigational aids were needed to help locate areas of interest.

f) Data histogramming capability was designed to assist in supervised training for feature selection.

g) Use with a variety of data types was desirable. At the moment, the program is being used both with LANDSAT data and digitized aerial photography.

h) The program had to be attractive to a wide range of users. This implied that operation should be easily learned and that the program be extremely tolerant of operator errors.

i) No capital was available for hardware. We were constrained to use existing equipment

INTERACTIVE GRAPHICS PROGRAMMING SYSTEM

We elected to design the program around an interactive graphics terminal, and the Madison Academic Computing Center's Univac 1110 computer. One reason was that several terminals are available on campus and are given excellent software and hardware support. Second, the ability to produce a television-type image during program execution, and the operator's ability to respond to the display, provided us with the man-machine interaction deemed essential. Third, graphics features allowed operator specification of data coordinates, graphical display of data histograms, and similar non-alphanumeric input and output.

We read and decode multispectral data for a fairly large area, retaining data for whatever bands are desired and reading data tapes at any of several possible resolutions. Then a portion of this data is displayed on the terminal by means of an array of characters. Each character is displayed only if a set of tests upon the multispectral data is passed. Complete flexibility is provided in the selection of characters, bands to be tested, and test bounds; all of these can be altered at appropriate points during operation.

Displays can be located anywhere within the region for which data was extracted, and can be shown at any of several resolutions. New displays can be called at any time, perhaps at different resolutions or with different character sets or bounds.

Given a display, data can be extracted simply by pointing at desired points or blocks of

Line printer "maps" duplicating displays and showing all extracted data points can be produced as desired.

Interactive computer terminals are becoming familiar in many applications including remote sensing data analysis. A typical terminal consists of a typewriter keyboard and some form of output device -- usually a typewriter, teletype, or cathode-ray tube display. Programs can be written so that interruptions occur at points where operator intervention is needed. Keyboard responses can allow selection of options, decisions, or input of needed data, usually in response to something computed and displayed by the terminal. Such facilities with proper programming, can provide substantial versatility and convenience.

Graphics terminals, now becoming common, add some powerful features to basic interactive terminals. In addition to display or input of alphanumeric characters, they allow computer-produced drawings of points or line segments, and operator input of coordinate positions which can be formed into graphs, outline drawings, or complex figures. They also allow for transmission of graphical or two-dimensional data to the computer.

DATA EXTRACTION TECHNIQUES

After locating approximate coordinates of lakes by inspection of 9x9 inch imagery, data from Bands 5 and 7 was extracted. Displays were formed by "level slicing" on Band 7, since very low infrared reflectance of water causes extremely low brightnesses in that band. Although the displays were subject to a large number of geometric distortions, it proved generally easy for the terminal operator to recognize and identify lakes and to decide where to extract data.

Data points were then selected, with an average of three to five points per lake. If ground truth data were available from specified portions of a lake, or depth problems were known to exist, an effort was made to extract data from an appropriate region of the lake. Printer maps were produced to provide a documentary record; these show all lake names and data points . At the end of each run, printed and punched data output was produced.

Typically, one to three LANDSAT CCTs (each comprising a quarter of a scene) were analyzed in each day's operation -- these might include anywhere from one or two up to 50 lakes apiece. Economics of operation were highly dependent upon the number of lakes per scene since tape reading was a major part of computation expense. Detailed costs during a typical production run are shown in Figure 3 . This run, lasting 75 minutes, involved loading one tape and reading only one portion of it. Ten full and partial displays, and nine printer maps (each including at least one lake) were produced. The total computation charge (using late night computer rates) was just under $6.00.

Overall, about $4,000 of computer time and $6,000 for operator salaries were required to obtain data for the 3,000 lakes.

PRODUCTS AND CONCLUSIONS

Results supplied to DNR include, first, a machine-produced tabulation of lakes in each of 72 counties, listing in order of decreasing Band 5 reflectance and therefore at least approximately in order of decreasing turbidity; and a 35mm microfilm copy of all printer maps produced, showing locations of all data points. A sample output for one county is included in Table I.

Another result has been the computer program itself, which is now being used for research activities by DNR personnel. We anticipate that it will become an operational tool used by DNR staff for similar or related analysis.

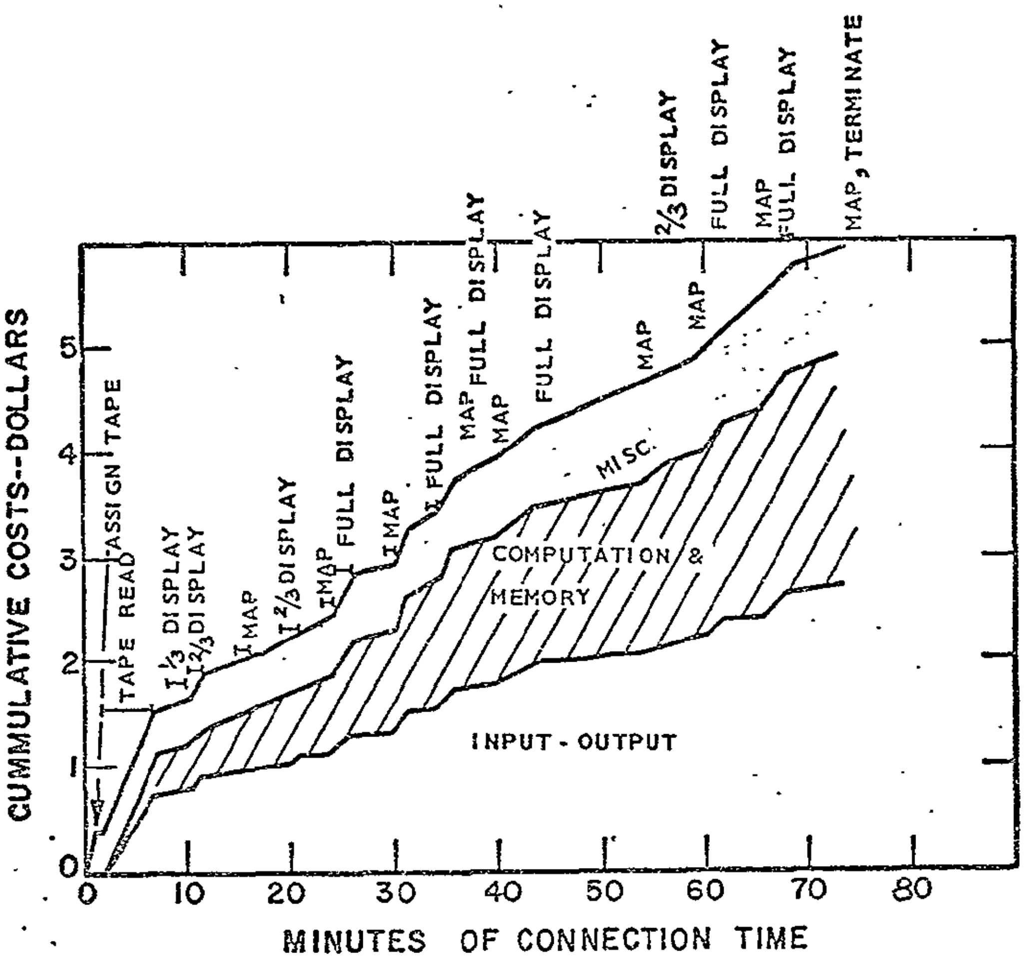


Figure 3--Computer costs for a Typical Production Run for Lake Classification.

TABLE 1.- SAMPLE OUTPUT SUPPLIED TO DNR: ALL LAKES IN COLUMBIA COUNTY RANKED IN DECREASING ORDER OF AVERAGE BAND 5 REFLECTANCE

RANK	LAKE NAME	NUMBER OF POINTS	BAND 5 AVERAGE	BAND 5 RANGE	SCENE IDENTIFICATION
1	Swan	4	16.50	16 - 18	1378-16151 3
2	Long	2	15.50	14 - 17	1378-16151 3
3	Lazy	3	14.67	14 - 15	1378-16151 3
4	Park	4	14.50	14 - 15	1378-16151 3
5	Spring	3	14.00	14 - 14	1378-16151 3
6	Lake Wisconsin	9	14.00	13 - 15	1378-16151 3
7	Becker	2	13.50	13 - 14	1378-16151 3
8	Silver	2	13.50	13 - 14	1378-16151 3
9	George	2	13.50	13 - 14	1378-16151 3
10	Wyona	2	13.50	13 - 14	1378-16151 3
11	Crystal	1	13.00	13 - 13	1378-16151 3

A much more extensive ground truth effort is now being planned, in which DNR field staff will be obtaining secchi depths and related data in conjunction with LANDSAT overflights.

Navigation procedures are being developed to allow coordinate transformations from scene to scene. These will be used to inexpensively obtain additional data over the course of a full season. Also, data from bands other than Band 5 will be incorporated. This multispectral multitemporal analysis is expected to yield better measures of trophic status.

SUMMARY

A cooperative program involving University researchers and natural resource managers has utilized LANDSAT data to produce an economical trophic status assessment of 3000 Wisconsin lakes. Computer programs have been developed which allow easy, rapid access to LANDSAT data which can be used by non-research personnel for production data extraction. Capital expenses are low, and operating costs are very reasonable compared to expenses to acquire in-site data of comparable quality.

REFERENCES

1. F. Scarpace, L.T. Fisher, and R. Wade, "Lake Classification Using ERTS Imagery," Proc. Symp. on Remote Sensing and Photo Interp., Comm. G, ISP, Banff, Alberta, Canada, Oct. 1974

2. A.N. Williamson, "Mapping Suspended Particle and Solute Concentrations from Satellite Data," U.S. Army Engineer Waterways Experiment Station Report (1974).

6 copies

APPLICATION OF REMOTE SENSING TO THE LOCATION OF HYDROLOGICALLY ACTIVE (SOURCE) AREAS

Achi M. Ishaq

Under the supervision of Professor Dale D. Huff

Recently a hypothesis generally known to hydrologists as "the source area concept" has gained considerable attention and theoretical support through the efforts of many investigators (Hewlett, 1961; Betson and Marius, 1969; Dickinson and Whiteley, 1970; Hewlett and Nutter, 1970; Dunn and Black, 1970; Hills, 1971; Freeze, 1972; Lee and Delleur, 1972; Engman and Rogowski, 1974). Common to all these authors' concepts is a recognition that surface and subsurface runoff is geographically concentrated at hydrologically active portions of a basin. In essence, this concept includes two simultaneous processes which together produce storm runoff:

(a) The perennial channel system expands and extends into zones of low storage capacity and directly intercepts precipitation which is rapidly incorporated into streamflow.

(b) The expanding channel system is fed by subsurface flow, which enters at a slower rate than direct runoff, but may be responsible for the bulk of storm flow in some watersheds.

Identification of these areas in a watershed will help not only in developing a more accurate "runoff generation model," but will also have numerous uses in areas such as water quality, stream classification, rural drainage, erosion and soil conservation, etc. Since identifying these areas by conventional field methods would be extremely time consuming and expensive, development of remote sensing identification and delineation systems is an attractive alternative. To pursue this alternative, a comprehensive study including hydrologic investigations and analysis of remote sensing imagery of Lowery Creek watershed in Wisconsin was undertaken.

In the remote sensing efforts a method for identifying source areas has been established from the analysis of color infrared imagery. A map showing the source areas of Lowery Creek watershed as of April 25, 1973 was prepared. Densitomentric analysis of the infrared imagery was conducted and examination of transmittance curves for high moisture zones indicated that source areas may be delineated on the basis of the ratio of their transmittance at 550 nm to that at 675 nm. These results may be coupled with digital techniques for the purposes of automating the source area mapping process.

As an integral part of the remote sensing efforts, field studies were established at the source areas determined from remote sensing analysis to investigate depth variation of soil moisture with time. In addition, streamflow and precipitation monitoring sites were established. In order to establish the physical differences between source and nonsource areas ground truth with respect to gravimetric soil moisture was obtained in these areas and was related to their corresponding imagery. Statistical analysis of soil moisture and other data revealed that soil moisture in source areas was higher than in nonsource areas. It was inferred from the same analysis that soil moisture in source areas was least affected by time variation.

A deterministic runoff simulation model based on the source area concept was formulated. Since this model required more data than was available, runoff simulations for a limited number of rainfall events were performed using a simple source area overland flow model. The results of these simulations mainly confirmed the source area hypothesis.

Approved *Dale A. Wolff*

Date *December 17, 1974*

CASES IN THE RELATION OF RESEARCH ON REMOTE SENSING TO DECISIONMAKERS IN A STATE AGENCY

By James W. Jondrow, Program Coordinator, Environmental Monitoring And Data Acquisition Group and Center for Biotic Systems, Institute for Environmental Studies, University of Wisconsin-Madison

ABSTRACT

Research on the application of remote sensing can be used effectively in solving problems of water quality and land use if researchers and the state agency personnel having responsibilities in this area work together to assure that research projects and agency needs are closely aligned and remain so. However, goals and projects developed to fit the requirements of research units as well as the state agencies profit by the use of several management tools. This paper describes the characteristics of several processes that transfer research results to the government agencies. Then the management of three projects and the Data Center are delineated to illustrate the application of these tools in the effort to guarantee the applicability of university research to agency needs.

I. INTRODUCTION

Research on the application of remote sensing to the problems of water quality and of land use can be valuable to state and regional governmental agencies that have responsibilities for planning, monitoring, and enforcement in these areas. But in order that the research results mesh with agency needs, conscious efforts must be made to assure that research and needs are closely related and remain parallel or converge.

In the course of research on several remote sensing projects at the University of Wisconsin, observations were made of the use of various management tools in order to assess their effects on the anticipated relevance of the remote sensing research to the needs of these government agencies. Among these tools are different organizational structures and ways of functioning, which are applied to the design and management of projects and to the communication of research results. The observed events on which this paper is based were not controlled experiments but were planned attempts to assess the methods while the remote sensing projects -- centered on the scientific understanding of the physical events involved -- continued. Members of the research teams chose to try to solve by the use of these different management tools the communication and relationship problems that developed in the natural course of the research. Solving these problems makes available to agency use material and technology previously obscured from their view.

The results of remote sensing projects can be used by a governmental agency in any of several ways.

1. The agency secures data or information it needs:
   e.g., the area within a particular isotherm in a power plant thermal plume.

2. The agency uses technology transferred to it from the research body: e.g., a technique for monitoring eutrophic levels of a lake.

3. The agency gains a theoretical understanding of a problem it faces: e.g., why thermal plumes behave as they do under certain wind and wave conditions.

This paper treats only the first two of these uses: (1) data and information flow, and (2) technology transfer.

After discussions of the characteristics of these processes, the paper illustrates in the management of three projects and a remote sensing data center the use of some tools for influencing these processes.

II. CHARACTERISTICS OF THE PROCESSES OF DATA AND INFORMATION FLOW AND TECHNOLOGY TRANSFER

A. Data and Information Flow

The elements of the flow of data and information in a remote sensing operation may be viewed as a process of communication across the interfaces between different roles necessary to the process (see Figure 1). An interface in this process is a point at which the output of one part or role of the process becomes the input to another part. A group may perform one role, an individual may, or several roles may be performed by one individual. This description is an adaptation of the standard military diagram for the basic information cycle.1

In a simple case, the flow of communication through this process is supposed to begin with the person in Role 1 -- Decision Making -- articulating a problem to someone in Role 2 -- Analysis and Interpretation: e.g., How can we more often update land cover information for land use planning? The problem is analyzed in Role 2, resulting in tasks being assigned to persons in Role 3 -- Data Processing: e.g., Can land cover maps showing urban, forest, agricultural and wetlands areas be produced and updated every six months? This step may involve the communication of tasks in several directions for different areas of investigation which may be alternatives or different phases of the analysis of the problem. Data Processing Role, upon receipt of the tasks, determines how data can be acquired to fulfill the tasks and plan missions for this acquisition: e.g., Get LANDSAT data for April and September 1975. In the Data Acquisition Role, when raw data are secured they are communicated to the Data Processing Role: e.g., LANDSAT tapes April and September 1975. The information is extracted from the data in the Data Processing Role to produce maps that become the input upon which the Analysis and Interpretation Role now studies the problem with which the process was started. Comparison of these maps with other sources of information is made and, on the basis of this, recommendations go to Decision Making: e.g., Compared to maps produced by ground parties, accuracy and cost of remotely sensed maps have these advantages and limitations. On the basis of these recommendations, the decisionmakers now have the possibility of a decision about the problem that was raised in the first place.

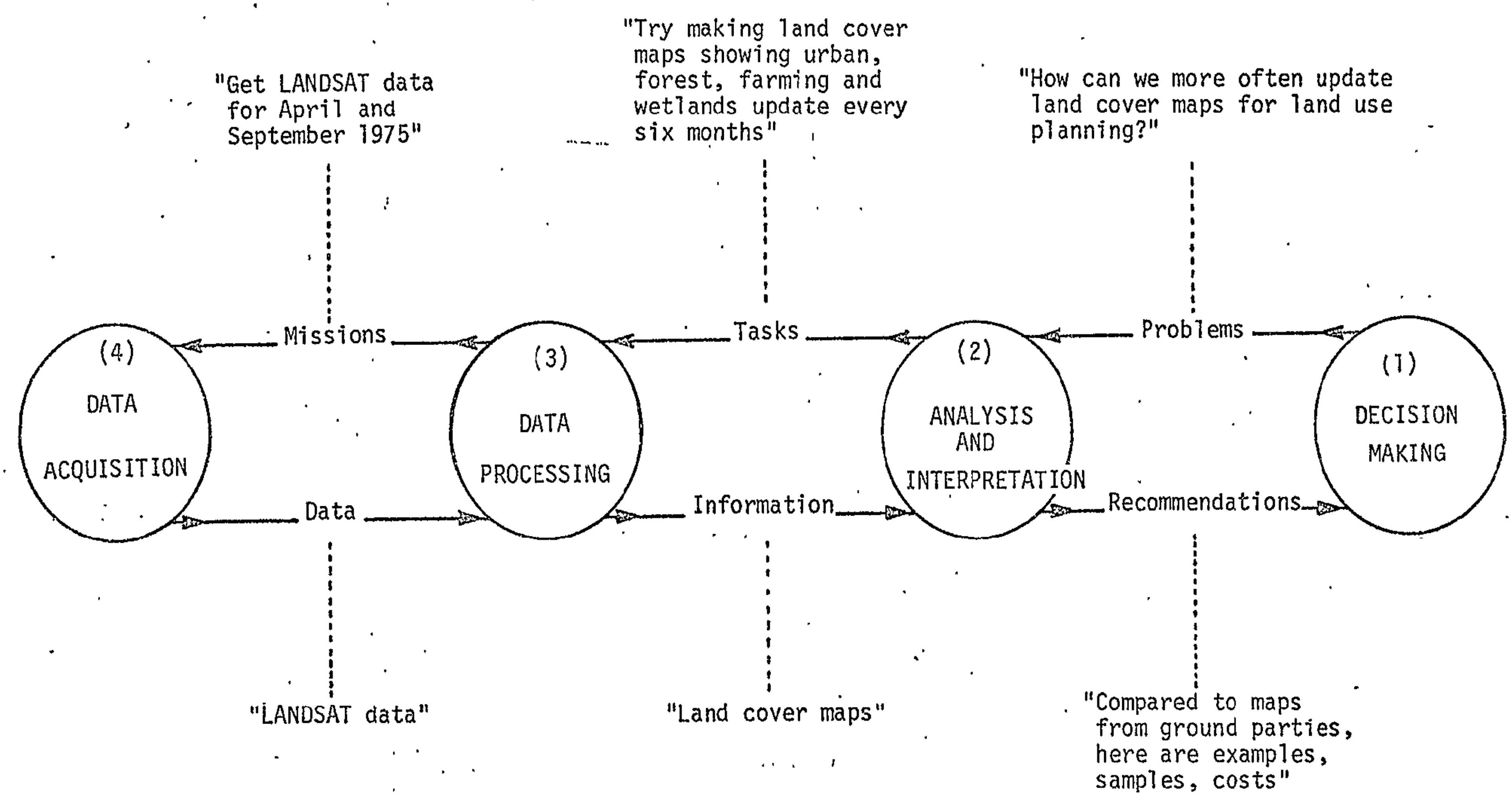


Figure 1. Diagram of data and information flow showing four distinct roles and communication across the interfaces between them. Adapted from Arnold H. Lanckton, "Remote Sensing: International Market and Market Trends," presented at Conference of Remote Sensing, Institute for Graphic Communications, Ipswich, Mass., October 1973.

The above description is referred to as the simplest case because it is assumed that the roles (1), (2), (3) and (4) are clearly defined and performed by separate persons and that communication at the (1)-(2), (2)-(3), and (3)-(4) interfaces is uninhibited. In none of the projects described in this paper were these assumptions true. Lack of clarity in the roles of the decisionmakers and of the analysts and interpreters led to an emphasis on clarifying these roles. The interfaces at which communication in the projects studied here was needed, but at which observation indicated communication was not clear, were those from (1) to (2), (2) to (3) and (2) to (1) (Figure 1).

Some of the complications involving role (1), role (2), and the interface (1)-(2) and (2)-(1) were the result of uncertainty about the boundary between roles. In most cases, decisionmakers were in a state agency, but some of the analysts and interpreters were in the same state agency. Other analysts and interpreters were researchers in the university. The boundary between university personnel and state agency personnel within the Analysis and Interpretation role at times produced groups with two distinct points of view, each doing analysis and interpretation. In these cases the simple diagram should be augmented, as in Figure 2. The interface between (2A) and (2B) is subject to the possibilities of misunderstanding between the research world and the practitioner world discussed in Section II.B.

The interface between (2) Analysis and Interpretation and (3) Data Processing is difficult because the experience of researchers within the university has led them not to be clearly aware of distinctions between roles. In most research projects, analysis of the problem, formulation of tasks, data processing, production of information, and interpretation of information are all combined in the work of one person or one coherent group. Communicating with others in an extended process or confining himself to one distinct role while someone performs another on which he is dependent are unfamiliar skills for many university researchers. This unfamiliarity with these role distinctions may mean that research does not produce recommendations that would be of use to a decision-making person, but would be useful for making conclusions about hypotheses that were to be tested. A university researcher may believe that he has completed the whole project when, in fact, the information flow sequence has not been carried to the point where a useful product has been produced. There is no reason why one person cannot occupy several roles in this process, but experience indicates that it is important for each individual or agency to recognize as clearly as possible what the different roles are and how they relate to the roles on either side in the flow sequence.

To help the data and information flow process to proceed efficiently, it became an objective of management of the projects involved to improve communications across the interfaces between roles in the process and to clarify the distinct roles. Understanding of a person's role and of other roles in the process seemed to be one of the best tools for improving this communication. Another tool was clarifying the boundaries between agencies, and relating them to distinctions in role. Dialogue, or extended two-way communication with persons on the other side of an interface was another tool useful for improving communication. Finally, inclusion of persons in all the various roles of the data and information flow in the early planning of projects was an essential tool.

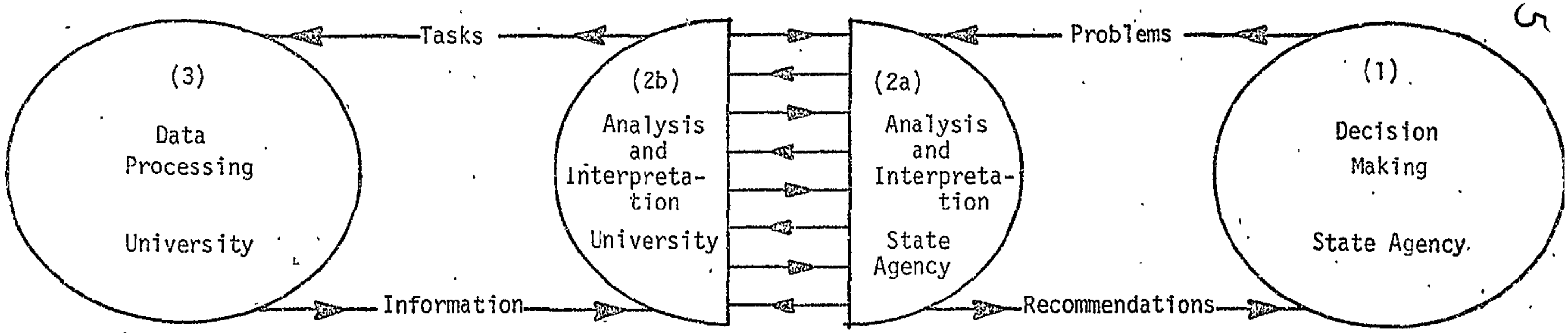


Figure 2. Detailed section of diagram of flow of data and information showing relation between state agency staff members and university research personnel when both are involved in the role of analysis and interpretation.

B. Technology Transfer

When an objective of research is to provide a means by which a governmental agency may solve a problem confronting it without continued dependence on the research organization, the transfer of technology becomes crucial. While many of the staff members of state agencies are scholars at work in the application of scholarship, their positions in governmental agencies make it most likely that they operate as practitioners of science rather than as researchers of science. In his article "Relations between Researchers and Practitioners", James P. McNaul[2] lists some areas of difference between researchers and practitioners. The following are adapted from his list with illustrations from Wisconsin projects.

1. The value system of technology, or of the practitioner, is the use of knowledge: "We need a practical way to clean up the lake water." For science, or the researcher, the value system is the increase of knowledge: "We need to understand lake eutrophication."

2. The primary communication pattern for practitioners is through technical agencies or companies: "We'll talk to the Corps of Engineers or consultants from water treatment companies." The primary communication pattern for researchers is through scientific journals: "We'll have to do a literature (journal articles, not brochures from practical companies) search."

3. The time frame required of practitioners is generally short: "We'll need a plan to show some progress in cleaning up lakes before the end of this year." That for researchers is longer. "This will take about the three years that a graduate student usually requires to complete a research project in collaboration with a professor."

4. Practitioners must be concerned about uniqueness in their products or policies: "Clear Lake is becoming choked with weeds, and swimmers and boaters want to have it cleaned up." Research scientists are most interested, on the other hand, in the discovery of patterns that constitute theoretical principles that can be generalized: "We need to understand whether the weed growth is a perfectly normal phase in the lake ontogeny."

5. Practitioners have to assume that the knowledge on which they are going to act has some finality: "If we do this the lake water will be improved." Scientific researchers, on the other hand, think of scientific knowledge as never final: "If we take this action we may discover another whole set of circumstances about the water quality that we don't understand."

6. The conditions under which scientific practitioners operate do not allow manipulation of their environment to allow certainty about the variables involved in decisions: "We've got to find something to do about Clear Lake with the weeds, the swimmers, the boaters, and the septic tanks as they are." Research scientists, on the other hand, try to build experimental designs in which some factors can be controlled to allow variables to be studied and measured: "If you can

just stop the effluent from all the septic tanks around the lake for three years, we can gain an understanding of what is happening to the weeds and sediment in the lake, and then we can understand what might be done about it."

It should be emphasized that while the differences in viewpoint between practitioner and researcher have been highly instructive in allowing university researchers and state agency staff members to deal with differences in their viewpoints, neither "practitioner" nor "researcher" completely applies to any group of individuals. These are models and not total characterizations.

To aid in the management objective of transfer of technology as a result of these research projects, attempts were made to help persons on the research side and the agency side learn the language and customs of the other, expect problems in the transfer, and expect to be able to solve the problems of transfer through working together. Dialogue was an important tool in this process. Tools used also included workshops, small group meetings, collaborative planning, collaborative data acquisition, site visits, temporary switching of roles, and cooperative work on manuals on the technology. Collaboration in preliminary planning before a research project commenced was found to be very important to aid transfer of technology.

III. CASES ILLUSTRATING PROBLEMS OF FLOW AND TRANSFER

A. Remote Sensing Research for Monitoring Eutrophic Level of Lakes

Researchers at the University of Wisconsin had been at work for several years developing means by which water quality parameters could be determined by remote sensing when the Department of Natural Resources (DNR) of the State of Wisconsin was faced with a critical application problem. The department was required to make an assessment of the eutrophic level of all lakes within the state having an area larger than 100 acres. The assessment of thousands of lakes by means of ground sampling seemed financially impractical. Suggestions that LANDSAT-1 or high-altitude aerial data be used for this assessment were met with reservations by staff of the Department of Natural Resources. Problems of resolution of LANDSAT-1 data and reliability of analysis seemed to provide good grounds for skepticism. When trial tests were made, however, a technique appeared possible. Research that was then designed to include close collaboration between researchers and users produced a useful technique. The DNR is already knowledgeable about this and is preparing to use its own interactive terminal for analysis of LANDSAT-1 data. Its own technicians will use the technology developed to monitor lake eutrophic levels.

1. What was done. - Staff members of the DNR having responsibility for planning and enforcement of water quality programs had been advisory members of the steering committee for a project on remote sensing for some time. They brought the problem of monitoring eutrophic levels of lakes as a possible goal for remote sensing research. In order to be sure that goals for research would

be formulated in such a way that the questions answered would be clearly related to the questions as they face the DNR, the role of DNR staff members in the management of the remote sensing project was strengthened. DNR staff members became principal investigators along with university research personnel. As a result of this, they participated in deciding specific objectives for research each year, formulating the budget for the proposed research, deciding research sites and time schedules, supervising laboratory and field workers, contributing sections to interim and final reports, and discussing or clarifying final reports wherever they were presented. No attempt was made to have the roles of the university researchers and DNR researchers interchangeable. Rather, they were complementary to one another.

The specific work of principal investigators from the DNR and the university took place within a general dialogue between DNR staff and university researchers over what is possible in remote sensing. To initiate one phase of the dialogue a one-day workshop on current work on remote sensing was presented for personnel of the DNR. University staff did not know which people in the DNR would be interested. The management of the DNR canvassed their organization: about 30 of their staff members representing a wide variety of interests took part in the workshop.

University researchers led off each session with a brief description of the work in which they were presently engaged, leaving at least 50% of the time for free discussion. Some of those attending felt afterward that a longer time could have been spent on each topic, but experience indicates that the attempt to extend a familiarization session beyond one day produces diminishing returns.

In the course of the workshop, participants were urged to make arrangements to pursue specific questions by individual or small group arrangements on a more limited topic. One example of this occurred several months after the workshop when a small group met to discuss specifically what could be done through digital analysis of ERTS imagery of lakes to monitor eutrophic levels. One university researcher had prepared a program for image analysis by means of an interactive computer terminal and arranged to explain the possibilities and limitations of this process to operating personnel of the DNR. This small-group, one-half day discussion, including demonstration, was focused clearly on further development of this particular piece of technology. Progress toward fulfilling the need of the DNR and areas in which greater development was needed became clear in the interaction within the small group. As a result of this meeting arrangements were made for refining the technique and for establishing a means by which employees of the DNR would develop proficiency in the use of this program. Although hired by the DNR they would work at the university under the supervision of a university researcher.

Finally, on the basis of experience of the DNR personnel who are developing competency in the use of this interactive program for assessing lake eutrophic level, instructions will be prepared by researchers bringing together theory and technique in a manner that will allow the DNR to use its own employees and its own interactive computer terminal to carry on a program of continued operation without reliance on university personnel. The manual will not only give instructions but will explain theory and limitations of the techniques in order that the DNR can be clearly aware of the areas in which the application of the technique will be dependable.

2. Data and Information Flow. - While research on monitoring and eutrophic level of lakes has developed into a transfer of technology to the DNR, it has also involved data and information flow. Decisionmakers in the DNR needed to know the eutrophic level of each lake in the state as soon as possible. This problem was communicated across the (1)-(2) interface (see Figure 1) to university researchers in the course of general meetings of the Steering Committee of the research project and the workshop described in III.A. University researchers collaborating with DNR personnel analyzed the problem and defined the tasks of identifying lakes, analyzing density on LANDSAT-1 and RB-57 imagery, relating this to ground truth, and establishing a classification system. Data requests in this case went from university researchers to NASA for LANDSAT-1 and RB-57 imagery. The data were received for processing by the university and by DNR personnel. In this particular case, the data processing and the analysis and interpretation become intermingled since interface (3)-(2) involves an interactive computer program. After the lake to be studied has been identified on the digitized computer-compatible tape made from LANDSAT-1 or RB-57 imagery, the researcher viewing the image on a television screen is able to choose areas of the lake from which data samples will be taken to establish characteristic readings for the whole lake. This allows him to avoid idiosyncracies in determining density readings from the area of the lake that might be caused by the large pixel size of LANDSAT-1 imagery or other conditions he can identify by viewing. In this process, he can also choose between different scanner bands of one image and images from different dates. By a series of questions and answers and of images, the data are refined and interpreted. The data and information flow sequence is finally completed when the eutrophic level is reported to the decision-making agency.

At two points the communication at an interface was more complicated than the simple diagram (Figure 1) indicates. Figure 3 illustrates the nature of the communication at the (1)-(2) interface in the formulation of this problem. The communication across interface 1-2A-2B has been stylized but it can be seen from the scheme depicted in Figure 3 that numerous elements of interactive communication back and forth across these interfaces are necessary before a problem is formulated clearly. At each point the university researchers or DNR staff members felt they were asking a clear question or making a clear statement. The need for elucidation each time they communicated across the interface made the attempts to communicate burdensome and made disengagement seem attractive. But with continuation of the communication, productive work was done. If communication difficulties at an interface appear to disable the data and information flow, greater concentration on dialogue -- message and response or question and answer -- may free communications and the data information flow.

A diagram similar to Figure 3 could be drawn for the interface between (3) and (2) in the return of information for analysis and interpretation by means of the interactive computer program. A diagram of this communication would appear as a series of questions and answers, questions and clarifications across the interface (3)-(2) until the operator received the data that would be best used to characterize the eutrophic level of the lake. The operator would relate data received from imagery to data received from other sources during his interaction with the digitized data displayed by the computer terminal, before final interpretation was made. In research projects in which no computer interactive program is involved, this kind of interchange back and forth between data processors and analysts and interpreters may be necessary in order to clearly define the data.

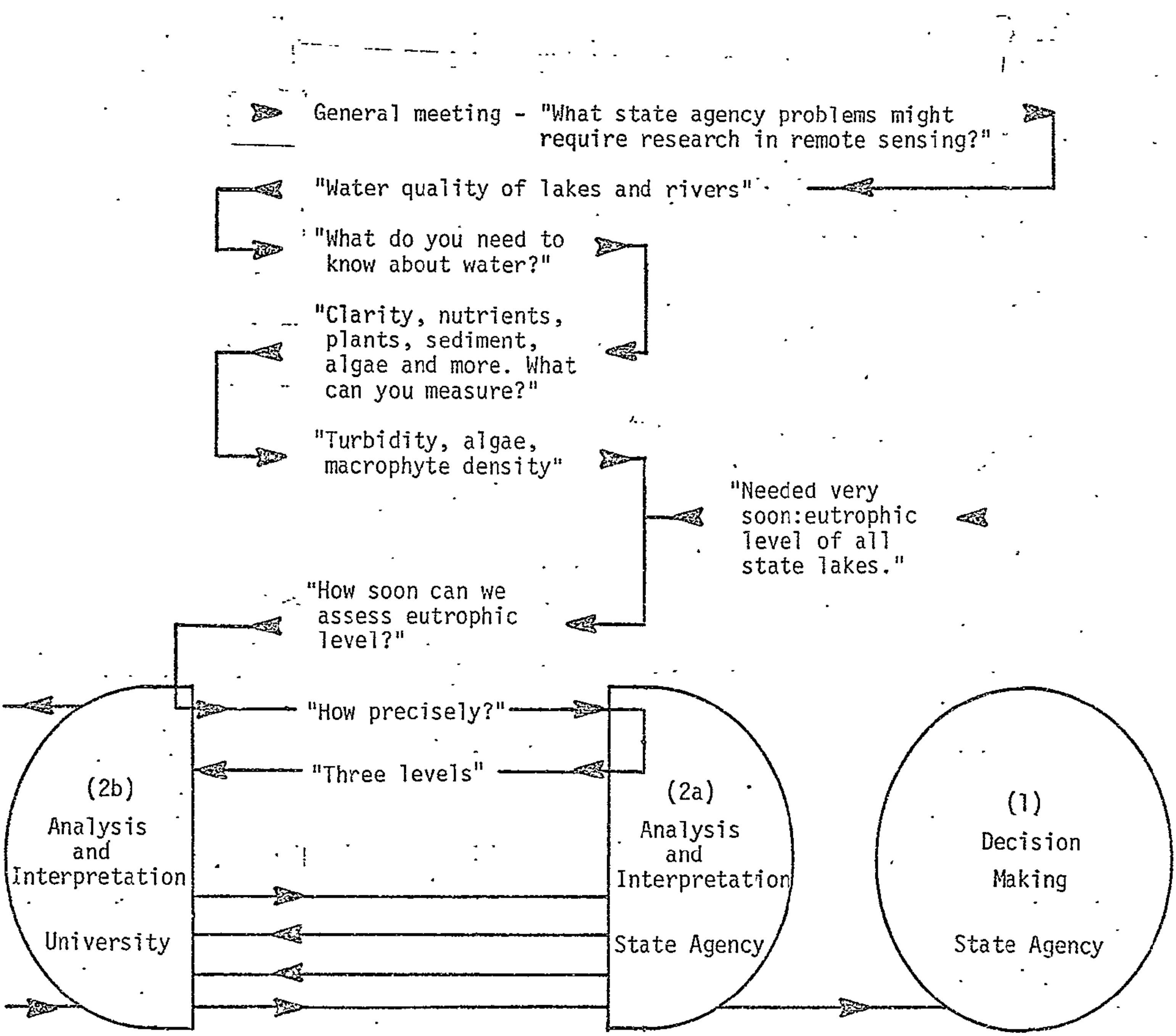


Figure 3. Detail of section of Figure 2, diagram of data and information flow, showing typical steps in the communication across the (1 - 2a) and (2a - 2b) interfaces.

3. Transfer of Technology. - In this project, a technique was being developed that ultimately was transferred for use to the DNR. It can be assumed that all of the differences of viewpoint referred to in the previous section could potentially inhibit transfer of this technology. Here are some ways used to get around differences in viewpoint in several areas.

(a) Value systems: The primary emphasis to be expected of research personnel in this project would be an understanding of why differences in reflectance of water bodies would be related to the eutrophic level of the lake. The emphasis of DNR staff members would be to assure the development of a useful tool for establishing the eutrophic level. Because the agency staff members and researchers sit together in planning research and have equal voices on the Steering committee for the project they are able to work out the implications of their different points of view about what is the most important product of the research. They have been able to maintain two emphases: (1) the development of a satisfactory technology within a reasonable time and (2) the understanding as fully as possible of the reflectance phenomena connected with eutrophication of lakes. These two emphases broaden the perspective of each group in work on the research.

(b) Uniqueness or generality of the result of research: University research personnel would like to develop a generalized theory of lake water quality while DNR personnel need to have specific categories of eutrophication established for each lake. It has generally been agreed in planning sessions and exchanges between principal investigators that the work to determine specific classifications of the lakes must go first, but at the same time generalized work on the dynamics of lake eutrophication need to be going on. Were it not for the emphasis given by DNR personnel in planning this research, it is possible that the result would have been a highly theoretical treatment of lake eutrophication that would never have been usable by the DNR.

(c) Time frame: Differences in time frame have been worked out by interaction between the principal investigators during the design and execution of the project. University researchers feel rushed and have to do things more quickly than they otherwise would. Were it not for the emphasis on getting a product fairly soon from the research it is possible that a technology developed might have come along too late to be useful in this specific problem.

(d) Manipulation of the environment: The extent to which the environment should be manipulated in order to isolate particular variables in the research has been resolved by collaboration by the principal investigators planning and executing the research. It is probable that university researchers on their own would have relied more on work in test tanks where conditions can be arranged and manipulated to suit the needs of measurement. Application to specific bodies of water might have been left to personnel of the using agency. As a result of collaboration between the using agency and the university researchers, however, the researchers have gone as far as they are able in making measurement on existing water bodies as they occurred in the environment. It is expected that there will be a movement back and forth between actual field conditions and laboratory conditions as steps are made in the progress of the research. The technology that is being developed, however, is useful in lakes as they actually exist.

(e) Communication patterns: Differences in communication patterns between the researchers and science practitioners have influenced the form in which final results of the development of this technology will be published. Research results still will be submitted to journals for journal articles; in addition, in order to facilitate the transfer of technology, a user's manual is being prepared to explain the use of the technique, the training of personnel to use it, and limitations to be observed in its use. These matters ordinarily would not be covered in journal articles produced by university researchers. The production of a user's manual grew out of collaboration between DNR personnel and university personnel.

(f) The finality of knowledge: Differences in viewpoints over the finality of knowledge contained in the technology largely remain. University research personnel as a result of their collaboration with DNR personnel probably understand better the need of the operating agency for a technique that represents a solid answer to the problem. Yet university research personnel cannot abandon their dedication to the pursuit of knowledge and the understanding that tomorrow we will learn more and what we know now will possibly be obsolete. The continued skepticism of research personnel about how final their answers are will probably continue to bother the users of the technique, but greater understanding and appreciation of these two different viewpoints will probably reduce misunderstandings that might slow the transfer of technology.

B. Importance of Including Decisionmakers in Preproposal Planning of Research on the Regional Land Use Process

Strong negative attitudes toward the use of data from LANDSAT-1 for regional land use planning and toward the research process seeking to evaluate the potential use of the data were experienced in one project. This appeared to be attributable to the lack of opportunity for input from decisionmakers in the preproposal planning for the research.

As part of the research entitled "Evaluation of the Application of ERTS-1 Data to the Regional Land Use Planning Process", an advisory council was formed. The function of the advisory council, including county planners, regional planners, state planners, private planners, and other members of the planning community, was to interact with the project investigators to attempt to involve the land use data users in the evaluation of the application of the data generated from satellite and high-altitude aircraft for regional and state land use planning.

The advisory council met three times: the first for familiarization with the characteristics, capabilities, limitations of the ERTS system; the second and third for full-day workshops directed toward the evaluation in user terms of the research investigation. Some of the advisory council found in the investigation new potential uses of the ERTS-1 data, and approved the conclusions of the research. A few, however, felt that the investigation itself was not necessary, since it would have been clear from the beginning of the preproposal planning, had regional planners been involved at that point, that satellite data could not meet the needs of regional planners. The Assistant Director of a Wisconsin Regional Planning Commission wrote that since "in Wisconsin regional planning is local planning", the detail for local planning could not be secured from satellite imagery.[3] While there was not agreement to this idea, a generally agreed understanding of what was meant by "regional planning" was so basic to the research that such a question should have been anticiapted in the design of the research.. Since there was not opportunity to include very much preproposal input from decisionmakers in the design of the research, a potential problem in the project was not discovered until late in the work.

The Advisory Council member who took exception to the view of regional planning in this project suggested that "actual users of data to be derived from research programs at the university or operational programs at the state level be included in the structure preceding the actual operations of programs and specific studies in order that these users may provide input regarding specific needs."[4]

In this case the debate stimulated by this incident may have served to bring out more in the responses of potential users of remote sensing data than would have been seen if the opportunity for more preproposal planning had been present. Certainly NASA had gone far to try to include the planning community as users in the preparations for the ERTS research, but not all possible users could be involved.

For a university approaching the planning of research related to the needs of governmental agencies, preproposal planning must include adequate input from the expected user agencies. Yet money is not readily available for this very important preproposal planning. Some mechanism must be found to support research planning in this phase if user-related research is to continue.

C. Meeting of the Minds in Preparation of Land Cover Maps

In a small research project in which difficulty had been experienced in the data and information flow process, a contract was used to clarify communication at the interface.

1. What was Done. - When the results of a research project on the use of LANDSAT-1 data for statewide land-use planning functions were presented to the decision-making organization, the results did not seem to answer the questions that had been proposed. Discussion of the problem afterward indicated that while there had been communication between the research staff and the decision-making agency, the two groups had not developed compatible understandings about the work involved. When a new project was being considered, the decision-makers and the researchers used a technique from the business world to clarify the understanding between them. A contract was drawn up clearly specifying the expected product from the research.

In this case, the decisionmakers were identical with the interpretation and analysis personnel. Their need was for land cover maps made from LANDSAT-1 imagery. Researchers were in the role of data processers. While it seems rather simple to write a contract clearly specifying that maps of a certain type will be delivered, the comparison of ideas and perceptions that went into the discussion of terms for the contract helped parties on each side of the interface to communicate and agree and to spot potential misunderstandings. If the preparation of a contract, however, is a perfunctory matter, it may not serve much useful purpose in clarifying the flow of data and information across the interface.

D. A Data Center in the Data and Information Flow Process

A Data Center, maintained to serve as a library for data acquired by several remote sensing projects and to make remote sensing data available to users, occupies a unique place in the data and information flow sequence.[5] In operation for several years, the Center makes available low altitude color and color infrared photography, thermal imagery, high-altitude RB-57 imagery, LANDSAT-1 70mm and 9" transparencies, and a 16mm Browse file of LANDSAT-1. Publications to support the imagery are also available. Announcements of the imagery available are mailed to potential users, and a catalog of imagery available is distributed.

If the Data Center is considered in relation to the diagram of data and information flow, Figure 1, several characteristics are suggested. User input into the data and information flow process is limited to "after the fact" input -- the data have already been acquired and are waiting there. They cannot be changed to respond to the potential user's needs. This may be expected to produce lower credibility than would data from a process into which the user had input. But this may be balanced by another factor: the data can be compared with other data from different sources. This gives a degree of discretion to the user, and may help credibility.

In the case of the Data Center, the question of communication among the roles represented in the data and information flow may be different from the diagram in Figure 1, depending on the role of the potential user. Figure 4 is a revision of the diagram in Figure 1, to indicate two special cases of communication. The person looking at data in the Data Center is looking across the interface toward the (4) Data Acquisition role. But this person may be (1) a Decisionmaker, (2) an Analyst or Interpretor, or (3) a Data Processor. If he is a Data Processor, the flow of data should be the same as in the simple case shown in Figure 1. If he is in the role of an Analyst or Interpreter he may not directly make sense out of data. Processing probably is needed. In the operation of the Data Center, users who need help in understanding the imagery are sometimes given help by researchers in remote sensing. This is a way of filling the need for a Data Processor in the data and information flow. The path of communication is on the curved line by-passing the Data Processing role with the assistance of a person brought in to help the user.

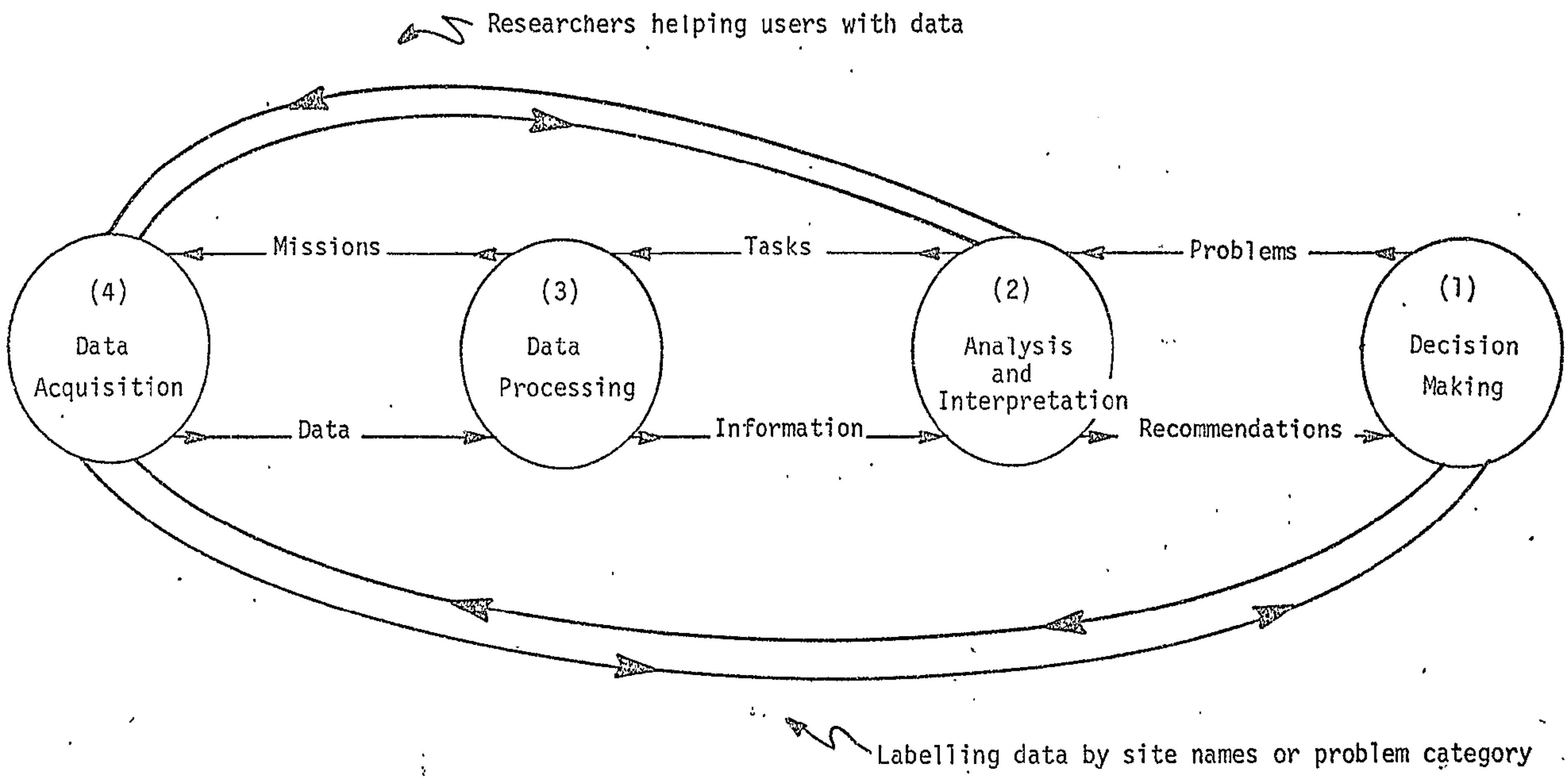


Figure 4. Diagram of data and information flow revised from Figure 1, illustrating the addition of research personnel and the use of lay-oriented labelling to complete process of information flow in a Data Center.

A practice adopted by the Data Center to represent the data in lay rather than technical terms, indicates another special communication problem. To help lay persons, site names were assigned and an "industry category" created to permit access to the collections by the type of problem being studied. (For example, in a cross-reference section of the card catalogue, film of power plant effluents are grouped together, algae blooms are grouped together, and paper mill effluents are grouped together.) This is an attempt, from the point of view of the data and information flow, to aid a (1) Decisionmaker in communicating across the (2) Analysis and Interpretation and (3) Data Processing roles, shown by a curved line on Figure 4. It would seem to be important that in this case adequate supplementary help be available to allow the decisionmaker to be able to encompass the whole data and information flow process in one move, while several distinct moves are ordinarily needed.

The final question about the place of the Data Center in the process is related to the proposal that a survey be made to seek from users an indication of their needs. In this case, is the Data Center in the role of Data Acquisition (4), asking users as though they were (3) Data Processors, and (2) Analysts and Interpreters, and (1) Decisionmakers? These roles probably must be kept separate in the survey questions - with the normal role of the potential user identified - in order that the questions may presuppose the right context. But in asking the questions the Data Center may be functioning as a combination of (4) Data Acquisition and (3)Data Processor, seeking information from primarily (2) Analysis and Interpretation, but needing another step, interpretation, to allow open communication with (1) Decisionmakers. This illustrates the special problems of the Data Center Survey: It represents a particular case in which the distinctions in role in the data and information flow must be clearly uncdrstood, since the meaning of questions and answers will depend upon which interface the communication is assumed to involve.

IV. CONCLUSION

If the necessary result of research is useful technology or useful information available to decisionmakers in governmental agencies, this result will be most likely to develop if objectives of the research from the beginning of the planning include the flow of information or the transfer of technology. This adds a dimension to what scientists would call "pure"research, requiring of the researchers and the potential users not only scientific clarity, but also skill in "extra-ordinary" communication. Such ability is distributed no more equally among individuals than is scientific skill.

Some tools of communication, such as meetings or reports, may not be valued by scientists because these tools are common to nonscientific, everyday enterprises where their functions are blurred and their execution often is inept. This negative appraisal may lead to reluctance to use such tools, even when they are necessary.

To include in a research project the dimension of relevance to decisionmaking, objectives and specific tasks should be designed to call attention to the need for communication as part of the process of research. Aids should be available to supplement the communication skills of researchers and decisionmakers. Time schedules should allow participants in the research to withhold their judgements of what is being communicated, or whether communication is successful, long enough for the dialogue necessary at crucial points to mature (see Figure 3). Finally, participants in the research and decision-making aspects of this enterprise must be helped to expect success in finding the relationships between research and use wherever there are possibilities for such a connection.

NOTES

1. Adapted from Arnold Lanckton, "Remote Sensing: International Market and Market Trends", presented at Conference of Institute for Graphic Communications, Ipswich, Mass (October 1973).

2. James P. McNaul, "Relations between Researchers and Practitioners", in The Social Contexts of Research, S. Nagi and R. Corwin, eds. (New York: Wiley-Interscience, 1972).

3. James L. Clapp, "Evaluation of the Application of ERTS-1 Data to the Regional Land Use Planning Process", Final Report, prepared for the National Aeronautics and Space Administration, Contract Number NAS5-21754, pp. 269-279 (23 October 1974).

4. Ibid.

5. The basic material on the Institute for Environmental Studies Data Center upon which this interpretation of processes in the Data Center was based, was furnished by Barbara Kenny, Data Coordinator.