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LAKE WATER QUALITY MAPPING FROM LANDSAT

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1. INTRODUCTION

The University of Wisconsin and Wisconsin state agencies have been engaged in interdisciplinary work on remote sensing of water quality since 1968. Under primarily NASA funding, laboratory, boat level, airborne and satellite analysis has developed to the point where the lakes in three LANDSAT scenes were mapped by the Bendix MDAS multispectral analysis system.

Field checking the maps by three separate individuals revealed approximately 90-95% correct classification for the lake categories selected. Variations between observers was about 5%.

From the MDAS color coded maps the lake with the worst algae problem was easily located. This lake was closely checked and a pollution source of 100 cows was found in the springs which fed this lake. This report covers the theory, lab work and field work which made it possible for this demonstration project to be a practical lake classification procedure.

2. LAB VERSUS FIELD DATA

To correctly apply remote sensing to lake classification, one must consider factors which do not exist when using remote sensing for classifying vegetation or other non-water features. The specular reflection of the skylight from the water surface is the major factor present with water which is not present with vegetation mapping. This factor can be a considerable value (Piech, 1971). There are other factors such as diffuse reflectance from dirt and foam on the water surface, which add to the total satellite signal. Also in many cases signals from the bottom of the water body are present. However, it is the material in the volume of the water, such as algae, humic material, silt, etc. which causes the backscatter that relates to water quality.

Assuming that there are no bottom signals present, if a very deep clear lake appears on a scene, the strength of the signal from this lake is caused by the surface signals, a small amount of backscatter from the pure water particles themselves and any atmospheric effects. Assume that another lake (Lake #2) contains certain dissolved or suspended impurities that interact with the incoming light. If the signal from the clear lake is subtracted from the signal from Lake #2 the residual signal is only due to the impurities in Lake #2. If this residual is determined at different wavelengths a "satellite residual fingerprint" results for that impurity.

Impurities of a clear lake, of course, are insignificant and the residual fingerprint for a clear lake is flat at about zero across the spectrum. Humic water (sometimes called "brown water", etc.) which is common in northern lakes, absorbs blue energy and has a residual curve which in the blue region dips below that for clear water (a negative value). Algae or silt added to clear water, however, causes increased reflectance and the shape and height of the fingerprint curves can be obtained from both satellite and laboratory data. For laboratory data the values are called "laboratory difference" curves and are determined by manipulating the relative reflectance from a water sample compared to the reflectance from a standard panel. Figures 1 and 2 show "laboratory difference" and "satellite residual" curves for clear water, humic water and heavy algal water.

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3. TIME OF YEAR

If one is interested in lake eutrophic classification, then such analysis should be done in late summer when the maximum amount of lake nutrients is converted into algae and lake weeds (biomass). Both algae and lake weeds can be identified from the LANDSAT satellite data.

Figure 3 shows various curves which show that the maximum biomass is produced in the last two weeks of August to the first week in September.

4. LAKE CLASSIFICATION

Satellite residual fingerprints for silt, lake weeds and sand bottom, are unique and can be identified by the computer and printed out in some appropriate color on the lake classification map. In late summer during maximum algal growth the remaining lakes (lakes without silt, weed or bottom signals) will be some combination of clear water, humic water, and algae. These waters can be plotted on a curve such as shown in Figure 4, which is similar to a lake classification scheme originally suggested by Wetzel.

Figure 4 shows four lake types chosen from the map classification scheme used, but more categories are possible. Figures 5, 6 and 7 are profiles across the curve on Figure 4 showing satellite residual fingerprints of various lakes recognized by the MDAS analysis equipment.

All the lakes in the areas mapped were put into one of the following classes:

Class	Color on the Map
deep clear water	Blue
light to medium algae	Blue-Green
medium to heavy algae	Green
humic water or mud bottom with wild rice growing on it	Brown
sand bottom or silt in the water	Yellow
lake weeds	Red
unclassified	Black

For navigation purposes, white and two tones of grey were used for cities, open fields, and woods. Black was used for unclassified areas. More lake categories and colors were initially printed out but it was found that the eye can only reliably distinguish about 10 colors and that too many colors are confusing. Most lakes had different colored pixels within the lake indicating perhaps a sand bar on one end, a weed bed at the other and perhaps even a humic water stream discharging into the lake somewhere else.

5. FIELD CHECKING

The MDAS color coded maps were field checked during the summer of 1975. This was accomplished by aerial observations and ground sampling. Two botony experts and one state DNR lake expert participated in the checking as well as the author.

The two botony experts and the author, took the MDAS hard copy and analyzed each lake as to the appropriate classification of all the pixels within the lake. They concluded that the lake classification was either excellent, good, satisfactory, or unsatisfactory. If the lake was classified as excellent, good or satisfactory, the classification was said to be correct. Each observer took notes separate from the other two. The percent average correct classification for the lakes mapped on the three LANDSAT scenes was 96%, 93% and 92%.

There was about 5% variation between observers doing the checking. It was concluded that the color coded lake classification map was as accurate as any present means of checking it.

6. COWS IN THE SPRINGS OF PRAIRIE LAKE

One will note that for the lakes containing algae (Figure 7) that Prairie Lake had the highest algae fingerprints of all the lakes analyzed. Furthermore the north end of Prairie Lake always indicated a higher algae concentration than the south end.

Low level aerial photos and aerial observations showed that the highest algae concentration was at the mouth of Rice Creek which empties into the north end of Prairie Lake. Further lower level aerial investigations and ground checking revealed about 100 cows in about 70 springs in a small unique wooded area which is the primary headwaters of Rice Creek. Since each cow contributes approximately as much pollution as 10 people, this cattle yard had the approximate pollution equivalent of a community of 1000 people dumping their raw sewage into Rice Creek (see Figures 8, 9, and 10). The citizens of Barron County, Wisconsin, around the Prairie Lake, as a result of the LANDSAT data are taking corrective action with regard to the cows in the springs of Prairie Lake, and hopefully soon the quality of water in Prairie Lake might improve because of the perspective view shown by LANDSAT.

ACKNOWLEDGEMENTS

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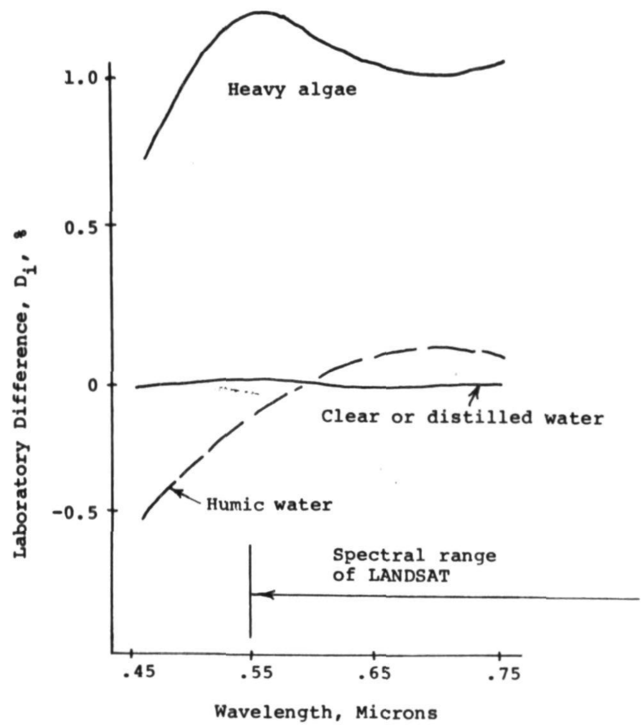


Figure 1. Characteristic laboratory "fingerprints" of two types of material in water. Laboratory difference, $D_i=(\rho_{v_i}-\rho_{v_1})/\rho_{PL}$ where ρ_{v_1} and ρ_{v_i} are the volume reflectance for distilled water and the water in question. ρ_{PL} is the reflectance of a standard panel.

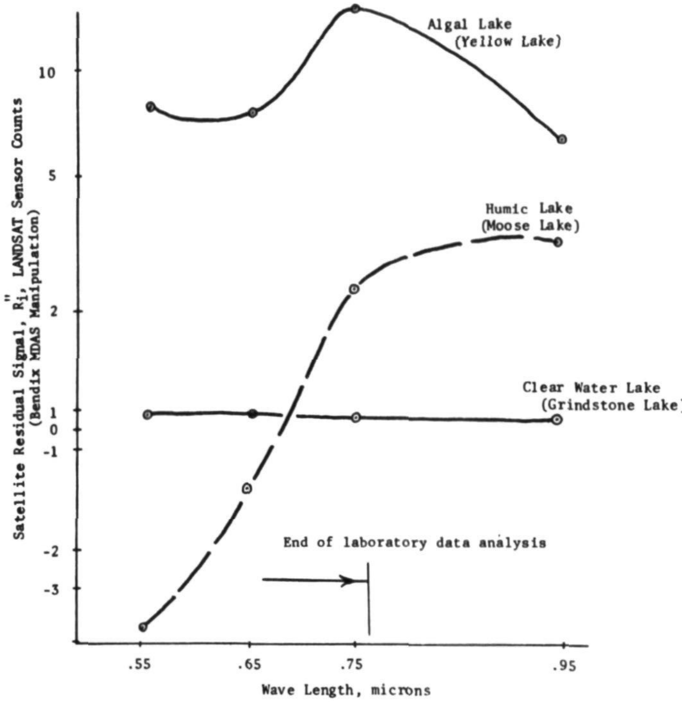
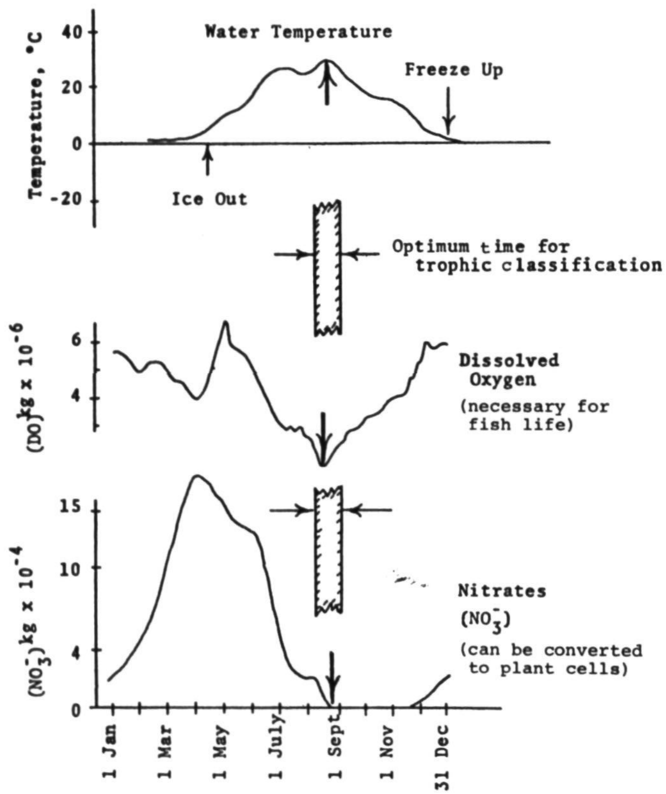
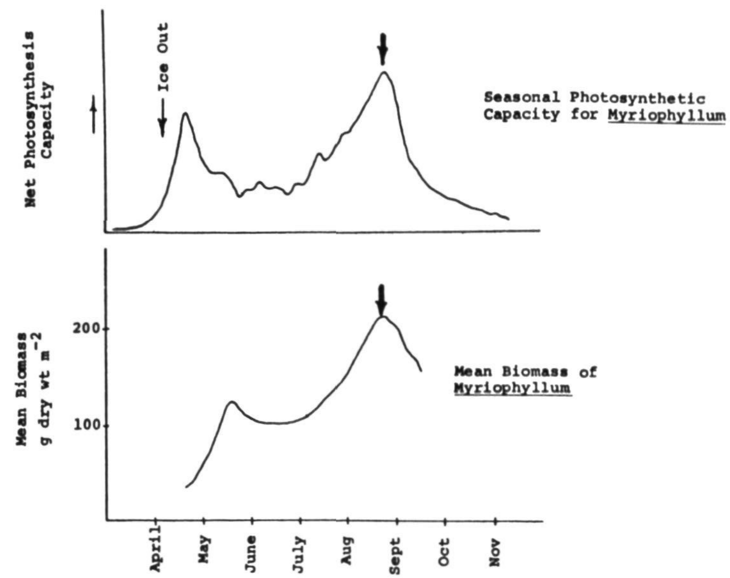


Figure 2. Characteristic fingerprints from satellite residual signal, R_i'' for the three water types. (From Scherz, Crane and Rogers, 1975).

$R_i'' = (\rho_{vi}-\rho_{v_1})H_o'\frac{\tau}{\pi}$ where H_o' and τ are total irradiance and atmospheric transmittance, respectively.



Water temperature, dissolved oxygen, and nitrates plotted against time. Lake Mendota, 1971. Data from Stauffer, Robert Elihu, Ph.D. thesis, University of Wisconsin, 1974.



Seasonal photosynthetic capacity and mean biomass of Myriophyllum spicatum (rooted lake weed) in Lake Wingra (Madison area lake) in 1971. (Modified from Adams and McCracken, 1974).

Figure 3. Various curves showing that the ideal time for trophic classification of lakes by remote sensing is a several week period in the last part of August to the first part of September.

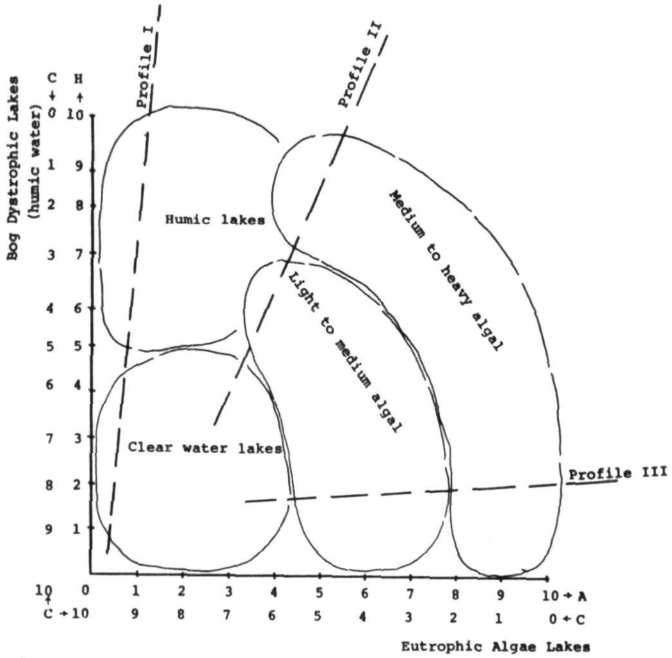


Figure 4. Scheme used to classify lakes from LANDSAT data. This curve is based upon a (non-remote sensing) lake classification scheme originally proposed by Wetzel. Satellite residual fingerprints along profiles I, II, and III are shown in Figures 5, 6 and 7.

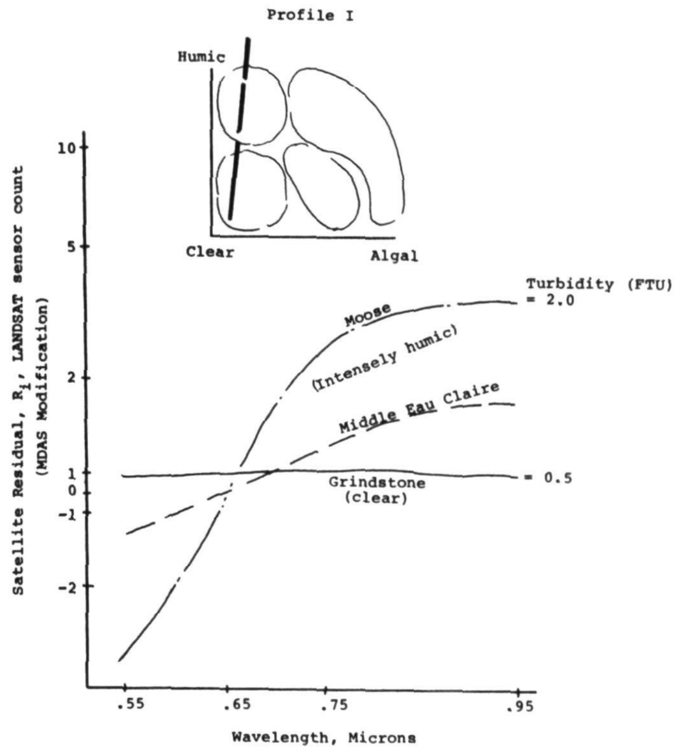


Figure 5. Satellite residual "fingerprints" for clear, moderate and intensly humic lakes (profile I in Figure 4).

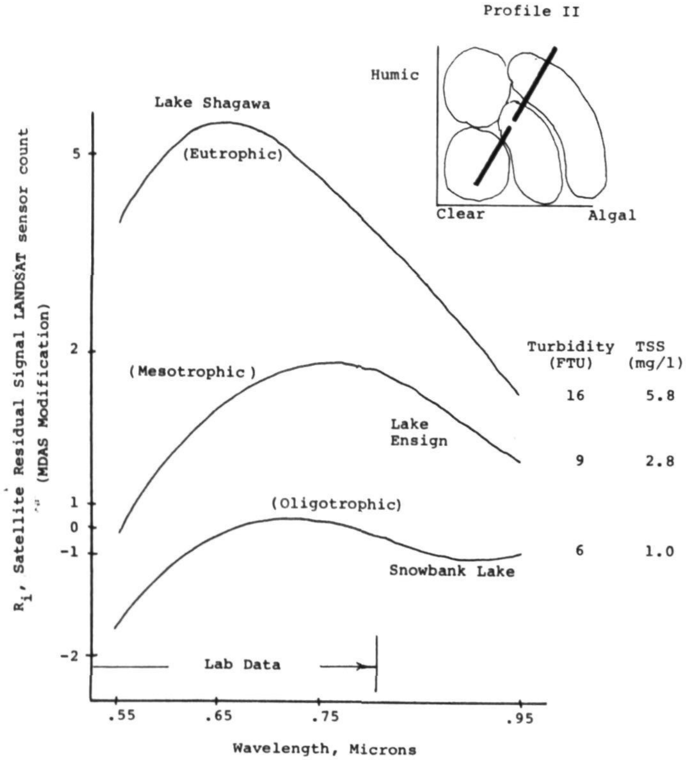


Figure 6. Satellite residual "fingerprints" of moderately humic lakes containing various amounts of algae (profile II in Figure 4). Three lakes near Ely, Minnesota. Shagawa = eutrophic, Ensign = mesotrophic, Snowbank = oliogotrophic.

TSS = Total Suspended Solids

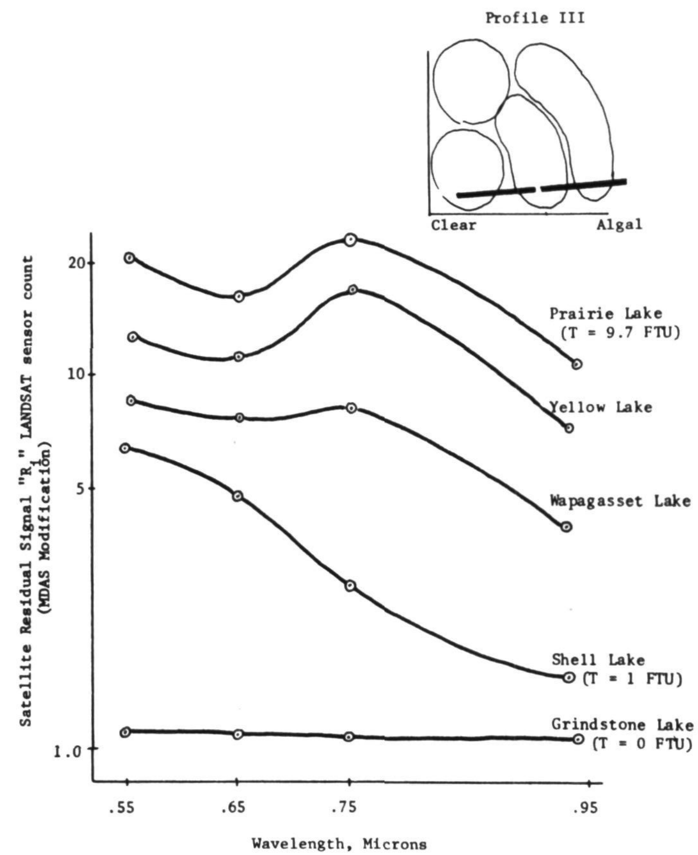
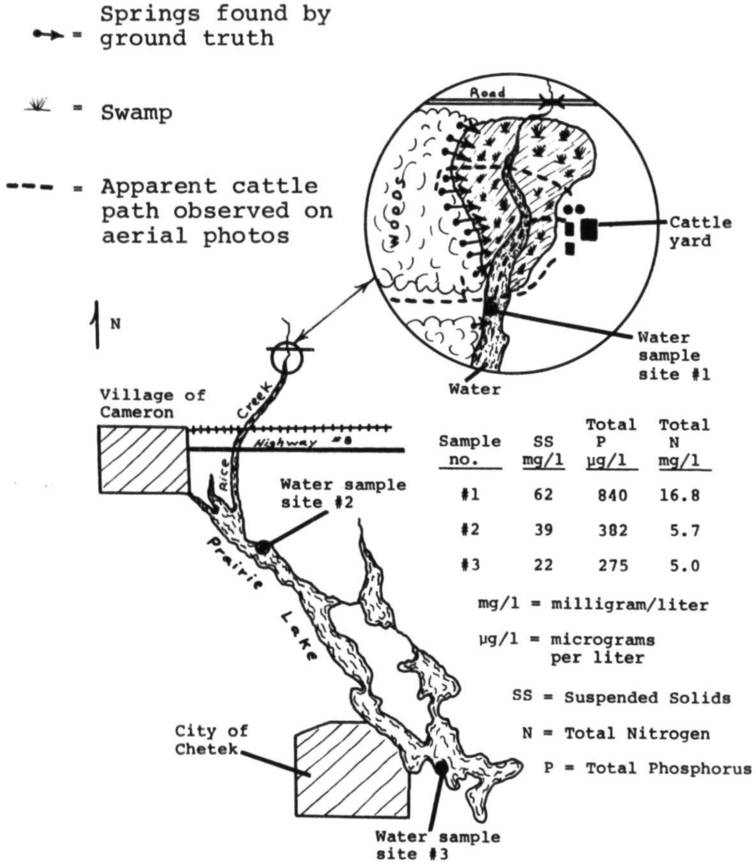


Figure 7. Satellite residual "fingerprints" of non-humic type lakes (Clear water type) containing various amounts of algae. (Profile III in Figure 4). T = turbidity.



Sample no.	SS mg/l	Total P µg/l	Total N mg/l
#1	62	840	16.8
#2	39	382	5.7
#3	22	275	5.0

mg/l = milligram/liter

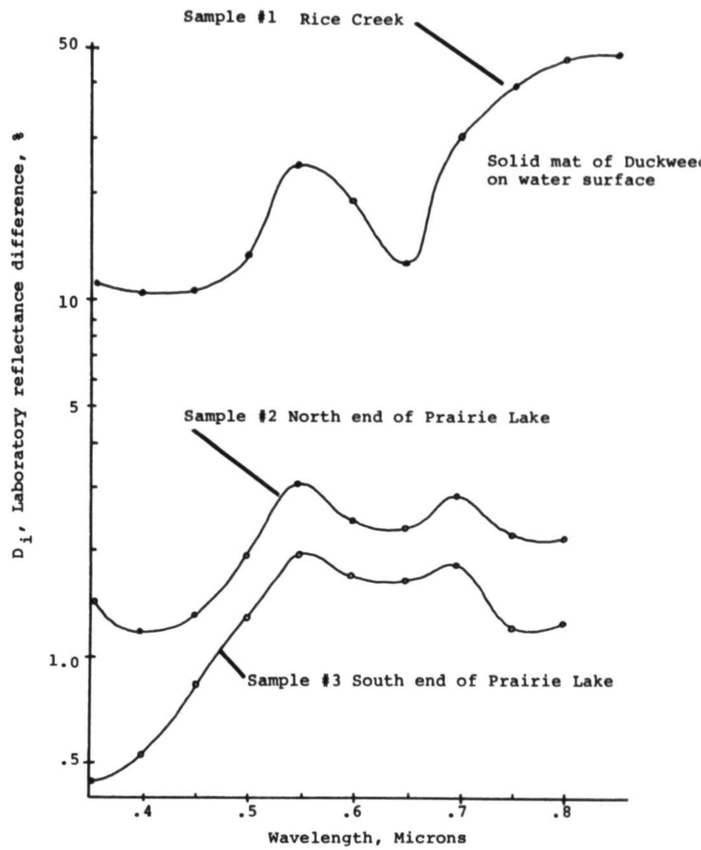
µg/l = micrograms per liter

SS = Suspended Solids

N = Total Nitrogen

P = Total Phosphorus

Sketch showing Prairie Lake, and cattle yard on Rice Creek.



Laboratory reflectance differences for water samples from Prairie Lake and Rice Creek.

Figure 8. Map and lab data relating to water sample collected from Prairie Lake on 17 August 1976.

Figure 9. A cow in one of the approximately 70 springs which feed Rice Creek.

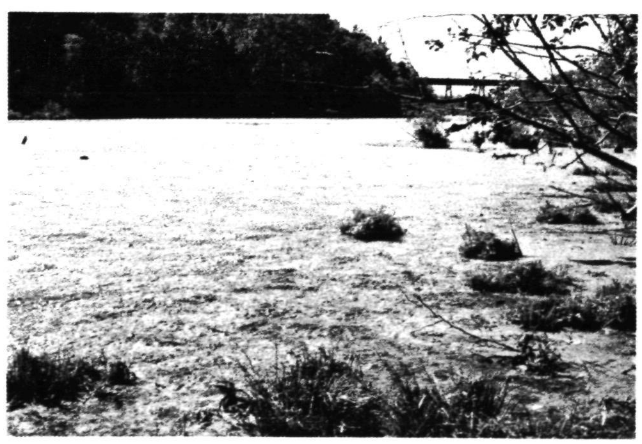


Figure 10. A view of Rice Creek from Sample Site #1 looking south toward Prairie Lake. A dense mat of duckweed and filamentous algae makes Rice Creek appear as a green field. Total phosphorus concentrations from this water were several times higher than expected from other lakes with serious algal problems. Water from beneath the duckweed had total nitrogen concentrations between 50% and 75% as high as expected from municipal sewers.