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

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16. Abstract

This paper reports on the results achieved during the fifth three month period to establish cost benefits of LANDSAT for the surveillance and control of Lake eutrophication. This goal is being accomplished by producing LANDSAT products for an EPA modeling study of Saginaw Bay and inland lake surveys by the Michigan and Wisconsin DNR's. These user agencies are, in-turn, providing detailed ground truth on water quality and are participating in studies and evaluations to determine the cost benefits of LANDSAT.

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PREFACE

Program Objectives

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

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

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

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

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

Scope of Work

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

For each of these three programs, this investigation is analyzing and interpreting LANDSAT data to provide the three user agencies with land-use and lake water quality information about their specific test areas. The usefulness of LANDSAT data to each type of study and the cost benefits of its use over alternative data collection systems is being evaluated.

Conclusions

Chemical and biological water quality data collected July 31, 1975 at 16 stations within Saginaw Bay, Michigan, in concert with a LANDSAT overflight, have been processed to enable prediction of water quality in non-sampled areas. Measurements included; temperature, secchi depth, conductivity, chloride, chlorophyll ā, total kjeldahl nitrogen and total phosphorous. When these were treated as dependent variables and LANDSAT measurements as independent variables, and processed with a stepwise linear regression analysis, all but one parameter had correlation coefficients greater than that for the 99% level of significance. For this image date and phase of the investigation regression equations expressed with the pair of bands 4 and 5 rather than the ratio of band 4/band 5 provided higher (improved) correlation coefficients for all the water quality parameters studied (temperature, secchi depth, chloride, conductivity, total kjeldahl nitrogen, total phosphorus, chlorophyll ā, total solids and suspended solids). Results of the regression were used to map the water quality parameters over the entire bay.

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ILLUSTRATIONS

1. REVIEW OF PROGRAM AND RESULTS

This section reports on the work accomplished and results achieved during the fifth three month period of a program to establish the cost benefits of LANDSAT for the surveillance and control of lake eutrophication. To accomplish this goal, LANDSAT data products are being generated to support the Environmental Protection Agency (EPA) modeling study of lake eutrophication in Saginaw Bay; the State of Michigan's survey of inland lakes and watersheds for the purpose of assessing the effects of watershed land use on lake water quality; and the State of Wisconsin's lake survey to determine eutrophication status, causes, effects, and control treatments.

These user agencies are providing, at no cost to NASA, user needs which include desired data formats, data timeline requirements (i. e., how fast data are needed and how long it maintains its value before update is needed), and data accuracy requirements (i. e., geometric and classification accuracy). These agencies are also providing detailed ground truth on water quality and watershed land use in conjunction with LANDSAT overflights and are participating in studies and evaluations to determine the usefulness and cost benefits of the LANDSAT data products.

The remainder of this section is subdivided to report on the work accomplishments and results achieved to support the on-going water quality programs of the three user agencies.

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

Coordination meetings were held with the EPA in order to review LANDSAT data requirements and to develop plans to provide the needed aircraft and LANDSAT support.

The EPA is sponsoring a study of water quality in Saginaw Bay, which has now been extended indefinitely beyond its original termination date of June 1976. Important goals of this study are to describe, on a seasonal basis, the circulation and water masses in Saginaw Bay; to monitor inputs of nutrients from its watershed; and to develop and evaluate models for predicting water quality in the basy as a function of various control strategies.

To achieve these goals, the EPA is using LANDSAT data products produced by this investigation and surface/subsurface measurements obtained by the Cranbrook Institute of Science, under the direction of Dr. V. Elliott Smith (LANDSAT Co-Investigator). The surface measurement program has been underway since April of 1974. From each of 61 stations distributed over Saginaw Bay, some 30 water quality parameters are determined on an 18-day cycle that coincides with the LANDSAT overflights. On 1 April 1975, this measurement program was shifted from the LANDSAT-1 to the LANDSAT-2 schedule.

The first clear LANDSAT scene of the bay, coincident with surface measurements at the bay stations, was a 3 June 1974 scene. Techniques used in the computer processing of this scene were reported in the first Type II report. The results achieved in processing this scene cover three phases of the investigation. Phase I was reported on in the first Type II report, Phase II in the third Type II report, and Phase III in the fourth Type II. A second scene, 31 July 1975, was reported for Phases III and IV.

Phase I - Of particular importance was the demonstration of a technique for editing LANDSAT measurements using the latitudes and longitudes of bay stations having known (measured) water quality parameters. At the time of the initial processing effort, the only parameter fully reduced for all bay stations which is a good indicator of turbidity was Secchi depth. Consequently this initial processing effort resulted in a geometrically-corrected color-coded image of Saginaw Bay showing nine discrete colors (categories) of turbidity, as indicated by nine Secchi depths between 0.3 and 3.3 meters.

Phase II - To determine further relationships between LANDSAT measurements and water quality parameters the 3 June 1974 measurements from 27 bay stations of known chemical and biological parameters were edited and processed by a stepwise linear regression program. The water quality parameters included; temperature, Secchi depth, conductivity, chloride, chlorophyll ā, sodium, potassium, magnesium, calcium, total dissolved phosphorous, total kjeldahl nitrogen and total phosphorous. When these parameters were treated as dependent variables and LANDSAT measurements as independent variables all but one water quality parameter had correlation coefficients greater than that for the 95% level of significance. The regression correlation coefficients varied from 0.99 for total phosphorus to 0.72 for chlorophyll ā corrected. Five of the water quality parameters were best correlated with LANDSAT Band 6 alone. One parameter, temperature, related to Band 5 alone and only two bands were justified for mapping the remaining six parameters.

Phase III - This phase concerns the use of similar computer processing techniques, however in the first application of the regression technique (Phase II) only the four LANDSAT bands were considered as the independent variables and it was concluded that Band 6 alone was sufficient and the most important band for predicting values of most of the water quality parameters. This investigation has extended this analysis by using ten independent variables; the LANDSAT bands individually (Bands 4, 5, 6, and 7); and the six non-redundant ratios (Bands 4/5, 4/6, 5/7, 5/6, 5/7, and 6/7) in the regression program to process the 3 June 1974 scene and a 31 July 1975 scene (2190-15404). This analysis shows that most water quality parameters are more strongly correlated to a ratio of bands rather than one band. The correlation of these parameters with one another indicates that the transport of Saginaw River water can now be traced by a number of water quality parameters, one or more of which are directly detected by LANDSAT. Chloride, conductivity, total Kjeldahl nitrogen, total phosphorus, and chlorophyll ā are best correlated with the ratio of LANDSAT Band 4 to Band 5. Temperature ans Secchi depth correlate best with Band 5.

Phase V - For this report (Phase IV) further consideration was given to the data processed in Phase III for the 31 July 1975 scene. The regression data was re-organized to re-evaluate the ratio versus the non-ratio approach. Phase III results indicated that if both single bands and ratios are considered in the multiple regression program, a ratio is chosen over a single band in the first step. In this phase however, only bands 4 and 5 were considered. One program run gave the results for the bands as a pair (Table 1) and a second for the ratio of the same two bands. (Table II)

The two different approaches are compared in Table 3 for each water quality parameter studied. A check of the regression correlation coefficients will show that the two approaches generally produce similar correlation levels; the exception is temperature which is significantly improved by the pair approach. Thus if one has to choose either a ratio or a pair approach the pair approach may be preferred. Many workers had suggested that a ratio approach, in the automatic data processing of LANDSAT data, is far superior than a single or band pair approach. This report does not support this conception for water quality parameters for the study scene.

Figures 1-4 are included here as examples of the comparison of the pair and ratio approach for two selected water quality parameters. Figure 1 shows the measured versus predicted levels by the ratio approach for total solids for each of the 16 stations. The dotted lines indicate one standard deviation about the 1:1 line. Figure 2 shows the same water quality parameter but predicted by the pair approach. In this case the change is not significant. Figures 3 and 4 provide an example of a significant change

TABLE I

Regression Equations By Band Pairs

Regression Equation (Pair)
Saginaw Bay 7/31/75 (16 Samples)

Temperature (^{O}C)	= 9.61 + 0.007 (Band 4) + 0.572 (Band 5)
Secchi Depth (m)	= 8.24 + 0.142 (Band 4) - 0.458 (Band 5)
Chloride (mg/l)	= 9.489 - 2.040 (Band 4) + 3.202 (Band 5)
Conductivity (micromhos)	= 194.2 - 7.72 (Band 4) + 13.79 (Band 5)
Total Kjeldahl Nitrogen (mg/l)	= 0.419 - 0.102 (Band 4) + 0.153 (Band 5)
Total Phosphorus (mg/l)	= -0.0069 - 0.0033 (Band 4) + 0.0059 (Band 5)
Chlorophyll $\bar{a}$ (ug/l)	= 0.908 - 1.02 (Band 4) + 1.67 (Band 5)
Total Solids (mg/l)	= 154.1 - 7.73 (Band 4) + 12.93 (Band 5)
Suspended Solids (mg/l)	= 41.04 - 8.32 (Band 4) + 11.57 (Band 5)

TABLE II

Regression Equations By Band Ratios

Regression Equation (Ratio)
Saginaw Bay 7/31/75 (16 Samples)

Temperature (^{O}C)	= 48.3 - 15.7 (Band 4/Band 5)
Secchi Depth (m)	= 14.8 + 11.1 (Band 4/Band 5)
Chloride (mg/l)	= 99.3 - 57.1 (Band 4/Band 5)
Conductivity (micromhos)	= 650. - 264.8 (Band 4/Band 5)
Total Kjeldahl Nitrogen (mg/l)	= 4.46 - 2.66 (Band 4/Band 5)
Total Phosphorus (mg/l)	= 0.18 - 0.111 (Band 4/Band 5)
Chlorophyll $\bar{a}$ (ug/l)	= 303. - 189.4 (Band 4/Band 5)
Total Solids (mg/l)	= 543.8 - 235.8 (Band 4/Band 5)
Suspended Solids (mg/l)	= 50.1 - 30.2 (Band 4/Band 5)

TABLE III

Regression Correlation Coefficients and Standard Error of Estimate for Pair and Ratio Approach

Saginaw Bay 7/31/75 (16 Samples)

Water Quality Parameter and Range		Regression Correlation Coefficient	Standard Error of Estimate
Temperature (20 - 27°C)	ratio	.62	1.56
	pair	.94	0.68
Secchi Depth (0.6 - 5.5 m)	ratio	.64	1.06
	pair	.73	0.97
Chloride (6 - 24 mg/l)	ratio	.92	1.9
	pair	.92	1.9
Conductivity (211 - 294 micromhos)	ratio	.92	8.9
	pair	.93	8.6
Total Kjeldahl Nitrogen (0.1 - 1.0 mg/l)	ratio	.93	.08
	pair	.94	.08
Total Phosphorus (0.002 - 0.039 mg/l)	ratio	.91	.0039
	pair	.94	.0035
Chlorophyll ā (1.8 - 68.5 ug/l)	ratio	.87	8.5
	pair	.90	7.6
Total Solids (150 - 244 mg/l)	ratio	.78	15
	pair	.79	15.
Suspended Solids (1 - 13 mg/l)	ratio	.72	2.2
	pair	.74	2.3

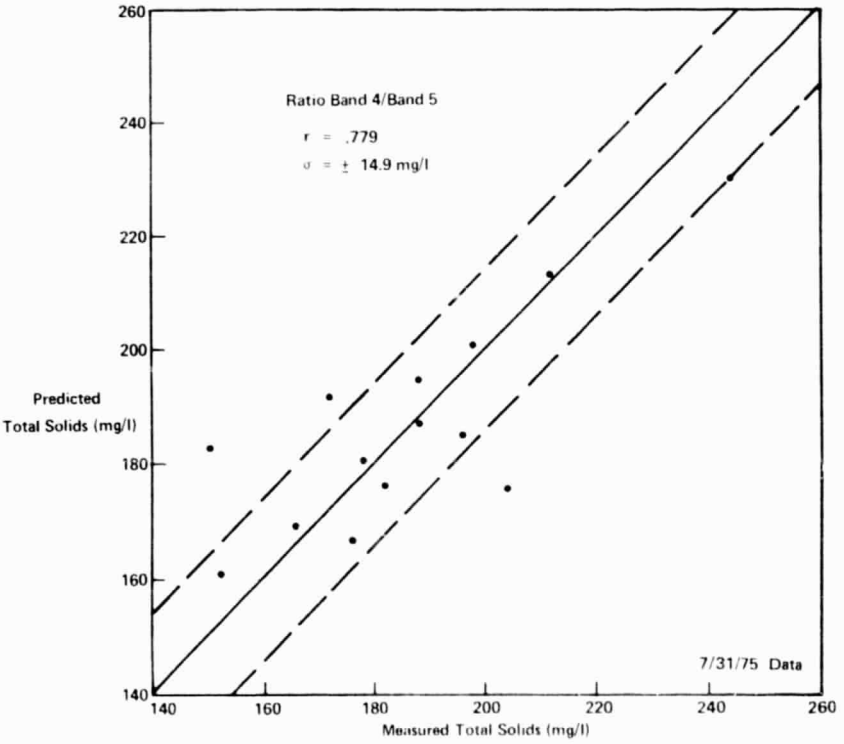

FIGURE 1

Predicted Versus Measured Total Solids, Ratio Approach

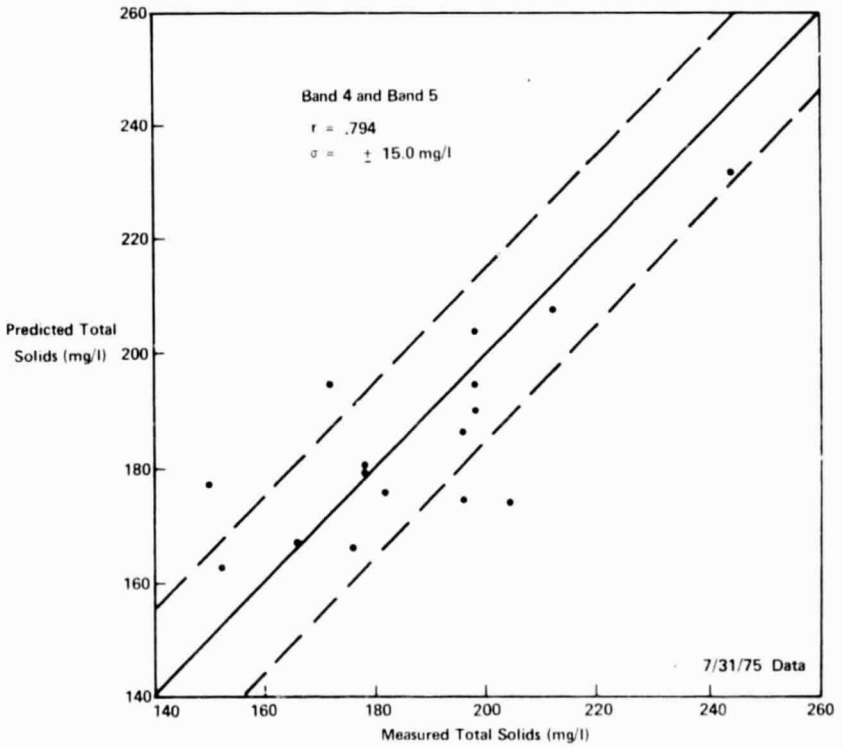

FIGURE 2

Predicted Versus Measured Total Solids, Pair Approach

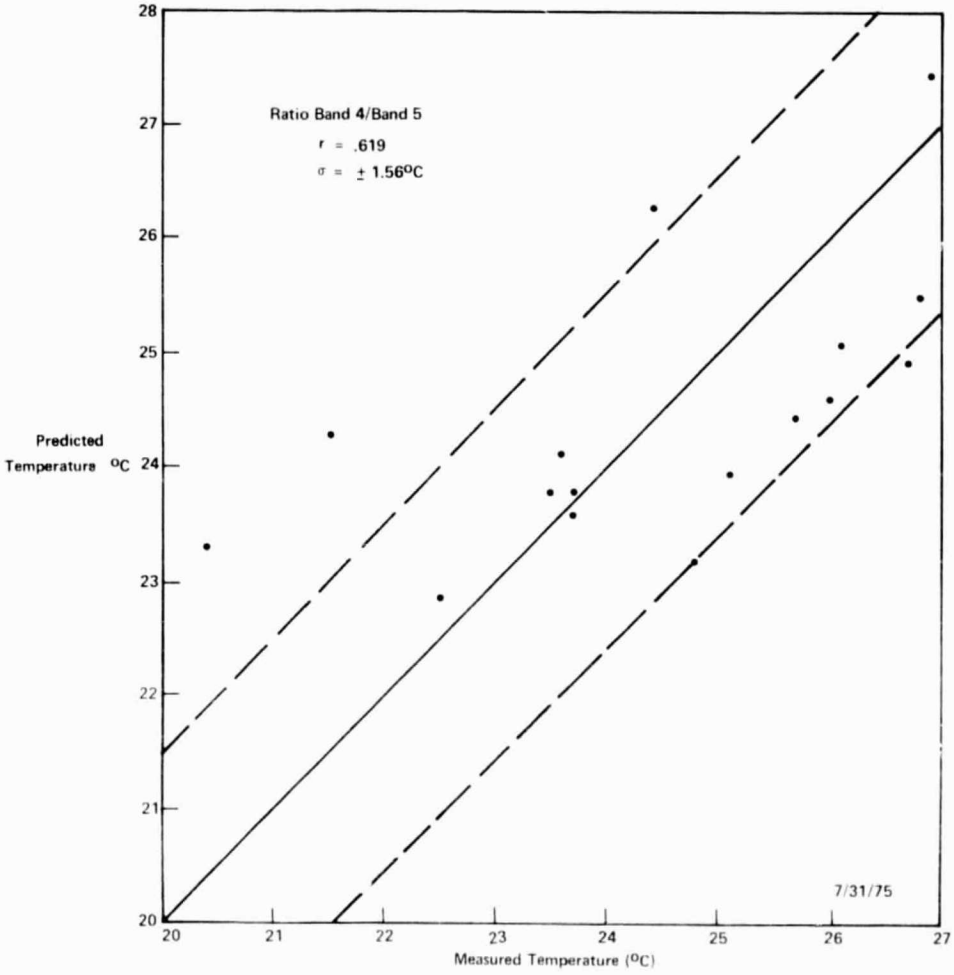

FIGURE 3

Predicted Versus Measured Temperature, Ratio Approach

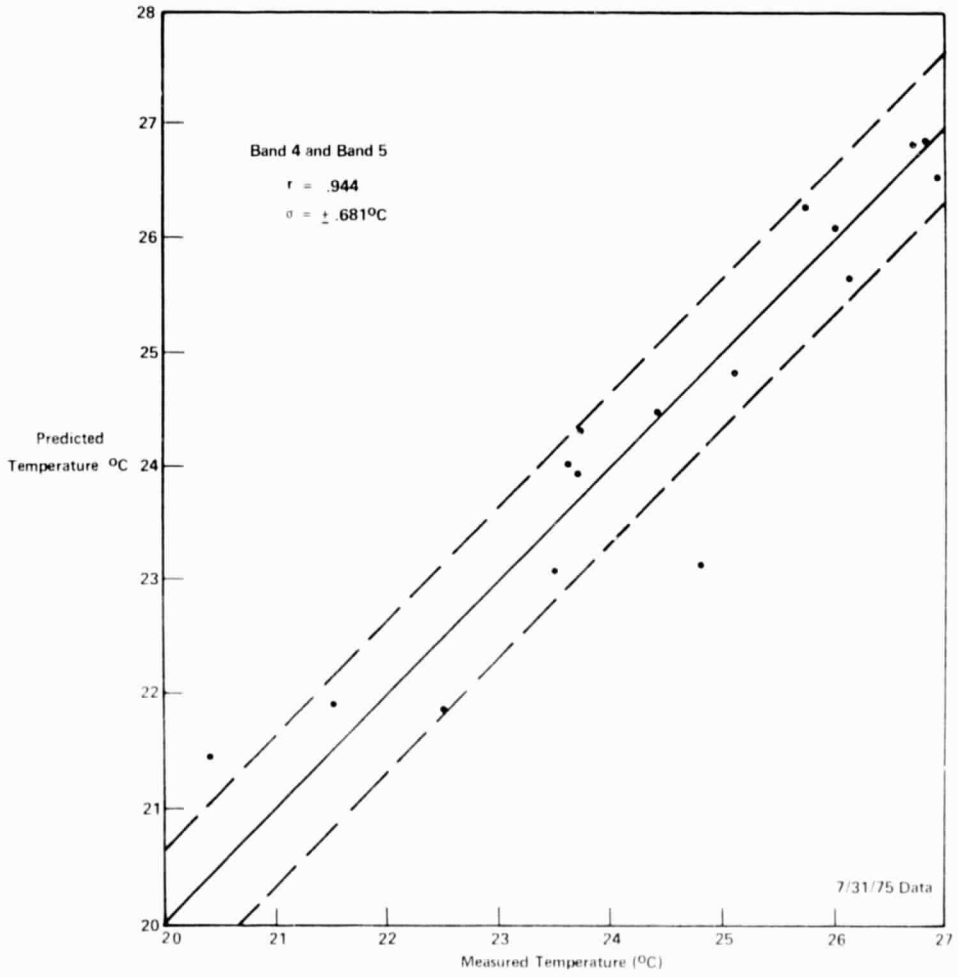

FIGURE 4

Predicted Versus Measured Temperature, Pair Approach

in the results between the pair and ratio approach.

Further consideration will be given to a non-linear regression analysis and to techniques to produce a color coded map of Saginaw Bay to which these predicted levels can be related.

1.2 SUPPORT FOR MICHIGAN'S SURVEY OF INLAND LAKES AND WATERSHEDS

To review the State of Michigan program, the Michigan Department of Natural Resources (DNR) is committed, under the State Federal Water Pollution Control Act (Act 92-5000), to a state-wide survey of public lakes and their watersheds for the purpose of assessing the degree of eutrophication in these lakes and the potential for further enrichment and pollution resulting from landuse development in the watershed. A requirement of the DNR program, as well as programs of other governmental agencies concerned with the maintenance and control of water quality, is to develop a knowledge of the interrelationships between the water quality parameters (turbidities, chlorophyll concentrations, etc.) and watershed land-use parameters (categories and coverage).

To obtain the needed information, the Michigan DNR has selected 19 test lakes whose watersheds contain various levels of urbanization. LANDSAT data acquired on July 30, 31, and August 1, 1975 will be used to inventory land cover within these watersheds. The land cover mapped by LANDSAT will be correlated with lake water quality measurements obtained by the DNR and the University of Michigan Biological Station. LANDSAT capability to map water quality parameters directly as done for Saginaw Bay will also be investigated.

The third Type II report reviewed two recently completed investigations which demonstrated LANDSATs capability to inventory watershed land-use and the techniques that will be used for the Michigan inventory.

Computer processing of the LANDSAT CCTs for the test area lakes and surrounding basins has been initiated for the northern tip of the Lower Peninsula of Michigan.

1.3 SUPPORT FOR WISCONSIN'S SURVEY OF INLAND LAKES

As noted earlier, the Wisconsin DNR is also attempting to develop a method of lake classification by trophic level, as required by Section 314 of Federal Water Pollution Control Amendments (1972). Accordingly, the Wisconsin DNR is evaluating the utility of LANDSAT data products directed towards this goal.

The second Type II report described the techniques used by this investigation to categorize several hundred lakes in the Madison and Spooner, Wisconsin area. Spectral curves have been defined through computer processing of LANDSAT data for Summer (Madison area lakes) and Spring (Spooner area lakes) for the following types of lakes; clear water, tannin water, algal water, red clay, glacial silt, sand bottom, weeds in algal lake, weeds in tannin lake, weeds in general, mud bottom in tannin lake, and wild rice from mud bottom in tannin lake. Categorization of both Spring and Fall LANDSAT imagery is being considered to help separate bottom type from water type.

For example if one uses only Spring data the tannin lakes with mud bottoms are confused with clear water lakes, and if one uses only Summer data then the signals from the rice beds are confused with those from tannin lakes.

2. SIGNIFICANT RESULTS

Computer techniques have been developed for mapping water quality parameters from LANDSAT data, using surface samples collected in an ongoing survey of water quality in Saginaw Bay (Lake Huron), Michigan, sponsored by the US Environmental Protection Agency. Chemical and biological parameters were measured on 31 July 1975 at 16 bay stations in concert with the LANDSAT overflight. Application of stepwise linear regression to nine of these parameters and corresponding LANDSAT measurements for bands 4 and 5 only resulted in regression correlation coefficients that varied from 0.94 for temperature to 0.73 for Secchi depth. For this image date and phase of the investigation regression equations expressed with the pair of bands 4 and 5 rather than the ratio of band 4/band 5 provided higher (improved) correlation coefficients for all the water quality parameters studied (temperature, Secchi depth, chloride, conductivity, total kjeldahl nitrogen, total phosphorus, chlorophyll a, total solids and suspended solids). Results of the regression analyses will be used to map the water quality parameters over the entire bay.

3. PROBLEMS

No problems are impeding this investigation.

4. RECOMMENDATIONS

None

5. PUBLICATIONS

No official publications, but a report to one technical symposium is planned for May 1976.

6. FUNDS EXPENDED

Total expenditures through 31 March 1976 are $60,300.

7. DATA USE

A tabulation showing the total value of the data allowed and received through 31 December 1975 follows:

Value of Data Allowed	Value of Data Ordered	Value of Data Received
$5,550	$3,243	$3,243

8. AIRCRAFT DATA

By prior arrangement with NASA Johnson Space Center in Houston, supportive M^2S and photographic coverage of the test areas in Michigan (August 18, 1975, Flight No. 2, Mission 317) will be reflown between July 1 - September 1, 1976 and time-phased with LANDSAT 2 overpass.