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NASA PROGRESS REPORT

SPATIAL CHARACTERIZATION OF ACID RAIN STRESS IN CANADIAN SHIELD LAKES

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1.0 OBJECTIVE

The acidification of lake waters from airborne pollutants is of continental proportions both in North America and Europe. A major concern of the acid rain problem is the cumulative ecosystem damage to lakes and forest. The number of lakes affected in northeastern United States and on the Canadian Shield is thought to be enormous. Our principal research objective is to examine how seasonal changes in lake transparency are related to annual acidic load. Further, the relationship between variations in lake acidification and ecophysical units is being examined. Finally the utility of Thematic Mapper (TM) based observations to measure seasonal changes in the optical transparency in acid lakes is being investigated.

Previous investigations have suggested that dissolved organic carbon (DOC), which originates from the dissolution of humic substances, controls transparency in most Canadian Shield Lakes. It has also been established that aluminum, which is abundant in the local rocks and soils, is easily mobilized by acidic components contained in spring runoff. The presence of any significant amount of aluminum induces a loss of DOC from the water column by coagulation, resulting in increased optical transparency. This process has not been observed in normal lakes associated with buffered geologies. In a normal lake, transparency would tend to decrease in time with seasonal phytoplankton productivity cycles. Thus seasonal changes in the optical transparency of lakes should potentially provide an indication of the stress due to acid deposition and loading.

The potential for this optical response is related to a number of local ecophysical factors with bedrock geology being, perhaps, the most important. Other important factors include sulfate deposition, vegetative cover, and terrain drainage/relief. The area of southern Ontario under study contains a wide variety of geologies from the most acid rain sensitive granite quartzite types to the least sensitive limestone dolomite sediments. Annual sulfate deposition ranges from 1.0 to 4.0 grams per square meter.

2.0 APPROACH

Water quality parameters are being measured along with insitu optical data in representative lakes in the Canadian Shield. This is being done to calibrate a Bio-Optical Model which defines the linkages between the acid rain induced chemical lake processes and the upwelling radiance sensed by the Thematic Mapper sensor on Landsat. A spring/summer scene pair with companion field measurements is being collected in selected study sites located in northern Ontario. These data will be used to investigate possible formulations of the multitemporal remote sensing causal relationships between pH and observed changes in water transparency.

It is hypothesized that a verifiable relationship exists between seasonal changes in water quality associated with the level of lake acidification and Thematic Mapper radiometry. The verified Bio-Optical Model will be used to establish the limits for which such relationships are inherently valid, and together with the field data, the set of ecophysical units and water quality conditions where the Landsat approach is valid. Under these restrictions lakes within an ecophysical stratum will be assigned a value for the degree of acidification based upon the TM multitemporal relationship. These results will permit one to test the hypothesis that the severity of lake acidification is not uniform over large areas, but rather that variations exist which are strongly related to ecophysical units and proximity to probable sources of atmospheric inputs.

3.0 ACTIVITIES BY TASK

3.1 STRATIFICATION OF ECOPHYSICAL PARAMETERS (TASK 1)

The Canadian Shield area covered by three Landsat TM scenes has been stratified into ecophysical units based upon soil/bedrock sensitivity, vegetative cover, terrain/drainage, and acid deposition. The objective of the stratification is twofold. First, it is intended to reveal the location, status and co-occurrence of environmental attributes which influence lake acidification. Second, it provides a basis to characterize each lake within the study areas as an aid to the sampling design.

A total of 694 ecophysical units have been mapped in the three Landsat scenes which comprise the northern Ontario study area (Figure 1). Maximum likelihood cluster analysis was used to identify ten statistically significant ecophysical types. The mean acidification sensitivity rating of these groups ranged from 3.5 to 7.8. The field sampling program involved gathering data from nine of the ten ecophysical types.

The stratification procedure itself cannot reveal the physical significance of the co-occurring ecophysical attributes deemed important to lake acidification. The physical significance is established by

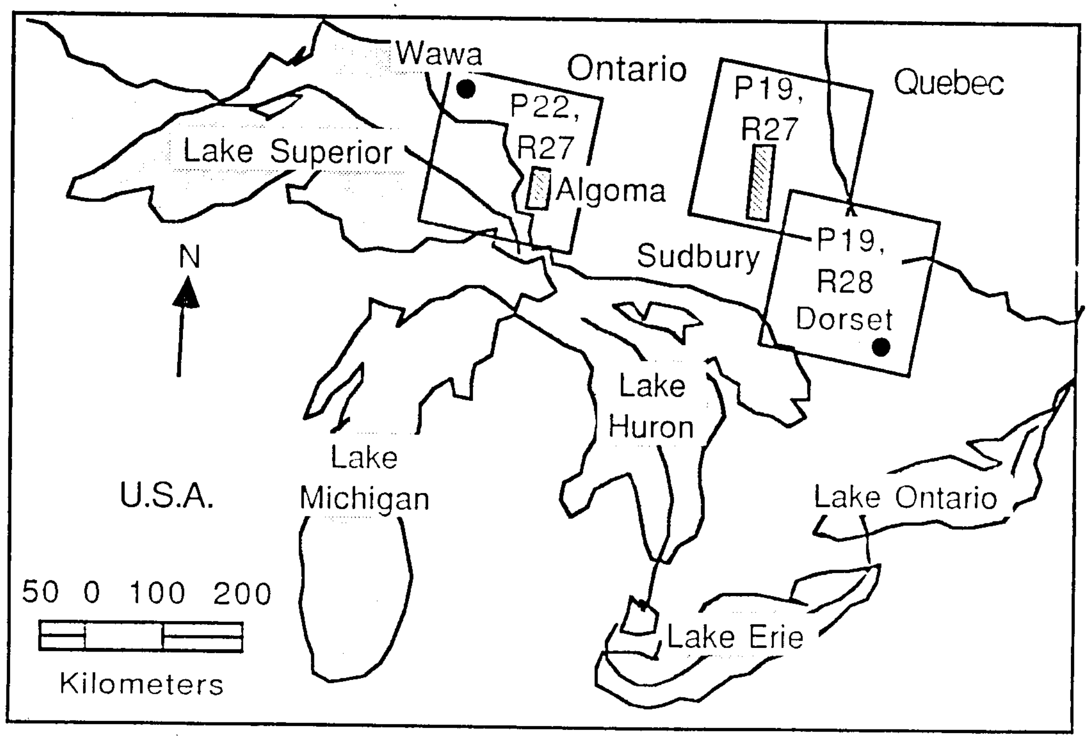

FIGURE 1. LOCATION OF LANDSAT TM STUDY SITES

examining the relationship between the ecophysical strata and the water quality (WQ) variables. An analysis was performed to test the hypothesis that the mean WQ parameter was significantly different between pairs of strata. Results were compiled at the 5% significance level and suggest that DOC, pH, sulfate, and aluminum are related to the level of ecophysical acidification sensitivity. This analysis is summarized in Table 1 and suggests that the most acid sensitive strata (5,7,9) have lake waters with lower DOC and pH values and a higher aluminum content than those with less sensitivity (1,2,3,4). Thus the clustering analysis appears to have produced strata with lake WQ conditions which are characteristic acid sensitive lakes. The most important optical connection is with DOC, which provides a basis for a remote sensing identification.

3.2 SITE SELECTION (TASK 2)

Site selection was based upon the stratification and clustering analysis described above and each of the following considerations: (1) availability of historical water quality and remote sensing data, (2) existing Canadian initiatives to collect site specific data, (3) site accessibility, and (4) coverage of ecophysical lake types. Sites selected included (1) Algoma, (2) Sudbury, (3) Wawa, and (4) Dorset.

During August 1986 field data were gathered from each of these sites which included 21 WQ parameters (296 lakes), detailed subsurface optical measurements (12 lakes), airborne spectral radiometer measurements (102 lakes), and Landsat data from sites 1, 2, and 3. Most of these measurements were made in the Algoma and Sudbury sites which are shown as Figures 2 and 3. Water quality data were collected from a large number of lakes by the Ministry of Environment. PROBAR spectral radiometer measurements were made in most of these lakes which were larger than 20 hectares and which were found to be suitable for a helicopter measurement. The subsurface optical measurements were made in a representative set of lakes at each site.

TABLE 1

ANALYSIS OF VARIANCE RESULTS WQ PARAMETERS WITH CLUSTER PAIRING

Significant Cluster Pairs at 5% Level

CHL-a	DOC	SD	SO_4	AL	pH	
1-8	1-7	1-7	1-2	3-7	1-2	3-7
1-5	2-5	2-7	1-3	4-5	1-3	3-8
1-7	2-7	2-9	1-4	5-7	1-4	3-9
1-9	2-8	4-7	1-5	5-9	1-5	3-10
	2-9	5-7	1-6	7-8	1-6	4-5
(4)	3-5		1-7		1-7	4-7
	3-7	(5)	1-9	(5)	1-8	4-9
	3-9		2-7		1-9	5-6
	4-8		3-7		1-10	5-8
	4-5		3-9		2-3	5-10
	4-7		4-5		2-4	6-7
	4-9		4-7		2-6	6-9
	7-8		4-9		2-7	7-8
			5-7		2-8	7-9
	(13)		7-8		2-10	7-10
			7-9		3-4	
			8-9		3-6	
			(17)			(32)

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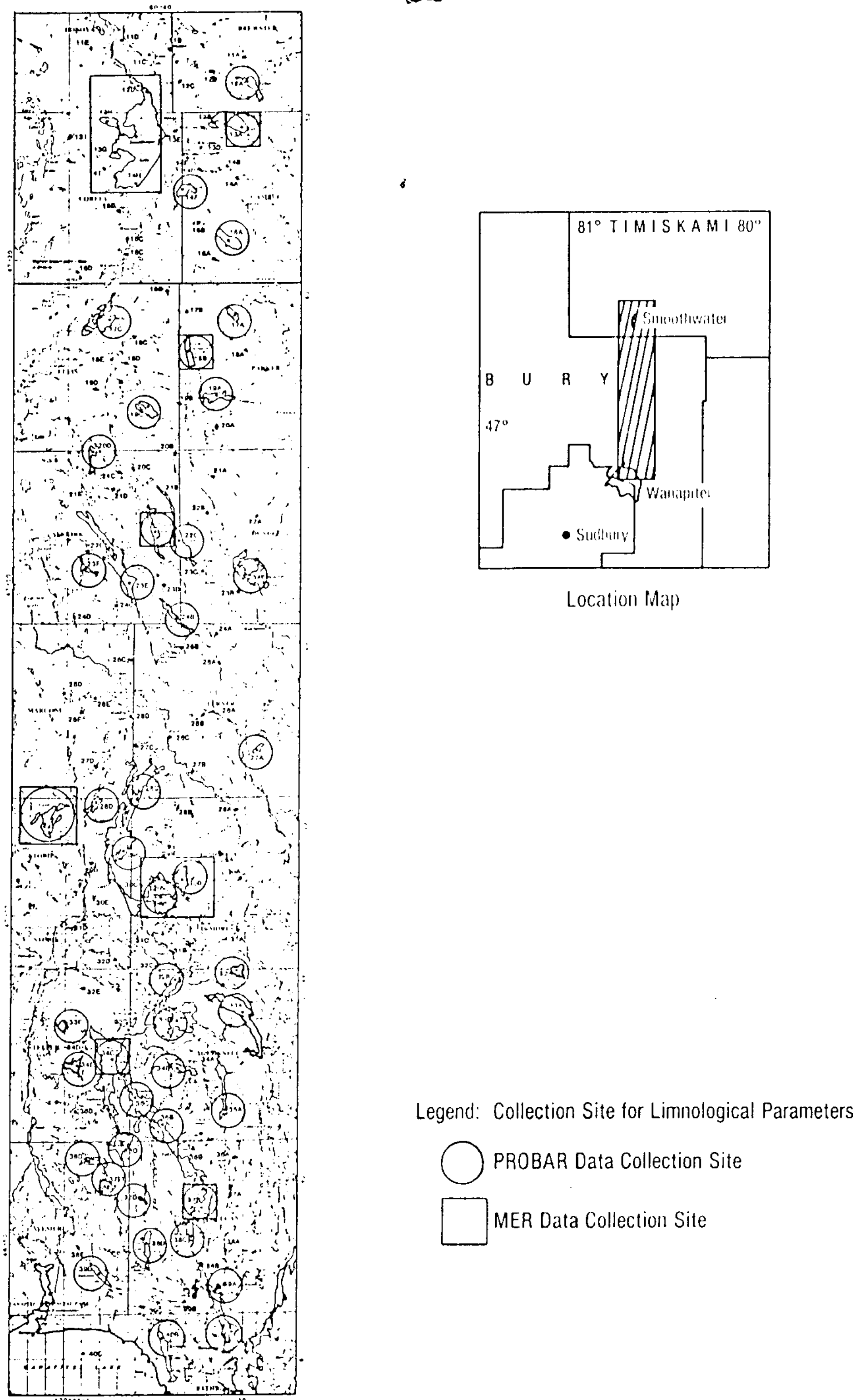
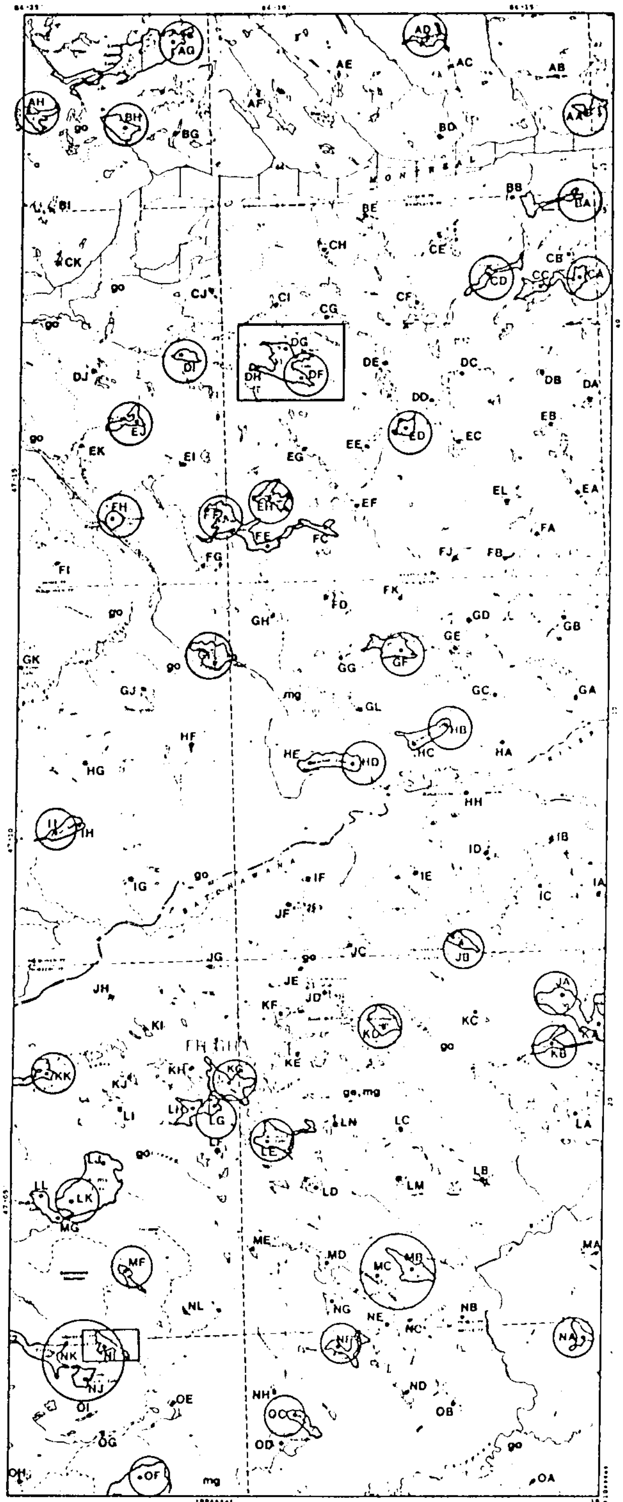
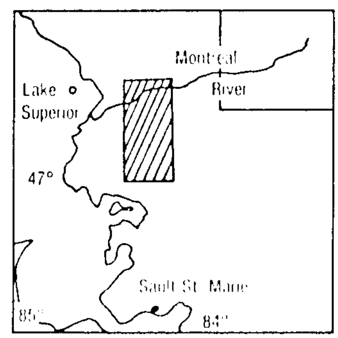


Figure 2. LAKES SAMPLED WITHIN THE SUDBURY STUDY AREA





Location Map

Legend: Collection Site for Limnological Parameters

PROBAR Data Collection Site

MER Data Collection Site

Figure 3. LAKES SAMPLED WITHIN THE ALGOMA STUDY AREA

3.3 LIAISON ACTIVITIES WITH THE CANADIANS (TASK 3)

A cooperative program with Canadian agencies and universities interested in the remote sensing aspects of the acid rain problem have resulted in an informal joint program which includes four major Canadian participants. These are Professor Roger Pitblado of Laurentian University Sudbury, Ontario, Dr. John Forestcue of the Ontario Geological Survey (OGS), Dr. Vernon Singroy of the Ontario Centre for Remote Sensing (OCRS), and Professor Michael Dickman from Brock University, Saint Catherines, Ontario. The Canadians are funded through The Ministry of Environment (MOE) and the Ontario Geological Survey.

3.4 DEFINITION OF MULTITEMPORAL RADIOMETRIC RELATIONSHIPS TO ACIDIFICATION (TASK 4)

In this task a TM radiative transfer model will be calibrated to predict possible multitemporal changes in signal level which result from field measured changes in optical and chemical properties. Work has proceeded on this model to include specific calibration for the Landsat TM sensor. The model treats atmospheric optics, water optics, and the wind ruffled air-water interface. Calculations made for typical atmospheric conditions suggest that TM band one (450-520nm) sensitivity to changes in the upwelling radiance is 0.06024 mW/cm^2.sr.nm/DN (digital number). If we assume the downwelling irradiance is 100 mW/cm^2.nm count at the water surface than the surface reflected signal will change by 5.5 counts per one percent change in surface reflectance. A maximum of 2.86 counts change will be observed for a one percent change in subsurface reflectance. The standard deviation of the mean extracted signal is typically 1.0 to 1.5 counts in TM band one but was in some instances as large as two or three counts. The hypothesized seasonal changes in TM DN count levels which result from changes in lake DOC concentrations are presently unknown. The projected TM sensitivity suggests that TM band one will not be sensitive to subsurface reflectance changes which are less than 0.5 percent. More realistically, one or two percent changes in reflectance will be necessary to see a seasonal change in the TM DN value.

3.5 DATA PROCESSING (TASK 5)

Thus far the extraction software has been applied to the following TM scenes;

Path 22, Row 27 of 27 May 1985, and 18 August 1986, and
Path 19, Row 27 of 22 May 1985, and 13 August 1986.

Brightness values were extracted from the approximate center of each lake based upon the latitude and longitude of each lake center. A 3 by 3 pixel area was extracted and the mean brightness in each band was recorded. The standard deviation of each sample was also retained which had a typical value of one DN count in TM band one. These extracted mean values were then correlated to water chemistry data collected during August 1986.

The MER-1000 subsurface upwelling and downwelling spectral irradiance data were collected in the field at variable sampling depths below the lake water surface. These data were first used to interpolate the irradiance data to common depths on a logarithmic scale before computing values of subsurface reflectance. The slope of the depth log-irradiance regression equation defines the average irradiance attenuation coefficient (K). The thickness of the mixed layer was easily determined from the temperature depth profile. The irradiance attenuation coefficient changes very little within the mixed layer, but rapidly within the transition zone (thermocline). We therefore used only irradiance measurements from the mixed layer to make the K-value determination. Subsurface spectral reflectance was calculated at 2,4,6, and 8 meters below the surface. Example reflectance curves are shown in Figure 4, along with the DOC and Chlorophyll-a measurements. The impact of DOC and

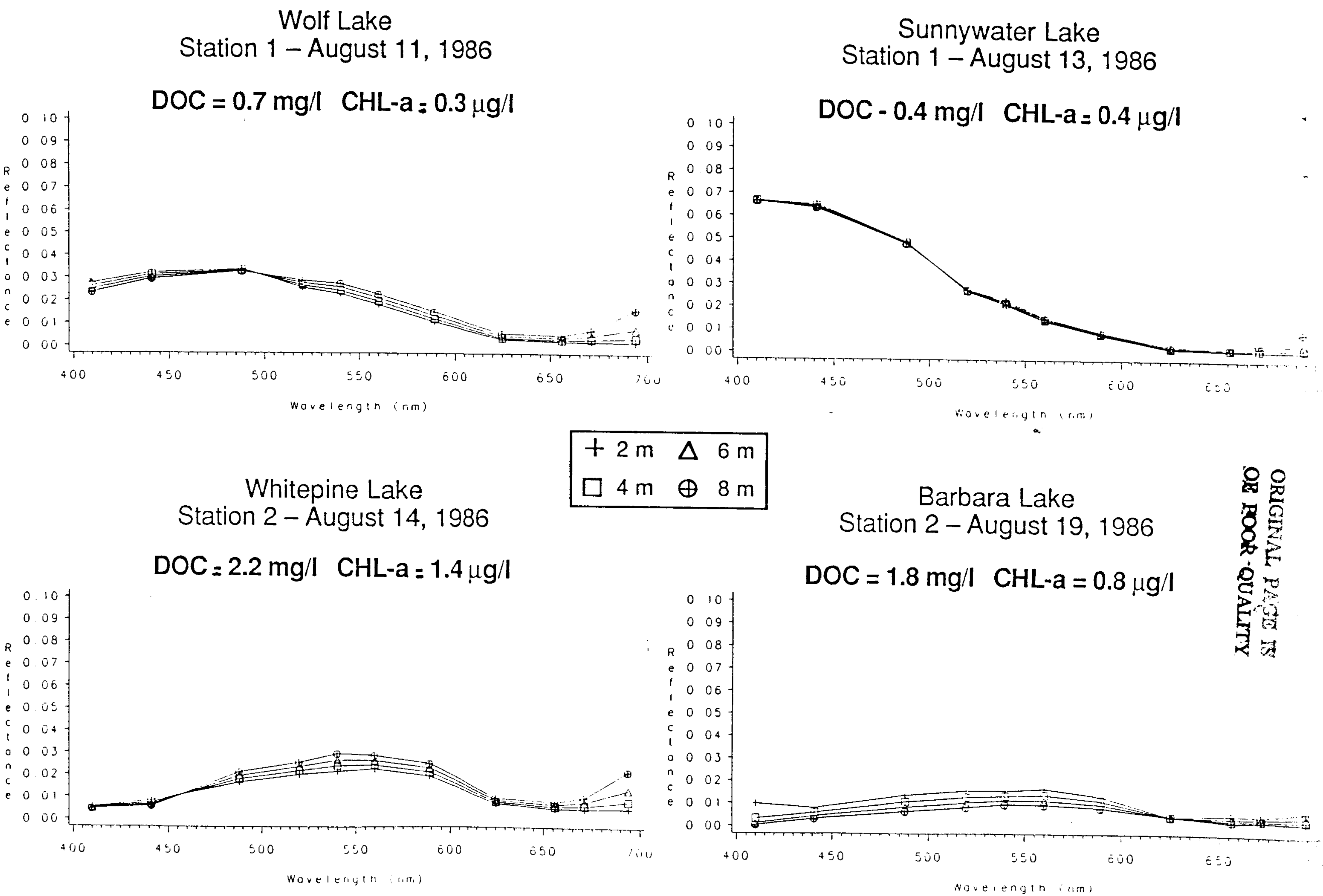


FIGURE 4. SUBSURFACE SPECTRAL REFLECTANCE (MER)

Chlorophyll-a on reflectance is apparent. As DOC increases the blue-green portion of the reflectance spectrum is diminished due to the high selective absorption. Chlorophyll-a also diminishes the measured reflectance below 520 nm, due to absorption. At wavelengths greater than 520 nm absorption is reduced and backscattering increases. The reflectance calculations at 700 nm are not considered valid since the irradiances are very small and contaminated by sensor noise.

3.6 DETERMINATION RELATIONSHIPS WITH FIELD DATA (TASK 6)

In this task the relationships that exist between lake water quality variables, optical measurements, and seasonal changes in TM radiometry with lake acidification are being determined. WQ data from the Sudbury site showed good correlation between pH and DOC (rho=.64, P(Ho)=.0007) as well as DOC and Chlorophyll-a (0.92,.0001). Correlation of pH with DOC is the greatest for DOC values less than 3.0 mg/l, as shown in Figure 5. Also shown in the figure are the data for Algoma, which shows virtually no correlation. The extracted TM band one DN counts exhibit parallel relationships with DOC. Significant correlations between DN counts were found to be -.623 for DOC; -.371 for pH; and -.419 for Chlorophyll-a for the Sudbury data, while no correlations were evident with the Algoma data.

3.7 SPATIAL ASPECTS OF ACIDIFICATION (TASK 7)

An analysis will be performed to interpret the spatial aspects of lake acidification. In this task each lake within an ecophysical stratum will be assigned a value based upon a TM multitemporal acidification relationship. These values will be used to assess the significance of atmospheric inputs, and the level of acidification, in relation to ecophysical parameters. Currently no work is being performed on this task.

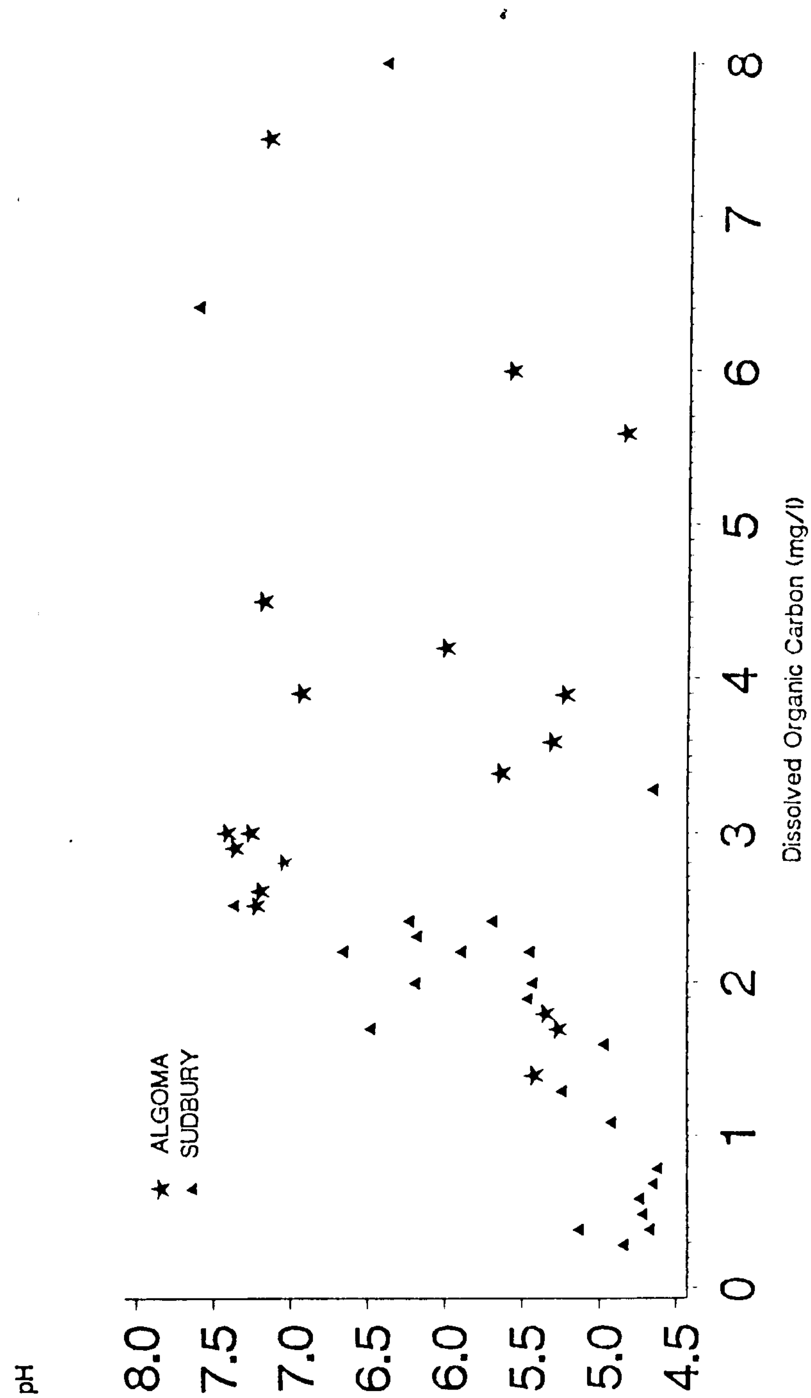


FIGURE 5. pH VERSUS DISSOLVED ORGANIC CARBON FOR ALGOMA AND SUDBURY SITES, AUGUST 1986 DATA

4.0 TECHNICAL PROBLEMS

The time needed to complete the scheduled data collection during May-June 1987 and analyze the requested TM coincident coverage will necessitate a six month no cost time extension to complete this applications research.

5.0 PLANS FOR THE NEXT REPORTING PERIOD

A second field trip will begin 1 May and last through 30 June 1987 to collect the spring portion of the needed spring/summer data pair. This trip is envisioned to be structured differently than the first trip made last August. Instead of a single visit to many lakes as was the case for August 1986, we will make several visits to the same lakes in order to observe the expected DOC induced reflectance changes which are thought to occur during the spring period. Field methods used during the August trip involving use of the Biospherical MER-1000 submersible radiometer have been improved upon and it is expected that eight to twelve lakes can be covered in the same day. During the previous August 1986 field work subsurface measurements were gathered usually from only a single lake per day. Initial collection of field data will begin during the first part of the next period. Field data will be reduced after the field trip and data will be exchanged with the Canadian investigators. Staff at the MOE will analyze water samples for a complete profile of WQ parameters.