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Landsat Analysis of Lake Quality

A semi-automatic data acquisition and handling system, in conjunction with an analytical categorization scheme, can be used to classify all the significant lakes in the state of Wisconsin.

INTRODUCTION

THERE ARE NEARLY 15,000 lakes in the State of Wisconsin covering 383,401 hectares (947,384 acres), excluding Great Lakes boundary waters. These lakes are an extremely important natural resource to the state. Not only is water a necessity for agricultural and urban uses, but in the State of Wisconsin it is also a prime resource of the tourism industry. Tourism directly or indirectly provides 18 percent of job related revenue in that state. As the number and extent of the state's uses of water have increased, so has the rate of eutrophication in many of its lakes. In 1974 the Wisconsin Department of Natural Resources (DNR) initiated a project to investigate the feasibility of using satellite imagery to monitor the water quality of inland lakes.

Both federal legislation (PL92-500, the Federal Water Pollution Control Act Amendments of 1972, Section 314) and state legislation (Wisconsin's Lake Protection and Rehabilitation Law, chapter 301 of Assembly Bill 766, 1973) require the DNR to monitor and/or classify all the significant lakes in the state. Because the cost of comprehensive ground sampling would be prohibitive, it was thought that the use of Landsat imagery might be a cost effective method to accomplish the task. In the spring of 1974 a joint project, funded by the DNR, was begun between the University of Wisconsin-Madison and the DNR Bureau of Water Quality to investigate the feasibility of using Landsat imagery for lake classification.

KEY WORDS: **Classification; Data acquisition; Images; Inland waterways; Lakes; Landsat; Trophic level; Wisconsin**
ABSTRACT: A cooperative program between the Wisconsin Dept. of Natural Resources (DNR) and the Univ. of Wisconsin—Madison (UW—MSN) has resulted in the assessment of the trophic status of a number of inland lakes in Wisconsin. The feasibility of using both photographic and digital representations of Landsat imagery was investigated during the lake classification project. The result of the investigation has been a semi-automatic data acquisition and handling system which, in conjunction with an analytical categorization scheme, can be used to classify all the significant lakes in the state.
REFERENCE: Scarpace, Frank L., Holmquist, Kenneth W., and Fisher, Lawrence T., "Landsat Analysis of Lake Quality," *Photogrammetric Engineering and Remote Sensing*, Journal of the American Society of Photogrammetry, ASP, Vol. 45, No. AP5, May, 1979

Initial Investigations

Initially, this project[1] investigated Landsat photographic imagery. Band 5 signal values were derived from both the 70 mm and the 7-inch positive transparencies using a spot densitometer. Analysis of the 7-inch transparencies was discontinued when it was found that the imagery was not radiometrically correct. Subsequently, a preliminary ranking of the lakes greater than 40 hectares in size was accomplished using the 70-mm transparencies. One large drawback to this data gathering process is that the same amount of time had to be spent to extract a second band of data for each lake as was spent on the first band.

Analysis of Digital Imagery

In conjunction with the Wisconsin DNR, was decided that lakes between 8 and 40 hectares also would need to be studied. It was found through the preliminary study with the 70 mm imagery that lakes with an area less than 40 hectares were too small to reliably monitor using this imagery. As a result, development of computer-assisted analysis techniques using the digital tapes from Landsat was begun.[2]

The analysis program was designed around an interactive graphics terminal (a Princeton Electronics Products Model 801) and the Madison Academic Computing Center's UNIVAC 1110 computer. This terminal was chosen because several terminals are available on campus and are given excellent software and hardware support. These terminals are capable of producing a television-like image during program execution. The operator's ability to respond to the display provided the man-machine interaction deemed essential for this project. Additionally, graphics features allowed the operator to easily specify data coordinates and the computer to graphically display data histograms and similar non-alphanumeric input and output information.

The relationship between Band 5 scene brightness and Secchi disk depth was developed using digital data derived from 11 lakes within the state. Using this relationship, all examined lakes were ranked within each county in order of increasing Secchi disk depths from the Landsat digital tapes. Typically, one to three Landsat computer-compatible tape files (quarter scenes) were analyzed in each day's operation. The analyses included anywhere from one or two up to 400 lakes on each file. Overall, about $4000 of computer time and $6000 for operators' salaries were required to obtain data for 3000 lakes.

Results supplied to the DNR included a machine-processed tabulation of lakes in each of 72 counties listed in order of decreasing Band 5 reflectance and, therefore, at least approximately, in order of increasing Secchi disk depth. A 35 mm microfilm copy of all computer printer maps showing locations of all data points was also supplied. These data were submitted to the Environmental Protection Agency by the DNR in the spring of 1975.

Since Secchi depth is a somewhat arbitary water quality parameter, turbidity also was measured in 27 lakes. These values were correlated with the quantity [Lake Band 5 - Clear Lake Band 5]. The correlation between measured turbidity and this residual Band 5 signal (Figure 1) was very good.

Because determining the trophic status of a lake is more complex than just determining turbidity, other studies were initiated in the summer of 1975. These included a time series analysis of satellite data variation over the open water season. The time series analysis was performed to evaluate the variability of lake reflectance as the growing season progressed from the early spring through the summer to the fall. Twenty southeastern Wisconsin lakes were identified on individual frames from the following dates: 9 August 1972, 11 June 1973, 17 July 1973, and 22 August 1973. These lakes range from oligotrophic to fairly eutrophic. Band 5 brightness values from each of the lakes for each of the dates were found. As might be expected, the exposure in Band 5

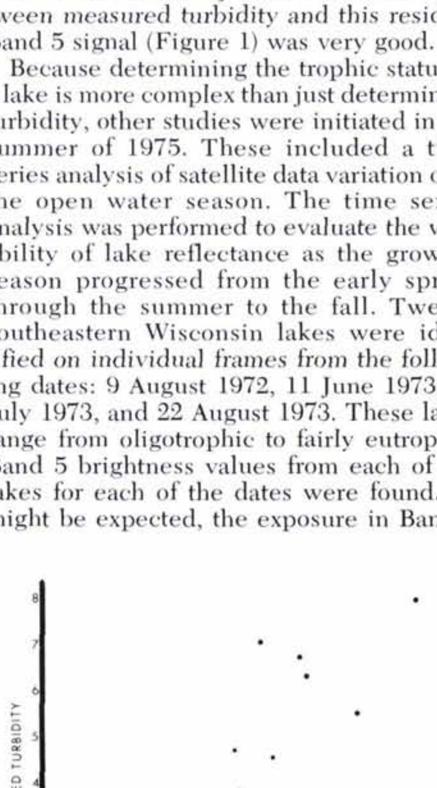

Fig. 1. A plot of observed vs. predicted values of turbidity for a number of lakes in Wisconsin. The predicted turbidity values are derived from Landsat Band 5 data.

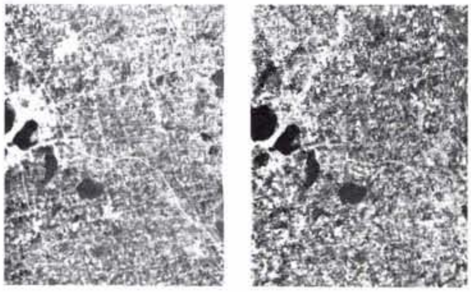

FIG. 2. Portions of two Band 5 Landsat scenes. Left protion is 3 August 1975, right portion is 26 September 1975. Note change in reflectance from the lakes.

increased for almost all the lakes as the algal turbidity levels increased during the summer months and then decreased in the fall. Figure 2 illustrates the change in Band 5 exposure due to turbidity between 3 August 1975 and 26 September 1975.

It was found through further analysis that exposures were consistently significantly higher in August 1972 than in August 1973. Upon careful examination of the imagery, it was found that a light atmospheric haze covered Wisconsin on 9 August 1972. The preliminary ranking of lakes using digital data did not incorporate any correction of the data for atmospheric effects. In some counties which were ranked with data from two different scenes, all lakes from one scene were ranked first and all lakes from the other scenes were ranked second. This effect was attributed to the differing atmospheric effects on the two scenes. Figure 3 illustrates how atmospheric effects can change significantly from one day to the next. The necessity of some sort of atmospheric attenuation correction became apparent.

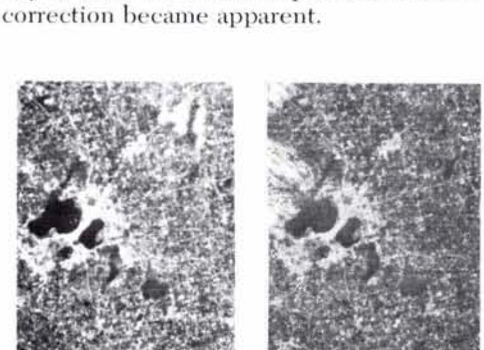

FIG. 3. Portions of two Band 5 Landsat scenes. Left image is from 16 July 1975, Scene 2175-15581. Right image is from 17 July 1975, Scene 2176-16035. Note the difference in lake reflectance from one day to the next due primarily to atmospheric differences.

Through time series investigations over the growing season of both ground calibration and satellite data, it is apparent that no one-time remote sensing sampling technique would be adequate to monitor something as dynamic as a water body. It would be possible, for instance, to classify a lake which is quite eutrophic as oligotrophic if it was sampled the day after a large algal bloom had died off. The algal population of a lake will, under the proper conditions, reproduce and grow very quickly resulting in an intense algal bloom. However, when this population exhausts its nutrient supply, it will very quickly die out almost entirely. The dead organic matter will settle to the bottom; if the lake was sampled at this time it would appear quite clear and clean. Figure 4 illustrates the variation of turbidity with time from spring through summer and into fall. The top two plots are of data from 1975 and the other two depict 1976 data.

The primary source of turbidity in these lakes is algae. The level of the algae population is highly indicative of the trophic state for these lakes. Dissimilarities exist in the turbidity versus time plots both from one lake to another and from one year to the other for the same lake. These dissimilarities show the necessity of monitoring lakes at least two or three times over the open water season.

The results to this point had led to three major conclusions: (1) the Landsat multispectral scanner is capable of monitoring lake trophic condition; (2) multi-temporal satellite data is necessary, and (3) corrections for atmospheric effects on data must be made.

SEMI-AUTOMATIC TECHNIQUES

The requirement that lake classification should be derived from the analysis of up to three dates of Landsat imagery mandated a major effort in software development. Details of lake data extraction programs and files are documented elsewhere.[4] Only a short description of the data extraction procedures will be related here.

Each lake is located on USGS topographic maps, and the coordinates of a bounding polygon are stored on a computer file. Each Landsat tape is navigated; then data from Bands 4, 5, and 6 within the lakes are extracted and stored for later classification. The only interpreter assistance usually necessary in this process is in the satellite navigation procedure along with inspecting the output of the extraction program to confirm that the navigation was accurate. A block

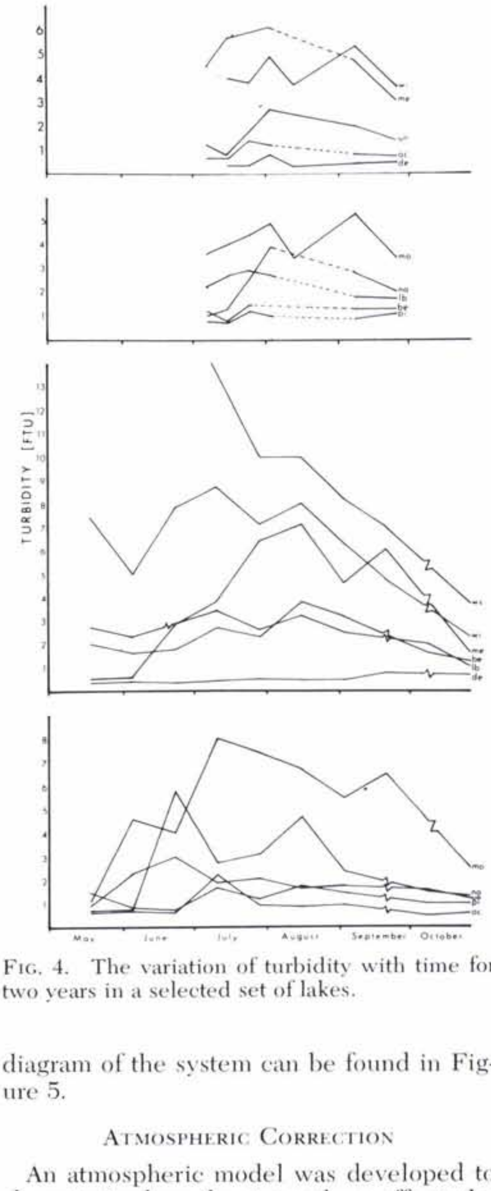

FIG. 4. The variation of turbidity with time for two years in a selected set of lakes.

diagram of the system can be found in Figure 5.

Atmospheric Correction

An atmospheric model was developed to characterize how the atmosphere affects the sensed energy and a scheme was devised to correct for its effects. This model builds on ideas expressed by Rogers *et al.*[3] and Scherz *et al.*[5]

Figure 6 illustrates the energy monitored by Landsat. The quantity denoted by G is the signal we would wish to record. The signal actually recorded by Landsat is the quantity G modified by the atmosphere plus an additional atmospheric scattering term. In mathematical form the signal recorded is

$$S = \alpha G + \beta$$

where G is the light reflected by any matter present in the lake, α is the atmospheric absorption coefficient, and β is the atmospheric scattering and clear water reflectance term. Because of the additive term β, ratio techniques alone cannot normalize the atmospheric effects from scene-to-scene.

Atmospheric scattering increases the signal recorded by the scanner proportional to the amount of light which the atmosphere reflects back toward the satellite. Quantification of this parameter would require a large panel which would absorb all incident radiation (or a panel of known low reflectance). Any signal received from that point would be due to atmospheric reflection and scattering. Due to the pixel size and the response time or "modulation transfer function" (MTF) of the scanner, a panel of approximately 6 hectares (15 acres) in size would be necessary to allow the scanner to reach equilibrium. Because it is difficult to find a nonreflective portion of the Earth, a very clear water lake is used as the closest approximation to this black surface. The clear lake (CL) data is subtracted band for band from every other lake in the scene resulting in the subtraction of approximately the atmospheric reflectance and the reflectance of the clear water:

$$(S - \beta)_i^j = (\text{lake}_i^j - \text{CL}_i^j)$$

where i is the band and j is the date.

It is not possible to determine the atmospheric absorption coefficient, α, with present techniques. A large ground area of known high reflectance is required. An attempt is made, however, to normalize it for all days to one "clearest day" (CD). Airports with concrete runways generally provide a

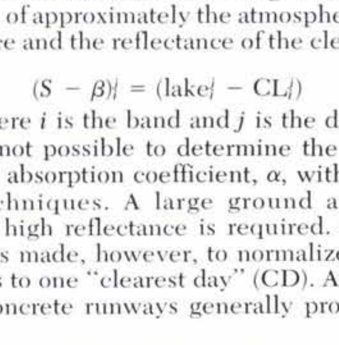

FIG. 5. Block diagram of software for Wisconsin's Lake Classificaton Programs.

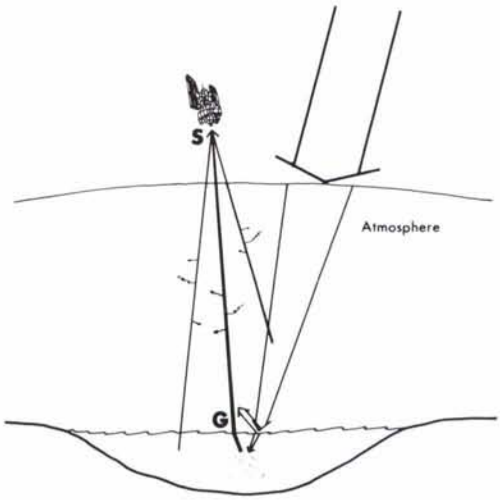

FIG. 6. A diagram illustrating the relationship between the incident solar energy and the energy detected by the satellite MSS.

large enough "panel" and are bright objects which do not appreciably change reflectance with time. It is assumed that the clear lake reflectance does not appreciably change with time either. Therefore, the change of this difference;

$$(\text{Airport}_i^j - \text{Clear Lake}_i^j)$$

from day to day must be due to differing atmospheric absorption. In the present scheme, the normalization factor is

$$A_{ij} = \frac{\text{clear day}}{\text{day}_j} = \left[\frac{\text{airport}_i^{CD} - CL_i^{CD}}{\text{airport}_i^j - CL_i^j}\right]$$

Therefore, the portion of the recorded signal due to the reflectance of the matter present in the water, and thus the value upon which the classification should be based, is

$$G_{ij} = [\text{lake}_i^j - CL_i^j]\left[\frac{\text{airport}_i^{CD} - CL_i^{CD}}{\text{airport}_i^j - CL_i^j}\right] = A_{ij}[\text{lake}_i^j - CL_i^j]$$

Categorization Scheme

An important part of any lake classification program is determining the type of product desired. Early in the investigation it was determined that thematic representations of the results of the classification were not desired. Figure 7 is a black-and-white rendition of a color coded lake classification. This classification was accomplished on a pixel-by-pixel basis using an elliptical table lookup classifier. The lakes depicted are located in southeast Wisconsin. As can be seen, the individual lakes do not have uniform water quality. If this type of scheme were used for state-wide lake classification, each of the lakes would have to be separately categorized after the classification in order to assign a trophic class.

It was determined that the desired product for this lake classifiction program was a tabular designation for each lake of interest indicating the lake water characteristic and the severity of any existing problem. To this end, DNR limnologists developed a lake categorization scheme (Table 1) and classified a number of lakes. The class numbers were assigned for use in the predictive model to be developed from the Landsat data.

Four DNR limnologists worked together utilizing their sample data and personal experience to classify 29 lakes according to this system. They used organic nitrogen content and Secchi disk depth to help validate their conclusions about these lakes. In addition, a list of characteristics of the various lakes such as algae, macrophytes, turbidity, and humic color was provided. The limnologists felt that the accuracy of their classification was within one class number. Subsequently, an additional 10 lakes were categorized. Table 2 lists the lakes which the limnologists classified and which were used in the analysis of the 1975 and 1976 Landsat scenes.

Experimental Results

Landsat data from three 1976 scenes (three dates, one area) and three 1975 scenes (three dates, one area) from southcentral and southeastern Wisconsin were extracted from the computer compatible tapes (CCTs). These data were corrected for atmospheric effects as described previously. Twenty of the 29 lakes that the DNR limnologists classified were present in the data set extracted from the 1975 data; 13 of these same lakes were present in the 1976 set. Subsequently, data from additional lakes were extracted from the 1976 scenes and were used only in the later analysis of the 1976 data.

TABLE 1. LAKE CATEGORIZATION SCHEME

Class		Class No.
Oligotrophic	— O	1
	Om	2
	Mo	3
Mesotrophic	— M	4
	Me	5
	Em	6
Eutrophic	— E	7

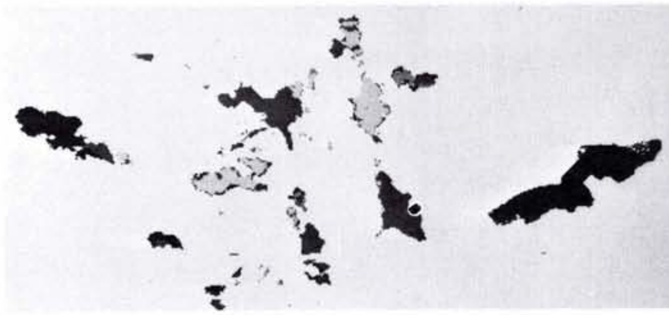

FIG. 7. A black-and-white rendition of a color coded thematic representation of lake water quality derived from Landsat. Dark is more eutrophic on this figure.

A nine-parameter regression was used to correlate the Landsat data with the DNR categorization. Regression parameters were (1) the average of the atmospherically corrected data over the three days for each band (these parameters comprise the average spectral signature for the lake); (2) the average variance of the corrected signal values within the lake over the three days for each band; and (3) the variance in the spectral signature from the average signature over time.

The parameters can be written as

$$P_1 = \left[\sum_{j=1}^{n} \bar{G}_{4j} \right] / n$$

$$P_2 = \left[\sum_{j=1}^{n} \bar{G}_{5j} \right] / n$$

$$P_3 = \left[\sum_{j=1}^{n} \bar{G}_{6j} \right] / n$$

$$P_4 = \left[\sum_{j=1}^{n} \sum_{e=1}^{m} (G^e_{4j} - \bar{G}_{4j})^2 \right] / n$$

$$P_5 = \left[\sum_{j=1}^{n} \sum_{e=1}^{m} (G^e_{5j} - \bar{G}_{5j})^2 \right] / n$$

$$P_6 = \left[\sum_{j=1}^{n} \sum_{e=1}^{m} (G^e_{6j} - \bar{G}_{6j})^2 \right] / n$$

$$P_7 = \left[\sum_{j=1}^{n} (P_1 - \bar{G}_{4j})^2 \right] / n$$

$$P_8 = \left[\sum_{j=1}^{n} (P_2 - \bar{G}_{5j})^2 \right] / n$$

$$P_9 = \left[\sum_{j=1}^{n} (P_3 - \bar{G}_{6j})^2 \right] / n$$

m = Number of pixels in lakes
i = Band
j = Date

$$\text{where } \bar{G}_{ij} = \left[\sum_{e=1}^{m} G^e_{ij} \right] / m$$

G^e_{ij} = Atmospherically corrected Landsat data
n = Number of dates

These nine values were calculated for each lake from the Landsat data and regressed with the trophic class numbers supplied by the DNR limnologists. The analysis was first performed using the 1975 imagery and 20 of the lakes classified by the DNR. The resulting regression equation was found to be

$$\begin{aligned} TC = 2.054 &- 0.9274P_1 - 2.039P_2 \\ &- 0.2778P_3 - 0.1420P_4 - 0.5076P_5 \\ &+ 0.0877P_7 - 1.0053P_8 + 0.0489P_9 \end{aligned}$$

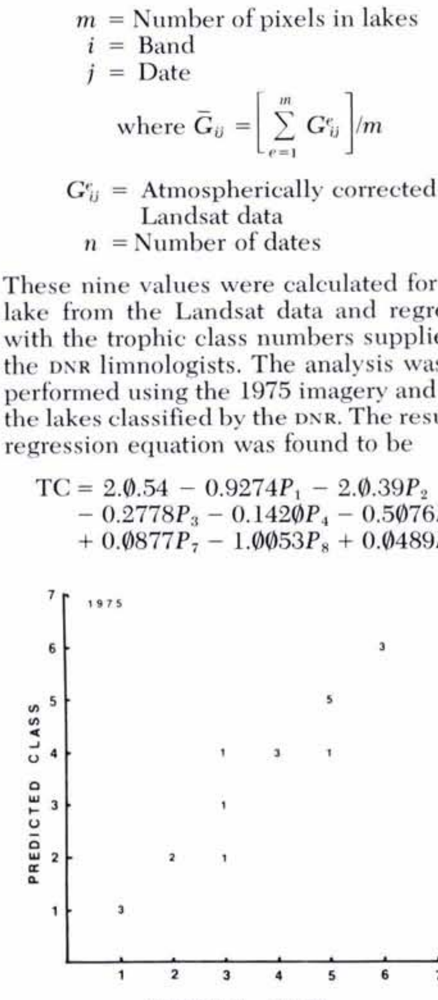

FIG. 8. The relationship between observed trophic class and predicted trophic class for the regression using 20 lakes for the 1975 imagery. The numbers on the graph indicate the number of lakes with that particular combination of observed class and predicted class.

TABLE 2. LAKES USED IN THE REGRESSIONS TO PREDICT TROPHIC CLASS (TC) FROM LANDSAT DATA. THE FIRST THIRTEEN LAKES ARE COMMON TO BOTH DATA SETS

1975 LAKES			1976 LAKES		
NAME	COUNTY	TC	NAME	COUNTY	TC
Upper Nemahbin	Waukesha	3	Upper Nemahbin	Waukesha	3
Mendota	Dane	5	Mendota	Dane	5
Monona	Dane	5	Monona	Dane	5
Park	Columbia	6	Park	Columbia	6
Waubesa	Dane	5	Waubesa	Dane	5
Kegonsa	Dane	5	Kegonsa	Dane	5
Rock	Jefferson	3	Rock	Jefferson	3
Ripley	Jefferson	4	Ripley	Jefferson	4
Pine	Waukesha	1	Pine	Waukesha	1
Oconomowoc	Waukesha	3	Oconomowoc	Waukesha	3
Beaver	Waukesha	2	Beaver	Waukesha	2
Lac La Belle	Waukesha	4	Lac La Belle	Waukesha	4
Nagawicka	Waukesha	4	Nagawicka	Waukesha	4
Castle Rock	Juneau	5	Big Green	Green Lake	1
Jordan	Adams	2	Emily	Dodge	6
Big Green	Green Lake	1	Beaver Dam	Dodge	6
Emily	Dodge	6	Fox	Dodge	6
Swan	Columbia	6	Sinissippi	Dodge	7
Devil's	Sauk	1	Wingra	Dane	7
Pewaukee	Waukesha	5	Geneva	Walworth	2
			Big Muskego	Waukesha	7
			Forest	Waukesha	4
			Lower Nashota	Waukesha	3
			North	Waukesha	3
			Pewaukee	Waukesha	5
			Crystal	Columbia	6
			Koshkonong	Jefferson	7
			Lower Namahbin	Waukesha	3
			Delavan	Dane	6

The results of the fit are depicted in Figure 8 after the predicted class numbers have been rounded to the nearest integer. As Figure 8 shows, only three lakes out of 20 are misclassified and in these cases only by one trophic class number. All of the lakes in this data subset are within the DNR criteria of an acceptable classification, i.e., within one trophic class of the observed class. Using the previous regression, approximately 170

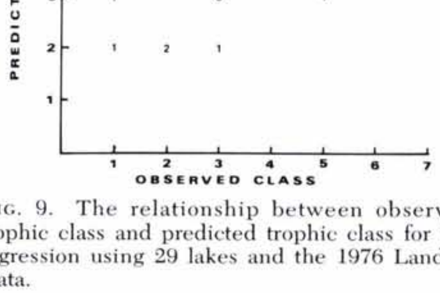

FIG. 9. The relationship between observed trophic class and predicted trophic class for the regression using 29 lakes and the 1976 Landsat Data.

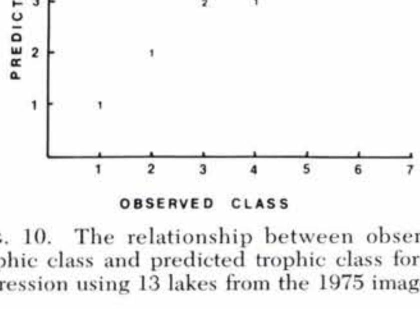

FIG. 10. The relationship between observed trophic class and predicted trophic class for the regression using 13 lakes from the 1975 imagery.

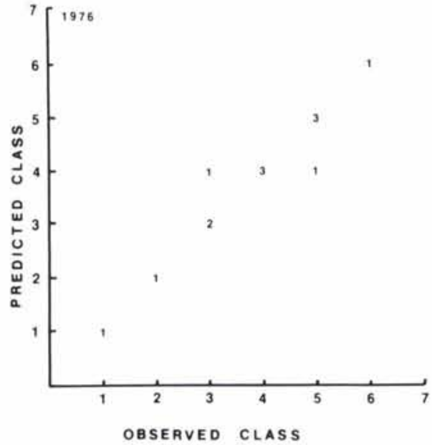

FIG. 11. The relationship between observed trophic class and predicted trophic class for the regression using 13 lakes from the 1976 imagery.

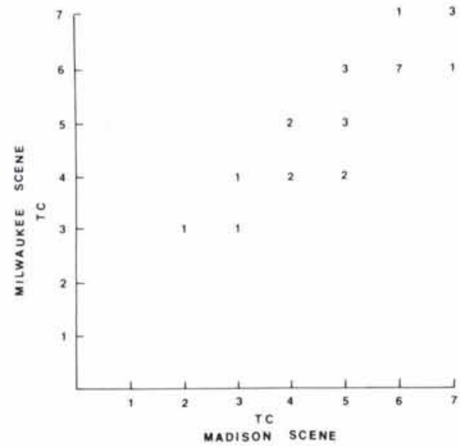

FIG. 13. A plot of the trophic class as predicted on the Milwaukee scenes vs. the trophic class as predicted from the Madison scenes. The same regression parameters were used in each case.

lakes in the 1975 scenes were classified. These results were given to the DNR limnologists who were then asked to categorize more lakes. Ten additional lakes (for a total of 39), of which they were "reasonably" sure of the classification, were categorized; these are the last 10 lakes in Table 1 under 1976. Little ground calibration data were available for these additional lakes.

Data from 1976 Landsat imagery were then investigated. Nineteen of the original lakes categorized by the DNR appeared in these scenes. The additional ten lakes were added and regressions performed. Figure 9 depicts the results. As can be seen, the fit is very good with only two lakes falling outside the DNR's acceptance criteria. To investigate the hypothesis that the classification scheme depends upon the year of the Landsat imagery, the first 13 lakes in Table 1 were independently regressed for each year. Figures 10 and 11 show the results of these regressions. As can be seen, the fit is equally good for each year.

Data for three additional scenes (centered on Madison, Wisconsin) were extracted (see Figure 5) and added to the data base. With these additional data, 34 lakes whose trophic class was known were present in the data base. These observed trophic classes were regressed with the Landsat derived data with the results depicted in Figure 12. Only three lakes out of the 34 were outside the acceptance criteria.

In order to investigate the scene-to-scene dependence of the lake classification programs, lakes classified in the sidelap area between the two sets of 1976 Landsat scenes (Madison and Milwaukee areas) were noted. Only lakes which had three dates of data for each scene were investigated. Twenty-seven lakes satisfied these criteria from each set of scenes. Figure 13 is a plot of the trophic class as predicted on the Milwaukee scenes versus the trophic class as predicted from the Madison scenes. As can be seen, 16 of the lakes were predicted as the same trophic class and the remaining lakes differed by only one trophic class. This lends confidence in the reliability of the trophic class predictions using the current lake classification algorithims.

Any trophic classification contains a certain amount of subjectivity. This is not only necessary but desirable, because part of the

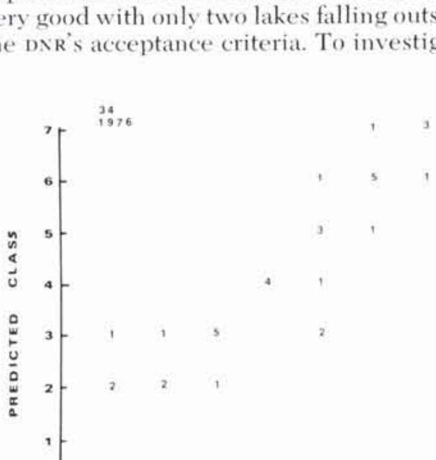

FIG. 12. The relationship between observed trophic class and predicted trophic class for the regression using 34 lakes from the 1976 imagery.

TABLE 3. REPRESENTATIVE LAKE CLASSIFICATION: WAUKESHA COUNTY, WISCONSIN

Lake No.	Lake Name	Class	Type	Dates
1	Ashippun	4	Algae	3
2	Beaver	3	Algae	3
3	Big Muskego	7	Algae	3
4	Cornell	6	Algae	3
5	Crooked	5	Macrophyte	3
6	Denoon	5	Algae	3
7	Dutchman	4	Algae	3
8	Eagle Spring	5	Algae	3
9	Forest	4	Macrophyte	3
10	Fowler	4	Algae	3
11	Golden	5	Algae	3
12	Hunters	5	Algae	3
13	Keesus	4	Algae	3
14	Lac LaBelle	4	Algae	3
15	Little Muskego	5	Algae	3
16	Lower Genesee	4	Algae	3
17	Lower Nashotah	3	Algae	3
18	Lower Nemahbin	4	Algae	3
19	Lower Phantom	5	Algae	3
20	Merton Millpond	5	Algae	3
21	Mid Genesee	3	Algae	3
22	Montery Millpond	4	Algae	3
23	Moose	4	Algae	3
24	Nagawicka	4	Algae	3
25	North	3	Algae	3
26	Oconomowoc	2	Algae	3
28	Ottawa	6	Algae	3
29	Pewaukee	4	Algae	3
30	Pine	4	Algae	3
31	Pretty	3	Algae	3
32	Rainbow Springs	5	Algae	3
33	School Section	6	Algae	3
34	Silver	3	Algae	3
35	Spring	7	Algae	3
36	UN S23,14T8R17	5	Algae	3
37	Upper Genesee	5	Algae	3
38	Upper Nashotah	3	Algae	3
39	Upper Nemahbin	3	Algae	3
40	Upper Oconomowoc	6	Algae	3
41	Upper Phantom	5		3
42	Waterville Millpond	5	Algae	3
43	Wood	5	Algae	3

definition of eutrophication involves public standards of acceptability. Some of the data variability not accounted for by the trophic class regression equations is undoubtedly due to this subjectivity.

TYPE CLASSIFICATION

The second part of the classification program is classification of lake types. These techniques differ little from land cover classification algorithms in use by other Landsat investigators.[6-9] The only real difference in this study is that the lake type is determined based on statistics from all the lake pixels, not on a pixel by pixel classification.[10]

Both "parallelepiped" and "elliptical table look-up" classifiers were investigated. The parallelepiped classifier met with only limited success, and the present configuration of the lake classification programs uses the elliptical classifier for the lake type determination. Satisfactory training sets for the classifier have been established for clear lakes, macrophyte lakes, and algae lakes. Sufficient statistics have not yet been established for lakes with multiple problems such as algae mixed with silt because most of the lakes in southeastern Wisconsin are algal lakes. It is anticipated that, when the northern part of the state is finished in the spring of 1978, the type classification will be complete.

Discussion and Conclusions

During the latter part of the summer of 1977 nine Landsat scenes were analyzed using the set of lake classification programs schematically represented in Figure 5. This procedure resulted in a classification of approximately 250 lakes in southcentral and southeastern Wisconsin. Table 3 is representative of the output of the lake classification programs for one county. Included in the tabulation by county is (1) lake number, (2) lake name, (3) predicted trophic class, (4) lake characteristic, and (5) the number of dates used to predict the trophic class and lake type.

As was previously discussed, we feel that at least three dates of Landsat data are needed to adequately classify a lake. Unavoidably, cloud cover will obscure some lakes so it may be that classification must be performed with fewer dates. The programs will still classify a lake if only one date of data is present, but the quality of the prediction is suspect.

An important aspect of this classification is its flexibility. It is apparent that there is a large variability in the definition and criteria for lake classification. This is true not only for lake classification schemes in differing states, but also true within the state of Wisconsin itself. People from different areas of the state have significantly different ideas as to the characteristics of an oligotrophic and eutrophic lake. A moderately clear lake would be classified as oligotrophic by people in southern Wisconsin, but this same lake might be classified as mesotrophic or eutrophic by people in the northern part of the state. This may be reasonable since, in addition to objective technical tests, trophic status should be dependent on public standards which may differ between regions within a state. The flexibility of this lake classification program is that a different regression model can be developed for each region for which it is necessary. Once the data have been extracted from the Landsat tapes and corrected for atmospheric effects, any of the possible regression models could be used.

The results of the regressions between Landsat data and DNR supplied trophic class numbers are very good. Virtually all of the lakes with good "ground calibration" were classified correctly within the DNR criteria. The results of the lake classification programs executed for the southeastern portion of the state have received favorable review from the DNR.

The computer and personnel costs for executing the lake classification programs are very modest. The nine scenes thus far completed have averaged less than \$150 for computer costs and less than two weeks of personnel time per scene. Coupled with the \$200 per scene costs for data acquisition, lakes in one scene with three dates of imagery can be classified for approximately \$1000 plus four weeks of personnel time. The estimated cost of classifying the lakes in the whole state of Wisconsin is \$13,000 to \$14,000 plus approximately twelve months of personnel time. Wisconsin DNR personnel are now being trained to run the computer programs and are planning to classify the remainder of the lakes in the state. This project should be completed by the end of 1978.

We believe that this project has demonstrated a cost-effective example of digital processing of Landsat imagery for water quality assessment. The success enjoyed with regard to implementing the program as an operational project within the DNR has come about because of the close cooperation between DNR and University personnel from the inception of the project. Techniques developed here could quite feasibly be extended to other states.

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